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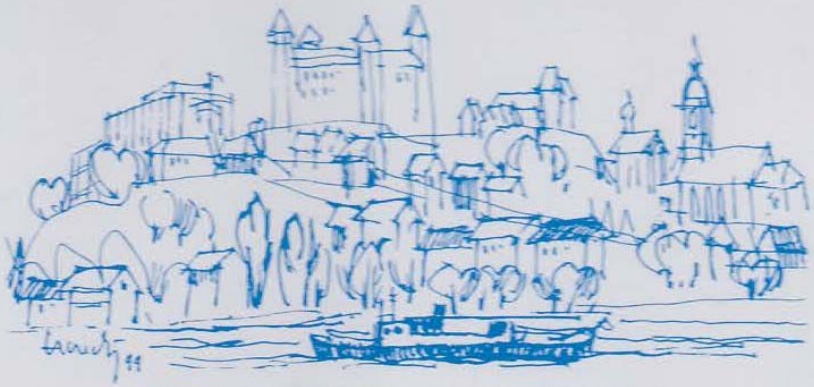

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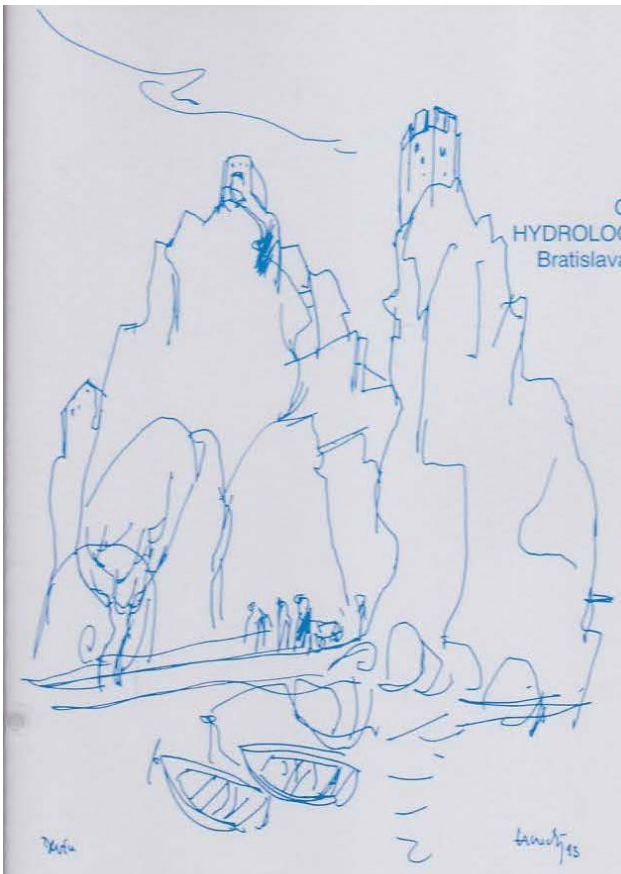

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Neue Entwicklungen beim Erfassen und Auswerten von Strömungen mit der Ultraschall-Doppler-Technik (ADCP)

Matthias Adler, Uwe Nicodemus

Zusammenfassung: Kenntnisse über das Abflussgeschehen sind eine wesentliche Grundlage zur Lösung von technischen Aufgaben und wissenschaftlichen Fragen der Gewässerkunde. Strömungs- und Abflussdaten werden u.a. in den Bereichen Niedrig- und Hochwasservorhersage, Wasserbewirtschaftung, Gewässergüte, Flussökologie, Flussmorphologie, Klimaforschung, Hochwasserschutz und Wasserkraft genutzt. Der Einsatz von akustischen Doppler-Geräten (ADCPs) zeigt, wie durch Verwendung moderner Technologie Messaufgaben trotz steigender qualitativer und quantitativer Anforderungen wirtschaftlicher als mit herkömmlichen Verfahren erledigt werden können. Die in der Bundesanstalt für Gewässerkunde entwickelte Software AGILA bietet neue Möglichkeiten der Visualisierung und Auswertung von ADCP-Strömungs- und Durchflussdaten

Schlüsselworte: Abflussmessung, ADCP

Acoustic Doppler Current Profiles (ADCPs): New Developments in the Acquisition, Evaluation and Visualisation of Streamflow Data

Abstract: The knowledge of discharge data is essential for the solution of technical problems and scientific questions in hydrology and water resources management. Current and discharge data are needed for low flow and flood forecast, water resources management, water quality assessment, river ecology and waterpower. The use of Acoustic Doppler Current Profilers (ADCP) proves that an increasing demand for current and discharge data can be covered at fairly low cost compared to traditional methods. The Federal Institute of Hydrology of Germany has developed a software package called AGILA which offers advanced possibilities for the visualisation and evaluation of streamflow data acquired with ADCPs.

Key words: Discharge Measurement, ADCP

1 ADCP-Messprinzip

Akustische Doppler Geräte zur Strömungs- und Durchflussermittlung sind unter der Bezeichnung Broad Band Acoustic Doppler Current Profiler, BB-ADCP, bekannt. Eine ADCP-Messung läuft schnell und ohne Hilfsgeräte ab. Der ADCP wird mit einem Boot von Ufer zu Ufer über den Messquerschnitt geführt. Dabei werden sowohl die Strömung als auch die Gewässersohle akustisch „abgetastet“. Während der Messfahrt werden drei Größen kontinuierlich ermittelt (Abb. 1):

- Strömungsgeschwindigkeiten im Querschnitt als Vektoren
- Bootsgeschwindigkeiten über Grund als Vektoren
- Wassertiefe.

Aus diesen Daten wird der Durchfluss berechnet. Der große praktische Vorteil des ADCP-Verfahrens besteht darin, dass während der Fahrt gemessen werden kann (Moving Boat Methode). Mit ADCP´s können Durchflüsse wesentlich wirtschaftlicher und schneller bestimmt werden als mit konventioneller Technik, bei der hydrometrische Flügel eingesetzt werden.

Auf Grund des Messprinzips ist bei ADCP-Messungen eine Mindestwassertiefe von 1 m bis 1,5 m erforderlich. Dies ist bei ca. 80 % der Messstellen an deutschen Wasserstraßen gegeben.

2 Einsatz der ADCP-Technik an deutschen Binnen-Wasserstraßen

Die Wasser- und Schifffahrtsverwaltung ist im Binnenbereich nach dem aktuellen Stand mit sechs ADCPs ausgestattet.

Die ADCP-Boote wurden nach dem Prototyp der Bundesanstalt für Gewässerkunde ausgewählt und ausgestattet (Abb. 2). Die auf einem Anhänger leicht zu transportierenden, also „trailerbaren“ Kunststoffboote wiegen ca. 2 t und sind 6 m lang. Der ADCP ist in einem Schacht im vorderen Teil des Bootes untergebracht und dort optimal gegen Stoßbeschädigungen gesichert. Im Gegensatz zu einem Stahlboot arbeitet im Kunststoffboot der ADCP-Kompass zur Bestimmung der Strömungsrichtung ungestört. Wegen der geringen Wasserverdrängung der ADCP-Boote bleibt die natürliche Strömung i.a. praktisch unbeeinflusst.

Die trailerbaren Boote werden verwendet, um auf der Straße schnell von Messstelle zu Messstelle zu gelangen. In Ausnahmefällen, wenn das Anfahren der Messstellen, die im Schnitt 30 – 50 km auseinander liegen, auf dem Fluss praktikabler ist, bleibt das Boot auf dem Wasser. Es hat eine Reisegeschwindigkeit von ca. 30 km/h. Das grundsätzliche Einsatzkonzept sieht jedoch keine langen Aufenthaltszeiten auf dem Boot vor. Die eigentliche Messzeit beträgt nur 10 – 15 Minuten. Pro Tag kann an etwa 2 bis 3 Pegeln gemessen werden.

Ein neuer Geräteträger ist das ferngesteuerte ADCP-Boot „Drohne“, das die Bundesanstalt für Gewässerkunde für den Einsatz in langsam fließenden Flüssen und Kanälen entwickelt hat (Abb. 3). Im Gegensatz zu größeren Messschiffen verfälscht die „Drohne“ wegen ihrer geringen Verdrängung und dem kleinen Antrieb die natürliche Strömung kaum. Dieser Vorteil führt bei extrem geringen Fließgeschwindigkeiten zu einer deutlichen Verbesserung der Messgenauigkeit.

3 Das Auswerteprogramm TRANSECT des ADCP-Gerätehersteller s

Die Auswertung von ADCP-Messungen erfolgt mit dem Programm „TRANSECT“, das Bestandteil des ADCP-Systems ist und vom Gerätehersteller entwickelt wurde. Es liefert als einzig verwertbares Resultat den Abfluss Q. Zwar werden auch z.B. Querschnittsgeometrie und Geschwindigkeitsverteilungen ermittelt, diese Daten sind jedoch nicht verwertbar, weil sie vom Weg des Bootes von Ufer zu Ufer abhängen. Bei einer schrägen Flussquerung würde sich z.B. eine größere Querschnittsfläche ergeben als bei einem Messweg normal zu den Ufern. Die Abhängigkeit vom Messweg betrifft alle hydraulischen und geometrischen Ergebnisse außer dem Durchfluss Q.

4 Das Auswerteprogramm AGILA der Bundesanstalt für Gewässerkunde

Mit dem in der Bundesanstalt für Gewässerkunde entwickelten Programm AGILA können die Daten von ADCP-Messungen so verarbeitet werden, dass alle Ergebnisse unabhängig vom Messweg sind. Dazu wird in einem ersten Berechnungslauf aus den gemessenen Strömungsgeschwindigkeiten die Hauptströmungsrichtung bestimmt. Normal dazu verläuft der Bezugsquerschnitt. AGILA rechnet dann alle ADCP-Daten durch vektorielle Projektion in die Ebene des Bezugsquerschnitts um (Abb. 4). Die wesentlichen Kennlinien und Parameter einer Auswertung werden ermittelt:

- Querschnittsgeometrie und Verteilung der Strömungsgeschwindigkeiten einer Einzelmessung (Abb. 5)
- Überlagerung und Mittelung von Einzelmessungen (Abb. 6)
- Berechnung von durchströmter Querschnittsfläche A, Querschnittsbreite b, mittlerer Strömungsgeschwindigkeit V_m, mittlerer und maximaler Wassertiefe h_m und h_{max}, hydraulischem Radius r_{hy} usw. (Abb. 7)
- Detailanalyse einzelner Messlotrechten (Abb. 8 und 9)

Die Software AGILA wird von der Wasser- und Schifffahrtsverwaltung zum Auswerten von ADCP-Messungen und zum Archivieren der Berechnungsergebnisse an Binnenwasserstraßen

verwendet. Ein weiteres Programm zur Berechnung und Visualisierung von ADCP-Messungen in Tideflüssen ist in der Entwicklung.

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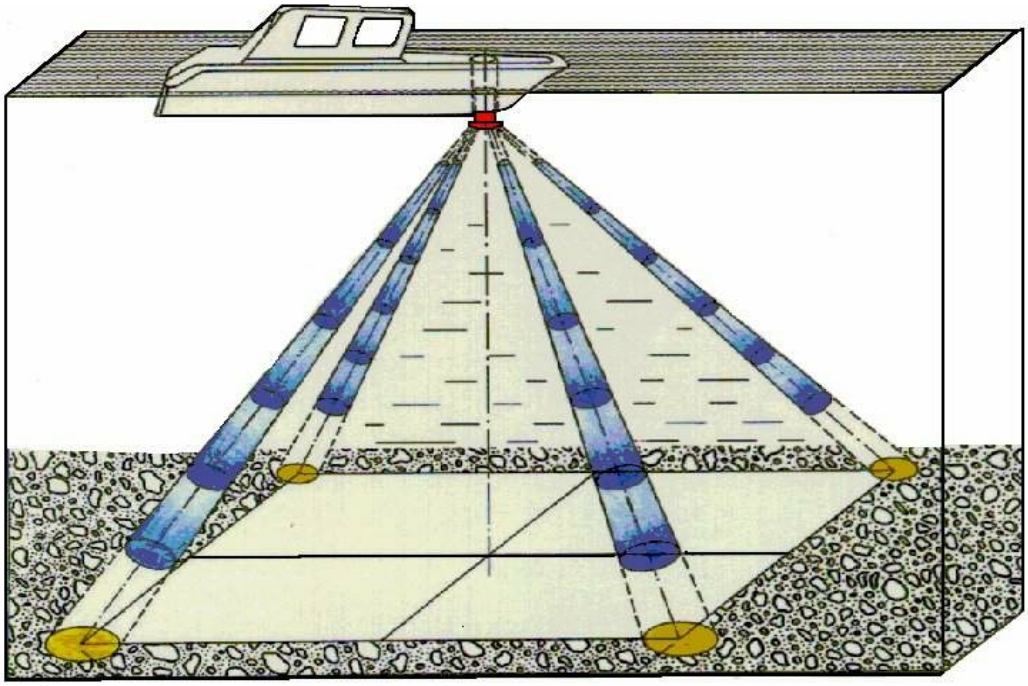

Abb. 1 Prinzip der ADCP-Messung

Abb. 2 ADCP-Messboote bei Vergleichsmessungen

Abb. 3 Ferngesteuertes ADCP-Boot „Drohne“ der Bundesanstalt für Gewässerkunde

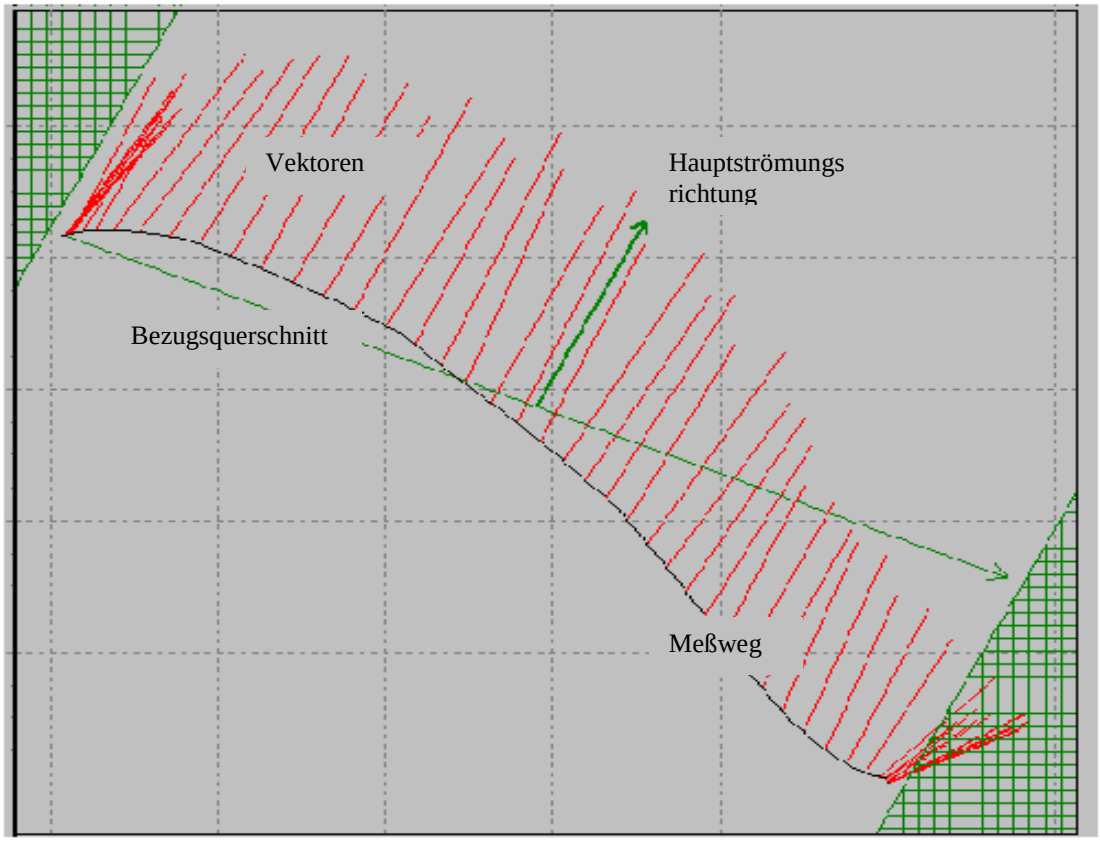

Abb. 4 Messweg, Geschwindigkeitsvektoren und Bezugsquerschnitt einer ADCP-Messung

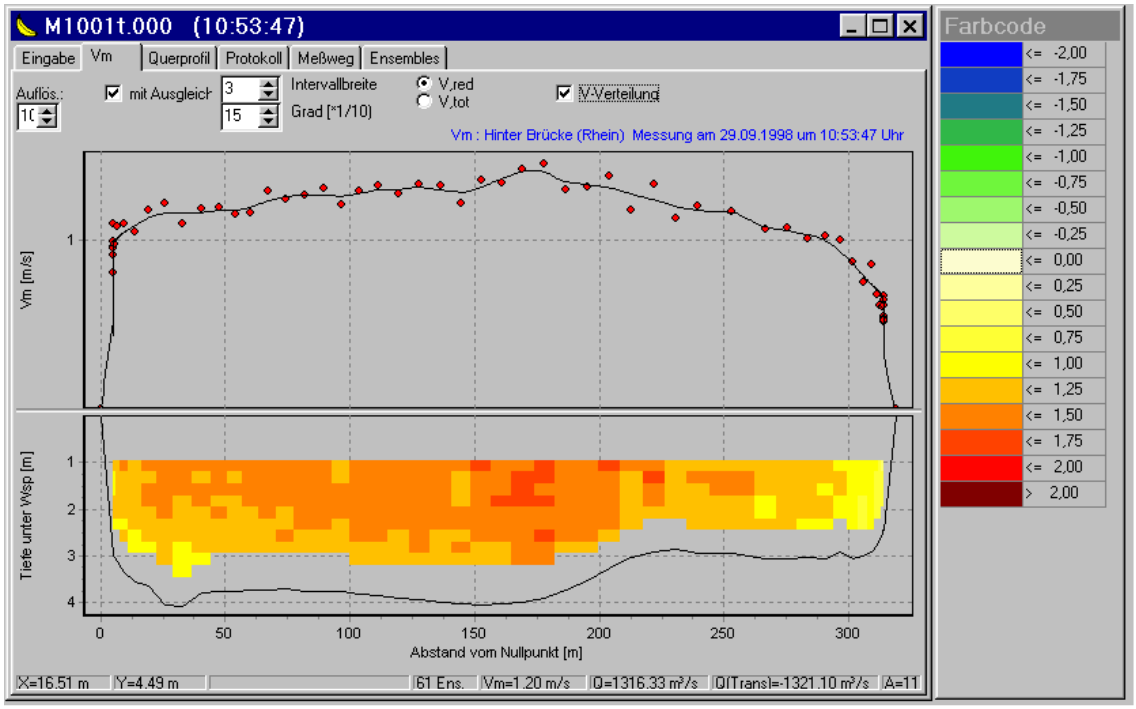

Abb. 5 Querschnittsgeometrie und Verteilung der Strömungsgeschwindigkeiten einer ADCP-Messung

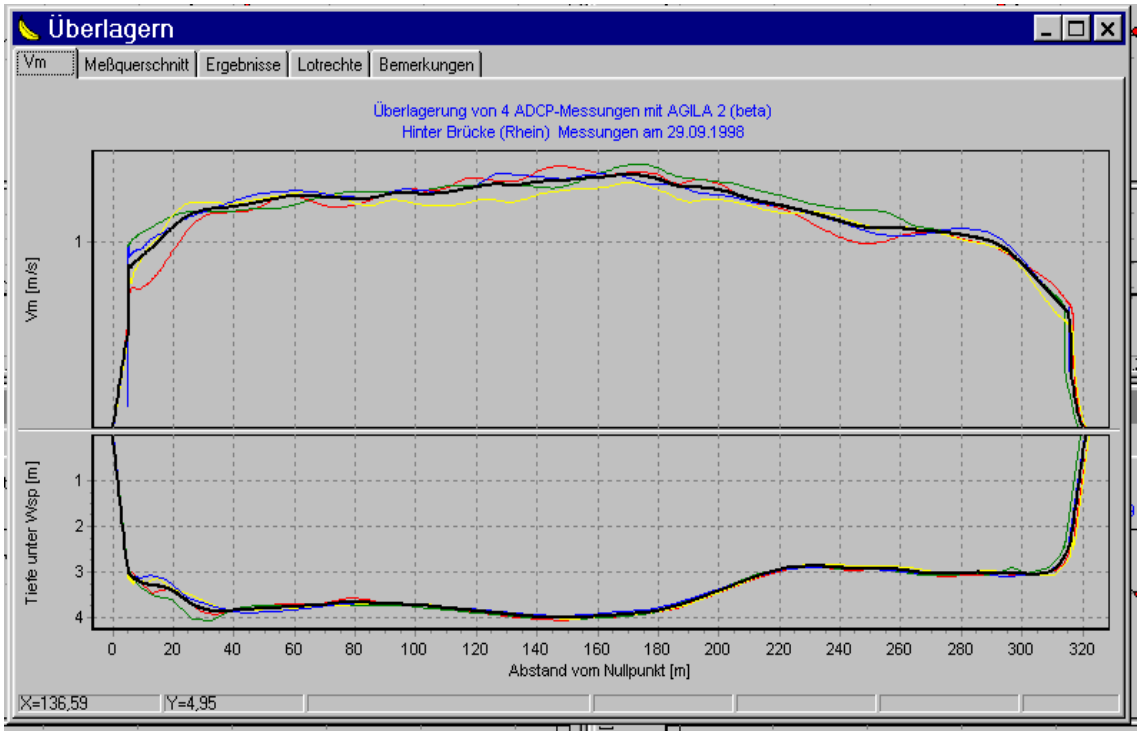

Abb. 6 Überlagerung und Mittelung von ADCP-Messungen

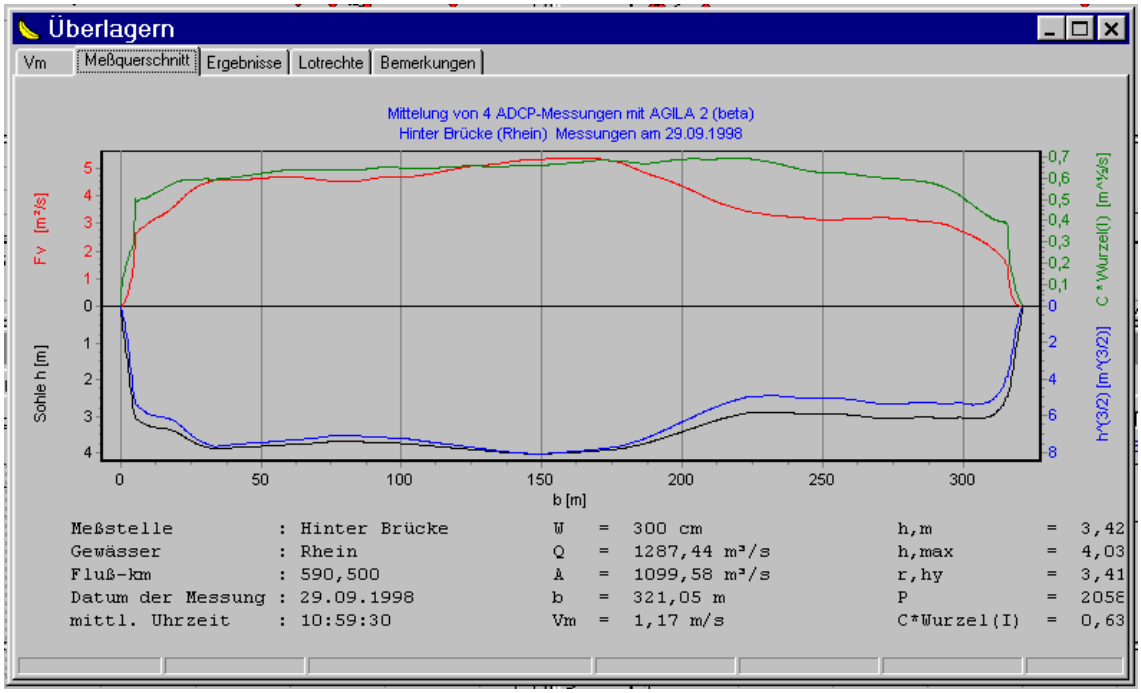

Abb. 7 Geometrische und hydraulische Kennwerte eines Messquerschnitts

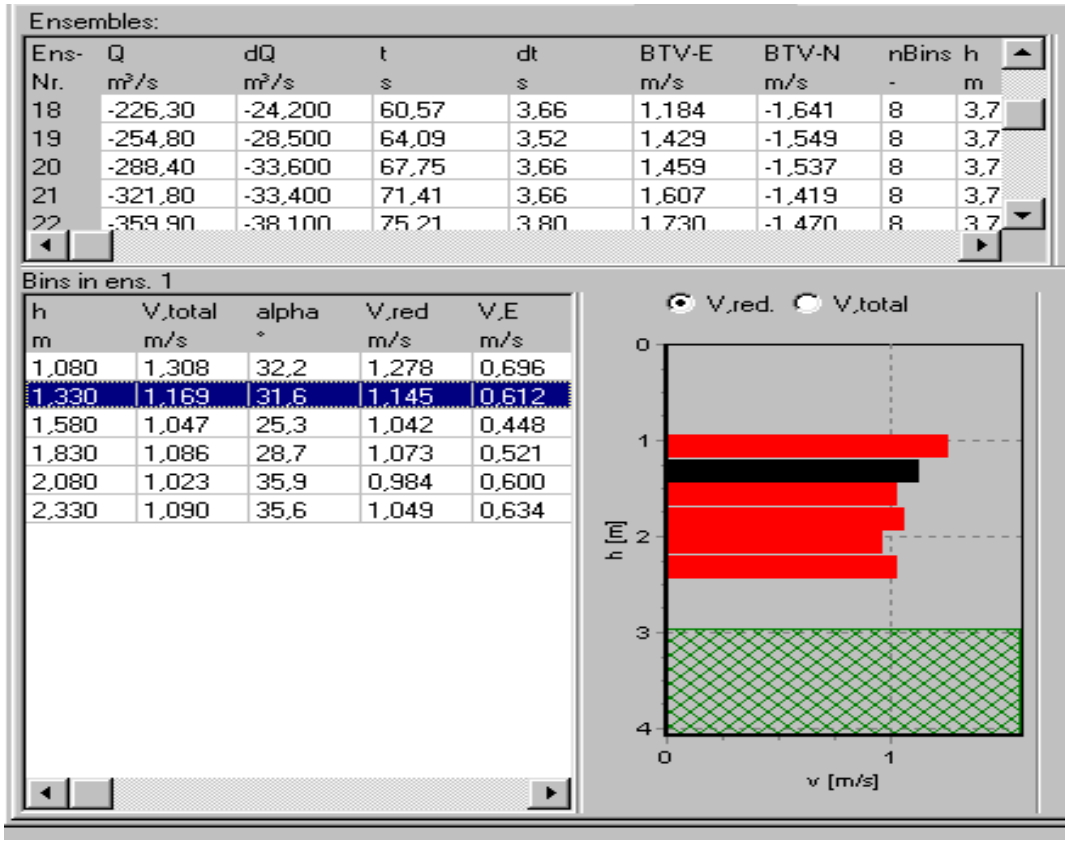

Abb. 8 Verteilung der Strömungsgeschwindigkeiten (Beträge) in einer Messlotrechten

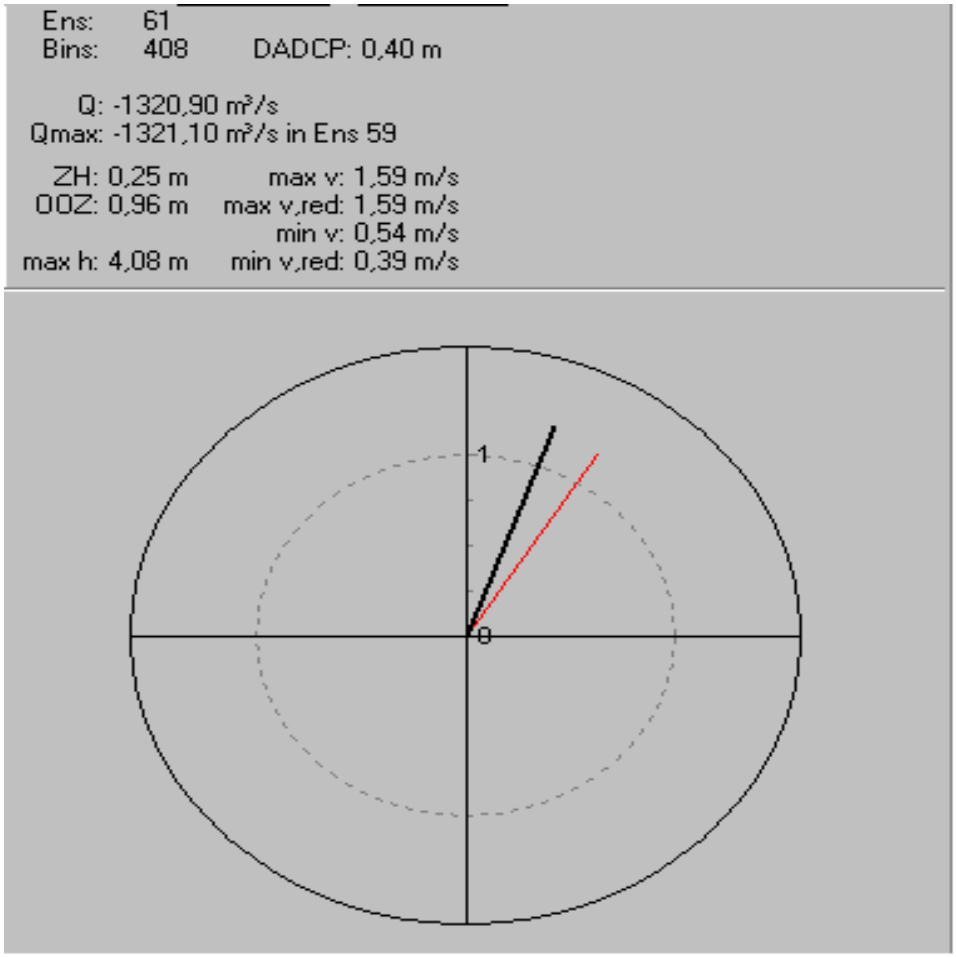

Abb. 9 Verteilung der Strömungsrichtungen (Beträge und Richtung) in einer Messlotrechten

Automated Information System for Forecasting Long-Term River Runoff

Natalya A. Agaltseva, Ludmila N. Borovikova, Alexander V. Pak

Abstract: In the conditions of the dry climate and extreme deficit of water resources in the Central Asian region the estimation of the water availability for the forthcoming year is very important. The main objective of the long-term runoff forecasting is the prediction of the extreme anomalies, i.e., low and high water availability with the rare frequency. The application of mathematical models of the runoff is the prospective of the development of the regional hydrological forecasting. The technique of forecasting is based on the deterministic models. The model set will also provide for the estimation of the snow cover in mountains and glacial runoff. For the practical application of the mathematical models of the runoff formation the automated informational system of hydrological forecasting has been developed. The system is comprised of the base of hydrometeorological data and software complex, which realized the main blocks of the model. The softwares realize the following: model adaptation to the individual basin, the optimization of the parameters of the model of transformation of the melt and rain contributions into the river flow, the algorithm of the flow calculation and forecasting. The developed system provides for the forecasts by the main hydrological objects located in the flow formation zones of Amudarya and Syrdarya rivers including the inflows into the big water storages of the river.

Key words: Informational system, database, stochastic and deterministic models, forecast, hydrograph, rivers runoff, contribution, transformation.

Automatisches Informationssystem zur langfristigen Abflussvorhersage

Zusammenfassung: Unter den trockenen klimatischen Bedingungen und dem extremen Defizit an Wasservorräten in der mittelasiatischen Region ist die Abschätzung der Verfügbarkeit von Wasser im nächsten Jahr sehr wichtig.

Das Hauptziel langfristiger Abflussprognosen ist die Vorhersage extremer Anomalien, d.h. kleiner oder großer Verfügbarkeiten von Wasser mit seltenem Auftreten. Die Anwendung mathematischer Modelle ermöglicht die Perspektive für die Entwicklung der regionalen hydrologischen Vorhersage.

Die Methoden der Vorhersagen basieren auf deterministischen Modellen. Der Modellkomplex ermöglicht auch die Abschätzung der Schneebedeckung der Berge und des Gletscherabflusses. Mit dem Ziel, die mathematischen Modelle der Bildung des Abflusses in der Praxis anzuwenden, wurde das automatische Informationssystem für hydrologische Vorhersage entwickelt.

Das System umfaßt eine hydrometeorologische Datenbank sowie die Software für die Hauptkomponenten des Modells.

Die Software realisiert folgendes: Anpassung des Modells an das jeweilige Einzugsgebiet, Optimierung der Modellparameter für die Umformung von Schmelz- und Regenwassers in Abfluß, die Abflußberechnung sowie die Vorhersage.

Das entwickelte System erlaubt Prognosen für die wichtigsten hydrologischen Objekte in den Einzugsgebieten der Flüsse Amu-Darja und Syr-Darja, inklusive der Zuflüsse in die großen Stauseen der Flüsse.

Schlüsselwörter: Informationssystem, Datenbank, stochastisch-deterministische Modelle, Vorhersage, Abflussganglinie, Abfluss, Eingang, Umformung.

1 Introduction

The most important characteristic of runoff formation in watersheds of the Aral Sea basin is the strong dependence of all components of the water balance on orography and altitude. The total area of runoff formation in the Amudarya River basin is about 200 000 km^2 and in the Syrdarya River basin it is approximately 160 000 km^2. The region of runoff formation encompasses about 80 % of the total area of the Syrdarya River and Amudarya basins and this total area of runoff formation represents 20 % of the Aral Sea drainage basin.

Improved hydrological forecasting in the Syrdarya and Amudarya River basins for the April-September season is achieved by the application of models that provide a deterministic and stochastic and deterministic description of the rivers runoff formation and simulation of his hydrograph or bunch a hydrographs each of which has its probabilistic evaluation.

The application of the deterministic model is the first step in the course of the elaboration and use of the model forecasting techniques. The next step in the development of the simulation of the process of the flow formation was the development of the stochastic and deterministic model of the runoff transformation. It makes it possible to calculate and forecast the runoff in the probabilistic form using the deterministic model.

2 Description of deterministic runoff model

2.1. Computations of solid and liquid precipitation input on the surface of a watershed

The model of snow cover formation in mountainous basins is based on the average precipitation, including its dependence from altitude z and L the characteristic of macro-orography, i.e. $p = p(z,L)$. This function $p(z,L)$ can be expanded into a Taylor series by assuming temporal stability of the coefficients k_2 to k_6:

$$p(z,L) = p(z_0, L_0)[1 + k_2(z - z_0) + k_3(z - z_0)^2 + k_4(L - L_0) + k_5(L - L_0)^2 + k_6(z - z_0)(L - L_0)]$$

Snow accumulation in a basin is computed as a balance between income and loss of solid precipitation, taking into consideration water freezing inside the snow pack.

The input information includes precipitation, air temperature and moisture deficit by the measurements on the observational network of stations and posts and also the physical and geographical characteristics of the basin. The period of calculation begins since October. At every temporal step by the altitude zones the liquid and solid precipitation, snow cover dynamics (accumulation and melting), evaporation, input of the melted and rain water on to the watershed are calculated in the grid points.

2.2. Model of meltwater and rain input transformation into runoff

In the considered mathematical model (Borovikova et al., 1972) the river basin is presented in the form of two parallel and consequently connected capacities. The first is an analogue of an upper ground layer where relatively fast transformation of snowmelt and rain water that enters the watershed surface take place. The second layer describes transformation of water in deeper layers. It is assumed that the melted input q_m is directed entirely to enhance the upper layer water content. Rain input q_r is transformed rapidly into runoff and also feeds the upper layer. Outputs from the upper zone are: evaporation E, inflow to the outlet of basin Q_1, and infiltration of water to the lower zone $Q_{1.2}$. It is assumed that outputs from the lower zone are: inflow to the outlet of basin Q_2 and infiltration of water out of the basin boundaries P. Runoff at the outlet of basin is considered as sum:

$$Q(t) = Q_1(t) + Q_2(t) + Q_{\min}$$

where Q_{min} is the mean long-term minimum runoff. Q_{min} equals the baseflow during winter time.
Operation of the two-zone system is described by differential equations:

$$dW_1 / dt = q - E - Q_1 - Q_{1.2}$$

$$dW_2 / dt = Q_{1.2} - Q_2 - P$$

where W_1 and W_2 are the water content of the upper and lower zones, q is input of meltwater and rain water:

$$Q_1 = c_1 W_1$$
$$Q_{1.2} = c_{1.2} W_1^{\,2}$$
$$Q_2 = c_2 W_2$$
$$P = c_{2.0} W_2,$$

where C_1, $C_{1.2}$, C_2, $C_{2.0}$ are parameters of transformation. Numerical realization of the transformation model is done in two stages: optimization of parameters C_1, $C_{1.2}$, C_2 and $C_{2.0}$ by the Rosenbrock-Story method and computation of a 10-day hydrograph. Optimizations use the root mean square deviation of. computed minus measured water discharge. The other parameters that are used in the models are estimated from empirical data.
The fig. 1 and 2 are the examples of the runoff hydrographs calculation by the deterministic model for the little and large watersheds.

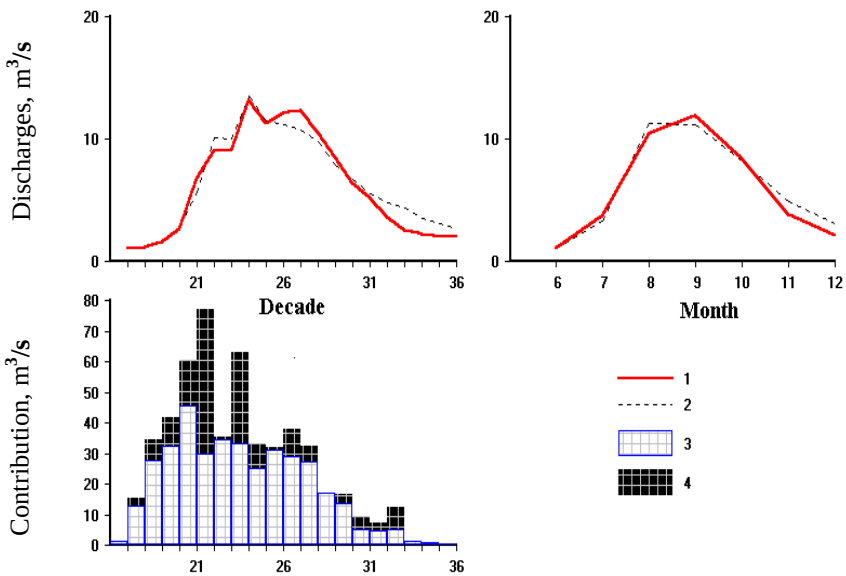

Fig. 1 Combined hydrographs of Padshaata river runoff for 1985
1 – measured runoff value
2 – forecasted runoff value
3 – melted
4 – rain
5 – glacial.

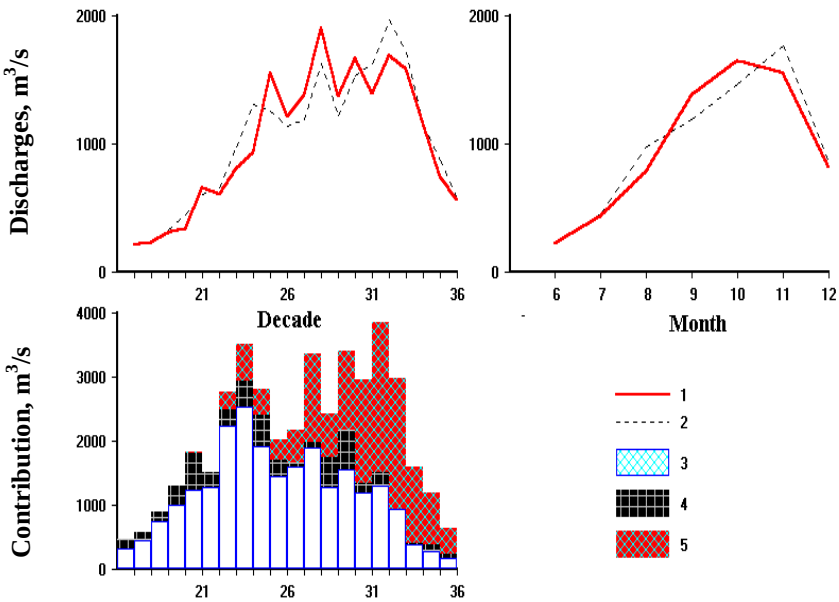

Fig. 2 Combined hydrographs of Vaksh river runoff for 1987

1 – measured runoff value
2 – forecasted runoff value
3 – melted
4 – rain
5 – glacial.

3 Methods and technology of runoff forecasting

Development of the forecasting method for each basin on the basis of the considered model includes the following stages (Fig. 3):

- analysis of the conditions of runoff formation;
- preparation of maps;
- numerical description of fields of precipitation, air temperature, and humidity deficit, and determination of extrapolation formulae parameters;
- computation of rain, melted snow;
- calculation of glacial runoff (for the rivers with glaciers);
- estimation of transformation parameters for the years with different water availability (dry years, humid years and medium humid years);
- calculation of the runoff hydrograph by deterministic model and estimation of the quality by the dependent and independent data;
- calculation of the conditional density of the discharge probability.

Climatic values of meteorological elements or forecast anomalies of air temperature and precipitation are used as initial information for runoff computation and forecasting. Long-range forecasts provide a modelling base in order to analyze different scenarios of runoff formation in a basin.

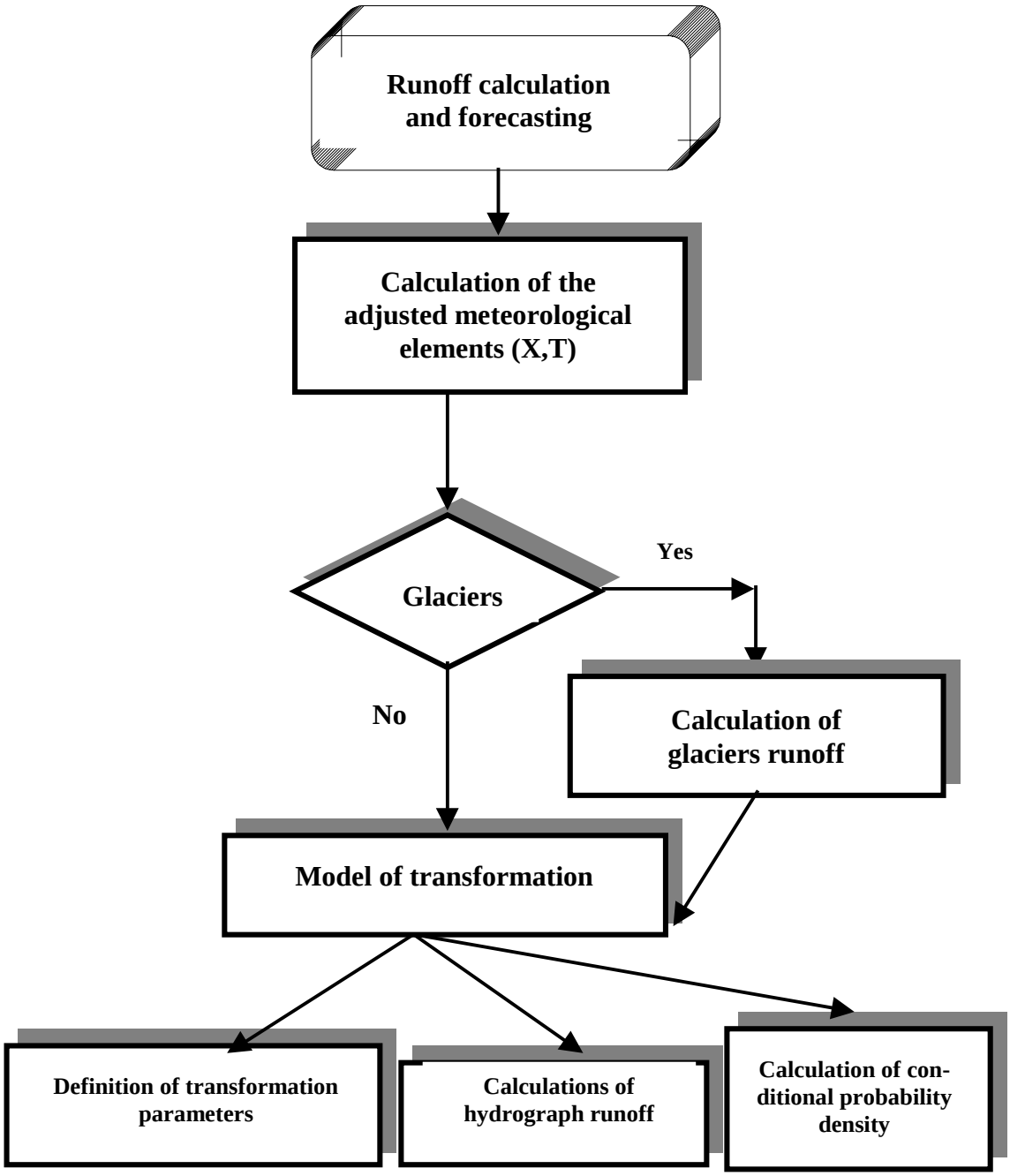

Fig. 3 Technological pattern of the work of AISHF system

The automated information system of hydrological forecasts (AISHF) was developed for practical applications of mathematical modelling of runoff hydrographs. This system includes (Fig. 4) a hydrometeorology database and specialized software. The software serves the four main functions of the AISHF system:

- to form, load, lead archives and operative database;
- improvement in hydrograph prediction;
- runoff forecasting methods for mountainous rivers, provides operational forecasts for any time period;
- interactive analysis of previous, current and future hydrological conditions in a basin.

The data base is formed by two main informational groups:

- physical and geographical characteristics of the river basins – digital description of the relief of the area, the parameters of meteorological fields, the parameters of transformation model, etc.
- hydrometeorological information which includes: the measured data of precipitation, air temperature, water dicharge and others at observational network of stations and posts and results of calculation of the adjusted meteorological elements, snow reserves, by the altitude zones of basins, the depth of the seasonal snow line, the contribution of the melt and rain water on to the catchment, the glacial runoff.

Information in the database is categorized by areal criteria. The largest areal unit is a region.

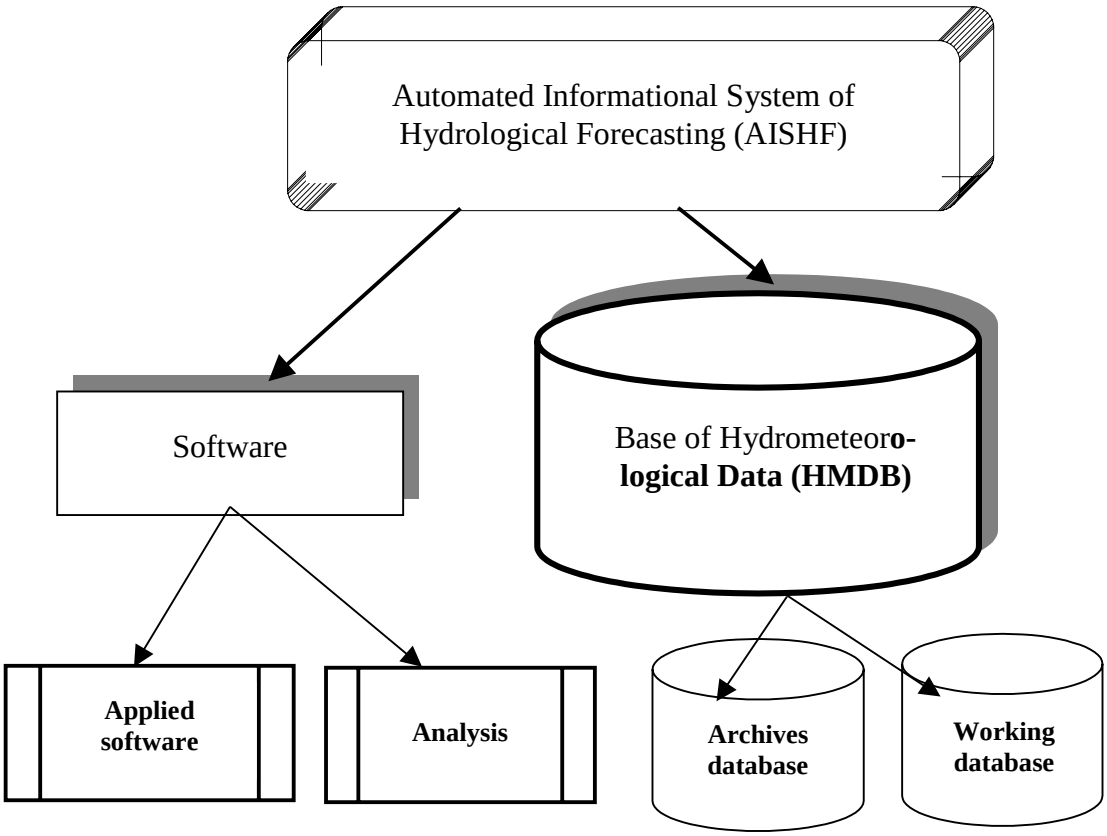

Fig. 4 General structure of AISHF system.

At present the main hydrological regions in the Syrdarya and Amudarya rivers basins are included into the system of forecasting. They are Chirchik-Akhangaran basin, the Alay range, the Fergana range (south-western slope), the right-hand affluents of the Syrdarya, Zeravshan, Vaksh, Pyandge, Kafirnigan rivers. Each region is characterized by the system of particular watersheds which compose the total hydrological basin. The system is applied to produce the forecasts of main hydrological objects and of transborder streams being located in the zone of the Amudarya and Syrdarya rivers runoff formation including affluents into the large reservoirs of the region.

Table Reliability (%) of monthly and seasonal forecasting runoff of mountainous rivers of Central Asia

RIVER	MONTHLY FORECASTING						VEG.
	PERIOD OF FORECASTING						
	1 month	2 month	3 month	4 month	5 month	6 month	
1. Akhangaran	92	90	95	90	90	80	93
2. Chatkal	85	85	82	85	77	70	90
3. Pskem	82	86	80	68	76	57	86
4. Inflow into Charvak reservoir	86	82	82	82	79	84	84
5. Ugam	85	85	80	81	78	80	90
6. Padshaata	80	82	81	81	79	79	92
7. Gavasaj	84	82	83	85	79	80	90
8. Chadak	82	81	81	83	80	80	92
9. Tentjaksaj	82	80	70	68	59	79	79
10. Kugart	82	81	73	68	57	-	73
11. Jassi	76	64	62	68	62	-	70
12.Karakuldja	76	71	60	60	68	68	80
13. Tar	-	60	63	71	71	-	71
14. Kurshab	90	90	71	75	79	86	88
15. Isfairam	-	59	67	71	71	100	80
16. Cokh	-	70	68	72	64	64	80
17.Inflow into Andijan reservoir	-	93	69	73	87	60	87
18. Zeravshan	-	58	73	65	73	68	77
19. Kafirnigan	91	88	84	80	78	78	92
20.Vaksh – inflow into Nurek reservoir	72	70	70	72	71	80	92

4 Conclusion

In the conditions of the extreme deficit water resources on the Central Asian territory the solution of the problem of long-term forecasting is very important for the economical development of Uzbekistan and other Central Asian states. At present with the use of the presented technique the forecasts for the main hydrological bodies in Sydarya and Amidarya river basins are being issued at Hydrometeorological Centre of Republic of Uzbekistan. The forecasted values agree with the best-estimated values got in the world hydrological forecasting. The use of the automated informational system of hydrological forecasting and calculations made it possible to improve the quality of hydrological forecasting significantly and to meet the requirements of the numerous users of the water resources information. The system can be used for the solution of the problem of the water resources management in the region.

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Observation Networks of Subsurface Waters in Hungary

György Ágotai

Abstract: The development of the observation networks of subsurface waters has started collecting of data of shallow groundwater, karst and artesian water and spring. The observation network of shallow groundwater and karst water has been developed by drilling of new wells In many cases the observation wells were pumped earlier in the artesian aquifers. The primary aim was to observe the effect of the water production from subsurface aquifer and dewatering at mines. At the beginning the observation networks were developed by VITUKI (Water Resources Research Centre). Today the networks belong to the Regional Water Authorities, under the supervision of VITUKI.

Key words: groundwater, subsurface water, observation networks, water production, dewatering, hydrographic service

Grundwasser-Beobachtungssysteme in Ungarn

Zusammenfassung: Auf Grund der Entwicklung des Grundwasserbeobachtungsnetzes ergibt sich eine große Datensammlung des bodennahen Grundwassers, des Karst- und artesischen Wassers sowie der Quellen. Für die Beobachtung des bodennahen Grundwassers und des Karstwassers wurden neue Brunnen abgeteuft. In manchen Fällen handelt es sich um Brunnen, aus welchen früher artesisches Wasser gepumpt wurde. Das ursprüngliche Ziel war, die Auswirkungen von Wasserentnahmen für Wasserversorgungen und von Wasserhaltungen in Bergwerken zu beobachten. Anfangs wurde das Beobachtungsnetz vom Forschungszentrum für Wasserwirtschaft (VITUKI) ausgebaut und betreut. Heute wird es von den regionalen Wasserwirtschaftsdirektionen, unter der Aufsicht von VITUKI betrieben.

Schlüsselworte: Grundwasser, unterirdisches Wasser, Beobachtungsnetz, Wasserförderung, Bergwerk-Entwässerung, Hydrographischer Dienst

1 Introduction

In the former centuries the population got the water supply from rivers, and springs and shallow ground water (from dug wells) in Hungary. The research of the deeper aquifers has started at the beginning of the last century, because of the growing of water consumption. New wells were drilled in the basin regions, and around the big cities. At the end of the nineties the water production has changed. The two-thirds of water demand is supplied from deep groundwater nowadays. In the early century was unknown the water supply from these aquifers.

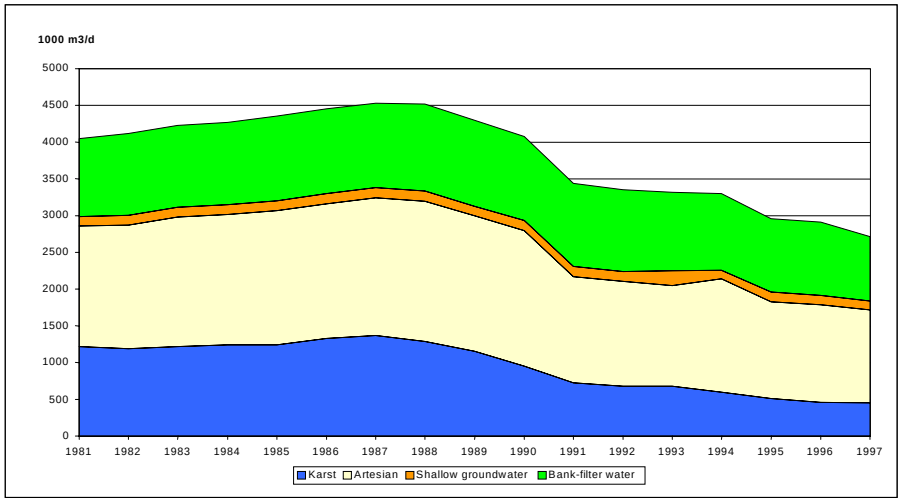

Fig. 1 The rate of the water production from the groundwater

A lot of mines and factories were shut down in the early of nineties. At last but not least, the price of the water has grown up, and the water demand has decreased (**Fig.2.**). The high price of the water made population reduce water consumption.

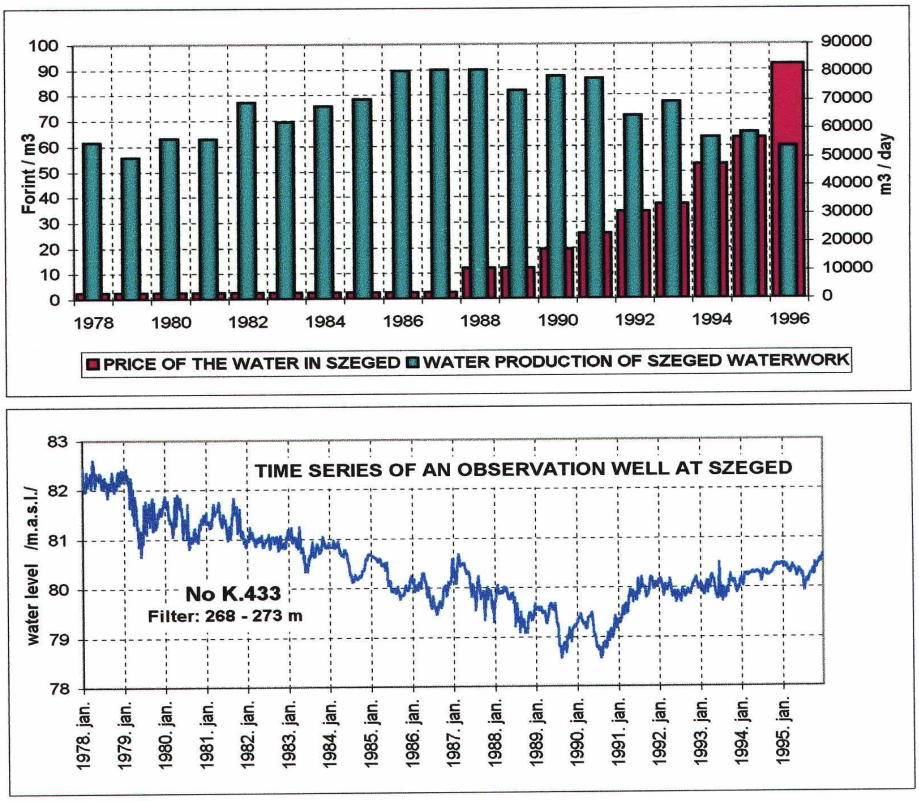

Fig.2 Connection among the water production and the price of the water and the water level of an observation well

In Hungary the hydrographic observations started step by step. More than hundred years ago started the measuring of the surface waters. This program was on schedule, when started the observation of subsurface waters (shallow and deep groundwater). The measuring of the deeper aquifers started in the Transdanubian Mountain Range. This is the biggest karst area in Hungary. The last step was the setting up the observation network of the artesian aquifers (the biggest area is the Great Hungarian Plain). In Hungary the subsurface waters are divided into shallow groundwater, karst and artesian water. In Hungary we use “shallow groundwater” phrase for the subsurface water in the first aquifer.

2 Observation networks

2.1. Shallow groundwater

The first observation wells were drilled in the early thirties to observe the change of water level in shallow groundwater. The development of the network has become faster in the fifties and has extended all the country. Today the number of the observation wells are more than, 1600 (high priority wells). We use “high priority wells” phrase for wells, which have to be measured permanently and the costs are covered by budget.

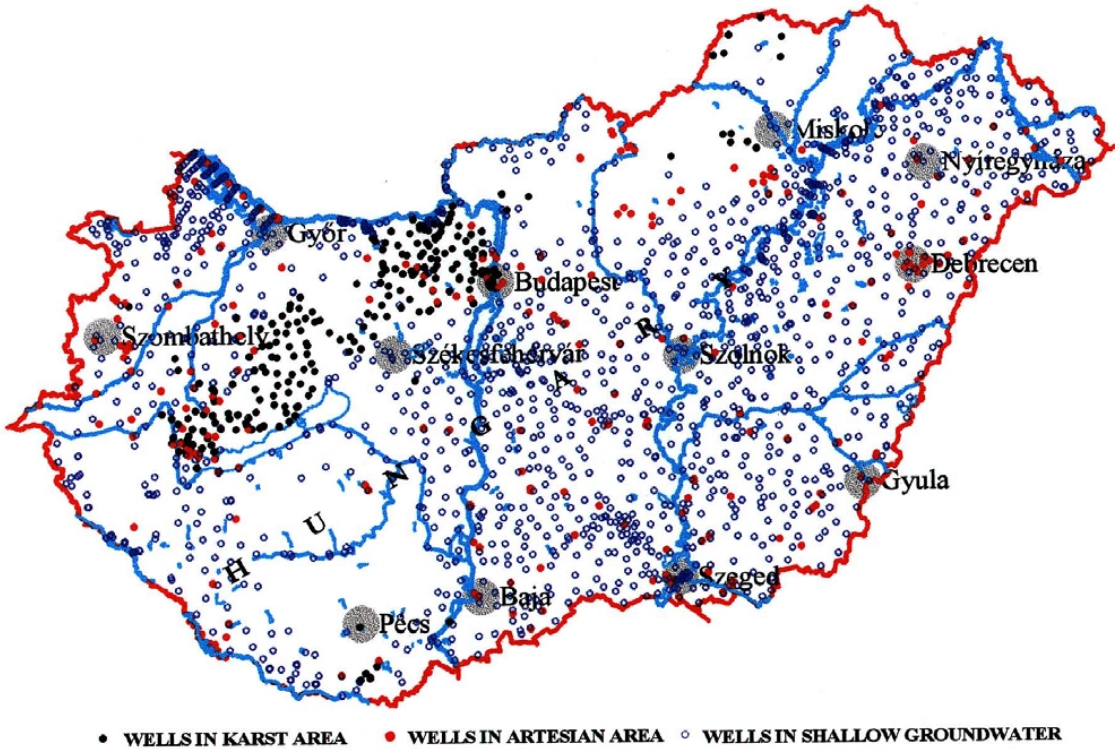

Fig. 3 The observation networks of groundwater in Hungary (high priority wells)

One part of the wells were drilled to research the change of the water table in natural condition. The other part of wells were observed to solve some water management problems. About 10-15 years ago the biggest problem was the decrease of precipitation. Last decades a groundwater depletion was caused by dry weather in the higher part of the area between the Rivers Danube and Tisza. In that area the aquifers are pleistocene sands and running sands. The water capacity of this aquifer is small. The water table decreased because of the decrease of precipitation

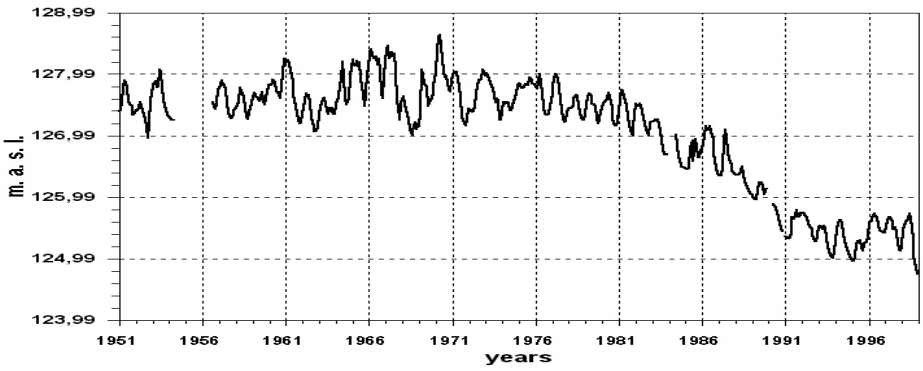

Fig.4 Time series of an observation well (Kiskunhalas No. 924) on the higher part of the area between the Rivers Danube and Tisza

In the eighties the decline of water table reached 2 meters on the higher part of that area. Under these conditions, the agricultural production is decreased, and social status of the population is gone down. The making up water would have been too expensive from the rivers. In the same time there wasn't groundwater depletion in the valley of The Danube and Tisza (**Fig.5.**). The aquifers connect to the river beds, and canals, and from the higher parts the flow infiltrates in that area.

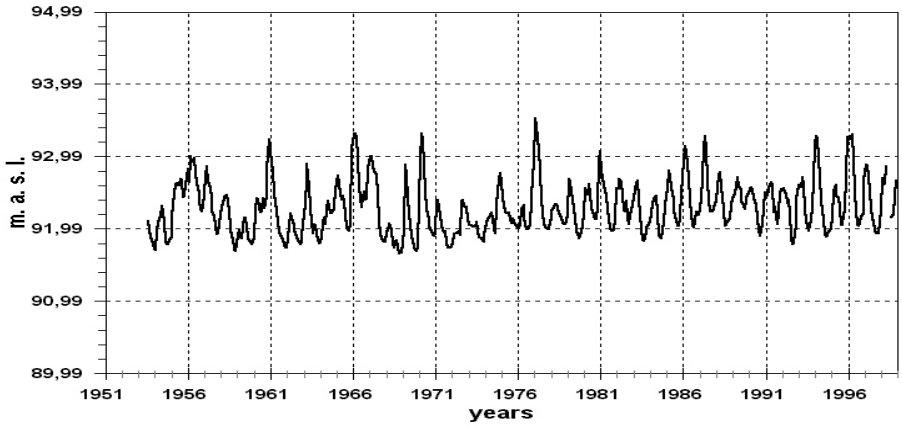

Fig. 5 Time series of an observation well (Kunszentmiklós No. 808) in the Danube valley

A lot of trouble is caused by the high groundwater-table. There was too much precipitation in the lower parts of the basin (not only in Great Hungarian Plain). The aquifers are full of water and they aren't able to store more water. Inland waters were in huge areas this spring. In a basin area, like Hungary need a lot of observation wells to search and to solve problems which were introduced as above. The average depth of these wells are not more than 10 meters. This network is able to observe the extreme change of water level. Today 360 digital measuring instruments are installed.

2.2. Karst waters

The observation of the water level of the deeper aquifers started in the early fifties, in the Transdanubian Mountain Range (this is the biggest karst area in Hungary). The main aquifers are Trias, Eocene, Miocene limestone and dolomite. A few decades ago big bauxite and coal deposits were discovered. These mineral resources were under the karst water level. The interest of the mining needed for dewatering. The first wells were drilled in the early fifties to observe the effect of the dewatering. The spot of the well were planned to collect correct information about the change of water level. The drilling of the observation wells were financed by budget. Two big networks were developed. One of them belonged to the mining companies, and they were around the mines. The other networks belonged to the VITUKI, and the wells were drilled among the mines. From the fifties till the eighties the network had extended all the mountain. In the early years the dewatering caused damage around the mining claim only (decreasing of water level reached 50-100m, sometimes it was more than 100m). Later the depression has extended the biggest part of the Mountain. From 1966 till 1991 the dewatering were bigger than the infiltration of precipitation (**Fig.6.**).

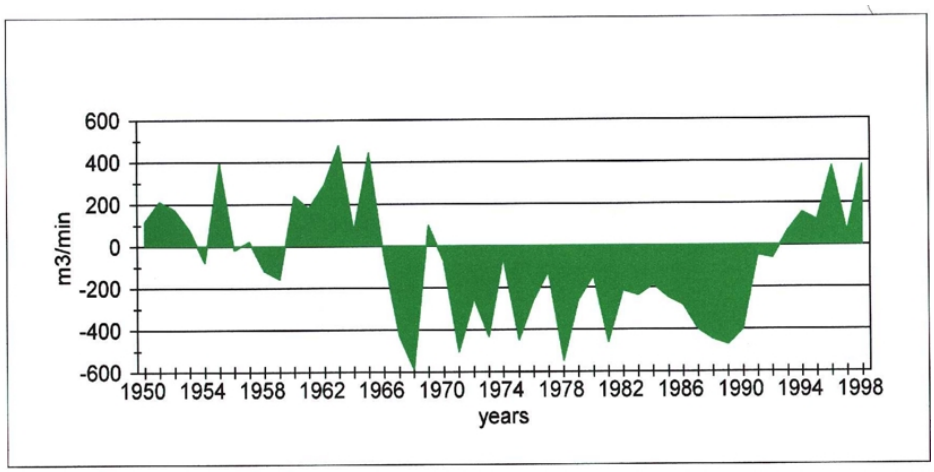

Fig. 6 The water balance of the water production and infiltration in Transdanubian Mountain Range

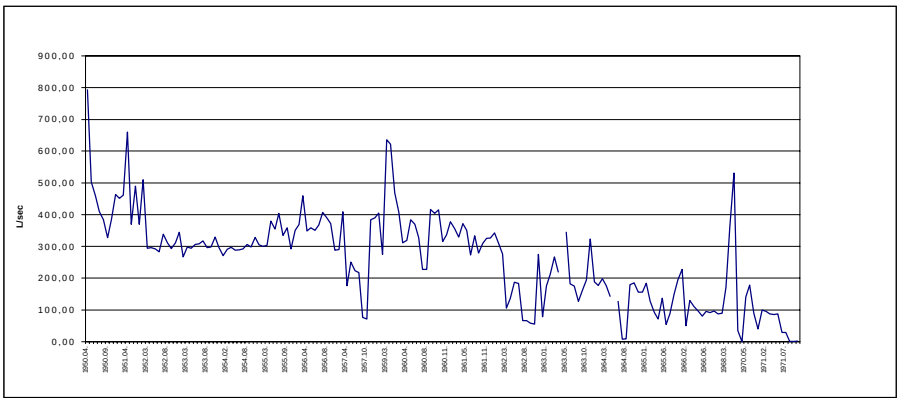

Fig. 7 Decreasing of the discharge of a karstic spring in the north-east part of the Transdanubian Mountain Range (Tata, Fényes spring)

The discharge of the springs had decreased and a few dried out because of dewatering (**Fig.7**). The discharge of Hévíz lake has decreased almost with fifty per cent. This is the biggest thermal lake in Europe – diameter is 200 m, the spring-cave is 40 m under the water surface. The decrease was owing to the depression, which evolved from dewatering of the bauxite mine. The distance between the lake and the mine is about 30 km. The (**Fig.8**) shows an observation well, which is 20 km from the bauxit mine.

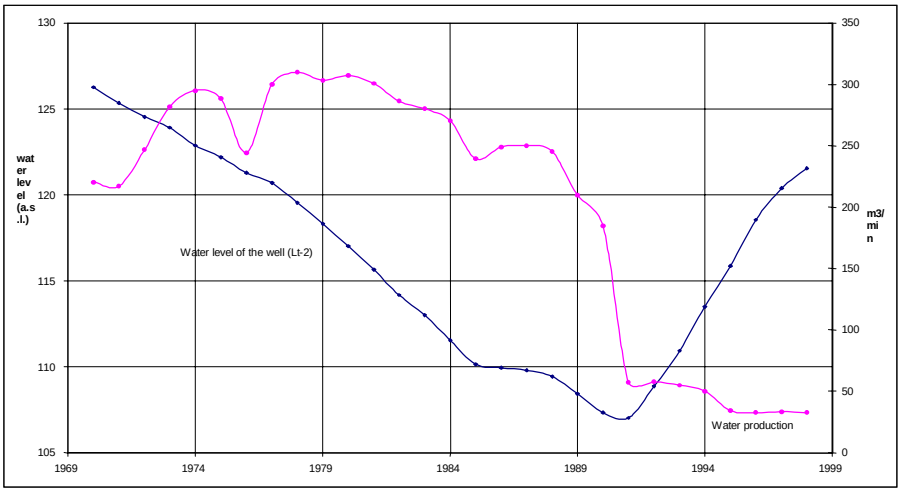

Fig. 8 Connection of the water level of an observation well and the dewatering of the bauxit-mine at Nyírád

In the early nineties the mining exploration had finished and the mining companies were shut down because of financial and environmental problems. The most important observation wells of mining companies were handed over to the Regional Water Authorities. The big dewaterings had finished, and the water levels has started rise first of all around the mines. Today this process are controlled and observed by this network. Nowadays more than 250 observation wells are in the Mountain. The network belongs to the Water Authorities.

2.3. Artesian waters

The observation of artesian waters started in the early seventies in the Great Hungarian Plain. That time a lot of local and regional waterworks were built to satisfy the growing of the water consumption of the great cities and industrial plants. The main aquifers are Pleistocene and upper Pannonian (upper Pliocene) pebble, sand, fine sand. At the borders the depth of the aquifers are 50-100 m, inside of the basin reach 500-600m. In the south part of Tisza valley (Szeged) the depth of the wells are 4-500m and the water temperature are between 20-30 ^{o}C. The water production had grown up from the early sixties till the last years of the eighties. That time the price of the water was very low. The first wells were drilled to observe the effect of water production around the waterworks of great cities. A few years later the network spread over the all area. The depression reached 10-15m around the waterworks, it was caused by discharged (**Fig. 9**).

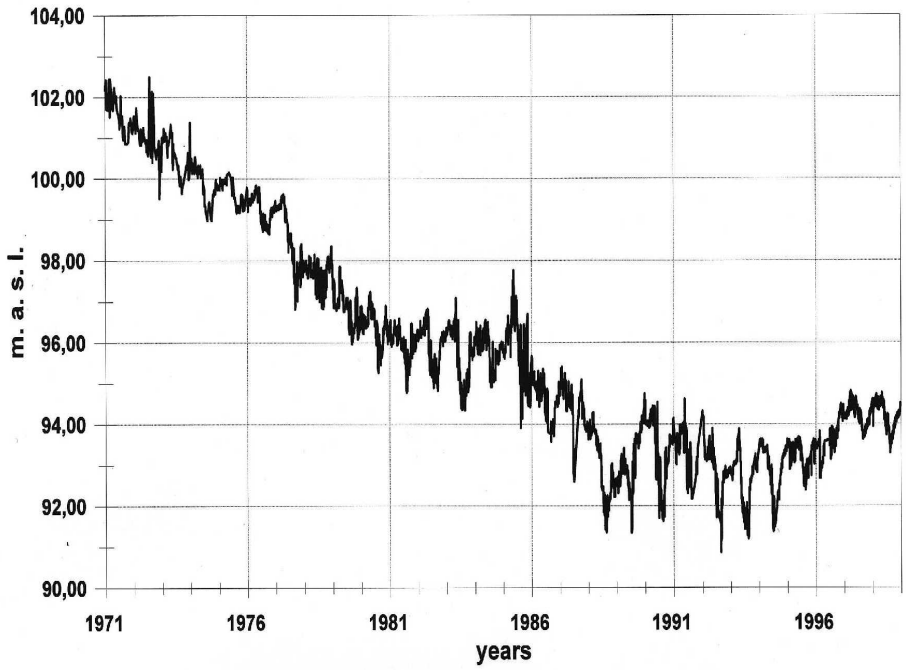

Fig. 9 Time series of an observation well of Kecskemét waterworks (Kecskemét, No 790) The filter: 218-263 m

The decrease of the pressure extended all the aquifers in all the area (The average was 0.03 bar a year). The development of the observation network has grown up step by step (in every 5-10 year). The first wells belonged to the waterworks. The network has developed by VITUKI from the middle of the seventies Because of financial problems we weren't able to drill new observation wells (except some wells) and we used ones, which were pumped earlier. We exam these wells, that the filter was clean or not, inverted capacity was good, or not. This way we were able to develop the network rationally. The development started in the early nineties in the other parts of Hungary. The development finished in the middle of the nineties. Today more than 300 wells are in the country (high priority wells) to observe the artesian aquifers.

2.4. Thermal waters

Hungary is rich in thermal waters because of the deep basin structure. The aquifers are in the karst and in the artesian area too. Most of wells are in the Great Hungarian Plain, where the aquifers are Pannonian and Pliocene fine sands. The water temperature changes between 30-99 ^{o}C. The thermal waters are used for heating of green houses, and balneology and balneotherapy purposes. There are big pressure decrease in the aquifers, because the recharge is too small. Today more than 60 wells are observed. They are belonged to the karst and artesian networks.

Nowadays there are more than 550 wells in the groundwater networks (karst, artesian and thermal) and 230 digital measuring instruments are installed.

2.5. Springs

Measuring of the discharge of the springs started in the early eighties , except Hévíz lake, which has been observed from the fifties. We measured discharge of springs in the early decades, but they haven't been happened permanently (there were too few measuring at too many springs). Today 50 springs are measured (high priority). We would like to develop this network, and use more digital measuring instruments. We hope, that we will have more money for this purposes (for example: to build measuring weirs).

3 Data collecting from waterworks

The Regional Water Authorities have been collecting data about the wells of waterworks and industrial plaints from 1978. The owners have to measure their wells in every month (water production, static and dynamic water level and sometimes water quality). Data are sent to the Authorities once a year. More than data of 5500 wells are collected today. All the data are available on Pc (Hydrogeological Information System). This system helped us to know more about the water production from the deeper aquifers.

4. Hydrographic Service

The hydrographic measuring had been done regularly by VITUKI. In the first years the task was the measuring of discharge of the rivers. The development of the groundwater observation networks started a few years later. These years the measuring, data collecting and development belonged to the VITUKI. Today the networks belong to the Hydrographic Teams of the Regional Water Authorities (under the supervision of VITUKI Plc). These teams are supplied well with cross-country cars, measuring instruments and computers. The data are available on Pc at the Regional Water Authorities and in VITUKI too. The data are public for everybody. The priority of the development is: optimum size of the networks, and increasing of the number of digital measuring instruments. Demand is in the development of measuring instruments: long lifetime, slight maintenance, electronic data collecting and store, Pc connection.

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Storm Flood Prediction at the Mati River Basin

Bardhyl AVDYLI, Marenglen BUKLI

Abstract: The prediction of the discharge hydrographic from the precipitation on the basin of the rivers of our country is treated in this article using the mathematical model of the unit hydrographic.

Many hydrological processes concerning discharge prediction in varied climatological and geographical condition of our country is treated in this study too. Mathematical models methods and their algorithms are given using computers to provide short-term forecasts of stream-flow

Key Words: Hydrograph, unit hydrograph, storm flood, runoff, stream flow, antecedent precipitation, effective rainfall, flow concentration, soil moisture, out-flow, mathematical model, computing technique, block-schemes, algorithms, applications.

Hochwasservorhersage im Becken des Flusses Mati

Zusammenfassung: In diesem Artikel wird die Vorhersage des Abflusses aus Niederschlag für das Flußbecken des Mati unter Anwendung des Einheitsganglinienverfahrens behandelt.

Ebenso werden in dieser Studie viele hydrologische Prozesse behandelt, welche die Abflussvorhersage unter den unterschiedlichen klimatischen und geographischen Bedingungen unseres Landes betreffen. Mathematische Modelle und deren Algorithmen zur kurzfristigen Vorhersage von Abflüssen durch die Verwendung von Computern werden angeführt.

Schlüsselwörter: Hydrograph, Einheitsganglinienverfahren, Hochwasser, Ablauf, Strömung, vorangehender Niederschlag, wirksamer Niederschlag, Konzentrationszeit, Bodenfeuchte, mathematische Modelle, Algorithmen, Anwendungen.

Mathematical Model

Using mathematical model of unit hydrographic solves forecasting of the discharge hydrographic or flood forecasting problems for short-term period on the basin of the Mati River. The modern computing technique of the Informatic Institute and applied mathematics in Tirana is used in large scale.

Block-schemes and algorithms that are constructed up to now will be gathered in the future and will be formed general schema for the prediction and regulation of the rainfall-runoff in the cascades of the rivers of our country.

1. Determination of runoff from rainfall data

The method of forecasting flood from storm rainfall consists usually of deducting the amount of loss of water from the process of rainfall amount over the basin in order to obtain the process of effective rainfall amount producing runoff.

Loss deduction computation

(1) Computation of the antecedent rainfall amount Pa.

In humid regions rainfall loss occurs predominantly during the initial period of rainfall. For the drainage basin of the Mati River, during a rainfall interval, amount of initial loss depends on the soil moisture antecedent to that rainfall. On the other hand, or in turn, the antecedent soil moisture depends on the antecedent rainfall amount (i.e., rainfall amounts in a number of 15 days antecedent to that rainfall of the Mati basin). [1], [2].

Soil moisture Pa (generally known as the antecedent precipitation index) is often assumed to decrease proportionally with the time; hence from time t (in days) to time (t+1),

$$\mathbf{Pai,\ t+1 = Ki * Pai,\ t}$$

in which, Ki -coefficient to be determined by the meteorological conditions at the i-th station.

During these processes, comparison is made between Pai + Pi, t and Imax, i - stands for the saturated soil moisture content at the i-th station.

In the case of the Mati river basin the saturated soil moisture is determined $I_M = 120$

The process is continuing at the second day of evaluating Pa, and so on:

$$\mathbf{Pai,\ t+2 = Ki\ (Pai,t+1 + Pi,t+1)}$$

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in which Pit, Pi,t+1, ... Respectively rainfall amounts on the i-th, (t+1)-th, ... days at the i-th station, i=1,2,.....,N; N-being the total number of reporting rainfall stations over the basin, I-being total number of days in evaluating Pa.

This process is continuing until Pa is evaluated up to the first day of the current rainfall.

(2) Computation of the effective rainfall amount R.

Referring to the rainfall runoff relation of the Mati river basin

1. When $\sum_{t=1}^{t} \mathbf{Pi,t + Pai,t - IMi \leq 0}$ no runoff being produced.

Then take Ri, t = 0 wherein t-stands for the t-th time interval after the beginning of the current rainfall. Generally Δt = 6 hours are taken for a time interval. Ri,t -effective rainfall amount in the t-th time interval at the i-th station.

2) When $\sum_{t=1}^{t} \mathbf{(Pi,t + Pai,t - IMax,i) > 0}$, runoff being formed,

a) During the first time interval of runoff forming

$$\mathbf{Ri,t = Ki * \sum_{t=1}^{T} (Pi,t + Pai - IMi)}$$

b) During the subsequent time intervals, **Ri,t = Ki * Pi,t** wherein Ki - the slope on the rainfall runoff correlation diagram:

$$\mathbf{R = f(P + Pa)}$$

at the i-th station, at the case of Mati river basin this diagram is constructed for the Shoshaj and F. Klos station. All the above computations are made with regard to Mati-Shoshaj and F.Klos stations. Computation of the average effective rainfall amount R over the entire drainage area is computed from those over the subbasin using the proportion of the area controlled by each station as waight.

2. Determination of the runoff process.

Determinations of the surface runoff process from effective rainfall process are made by means of unit hydrographic through composition. [2], [3], [4].

Ordinates of the surface-runoff process are determined by

$$Qt = \sum_{i=1}^{m} q\,[\Delta t,\ t - (i-1)\,\Delta t\,] * Ri$$

Qt - is discharge at time t, being the sum of the partial runoff amounts, produced by different Ri, q[Δt, t] - ordinate at the t-th time interval.

The unit hydrographic is corresponding to a time interval Δt of the effective rainfall.

m -number of time intervals of the effective rainfall.

Application

The calculation of the flow concentration of the drainage basin Mati-Shoshaj River is carried out by the unit hydrographic method. Unit hydrographic of this basin is applied for the prediction of the other discharge hydrographic, based on effective rainfall amounts during a time interval Δt = 6 hours.

The infiltration reports fc as average for this basin is 8 mm/6 hours. The prediction of storm flood in this station is realized successfully.

The errors at the prediction of the peak discharge are from 1 - 5 %.

Storm flood prediction is made for many effective rainfall of the Mati basin such as 9. 05. 1978;

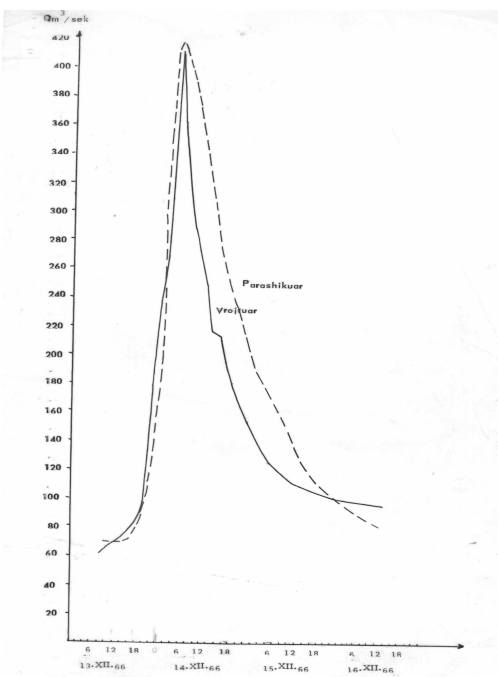

Fig. 6 HIDROGRAFI I RRJEDHJES SE PARASHIKUAR DHE TE VROJTUAR PER PLOTEN 13.XII.66 MATI-SHOSHAJ

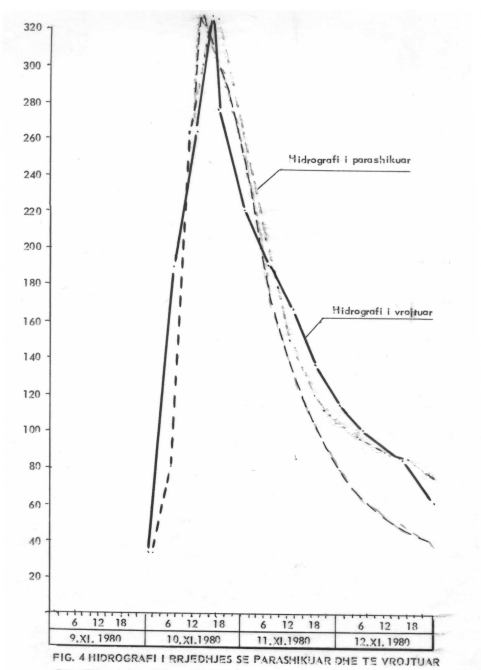

FIG. 4 HIDROGRAFI I RRJEDHJES SE PARASHIKUAR DHE TE VROJTUAR PER PERIUDHEN 9.XI. 1980 - 13.XI. 1980 , MATI - SHOSHAJ

9. 11. 1980; 13. 12. 1966 and so on.

Conclusions

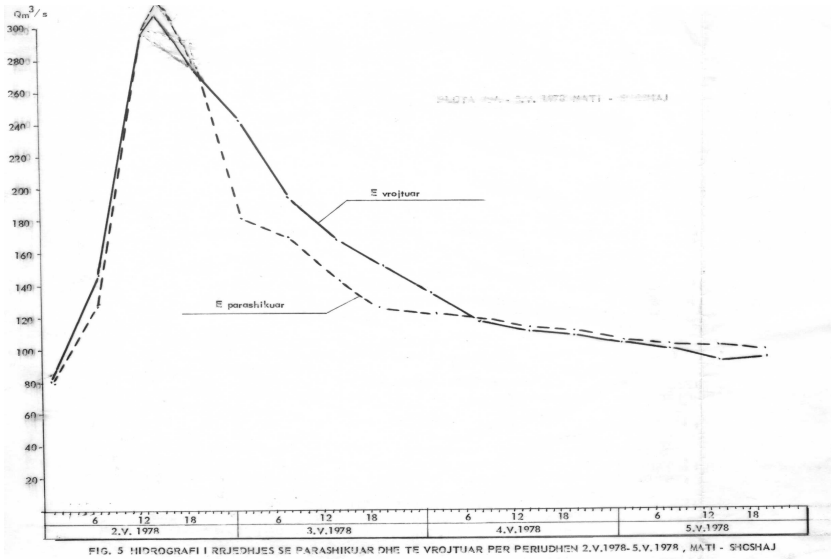

FIG. 5 HIDROGRAFI I RRJEDHJES SE PARASHIKUAR DHE TE VROJTUAR PER PERIUDHEN 2.V.1978- 5.V.1978 , MATI - SHOSHAJ

1. Determination of the surface runoff process from the effective rainfall process is made by means of unit hydrographic and is obtained satisfied results for the Mati river basin.
2. The drainage basin of the Drini and Mati rivers needs to provide with up to date techniques on observations, broadcasting and processing of hydro-meteorological data for the purposes of hydrological forecasts.

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Development of the System of Hydrological Forecasting in Hungary

Péter Bartha

Abstract: Hungary's endangerment by floods in basically determined by her being situated in the very middle of the Carpathian Basin, compelling her to frequently protect herself from flood waves arriving from the surrounding mountains. An efficient flood defence, however, is only possible, if the expectable future development of the hydrological scenario is known. The goal of the planned development of hydrological forecasting is to issue a flood- and a daily forecast with a lead-time of minimum 24 hours, possibly both for all daily reporting and for all flood hydrologically critical gauging stations of the country.

Key words: hydrological forecasting system, flood forecasting, flood warning, lead time of forecast

Entwicklung des hydrologischen Vorhersagesystems in Ungarn

Zusammenfassung: Ungarns Gegährdung durch Hochwässer is grunlegend durch seiner Lage in des mittleren Teils des Karpatenbeckens bedingt, wodurch es vielfach gezwungen wird, sich vor den aus dem ungebenden Gebrirge herabstüremnden Hochwassässern zu verteidigen. Wine wirksame Hochwasserbekämpfung ist jedoch nur möglich, wenn die erwartbare zukünftige Entwicklung der hydrologischen Szenarios bekannt ist. Das Ziel der vorgesehenen Entwicklung von hydrologischen Verhersagungen ist die Erstellung von Hochwasser- und Tagesvorhersagen mit einem Zeitvorsprung von wenigstens 24 Stunden, undzwar möglicherweise für alle täglich meldeneden und für alle hochwasserhydrologisch kritischen Pegelquerschnitte des Landes.

Schlüsselworte: hydrologische Vorhersagesystem, Hochwasservorhersage, Zeitvorsprung

1 Introduction

On the national territory of Hungary, there are 22 rivers (not counting a number of minor water courses and canals) with a total length of 2800 km. Among them, very typically, there are only four smaller ones whose catchment areas are situated almost completely within Hungary. The hydrological regime of the rivers is rather extreme. Flood discharges are ten to one hundred times as high as low-flow discharges. Consequently, water level fluctuations amount to several meters. The total area under flood level (including the wash-land between the flood levees), is 25,000 km^2, i.e., 27% of Hungary's national area and 40 % of her lowland area.

Hungary's endangerment by floods in basically determined by her being situated in the very middle of the Carpathian Basin, compelling her to frequently protect herself from flood waves arriving from the surrounding mountains. According to flood statistics, each 5-6 years considerable, and each 10-15 years very high flood waves have to be expected, in a rather random spatial distribution, in the smaller and greater catchments of the Danube Basin.

Essentially, the basis of the flood protection system aiming at the mitigation of flood damages, are the levees running parallelly to the riverbeds. The total length of main levees is 4200 km, representing the highest specific value, as referred to the country's national territory, in whole Europe. Other methods of flood control – flood storage and diversion -, successfully adopted in other countries, could hardly be adopted economically in Hungary, due to her natural circumstances. Active measures of flood control can be taken only at a few sites, by building emergency flood reservoirs. Between 1850 and 1972, Hungary was hit by 80 catastrophic floods, - the areas inundated by them totalling to about 38,000 km^2 -, 80 % of which having occurred before the turn of the century. In the last decades, the combination of levee strengthening and active/modern flood defence prevented extensive areas from inundation. An efficient flood defence, however, is only possible, if the expectable future development of the

hydrological scenario is known, so that the necessary measures to be taken can be determined on the basis of this knowledge.

It is the task of hydrological (flood) forecasting to determine the expectable development of the hydrological (flood) scenario. In order to correctly evaluate the state-of-the art of hydrological (flood) forecasting in Hungary, a clear picture has to be offered about the concept and the methods of hydrological forecasting as well as about the sources of its errors. By comparing the present Hungarian practice with the most advanced forecasting systems of other countries, the strategy of methodological development can be selected and recommended, by whose adoption the Hungarian forecasting system could achieve the world standard, thus considerably improving both security and efficiency of flood defence.

2 Concept, methods and accuracy of hydrological (flood) forecasting

It is only a minor part of cases when the knowledge of the actual hydrological situation alone is sufficient for efficiently solve water management, water damage prevention and other problems. The task of hydrological forecasting is to determine the expectable development of hydrological processes until an exactly defined date or period in the future. Thus hydrological forecasting is basically different from statistical estimations – erroneously called “forecasting” by some experts – aiming at statements about the probability of occurrence in the future of certain hydrological phenomena.

Based on the knowledge about the actual (present-day) hydrological situation and about the actual stage of meteorological and other processes, influencing the hydrological events, as well as on the scientific knowledge available from these processes, hydrological forecasting makes an attempt to determine the future stage of the hydrological process investigated. Thus the basis of forecasting is always the knowledge available about the investigated process and the factors influencing the latter. The actual situation of these processes, however, is only known from measurements biased themselves by errors, so that they never can be considered representative.

Both scientific knowledge about the physical processes taking place and the computation methods developed on their basis can lead, even in the optimal case, only to a rough approximation of real physical processes, thus offering a rather simplified model of the latter. In other words, our scientific knowledge about these processes is far from being complete.

Finally, it has also to be pointed out that a faultless forecast could not be issued even in the case when both the exact status of all influencing factors in the moment of this issue and a mathematical model perfectly describing the phenomenon investigated were known. It is to say, forecasting starting from the present stage, is concerning a future stage of the process. Thus, in order to compile a faultless forecast, it would be also necessary (beside the ideal condition listed above) that the hydrological process to be forecast, be isolated from its influencing processes (e.g., weather conditions) until the time horizon of forecasting, since the development of the latter processes is unknown at the time of issuing the forecast. This is of course physically impossible in the case of natural processes, since the hydrological process cannot be separated for any period from the influencing effect of meteorological processes. Consequently, it is inevitable that where will be always a certain difference between the real and the forecast status of the hydrological process.

Summarizing, it can be stated that there is an inevitable divergence between forecast and real hydrological values, due to the following facts:

- The measured data, characterizing the relevant processes, are not fully representative and are biased by errors.
- The models used for hydrological forecasting are never completely describing the natural processes investigated.

- During the lead-time of forecasting, the influencing factors keep changing, the measure of these changes until the time horizon of the forecast is unknown, influencing all the same the processes to be forecast.

As already pointed out before, hydrological forecasting is essentially an estimation referring to a chronologically defined future stage of the hydrological process investigated. The “lead-time” is the difference between the date of issuing the forecast and the future date for which it is issued. Since forecasting always refers to the future, the lead-time is always a positive quantity.

However important the increase of the lead-time might be for the users, it is limited by the fact that with increasing lead-time also the effect of the influencing factors onto the hydrological process increases, thus paralelly the accuracy of the forecast decreases. When surpassing a certain limit value of the lead-time, the forecast stops offering any more information as compared with the starting situation, thus becomes pointless. This limit value is the possible maximum lead-time of short-time forecasts.

Necessarily, accuracy and lead-time of forecasting are in inverse ratio to each other. The expectable accuracy of the forecast, however, is basically determined by the variability of the predicted hydrological element during the lead-time. Therefore, whenever qualifying the goodness of a forecast, both its lead-time and the variability of the hydrological element to be predicted have to be taken into account.

In Hungary, the principal user of hydrological forecasts is water damage prevention, and within it, mostly flood defence. Other important users are navigation and water resources management. Also the population display a certain interest for hydrological forecasting (and hydrological information in general), mostly from the viewpoints of flood defence, tourism and sports (angling).

Among the predicted elements, forecasting of water stages is predominant. Due to the frequent ice floods in this country, forecasts of various ice phenomena are also required. The rather limited requirements of flow discharge and water mass predictions are for a better operation of storage reservoirs (whose total volume is rather limited in Hungary), particularly for peak-discharge mitigation by the latter.

In Hungary, most regularly issued forecasts belong to the short-range category. The National Service of Hydrological Information, however, has been preparing also long-range forecasts of the expectable water volume of spring runoff and of the maximum water stages. There is a particularly high interest for long-range forecast, which at present only partially can be satisfied. It is to say, a forecast can be issued only at that time and only for such a lead-time, for which the future value is decisively determined by the status of both the hydrological process to predicted and that of the physical/natural processes influencing the latter, as observed when issuing the forecast. Since such information are only available about selected hydrological elements and from certain catchment areas, the possibilities of long-range forecasting in Hungary are limited, independently from the know-how available.

3 State-of-the-art of hydrological forecasting in Hungary

Due to the endangerment of a considerable part of Hungary’s national area, the topic of hydrological forecasting has always been a timely issue. The present-day hydrological forecasting system of Hungary came into being on the basis of the results of methodological development efforts taken place from 1979 to 1986. Practically each of the 12 District Water Authorities (DWAs) of the country is issuing hydrological forecasts, while also the National Hydrological Forecasting Service, working in the framework of the Hydrological Institute of Water Resources Research Centre p.l.c. (VITUKI) is heavily involved in this activity. Forecasting by the DWAs is primarily concentrated onto flood peak forecasting. Daily water stage and discharge forecasts, on the other hand, are continuously issued practically only by the National Hydrological Forecasting Service of VITUKI.

Only the National Hydrological Forecasting Service of VITUKI is issuing long-range hydrological forecasts, based on snow resources accumulated during the winter, for the Rivers Danube and Tisza for the spring period (March-May). The same institution compiles ice forecasts with a lead-time of 3-4 days for the two great rivers.

Flood forecasts are being compiled in accordance with the regulations of the Flood Hydrometeorological Service (ÁHSz) issued in 1995. This document includes, beside of flood forecasts, also the prescriptions for compilation and diffusion of daily forecasts, because the latter of course are serviceable also for flood defence. For flood-free periods, there are no special regulations about how to issue forecasts, probably due to the fact that they are almost exclusively in the competence field of the National Hydrological Forecasting Service of VITUKI.

As for the present-day practice of hydrological forecasting in Hungary, it has to be admitted that its methodology reflects the development level of the 1980s. One meets only very seldom graphical methods, while the numerical regression methods are widely spread. A precipitation-runoff model for forecasting purposes is being adopted, however, only by the National Hydrological Forecasting Service of VITUKI.

There is a considerable backwardness in establishing the necessary contacts between forecasting methods and data bases. The basic data of forecasting still flow in the traditional way into the computerized forecasting systems. Similarly, there is no on-line contact yet between forecasting and the gradually established telemetric systems either. One of the unsolved tasks is the prompt computerized checking of operative data used for forecasting. Obviously, erroneous input data can result only in an erroneous forecast. Thus the reliability of basic data is the fundament for the reliability of the forecasts.

The forwarding of hydrological data, forecasts and flood alarms to the users is secured on the following three levels:

- On national level, it is the National Hydrological Forecasting Service of VITUKI that publishes daily hydrological data on the Daily Hydrological Chart, in the daily water stage report broadcast by Radio Petőfi, in the pictorial bulletin of Hungarian Television and on WEB (WWW.VITUKI.HU)
- On regional level, it is the District Water Authorities (DWAs) that forward hydrological and flood information to the consumers.
- Beyond the general information, industrial and trade companies can obtain special additional information both from the National Hydrological Forecasting Service and from the District Water Authorities.

4 Timeliness and strategy of the development of forecasting

In spite of the successful forecasting of the latest high floods one can see a substantial possibility of further development by utilizing the results of computer techniques and of the communication revolution. Nowadays there are no limits any more for adopting computer techniques, offering a broad variety of possibilities to develop day by day new tools and solutions, to be integrated also into the instrumentarium of hydrological forecasting. The physical and statistical laws of the genesis and movement of flood waves are extremely complex. Consequently, their short-, middle- and long-range forecast can only carried out by operating well-established systems of data observation, forwarding and processing.

One more reason for speeding up development of hydrological forecasting is the fact that meteorological forecasts, serving as its basis, have gone through a rapid development during the last years. The digital with lead-times of several days, prediction fields prepared by the great European centres of meteorological forecasting, are available in Hungary, too. also the data, integrated for Hungary's national territory, of radar-measured precipitation can be obtained from the Hungarian Meteorological Service. All this opens never dreamed-of possibilities for

the development of the activities related to hydrological forecasting. It is obvious that the advantages originating from the development of meteorological forecasting must be used for increasing the accuracy and the lead-time of hydrological forecasts. At the same time, one has to be aware of the fact that at present the possibility of such utilisation is rather limited, due to the actual low level of the hydrological forecasting system, so that an updating of the latter has become an indispensable requirement.

The goal of the planned development of hydrological forecasting is to issue a flood- and a daily forecast with a lead-time of minimum 24 hours possibly both for all daily reporting and for all flood-hydrologically critical gauging stations of the country. In the new forecasting system, the present separation between daily and flood forecasts has to be eliminated: both kinds of forecasts should be handled in the framework of one system, ensuring methodically the harmonization between the two kinds. The forecasting system should contain objective, computerized processes enabling the issue of forecasts by utilizing the flood-hydrological data systems yet to be developed. This new forecasting system should ensure the building-in of the new forecasting products of the Meteorological Service and their utilization in hydrological forecasting.

High reliability of forecasting basic data is one of the fundamental requirements of the forecasting system to be developed. As a consequence, the quality-checking system of these basic data has to be established either as a part or a completion of the forecasting system. Also a new system of publishing the results of forecasting has to be developed, by utilizing the existing national information system of water management and the new possibilities offered by INTERNET. As an element of quality control of forecasting, a system for storing, processing and evaluating its results has also to be established.

The new forecasting system, resulting from the planned developing activity, beyond supporting the solution of water resources management and water damage prevention tasks, may ensure the services to the full circle of users, including public information. The main elements of the strategy of development are the following:

- The elements of the system must be developed in a well-harmonized and complex way.
- Development must take place along various parallel lines, imbedded into related developments of the interested branches of water management (development of the facilities for water damage prevention, development of informatics, development of operational hydrology, development of communication and data forwarding, etc.).
- In order to harmonize these developments among each other, projects have to be launched for the realization of carefully examined development programs.
- The expert background of flood forecasting has to be broadened.

It was recommended to realize the development tasks of forecasting, on the basis of the above strategy, in the framework of a project. If starting the project as early as possible (but by no means later than in 2000), its successful finishing can be planned, with putting into operation the new forecasting system, for the end of the year 2003. The utilization of partial results of development can start, however, at an earlier date, in the form of experimental operation. In such a way, it can be ensured that the results of the development can be utilized already from 2001 on, in a continuously increasing extent, for supporting the activities of water resources management and flood defence.

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The Contribution of Italy to the Danube Monitoring

Giuseppe Batini, Marcello Benedini, Michela Munari

Abstract: The Alps are the divide of the Danube basin, but their southern slope is almost entirely in Italy and belongs to the typical climatic zone of several Italian regions, completely inserted in the Mediterranean reality. A better knowledge of the climate and hydrology of this area can be useful also for solving the actual problem of such a great river, that seems now to be deeply affected by a global climatic change.
The contribution of Italian monitoring and scientific structures can be very important in these perspectives.

Key words: Climatic change, Drought, Flood

1 Italy and the Danube basin

From a geographic viewpoint, the Danube basin affects also the territory of Italy and the Italian Government is officially involved in the international problems arising for the management of such a great river. The portion of Italian territory belonging to the Danube basin extends only over 139 km² and consists of the upper catchment of River Drava-Drau that originates in the Dolomites and flows in a narrow alpine valley. In its downstream reaches this river becomes one of the major tributaries of the Danube and after crossing Austria, Hungary and Croatia for more than 700 km, it joins the main river in Yugoslavia. Nevertheless, at the gauging cross-section of Versiaco-Viershach, close to the border with Austria, its daily mean flowrate is of the order of 3 m³/s, with an observed maximum of about 14 m³/s. For its hydrological aspects, the Italian reaches of Drava-Donau have a very small effect on the main river. Their hydrological regimes, as well as their management problems, have to be considered separately.
In a more general view of the Danube, that covers a huge portion of Europe, one cannot neglect that the alpine chain is for a large extent the southern divide of the basin. Many important tributaries originate in the Alps, particularly in the Austrian territory. Consequently, the hydrological conditions of the Alps have a remarkable effect on the main river, at least on its upstream reaches. To this aim, all the information concerning climate and precipitation in the Italian Alps can be useful to better understand the present and future Danube hydrologic peculiarities, in a view of the basin's water management policies.

2 New climate pattern in the Mediterranean area

The Mediterranean area, into which are inserted all the Italian regions, is undergoing a slow but sufficiently clear modification, shifting to drier conditions, with shorter precipitation and higher temperature (Rossi *et al*., 1992).
In the Italian territory attention should be given to the regions located in the Northeast corner, which are closer to the Alps and to the Danube basin.
Several investigations have been conducted for this area, to identify climate anomalies and possible trends. The results have been sometimes inconsistent. So far, the 1988-1991 period has been the worst, as concerns the shortage of water and the presence of dry conditions. A precipitation deficit, in comparison with the mean values of a long series of records, is the main indicator of such a situation. In Northern Italy, usually considered a water rich area, the deficit was up to 18% in 1989, compared to the country value of 24% in the same year. The latter includes obviously the observations in the Central and Southern regions, where the shortage was indeed much higher. In some areas at the foot of the Alps the observed deficit was also very high: during the 1989-90 winter season (from September to March) a 45% shortage was recorded in the area around Udine and 40% in the catchment surrounding Trento and Bolzano-Bozen.

Another indicator is the air temperature, for which the comparison to the mean values of a long observation sequence can give a clear indication. In places around the north Adriatic Sea, like Trieste, the mean annual temperature has been 6% higher in 1990 and 2% in 1992. At Brescia, which is also located at the foot of the mountain, it has been 3% higher in 1990.
The increased temperature and the reduced precipitation have caused a worrisome shortage of running water in some rivers, originating from the Alps. River Brenta had a 42% deficit in 1990 and River Adige 29%. Shortage of water affected also the alpine lakes, particularly Lake Garda, and the aquifers of a large area at the foot of the Eastern Alps.
The data relevant to the 1988-1991 period have emphasised an unusual dry period, occurred after several years of observation. Several events have occurred during the same period and some trends could be presumed, but not entirely confirmed. It might be inappropriate and perhaps incorrect to speak of a foreseeable trend to a drought. In any case there are sufficient reasons to control the climate and the hydrology in the next future.

3 Climate and hydrology in the Alps

For the objectives of this analysis, the attention is concentrated on the Sesto-Sexten meteorological station, controlled by the Hydrographic Office of the Bolzano-Bozen Province. Like several other stations in the area, it benefits from a very long series of data and is significant of a very large zone.
Sesto-Sexten is located in a sub-catchment of Drava-Drau, at an elevation of 1310 m a.s.l., and is surrounded by very high peaks, reaching 3145 m a.s.l.
Several considerations can be drawn from the available data. Of great interest is the number of rainy days per year, as shown in Fig. 1 in which a simple linear regression puts into evidence a clear trend to decrease. During a 70-year time interval the average

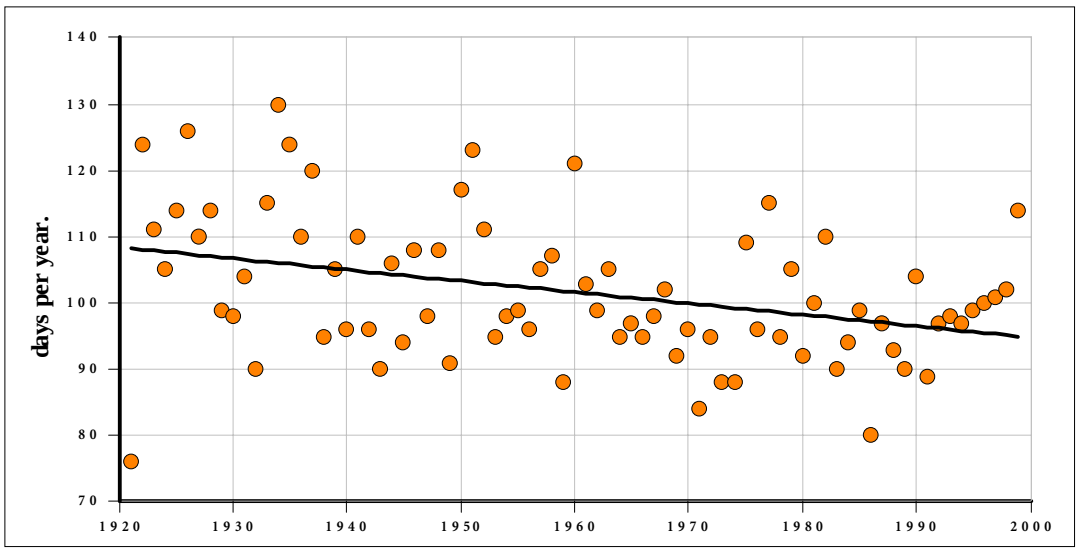

Fig. 1 Rainy days per year at the Sesto-Sexten meteorological station.

value has decreased around 110 days per year to 95 days per year.
The trend to drier conditions seems to be confirmed by the precipitation records, although the sequence of data shows a very high irregularity, with values sometimes much greater than the average followed by much smaller ones. The mean value of the period is 884.1 mm/year and a linear regression shows higher average values at the beginning and lower values at the end. The reduction of the annual precipitation can be roughly estimated of 10 % and occurs mainly in winter but is also remarkable in July, the typical summer month. It is worthy to mention that in the alpine area this season has normally the highest precipitation. July in particular is sometimes characterised by a total rainfall of more than 200 mm.

A deeper analysis can take into consideration the mean decade values of the annual precipitation. Starting from the 1941-1950 decade, when the mean value was 947,3 mm/year, there is a clear trend to decrease, also in last 1991-2000 decade, although not yet complete.
Very significant is the air temperature, recorded during the last 50 years. Fig. 2 shows the mean annual values. As concerns the maximum, the average is now up to 3 °C higher than in 1950.

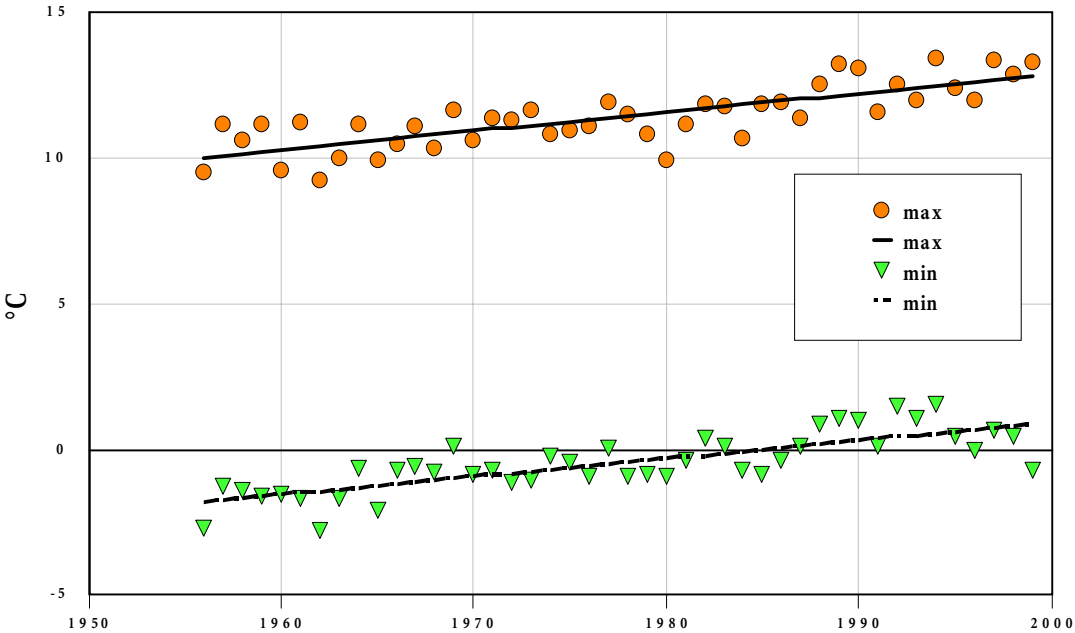

Fig. 2 Mean annual temperature, maximum and minimum, at Sesto-Sexten meteorological station.

The climatic change of the past 50 years has been remarkable particularly in winter, when the annual average value is now over 0°C. Just a few decades ago it was -2°C. Significant is the monthly average temperature in January, the coldest month, which is now around –8°C, more than 2°C above the average of the early fifties.
The analysis of the maximum values is also significant, as it characterises the terms for the hydrological balance. The monthly average temperature in July, the hottest month, is now about 2°C higher than during the early fifties.
A decrease of snowfall and reduction of persistence of snow on the ground normally accompany the increased temperature.
If considered with the other terms described above, the increase of air temperature contributes to stress the probability of a drier period in the next future, with an expectable lower availability of water resources.
This very simple statistical consideration can cancel the optimistic appreciation that seemed to be justified by the fact that some recent year had precipitation records higher than the average values. It was only, in fact, an exceptional event above an ascertained trend. The theory of an overall climatic change seems to be confirmed, instead of that proposing a long period of dry and wet years alternation.

4 Heavy storms and floods

Another peculiarity of the Mediterranean climate seams to be the increased occurrence of precipitation events characterised by heavy rainfall concentrated in a very short time interval (Anselmo *et al*., 1989). Also in the alpine areas rainfall intensity of more than 60 mm/h has been recorded (Marchi *et al*., 1989). The highest values occur particularly in the October-

November period and cause high flowrate peaks in the receiving streams, which are now greater than the average values obtained with the corresponding long-term records.
These high precipitation events are responsible of flood not only in the mountain water body, but also downstream in the main rivers.
These aspects, which are now observed currently on the southern slope of the Alps, must be considered in the light of a broader analysis, able to include the most advanced approach to the climate behaviour in the whole Mediterranean basin, also to ascertain what is the extent of their inference on the Danube catchment after trespassing the alpine barrier.

5 Needs of more information

In line with the above considerations, a more accurate evaluation of the occurrence of dry periods in the Alps, as well as of the peak precipitation events, can be useful to explain the boundary conditions in which the Danube catchment is expected to reshape its behaviour in the near future. The information collected in the Northeast regions of Italy is therefore very useful to improve the knowledge of the Danube hydrology.
The Italian Department of Technical Services, in a joint effort with the local Hydrographic Offices, is conducting a very intensive updating of the monitoring structures all over the national territory, with particular attention to the alpine zones. The improved data collection system, based on the most advanced technological support, aims at defining the basic knowledge, that is necessary to identify the peculiarities of a foreseeable drought, but, at the same time, to focus on reliable mechanisms for high rainfall forecast, in relation to the generation and propagation of floods.
The efforts undertaken by the Italian monitoring structures make up an active commitment of international co-operation, in line with initiatives promoted by the European Union. In this activity the Department of Technical Services and the local Hydrographic Offices are particularly involved with the participation of the scientific community. The Hydrographic Office of Bolzano-Bozen is actively working to strengthen its ties with the contiguous areas that belong directly to the Danube catchment.

6 Monitoring and research

The research activity promoted by the Department of Technical Services, in co-operation with the Italian and the international scientific community, concerns several aspects of the foreseeable climatic change in Italy, in connection with the other Mediterranean countries. As concerns the hypothesis of drought, several items are presently under very deep investigation, involving all the expertise related to the climate problems. One of the main activities is in the frame of the EU programme “INTERREG II”, that has a specific section devoted to drought problems. An important tasks is the definition of drought in a way that is consistent both with the hydrology and the economic consequences. This is achieved through the development of tools able to compute “drought indices”, (Bordi and Sutera, 2000) useful for forecasting estimates at various time scale. Emphasis has been put so far on “drought indices” directly related to the occurrence of precipitation.
Such tools have been validated simulating “a posteriori” a period during which the southern regions of Italy have experienced severe dry situations. An investigation on the appreciable anomalies of surface temperature, sea level pressure and precipitation rate provides further improvement in the knowledge of the mechanisms governing the climatic pattern. A positive surface temperature anomaly combined with that of a negative precipitation rate indicates a large-scale situation favourable for the continuation of an already existing dry situation.
To comply with its institutional mandate the Department is proposing a “Drought Bulletin” able to provide the responsible authorities with an instrument useful to take decision in matters concerning water resources. A distinct feature of the “Bulletin” will give information on the

availability of the water resources, after a diagnosis of data summarising climate conditions at three different spatial scales, namely global, regional and local.
To complete this picture, the current research is also oriented to focus on the connections of drought with aridity, taking in due account also the possibility of desertification, in some characteristic areas. This is under the consciousness that similar problems are touching not only the Mediterranean countries, but also the inland Europe, and will be therefore affecting also the Danube basin.
As concerns floods, the main interest is now on forecasting tools. As a forecast of more than 10 days appears to be still inappropriate, the most successful applications are those relevant to short term for flood propagation and for the inundation of areas around the most critical stretches of a river. These tools are based on real time information, mostly provided by satellite.
In line with this the Department has started a concerted action to develop tools able to forecast, primarily, the surface runoff and the free surface level, for a given flowrate, taking also in due account the area prone to inundation. For the development of tools able to forecast flood events, particularly in a medium-small size catchment, the importance of orography and the presence of unstable meteorological conditions are essential.
These aspects concern the typical situation of the various Italian regions; the alpine zone deserve a very high attention, in line with the efforts to provide these zones with the most advanced equipment for meteorological and hydrological observations. Several radar equipments have been already installed, mostly on high elevation sites, able to give suitable information for meteorological forecast.
The alpine area facing into the Danube basin is now one of the best equipped zones of Italy, working in connection with the meteorological stations located in the other countries belonging to the same basin.
As concerns the future programmes, worthy to be mentioned is the co-operation named "INTERREG III", to be launched in short time, which will focus on the problems of a very large area that includes both the Danube and some Italian regions. In such a context the Italian structures are expected also to provide information suitable for the solution of the future water problems in the Danube basin.

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Stochastico-Determinate Mathematical Model of a River Runoff Probability Forecast

Juri M.Denisov, Natalya A.Agaltseva, AlexanderV.Pak

Abstract: The application of mathematical models of the runoff is the perspective of the development of the regional hydrological forecasting. The stochastic and deterministic models of rivers runoff formation is a new stage of the development for mathematical models rivers runoff. These models for probability hydrological calculations and forecasting have been designed. Besides, a great attention is paid to spesific description of ways of approach for determinate structures of diffuse tenzor included into developed model.

Key words: Stochastic and deterministic mathematical model, runoff rivers, forecasting, conditional density of the discharge probability.

Stochastisch-deterministische mathematische Modelle für Wahrscheinlichkeitsvorhersage des Abflusses

Zusammenfassung: Die Anwendung mathematischer Modelle des Abflusses ist der Ansatz für die Entwicklung regionaler hydrologischer Vorhersage. Die stochastischen und deterministischen Modelle für die Bildung von Abflüssen in Flüssen sind eine neue Ebene der Entwicklung mathematischer Abflußmodelle. Es wurden diese Modelle zur Berechnung hydrologischer Wahrscheinlichkeit und Vorhersage entwickelt. Große Aufmerksamkeit wurde der Beschreibung der Wege zur Annäherung an die Struktur des Diffusionstensors geschenkt.

Schlüsselwörter: stochastisch-deterministisches Modell, Abfluss, Wahrscheinlichkeitsberechnungen und Vorhersage, absolute und relative Dichtefunktion der Abflusswahrscheinlichkeit, Diffusionstensor.

1 Introduction

For the first time stochastic and determinate models appeared at the beginning of the 90th enabling one to compute unconditional probability density of intra-annual water discharge for a certain year (Denisov & Volkovich, 1990; Denisov, 1996). However, practical demands of hydrology on probability forecasts have required the development of stochastic and determinate model of rivers runoff with conditional probability density. Such a model was created in SANIGMI in 1998 (Agaltseva et al, 1998).

This paper presents the results of further development of the probability prognostic model. An attempt has been also made to reveal the structure of diffuse tenzor being a member of this model.

2 Mathematical model with the conditional probability density

To develop this model, partial differential equation for three-dimensional probability density $f(Q, dQ/dt, d^2Q/dt^2; t)$ should be derived, and boundary conditions for this equation should be defined with further computation of conditional probability density in the form $\psi(Q(t+\Delta t)|Q(t);t)$.

Water discharge in time $t+\Delta t$, when discharge in time t is known will be written as the sum of the three terms of Tailor-series expansion:

$$Q(t+\Delta t) = Q(t) + \left.\frac{dQ}{dt}\right|_t \Delta t + \frac{1}{2}\left.\frac{d^2Q}{dt^2}\right|_t \Delta t^2$$

The discharge itself and also its first and second derivatives on time should be considered as coordinates of some three-dimensional space. Let us denote:

$$x=Q; \qquad y = \frac{dQ}{dt}; \qquad z = \frac{d^2Q}{dt^2}$$

Then let us introduce probability density flux $\vec{q}_f$, which incorporates convective

$$\vec{q}_{fk} = f \cdot \vec{u}$$

and diffuse (entropy) components

$$\vec{q}_{fd} = -D \cdot Gradf$$

i.e.

$$\vec{q}_f = \vec{q}_{fk} + \vec{q}_{fd} = f \cdot \vec{u} - D \cdot Gradf \qquad (1)$$

Here D is diffuse tenzor, $\vec{u}$ is speed vector in phase space.

$$\vec{u} = \frac{dx}{dt}\vec{i} + \frac{dy}{dt}\vec{j} + \frac{dz}{dt}\vec{k} =$$

$$= \frac{dQ}{dt}\vec{i} + \frac{d^2Q}{dt^2}\vec{j} + \frac{d^3Q}{dt^3}\vec{k} = \qquad (2)$$

$$= y\vec{i} + z\vec{j} + \frac{dz}{dt}\vec{k}.$$

2.1 Estimation of $\vec{u}$ velosity in the phase space

In the case when sources and runoff cannot be observed, which is characteristic for the perennial streams, differential equation of the probability density balance will be written as:

$$\frac{\partial f}{\partial t} + Div\ (f \cdot \vec{u} - DGradf) = 0 \qquad (3)$$

Here Div and Grad are operators of difference and gradient in phase space.
Speed $\vec{u}$ in phase space is determined from the mathematical model of the runoff hydrograph. As an example, the linear two-dimensional model of the river runoff will be taken which is represented by linear ordinary differential equation of the second order.

$$\frac{d^2Q}{dt^2} + \alpha_1 \frac{dQ}{dt} + \alpha_0 Q = \beta_1 \frac{dQ_P}{dt} + \beta_0 \cdot Q_P \qquad (4)$$

Here α_0, α_1, β_0 and β_1 are parameters which are larger or equal zero; Q_P is discharge of water from the catchment surface which is accumulating owing to both precipitation and snow and ice melting.
Let us denote:

$$\varphi(t) = \beta_1 \frac{dQ_P}{dt} + \beta_0 \cdot Q_P \qquad (5)$$

According to the introduced notations, differential equation (4) will be expressed as:

$$z + \alpha_1 y + \alpha_0 x = \varphi(t) \tag{6}$$

In order to define the values of *dz/dt* (2), it is necessary to differentiate (6) by *t*.

$$\frac{dz}{dt} + \alpha_1 \frac{dy}{dt} + \alpha_0 \frac{dx}{dt} = \frac{d\varphi}{dt}$$

or

$$\frac{dz}{dt} + \alpha_1 z + \alpha_0 y = \frac{d\varphi}{dt} \tag{7}$$

Then

$$\frac{dz}{dt} = \frac{d\varphi}{dt} - (\alpha_1 z + \alpha_0 y) \tag{8}$$

and expression (2) for speed $\vec{u}$ will be written as follows:

$$\vec{u} = y\vec{i} + z\vec{j} + \left[\frac{d\varphi}{dt} - \left(\alpha_1 z + \alpha_0 y\right)\right]\vec{k} \tag{9}$$

and

$$\frac{d\varphi}{dt} = \beta_1 \frac{d^2 Q_n}{dt^2} + \beta_0 \frac{dQ_n}{dt} \tag{10}$$

Thus, applying the mathematical model of the runoff we have derived the expression for speed $\vec{u}$ through coordinates of phase space as well as derivative by *t* of the known function *φ(t)*.

2.2 Initial and boundary conditions

And now let us consider the boundary conditions. As it is known that water discharge cannot be negative, i.e. $x \geq 0$, then the value *f* flux across the plane $x = 0$ does not have to be observed. This condition is expressed by the following equation:

$$f(0, y, z; t)\, y - \left(D_{xx} \frac{\partial f}{\partial x} + D_{xy} \frac{\partial f}{\partial y} + D_{xz} \frac{\partial f}{\partial z}\right)\Big|_{x = 0} = 0 \tag{11}$$

where D_{xx}, D_{xy}, and D_{xz} are components of diffuse tenzor.
The remaining boundary conditions will be:

$$\lim_{x \to \infty} f(x, y, z; t) = 0, \tag{12}$$

$$\lim_{y \to -\infty} f(x, y, z; t) = 0, \tag{13}$$

$$\lim_{y \to +\infty} f(x, y, z; t) = 0, \tag{14}$$

$$\lim_{z \to -\infty} f(x, y, z; t) = 0, \tag{15}$$

$$\lim_{z \to +\infty} f(x, y, z; t) = 0 \tag{16}$$

For the simple determination of the function *f(x,y,z;t)* the initial condition should be written

$$f(x, y, z; 0) = \omega(x, y, z). \tag{17}$$

2.3 Estimation of the conditional probability density

Then conditional probability density ξ of values *y* and *z* with the given value of *x* should be determined. It equals

$$\xi(y, z | x; t) = \frac{f(x, y, z; t)}{\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y, z; t)\, dy\, dz}$$

In order that *Q* in time $t + \Delta t$ may have the given value, provided that in time *t* it is equal to *Q(t)*, it is necessary to follow the equation:

$$[Q(t + \Delta t) - Q(t)] = \Delta t \cdot y + \frac{1}{2} \Delta t^2 \cdot z \tag{18}$$

Let us determine the conditional function of distribution $F(Q(t + \Delta t) | Q(t); t)$, i.e. the probability of the case when random variable $Q^*(t + \Delta t)$ is smaller than $Q(t + \Delta t)$, provided that water discharge *Q* in time *t* is equal *Q(t)*. This distribution function is equal

$$F(Q(t + \Delta t) | Q(t); t) = \int_{-\infty}^{\infty} dy \int_{-\infty}^{z_1(Q(t+\Delta t))} \xi(y, z | x; t) dz \tag{19}$$

where

$$z_1(Q(t + \Delta t)) = \frac{2}{\Delta t^2} [Q(t + \Delta t) - Q(t) - \Delta t \cdot y] \tag{20}$$

Then unknown conditional probability density being expressed as

$$\psi(Q(t + \Delta t) | Q(t); t)$$

will be determined as a derivative of the distribution function by $Q(t + \Delta t)$, i.e.

$$\psi(Q(t + \Delta t) | Q(t); t) = \frac{\partial F}{\partial Q(t + \Delta t)} = \frac{\partial F}{\partial z_1} \left| \frac{\partial z_1}{\partial Q(t + \Delta t)} \right|$$

Consequently,

$$\psi(Q(t + \Delta t) | Q(t); t) = \frac{2}{\Delta t^2} \int_{\infty}^{\infty} \xi(y, z_1 | Q(t); t) dy \tag{21}$$

Thus, the unknown probability density has been determined.
Let us return to diffuse tenzor *D*. If we denote by x_i the phase coordinates, then diffuse tenzor components will be $[x_i x_j / t]$. Besides, this tenzor appears to be symmetric. Values of tenzor components are apparently linked with phase coordinates measurement errors and function $\varphi(t)$ computation as well as the degree of the model agreement with natural process.
The satisfy the dimensions of tenzor components and its symmetry as well as tenzor dependence on errors of initial information, the following expression for its components should be taken as one of the possible versions:

$$D_{ij} = D_{0ij} \cdot \delta_{ij} + k_D \left(\sigma_i \left| \frac{dx_j}{dt} \right| + \sigma_j \left| \frac{dx_i}{dt} \right| \right) \tag{22}$$

where σ_i is the root mean-square error of coordinate x_i, determination; $k_D > 0$ is the dimensionless coefficient of proportionality; D_{0ij} are diffuse coefficients linked with the model error; δ_{ij} is Kroneker's symbol.
If in accordance with the structure of tenzor *D* components we multiply it by *Gradf*, without taking into account the first term of the equation, then this product, as it can be easily shown, will be as follows:

$$D_1 \cdot Gradf = k_D \cdot \sum_i \left[\sigma_i (\vec{\chi} \cdot Gradf) + \left| \frac{dx_i}{dt} \right| (\vec{\sigma} \cdot Gradf) \right] \cdot \vec{e}_i \tag{23}$$

where D_1 is diffuse tenzor (22) without the first term, $\vec{e}_i$ is a single vector of phase coordinates, vectors $\vec{\sigma}$ and $\vec{\chi}$ are respectively:

$$\vec{\sigma} = \sum_i \sigma_i \cdot \vec{e}_i, \qquad \vec{\chi} = \sum_i \left| \frac{dx_i}{dt} \right| \cdot \vec{e}_i \tag{24}$$

Then according to the above-mentioned, (23) will be written as:

$$D_1 \cdot Gradf = k_D [(\vec{\chi} \cdot Gradf)\vec{\sigma} + (\vec{\sigma} \cdot Gradf)\vec{\chi}] \tag{25}$$

Four values k_D , D_{011}, D_{022} and D_{033} should be found processing from the condition that mathematical expectations $\bar{x}, \bar{y}$ and $\bar{z}$ coincide with their values computed for the given year by determinate model.

3 Probabilistic runoff forecasting

At present together with the traditional techniques of the calculation and forecasting of the runoff the probabilistic analogues of the probabilistic techniques are being developed and introduced into the operational practice. Their principal distinction from the usual techniques is that they for calculation and forecasting of the density of the probability of the water discharge.
Despite the deterministic models of the river runoff forecasting this method provides for the calculation and forecasting not only of the *Q* value of the water discharge at any *t* time, but *Q* value of the probability density at any time $t - f(Q,t)$.
Getting as a output the stochastic and deterministic model $f(Q,t)$ probability density, we can calculate the following characteristics:

- mathematical expectation of $\overline{Q}$ discharge by the formula

$$\overline{Q}(t) = \int Q(t) f(Q,t) dQ \tag{26}$$

- the probabilistic estimation (p) of the expected range of the runoff being forecasted ($Q_1 \le Q \le Q_2$, where Q_1 and Q_2 – the low and upper thresholds of the variation of the value of the forecasted water discharges) by the formula:

$$p(Q_1 \le Q \le Q_2) = \int_{Q_1}^{Q_2} f(Q,t) dQ \tag{27}$$

integral (27) is calculated numerically by the modified Sympson's technique using the formula:

$$J(a,b) = \frac{b-a}{3N}\left[\sum_{i=1}^{N}(3-\cos\pi i)Y_i - (Y_0 + Y_N)\right]$$

where a and b are the low and upper thresholds of integral (27), which equal Q_1 and Q_2, respectively; Y_i – subintegral expression (27); N – number of points of the dividing of the integration domain (N – even).

Having prescribed different options for the probable range of the range of the values Q_1 and Q_2 of the forecasted runoff, we can get the corresponding options of their probabilistic estimations by the formula (27).

Let's consider the issue of the practical application of the stochastic and deterministic model in the probabilistic runoff forecasting. As an example the calculations of the snow reserves, the melt and rain water contributions onto watershed of Akhangaran river surface in 1960 and the model calculations of the runoff hydrograph by the stochastic and deterministic model were executed. Fig. 1 shows the results of numerical experiments. The first present the calculation of the hydrograph by the deterministic model of the runoff (Q_S) forecasting and second – the mathematical expectation of the discharge values in the prescribed year ($\overline{Q}$), calculated by formula (27).

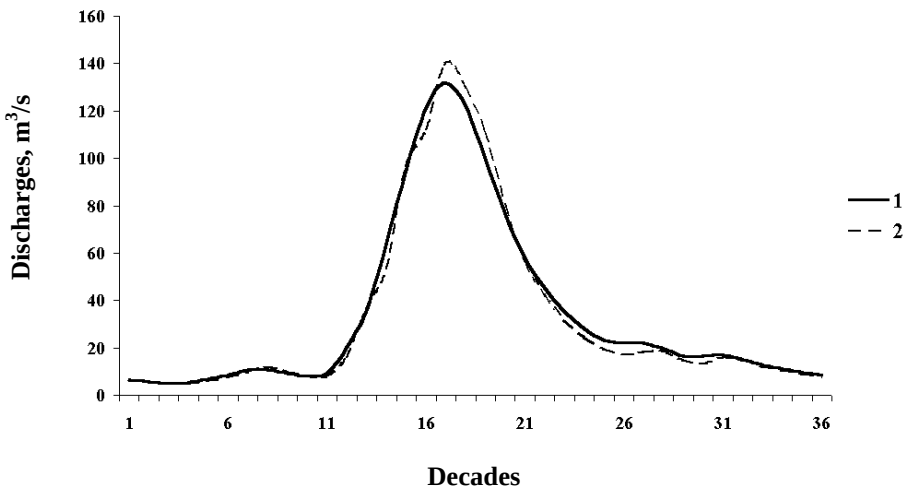

Fig. 1 Hydrograph of Akhangaran river runoff for 1960

1 – discharge value calculated by deterministic model (Q_S),

2 – mathematical expectation of the discharge value in the prescribed year ($\overline{Q}$).

The next step of calculation is the prescribing of the options of the probable range of the forecasted flow values Q_1 and Q_2 for the forecasted period and their probabilistic estimations.
Thus, the application of stochastic and deterministic models increase qualitatively the informativity of the produced forecasts and allows to take the optimum decisions in the operational work.

4 Conclusion

The stochastic and deterministic models open a new independent scientific approach to the application of the river runoff taking into account both deterministic and stochastic components of the runoff formation factors.
The calculation and forecasts of the runoff by these models provides for more reliably definition of the strategy of optimum management of the water resources and extreme situations.

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Development of a Short Term Real Time Runoff Forecasting Method for the Austrian Danube

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Abstract: In this paper a real-time runoff forecasting model for the Austrian Danube is presented. It is part of a comprehensive discharge forecasting system being developed for estimating future energy production from a system of hydro power plants. The model presented here provides forecasts for up to 24 hours lead-time at an one-hourly time-step. It makes use of streamflow at 32 runoff gauges, areal precipitation for up to 24 regions, and meteorological precipitation forecasts. The model is named HYSIM, specific versions of which are in operational use for predicting discharges at the Austrian rivers Drau and Salzach. It consists of modules representing rainfall-runoff transformations, runoff routing (with and without accounting for lateral inflows due to rainfall), flood routing during floods which may involve flow into wetlands and lowland forests, superposition of tributaries, and reservoir management. Modelling flow at the Austrian Danube required the development of new modules, e.g. a smoothing algorithm for addressing difficulties resulting from anthropogenic effects on the hydrographs.

Key words: discharge forecasting model, HYSIM, Austrian Danube, Bayes- Kalmanfilter algorithm, anthropogenic effects.

Entwicklung eines neuen operationellen Durchflussvorhersagemodells für die Österreichische Donau

Zusammenfassung: In dieser Arbeit wird das operationelle Vorhersagemodell HYSIM vorgestellt Es ist Teil eines größeren Durchflussvorhersagesystems, das im Auftrag eines Energieerzeugungsunternehmens zur besseren Abschätzung der zu erwartenden Durchflüsse entwickelt wurde. Die hier präsentierte Komponente liefert stündliche Prognosen bis zu 24 Stunden in die Zukunft und benützt dazu ca. 32 Durchflussmessstellen, Gebietsniederschläge, die sich aus dem Mittel mehrerer Niederschlagsmessstellen bilden, und meteorologische Niederschlagsprognosen. Das Modell selbst, das in angepassten Versionen bereits seit einigen Jahren Durchflussprognosen für die österreichischen Flüsse Drau und Salzach liefert, besteht aus mehreren Modulen wie der Niederschlags- Abflussmodellierung, dem Wellenablauf im Flussschlauch mit und ohne zusätzlichem Abfluss zufolge Niederschlags, dem Wellenablauf während Hochwässern, die Überschwemmungen in die Vorländer und Flussauen zur Folge haben, einem Überlagerungsmodul für die Zusammenführung einzelner Zubringer sowie der Möglichkeit, die Vorabsenkung in einzelnen Stauräumen zu berücksichtigen. Die Modellierung der österreichischen Donau erfordert zusätzlich die Entwicklung weiterer Bausteine, wie zum Beispiel einem Glättungsalgorithmus für stark anthropogen beeinflusste Ganglinien.

Schlüsselworte: Durchflussprognose, HYSIM, österreichische Donau, Bayes- Kalmanfilter, anthropogener Einfluss.

1 Introduction - Description of the Forecasting System

Due to the liberalisation of the electricity market in the EU it has become more important for electricity companies with a high percentage of hydro power production to optimise their operation rules. One of these tools is a forecasting system for runoff up to some days ahead, which can be used as an input to optimisation models of plant operation. The runoff forecasting system presented here is part of such a large program.

The entire forecasting system consists of four different types of models as shown in Figure 1.

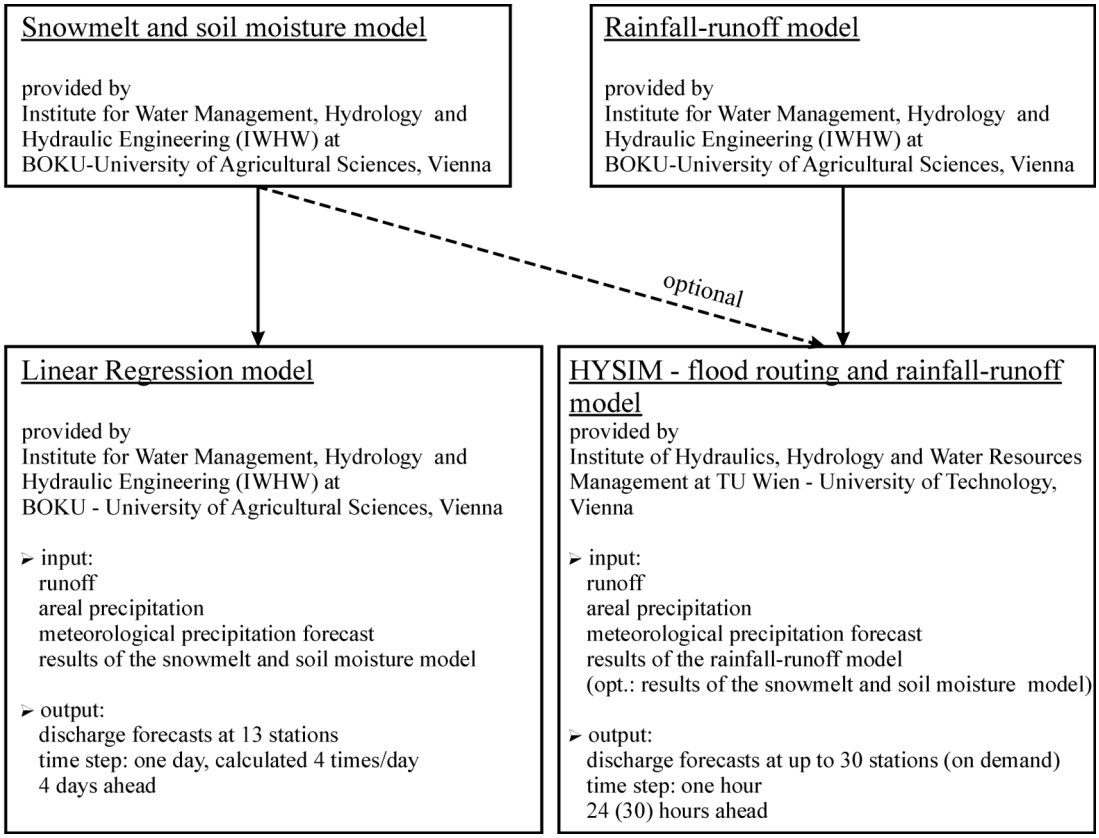


Fig. 1 Interaction of the models

All models make use of data from various sources which are transmitted to a central database. These data are:

- discharge at gauging stations from Austrian and German hydrological services
- discharge from Austrian and German hydro power plants
- precipitation (rain gauges); readings from several gauges are combined to areal precipitation in order to reduce the amount of data (24 regions are defined) and to have a single value of precipitation for hydrologically similar regions.
- temperature measurements at four altitudes from stations of the Austrian and German hydrological services, which are also combined into areally averaged values for 24 regions.
- precipitation forecasts up to 96 hours ahead provided by the Austrian meteorological service (ZAMG) at 6-hourly time-steps.

The database is used by the following four models:

1.1 Snowmelt and soil moisture model

The snowmelt model uses temperature data at four different altitudes which are interpolated to the elevation layers by means of pluviometric gradients. Snow accumulation is estimated using precipitation data and hypsometric functions. Soil storage and runoff formation is represented by a non-linear two storage concept. The output of the model and its combination with different subcatchments are used as predictors for the linear regression model. The applicability of the snowmelt runoff in some of the defined precipitation areas as an input to the HYSIM model has to be tested.

1.2 Rainfall-runoff model

This model consists of four linear reservoirs, which use results of the snow- and soil-model. The four reservoirs represent surface runoff, interflow, base-flow and pre-event discharge.

Discharge values at two stations (Traun at Pucking and Enns at Steyr) calculated by this model are used as input for the HYSIM forecasting system. It is planned to also apply the model at the gauge Landshut at the river Isar (Bavaria).

1.3 Linear regression model

Multiple linear regression models are defined for 13 reference gauges in the entire catchment to estimate the daily mean runoff. The models make use of more than 30 upstream discharge and precipitation gauges. Furthermore meteorological forecasts (precipitation) and soil model runoff estimates are used as predictors. The models are developed as difference models to achieve the statistical requirements. The potential lead time is four days.

1.4 HYSIM

The HYSIM runoff forecasting system is a river basin model that consists of several modules, each of which is tailored to the specific requirements of the processes to be described in a particular part of the catchment (Gutknecht, 1988). For each module the parameters of the hydrological model are estimated on-line from runoff observations by a recursive Bayes-Kalmanfilter algorithm which accounts for model and observation uncertainty. Mathematical details of the model are given in Schnatter (1988) and Schnatter et al. (1987). Setting up the model can be seen as looking for the adequate hydrological components rather than as calibrating model parameters (Kirnbauer, 1987).

The *rainfall runoff model* uses observed and predicted areal rainfall as input variables and observed runoff as an output variable. Effective rainfall is estimated on-line from input and output by a dynamic adaptive Bayesian estimation algorithm based on the assumption of a variable runoff coefficient. The altitude of the transition line of rain- and snowfall is taken into account by reducing the absolute amount of precipitation by the percentage of the catchment lying below the 1.5°C level. Effective rainfall and a quantity defined as rainfall minus effective rainfall are then transformed by unit hydrograph transfer functions with low and high time constants respectively and are superimposed with the recession curve of the pre-event runoff.

The propagation of a flood wave in a reach of a river is described by the *flood routing module*. In its basic form, this module makes use of the Nash cascade approach with the number of linear reservoirs and the time constants as the parameters of the model. These parameters are estimated on-line together with a correction factor (or an additive correction) which accounts for the fact that often conservation of mass is not applicable along a reach. If, during great floods, overtopping over the flood levee occurs, this phenomenon is described by an additional flood routing module. The overtopping proportion of the flood discharge is then modelled by a cascade with a larger time constant. If heavy rainfall along the reach produces substantial runoff, another module of the flood routing model is applied. In this case, areal precipitation along the reach together with the inflow at the upstream gauging station is used as the model input and the outflow at the downstream gauge as the output. The model can be seen as a combination of the simple flood routing module and a simplified form of the rainfall runoff module.

Confluence of rivers or of a river and its tributaries is modelled by a *superposition model*. Inflow discharge from all tributaries is the model input and observed runoff at or downstream the confluence is the model output. This module has different configurations: Each tributary can be routed to the outlet of the reach either by assuming simple translatory movement or wave

deformation. In the latter case a flood routing module is applied to the respective tributary. In all cases, a dynamic adaptive correction algorithm, either multiplicative or additive, is applied.

Setting up the forecasting system for the Danube and its tributaries is still under way and is performed in close cooperation with the users of the forecasts, following the strategy described in Gutknecht (1991). In contrast to forecasting systems used for flood warning alone, much emphasis must be put on the accuracy of the forecasts in those ranges of the discharge, where small differences in discharge cause great differences in energy production.

The strong anthropogenic impact on the runoff regime especially at the Inn river, which is caused by reservoir operation in the upper course of the river tends to deteriorate the accuracy of the forecasts. This problem motivated us to develop a smoothing algorithm which produces runoff hydrographs as close as possible to the natural runoff regime. This algorithm had to be incorporated as a new module in the forecasting system and will be described in chapter 3 of this paper.

2 HYSIM model configuration for the Austrian Danube

The current version of the model setup together with modules to be configured in the future are shown in Figure 2.

The most upstream gauging station at the river Inn is Innsbruck (INNS, catchment area 5792 km²), the hydrograph is highly influenced by reservoir operation. Natural runoff of the alpine river Inn is mainly concentrated in summer. From October to March, precipitation occurs mainly as snow. In this case, temperature data are of high importance for modelling rainfall-runoff events. Snowmelt in spring and early summer together with rainfall events are responsible for high flows.

The first tributary is the Ziller with its gauge Hart (PHART, catchment area 1095 km².) This stream is also highly influenced by reservoir operation. The station is introduced to the system without forecast –because the rainfall-runoff module would not yield forecasts according to the measured values due to the anthropogenic influence.

The next tributaries are the Brandenberger Ache on the left side with its gauge Mariathal (MRTH, catchment area 273 km²). and the Brixentaler Ache on the right side with the gauging station Bruckhäusl (BRBA, catchment area 322 km²). The runoff at both of the stations will be modelled by the HYSIM rainfall-runoff module. The streams join the system with calculated forecasts during rainfall events and as observed values only during dry periods.

The river Inn leaves Austrian territory between the gauge Brixlegg (BRIX) and the hydro power plant Nussdorf (KWNU) before the left hand tributary Mangfall (MANG) joins the Inn. For this station runoff due to rainfall is already configured within the HYSIM module, but has not yet been integrated in the operational model.

The river reach between Brixlegg and the mouth of the Mangfall is highly influenced by orographic precipitation due to the topographic barrier of the northern Alps. This fact has been taken into account by modelling the runoff due to areal precipitation between the upstream and the downstream gauge, because the discharge increase due to this effect cannot be compensated by the correction factor described in chapter 1.4. Therefore the additional flood routing module has been configured.

The river Salzach is modelled starting from the most upstream gauging station Golling (GOLL). There are three flood-routing modules and one superposition module in operation. The need for using two rainfall-runoff modules as seen in Figure 2 still needs to be tested.

The junction of the rivers Inn and Salzach is situated upstream of the Braunau-Simbach (KWBS) hydro power plant, where forecasts of the model are needed. At this point, forecasts of satisfying quality with up to 10 hours lead-time can be provided.

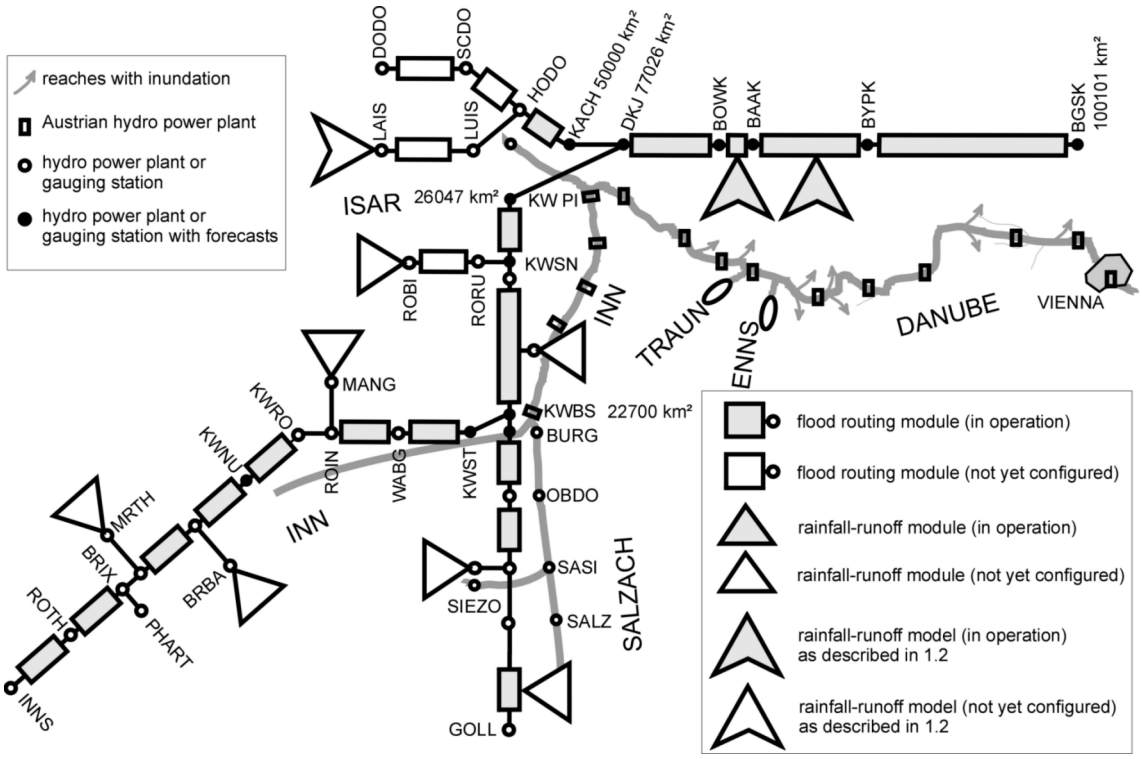


Fig. 2 Model configuration

The next tributary modelled by the rainfall-runoff module is the stream Rott with its gauge Birnbach (ROBI, catchment area 865 km²). The hydrograph has, in contrast to the previously presented tributaries, no alpine character. Tthe runoff is evenly distributed throughout the year with floods occurring both in winter and summer. In summer, the runoff coefficient is significantly lower than in winter, and therefore the model has to use two sets of parameters.

The confluence of the rivers Inn and Danube is situated at the town Passau, which is on German territory. The mean discharge in 1999 was 794 m³/s for the Danube and 860 m³/s for the river Inn. The upstream reach of the Danube is modelled by 3 runoff routing modules. The most upstream station is Donauwörth (DODO), which is introduced into the system with observed discharge values. The hydrographs of the alpine river Inn and of the lowland river Danube show different characteristics. At the Danube, floods occur both in summer and in winter. Winter events tend to be generated during periods with temperatures above 0°C and rain falling on a shallow snow cover, while summer events tend to occur during periods of persistent rainfall. The time to peak of flood hydrographs is longer at the Danube river (up to three days) as compared to the Inn (a maximum of one day), so after superposition at the the junction double peaks tend to occur.

The right hand tributary to the Danube called Isar is modelled by one runoff routing module. The most upstream station Landshut is introduced with a rainfall-runoff model as described in chapter 1.2.

The reach of the Austrian Danube is modelled by three runoff routing modules, two tributaries on the right hand side, the Traun with the gauge Pucking (TRPU) and the Enns with the gauge Steyr (STEYR) are also modelled by the rainfall-runoff model as described in chapter 1.2.

At the 'center of gravity' of energy production, the hydro power plant Ybbs-Persenbeug (BYPK) the model provides forecasts of up to 24 hours in advance. In future, the possibility of extending the forecasts to up to 30 hours using the rainfall-runoff forecasts for the tributaries will be tested.

3 Smoothing hydrographs

As mentioned before, it has been necessary to modify discharge values as a consequence of two issues:

- Most of the hydrograps are highly anthropogenically influenced. Reservoir and hydro power plant operation cause oscillations which cannot be calculated by the model describing natural processes. Therefore the hydrographs have been smoothed, in an attempt to mimic natural conditions.
- As a side effect the problems with missing data of the present on-line model can be reduced by calculating weighted means over a number of values.

The first approach of performing spectral analyses for each hydrograph did not yield useful results. The 12h and 24h frequencies due reservoir operation, which were found by the spectral analysis, are also visible by simple visual inspection. Furthermore, eliminating 12h or 24h frequencies would mean a loss of information for the system. The unwanted oscillations are in the range of 1 to 5 hours.

The next approach was to calculate weighted averages over the current value over a moving window, which gave good results. The number of values in the window can be different for different gauges. The weights have been assumed to decrease with time lag, exponential and linear decreases were investigated. The linear decrease yielded the best results (Drabek, 1999). Figure 3 shows two hydrographs – the red one represents the original measured values at the hydro power plant Stammham (KWST; at the river Inn in Germany), the blue is the smoothed hydrograph. The weighted average is calculated by the current and the 6 previous hourly values by a linear kernel.

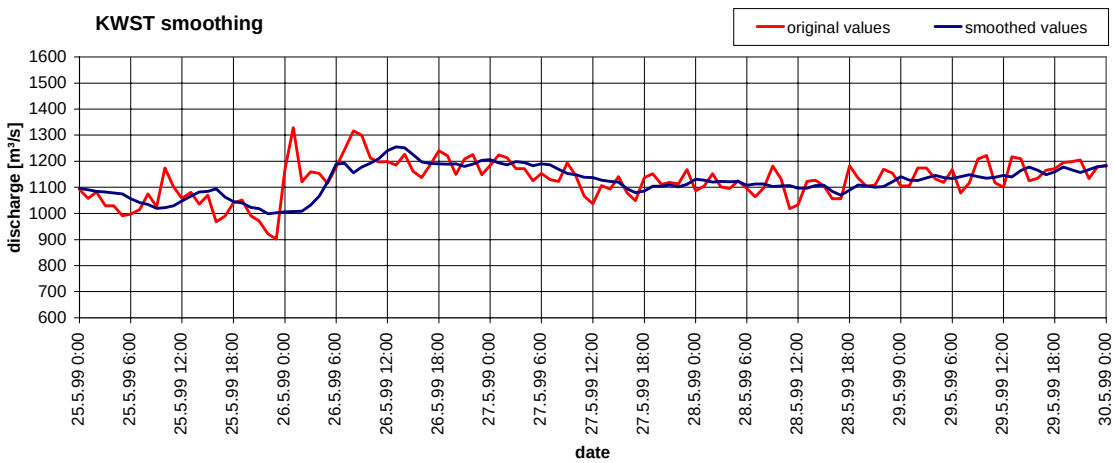


Fig. 3 Comparison of measured and smoothed hydrographs

By comparing these two hydrographs one can see that the oscillations can be eliminated by the smoothing algorithm. The step increase in discharge between 25.5.99 23:00 and 26.5.99 01:00 has been smoothed, which causes a time-lag, that depends on the number of averaged values.

Only two of all the stations (KWST and OBDO) have been averaged over 7 values, because these hydrographs show the largest oscillations. All other gauges and hydro power plant discharge values have been averaged over 5 values, so that the time-lag can be minimised while the effect of smoothing is maximised.

Figure 4 shows the effect of smoothing on the forecasts. The black line is the hydrograph as shown in Figure 3. Every single red 'tail' with its starting point at the measured discharge value is a 1 to 12 hour forecast. The blue graph below the discharge is the so called 'transformed

wave': This is the inflow to the module which is transformed into an outflow by a time independent and linear impulse response function (Schnatter et al., 1987).

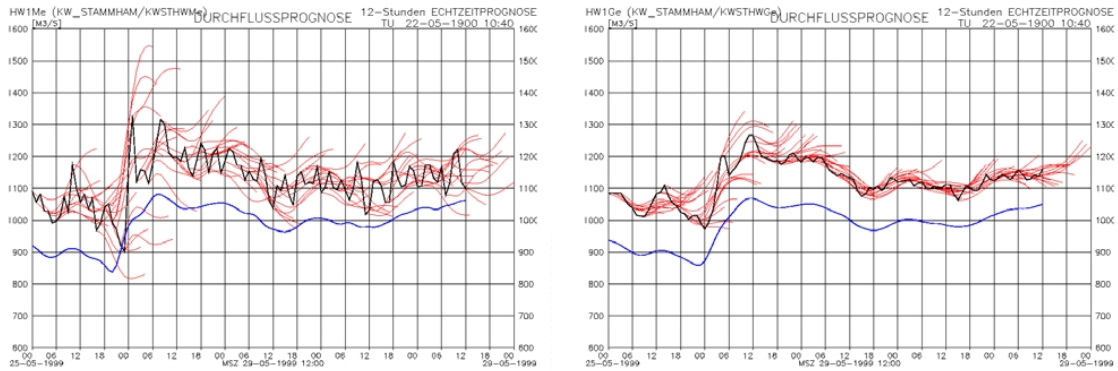


Fig. 4 Forecasts without (left) and with (right) smoothed hydrographs

By comparing these two plots one can see, that the model calculates much more accurate forecasts by using smoothed runoff values than by using observed data. One of the problems with the oscillations due to anthropogenic effects (as shown in Figure 4, left plot) is that, as flow is passed through the runoff routing modules, the disturbances tend to be enhanced. This is a consequence of the self adaptive nature of the algorithm where differences between observed and simulated flows are interpreted as a result of natural hydrologic processes.

Prediction errors can be significantly reduced when using smoothed hydrographs, particularly for those stream gauges where large oscillations occur. This is illustrated in Figure 5 for the case of Stammham. Errors are calculated as difference of observed and predicted runoff values depending on the lead-time. Over-estimations are plotted as positive, under-estimations as negative errors.

The red line shows mean and standard deviation of the forecast errors using observed discharge values. Up to 6 hours lead-time the standard deviation of the forecast errors is within ±5%. From a lead-time of 6 hours on the errors expand up to 15% for the 24 hours ahead forecast. This effect occurs due to the specific behaviour of inflow and outflow hydrographs. The inflow from the upstream gauge (blue line in Figure 4) is already smoothed by calculating the 'transformed wave' by a linear impulse function while the outflow data are oscillating due to power plant operation. Using smoothed outflow data the 'transformed wave' and the modified observations become more related (Figure 4). Therefore the standard deviation of the prediction errors starts with a smaller value. The 5%-tag is reached with 10 hours lead-time. The prediction errors can be significantly reduced by using the smoothing algorithm.

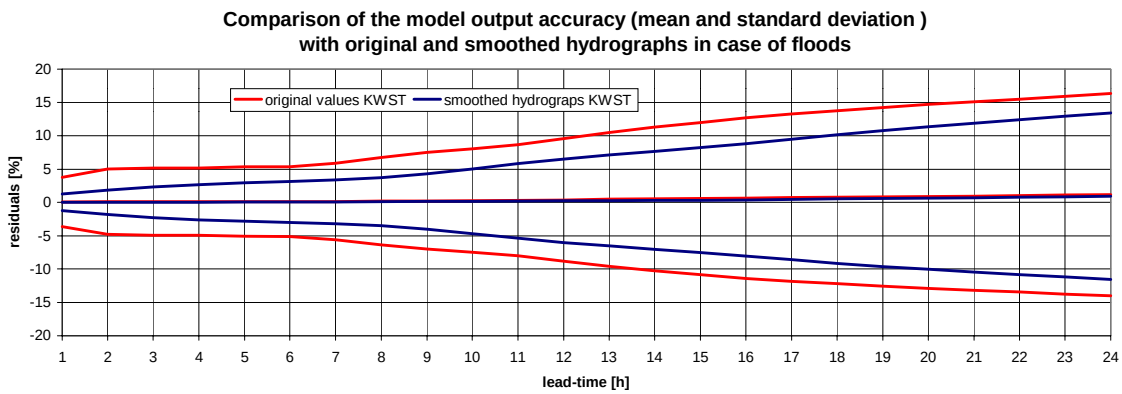
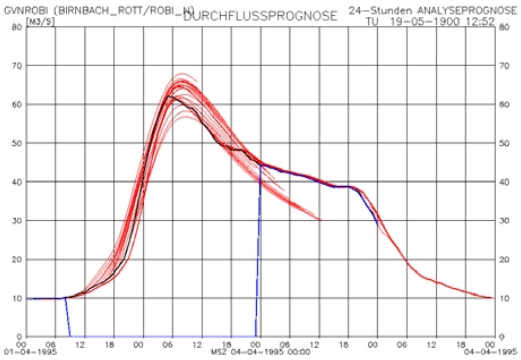


Fig. 5 Forecast errors without and with hydrograph smoothing for the hydro power plant Stammham

4 Outlook: implementing additional rainfall-runoff modules

The ongoing work concentrates on testing the need for HYSIM rainfall-runoff modules for several tributaries. The results of the regional analysis performed by Blöschl and Merz (2000) are used for identifying hydrologic situations that give rise to changes in runoff in the main Austrian streams and for assisting in choice of model structure. Figure 6 shows a result of the module at ROBI for one rainfall event using the developer's mode of the model that makes use of predicted discharge and rainfall values.



The advantage of modelling runoff due to rainfall from tributaries is that the system gets information on the *impulse* coming from these streams. The *amount* of discharge during floods is within 2 to 15 percent of the discharge at the receiving stream.

Fig. 6 Discharge predicted by the rainfall-runoff module in developer's mode

This study has shown that it is possible to generate accurate runoff forecasts for a large basin such as the Danube on a real-time basis. One of the main problems has been the effect of hydro power operation which has been solved by implementation of a smoothing procedure. First results show that implementing rainfall-runoff modules for tributaries will yield more accurate forecasts during flood events in the main stream.

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Mathematical Modelling and the Operative Management of Flood Discharges in a Large River Basin

Karel Drbal, Miloš Starý

Abstract: The paper provides a description of the BW model, which is suitable for the flood run-offs simulation and their operative management within a large river basin representing a complex water management system. The BW model was created and tested for the middle and lower parts of the Svratka, Jihlava and Dyje River subcatchments (The Danube River subcatchmants) including the most important reservoirs (Brno, Dalešice, Mohelno, Vranov and Nové Mlýny Reservoirs). A premise which was tested during the solution was that the upper parts of the river basins and their tributaries upstream the reservoirs were described by an rainfall-runoff model. Concerning the BW model, transformation of the stream channel discharges was described by means of robust regression. The problem of fuzzy control was solved in detail for the subsystem of Vranov and Brno Reservoirs. In case of the Vranov Reservoir there were tested both the process of specialized learning of fuzzy controller and process of determination of target behaviour of the reservoir by means of optimization.

Key words: Flood control, operative reservoirs control, robust regression, fuzzy control, neuro-fuzzy model.

Mathematische Modellierung und wasserwirtschaftliche Betriebslenkung der Hochwasserdurchflüsse im weiträumigen Einzugsgebiet

Zusammenfassung: In diesem schriftlichen Beitrag ist ein Modell BW beschrieben. Es passt zu der Simulation der Hochwasserdurchflüsse und des zugehörigen Betriebsbewirtschaftens in einem weiträumigen Einzugsgebiet und im Inneren des komplizierten wasserwirtschaftlichen Systems. Das Modell BW ist für die mittleren und unteren Teile der Einzugsgebiete der Svratka (Schwarzau), der Jihlava (Iglau) und der Dyje (Thaya) zusammengestellt und getestet worden. Diese Flüsse gehören zum grossen Flussgebiet der Donau. In diesem Modell werden auch die berühmsten Stauseen Brněnská (Brünner), Dalešice, Mohelno, Vranov (Frain) und Nové Mlýny (Neue Mühlen) umgefasst. Im Rahmen der Aufgabenlösung sollte eine Voraussetzung getestet, dass obere Teile der Einzugsgebiete bezüglich auf Flüsse und deren Zuflüsse stromaufwärts der Stauseen sind mit Hilfe des Niederschlag-Abfluss Modelles beschrieben worden. In dem Modell BW wurde eine Durchflusstransformation in Flussbetten mittels der Robustregression Modelle charakterisiert. Die wasserwirtschaftliche Lenkung beruht auf sogenannter Fuzzyregulation, die ist für Stauseesubsysteme Vranov und Brněnská ins einzelne gelöst worden. Bei dem Speicher Vranov ist ein Bestimmungsfortgang des spezialisierten Fuzzyregulators und des Zielbenehmens der Stauseen mit Hilfe der Optimalisierung getestet worden.

Schlüsselwörter: Hochwasserschutz, Wasserwirtschaftliche Betriebslenkung der Stauseen, Robustregression, Fuzzyregulation, Neuro-fuzzy Modell

1 Introduction

A knowledge of regularities of the origin and genesis of flood water run-offs from a river basin depends in most cases on simulation of the mentioned phenomenon with taking into account the most important causes. Though there are available numerous possibilities and approaches, not all of them are suitable for the purpose of knowledge of extreme discharges creation in a large catchment. Among the most used technologies applied at the present time in the water

management practice belongs an application of mathematical models too. The development and extension of mathematical modelling was determined by an intensive development and mass utilization of high-performance computing technology.

The problem of control of the complex and large systems as well as numerous links among the individual elements require a system approach. It consists in managing progress tasks such as uncertainty of knowledge about the system and decision, description of the controlled system, algorithmization, creation of model of the system (in case of the model approach of management), optimization of the control, real time control etc.

2 Control of water management systems

From the point of view of mutual links between the control system and controlled object it is the *on-line* system that is used for control of water management systems. In the course of management the computer determines the operational regime of the managed object, gives appropriate setting of regulatory elements. This information is passed on an operator who can or need not implement it during the control process. Feedback is closed by the operator and the computer working in real time fulfills the function of an ”adviser”. The system is suitable for processes control with the length of particular stages of control in the order of hours or days.

Concerning the Odra River basin (CR), for the flood discharge control in the real time there is used the HYDROG model [5]. Algorithm simulates rainfall-runoff process within the river basin and respects time variability of the surface and underground runoff. The model used in terms of the Ostravice River basin has been applied at some other subcatchments of the Odra River.

From application of the above methods of artificial intelligence (esp. neural networks) in the field of water management it would be efficient to mention the work [7] describing optimization of sewerage network control in Copenhagen for municipal agglomeration drainage during storm rainfalls [6]. Application of neural networks as warning system was tested in the Ostravice River basin (CR) [6]. Neural network operates as a very quick analyzer of initial behaviour of the system and forecasted precipitations, determines the state of emergency of water management systems and accordingly the necessity to start the operative management and estimates the received effects.

Application of control algorithms presuming a quick possibility of multiple repeating of simulations of the system behaviour on the basis of changed positions of gates can in cases of large catchment models mean great demands on computing technology, processor speed etc. Use of simplifying methods for description of water flow in river network (regression models, neural networks, neuro-fuzzy models) can represent a common starting point for construction of control algorithms. Certain possibilities are given in [3], where linear regression models and a modification of Kálman filter were tested in catchment of 5742 km^2 (Japan) to describe the rainfall-runoff process. It was fuzzy control that was selected for the management of 5 reservoirs.

3 BW Model

In the Brno Branch office of the Water Research Institute there was developed BW model [1] suitable for operative management of flood process in a large river basin (VS - complex water management system) with the aid of fuzzy control. Input of the solution comprises immediate state of the system, prediction of inflow into the upper profiles of a subsystem and a course of previous inflows into the subsystem in time, when the decision of setting positions of control gates was made, being output of the control algorithm.

3.1 Regression models

Simulation of flood run-off genesis in a river basin presumes the selection of suitable approach and subsequent model development; it should be quick and reliable enough, with minimum demands on input data from the point of view of its creation and construction and finally, its maintenance itself - resp. its updating would not be more difficult and time data demanding than the phase of its creation. The mentioned concise characterization of the needed tool answers to the hydrological models belonging to the group of black box models, where can also be ranged the regression models. In the BW model there are used the robust regression approaches.

The robust regression methods are an important complement of the regression analysis by linear models based on the classic least-squares method (LS). Using these techniques gives results similar to the least-squares regression if the data errors have got normal distribution $N(0,\sigma^2)$. The results are substantially different if the errors don't satisfy the normality condition or even if the data contain significant outliers.

In the BW model there was used the least trimmed square (LTS) regression for fitting the linear regression model [4].

Estimation of the $\hat{\vec{\beta}}_{LTS}$ minimizes the sum of q quadrates of residuals

$$\min_{\beta} \sum_{i=1}^{q} r_i^2(\vec{\beta})_{i:m} ,$$

where $(r^2)_{1:m} \leq \ldots\ldots \leq (r^2)_{m:m}$ are ordered quadrates of residuals (as the first are calculated those quadrates that are later on ordered).

3.2 Fuzzy regulation

Fuzzy regulation is concerned in those cases that the regulated system contains the system of fuzzy logic (FL). As a founder of FL, a discipline ranged into the group of methods and approaches of artificial intelligence, is often designated L. A. Zadeh, [9], who in 1973 formulated so called principle of incompatibility: "As the complexity of a system increases, our ability to make precise and yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance become almost mutually exclusive characteristics." In the field of water management this principle resonates with certain urgency and reminds that mathematical modelling has its limits given by the reality complicacy as well as by our ability to describe it in such a way that the result can still fulfill its original purpose.

Fuzzy interference systems (FIS) are also known as fuzzy-rule-based-systems, fuzzy models, fuzzy associative memories or the above mentioned fuzzy logic controller. Resulting from simple characteristic of FIS, the computing system is based on fuzzy set theory using fuzzy implications and fuzzy deductions.

Fuzzy control is still the most successful practical application of fuzzy sets. The present interest in fuzzy theory is mostly given by successful applying the fuzzy control in case of consumption products and industrial systems [8].

Fuzzy inference system is composed of five functional blocks (see Fig. 1)

A. a ***database*** which defines the membership functions of the fuzzy sets used in the fuzzy rules;

B. a ***rule base*** containing a number of fuzzy IF-THEN rules;

C. a ***fuzzification interface*** which transforms the crisp inputs into degrees of match with linguistic values;

D. a ***decision-making unit*** which performs the inference operations on the rules;

E. a ***defuzzification interface*** which transforms the fuzzy results of the inference into a crisp output.

Usually, the rule base and the database are jointly referred to as the ***knowledge base***.

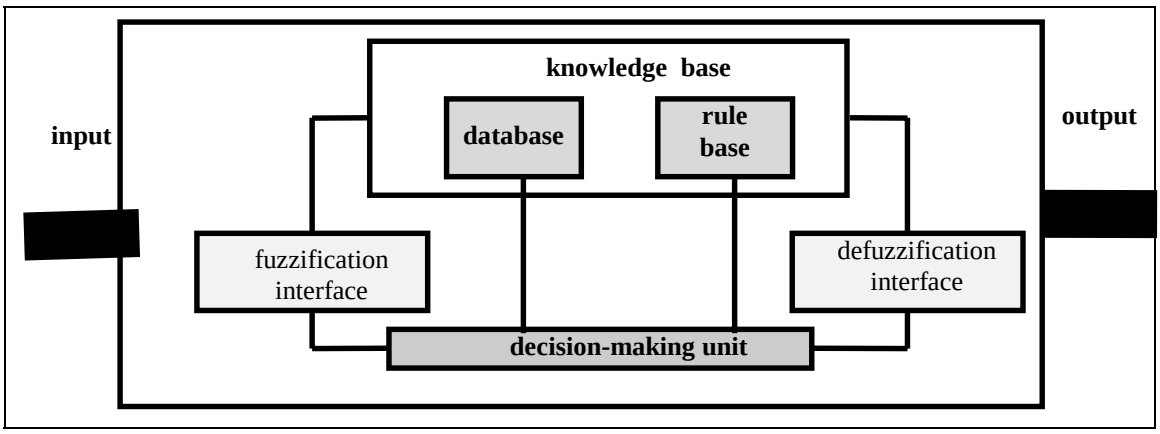

Fig. 1 Fuzzy inference system

Depending on the types of fuzzy reasoning and fuzzy IF-THEN rules employed, most fuzzy inference systems can be classified into three types (see Fig. 2):

Type 1: The overall output is the weighted average of each rule's crisp output induced by the rules firing strength (the product or minimum of the degrees of match with the premise part) and output membership functions. The output membership functions used in this scheme must be monotonic functions.

Type 2: The overall output is derived by applying "max" operation to the quantified fuzzy outputs (each of which is equal to the minimum of firing strength and the output membership function of each rule). Various schemes have been proposed to choose the final crisp output based on the overall fuzzy output; some of them are mean of maxima, maximum criterion, centroid of area, bisector of area average, etc.

Type 3: The overall output of each rule is a linear combination of input variables plus a constant term, and the final output is the weighted average of each rule's output.

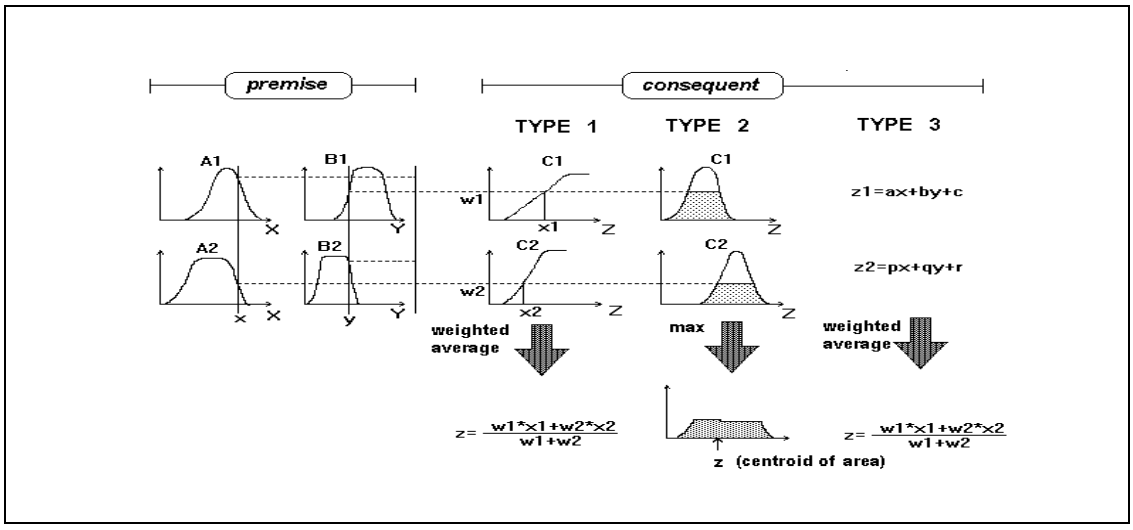

Fig. 2 Generally used fuzzy rules and fuzzy logic mechanism FIS

The fuzzy inference systems type 1 and 2 are also called as Mamdani, the type 3 as Sugeno or Tagaki-Sugeno [8].

The Fig. 2 utilizes a two-rule two-input fuzzy inference system to show different types of fuzzy rules and fuzzy reasoning.

4 Application and the received results

The BW model created for the subsystem of the Dyje-Svratka (12353 km^2) water management system consists of three parts: outflow modulus, reservoir modulus and control modulus. The created BW model was implemented in the environment of MATLAB [10]. The reservoir modulus was established for five reservoirs important from the point of view of their function (The Brno, Dalešice, Mohelno, Vranov and Nové Mlýny Reservoirs). To the purpose of simplification the Nové Mlýny system of reservoirs was described as one complex. Concerning the Vranov and Brno Reservoirs, the control modulus was elaborated in detail and applied fuzzy controllers Sugeno of 0 and 1st order, in case of the remaining ones there were applied intuitive types of fuzzy controllers Mamdani.

For describing the course of flood waves in the system of streams of a large catchment area there were used LTS models from the group of robust regression methods integrated in an outflow module. In river basins of the Dyje, Svratka and Jihlava Rivers there were integrated six regression parts describing the dynamic effect. For the individual model calibration there were used data of only one historical flood situation - usually that with peak discharge. This fact makes the problem of model maintenance easy, i.e. its updating is not too difficult.

The models presented sufficient accuracy satisfying the concept of their application in the structure of control algorithm. Results of the valid flood situations modeling within the subsystem of water management systems defined by the inflow profiles of the main stream reaches (water gauging stations Bílovice, Pisárky/Poøíèí, Rychmanov, Mostištì, Mohelno, Moravský Krumlov, Bo□ice and Vranov - see Appendix A) and by the end profile of historical water gauging station Dolní Vìstonice representing courses of sum inflows into the existing Nové Mlýny Reservoirs are given in Appendix B. The graphs contain courses of calculated values of the flood flows in two important station profiles of main streams: □idlochovice - the Svratka River, Ivanèice - the Jihlava River.

However, hydrological losses are not implicated in the BW model directly, their share is implicitly expressed in the form of regression equation of each of the six models. The impact of precipitations during the flood events was not implicated in outflow models as directly measured values. Both the input data analyses of the used historical flood events data and the simulation of rainfall-runoff relations in [1] showed that the impact of precipitations in the modelled subsystem area in the lower part of the Dyje River basin is not significant. On the contrary, top-priority effect show hydrograms in inflow profiles.

Control modulus was worked up in detail in case of the Brno and Vranov Reservoirs where were applied fuzzy controllers Sugano of 0 and 1st order enabling objective control algorithm adapting to data of the chosen flood situations by means of neural networks. For fuzzy controllers learning of both the reservoirs the product of ANFIS was used [2].

Referring to the Vranov Reservoir subsystem, there were tested fuzzy controllers of the bottom outlets and the turbine outflow of the hydroelectric power plant. As the control quantities there were chosen: instantaneous value of the reservoir inflow, difference of the instantaneous reservoir inflow value, inflow values in the time point shifted 24 hours ahead and finally, estimation of volume flow during the following 24 hours. For controllers debugging there was used an approach indicated as *specialized learning*. This process has at present a form of semi-automatic process of progressive (gradual) fuzzy controller adaptation to fulfill the given requirement in the control profile.

At the same time an approach of determination of the reservoir subsystem target behaviour was tested in case of the Vranov Reservoir subsystem. The resulting operative control simulation with learned fuzzy controllers proved far more better effect than specialized learning application, where the required sub-optimum was reached by progressive approaching.

5 Conclusion

The described BW model concept is one of possibilities of the problem solution. The integrated robust regression technologies showed both sufficient accuracy and computation speed meeting the original purpose referred to their application in the control algorithm structure. Without question, an application of fuzzy regulation shows to be an efficient solution in case of strong uncertainty such as the flood events genesis.

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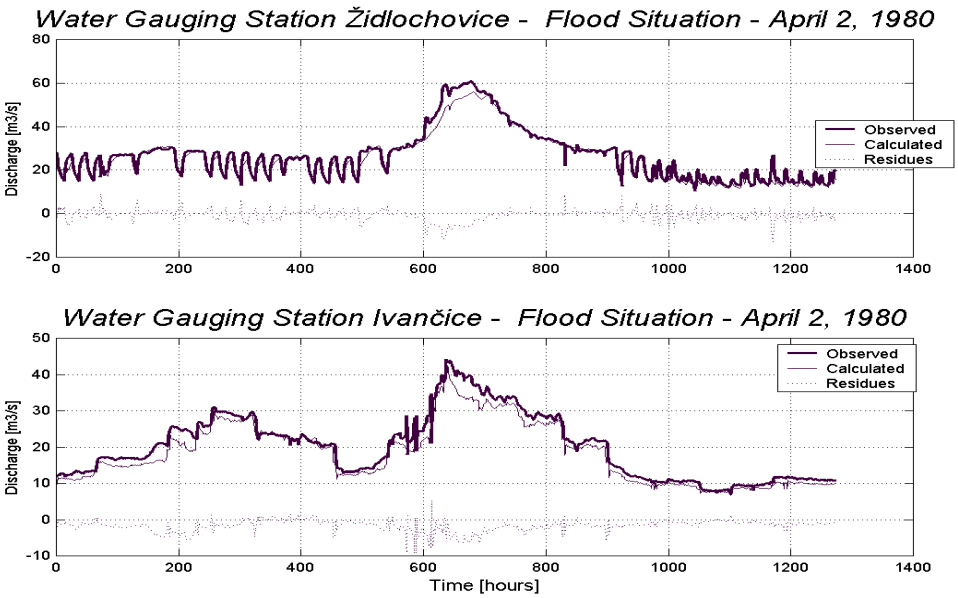
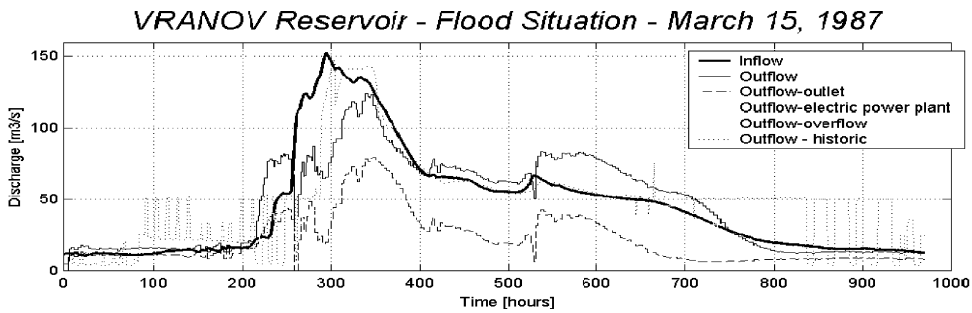
Appendix A

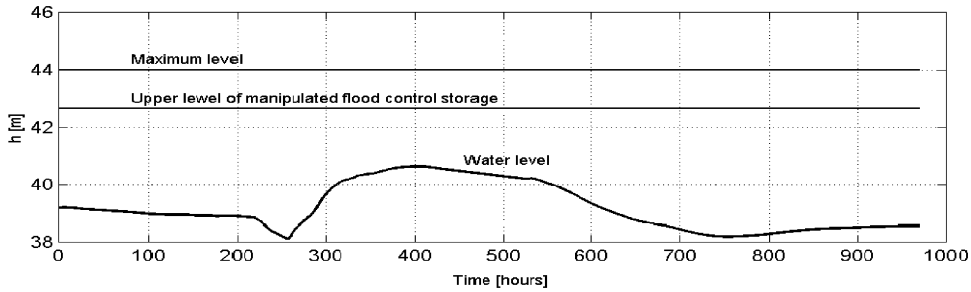
Situation in the Dyje River basin

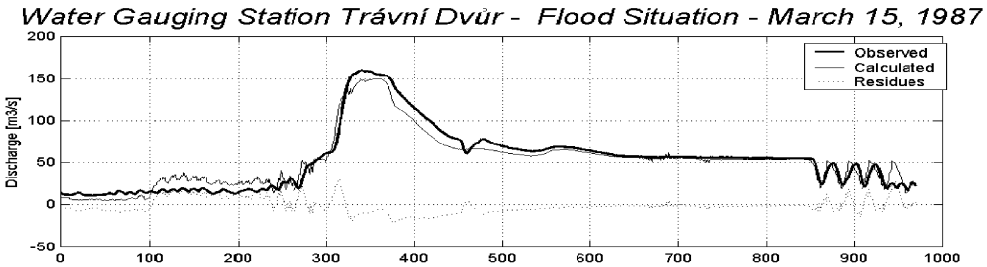


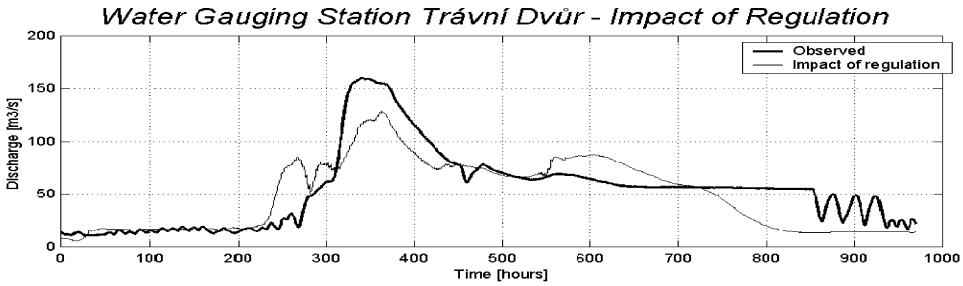
Appendix B

BW model - valid flood situation









Appendix C

The Vranov Reservoir - fuzzy control

(fuzzy controllers learned by ANFIS)

Internet-Bereitstellung von Inhalten des Deutschen Gewässerkundlichen Jahrbuchs (DGJ)

Heinz Engel

Zusammenfassung: Hydrologische Jahrbücher sind eine wichtige Quelle der Information für hydrologische Arbeiten in Verwaltung, Planung und Forschung wie für die Öffentlichkeit. Gefragt ist oft Aktualität und Verfügbarkeit. Veröffentlichungen in Buchform erschienen aber in der Vergangenheit meist mit erheblichem Zeitverzug und sind nur an ausgewählten Orten einsehbar. – Seit Ende 1999 stellt die Bundesanstalt für Gewässerkunde Inhalte des DGJ im Internet bereit. Dabei werden die Daten sowohl konventionell (als DGJ-Seiten) wie auch in verknüpften Tabellen und Grafiken präsentiert. Die Daten sind wenige Monate nach Ablauf des Berichtszeitraumes verfügbar und können vom Nutzer aus dem Rechner geladen und weiterverarbeitet werden.

Schlüsselworte: Hydrologische Jahrbücher, DV-Datenpräsentation

Internet-Presentation of Parts of the German Hydrologic Yearbook (DGJ)

Abstract: Hydrological yearbooks are an important source of hydrological information for administration, planning, research and the public. The requested data should be up-to-date and easily accessible. Yearbook publications in the past came out with considerable time delay and were accessible only at certain institutions and libraries. – Since 1999 the German Federal Institute of Hydrology has presented parts of the German Hydrological Yearbook (DGJ) in the Internet, both in the conventional DGJ format and in form of links to tables and diagrams. These data are available just a few months after the end of the reporting interval and may be downloaded and used for further processing.

Key words: Hydrological Yearbook, computer presentation of data

1 Allgemeines

Hydrologische Messungen und daraus abgeleitete statistische Daten bilden die unbedingt erforderliche Grundlage für die Lösung jedweder wasserwirtschaftlichen Aufgabe. Hydrologische Jahrbücher sind auch im Zeitalter elektronischer Medien eine wichtige Informationsquelle für Verwaltung, Planung und Forschung wie für die Öffentlichkeit. Dabei ist von Nachteil, dass die Bände des DGJ in der Vergangenheit oft mit erheblichem Zeitverzug erschienen sind und nur in Bibliotheken und bei ausgewählten Dienststellen eingesehen werden können.

2 Bearbeitung des DGJ

Die Erstellung des DGJ geschieht seit dem Berichtszeitraum 1990 deutschlandweit einheitlich nach der „Richtlinie für die Aufstellung des DGJ“ (LAWA, 1994). Dabei wird ein gemeinschaftlich entwickeltes DV-Programmpaket eingesetzt, mit gleichen Berechnungsroutinen bei einheitlichem Layout. Es ist festgelegt, dass die pegelspezifischen Tabellen- und Grafikseiten von den jeweiligen Betreibern (Land, Bund) erstellt und als Postscriptfiles an die Herausgeber überstellt werden. Die Herausgeber (9 Länderdienststellen für 10 Teilbände) sammeln die Dateien der verschiedenen Pegelbetreiber und fügen die allgemeinen Seiten (Verzeichnisse, Titelseiten, Karten, ...) hinzu. Unterschiedliche Termintreue der Zulieferer und Finanzierungsschwierigkeiten verursachen immer wieder Verzögerungen bei der DGJ-Herausgabe, die bis auf mehrere Jahre anwachsen können. Von der Herausgabeverzögerung und deren Auswirkungen sind natürlich auch diejenigen Zulieferer

betroffen, deren Daten längst zeitnah aufbereitet vorliegen. – Ein Ausweg aus dieser Situation kann inzwischen mit (zumindest zeitweilig) paralleler Datenbereitstellung über elektronische Medien erreicht werden.

3 Präsentation hydrologischer Daten im Internet

Zur Erreichung leichterer Verfügbarkeit und größerer Aktualität stellt die Bundesanstalt für Gewässerkunde Daten der Pegel an den Bundeswasserstraßen seit Kurzem auch im Internet bereit. Dabei handelt es sich um aktuelle Tageswerte, ausgewählte tägliche Werte langer Zeitreihen und aufbereitete Werte gemäß „Richtlinie für die Aufstellung des DGJ“.

Die letztgenannten Daten basieren auf den schon erwähnten Postscriptdateien für den DGJ-Druck. Es gibt sie für Tabellen der Wasserstände, der Durchflüsse und der Schwebstoffe, jeweils zusammengefasst für 14-Montszeitabschnitte vom 1.11. des Vorjahres bis zum 31.12. des Berichtsjahres. Im DGJ werden die Tabellen beispielhaft durch einige wenige Grafiken visualisiert. – Im Internet sind zwei Wege für die Datenpräsentation gewählt:

- Die Darstellung der DGJ-Tabellen, so wie sie auch später im Jahrbuch zu finden sein werden.
- Die Darstellung des DGJ-Tabelleninhalts in Teilen und für Binnenpegel die direkte Nebeneinanderstellung der Wasserstände (W) und Abflüsse (Q). Ergänzend sind für die Daten aller Pegel auch Grafiken aufrufbar mit W und Q im gleichen Bild.

Die Bereitstellung der DGJ-Seiten im Internet soll kein Ersatz sein für die Veröffentlichung in Buchform; sie soll diese lediglich sinnvoll ergänzen. – Sobald die Postscriptdateien für einen Berichtszeitraum erstellt sind, werden sie ins Internet übernommen und dort solange vorgehalten, bis der jeweilige DGJ-Teilband gedruckt vorliegt. Als Zielvorstellung könnte dies bedeuten, dass im Internet immer der zuletzt abgelaufene Berichtszeitraum dokumentiert ist.

Im Einzelnen ist das DGJ im Internet wie folgt organisiert:

- Eröffnend wird dem Betrachter eine Übersicht über alle 10 Stromgebiete Deutschlands präsentiert.
- Auf Verlangen wird ein bestimmtes Stromgebiet als Insel dargestellt mit der Liste der darin von der Wasser- und Schiffahrtsverwaltung des Bundes (WSV) betriebenen Pegel **(Abb. 1)**.

Für einen ausgewählten Pegel (Abb. 1) können nun verschiedene Darstellungen gewählt werden:

- Jahresganglinie über 14 Monate mit gleichzeitiger Darstellung von W und Q. In der Kopfleiste werden die Hauptwerte genannt **(Abb. 2)**
- Auf Wunsch werden einzelne Monate in gleicher Weise dargestellt
- Um die Tageswerte tabellarisch zu zeigen, besteht die Möglichkeit, die Original-DGJ-Seiten W oder Q aufzurufen
- Die Monats- oder Jahreshauptwerte können als Tabellen aufgerufen werden, wobei jeweils W und Q übereinander ausgedruckt sind **(Abb. 3)**
- Die Dauertabellen werden ebenfalls auf separaten Seiten präsentiert **(Abb. 4)**
- Weitere Darstellungen sind in Vorbereitung und werden in den nächsten Monaten sukzessive realisiert (Liste der Tageswerte des aktuellen Berichtszeitraums, Grafik der Dauerlinien, Tages- und Hauptwerte der Tidewasserstände der Nordsee usw.).

Die hier beschriebenen Ansätze sind zur Zeit nur für Daten der WSV-Pegel des Bundes umgesetzt. Einzelne deutsche Bundesländer haben sich dem Weg der BfG angeschlossen, andere haben Interesse an der Lösung bekundet. Wie schon weiter oben festgehalten, sollen zunächst nur die noch nicht in Buchform veröffentlichten aber schon ermittelten DGJ-Seiten in das Internet eingestellt werden, d. h. die Daten füllen ein temporär bestehendes Zeitfenster, das sich mit fortschreitender Bearbeitung einerseits und fortschreitender Veröffentlichung im DGJ andererseits permanent verschiebt. Inwieweit und wenn, wie gegebenenfalls die Buchform verändert werden könnte, ist noch zu diskutieren.

Zur Zeit besteht unter den Fachleuten in den einschlägigen Gremien der deutschen Länderarbeitsgemeinschaft Wasser Einverständnis darüber, dass vom DGJ in Buchform vor allem hinsichtlich der langfristigen Datensicherung bis auf weiteres nicht abgegangen werden soll.

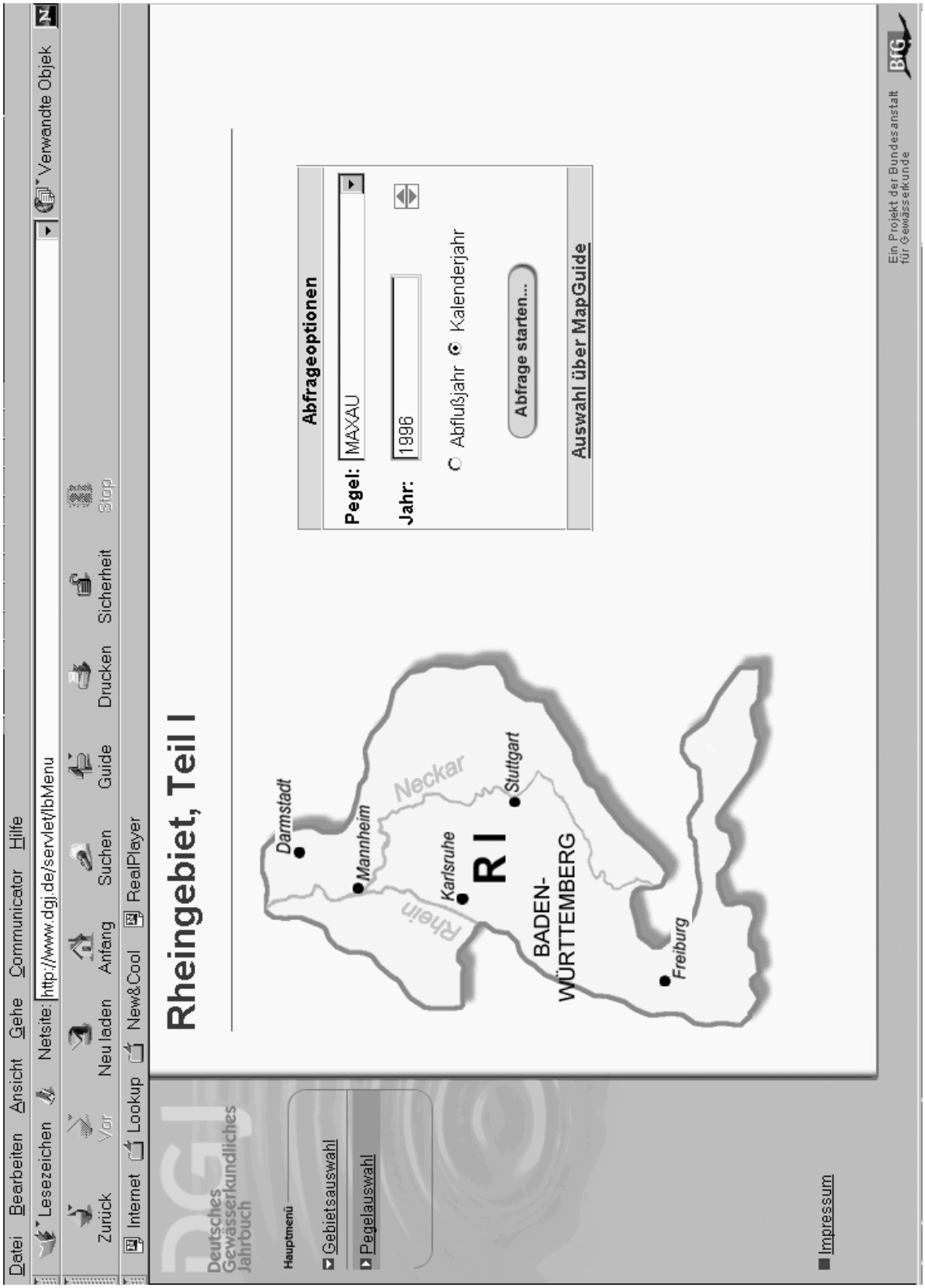


Abb. 1 Flussgebiet (Teilgebiet), dessen Pegeldaten in einem Teilband des DGJ dargestellt sind

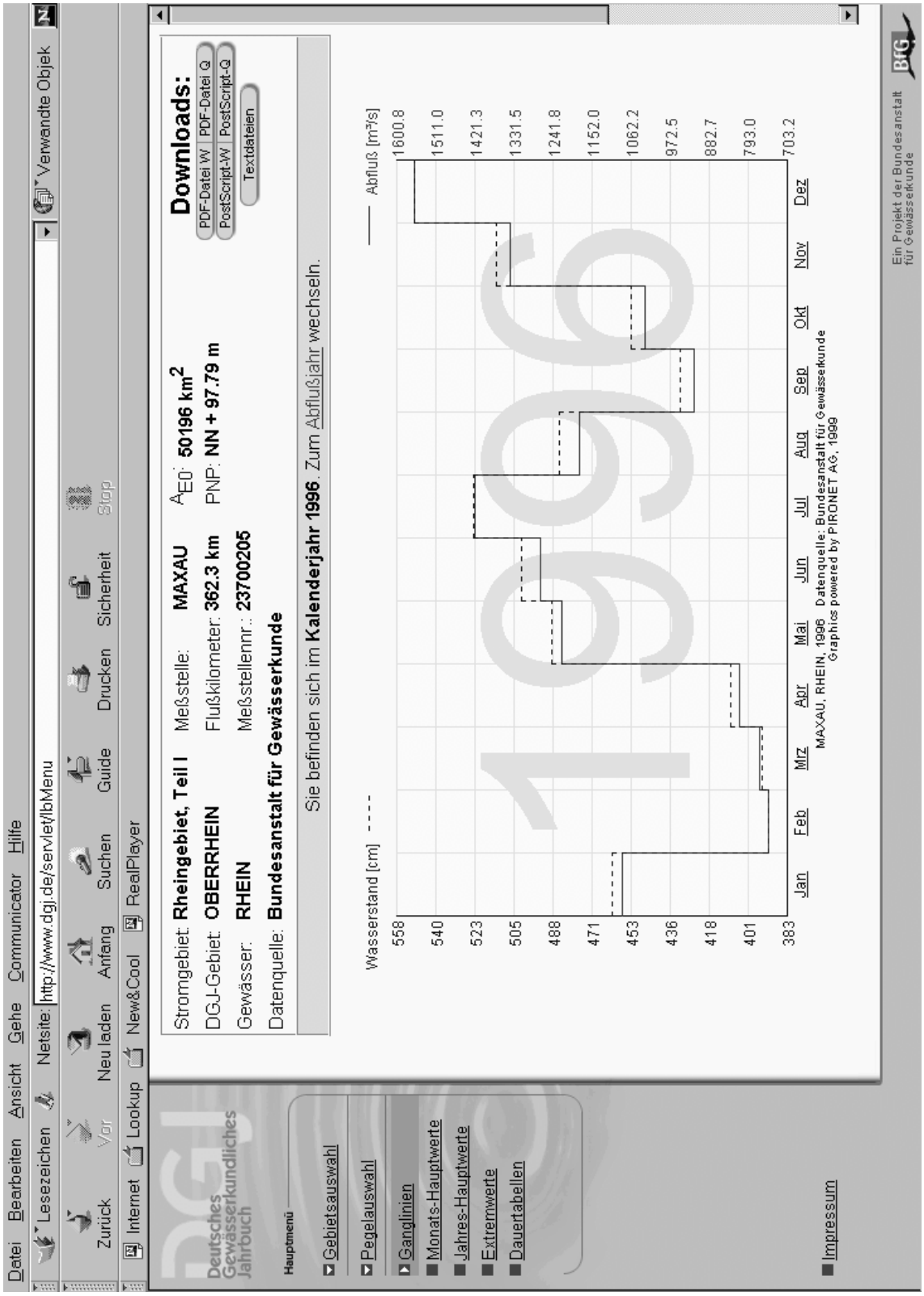


Abb. 2 Jahresganglinien (W, Q) eines Rheinpegels

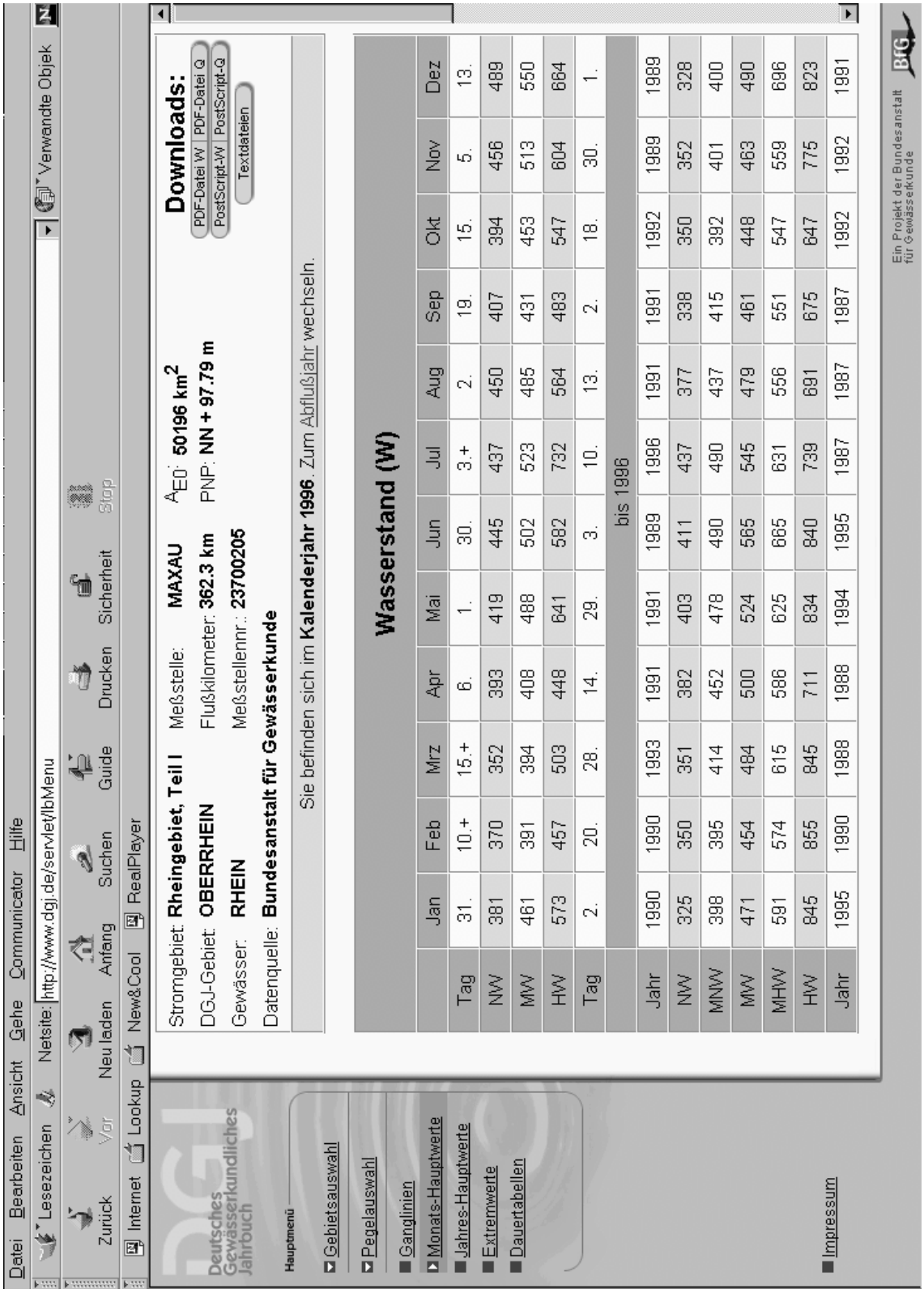


Abb. 3 Monatshauptwerte (W) eines Rheinpegels

Datei Bearbeiten Ansicht Favoriten Extras ?

Zurück Vorwärts Abbrec... Aktualis... Startseite Suchen Favoriten Verlauf E-Mail Drucken Bearbei...

Adresse http://www.dgj.de/servlet/lbMenu Wechseln zu Links »

Deutsches Gewässerkundliches Jahrbuch

Hauptmenü

- Gebietsauswahl
- Pegelauswahl
- Ganglinien
- Monats-Hauptwerte
- Jahres-Hauptwerte
- Extremwerte
- Dauertabellen

- Impressum

Stromgebiet: **Rheingebiet, Teil I** Meßstelle: **MAXAU** A_{E0}: **50196 km²**

DGJ-Gebiet: **OBERRHEIN** Flußkilometer: **362.3 km** PNP: **NN + 97.79 m**

Gewässer: **RHEIN** Meßstellennr.: **23700205**

Datenquelle: **Bundesanstalt für Gewässerkunde**

Downloads: PDF-Datei W | PDF-Datei Q | PostScript-W | PostScript-Q | Textdateien

Sie befinden sich im **Jahr 1996**.

	Wasserstand (W) in cm am Pegel					Abfluß (Q) in m³/s				
	1996		1987 bis 1996			1996		1931 bis 1996		
Unterschr.-dauer	Abflußjahr	KalenderJahr	Ob. Hüllwert	Mit. Wert	Unt. Hüllwert	Abflußjahr	KalenderJahr	Ob. Hüllwert	Mit. Wert	Unt. Hüllwert
(365)	756	701				3100	2590			
364	753	676	841	797	631	3080	2410	4340	3300	1450
363	701	664	821	765	601	2590	2290	4170	3050	1420
362	683	651	815	749	595	2440	2200	4040	2890	1420
361	676	642	803	740	593	2410	2140	3860	2810	1420
360	664	638	797	722	591	2290	2110	3810	2740	1380
359	651	636	780	717	587	2200	2100	3780	2680	1380
358	644	633	766	710	568	2150	2080	3480	2620	1380
357	633	627	753	706	556	2080	2040	3410	2580	1360
365	627	627	749	701	555	2040	2040	3410	2530	1360
350	590	593	731	674	544	1790	1810	3170	2340	1300

Abb. 4 Dauertabellen (W, Q) eines Rheinpegels

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Autor: Engel, Heinz, Bundesanstalt für Gewässerkunde, Kaiserin-Augusta-Anlagen 15-17, 56068 Koblenz, e-mail: Engel@bafg.de

The Utilisation of the RAMAP System to Forecast Extreme Hydrological Events

Martina Kimlová

Abstract: After the catastrophic July 1997 floods, and especially after the July1998 flash flood, the question of forecasting extreme meteorological and hydrological events is becoming ever more pressing. For this reason, the CHMI is acquiring new technologies, which will improve the situation in the Forecasting Service. In the Hydrological Forecasting Service, the operative information data from a meteorological radar were, so far, considered subjectively by the forecaster as rather supplementary only. So as to utilise the information supplied by the radar as effectively as possible, the **RAMAP** system, which processes the radar data, is presently being developed. Many water resources decisions may depend upon the manner, speed and quality of this processing. If these decisions are bad, they may result in the loss of human lives, at one extreme, or in the unnecessary release of flood warnings, at the other extreme.

Key words: floods, operative meteorological radar data, flood warning

Die Verwendung des RAMAP-Systems zur Vorhersage extremer hydrologischer Ereignisse

Zusammenfassung: Nach den katastrophalen Hochwässern im Juli 1997 und insbesondere dem Extremereignis im Juli 1998 wird die Frage nach der Vorhersage von extremen meteorologischen und hydrologischen Ereignissen immer dringender. Daher wendet das CHMI neue Technologien an, welche die Situation im Vorhersagedienst verbessern werden. Im hydrologischen Vorhersagedienst wurden Daten vom meteorologischen Radar bisher vom Bearbeiter subjektiv eher als Ergänzung berücksichtigt. Um die vom Radar gelieferten Informationen so effizient wie möglich nutzen zu können wird gegenwärtig des System RAMAP zur Bearbeitung der Radardaten entwickelt. Von der Art, Geschwindigkeit und Qualität dieser Bearbeitung können viele wasserwirtschaftliche Entscheidungen abhängen. Sind diese Entscheidungen schlecht, kann als ein Extrem der Verlust von Menschenleben, als anderes Extrem die Herausgabe unnötiger Flutwarnungen die Folge sein.

Schlüsselwörter: meteorologisches Radar

1 Introduction

The development of the **RAMAP** system for the processing of radar precipitation information, for the purpose of making hydrological forecasting more accurate, commenced in 1997. In the summer of 1998, the program was put to trial use in the Hydrological Forecasting Department of the CHMI Central Office in Praha - Komořany.

The **RAMAP** system processes radar information and makes possible its further utilisation. Unmanned, it continually monitors, records, and triggers warnings in the case of a limiting precipitation at a point or in the whole catchment, either in an individual time step or in a particular overall time period. According to the user's wish, the system is entered by optional areas of interest (subcatchments - Figure 1, administrative regions, vegetation areas, meteorological forecast regions, etc.), for which boundary values are set.

Fig. 1 Subcatchements

The system then continually checks for the exceedence of the critical precipitation values in the specified areas. The personnel has consequently quite a number of tasks, securing the localization of the extraordinary rainfall with the most achievable accuracy, and the drawing of the same into map bases for the needs of instant flood situation decision-making. For the securing of these services, the MapObjects system proved to be the most suitable one, as it is easily handled in the ORACLE medium, its response is sufficiently quick, and in future it offers the possibility of connection to the internet. This digital processing of radar information should remove some problems which prevented the successful operation of the warning system, and should make possible the full evaluation of the relatively expensive radar monitoring.

The summers are characterized by frequent occurrence of local thunderstorms with both short and long durations. These thunderstorms are particularly amenable to being localised and quantified with the help of radar information. During the summer season of 1999, the hydrologists of the CHMI Central Office in Praha were notified several times by the warning system of the occurrence of dangerous rainfalls, and twice a notification of substantial rainfall in the affected area was given out, on the basis of a **RAMAP** warning and after a consultation with the meteorologist on duty.

In September 1999, **RAMAP** was also installed, on a trial basis, in the Central Meteorological Room of the CHMI Central Office, where it should serve especially for the monitoring of dangerous precipitation events during night and early morning times. To the meteorologists and hydrologists, the program shall facilitate better orientation in the area affected by precipitation, and the delimination of catchments and streams that are endangered by more significant rises in water levels.

The evaluation of individual precipitation events, the sensitivity of radar analysis, and the consequent response in the affected area, are on-going during the present time. In the next stage of the project a goal has already been set, enabling the numerical and visual comparison of radar information with values that are recorded by precipitation gauges.

2 Evaluation of events in the year 1999 which reached a DFA (Degree of Flood Activity)

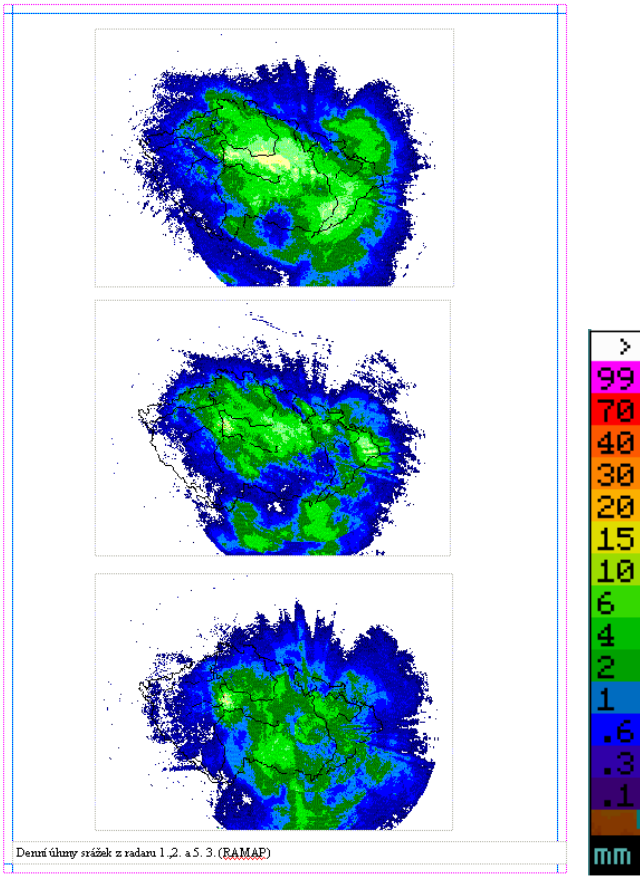
The events that were chosen for the evaluation were those, during which, in the year 1999, the third Degree of Flood Activity (DFA 3) was reached.

2.1. March 1999 event

At the beginning of the month, during massive snowmelts at middle and lower levels, coupled with concurrent more-substantial rainfalls (on the 1., 2. and 5. March, the average rainfall was 10 mm, and in north-eastern Bohemia up to 20 mm), a general overall rise in stream stages occurred.

On most streams in the catchments of the Labe, upper Vltava, Sázava, Berounka, and Ohře rivers, on the upper Odra, Opava, Olše, Lužická Nisa, Třebůvka, and Olšava rivers, on the Morava and Bečva rivers, and in the catchment of the Dyje river, the water levels rose, in the first decade of March, above the level of DFA 1, and at numerous cross-sections even above the levels of DFA 2 and DFA 3 (the Metuje, Tichá Orlice, Orlice, Dědina, upper and middle Labe, Cidlina, Mrlina, Sázava, Ohře, Morava, Třebůvka, Moravská Dyje and Svratka rivers). The rainfall forecast during these days was between 15 mm/day and 20 mm/day in the mountainous regions, and up to 10 mm/day elsewhere in the catchments. According to the meteorological radar, the daily totals on the whole of the area reached between 2 mm and 6 mm, whilst in eastern Bohemia and in Moravia they reached up to 15 mm, at some locations. This result is reliable with respect to the localisation, however the amount of rainfall that had actually fallen was, again mainly in north-eastern Bohemia, slightly underestimated.

Fig. 2 March event

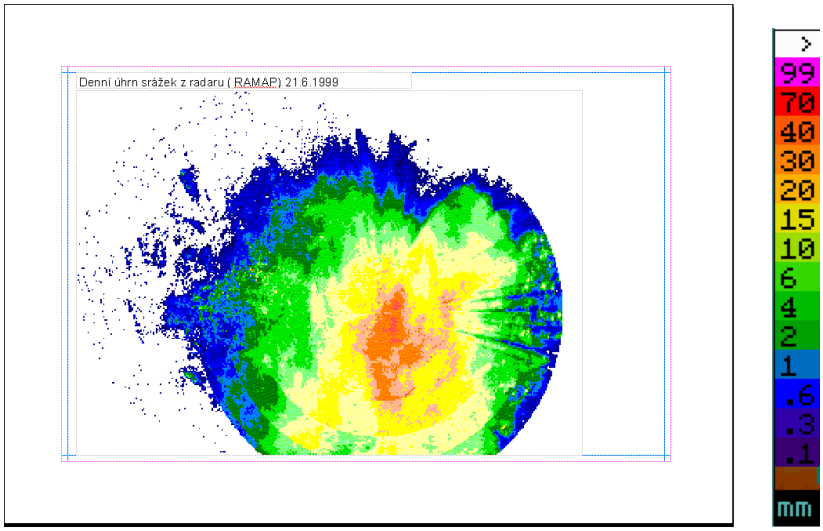


2.2. June 1999 event

During this month, rises to DFA levels occurred in the catchment of the Odra river, when the rainfall in Moravia, between the 19. and 20. June, was between 20 mm and 60 mm for the two days. On the 21. June, additional 50 mm to 90 mm of rain fell, while on the Lysá Hora gauge the total was 140 mm. The river stages of the Odra, Olše and Lučina rivers rose above the levels of DFA 1, those of the Lubina, Ostravice, Ondřejnice and Olešná rivers rose above the levels of DFA 2, and on the Stonávka

river, the stage rose up to the level of DFA 3. After the second precipitation wave, the Stonávka and Olše rivers again rose to the DFA 3 levels, whilst the other streams reached DFA 2 levels at maximum. In the Morava river catchment, DFA 3 was proclaimed on the Morava river itself, DFA 2 on the Bečva and Olšava rivers, and DFA 1 on the Desná river. The forecast precipitation values reached from 5 mm/day to 15 mm/day, in Moravia up to 30 mm/day, and in the Jeseníky mountains up to 60 mm /day. The radar again localised the precipitation well to middle Moravia and southern Moravia. On quite large areas, the value of 70 mm/day was exceeded, and therefore the radar information was slightly underestimated. Most significantly, the maximum total that occurred on Lysá Hora was „invisible“ for the radar.

Fig. 3 June event

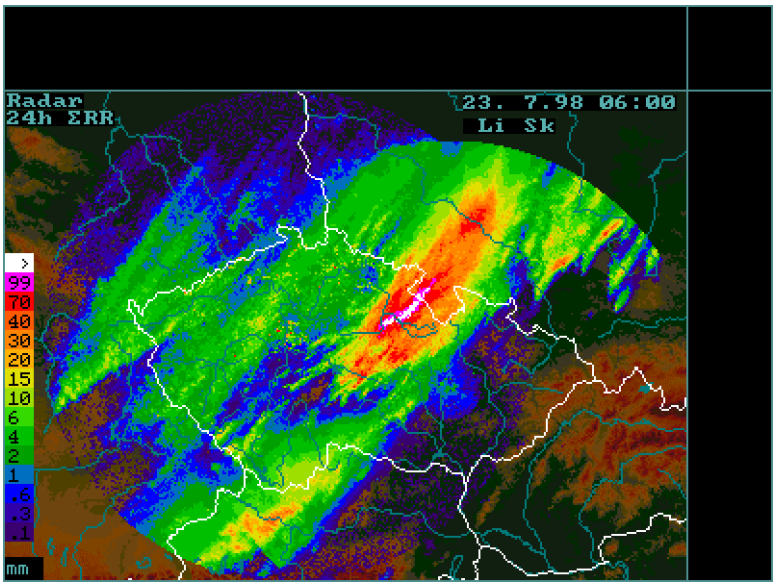


3 Evaluation of other available events where a DFA was reached

3.1. July 1998 event

As opposed to the proceeding year, when extremely high and long-duration rainfalls occurred, and the use of radar information was problematic, this case involved a local summer storm event, which was very accurately localised by radar. In the core of the storm, the maximum values reached up to 180 mm/day, so therefore the radar results were slightly underestimated. Despite this fact, the 23. July 1998 case confirms the high success rate and correctness of radar information obtained during substantial local precipitation events.

Fig. 4 July event



4 Conclusion

The overall evaluation of the chosen events looks rather contradictory (see the **Summary Table**). In the case of local storm events, of both short and long durations, the suitability of radar data utilisation was clearly confirmed. But even in these cases, one needs to keep in mind the fact that the radar slightly underestimates the precipitation totals. The utilisation of the radar information is questionable if precipitation occurs on a larger area, when the radar has an „obscured view“. It then at the best underestimates the precipitation, and at the worst it cannot detect it at all. Such situation has occurred in several cases, particularly in the more remote areas of south-western Bohemia and north-eastern Bohemia.

The utilisation of the **RAMAP** system in pinpointing substantial precipitation areas appears to have further possibilities in the combination of various types of boundary values, in dependence on previous precipitation events, season of the year, the height of the snow cover, etc. During the autumn and winter seasons, it will be possible to test **RAMAP** under these various conditions.

Radar information is very useful for making hydrological forecasts, however it is still but one of the possible auxiliary tools, and is not to be relied upon exclusively.

Summary Table

Time	Precipitation	Radar information
1.3.1999	Czech republic 5 to 10 mm, NE of Bohemia 10 to 35 mm	Czech republic 6 mm, E of Bohemia 10 mm
2.3.1999	Czech republic 5 to 10 mm, NE of Bohemia 15 to 30 mm	Czech republic 6 mm, E of Bohemia rarely 15 mm
5.3.1999	Czech republic 4 to 8 mm, NE of Bohemia 8 to 15 mm	Czech republic 6 mm
21.6.1999	N of Moravia 50 to 90 mm, rarely 140 mm (Lysá mountain)	Bohemia 10 mm, SE of Bohemia and Moravia 15 , partly 70 mm
23.7. 1998	NE of Bohemia 25 to 50 mm, rarely 200 mm	NE of Bohemia 30 to 160 mm

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Ein Hochwasservorhersageverfahren für die Steyr - Überarbeitungen und Neuentwicklungen zu einem bewährten Modell

Robert Kirnbauer, Gabriele Müller, Felix Fröschl, Gotthard Schönmayr, Siegfried Pöschl

Zusammenfassung: Stausee und Kraftwerk Klaus an der Steyr wurden vor 25 Jahren zur Energiegewinnung errichtet. Zusätzlich dient der Speicher zur Hochwasserretention. Das seit 1975 betriebene Modell zur Hochwasservorhersage wurde nun grundlegend überarbeitet und neu strukturiert. Das Ereignismodell wurde mit einem Wasserhaushaltsmodell gekoppelt. Die Berechnungen erfolgen nunmehr teilgebietsspezifisch. Verändert wurden das Abflussbildungsmodell, die Basisabflussberechnung und die Persistenzprognose für den Niederschlag. Das überarbeitete Modell verbessert die Vorhersagen, es ermöglicht Analysen abgelaufener Hochwasser und Szenariorechnungen. Damit steht ein modernisiertes, flexibles Werkzeug zur Hochwasservorhersage zur Verfügung.

Schlüsselworte: Hochwasservorhersage, operationelles Modell

Online Flood Forecasting Model for the Steyr River – Revised Edition of an Opertional Model

Abstract: Dam and power plant Klaus at the Steyr River have been built 25 years ago. Additional the reservoir has to protect floods. Therefore since 1975 a flood forecasting operational model is operating. Now this model has been revised an new stuctured. The operational model is combined with a water balance model and operates for each subbasin. The procedures for simulating runoff generation, base flow and precipitation forecasting have been changed. The revised model improves the forecasting results and includes options for analyzing recent floods and for simulating scenarios. A modernised flexible instrument for flood forecasting is now available.

Keywords: flood forecasting, operational model

1 Warum Überarbeitung eines bewährten Modells?

Die Steyr ist einer der größten Zuflüsse zur Enns, einem rechten Nebenfluss der Donau. Zur Energiegewinnung wurden vor ca. 25 Jahren Stausee und Kraftwerk Klaus an der Steyr errichtet. Da es im Jahresverlauf relativ häufig zu Hochwassern kommt, hat der Speicher zusätzlich Hochwasserschutzaufgaben gegenüber den Unterliegern zu erfüllen. Zur Hochwasserretention muss beim Herannahen eines Hochwassers der Stauspiegel vorabgesenkt und danach wieder auf die energiewirtschaftlich günstige Höhe angehoben werden. Um sowohl den Anforderungen des Hochwasserschutzes als auch der Energiewirtschaft entsprechen zu können, wird seit 1975 ein Modell zur Hochwasservorhersage betrieben (Kresser und Gutknecht, 1974a, b; Kresser et al., 1976).

Die Probleme bei der Hochwasservorhersage sind bekannt: Die bei einem Hochwasser ablaufenden Prozesse sind hochgradig instationär, nichtlinear und zufallsbehaftet. Jedes Modell stellt eine Vereinfachung der Wirklichkeit dar. Die Palette der in der modernen Hydrologie zur Verfügung stehenden Modelle ist groß, viele sind außerordentlich komplex und versuchen eine weitgehend physikalisch begründete Prozessbeschreibung. Es besteht aber eine Diskrepanz zwischen diesen komplexen Modellen, die oft viele, kaum fundiert bestimmbare Parameter aufweisen, auf der einen Seite und dem noch immer ungenügenden Verstehen der Prozessabläufe sowie den in der

ingenieurhydrologischen Praxis erforderlichen praktikablen, operationell einsetzbaren einfachen Modellen auf der anderen Seite (Abbott & Refsgaard, 1996).

Das Hochwasser-Vorhersagemodell aus dem Jahre 1975 betrachtet das ca. 542 km² große Einzugsgebiet des Speichers Klaus (Abb. 1) als Einheit. Das Modell hat sich in den nahezu 25 Jahren seines Einsatzes bewährt. Seit seiner Implementierung ist es mehrfach überarbeitet worden. Dennoch blieben Wünsche offen angesichts des „Nachhinkens“ der prognostizierten Scheitel, ihrer oft starken Überschätzung und einem starren Persistenzansatz für die Regenprognose.

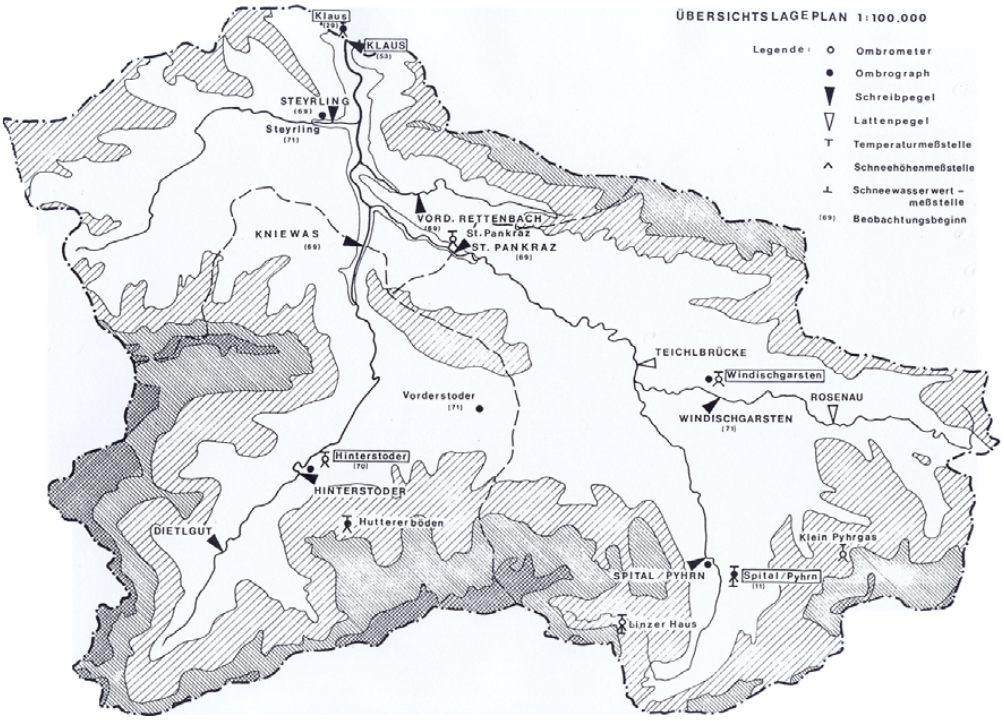

Abb. 1 Das Einzugsgebiet der Steyr bis zum Kraftwerk Klaus

Den Input in das bisherige Modell liefern die drei fernübertragenden Niederschlagsstationen Klaus, Hinterstoder und Windischgarsten, aus deren Werten ein flächengewichtetes Gesamt-Gebietsmittel gebildet wird. Die Berechnung der Abflussbildung erfolgt über ein Koaxialdiagramm, die der Abflusskonzentration über drei Unit Hydrographs in Abhängigkeit von der Effektivregenintensität im betreffenden Zeitintervall. Der Basisabfluss wird horizontal abgetrennt und während des Ereignisses als konstant angenommen.

Die lange Einsatzdauer, die erwähnten Schwächen des Modells und seine gewisse Starrheit gaben den Anlass, eine Modernisierung und Erweiterung ins Auge zu fassen (Gutknecht et al., 1997). Um die natürlichen Gegebenheiten, die unterschiedliche Überregnung und die jeweiligen hydrologischen Reaktionen der Teilgebiete besser berücksichtigen zu können, war das überarbeitete Modell teilgebietsspezifisch anzupassen und zu betreiben.

2 Überarbeitung und Neuentwicklung des Vorhersagemodells

Das überarbeitete Vorhersagemodell besteht aus einer Kombination von einem flächendifferenziert arbeitenden Wasserhaushaltsmodell mit einem Ereignis-Modell. Beide Modelle wurden jeweils für die Teilgebiete der drei Hauptzuflüsse zum Speicher - Steyr, Teichl und Steyrling - kalibriert. Als

Inputdaten gehen die Niederschlagsmesswerte der drei oben genannten Niederschlagsstationen, die an der Station Klaus gemessene Lufttemperatur und die Durchflussmesswerte an den drei Pegeln Kniewas/Steyr, St. Pankraz/Teichl und Steyrling/Steyrling ein. Im Normalfall sind die Niederschlagsstationen jeweils einem Teilgebiet zugeordnet. Zusätzlich ist es möglich, über die Elemente einer Matrix einem Teilgebiet einen gewichteten Mittelwert aus 2 oder 3 Niederschlagsstationen zuzuweisen.

Für die Berechnung des Wasserhaushaltes kommt das Modell BROOK (Federer & Lash, 1983; Forster, 1994) zur Anwendung. Um den unterschiedlichen Bedingungen in Bezug auf Wasserhaushalt bzw. Abflusskomponenten Rechnung tragen, wurde jedes der drei Teilgebiete nach den folgenden Kriterien in Teilflächen (Hydrotope) gegliedert: Höhenverteilung, Geologie, Boden und Vegetation bzw. Landnutzung (Quellen: Geologisches Kartenwerk von Österreich M 1:75 000, Blätter Kirchdorf, Liezen und Admont; Atlas der Geologie M 1:20 000, Nationalpark Kalkalpen, 1994; Klassifizierung der Bodentypen in Österreich M 1:1 000 000; Topografische Karte von Österreich M 1:50 000). Ergebnisse aus Ganglinienseparationen nach Schwarze et al. (1991) lieferten die Speicherkonstanten für das BROOK-Modell.

Im Tagesschritt werden die Wasserhaushaltsgrößen für jedes der drei Teilgebiete berechnet und die ermittelten Gebietszustände und Schneeschmelzraten an das Ereignis-Modell übergeben. Mit Hilfe eines typischen Tagesgangs (Blöschl und Kirnbauer, 1991; Kirnbauer et al., 1994) erfolgt eine Transformation der Tagesraten der Schneeschmelze in Stundenwerte.

Das Ereignismodell prüft anhand der aktuellen Messwerte von Niederschlag und Lufttemperatur, ob die Startbedingungen für eine Hochwasservorhersage erfüllt sind. Ausgehend von der Lufttemperatur und einem Gradienten für die Temperaturabnahme mit der Seehöhe wird die Höhenlage der Schneefall-Grenze bestimmt. Die zum Abfluss beitragende flüssige Niederschlagsmenge ergibt sich entsprechend den Flächenanteilen des Gebietes, die tiefer als die Schneefallgrenze liegen.

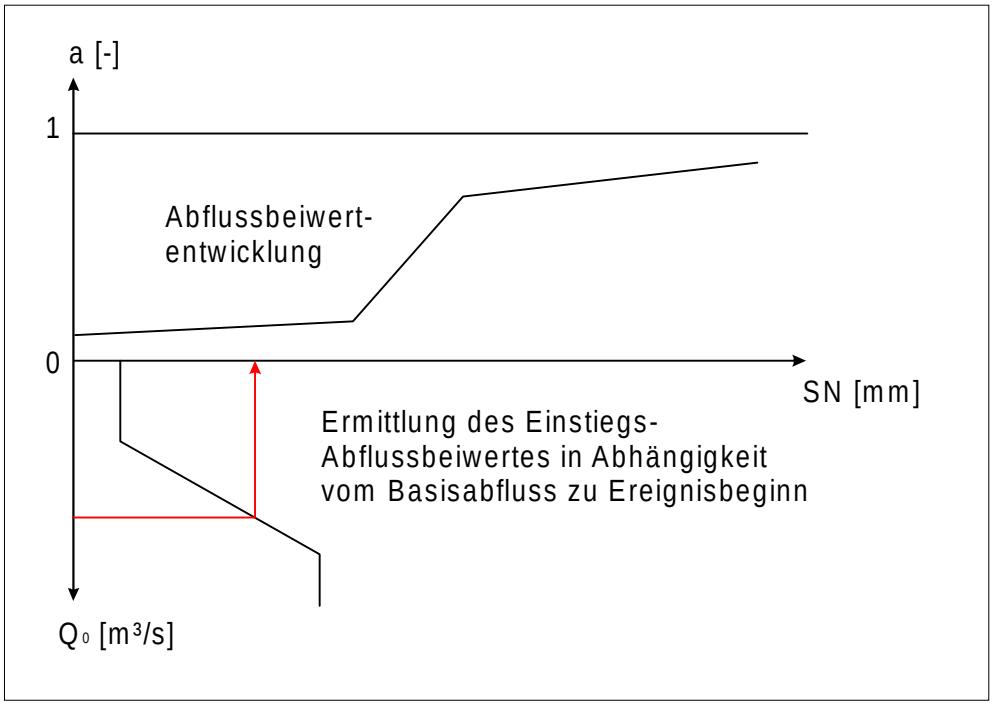

Abb. 2 Abflussbildungsansatz nach Kirnbauer (1988), mit a [-] – Abflussbeiwert; SN [mm] – Ereignisniederschlagssumme; Q_0 [m³/s] – Basisabfluss zu Ereignisbeginn

Die Berechnung der Abflussbildung geschieht über einen erweiterten Verlustratenansatz. Der Abflussbeiwert wird als monoton wachsende Funktion der Regensumme und des Basisabflusses zu Ereignisbeginn – als Vorfeuchtemaß – beschrieben. Mit diesem Abflussbeiwert wird der um eine konstante Infiltrationsrate verminderte Niederschlag multipliziert (Kirnbauer, 1988). So findet das Anwachsen des Abflussbeiwertes durch Auffeuchtung des Gebietes während des Ereignisses Berücksichtigung. Ist infolge hoher Vorbefeuchtung die Abflussbereitschaft eines Gebietes bereits zu Beginn sehr groß, sichtbar an einem erhöhten Basisabfluss zu Ereignisbeginn, wird von vornherein ein höherer Abflussbeiwert verwendet (Abb. 2).

Zur Berechnung der Abflusskonzentration stehen für jedes Teilgebiet drei unterschiedliche Unit Hydrographs zur Verfügung. Ihre Auswahl richtet sich nach der Effektivregenintensität. Der Basisabfluss setzt sich aus einem Auslaufanteil (Vorgeschichte) und einem Ereignisanteil zusammen. Der aus dem Ereignis resultierende Anteil wird durch Faltung der Differenz zwischen beobachtetem Regen und Effektivregen mit einem Basis Unit Hydrograph ermittelt. Die Parameter (Rezessionskonstanten) ergaben sich aus den Ganglinienanalysen nach Schwarze et al. (1991).

Die Vorhersage der Niederschläge beruht auf einer gedämpften Persistenzprognose. Dabei werden n zurückliegende Regenelemente arithmetisch oder gewichtet gemittelt und dieser Mittelwert als Niederschlag für jede der m folgenden Stunden angesetzt. Die Anzahl der berücksichtigten zurückliegenden Regenelemente wie auch die Anzahl der Prognoseintervalle sind wählbar. Unterschreitet an einer Station der Niederschlag das Abbruchkriterium von 0,2 mm/h, dann endet die Regenprognose für das betreffende Teilgebiet.

Die Berechnungen erfolgen für jedes der drei Teileinzugsgebiete separat, der Zufluss zum Speicher Klaus ergibt sich durch Superposition der Teilgebietsabflüsse. Der Abflussbeitrag für das Rest-Einzugsgebiet (Eigeneinzugsgebiet der Talsperre) wird als konstanter Prozentsatz des Abflusses aus dem Steyrlinggebiet abgeschätzt. Die Laufzeiten von den Teilgebietspegeln zum Prognosepunkt Klaus werden nicht berücksichtigt, da sie sich in Größenordnungen von weniger als einer Stunde bewegen, also geringer sind als ein Berechnungszeitschritt.

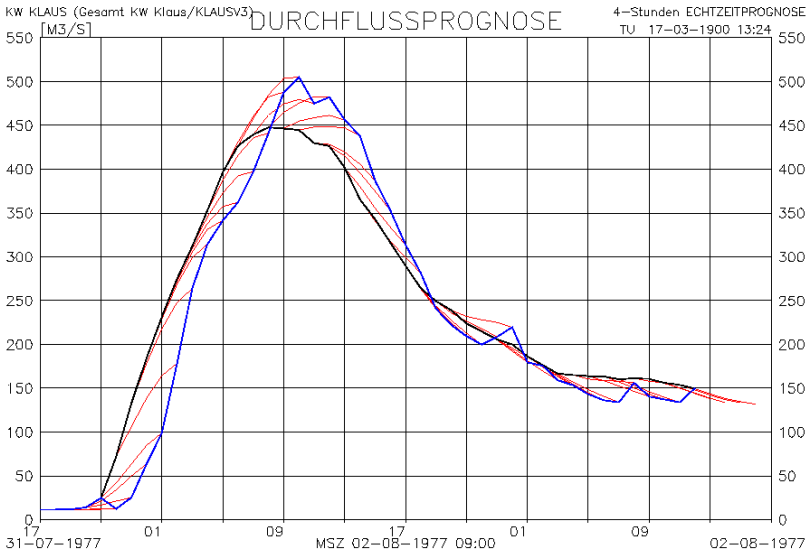

Abb. 3 Visualisierung der Prognoseergebnisse innerhalb des Vorhersagemodells (ohne Niederschlag); dargestellt sind die beobachtete Zuflussganglinie, davon ausgehend für jeden Zeitschritt der Prognoseverlauf über 4-Stunden sowie die Verbindungslinie der 4-Stunden-Prognosen

Für das Vorhersagen des Abflusses bietet das Modell vier Varianten an: 1.) Modellierung ohne Regenprognose und ohne Korrektur (reines Modellverhalten), 2.) dgl., jedoch mit Korrektur (Nachführung) entsprechend gemessener Durchflüsse, 3.) mit einer gedämpften Persistenzprognose für den Niederschlag und Korrektur, 4.) „Analyseprognose“ mit den tatsächlich beobachteten Niederschlägen. Diese letztgenannte Prognosevariante wird bei der nachträglichen Analyse abgelaufener Ereignisse verwendet und dient dazu, die Auswirkungen der Unkenntnis des zwischen dem Herausgabezeitpunkt und dem Bezugszeitpunkt der Vorhersage fallenden Niederschlages zu quantifizieren.

Die Vorhersageergebnisse für die Teilgebiete und das Gesamtgebiet werden visualisiert. Dabei stehen den Durchfluss-Vorhersagen jeweils die gemessenen Abflüsse sowie die Niederschläge gegenüber. Diese bestehen dabei nicht nur aus dem ermittelten Wert für die m-Stunde-Prognose, sondern aus der Darstellung des Verlaufes der Prognose, welcher für die Steuerung der Anlage im Hochwasserfall wesentlich aussagekräftiger als ein einziger Zahlenwert ist (Abb. 3).

3 Ergebnisse und Kritik

Abb. 4 stellt am Beispiel des Hochwasserereignisses vom 21. bis 23. Juli 1999 die Vorhersage-Ergebnisse des überarbeiteten Modells jenen aus dem bisherigen gegenüber. Die Ganglinien sind die Verbindungslinien der 4-Stunden-Vorhersagen, zusätzlich ist der beobachtete Durchfluss eingetragen.

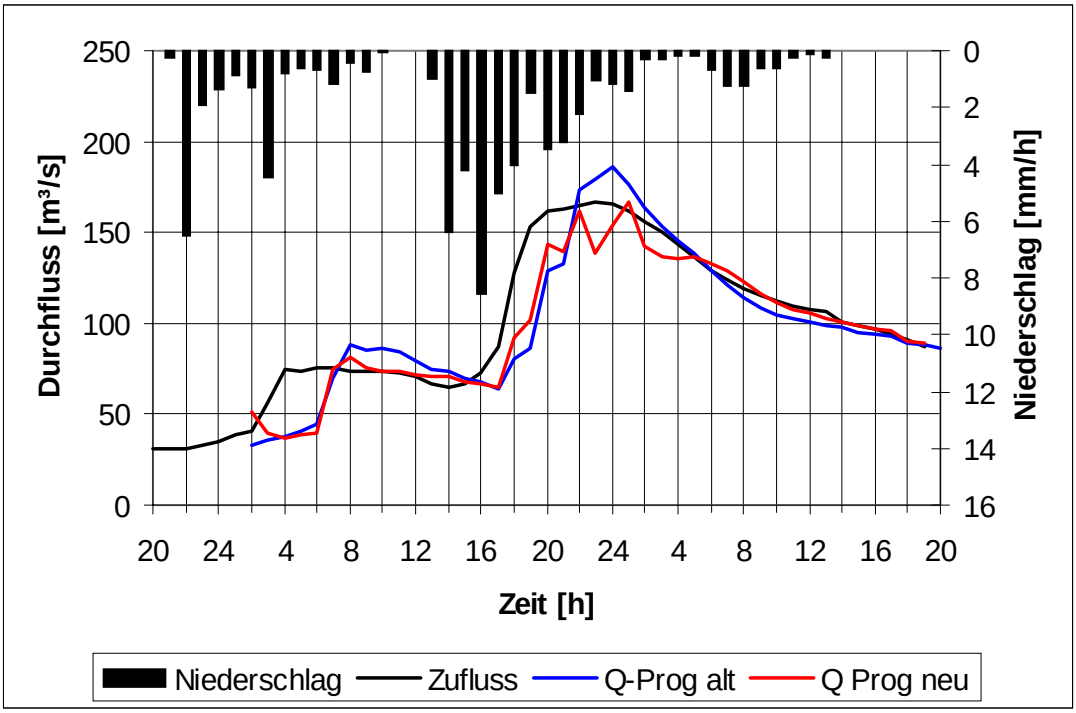

Abb. 4 Vergleich der mit dem bisherigen und mit dem überarbeiteten Modell berechneten 4-

Stunden-Vorhersagen des Durchflusses für das Hochwasserereignis vom 21.7.1999, 22 Uhr bis 23.7.1999, 19 Uhr im Einzugsgebiet des Speichers Klaus

An Hand dieses Hochwassers lassen sich einige Eigenschaften des Vorhersageverfahrens und spezifische Fehlerursachen beschreiben. Zu Ereignisbeginn (21.7.1999, 22 Uhr) kann weder das alte noch das neue Vorhersagemodell den beobachteten Abflussanstieg prognostizieren. Offensichtlich resultiert dieser aus Niederschlägen, die durch die vorhandenen drei Ombrographen nicht erfasst werden, denn aus den gemessenen Niederschläge ist dieser Anstieg nicht schlüssig erklärbar. Der Anstieg der Hauptwelle (22.7.1999, 16 Uhr) wird von beiden Modellen mit Verspätung erkannt. Die Ursache dafür liegt darin, dass der zwischen dem Herausgabezeitpunkt und dem Bezugszeitpunkt der Prognose fallende Niederschlag unbekannt ist. Diese Unkenntnis ist durch eine Persistenzprognose nur unzureichend kompensierbar. Im Scheitelbereich des Hochwassers übersteuert die neue Vorhersage weniger als die bisherige, denn die Persistenzprognose wird im neuen Vorhersagemodell früher abgebrochen als im alten.

Im Mittel über die 34 untersuchten Ereignisse (28 Sommer- und 6 Winterereignisse) liefert das überarbeitete Modell gute Vorhersagen. Es gelang weitgehend, die Übersteuerungen im Scheitel gegenüber dem bisherigen Modell zu verringern bzw. ganz zu vermeiden. Dies liegt einerseits am Abbruchkriterium für die Persistenzprognose, welches auf ein Unterschreiten einer Regenintensität von 0,2 mm/h gesetzt ist, andererseits am Deckelbetrag für die Regenintensität, der verhindert, dass selten auftretende, extreme Intensitäten zu stark in die Persistenzprognose eingehen.

Weniger deutlich fällt die Verbesserung hinsichtlich des Nachhinkens der Prognoseganglinie aus. Ein gewisser time lag lässt sich aber nicht vermeiden, weil man die zukünftigen Niederschläge nicht kennt. Da keine zutreffenden meteorologischen Niederschlagsprognosen vorliegen, musste auf die beschriebene Persistenzprognose zurückgegriffen werden.

Probleme bei der Prognose bereiten örtlich unregelmäßige Niederschlagsverteilungen und zeitlich schwankende Niederschlagsintensitäten. Bei einigen Hochwassern konnte eindeutig die ungleichmäßige räumliche Niederschlagsverteilung als Ursache für schlechte Prognosen identifiziert werden. Die an den verwendeten Stationen punktförmig gemessenen Niederschlagswerte waren nicht repräsentativ für die Fläche, der sie zugeordnet sind, die beobachteten Durchflüsse passten mit den beobachteten Regen nicht zusammen. Bei anderen Hochwässern war die zeitliche Variabilität des Niederschlages die dominierende Fehlerursache, denn abrupte Wechsel der Niederschlagsintensität sind mit Hilfe einer Persistenzprognose nicht prognostizierbar.

Gewisse Fehlerursachen sind unabhängig vom Vorhersageverfahren und unvermeidlich: Messfehler bei den „beobachteten“ Abflüssen (unsichere Pegelschlüssel im Hochwasserbereich; Pegel können unterirdisch umströmt sein) sind im Verlauf der on-line Vorhersage nicht erkennbar. Dasselbe gilt für Fehlregistrierungen bei der Messung des Niederschlages. Beim Vorhersageverfahren für das Gesamtgebiet Klaus wird der Abflussbeitrag des durch die drei Gebietspegel nicht erfassten Rest-Einzugsgebietes als konstanter Prozentsatz des Zuflusses aus dem Gebiet der Steyrling geschätzt. Diese Annahme kann bei speziellen Ereignissen unzutreffend sein.

4 Zusammenfassung

Das Modell zur Hochwasservorhersage für den Speicher Klaus wurde grundlegend überarbeitet und neu strukturiert. Das Ereignismodell erhielt eine Kopplung mit einem parallel laufenden Wasserhaushaltsmodell. Die Berechnungen erfolgen nunmehr teilgebietsspezifisch und ermöglichen so Vorhersagen auch für einzelne Teilgebiete. Verändert wurden die Berechnungsansätze für die Abflussbildung, die Basisabflussabtrennung und die Persistenzprognose für den Niederschlag.

Im Mittel erzielt das derzeit als Prototyp vorliegende überarbeitete Modell etwas bessere Hochwasservorhersagen als das bisherige, besonders hinsichtlich der Überschätzung im Hochwasserscheitelbereich. Durch die Kopplung mit dem Wasserhaushaltsmodell kann der tatsächliche Gebietszustand hinsichtlich der Vorbefeuchtung und hinsichtlich der Schneeschmelze bzw. Lage der Schneefallgrenze besser eingeschätzt werden. Diese Information zur Vorbefeuchtung ist wesentlich aussagekräftiger als der bisher verwendete und in der Ingenieurhydrologie noch immer weit verbreitete Vorregenindex. Das überarbeitete Modell bringt auch insofern einen Fortschritt, als es von der Struktur her flexibel und weitgehend konfigurierbar ist. Eine deutliche Modernisierung erfuhr weiters das Datenhandling durch die Implementierung einer Datenbankschnittstelle. Im off-line Betrieb erlaubt das Modell das Nachrechnen abgelaufener Hochwasser und Szenariorechnungen. Im Ergebnis der Überarbeitungen und Neuentwicklungen steht damit ein flexibles und praktikables Werkzeug zur Hochwasservorhersage für das Kraftwerk Klaus zur Verfügung.

5 Dank

Dank gebührt den Ennskraftwerken, dem Hydrographischen Zentralbüro und dem Hydrographischen Dienst Oberösterreich für die Bereitstellung und Aufbereitung der Daten. Für die Durchführung der bilanzgestützten Ganglinienanalyse zur Ermittlung der Abflusskomponenten und Speicherkonstanten sei Herrn Dr. R. Schwarze vom Institut für Hydrologie und Meteorologie der TU Dresden gedankt.

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New Approaches in the Slovenian Hydrological Forecasting Service

Mira Kobold, Mojca Sušnik, Janez Polajnar

Abstract: The timely and accurate flood forecasting is essential for the reliable flood warning. The effectiveness of flood warning is dependent on the forecast accuracy of certain physical parameters, such as the peak magnitude of the flood, its timing, location and duration. The conceptual rainfall - runoff models enable the estimation of these parameters and lead to useful operational forecasts. Some of the Slovenian watersheds are in the phase of setting up of hydrological models with WMS (Watershed Modelling System) software, which integrates digital terrain analysis and hydrological modelling. Model HEC-1 is used for surface runoff simulation. The results of simulations on the Savinja river basin are encouraging. In operational use of hydrological forecasting models, the precipitation data and parameters of base flow are required. The input for the rainfall can be real time rain-gauges data, or weather radar data, or meteorological forecasted precipitation.

Key words: watershed modelling, flood forecasting, hydrological modelling, precipitation, runoff, HEC-1

Neue Ansätze im slowenischen hydrologischen Vorhersagedienst

Zusammenfassung: Die zeitgerechte und genaue Vorhersage von Hochwässern ist für eine verläßliche Überflutungswarnung unerläßlich. Die Effizienz der Überflutungswarnung hängt von der Vorhersagegenauigkeit einzelner physikalischer Faktoren wie Hochwasserspitze, ihr Auftrittszeitpunkt, Ort und Dauer ab. Die konzeptuellen Niederschlags-Abflußmodelle ermöglichen die Abschätzung dieser Faktoren und führen zu brauchbaren Vorhersagen.

Für einige slowenische Einzugsgebiete ist der Aufbau hydrologischer Modelle unter Verwendung von WMS (Watershed Modelling System) im Gange, welches digitale Terraindaten und hydrologische Modellierung beinhaltet. Für die Abflusssimulation wird das Modell HEC-1 verwendet. Die Simulationsresultate für das Einzugsgebiet der Savinja sind ermutigend. Für die Verwendung hydrologischer Vorhersagemodelle werden Niederschlags- und Basisabflussdaten benötigt. Für den Niederschlag können tatsächliche Niederschlagsmessungen, Wetterradardaten oder meteorologisch vorhergesagte Daten verwendet werden.

Schlüsselwörter: Einzugsgebietsmodellierung, Hochwasservorhersage, hydrologische Modellierung, Niederschlag, Abfluss, HEC-1

1 Introduction

The hydrological forecasting service of Hydrometeorological Institute of Slovenia regularly observes the hydrological situations of Slovenian rivers, and issues the forecasts on the expected changes of discharges. In the case of flood waves, the data of the river stages, trends and threat of flooding are delivered to corresponding authorities. For the operational work in hydrological forecasting service the regression hydrological forecasting models for predicting the peaks of flood waves have been developed and used so far (Sušnik and Polajnar, 1998). These regression models, however, do not offer the whole information about the duration and the shape of flood waves.

The main idea of hydrological modelling is setting up the operative hydrological system for calculating the runoff on the outlet of the basin and also in the upstream cross sections. The torrential nature of the streams and fast runoff are characteristic for the most of the Slovenian rivers. Extensive damage is caused almost every year by floods affecting different regions of the country. The watershed of the Sava river to the border with Croatia is in the phase of setting up of hydrological models with WMS (Watershed Modelling System) software. It includes tools

for creating the watershed from GIS (Geographical Information Systems) data with interfaces to the hydrological modelling software. So far WMS has been implemented on the Savinja river basin, tributary of the Sava.

2 Watershed modelling

The advantage of the software used, is its ability to take digital terrain data for hydrological data development. The watershed of the Sava river with area of 10746 km^2 covers half of the territory of Slovenia. The watershed is divided to three subareas as shown in Fig. 1. The data of digital elevation model and vector data of streams were used to create digital terrain models by TIN (Triangulated Irregular Network) method (WMS, 1997). A topological representation of the basin, needed for hydrological model, is simultaneously generated. So far the hydrological model for the Savinja river basin is set up.

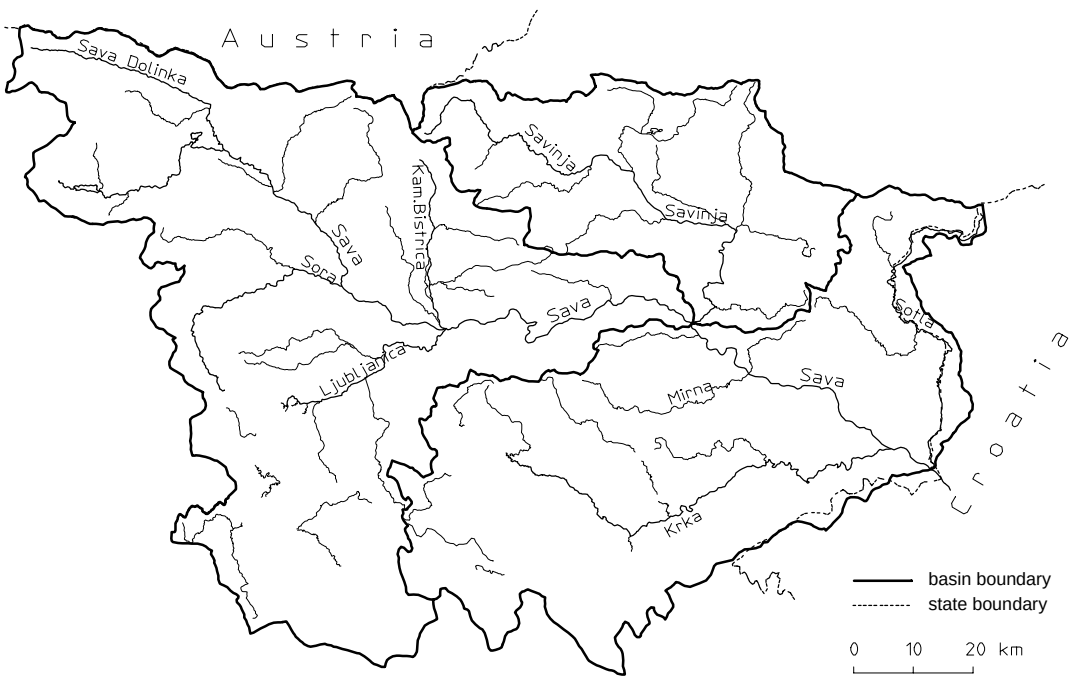

Fig. 1 Watershed of the Sava river.

2.1 The Savinja basin model

The Savinja river is the biggest tributary to the Sava river with drainage basin of 1847,7 km^2. Due to its runoff characteristics it has the important influence both on the forming of flood waves and to the forecast of the lower Sava river. Its drainage area can contribute up to 50% of the Sava river's discharge at extremely meteorological events. The floods occur mostly in autumn and the orographic precipitation in the upper mountainous part of the basin has main influence to the runoff. The storms can cause that some tributary flows rise more than a hundred times. In last ten years there were two big floods at the Savinja that caused enormous damage, one in November 1990 and another in November 1998. In plain areas the cities of Celje and Laško, as well as some upstream urban areas are threatened.

Sub-basins within major basin can be created by adding any number of additional outlet points along the stream network. For the Savinja basin the sub-basins were created regarding the position of hydrological gauging stations (Fig. 2).

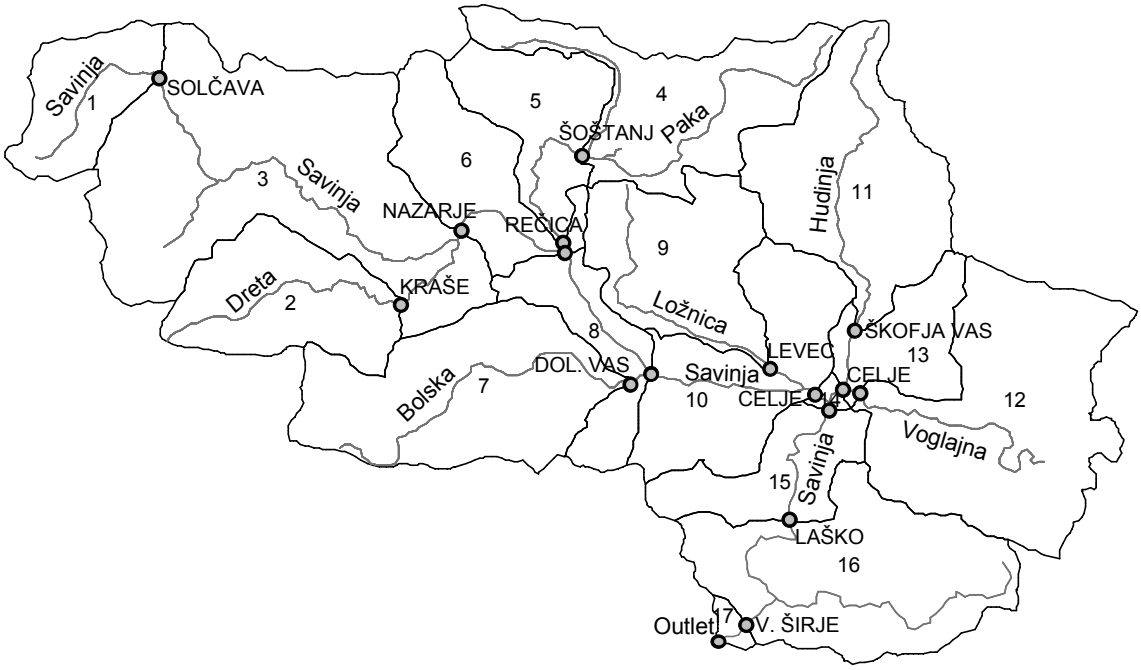

Fig. 2 Sub-basins delineation of the Savinja basin.

Since the terrain model is an accurate geometric description of the watershed, some parameters such as areas, slopes, and flow distances can be computed automatically and merged to hydrological models. The main characteristics of sub-basins are given in Table 1.

Table 1 The main characteristics of sub-basins.

Sub-basin No.	Area (km^2)	Average slope (%)	Sub-basin length (km)	Average elevation (m a.s.l.)	CN
1	63.80	45.3	11.39	1216	64
2	101.49	27.5	15.87	763	65
3	291.75	31.9	22.21	941	64
4	128.38	18.8	18.95	665	65
5	74.81	15.6	5.84	530	68
6	84.81	20.7	6.88	660	67
7	162.98	20.3	22.58	576	67
8	56.17	13.4	9.77	413	73
9	106.84	10.2	16.90	381	72
10	120.45	12.0	10.81	362	71
11	155.05	19.6	20.37	606	66
12	204.97	10.5	18.90	367	68
13	53.41	04.9	3.97	294	75
14	3.81	08.4	1.63	267	79
15	62.77	23.4	7.62	453	60
16	174.81	18.8	7.46	484	64
17	5.80	35.3	2.20	473	60

The SCS (Soil Conservation Service) curve number method was used to calculate the precipitation losses. Curve numbers (CN) are computed from maps of hydrological soil groups and specified land use. The values of CN correspond to average antecedent moisture conditions.

3 Hydrological modelling

Model HEC-1 has been used for surface runoff simulation. HEC-1 is well-known single event hydrological simulation model. A flood hydrograph package enables the flood forecaster to develop unit hydrographs using various methods, calculate loss rates and to route hydrographs, again using a variety of methods (HEC-1, 1990). It is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of meteorological, hydrological and hydraulic components. Representation of a component requires a set of parameters, which specify the particular characteristics of the component, and mathematical relations, which describe the physical processes. Model parameters represent temporal as well as spatial averages. The result of the modelling process is the computation of streamflow hydrographs at desired locations in the river basin.

Calibration of the model is one of the most important steps in any modelling problem. The model should be calibrated to observed flood data. HEC-1 provides a powerful optimization technique for the estimation of some of the parameters when gauged precipitation and runoff data are available. The input parameters of the model are adjusted until the output computed by the model is reasonably close to measured data.

For calibration and determination of parameters of the Savinja basin the highest flood wave situations from last ten years were chosen. For the selected flood situations the rainfall data for the rain-gauge stations operated within and near the Savinja basin were used. The distribution of rain-gauges is shown in Fig. 3. Among these, only five stations (No. 2, 279, 268, 301 and 452) give the temporal distribution. A method of Thiessen polygons was used to calculate the average depth of rainfall over sub-basins.

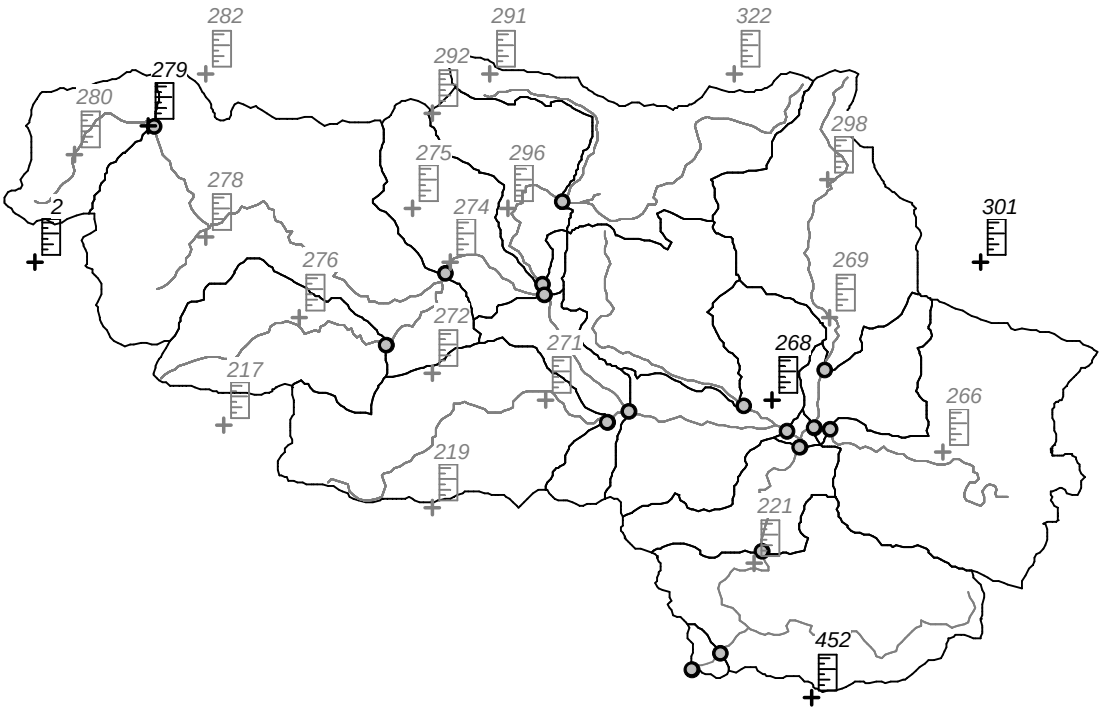

Fig. 3 The rain-gauges distribution.

During the calibration of the model and optimization of parameters the method of Snyder unit hydrograph with two parameters, lag time and peaking coefficient, (HEC-1, 1990), gave the best agreement with measured hydrographs. The SCS curve number method did not correspond well to all chosen flood wave situations. The cause is in different antecedent moisture conditions. The CN values are not really constant (Purwanto and Donker, 1991). The method of initial and uniform loss rate for computing precipitation losses were shown applicable to runoff simulation. Some additional analyses of precipitation losses will have to be done.

4 The results of analyses

After the calibration of the Savinja basin model several analyses were performed: the analysis of deviations of measured and simulated hydrographs, the use of radar data in hydrological modelling, and the sensitivity of model to rainfall.

4.1 The analysis of deviations of measured and simulated hydrographs

The analysis of simulated and measured peak discharges gave the absolute average deviation on locations of hydrological gauging stations (Table 2).

Table 2 The average deviations of measured and modelled peak discharges.

Hydrological gauging station	**Area (km^2)**	**Average deviation (%)**
Dreta – g.s. Kraše	100.66	31
Paka – g.s. Šoštanj	131.20	25
Hudinja – g.s. Škofja vas	156.50	27
Bolska – g.s. Dolenja vas	169.50	22
Voglajna – g.s. Celje	202.20	27
Savinja – g.s. Nazarje	457.30	12
Savinja – g.s. Laško	1663.60	10
Savinja – g.s.Veliko Širje	1841.90	9

The maximal average deviation is bigger in the mountainous part of the Savinja basin. Generally, the average absolute deviations of simulated and measured peak discharges are between 20 and 30% for smaller sub-basins, but 10% for the basin as a whole. The main reason of bigger deviations lies in the small number of rain-gauges with temporal records. Five stations with temporal data distribution, from which only two are located inside the Savinja basin, are not sufficient to take into account all orographic influences. For more accurate calibration of the model, more temporal distribution stations are needed, particularly in the mountainous parts.

4.2 The use of radar data in hydrological modelling

A rain-gauge network can miss significant rainfall, especially rainfall associated with intensive convective storms. The advantage of using radar for precipitation measurement is the coverage, it provides over a large area with high spatial and temporal resolution. Radar data, giving real-time areal rainfall totals over basins or sub-basins, could be used successfully as input into hydrological models of flood forecasting. The data of conventional radar on Mount Lisca, Slovenia, were used in the study. The radar precipitation data are underestimated with increasing distance from the radar. To use the radar data for hydrological applications, the radar data need to be calibrated with rain-gauge measurements. A correction function was derived and the analysis of accuracy of the radar-estimated areal rainfall was already done for the Savinja basin (Kobold and Zgonc, 1998).

The runoff simulation by radar precipitation data gave good agreement between measured and simulated hydrographs. However, use of radar data for hydrological applications has at the time being some flaws, such as incomplete series of data, poor representation in mountainous areas, and non adequate correction method with rain-gauge measurements, which have to be improved.

4.3 The sensitivity of model to rainfall

The sensitivity of the model to the rainfall error was tested for rainfall data deviation by 10%, 20% and 30%. This analysis has shown that the deviation of runoff is twice the rainfall deviation (Fig.4).

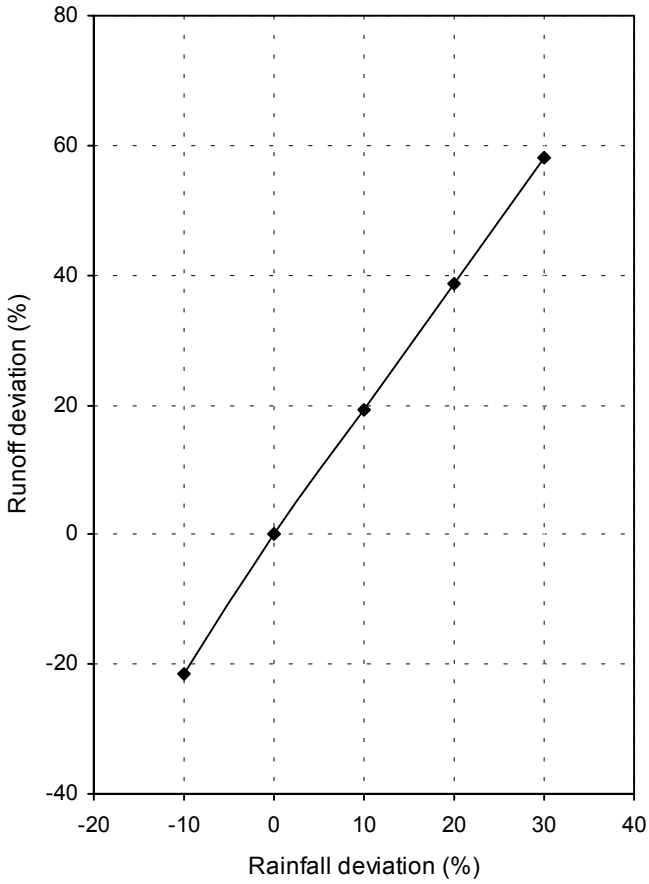

Fig. 4 Runoff deviation to rainfall deviation.

In operational use of hydrological model, an error in rainfall amount leads to two times greater error of discharge in the simulated hydrograph. Therefore, the accurate rainfall is the most important input into hydrological rainfall - runoff model.

5 Model verification

The model of the Savinja basin was verified on the flood wave situation from 3rd to 6th November 1998. The input data were parameters of base flow and rain-gauge precipitation. The process of simulation began on 2nd November 1998. The results of simulation gave good agreement with observed hydrographs. Computed and observed hydrographs for the most representative hydrological gauging stations Nazarje and Laško are shown in Fig. 5.

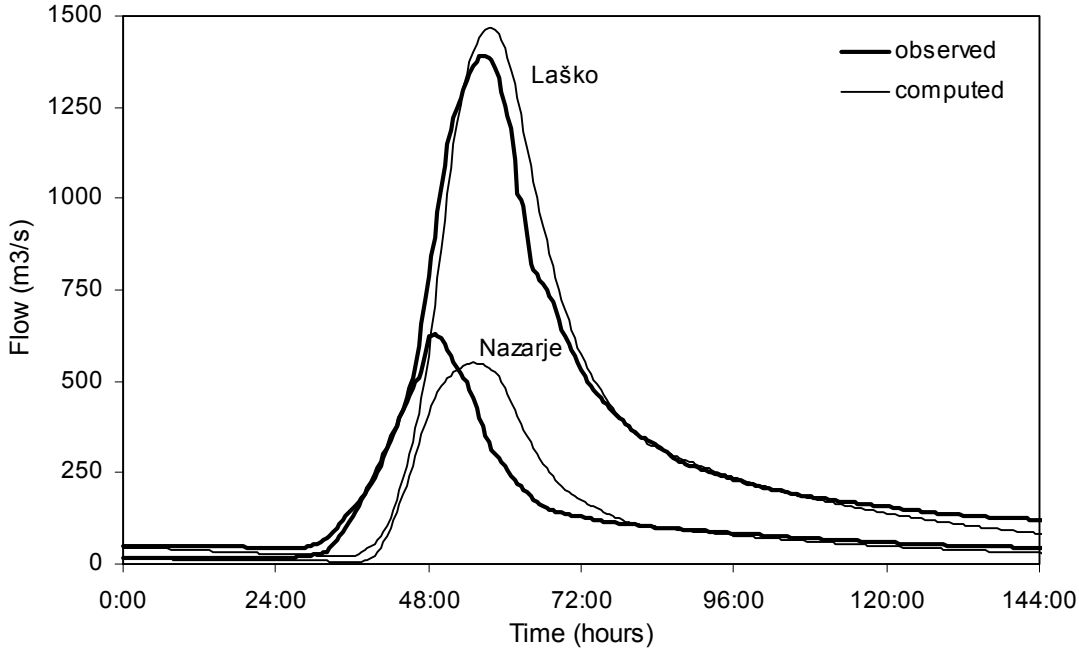

Fig. 5 The Savinja flood wave from 3rd to 6th November 1998.

The deviation of computed and measured peak discharges is 12,3% for gauging station of Nazarje and 5,5% for Laško. The deviations are in the range of average deviations, as well for the other hydrological gauging stations at the Savinja.

In operational use of the model, only precipitation and parameters of base flow are required. The input for the rainfall could be rain-gauge data, radar data, or forecasted precipitation by meteorological model ALADIN/SI used on Hydrometeorological Institute of Slovenia (Vrhovec et al, 1998). In the first phase, the forecasted precipitation can be used to calculate the forecasted hydrographs up to 48 hours ahead. It will serve for internal use only and will help hydrologists in hydrological forecasting service to issue warnings on imminent floods. During the rainfall event the precipitation data will be corrected by automatic rain-gauge data and radar data to obtain the short-term hydrological forecasts.

6 Conclusions

First verification of the model has shown good agreement between modelled and observed hydrographs. The practical aim of flood forecasting is to reduce the loss of life and the economic damage caused by floods. This aim can only be achieved if an accurate forecast is translated into a reliable flood warning.

Flood forecasting models are valuable if they operate in real time. Forecast accuracy is partly determined by the limitations of the on-line gauge network and the quality of data. The model has shown great sensitivity to rainfall data. Many floods are caused by intense precipitation where the distribution of rainfall has the major influence to the runoff. Results of testing the model have shown the need to develop precipitation prediction on micro scale. The improvements in meteorological modelling with the method of the dynamic adaptation and with better description of the relief with the resolution of 2.5 km (Žagar, 1999) assure the accurate forecasted precipitation. These are especially important as input into the rainfall - runoff models before flood wave situations.

The results of analyses also pointed out the necessity to expand and modernize the rain-gauge network to offer us on-line data.

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A Regional Method and Results of the Over Long-Term Hydrological Forecasts

Vladimir Konovalov, Lidia Karandaeva

Abstract: Charvak and Andijan reservoirs and Zeravshan river are in the number of the main water storage which intensively turned something to the advantage of the Republic Uzbekistan water economy. The user's organizations requested Central Asian Hydrometeorological Institute to submit in 1996 and in 1997 the forecasts of annual water inflow to the reservoirs for the 1997-2000 and 1998-2000 as well as annual runoff of Zeravshan river during of 1999-2003. The following approaches are used to come to the decision of the objective: correlation and spectral analysis of the quasi-periodic features of predictors long-term sets, determination of the main components of the homogeneous group of predictors, averaging of predictors and combining of the computation formulae, causal analysis, selection of the effective equations of multiply linear regression.

Key words: Predictability of runoff and its factors; local, regional and global predictors; multiply linear regression

Regionale Methode und langfristige hydrologische Vorhersagen

Zusammenfassung: Die Stauseen Charvak und Andischan, wie auch der Fluss Zerafschan, bilden einige der Hauptgewässer, die von größter Bedeutung in der Wasserwirtschaft der Republik Usbekistan sind. Die Nutzer ersuchten das Zentralasiatische Hydrometeorologische Institut in den Jahren 1996 und1997 Prognosen für die Jahreszuflüsse in die Stauseen in den Jahren 1997-2000 und 1998-2000, und im Jahre 1998 für die Jahresabflüsse des Flusses Zerafschan in den Jahren 1999-2003 zu geben. Für die Durchführung dieses Auftrages wurde folgendes Modell verwendet: Korrelations- und Spektralanalyse der quasiperiodischen Eigenschaften der langjährigen Reihen von Prediktoren, Feststellung der Hauptkomponenten der homogenen Gruppe der Vorhersageparameter, Methoden für die Mittelbildung der Prediktoren und Komplettierung der Gleichungen, Kausalanalyse und die Auswahl der effektiven Gleichungen der mehrfachen Linearregression.

Schlüsselwörter: Abflussvorhersage und ihre Faktoren, lokale, regionale, globale Prediktoren, Linearregression.

1 Introduction

It is known that hydrologic cycle in river basins of Central Asia consists of two basic periods:

a) accumulation of solid and liquid precipitation during of October-March in average, b) spring-summer runoff during of plants vegetation period or from April till September. Period of precipitation accumulation could be lasted till April or even May depending on altitude of basin above sea level. Let us take monthly and seasonal sums of precipitation and mean values of air temperature as climatic factors of two basic phases of regional hydrologic cycle. Besides the climate factors we may consider the runoff itself as additional predictor after certain transformation of its temporal range.

Computation the correlation matrix of annual runoff in the Syrdarya and Amydarya river basin showed (Konovalov,1988) that the temporal ranges as well in neighbor watersheds as remotely located ones are closely depended. It is possible to suggest that certain correlation dependence continue to exist between the runoff ranges shifted in time. Thus one or several shifted ranges could be considered as independent predictors or jointly with other variables. This hypothesis as well as application of different numerical methods is studied in the discussed paper.

2 Initial data

Three basic sets of potential predictors were formed to carry out the researches and numerical experiments.

1. Hydrological characteristics of Central Asia territory. Here were used 59 long-term (mainly for 1930-1995) series of seasonal and annual values of runoff for rivers within Aral Sea basin. Areas of an individual watersheds are varied from 400 km^2 till 310 000 km^2 and their mean weighted altitudes changed from 1.6 km till 4.6 km above sea level.

2. Local meteorological characteristics. This set includes long term series of monthly and annual sums of precipitation and averaged for months and year air temperatures measured on 44 meteorological points, located within Syrdarya and Amudarya river basin on altitudes from 1.0 km till 4.2 km above sea level.

3. Regional and global hydrometeorological characteristics, which presumably may influence directly or indirectly to the runoff formation of Central Asian rivers. Here were used the following:

- parameter of Sun activity (annual Wolf's numbers);
- mean annual temperature of Northern Hemisphere;
- annual sums of precipitation averaged for main part of former USSR area;
- direct solar radiation at the latitudes 40-60°N;
- mean annual air temperatures in Canadian Arctic;
- concentration of carbon dioxide in atmosphere;
- mean annual air temperatures and sums of air temperatures for May-September, June-September and July-September for Central Asia area at 1.64 km a.s.l. and within 35-41°N, 67-81°E rectangular;
- indices of general atmosphere circulation for Central Asia, according to Baydal (1961) method;

annual sums of precipitation and their values for October-March, October-April, October-May periods within Charvak, Andijan and Zeravshan basins.

Long term series of mean seasonal values of air temperature and atmosphere pressure in 15 points of Northern Hemisphere which are not correlated to each other were also included to the initial data set. Kim and Nikulina (1992) have revealed the location of these points.

Long-term series of mean monthly air temperature for Central Asia territory at 1.64-km a.s.l. and also series of annual and seasonal sums of precipitation and mean air temperatures for watersheds of Charvak and Andijan reservoirs and Zeravshan river basin were calculated by (Konovalov,1993) and (Konovalov and Karandaeva, 1993) developments. These methods are based on adjustment of the long-term series of meteorological observations to the given altitude, extrapolation of the obtained values to the nodes of regular grid with 0.5 degree step on latitude and longitude within rectangular 35-41°N and 67-81°E and subsequent averaging for all or part of nodes.

3 Methods of investigation

A multiple regression equation is proposed as an initial general formula for calculation of inflow to the reservoirs and Zeravshan river runoff:

$$Y^*(t) = b_0 + \sum_{k=1}^{3} b_k \cdot x_k(t-m), \qquad (1)$$

where $Y^*(t)$ is a certain predictant, b_0, b_k – are empirical parameters, $x_k(t-m)$ are independent variables shifted m years back relative to dependent variable or predictant, t – is time.

Selection of predictors and estimation of parameters in the equations of type (1) was performed by means of a PC program for multiple linear regression analysis compiled by V.G.Konovalov, using arguments, which provide maximum bulk coefficient of correlation of multiple regression. For the process of choosing the most appropriate variables, a method is used which takes into account all possible combinations of predictors by two, three, etc.

All series of the examined predictors were shifted back in time relative to the predictants series from five to ten years. A minimum shift of five years was made in order to make possible the computation of runoff until 2000. The learning set covers the period 1949-1984. An interval 1985-1994 was used to control the quality of the chosen equation. The procedure of selection have repeated again for those groups of predictors, which provide good quality of computations at least in five cases from ten ones. The following condition is adopted as quality criteria: $\Delta = |Y(t)-Y^*(t)| <= 0.674*\sigma_y$, where σ_y – is RMSD of an initial range of $Y(t)$.

The long-term ranges of mean monthly air temperature in 15 correlation independent points, located in the Northern Hemisphere, are tested as predictors to compute the inflow to Andijan reservoir and Zeravshan river runoff. These ranges were averaged by seasons: winter, spring, summer, autumn and shifted back in time from 5 till 10 years using one-year step. The following approaches are applied to reveal the most informative variables inside of these 24 data sets.

Averaging of variables within of 24 seasonal groups. The selection procedure to find the most efficient subset of variables, obtained after average from 2 till 7 terms, is performed by the method of examination of all possible composition of these terms. Thus we may obtain 6 averaged predictors for the each seasonal group. Finally a common set of predictors selected for all seasonal groups is formed. Numerical experiments with these data do not allowed to come to a satisfactory result.

Determination the main components of seasonal group of variables. The seasonal group in the our case presents a matrix (X_{ij}, i=1,..,15; j=1,..,46), consisted from 15 columns and 46 rows, which are temporal ranges of seasonal air temperature for 1949-1994. The main components of such matrix are the linear combinations of the form:

$$A_j^k = \sum_{i=1}^{15} X_{ij} \cdot \varphi_i^k , \qquad (2)$$

where φ_i^k are orthonormal vectors related to the maximum variance of given linear combination, k=1,...,15 is the number of orthonormal vectors, j=1,..,46 is explained above. Orthonormal vectors are the orthogonal eigen vectors of symmetrical correlation matrix (Maltsev, 1975). Decomposition of a function into a sum of natural orthonormal vectors is aimed to find the linear combination (2), having a maximum variance (Kazakevich, 1989) from a given data set. This linear combination consists the eigen vector of symmetrical correlation matrix related to maximum of eigen numbers. Further the linear combination is selected which not correlated to the first one and has a largest variability. The variability of the rest linear combinations is small after their not large number has been selected already. Thus from the total set of a potential predictors we may select their the most informative number. Using the method described above we obtained the equation having satisfactory quality to forecast inflow to the Andijan reservoir. However this formula was not recommended to users because of not stability the results in the additional test.

The search of influenced variables for inflow to Charvak reservoir was performed also on the base of the theory of causal analysis, have been developed by Arushanov and Korotaev (1994). According to this method, the criteria for consideration of one variable as «reason», and another one as «consequence» is value of certain coefficient G, which should be ≥ 1 for pair «air

temperature – water inflow». The generalized estimations of causal relations between seasonal air temperature at 15 independent points of the Northern Hemisphere and parameters of water resources are presented in the Table 1. It should be noted that values of a correlation coefficient less then 0.1 are not considered.

The «reasons», have been selected by this method were used further as possible predictors in multiple linear regression analysis. However the reliability of the forecasting formula turned out to be not satisfactory and those ones are not recommended for application.

An opportunities to receive the sought computational formula as the auto-regression equation or on the base of statistical qualities of temporal series (trends, periodical components) have been investigated also.

Table 1 Causal relations between seasonal air temperature and parameters of water resources.

Title of water basin Time interval	Using of seasons as "reason", %				Distribution the correlation values between reason and consequence, %		
	winter	spring	summer	autumn	0.1-0.2	0.2-0.3	0.3-0.4
Charvak reservoir							
April-September	30	35	15	20	66	29	5
October-September	36	21	13	30	57	38	5
Andijan reservoir							
April-September	25	24	27	24	67	27	6
October-September	21	21	21	37	78	18	4
January-December	25	27	18	30	65	28	7
Zeravshan river							
April-September	28	31	17	24	71	24	5
January-December	27	33	19	21	62	33	5

4 Results of runoff computations and their analysis

The formulae of type (1) for computation inflow to the reservoirs until year 2000 were received after examination the whole number of potential predictors. The example of satisfactory forecast equation and its parameters is given in the Table 2.

Table 2 Equation to forecast water inflow to the Charvak reservoir

Formula	δx_1	δx_2	δx_3	R	Δ	P_d %	P_N %	P_i %
$Q_{iv\text{-}ix} = 11.27*x_1+15.90*x_2+0.59*x_3-561.93$	0.31	0.33	0.36	0.63	68	69	30	70

Notes: $X_1 – \Sigma T_{v\text{-}ix}$ (8) mst.Sarytash, $X_2 – \Sigma T_{vii\text{-}ix}$ (10) mst. Sarytash, $X_3 – Q_{iv\text{-}ix}$(10) Chatkal river. δx_1-δx_3 - are contributions of predictors to the description of dependent variable; R - is a bulk correlation coefficient; P_d - is a reliability of forecasts in a learning set; P_i - is a reliability of forecasts in an independent set; P_N - is a reliability of norm forecasts in an independent set; $Q_{iv\text{-}ix}$ - is the mean runoff value for April-September (m^3/s); Δ - is the allowed error of forecast (m^3/s); ΣT - is the sum of mean monthly values of air temperature; Number in the round brackets - is the shift back in time (years); mst. – is a meteorological station.

The results of inflow calculations to Charvak and Andijan reservoirs and runoff of Zeravshan river during of April-September are presented in the Table 3.

Table 3 Results of inflow and runoff forecasting and their reliability

Years	Charvak reservoir		Andijan reservoir		Zeravshan river	
	Q_{mes} /N	Q_{for} /N	Q_{mes} /N	Q_{for} /N	Q_{mes} /N	Q_{for} /N
1995	0.9	**1.0**	0.6	1.1	0.9	**1.1**
1996	1.0	**1.1**	1.1	**1.1**	0.9	1.1
1997	0.9	**1.0**	0.5	1.0	0.8	**0.8**
1998	1.4	**1.4**	1.8	**1.6**	1.1	**1.1**
1999	1.0	**0.9**	1.3	0.7	0.8	**1.0**
2000		**1.1**		0.7		1.0

Notes: Q_{mes} and Q_{for} – are respectively measured and forecasted values of water resources related to their long-term norms N. Bold letters marks justified values.

For each of predictors in the efficient formulae of inflow computations to Charvak and Andijan reservoirs and Zeravshan river runoff were determined their contribution to description of predictant variability and number of cases of their utilization in forecasting equations.

Table 4 Frequency (in %) of different predictors in computing formulae

Water objects	Air temperature	Precipitation	Runoff
Charvak reservoir	59	22	19
Andijan reservoir	69	31	0
Zeravshan river	58	40	2

As anybody may see from the attached Table 4, the air temperature is turned out to be the most efficient predictor to compute the future values of water inflow and river runoff.

5 Conclusion

- The equations to forecast the necessary hydrologic parameters are obtained as the result of the fulfilled works. The reliability of the control forecasts using independent set is equaled to 60-70 %. Outside the independent set it is produced 12 forecasts of water inflow to the reservoirs and runoff of the Zeravshan river. Ten forecasts from this number are justified.
- The most frequent value of shift backward in time for all predictors is 7-10 years. This may be considered to be an evidence of definite periodicity in the series of hydrometeorological variables, which have been tested as predictors. Most likely that this feature of temporal series exists at least during of 60-70 annual interval of time inside of 20-th century that provide solution of the considered task.
- The method of multiple linear regression turned out to be the most efficient to obtain acceptable forecasting formulae. Authors are improved the procedure of variable selection in this method and made fore flexible the PC program.

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Development of a Hydrological Forecasting Model in the Elbe Basin

Jakub Krejčí, Pavla Řičicová, Jiří Zezulák

Abstract: The hydrological modelling system AquaLog is a component of routine daily forecasting procedure of the Prague office of CHMI. It is on-line linked to its operational database. The current forecasting version is used on lower parts of Labe, Vltava, Ohře, Berounka, Sázava and Jizera rivers. During the next year, the forecasting system will be gradually enhanced for entire Elabe system. Mathematical models are particularly important to be used in upper and intermediate catchments, where runoff is mostly initiated by precipitation, and in river systems of short lead time. Individual forecasting models will be first operated for smaller basins separately. After they become fully operational, individual models will be integrated into a single entity of the Elabe forecasting system.

Key words: hydrological modelling system, forecast, precipitation, catchments, automatic rain gauges

Die Entwicklung eines hydrologischen vorhersageModells für das Einzugsgebiet der Elbe

Zusammenfassung: Das hydrologische Modellierungssystem AquaLog ist Bestandteil des täglichen Vorhersageablaufes des Prager Büros des Tschechischen Hydrometeorologischen Institutes CHMI. Es ist mit dessen zentraler Datenbank online verbunden. Die aktuelle Version wird für die unteren Abschnitte der Flüsse Elbe, Moldau, Ohre, Berounka, Sazava und Jizera verwendet. Im Laufe des nächsten Jahres wird das System schrittweise auf die gesamte Elbe erweitert. Die Verwendung mathematischer Modelle ist besonders wichtig in oberen und mittleren Einzugsgebieten, wo der Abfluß vorwiegend von Niederschlag verursacht wird, und in Flußsystemen mit sehr kurzen Vorhersagezeiten. Einzelne Vorhersagemodelle werden zuerst für kleinere Becken getrennt erarbeitet. Sind diese Einzelmodelle voll funktionsfähig, werden sie zu einem Vorhersagesystem für die gesamte Elbe zusammengeführt.

Schlüsselwörter: hydrologische Modellierungsysteme, Vorhersage, Niederschlag, Einzugsgebiet, automatische Niederschlagsstation

1 Current flow forecasting in the Czech part of the Elbe basin

Hydrological forecasts in the Czech Republic are produced by the Czech Hydrometeorological Institute in co-operation with River Boards. The regional forecasts are issued daily for a total of 19 water gauging sites and their lead time in our runoff conditions ranges between several hours up to a maximum of one day. The AquaLog hydrological forecasting modelling system is operated daily by the Prague office with a link to the operational database of CHMI. The current forecasting version is based on a river network of the Elbe, Vltava, Ohre, Berounka, Sazava and Jizera Rivers divided into 20 sections, where the diffusion-translation TDR model is used for transformation of flows along the river channel, with calculation of runoff from precipitation by the APIc rainfall-runoff model in 15 sub-basins, and a possibility to apply the Anderson PACK model for formation and melting of snow cover in winter season. The Elber River is considered by the model at the Přelouč site, the Vltava River below the Vrané reservoir site, the Ohře River at the Louny site, the Sázava and Jizera Rivers along the whole length.

The main aim of the current works is to find other suitable hydrological modelling techniques which would be able to determine real time discharges, or water stages, with sufficient lead time for given sites, particularly during extreme runoff situations and which would allow timely warning of population and mitigation of flood damage. The forecasting techniques has been applied for upper and middle sections of watercourses, mainly at regions where runoff is

generated by precipitation and, in view of the lead time, the transporting periods are short. In the Elbe basin, the forecasting system has been gradually complemented across the whole basin.

The goals of the Elbe project, which has been solved in the framework of the grant "Extreme hydrological events in catchments" and partly in the project „Development of methods and forecasting models for flood protection needs" are to:

- select and test hydrological forecasting models from the point of view of their suitability for real time forecasts;
- install automatic rain gauges in pilot basins;
- calibrate the model parameters for selected basins verify gradually the forecasting methods using actual data and put it into a daily use.

2 Selection and testing of hydrological forecasting models from the point of view of their suitability for real time forecasts

An expert reference review of forecasting models was prepared for CHMI by the Czech Agricultural University, aiming to recommend suitable forecasting models for hydrological forecasting office, before starting this project. Following the recommendation, the implemented forecasting system should be (as far as possible) unified across the whole territory of the Czech Republic, or across the complete basins similar to the Elbe basin, including all the links to the hardware and software systems operationally processing meteorological and hydrological data, as well as to the need of the output updating. It is not only a financial advantage, but it also simplifies communication with the transmission systems (input from the automatic stations either own or external - the River Boards), similar problems will be dealt with comparably at all of the branch offices. An advantage with implementation of the modular AquaLog system, which is being operated since nineties for the lower Vltava River, the Elbe and the Ohre River with a link to the CHMI operational database, has already been highly regarded.

3 AquaLog

AquaLog is multipurpose decision-supporting system in field of water management and hydrology. It applies methods of deterministic modelling to investigate hydrological and environmental processes in the real time on historical data and, possibly, also on artificially generated data. Apart from field of operative hydrology AquaLog can assist as a tool to judge the measures taken in water management processes and different scenarios.

AquaLog was designed to be a modular system that contains a variety of modelling techniques and procedures and allows the user simulate the following hydrological processes:

- rainfall-runoff processes
- snow accumulation and ablation
- river routing
- simulation and control of reservoirs

Under a compact AquaLog shell a user can make use of three categories of modelling techniques accommodated in its library

- group of hydrological routing models
  - TDR - transport–diffusion analogy
  - DL1 - tree-shaped or looped system of interconnected river branches based on full solution of St.Vennat system by a implicit scheme

- SLF - Self-Tunning auto-regressive techniques for real time forecasting of stage, discharge

- group of hydrological catchment models
  - snowmelt simulation (according to Anderson)
  - APIc - the Antecedent Precipitation Index Continuos model
  - SAC - Sacramento model based on soil moisture accounting
- group of interactive simulation of hydraulic flow-control units
  - MAN - kinematic reservoir equation, controlled spillways and bottom outlets, power hose discharge control transfer of watery fee-flow channels

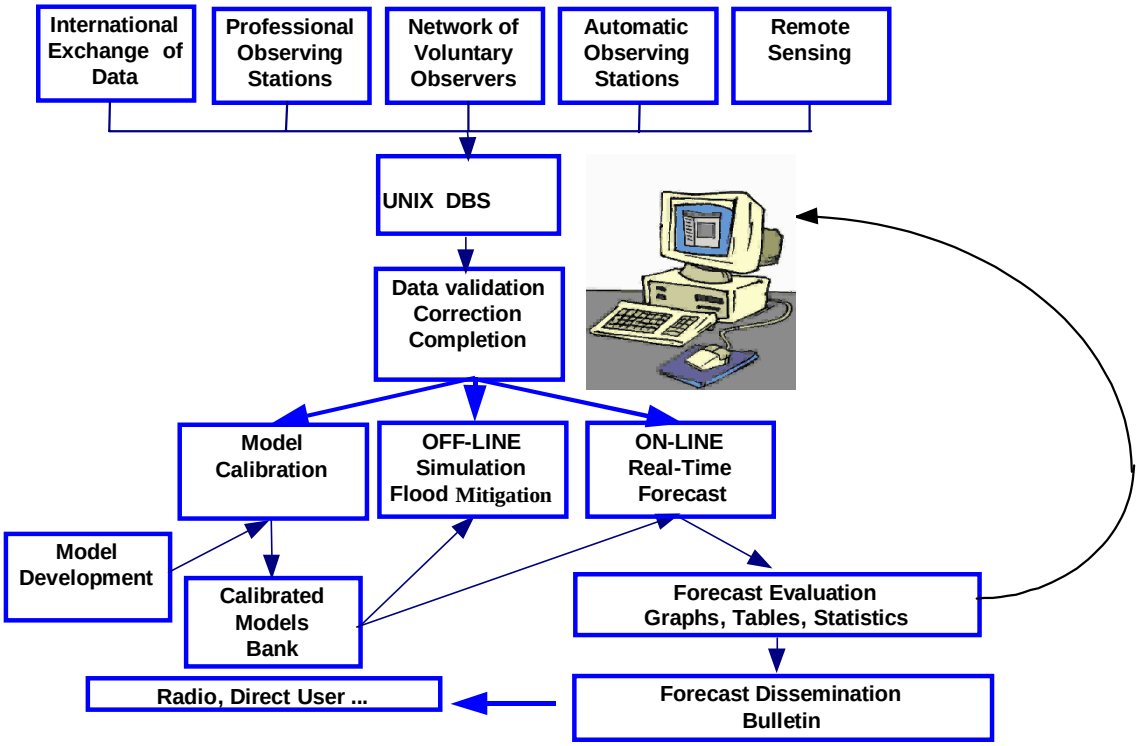

Figure 1. Scheme of flood forecasting system

AquaLog is currently being used by Central forecasting office of CHMI in Prague, and by regional departments in České Budějovice, Hradec Králové, Plzeň a Ústí nad Labem. In operational use, AquaLog interacts with operational database AquaBase, serving by semi-automated data processing on primary/secondary data interface.

In general, AquaBase consists of set of procedures, that are used as the tool in analysis and pre-processing of raw climatological and hydrological data to update time series used in forecasting by AquaLog. AquaBase basic tasks are:

- input of regularly observed data from primary data processing
  - Inter databank section 01 a 05

- SYNOP databank
- NOEL stations
- MULTILOG stations
- DBASE format

- analysis of primary processed data: validation (error detection) reparation and missing data entry
- graphical, tabular and statistical tools for primary processed data and their validation in manual or automated mode
- methods of supplementary processing and analysis of time series
- creation and maintenance of station files (characteristics of meteo- and hydro- stations)

In Figure 1, Aquabase is represented by item 'Data validation, Correction Completion. AquaBase incorporates managment and processing of the following categories of data:

- **station data** comprises a several groups of information
  - organisational aspects – station name, category of data, name of river/catchment, owner, ID code of user, ID code of AquaLog
  - topographical information, elevation, latitude, altitude, river milage, category
  - parameters used for the data checking and analysis – settings of a different tests of time series, inter-relational basis for neighbouring stations
- **time series**
  - products of the primary data processing (AquaBase input)
  - products of the secondary data processing (AquaBase output and AquaLog input)
  - forecasted time series to prolong forecast lead time

4 Installation of automatic rain gauges in pilot basins

Knowledge of runoff in basins without a reporting network of water gauging stations, or in basins where due to slope inclination the runoff increment is not available with sufficient lead time, depends on information on actual precipitation and on its numerical forecast. The density of the existing precipitation reporting network is sufficient for observation of regional precipitation in low-laying areas of the basins, in high and mountainous areas the network will need to be completed. About 800 precipitation observing stations are operated by CHMI, of which 115 stations are operated in a reporting regime (65 in the Elbe basin) providing 24 hour depths and there are only 35 professional stations (24 in the Elbe basin). During the flood periods the professional stations are required to increase the reporting frequency to one or three hour-interval. By the next two years automation of all of the operational stations is assumed.

During experiments with modelling in the Jizera basin in July 1997, the necessity of knowledge of distribution of precipitation during a day was fully confirmed for both of the flood situations (5 and 10-year discharges). It was definitely verified that the input data with the shortest time intervals described the shape of the flood hydrograph the best and that the peak prediction error decreased by up to 20%. Knowledge of actual precipitation in intervals shorter than 24 hours is absolutely necessary particularly for forecasting in mountainous areas. Therefore, the installation of automatic rain gauges in these basins is the primary condition for a successful forecast.

In the pilot basins the localities were indicated where it is necessary to complete the precipitation network. So far, eleven sites were selected, next year, according to experience with partial operation and according to financial possibilities their installation is assumed. It concerns

mainly installation of equipment to the rain gauging stations of the CHMI network. It is assumed that precipitation network of the River Board corporations will also be used. The installation will take place, according to the feasibility of financing, probably next year.

For the model operation, precipitation data from various sources are expected to be used, namely the data of the types such as SYNOP, INTER, AIM (measuring air pollution), precipitation observed in the hydrological stations, in the stations of the River Board corporations and in some of the automated climatic and rain gauging stations of CHMI.

5 Calibration of the model parameters for selected basins and their verification by using actual data and their routine operation

To complement the AquaLog forecasting system, the following most important localities were selected by the CHMI branch offices in the first part of the solution:

- basin of the Orlice River up to the Týniště site (it includes forecasts for sites of the Kostelec at the Divoká Orlice River and Malá Čermná at the Tichá Orlice River);
- basin of the Otava River up to the inflow to the Orlík reservoir (it includes forecasts for Sušice, Katovice and Písek sites);
- basin of the Mže River up to the Stříbro site (it includes forecasts of inflow into the Hracholusky reservoir);
- basin of the Radbuza River up to the Lhota-Plzeň site (it includes forecasts for the Staňkov site);
- basin of the Úhlava River up to the Štěnovice site (in includes forecasts for the Klatovy site and inflow into the Nýrsko reservoir);
- basin of the Úslava River up to the Koterov site;
- basin of the Ohře River up to inflow into the Nechranice reservoir;
- basin of the Teplá River up to inflow into the Březová reservoir;

Currently, the models are available to the branch offices for calibration using actual data. Next important localities were selected for the solution during this and next year :

- basin of the Lužnice River with the sites of Klenovice and Bechyně, including the Nežárka tributary
- basin of the Vltava River up to the inflow to the Orlík reservoir
- basin of the upper Elbe wits its tributories Úpa, Metuje

Significant attention was paid to preparation of data for calibration of the model in the first stage of the project, representing selection of suitable flood events in summer and winter season and of long-term historical observation of hydrological and climatological data (average daily discharge, daily precipitation depths, average daily temperature). For all of the basins, apart from other periods, data were prepared from the 1997 flood, for the Orlice basin also from 1988. Calibration of the individual modelling techniques was carried out by the AquaLogic company in accordance with the result of the tender selection procedure.

The calibrated pilot basins are gradually included into the forecasting systems. For verification in real time, the input data will include the actual observed precipitation, temperature, discharge, in winter season also water snow equivalent, and predicted precipitation for increasing the lead time of the forecasts. The forecasting models will be linked to the operational CHMI database and external data will be added from automatic stations of the Noel type (water stage, precipitation, temperature) and from the MULTILOG (discharge) recorders using the local area networks at the branch offices. It is assumed that the models will be operated daily on a continual basis, during a normal runoff situation once a day, during flood periods more frequently, according to the needs. The forecasts will be evaluated and compared with other methods. The individual forecasting models will be operated at first separately within the

basins, after putting them into a routine operation the models will be included into the whole AquaLog modelling system which is used for the middle and lower Elbe River.

Successful results are dependent not only on a good mathematical tool and credible input data but on an experienced forecaster as well, who gained his knowledge by every day work with this model.

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Die Möglichkeiten der langfristigen Frühjahrsabfluß-vorhersagen im Gebirgsflußbecken von der Theiß mit schrittweiser Berichtigung

Olga Luk'yanets, Mykhaylo Sosyedko

Zusammenfassung: In diesem Vortrag wurden methodische Grundlagen und eine Technologie der langfristigen Frühjahrsabflußvorhersagen im Theiß-Flußbecken vorgelegt. Dazu wird mathematisches Modellierungssystem angewandt, daß die Abflußformierung aus Schnee simuliert und räumliche Abschätzung der Abflußhöhen ermöglicht. Mit Hilfe dieses Systems werden kontinuierliche Abschätzungen der Dynamik der Bodendurchfrierung, Bodenfeuchtigkeit, Schneeansammlung und Schneeschmelze den ganzen Winter über an allen Hochzonen und Teileinzugsgebieten verwirklicht. Solcherweise gibt es die Möglichkeit, Abflußhöhen und maximale Abflußmengen beliebiger Wahrscheinlichkeit in notwendiger Anzahl von Flußquerschnitten vorherzusagen.

Schlüsselworte: Frühjahrsabfluß, Gebirgsflußbecken, Abflußvorhersagen, mathematische Modellierung, Abflußhöhen, Abflußmengen, kontinuierliche Abschätzungen, Schneeschmelze.

Possibilities of Long-Range Spring Flow Forecasting in the Mountain River Basin of the Tisza with a More Precise Gradual Definition

Abstract: Methodical basis and technology of the long-range spring runoff forecasting in the mountain river basin of the Tisza are presented. With that end in view mathematical modelling system of flow formation from snow is used which spatial distribution of runoff depth defines. With the help of this system continuous estimations of the dynamics of frozen soil layer, soil moisture, accumulate of snow pack and snow melting throughout the Winter on high-zones and particular catchments be carried out. Thus it is possible of forecasting of runoff depthes and maximum discharges at any probability in necessary gauge lines.

Key words: spring flow, mountain river basin, runoff forecasting, mathematical modelling, runoff depthes, discharges, continuous estimations, melting of snow.

1 Einleitung

Frühjahrsabflüsse formieren sich an der Gebirgsflüssen des Theiß-Einzugsgebiets (Abb.1) im Februar-April infolge der Schneeschmelze und auch teilweise wegen der Regenfälle in dieser Periode. Ein Gefahr der beträchlichen Frühjahrshochwässer entsteht ausserordentlich nach schneereichen Wintern, wenn 200-450 mm Wasser in der Schneedecke an den Gebirgseinzugsgebieten sich ansammelt. Während der letzen 60 Jahre werden 11-12 schneereiche Winter in den Karpaten vermerkt.

Im Durchschnitt bilden Frühjahrsabflußfüllen um 30-40 % vom Jahresabfluß, aber in einigen Jahren können sie 70-80 % erreichen. Im Falle des intensiver Frühjahrsverlaufs erreichen höchste Hochwasserspenden 800-1100 l/s · km² aus Flächen von 300-700 km². An der Theiß und in den Mündungsgebieten ihrer Zubringer (Borshawa, Latoryzja) werden bedeutende Flächen während der Hochwässer überschwemmt, weil die Wasserabführung durch kleine Stromgeschwindigkeiten verhindert ist.

Darum haben die Frühjahrsabflußvorhersagen große Bedeutung , um Schutzmaßnahmen im vorhinein zu verwirklichen.

Abb. 1 Theiß- Einzugsgebiet. Hydrometeorologisches Netz in der Ukraine

2 Mathematisches Frühjahrsabfluß-Modell

Das vorgeschlagene Vorhersagesystem "Theiß" (TS-6A) gründet sich auf die Anwendung des mathematischen Frühjahrsabfluß-Modell "SLOY-3". Das Letztgenannte dient als eine Strukturkomponente (Teilsystem) des Flußgebietsvorhersagesystems. In der Struktur dieses Modells wurden die Vorgänge berücksichtigt, die in einem Einzugsgebiet während der Winterperiode sich ereignen und zur Ansammlung der Schneevorräte, Veränderung der Bodenfeuchligkeit und Bodenverfrostungstiefe hervorrufen. Solcherweise verwiklichen diese Vorgänge die Vorbedingungen für den Frühjahrsabfluß infolge von Schneeschmelze. In den Gebirgseinzugsgebieten betrachten alle diese Vorgänge an Hochzonen, weil die hier mit verschiedener Intensität sich ereignen, daß es durch Raumveränderlichkeit von Schneedecke, Niederschläge und Temperaturablauf bedingt ist [2]. Das Modell zieht den Einfluß von Waldigkeit der Hochzonen, als auch Hangrichtungen in Betracht [6].

Die Modelllösungen erfüllen sich bis zu einem Vorhersagetermin nach dem Prinzip von Zustandsveränderlichen (state variables), welches man bedingungsweise so beschrieben kann:

$$st(t+dt)=st(t) + V_{st} \cdot dt, \qquad (1)$$

wo st(t+dt) und st(t) - Zustandsveränderlichen von hydrometeorologischen Werten in den Zeitpunkten t+dt und t,

V_{st} - Führungsveränderliche, die eine Geschwindigkeit der Zustandsänderung bestimmt,

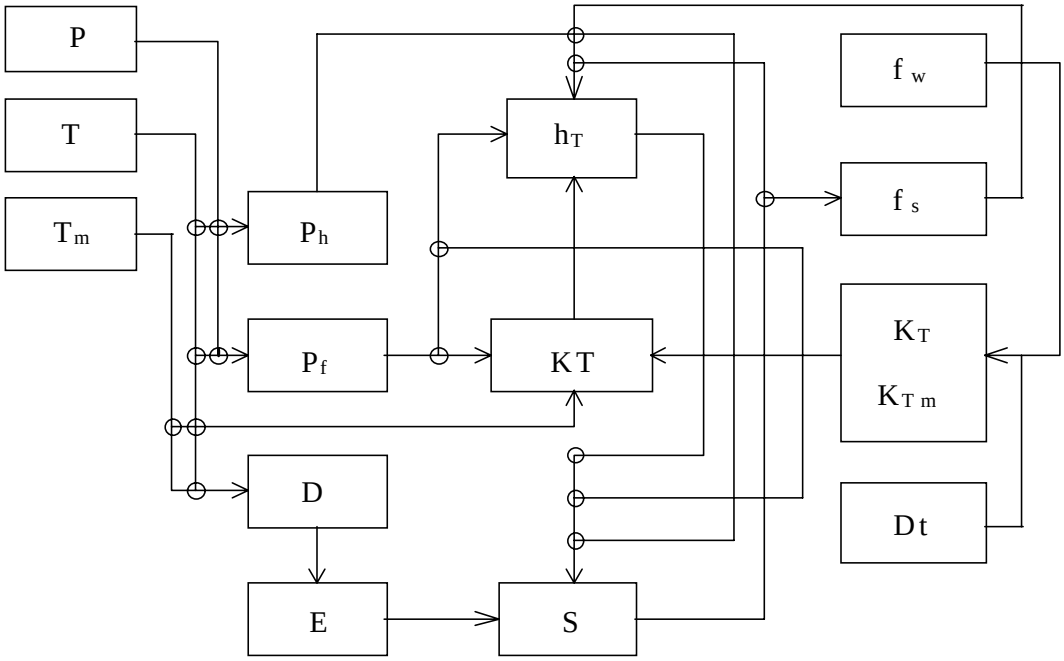
dt - Zeitschritt.

Dementsprechend wurden das Modell, seine mathematische und logische Ausdrücke und auch die Zusammenwirkung zwischen Strukturkomponenten hergestellt.

Das Modell "SLOY-3" hat vielfältige Lösungen in Beziehung auf Umfang der hydrometeorologischen Eingangsdaten. Bei Vorhandensein von notwendigen hydrometeorologischen Angaben werden zwei Grundvarianten für die Bestimmung der Anfangsverhältnisse in bestimmtem Vorhersagezeitpunkt verwendet:

(a) Wassergehalt der Schneedecke, Bodenfeuchtigkeit und Bodenverfrostungstiefe werden im Vorhersagezeitpunkt nach Angaben der Frostperiode berechnet (Abb.2);

(b) als Anfangsangaben werden dieselbe Werte benützt, die am Beobachtungsnetz gemessen wurden.



P - Niederschläge
P_h - harte N.
P_f - flüssige N.
T, T_m - Lufttemperatur (Tagesmittel, Maximum)
D - Sättigungsdefizit
E - Gesamtverdunstung
KT - potentielle Schneeschmelze
f_w - Gebietswaldigkeitsgrad
fs - Schneebedeckungsgrad
K_T, $K_{T\,m}$ - Temperaturkoeffiziente
Dt - Vorhersagedatum
hT - Wintertauabfluß
S - Wassergehalt der Schneedecke

Abb. 2 Die Struktur des Schneeansammlungs - Subsystems des Modells "SLOY-3"

Die Vorhersage der Frühjahrsabflußhöhe wird an bestimmten Teilflächen und allen Hochzonen jedes Einzugsgebiets mit Hilfe des Wasserhaushaltsverfahrens erstellt (Darstellung in mm):

$$h=S + SUMP - E - h_v + h_o \pm h_{dw} \qquad (2)$$

wo h - Abflußhöhe,

S - Wassergehalt der Schneedecke in einem Vorhersagezeitpunkt,

SUMP - Niederschläge in einer Periode von Vorhersagezeitpunkt bis zur Ende des Frühjahrshochwassers,

E - Gesamte Verdunstung in dieselber Periode,

h_v - Retentionshöhe des Schneeschmelz - und Regenwassers an der Oberfl äche des Einzugsgebiets,

h_o - Grundabfluß während des Hochwassers,

h_{dw} -- Höhe der Bodenfeuchteauffüllung oder des Abflusses übermässiges Wassers aus tätiger Bodenschicht (infolge von ihrer Übersättigung während des Tauwetters).

Im Laufe der Abflu ßmodellierung werden die Schneeschmelztemperaturen durch Gradtagfaktor-Verfahren unter Berücksichtigung der Gebietswaldigkeit und Schneeschmelzperiode berechnet [1, 4-6].

3 Raumstruktur des Vorhersagesystems

Das System TA_6A schließt ganzes Theiß-Einzugsgebiet in den Grenzen von der Ukraine ein. Die Raumstruktur des Systems wurde solcherweise geschaffen, daß es einen Einheitskomplex von Bestandteilen darstellt, welche zusammenwirken und gleichzeitig erm öglichen, landschaftliche und hydrometeorologische Besonderheiten einzelner Einzugsgebiete zu berücksichtigen [3]. Mit diesem Ziel und auch mit der Orientierung nach Informationsmöglichkeiten des Beobachtungsnetzes wurden 6 Teileinzugsgebiete in der Systemstruktur bestimmt.

Jedes Teileinzugsgebiet besteht aus zwei Teilflächen, die seinerseits durch 5 Hochzonen dargestellt sind (unter 400, 400-600, 600-800, 800-1000, über 1000 m).

Die Verzeichnis der Teileinzugsgebiete und entsprechender Flußpegel, in welchen der Abfluß vorhergesagt wird, sind in der Tabelle 1 angef ührt. Dabei werden die Zuflüsse aus den Einzugsgebieten von Oberer Theiß, Tereswa und Rika für die Abflußberechnung an den Theiß-Flußabschnitt von W.Bytschkiw bis Wylok benutzt. Der Zufluß aus dem Rumänien wird wie aus rechtsuferigen Gebiete bestimmt.

Tabelle 1 Raumstrukturkomponenten des Vorhersagesystems TS_6A

Teileinzugsgebiet	**Vorhersagepegel**	
	Fluβ - Pegel	**Fläche d. Einzugsgebiets, km^2**
1. Obere Theiβ	1.Theiβ - Rachiw	1070
1. Obere Theiβ 2. Tereswa 3. Rika	2.Theiβ - W. Bytschkiw 3.Theiβ - Tjatschiw 4.Theiβ - Chust 5.Theiβ - Wylok	3330 6470 7690 9140
2. Tereswa	10.Tereswa - U.-Tschorna 11.Tereswa - Neresnyzja	572 1100
3. Rika	13.Tereblja - Kolotschawa 15.Rika - Mishhirja 16.Rika - Chust	369 550 1130
4. Borshawa	21.Borshawa - Dowhe 22.Borshawa - Schalanky	408 1100

Teileinzugsgebiet	Vorhersagepegel	
	Fluß - Pegel	Fläche d. Einzugsgebiets, km^2
5. Latoryzja	24.Latoryzja - Swaljawa	680
	25.Latoryzja - Mukatschewe	1360
	26.Latoryzja - Tschop	2870
6. Ush	30.Ush - W.Beresnyj	653
	31.Ush - Saritschewe	1280
	32.Ush - Ushhorod	1970
	33.Tur`ja - Symir	464

Folglich besteht die Raumstruktur des Vorhersagesystems aus drei Stufen: Teileinzugsgebiete, Teilflächen, Hochzonen. Solches Strukturschema gewährleistet die Grundaufgaben der Systemfunktionierung:
(a) in die Abflußvorhersage setzen notwendige Anzahl von Flußpegeln;
(b) in Betracht vertikale und räumliche Veränderlichkeit der hydrometeorologischen Verhältnisse ziehen;
(c) Informationsmöglichkeit der hydrometeorologischen Standardbeobachtungen benutzen in vollen Umfang.
Zur Durchführung der Systems wird bedeutender Umfang der operativen Angaben herangezogen:
· Angaben aus 26 Abfußmeßstellen,
· meteorologische Angaben aus 10 Stationen, die auf die Höhen von 112 bis 1429 m ü.d.M. sich befinden,
· Angaben aus 30 Schneemeßstellen.

Die Ausnützung der Information aus obergenannten Meßnetzen fordert, die Flächenparameter für Bestimmung der meteorologischen Mittelwerte in den Hochzonen festzustellen. Diese Parameter gehören zu dem Parameterkomplex des Vorhersagesystems.

4 Technologie der Frühjahrsabflußvorhersagen

Die Grundhaltung der Vorhersagetechnologie sind mit Besonderheiten der Frühjahrsabflußbildung im Theiß-Einzugsgebiet in Einklang gebracht.

Die Möglichkeiten der Abflußvorhersagen mit der Zeitdauer in 20-40 Tagen beginnen seit erster Februardekade, wenn Wasservorräte in der Schneedecke gewöhnlich höchste Werte erreichen. Darum werden Vorhersagen von erster Februardekade bis Mitte März erstellt. Für diese Zeitpunkte sind Klimaangaben, die Zeitdauer der Vorhersagen kennzeichnen, gestellt (Tab.2).

Infolge der Instabilität der meteorologischer Verhältnisse während der Winterperiode und am Frühjahrsanfang, wird Notwendigkeit oft, besonders nach tiefen Tauwettern, geschaffen, früher erstellente Vorhersagen allmählich zu berichtigen.

Mittlere Schneeschmelzperiode in den Hochzonen, wo wesentliche Wassermengen sich bilden (200-800 m ü.d.M.), sind etwa 30 Tage gleich. Darum Technologie beabsichtigt die Vorhersagen von Abflußhöhen und Abflußfüllen, die während 30 Tage abfließen können.

Weil Intensität jedes Frühjahrsverlaufs im Vorhersagetermin im vorhinein nicht bekannt ist, entsteht die Notwendigkeit, ein Wahrscheinlichkeitsverfahren für die Bestimmung der

Höchstwassermengen und der höchsten Wasserstände zu gebrauchen. Dieses Verfahren besteht darin, daß obergenannte Werte für vier wahrscheinliche Wetterverhältnisse, die während einer Frühjahrsperiode sich ereignen können, gerechnet werden (Tab.3). Dabei werden Zusammenhänge zwischen Höchstwassermengen Q^m und Abflußhöhen h bestimmter Wahrscheinlichkeiten P verwendet [7]:

$$Q^m(P)=K_Q(P)\cdot h, \qquad (3)$$

wo $K_Q(P)$- Übergangskoeffizient.

Tabelle 2 Mittlere mehrjährige Kennwerte im Vorhersagezeitraum

Vorhersage-datum	Kenn-wert	Hochzonen (m)				
		bis 400	400-600	600-800	800-1000	>1000
Langsamer und gewöhnlicher Frühjahrsverlauf						
6-15.02	SUMP	125	120	120	115	110
	Pf	20	20	15	10	10
	MT	2.6	2.5	2.4	2.2	2.0
16-25.02	SUMP	105	100	100	95	90
	Pf	20	20	15	10	10
	MT	2.6	2.5	2.4	2.2	2.0
26.02-5.03	SUMP	85	80	80	75	70
	Pf	20	20	15	10	10
	MT	3.0	2.8	2.6	2.4	2.2
6-15.03	SUMP	65	60	60	55	50
	Pf	25	25	20	15	15
	MT	3.2	3.0	2.8	2.6	2.4
Intensiver und sehr intensiver Frühjahrsverlauf						
6-15.02	SUMP	125	120	120	115	110
	Pf	40	40	40	30	20
	MT	6.0	5.0	4.5	4.0	3.5
16-25.02	SUMP	105	100	100	95	90
	Pf	40	40	40	30	20
	MT	6.0	5.0	4.5	4.0	3.5
26.02-5.03	SUMP	85	80	80	75	70
	Pf	45	45	45	35	25
	MT	6.0	5.0	4.5	4.0	3.5
6-15.03	SUMP	65	60	60	55	50
	Pf	50	50	50	35	25
	MT	6.5	5.5	5.0	4.5	4.0

Erklärungen.

SUMP - Niederschlagssumme vom Vorhersagetermin bis zum Ende des Frühjahshochwassers.

Pf - Flüssige Niederschläge während der Schneeschmelzperiode.

MT - Mittellufttemperatur während der Schneeschmelzperiode.

Tabelle 3 Kennenwerte des Frühjahrsverlaufs im Theiß-Flußbecken.
(Hochzonen von 100bis 600m)

Kennzeichnung des Frühjahrsverlaufs	Wahrscheinliche Wetterverhältnisse in der Schneeschmelzperiode	
	Mittellufttemperatur, °C	Niederschläge, mm
1. Langsam	2-3	bis 10
2. Gewöhnlich	2-3	15-20
3. Intensiv	4-6	30-50 in 5-10 Tagen
4. Sehr intensiv	>6	30-50 in 2-4 Tagen

Im Vorhersagesystem funktioniert das Modell "SLOY-3" zusammen mit anderen Methodiken. Infolgedessen gibt es M öglichkeit, folgende Vorhersageproduktion darzustellen: Abflußhöhen, Abflußfüllen, höchste Wassermengen und Wassererstände (Tab.4, 5).

Tabelle 4 Ein Beispiel der Abfluβvorhersage

Das System TS_6A funktioniert

Die Vorhersagen von Abfluβwerten in 30 Tagen

Datenmaterial von 15.03.1999

Für gewöhnliche Verhältnisse wärend des Frühjahrs

Pegel - Nr.	Fluβ - Pegel	Vorhergesagte Abfluβwerte			
		Höhe, mm	Fülle, Mio m^3	Höchste Abfluβmenge, m^3/s	Höchster Wasserstand, cm
1	Theiβ - Rachiw	106-129	113-138	154-188	301-322
2	Theiβ - W. Bytschkiw	100-123	336-410	363-444	299-319
3	Theiβ - Tjatschiw	99-121	641-783	733-896	338-380
4	Theiβ - Chust	98-120	755-923	825-1008	241-259
5	Theiβ - Wylok	97-118	886-1083	1164-1422	188-253
10	Tereswa - U.-Tschorna	94-115	53-65	56-69	
11	Tereswa - Neresnyzja	157-192	172-211	267-326	129-154
13	Tereblja - Kolotschawa	111-136	41-50	66-81	
15	Rika - Mishhirja	124-151	68-83	198-242	259-281
16	Rika - Chust	117-143	132-162	228-279	365-387
21	Borshawa - Dowhe	112-138	46-56	107-131	274-294
22	Borshawa - Schalanky	89-109	98-120	134-164	712-767
24	Latoryzja - Swaljawa	96-117	65-80	144-176	163-190
25	Latoryzja - Mukatschewe	91-111	124-151	219-267	326-344
26	Latoryzja - Tschop	54-66	157-192	175-214	635-647
30	Ush - W.Beresnyj	71-87	46-57	100-122	

31	Ush - Saritschewe	68-83	87-106	218-266	260-282
32	Ush - Ushhorod	64-78	126-154	281-344	33-57
33	Tur`ja - Symir	60-73	27-33	63-77	107-121

Wasserabfluβ in 30 Tagen ins Ausland
(a) nach Ungarn - 994-1215 Mio m^3
(b) nach Slowakei - 281-343 Mio m^3

Tabelle 5 Ein Beispiel der Abfluβvorhersage (ukrainischer Wortlaut)

Працює програма TS_6A (Тиса)

Прогнозування шарів/об`ємів стоку, максимальних витрат/рівнів

Обчислення виконано 06. 02. 2000 р. о 15.59

дані на 05. 02. 2000 р.

За інтенсивних умов розвитку весняних процесів

N поста	**Річка-пост**	**Шар стоку, мм**	**Об'єм, млн. куб.м**	**Макс. витрата, $м^3/с$**	**Макс. рівень, см**
1	Тиса - Рахів	201-246	215-263	291-356	372-397
2	Тиса - В.Бичків	191-233	636-778	688-841	377-411
3	Тиса - Тячів	167-205	1085-1326	1241-1517	448-492
4	Тиса - Хуст	168-205	1293-1581	1413-1727	293-318
5	Тиса - Вилок	168-205	1537-1879	2019-2467	399-499
10	Тересва - Усть Чорна	224-274	128-156	134-164	192-208
11	Тересва - Нересниця	242-296	266-325	411-503	183-211
13	Теребля - Колочава	213-261	79-96	128-156	200-224
15	Ріка - Міжгір'я	222-271	122-149	355-434	314-355
16	Ріка - Хуст	219-268	248-303	428-523	441-473
21	Боржава - Довге	211-258	86-105	200-245	354-391
22	Боржава - Шаланки	203-248	223-273	304-372	813-828
24	Латориця - Свалява	188-230	128-156	282-345	245-270
25	Латориця - Мукачеве	186-228	253-310	448-547	410-446
26	Латориця - Чоп	112-136	321-392	358-438	683-700
30	Уж - В.Березний	201-245	130-159	281-344	419-449
31	Уж - Зарічеве	198-242	254-310	635-776	390-415
32	Уж - Ужгород	195-238	385-470	859-1051	241-295
33	Тур'я - Симір	191-234	88-107	201-245	187-205

Стік води за межі Закарпаття за 30 діб

(а) на територію Угорщини - 1783-2180 млн.м^3

(б) на територію Словаччини - 702-858 млн.м^3

5 Schlußbemerkungen

Unbeständige Wetterverhältnisse und häufige Tauwetter während der Wintermonate werden zur Veränderlichkeiten der Schneedecken- und Einzugsgebietsflächenzustände im Theiß-Flußgebiet herbeigeführt. In diesem Zusammenhang wird der Informationsdienst hier gezwungen, ständig Situationen zu überwachen und, wenn es nötig ist, forige Abflußvorhersagen zu berichtigen. Das Vorhersagesystem TS_6A stellt solche Möglichkeit im automatisierten Regime zur Verfügung.
Höchste Wasserstände an den Karpaten-Flüssen werden in gewissem Grad von Intensität der Frühjahrsverläufe beeinflußt. Darum ist es nicht geringfügig, die Wetterlagen im Süd- und Mitteleuropa zu beaufsichtigen, damit man rechtzeitig Information von eventuellen gefahrdrohenden Situationen bekommen kann.

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Die Struktur des Informations- und Vorhersagesystems im Flussbecken der Theiss (in den Grenzen der Ukraine)

Olga Luk`yanets, Mykhaylo Sosyedko

Zusammenfassung: Um der Zustand des Hydrologischen Nachrichtendienstes im Theiβ-Becken wesentlich zu verbessern, werden die Maβnahmen für die Bildung des Informations- und Vorhersagesystems (IVS "Theiβ") sich verwirklicht. Mit diesem Ziel schlieβt der Technologieraum vom IVS folgende Strukturbestandteile: automatische hydrometeorologische Detenbank, Komplex der Vorhersageverfahren und entsprechende Software. Als methodische Grundlage für das Teilsystem der Abfluβvorhersagen sind mathematische Modelle angewandt.

Schlüsselworte: Information, Vorhersagesystem, Technologieraum, Datenbank, mathematische Modelle

The Structure of Information and Forecasting System on the Tisza River Basin (in the Ukraine)

Abstract: In order to significant improvement of warning service on the Tisza basin measures to take for creation of information and forecasting system (IFS "Tisza"). The technology space of IFS includes following components: automatical hydrometeorological data bank, forecasting methods complex and respective software. In the capacity of basis for runoff forecasting mathematical modells are in use.

Key words: information, forecasting system, technology space, data bank, mathematical modells

1 Einleitung

Im Karpaten-Gebiet ereignen sich häufige Regen- und Schneeschmelzhochwässer, die oft Zerstörungswesen sich anschaffen. Doch gegenwärtiger Zustand des hydrologischen Nachrichtendienstes in diesem Gebiet ist unvollkommen - er entspricht der Intensität der Hochwasserbildung und Abfluβverläufe an den Gebirgsflüssen nicht.

Wesentliche Erhöhung der Informationsfähigkeit des Nachrichtendienstes in der Karpaten braucht die Schaffung der Informations- und Vorhersagesysteme (IVS), die alle Bestandteile dieser Tätigkeit umfassen müssen. Dazu werden die Maβnahmen für die Gründung des regionalen IVS "Theiβ" im Theiβ-Becken sich verwirklicht. Gegenwärtig ist dieses IVS auf den Versuchsbetrieb gestellt.

2 Die Struktur des IVS "Theiβ"

Für die Funktionierung des IVS "Theiβ" wurde vereinheitlichte automatisierte Technologie angewandt, die Erfüllung der folgenden Aufgaben gewährleistet:

* Bearbeitung der operativen hydrologischen und meteorologischen Mitteilungen, die aus dem Beobachtungsnetz zum regionalen Zentrum durch ein Fernmeldewesen eingehen;
* Erstellung der lang- und kurzfristigen Abfluβvorhersagen;
* Darstellung der Informationsdaten und Vorhersageerzeugnisse für verschiedene Verbraucher.

Mit diesem Ziel schließt der Technologieraum vom IVS folgende Bestandteile ein (Tab. 1): automatisierte hydrometeorologische Datenbank, ein Komplex der Vorhersageverfahren und problemorientierte Software, die Funktionstätigkeit des IVS bedient.

Tabelle 1 Die Struktur des Informierungs- und Vorhersagesystems ”Theiß”

Bestandteile des IVS und ihre Hauptfunktionen	**Beobachtungsdaten** **Vorhersageangaben**
(1) Automatiesierte hydrometeorologische Datenbank	
Erfassung, Erkennung u. Entkodierung der Telegrammnachrichten	Meteorologische Daten - 10 Stationen Hydrologische Daten - 38 Pegel Niederschlagsdaten - 30 Meßstellen Bodenfeuchtigkeit - 4 Stationen Wassergehalt d. Sneedecke - 30 Stellen
Qualitätsprüfung	
Datenbankformierung	
(2) Abfluβvorhersageteilsystem	
Langfristige landesweite Frühjahrsabfluβvorher-sage	Abfluβhöhe, Abfluβfülle, Höchst-wassermenge, Höchstwasserstand - 19 Pegel für 4 Wetterabläufe
Kurzfristige kontinuierliche Abfluβgangvorhersa-ge während d. Regenhochwässer	Abflüsse/Wasserstände an d. Theiβ u. ihren Nebenflüsse
Kurzfristige kontinuierliche Abfluβgangvorher-sage während d. Schneeschmelzhochwässer	Abflüsse/Wasserstände an d. Theiβ u. ihren Nebenflüsse
(3) Murgangerscheinungsteilsystem	
Wahrscheinlichkeitsvorhersage der Murgangerscheinungen	Murgangserscheinungskategorie in 4 Gebietssubteile für 3 Wetterabläufe
(4) Informationsteilsystem	
Abschätzung d. gefährlichen Situationen	Überschwemmung anliegendes Gebiet, starke Regen
Tageswasserstandbericht	
Tageswetterbericht	
Tabellenförmige u. graphische Darstellung der hydromet. Daten	Wasserstände, Niederschlags- u. Abfluβwerte
Kartierung der hydromet. Daten	Wassergehalt d. Schneedecke, Abfluβhöhe

3 Die Datenbank

Die Datenbank gründet sich auf typisiertes Muster unter Berücksichtigung des Umfang und der Art der hydrometeorologischen Angaben, die in kodierenden Form zum Informationszentrum in Ushgorod ankommen. Diese aufgenommene operative Iformation stellt ganzen Gesamtheit der meteorologischen, hydrologischen und agrarmeteorologischen Angaben für ständige und zusätliche Beobachtungstermine vor. Zu dieser Angaben gehören auch die Linienmessungen der Schneedecke, die nach 5 Tagen durchgeführt werden. Die Vorstellung über Informationsgehalt gibt Tabelle 1.

Die Datenbankformierung vollzieht durch die Erfülung mehrerer Arbeitsgänge, die unbedingte Qalitätsprüfung der aufgenommen und entkodierenden Angaben mittels Testgröβen einschliessen (Abb. 1).

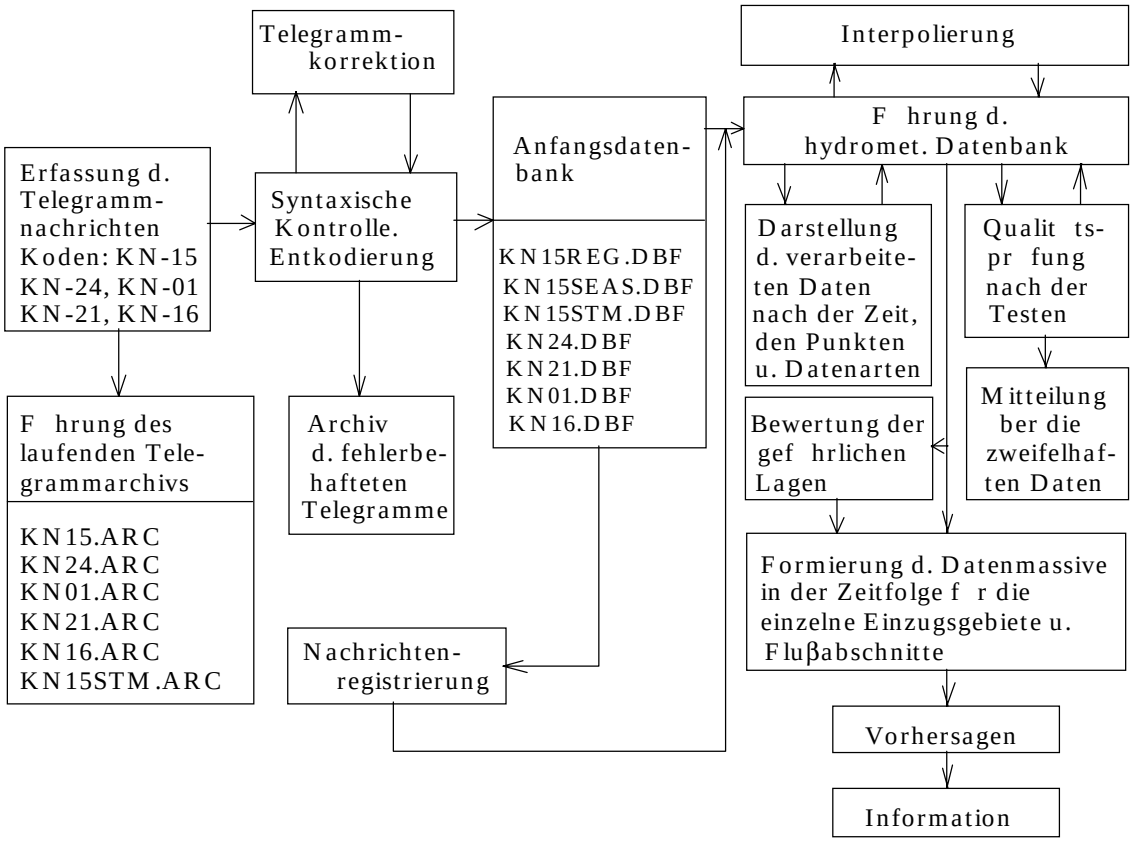

Abb. 1 Technologische Arbeitsfolge der Formierung der operativen hydrometeorologischen Datenbank

4 Die Vorhersageteilsysteme

Diese Teilsysteme dienen zur Abfluβvorhersage und Wahrscheinlichkeitsschätzung der Murgangerscheinungen. Sie bestehen aus Methodiken, die funktionieren mit der Datenbank zusammen und benützen ihre Angaben.

Zur Verfügung haben wir folgende Vorhersagenverfahren (Abb. 2).

(a) Langfristige Vorhersagen des Frühjahrshochwasserabflusses in den notwendiegen Pegelprofile und an den Höhenzonen mit verschiedenen Zeitdauern (20 - 30 Tage). Dabei

gibt es die Möglichkeit, die Vorhersagen für 4 im Frühling wahrscheinliche Wetterverläufe zu erstellen.

(b) Kurzfristige Abfluβgangvorhersagen ermöglichen, Abfluβmengen und Wasserstände an der Theiβ und ihren Nebenflüsse während der Regen- oder Schneeschmelzhochwässer in kontinuierlichem Regime zu bekommen. In diesen Methodiken werden räumliche Niederschlagverteilung und Schneeschmelzintensität auf den Gebirgseinzugsgebieten berücksichtigt.

(c) Die Vorhersage der Murgangkategorien zeigt wahrscheinliche Entstehung dieser Ereignisse in den bestimmten Einzugsgebieten. Wahrscheinliche Vorhersagen verwirklichen sich zeitlich und räumlich. Temporale Wahrscheinlichkeit zeigt unter der Bedingung, daβ die Wasserabgabeintensität sich bewahren oder vergrössern oder verringern wird. Räumliche Wahrscheinlichkeit bedeutet, daβ die Vorhersage mit der Bestimmung der einzelnen Gebietsteile vorstellen wird, ohne konkrete Murgangsherde zu nennen.

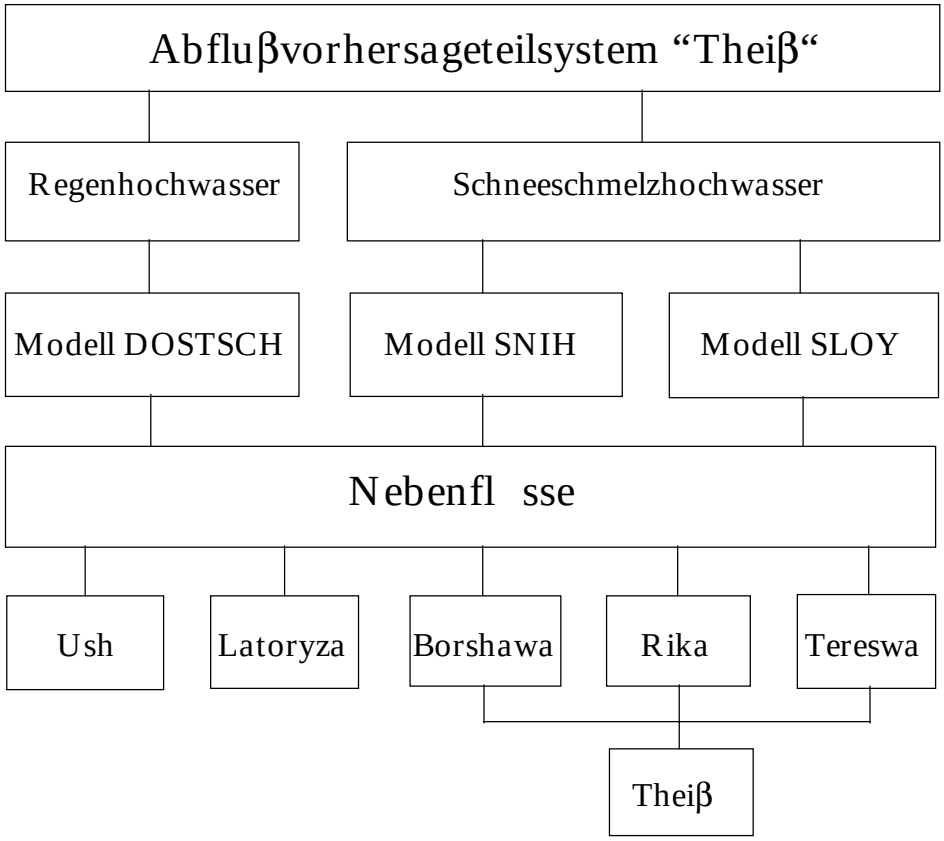

Abb. 2 Allgemeine Struktur des Abfluβvorhersageteilsystems ”Theiβ” (in der Ukraine)

Die in Praxis angewandeten Vorhersageverfahren beruhen auf mathematische Modelle mit verteilten Parametern [1-7].

5 Engebnisse und problemstellende Fragen

Ganze Technologiefolgen vom IVS ”Theiβ” wurden gegenwärtig bearbeitet. Jetzt finden Betriebsprüfungen des Systems statt.

In der IVS - Struktur ist die Möglichkeit geschaffen, um Funktionierung seiner Ketten im Falle, daβ einige Nachrichten abwesend sind, sicherzustellen. Auch die Struktur und Software des IVS erlauben, neue Vorhersagemethodiken und zusätzliche Informationsnachrichten ohne Änderung der bearbeitenden Technologielösungen zu gewährleisten.

Dennoch gibt es die Probleme, denen wir gegenüberstehen. Es handelt sich vor allem um ungenügende technische Ausrüstung der hydrometeorologischen Beobachtungsstellen im Theiβ-Fluβbecken. Gründliche Umgestaltung brauchen auch Fernmeldekanäle zwischen dem Datenyersammlungszentrum und Beobachtungsnetz. Wichtige Bedeutung wird die Anwendung der Niederschlagsfermessungen durch meteorologischen Radiolokator in der Funktionstechnologie des IVS haben. Die Lösung dieser Probleme wird die Verwirklichung bearbeitener IVS-Technologie im ganzen Umfang begünstigen.

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Stormy Rain – Catastrophic Flood in the Hydrographic Basin of the Cerna River on 11-12 July 1999

Zlatibor Macridin, Carmen Harabagiu, Florea Pisaru

Abstract: Between 11 – 12 July 1999, due to the meteorological conditions, has been produced a stormy rain. The amount of precipitation was, locally, 300 mm. Due to this rain occurred storm floods on torrents, tributaries and on the main stream, Cerna.

This paper present the water management in the hydrographic basin of river Cerna analyzes of the hydro-meteorological situation, the flood's generator factors and the consequence of those.

Key words: rain, flood, analyze, synthesis, probability.

Stürmischer Regen-Katastrophale Flut ins Hydrographische Schüssel von Cerna Fluß 11-12 1999. Juli

Zusammenfassung: Zwischen 11-12 1999. Juli, wegen der meteorologischen Zustände, ist einen stürmischen Regen produziert worden. Die Menge von Niederschlag war, örtlich, 300 mm. Wegen dieses Regens kam vor, Sturm überschwemmt auf reißen Ströme, Nebenflüsse und auf dem Haupt Strom, Cerna.

Dieses Papier-Geschenk das Wasser-Management in der hydrographischen Schüssel von Fluß Cerna analysiert von der Hydro-meteorologischen Situation, der Generator der Flut zerlegt und die Folge von jenen.

Schlüsselworte: Regen, überschwemmen Sie, analysieren Sie, Synthese, Wahrscheinlichkeit.

The hydrographic basin of river Cerna is situated in the southwest side of Romania (Figure 1.). Till the confluence with its main tributary, Bela Reca, the catchement area of Cerna has 545 km^2 and the length of the main stream has 64 km.

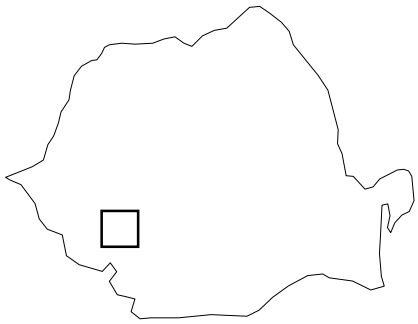

Fig. 1 Romania's map, the analyzed hydrographic area

Cerna is a mountain stream and its valley is considered one of the most beautiful and interesting from the Carpati Mountains. Average slope of the river Cerna is 24‰, characteristic for mountain rivers, and average slope of the catchement area is 386 m/km.

The hydrographic network is variable as aspect and flow regime because is very strong influenced by lithological diversity of the basin. The presence of the limestone, on large area, induces modifications in hydrographic network characteristics.

A schematic map of the river Cerna water management is presented in figure 2.

The flood occurred between 11-13 July on river Cerna, was the result of heavy rainfall.

The synoptic situation was determined by the presence of a low-pressure area, which facilitate on the anterior ridge, an input of cold air coming from south-south-west. This was followed by a strong lack of poise in the mountain area. The Tarcu, Godeanu, Cernei, Retezat and Mehedinti Mountains form the mountain area, from the geographical point of view.

The movement of the air front with velocities between 30-40 km/hour was followed, in this highly fragmented mountain area, by strong ascendant and descendent air currents.

The front, which initially was heading south-south-west, suffered a rotation to north-west and after that to south-south-est. The heavy rainfall covered the catchements of Raul Mare, Cerna and Motru river. The precipitations registered at the meteorological stations and at the rain gauges in the area are presented in the Table 1.

The rain nucleus occurred between 11 July at 21^{00} and 12 July at 6^{00}. The maximum measured precipitation summarizes 213 mm at the Iovanu's Valley reservoir. It is not known the rainfall on the alpine crests due to the lack of measurement stations in the area.

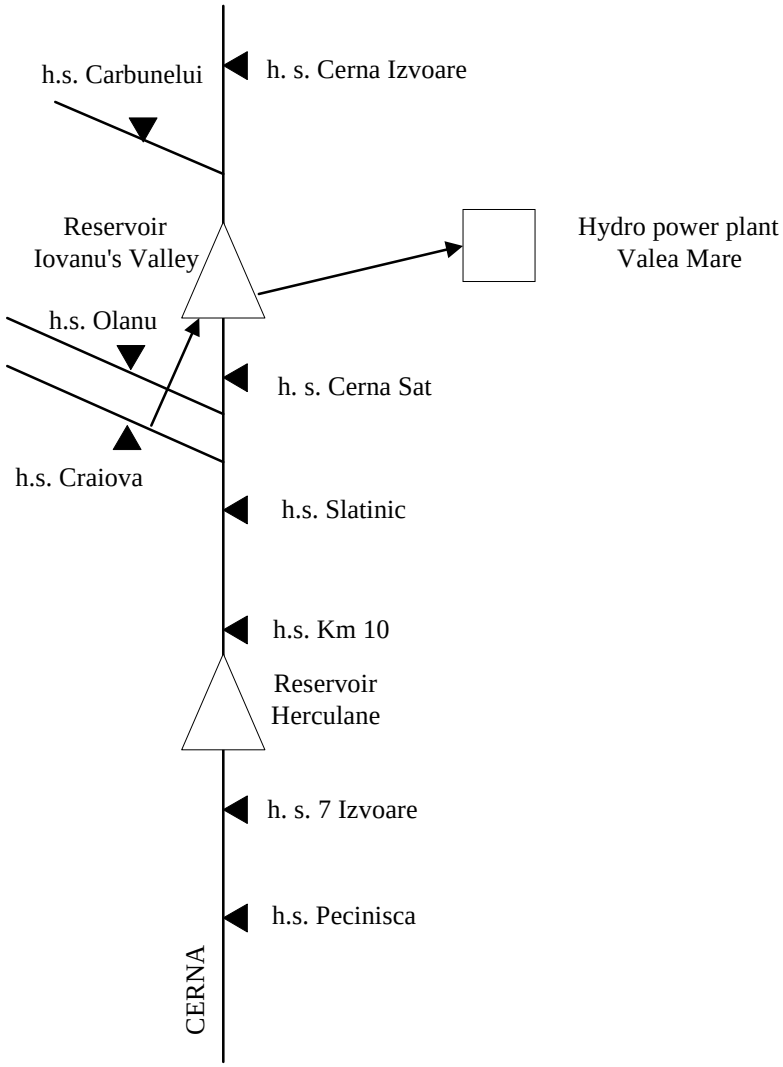

Fig. 2 The scheme of water management and hydrometric stations on main stream

Table1 Registered rainfall between 10 – 15 July 1999 at the meteorological stations and rain gauges

No	Meteorological/ rain gauges	10	11	12	13	14	15	Σ(11-12)
1	Lazar	-	40.2	135.6	-	-	-	175.8
2	Campul lui Neag	-	20.2	47.7	-	-	-	67.9
3	Closani	-	5.0	103.5	-	-	-	108.5
4	Tarmigani	-	4.7	183.6	-	-	-	188.3
5	Tarnita	-	4.5	169.2	-	-	-	173.7
6	Topolnita	-	68.2	65.0	-	-	-	133.2
7	St.M.Apa Neagra	-	20.3	193.2	1.6	17.5	10.0	213.5
8	Glogova	-	-	147.1	-	-	-	147.1
9	Gura Apei	-	-	80.7	-	-	-	80.7
10	Rusca	1.5	1.0	50.0	4.0	-	-	51.0
11	Fenes	4.9	-	77.0	-	-	-	77.0
12	Poiana Marului	6.7	13.0	76.1	-	-	-	89.1
13	Tarcu	-	17.5	46.4	2.6	15.6	-	63.9
14	Cuntu	-	3.8	26.9	-	4.8	-	30.7
15	Ac. Iovanu's Valley	-	20.3	193.2	1.6	17.5	10.0	213.5
16	Cerna Sat	14.5	2.3	193.4	-	13.0	5.5	195.7
17	Slatinic	3.4	19.3	115.1	-	3.2	10.0	134.4
18	Km 10	4.3	13.9	145.8	3.8	1.6	9.2	159.7
19	St.M. B. Herculane	-	30.0	121.2	4.8	-	-	151.2
20	Toplet	-	15.0	142.0	4.0	-	-	157.0
21	Mehadia	3.0	18.2	90.0	7.8	-	-	107.2

The greatest floods occurred in the upper catchement of river Cerna and Raul Mare covering a surface of around 400 km^2.

The area where this floods were produced is characterized by reduced length rivers - up to 21 km, with river slopes between 100 - 135 $‰$ and catchement areas with slopes around 420 - 430 $‰$.

There are three reservoirs in this area (Iovanu's Valley, Herculane and Gura Apei) which summarize an accumulated volume at the normal retention level of 344 mill. m^3 and which have strongly influencing on maximum flowing towards the downstream areas.

The reconstituted floods for the reservoirs were determined on the basis of characteristic courves, supplementary hourly readings and formula:

$$Q_{nat} = Q_{mas} + Q_{dev} + Q_{gol} + Q_{uz} \pm \frac{\Delta W}{\Delta T}$$

where: Qnat is the reconstituted discharge; Qm is the measured discharge; Qw is the spillway-evacuated discharge; Qoutlet is the discharge evacuated throws the bottom outlet, Qh is the discharge used for the hydropower; ΔW represents the volume variation during the considered period and ΔT represents the time step.

At the hydrometrical stations situated upstream of this reservoirs, the maximum discharges and the floods volumes were determined using topographical measurements, hydraulical and global balance computations in the reservoir sections because this hydrometrical stations were completely destroyed by the flood wave.

For the hydrometrical station Cerna Izvoare and Carbunelui, the reconstituted flood waves on the basis of topographical measurements are presented in the Figure 3.

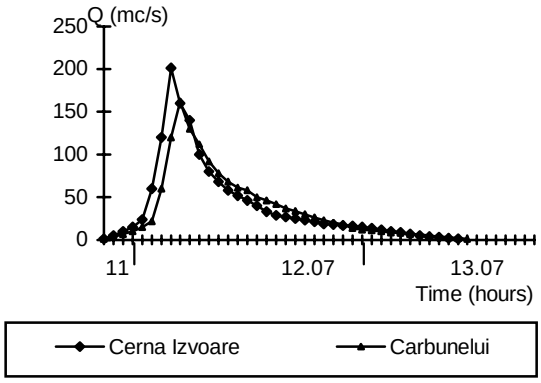

Fig. 3 Flood waves hydrographs at the Cerna Izvoare and Carbunelui hydrometrical station

On Raul Mare the flood was totally retained by the Gura Apei reservoir. This is the reason why it was not necessary to reconstitute the flood for the hydrometrical stations downstream the dam. The flood produced in the Raul Mare catchement area was necessary for a holistic analyzes of the phenomena and it not consists the aim of this presentation.

In the Iovanu's Valley reservoir, the input flood wave was evacuated on spillway and, transferred to hydro power station Valea Mare. This made possible to observe the natural regime hydrographs on corresponding rests of basin area in all hydrometrical stations situated downstream the reservoir.

Reconstitute of the flood waves on river Cerna was made as following:

- On the basis of observations at the Iovanu's Valley reservoir, the flood wave at the dam axis is presented in the fig. 4.

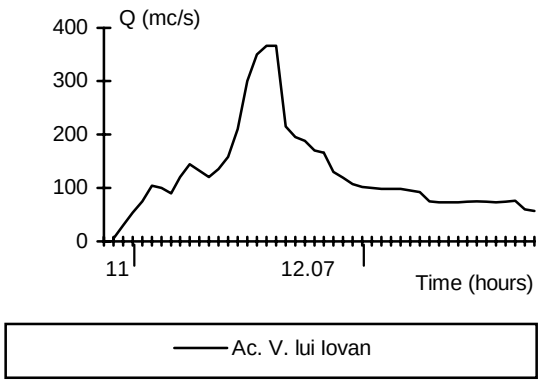

Fig. 4 The flood wave hydrograph reconstituted in the Iovanu's Valley dam axis

- For the hydrometrical stations situated downstream the Iovanu's Valley reservoir, the flood wave was moved on the main stream and placed over the measured hydrographs on corresponding rests of basin area at hydrometrical stations, with the travel times established from the velocities.

The reconstituted flood wave hydrograph, which resulted for Pecinisca hydrometrical station is illustrated in fig. 5.

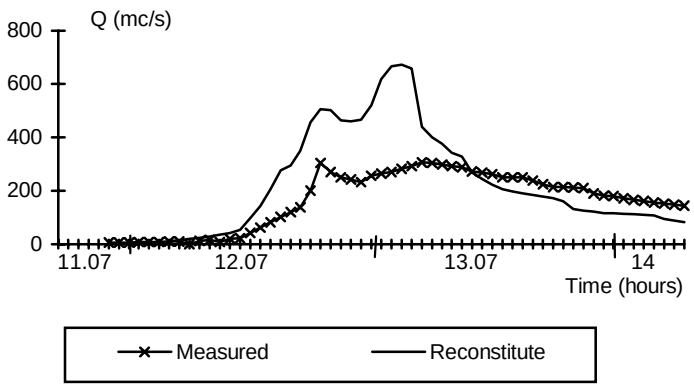

Fig. 5 Flood wave hydrographs: measured and reconstituted at Pecinisca hydrometrical station

Table 2 Parameters of natural flood waves for the rest of basins and for reconstituted flood waves. Cerna hydrographic basin, July 1999

No	River	Hydrometric station	F (km^2)	H_{med} (m)	Q (m^3/s)	W x 10^6 (m^3)	h_s (mm)	q_{max} ($l/s/km^2$)
1	Cerna	Cerna Izvoare	43.0	1220	201	8.60	200	4674
2	Carbunelui	Carbunelui	42.0	1436	162	5.778	138	3857
3	Cerna	Dam axis V. Iovan	128	1290	366	17.82	139	2859
5	Cerna	Cerna Sat rest of basin	39.0		120	5.904	151	3077
6	Cerna	Cerna Sat	170	1247	436	22.924	135	2565
7	Schitul Craiovei	Craiova	38.0	1252	36.5	1.476	38.8	960
8	Gura Olanului	Olanu	47.0	1294	45.0	1.89	40.2	957
9	Cerna	Slatinic rest of basin	222		134	7.56	34.0	604
10	Cerna	Slatinic	352	1100	492	30.484	86.6	1398
11	Cerna	Km 10	425	1000	594	36.0	84.7	1398
12	Cerna	7 Izvoare	488	927	636	37.98	77.8	1303
13	Cerna	Pecinisca rest of basin	48.0		38.0	1.296	27.0	792
14	Cerna	Pecinisca	545	911	672	39.78	73.0	1233

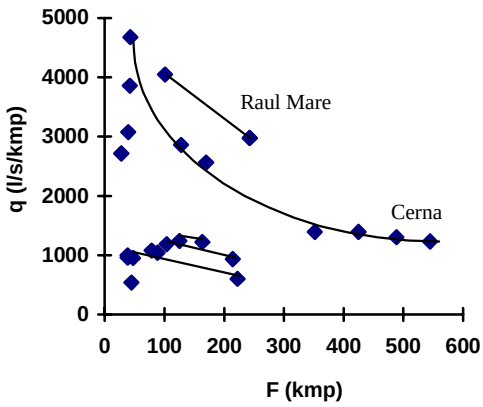

Fig. 6 Synthesis relation q = f (F)

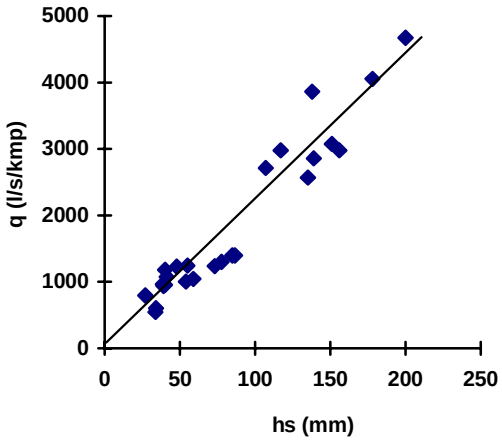

Fig. 7 Synthesis relation q = f (hs)

The flood wave parameters were determined at the hydrometrical stations from this area and they are presented in the Table 2.

As a result of this parameters were founded the following type of synthesis relations: q=f(F) (fig.6) and q=f(h_s) (fig. 7) with q as specific discharge (l/s/km^2); F represents the catchement surface till the considered hydrometrical station (km^2) and h_s represents the land surface flow (mm).

In order to insert the reconstituted flood peak resulted for Pecinisca (Q_{max}=672 m^3/s) into the probability curve of discharges, a statistical computation for the maximum discharges was realized in this section. The data series starts since 1924, with interruption in 1932, between 1937- 1937 and 1941-1946.

From the statistical data processing occurs that, for variation coefficient (Cv) of 1.00, symmetry coefficient (Cs) of 4.00 and, by using the theoretical probability curve Pearson III, the maximum peak with a 1% probability is 650 m^3/s.

The reconstituted flood peak at Pecinisca (Q_{max} = 672 m^3/s) is covered by the 1% probability. Also, the maximum reconstituted flood peaks at all hydrometrical stations on Cerna main stream are assured by the 1% probability.

The historical statements about the catastrophic floods produced on Cerna river are presented in the Ilie Cristescu's book "The wanders of Cerna" (1996). Cristescu had quote chronicler_Stoica

of Hateg about the flood from 1808: "during the night from 11 to 12 October 1808, Cerna's waters at Baile Herculane had grown more then three meters above the normal level and the bridge from Prolaz was broken". From recent estimations resulted that, the flood that occurred in 1808 had a 400 m^3/s discharge.

Other major floods produced on Cerna river occurred in 1911 and 1940 (Q_{max}= 500 m^3/s).

Studying the statistical existence of yearly heavy rainfall in time and space of head, in 1994 Diaconu establish the general connection expression for space-time synthetic probability curve:

$$\left(\bar{X}_{24}\right)_{p\%T} = A_p - B_p \log\left(F_B + F_0\right)$$

with: Ap and Bp are constants related to p%T and area; Fo is a constant related to the area for which are made the linear connection: $(X_{24})_{p\%} - \bar{\log}\,(F_B + F_0)$.

It can be obtained, by using a direct or interpolated mode, the average layer hp (mm) for yearly maximum rainfall in 24 hours with a exceeding-equaling probability p%T fell on a surface F_B.

River Cerna is located in the 4th area where, for a 1% probability, the values are: Ap=355; Bp=43 and Fo=6 km^2. As a result of the computations the average layer (mm) of the yearly maximum rainfall in 24 hours, for Cerna Izvoare hydrometrical station (F_B = 43.0 km^2), is 282 mm (1% probability).

Conclusions

In consequence, the maximum discharges for a 30 km^2 catchement area were registered in the Craul Mare basin, the specific discharges were q = 4.8 $m^3/s/km^2$, followed by Cerna with q = 4.15 $m^3/s/km^2$ until q = 1.7 $m^3/s/km^2$ for rivers situated in the vicinity areas.

From the synthesis relation $q=f(h_s)$ resulted that for a 30 km^2, the land surface flow was around 230 mm. It was admitted an overflow coefficient α=0.8 which multiply the land surface flow. Resulted that the fell layer (h_p) was 288 mm. This confirms the fact that the average rainfall in 24 hours has a 1% probability as resulted by the computation.

In the case of this phenomenon, the rainfall with 1% probability generated floods with a 1% probability. The phenomenon made possible the analysis of practical application method developed by Diaconu. By forecasting floods with different probabilities the defense action can be organized in due time in order to prevent unfortunate events.

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Schneereiche Winter im Transkarpatengebiet und Intensität der Lawinenerscheinungen und Schneeschmelzhochwässer

Tetjana Maslowa, Wolodymyr Grystschenko

Zusammenfassung: Es wurde eine Analyse der Häuftigkeit schneereicher Winterperioden im Theiß-Becken, die durch Wassergehalt der Schneedecke eingeschätzt werden, vorgelegt. Der Schneereichtum begünstigt Schneelawinenabsteigen. Es wurden lawinengefährdete Gebiete und die Häufigkeit des Lawinenabsteigens behandelt. Bedeutende Schneeschmelzhochwässer geschehen hier in den 30-40% Jaren mit schneereichen Wintern.

Schlüsselworte: schneereiche Winter, Schneelawinenerscheinungen, Häuftigkeit der Lawinenabsteigens, Schneeschmelzhochwässer.

Snowy Winters in the Transcarpathians and Intensity of Avalanche Phenomena and Snow Melt Flood

Abstract: Frequency analysis of snowy winter expressed through snow pack water equivalent in the Tisza basin is presented. Many - snowy conditions cause avalanching. Dangerous avalanche localities and avalanche phenomena probability are described. High snow melt floods be observed 30-40 % in snowy winter years.

Key words: snowy winters, snow avalanche phenomena, frequency of avalanching, snow melt floods.

1 Schnee- und Lavinenverhältnisse

Die Untersuchungen der Schneedecke in den Karpaten (insgesondere im Transkarpatengebiet) sind infolge beträchtlicher Veränderlichkeit ihrer Charakteristika während einer bestimmter Wintersaison und vom Jahr zu Jahr für praktische Ziele von wichtiger Bedeutung.

Das Entstehen der Schneedecke in den Bergen, ihre räumlich-zeitliche Verteilung und Dynamik der Wassergehalt der Schneedecke werden durch mehrere Faktoren bestimmt u.z.: meteorologische Verhältnisse, Geländegestaltung und Exposition, Höhe über dem Meeresspiegel. Wenn wir das gesamte Territorium des Transkarpatengebietes betrachten, so beeinflußt die Gebirgenlage in bezug auf die Luftmassenverlagerungswege bei unterschiedlichen Wettersituationen die Verteilung der Schneedecke in hohem Grade. Dies kommt dadurch zum Ausdruck, daß sich die Schneevorräte mit der Geländehöhe vom Nordwesten nach Südosten vergrößern. Darüber hinaus ist eine ständige überschreitung der Schneevorräte an den Abhängen der nordöstlichen Exposition infolge der Schneesturmabdrift zu vermerken.

Der Wert der Angaben über wahrscheinliche, insbesondere maximal mögliche Wassergehalte im Schnee und über ihre Verteilung auf der Fläche wird durch ihre Anwendung in vielen Bereichen praktischer Tätigkeit bestimmt. Das sind die Berechnung der Belastung der Baukonstruktionen, Betreiben der Verkehrswege sowie Maßnahmen zur Beseitigung zerstörender Wirkungen der Schneelawinen. Die Informationen über die Art und Weise der Schneedecke finden bei der Vorhersagen des Frühjahrsabflusses in den Einzugsgebieten des Theiß-Beckens eine ziemlich umfangreiche Anwendung.

Die umfangreichsten Beobachtungen der Schneedecke werden im Theiß-Becken seit 1946-1950 durchgeführt. Dazu gehören tägliche Messungen der Höhe und der Dichte der Schneedecke in den Stationen und Posten, Messung ihrer Charakteristika auf bestimmten Routen inklusive

Hochgebirgsgebiete (bis zu Höhen von 1100-1200 m abs.). Aufgrund der Angaben von 30-50 Stellen wurden allgemeingültige Schlüsse gezogen, um mehrjährige Meßwerte [3,5,6] zu bekommen. Unten werden die wichtigsten davon angeführt.

Die Bildung einer beständigen Schneedecke im Hochgebirge fällt durchschnittlich auf die dritte Novemberdekade und im Tiefland (Transkarpatentiefebene) - auf die dritte Dezemberdekade. Die beständige Schneedecke wird vom Tiefland aus vom Ende Februar bis zur ersten Aprildekade zerstört. Somit dauert sie im Durchschnitt 60 bis 130-140 Tage. Durchschnittliche Maximalhöhen der Schneedecke liegen entsprechend bei 20-160 cm und nehmen mit der Höhe allmählich zu. Maximale Wassergehalte des Schnees werden vorwiegend bis zur zweiten und dritten Februardekade gebildet. Den unterschiedlichen Höhenzonen eigenen Witterungsverhältnissen entsprechend können sich die Höhen der Schneedecke und die Wassergehalte darin im Tiefland im Lauf des Winters ändern, da hier häufig Tauwetter zu beobachten ist. Im Hochland hat der Schnee eine höhere Stabilität.

Von großem Wert sind die Informationen über die Häuftigkeit schneereicher Winterperioden, da diese Unbequemlichkeiten oder sogar Probleme für die Bevölkerung und die wirtschaftliche Tätigkeit bereiten.

Im Lauf der letzten 60 Jahre hat es im Transkarpatengebiet 11 schneereiche Winter gegeben, wenn Wassergehalte der Schneedecke in Gebirgseinzugsgebieten 200 mm überschritten (Tab.1).

Tabelle 1 Maximale Wassergehalte der Schneedecke im Theiß-Becken während schneereicher Winterperioden

Jahr	**Wassergehalt in der Schneedecke, mm**	
	Gebirgsgegend	**Niederland**
1940-1941	200-450	-
1951-1952	150-250	15-30
1954-1955	120-260	20-50
1955-1956	90-210	15-50
1963-1964	140-270	30-80
1966-1967	130-210	50-150
1967-1968	120-310	20-40
1973-1974	90-310	30-70
1975-1976	160-300	50-120
1986-1987	110-280	100-140
1998-1999	200-380	100-150

Insbesondere haben sich die Winter in den Jahren 1941 [1], 1968, 1976 und 1999 ausgezeichnet, was von fehlender stabiler Häufigkeit an Schneereichtum zeugt. Jedoch könnte man behaupten, daß solche Winter im Durchschnitt maximal einmal pro 15 Jahre eintreten. Dabei ist eine bestimmte Gesetzmäßigkeit bei der räumlichen Lage der Schneedecke zu beobachten: am meisten Schnee häuft sich immer im östlichen Gebiet der Transkarpaten (Rika-, Tereblja-, Tereswa- und Obertheiß-Becken), so wie es im Winter 1998/1999 war (Abb.1).

Schneereiche Winter im Bergland ist eine Bedingung, die intensive Schneelawinenaktivität begünstigt [2,3,4]. Bildung und Absteigen der Lawinen werden durch einen komplizierten Komplex an lawinenbildenden Faktoren bedingt, die wichtigsten davon sind Relief und

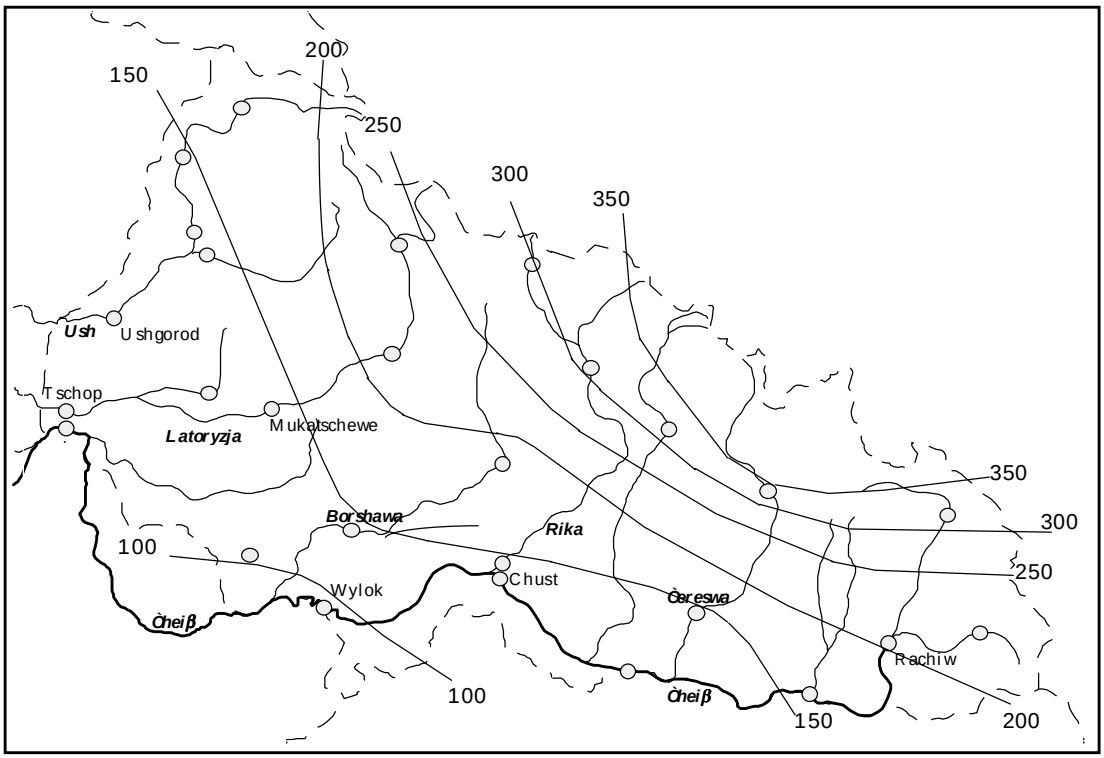

Abb. 1 Wassergehalte der Sneedecke 20.02.1999 (mm)

Witterungsfaktoren wie Niederschläge in Form vom Schnee, ihre Anzahl, Höhe und Intensität des Schneezuwachses, Temperatur- und Windverhältnisse.

Das gesamte Bergland des Transkarpatengebietes mit 300 m abs. angefangen befindet sich in der Zone der Schneedeckehöhen, die für Lawinenbildung ausreichend sind (das sind die Höhen ab 30 cm Schnee und mehr) [2,4]. In diesem Zusammenhang sind hier Lawinen an den Berghängen mit der Neigung von 20-45 Grad in den Höhen von 300 bis 2000 m abs. verbreitet. Die größte Lawinenlaufsreckenlänge beträgt über 3 km, die meist verbreitete - 100-500 m. Die Flächen der Lawinenherde betragen 40-50 ha, am meisten 1-5 ha. Im Hochland des Transkarpatengebietes erfolgt das Absteigen der Lawinen manchmal einige Male im Winter an demselben Ort, am häufigsten einmal jährlich oder einmal im Lauf einiger Jahre (Tab.2). Der große Umfang des durch eine Lawine abgetragenen Schnees reicht bis auf 0,5-1,0 Mio m^3, gewöhnlich reicht er von einigen Hunderten bis Dutzenden Tausend m^3.

Hier und da verursachen intensive Schneefälle und Tawetter in bezug auf Umfang kleinere, dafür jedoch massenhafte Lawinen. Nach Genesis sind hier Feuchtschnee- (beim Tauwetter) und Trockenschneelawinen aus frischgefallenem und Sturmschnee verbreitet.(Tab.3)

Die meisten Lawinen steigen im Winter und im Frühling ab (zum größten Teil im Februar - März; die ersten wurden im Oktober, die spätesten im April festgestellt).

Die meist lawinengefährdeten Gegenden des Transkarpatengebietes (sieh Tab. 2) sind die Gebirge Tschornogora, Gebirgskörper von Rachiw, Swydowez (Flußbecken der Weißen Theiß, der Schwarzen Theiß, Kosiwska und Schopurka, teilweise Tereswa), Krasna (Tereswa- und Tereblja-Becken), Borshawa (Rika-, Borshawa- und Latoryzja-Becken), die Polonyna Runa und Lautjanska Golyzja (Ush-Becken). Selbstverständlich verändert sich die Intensität der Schneelawinenprozesse vom Jahr zu Jahr, daß in erster Linie mit dem Schneereichtum der Winterperiode zusammenhängt (Tab.4).

Tabelle 2 Lawinengefährdete Gegenden des Transkarpatengebietes

Gebirgskörper	Flußbecken	Schneelawinen-häufigkeit
Werchowyna-Rücken	Ush-, Latoryzja-, Borshawa-, Rika-Oberlauf	einmall in 2-3 Jahren
Gorgany	Rika-, Tereblja-, Tereswa-, Theiß-Oberlauf	fast jährlich
Polonyna-Rücken:		
- Runa	Ush	einmall in 1-3 Jahren
- Borshawa	Latoryzja, Borshawa, Rika	jährlich
- Krasna	Tereswa, Tereblja	jährlich
Swidowez	Tereswa, Schopurka, Kosiwska	jährlich
Tschornogora	Theiß-Oberlauf	jährlich
Rachiw-Gebirge	Theiß-Oberlauf	jährlich

Tabelle 3 Anzahl der Genesis nach unterschiedlichen Lawinen laut Angaben der Beobachtungen der Schneelawinenstationen Posheshewska und Plaj*

Period	Posheshewska (1440 m)			Plaj (1330 m)		
	Lawinenanzahl					
	aus trocke-nem Schnee	aus feuchtem Schnee	insgesamt	aus trocke-nem Schnee	aus feuchtem Schnee	insgesam t
1976-85	86	73	159	22	46	68
1986-95	82	72	154	29	70	99

*Posheshewska befindet sich im Gebiet Iwano-Frankiwsk, repräsentiert jedoch das transkarpatische Tschornogorengerbirge.

Der Winter 1998-1999, der sich durch die Intensität der Lawinenbildungen auszeichnete, war extrem schneereich. In den meisten Orten überschritt die Höhe der Schneedecke die maximale während der Beobachtungszeit (Ausnahme das Jahr 1941). Es versteht sich von selbst, daß die Schneelawinen in diesem Winter große Verbreitung hatten.

Nach den scneereichen Wintern im Teiß-Gebiet ist leicht möglich, daß bedeutende Schneeschmelzhochwässer sich bilden werden. Die Beobachtungsangaben zengen, daß solche Hochwässer während intensiver Frühlingsverläufe sich ereignen. Es geschieht hier ungefähr in den 30-40% Jahren . Doch Vorhandensein der großen Wassergehalte in der Schneedecke bedeutet auf jeden Fall nicht, daß hohes Frühlingshochwasser unbedingt sich ereignen wird. In manchen Jahren kann die Schneeschmelze 2-3 Monate dauern, und maximale Abflußmengen werden in diesem Fall niedriger sein, als bei verhältnismässig kleinere Wassergehalte (Tab. 5).

Tabelle 4 Angaben über aufgezeichnete Lawinen in der Zeitperiode vom 1986-1997

Winter, Jahre	Anzahl			Gesamtvolumen der Lawinen, Mio m^3
	der beobachteten Lawinen	der Perioden mit der Lawinenbildung	der Tage mit der Lawinenabstegen	
1985-86	233	6	22	4,2
1986-87	302	5	14	3,6
1987-88	253	6	14	0,3
1988-89	99	3	7	0,4
1989-90	27	1	1	0,2
1990-91	112	1	1	0,1
1991-92	30	7	8	-
1992-93	114	7	7	2,9
1993-94	84	6	9	1,9
1994-95	21	8	14	0,2
1995-96	130	5	7	2,1
1996-97	26	3	4	0,2

Tabelle 5 Maximalle Frühjahrsabflußmengen an den Flüssen im Theiß-Flußbecken nach den verschiedenen schneereichen Wintern

Wassergehalte der Schneedecke an den Einzugs gebieten (mm)	Maximale Abflussmenge (m^3/s)			
	Theiß - Rachiw	Theiß - Wylok	Latoryzja-Mukatschewe	Ush - Ushgorod
120-310	110-200	700-2000	90-400	130-650
200-380				
200-450				
90-160	240-440	1300-2600	250-570	730-1120
150-250 110-280				

2 Schlussfolgerungen

Die bedeutendste Schneedecke bildet sich jeden Winter im östlichen Transkarpatengebiet, d.h. im Oberlauf der Theiß und in den Einzugsgebieten ihrer Nebenflüsse (Tereswa, Tereblja, Rika). Die Mittelhöhen des Geländes auf diesem Territorium liegen über 700-800 m abs. und die Abhänge - 300-450‰ . Daher zeichnet sich diese Gegend durch gefährliche Bedingungen in bezug auf die Intensität des Schneelawinenabsteigens und der Häufigkeit der Schneeschmelzhochwässer.

Während schneereicher Winter reichen maximale Wassergehalte der Schneedecke in den Gebirgseinzugsgebieten des östlichen Transkarpatengebietes 250-450 mm, und Schneelawinen sind in der Wintersaison einige Male zu beobachten. Während solcher Winterperioden kann sich eine bedeutende Schneedecke auch im ganzen Unterlauf des Theiß-Beckens, häufig mit maximalen Wassergehalte bis 100-150 mm, bilden.

Es gibt keine Stabilität bei der Häufigkeit schneereicher Winterperioden. Im Durchschnitt treten diese einmal alle 5-6 Jahre ein, jedoch wiederholten sie sich auch alle 1-3 oder 11-12 Jahre.

Da es nach schneereichen Wintern mit Wärmeeinbruch die Gefahr der Bildung bedeutender Schneeschmelzhochwässer an den Flüssen des Theiß-Beckens besteht (wie es z.B. im Jahre 1970 der Fall war), gewinnt unter diesen Bedingungen die Analyse der Entwicklung atmosphärischer Prozesse über dem Südwesten der Ukraine und dem Territorium der Nachbarlander zwecks rechtzeitiger Warnung über die Wahrscheinlichkeit gefahrlicher hydrologischer Erscheinungen an großer Bedeutung.

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New Concepts in Flood Forecasting and Mitigation

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Abstract: A short review of the evolution of flood forecasting in Central Europe is presented. It is noted in particular that although in the Kingdom of Bohemia, which was a part of the Austrian Empire, there is a long tradition of hydrological observations and their use for hydrological forecasting, this tradition has not contributed to a rapid progress of these activities. It is the introduction of statistical methods that marked the modern development of forecasting from empirical routing to models used today. For a long period the routing concerned only floods yet the complex activities in flood disaster prevention, which are today identified in particular by the international programs, are possible only by close cooperation of different scientific, management, behavioral ,ecological, administrative and economical entities. This is also the way to make substantial progress in the mitigation of disasters of different origins. This is demonstrated by the analysis of several recent cases of disasters of meteorological origin.

The alleged panacea of computerization and modelisation of the Early Warning Systems (EWS) is discussed and some examples from the field of flood forecasting and subsequent flood related mitigation are presented. Some of the most important problems are identified and possible ways of their solutions are proposed for conditions of the Danube basin countries on basis of experience in the Czech Republic

The Conference is informed also of a relevant newly initiated international cooperation in the Central European region.

Key Words: Flood Forescasting, Disaster Mitigation, International Cooperation

Neue Konzepte zur Hochwasservorhersage und Vorsorge

Zusammenfassung: Es wird eine kurze Übersicht über die Entwicklung der Hochwasservorhersage in Mitteleuropa gegeben. Speziell wird angemerkt, dass obwohl das Königreich Böhmen als Teil Österreich-Ungarns eine lange Tradition hinsichtlich hydrologischer Beobachtungen und deren Verwendung für die hydrologische Vorhersagen hatte, diese Tradition nichts zum schnelleren Fortschritt beigetragen hat. Es ist die Einführung statistischer Methoden, die die moderne Weiterentwicklung von Vorhersagen aus empirischen Ansätzen zu heute angewandten Modellen kennzeichnen. Lange Zeit wurden nur Hochwässer und nicht die komplexen Tätigkeiten zur Vermeidung von Hochwasserkatastrophen berücksichtigt, welche heute in speziellen internationalen Programmen erkannt werden, und die nur durch die enge Zusammenarbeit der unterschiedlichen wissenschaftlichen, administrativen, ökologischen und ökonomischen Einrichtungen möglich sind. Dies ist auch der Weg, um substanzielle Fortschritte in der Vorsorge vor Katastrophen unterschiedlicher Ursachen zu machen. Dies wird anhand der Analyse einiger neuerer Fälle von Katastrophen meteorologischen Ursprunges aufgezeigt.

Die angeblichen Patentrezepte bei der Berechnung und Modellierung des Frühwarnsystemes werden diskutiert und einige Beispiele aus dem Bereich Hochwasservorhersage und daraus resultierender Vorsorge werden präsentiert. Einige der wichtigsten Probleme werden erkannt und mögliche Wege zu deren Lösung werden im Hinblick auf die Donauanrainerstaaten aufgrund der Erfahrungen in der Tschechischen Republik vorgeschlagen.

Schlüsselwörter: Hochwasservorhersage, Katastrophenvorsorge, Internationale Zusammenarbeit.

1. The forecasting of hydrological events in Central Europe has a long tradition. Indeed the Imperial Austria and in particular the Kingdom of Bohemia established their hydrological services in the mid -nineteen century and the rivers were observed in all parts of the Austrian Empire. However tradition and bureaucracy are not necessarily the phenomena which contribute to the progress and development of science in all circumstances. Thus the Czech Hydrological Service ,which until after the Second World War was independent from the meteorological one, used in forecasting of stages and discharges with relative success and self-satisfaction the methods based on long-term observations in many gages on the rivers and their transfer (mainly graphical) relationships downstream. Similar methods were used also in Germany and France and several other European countries.

2. It was only with the availability of literature from the USA and USSR, that the above forecasting methods were made more effective with the introduction of statistical science applied to hydrology in the 1930s and widely developed during the war by services of these countries for their war efforts. Yet the number of hydrologists in Europe which accepted this intrusion of a science not previously even taught to civil engineers or natural scientists (mostly physical geographers) involved in practical applications of hydrology, such as forecasting, was relatively small. Conservative approaches based on empiricism had a preference also in view of the possible consequences of incorrect forecasts.

The engineering efforts in hydropower developments did require the introduction of statistics in hydrologic and hydraulic design; indeed the introduction of N-year flood was acquiring respectability around Europe already in the years before the war .This development was also strengthened by bridges built between hydrology and meteorology after the war in the Czechoslovak Republic assisted by the Russian example. The administrative joining of the two services in one :hydrometeorological service was not, however, a particular necessity to provide advances in hydrological forecasting .Thus, for example, in the USA , Italy or Hungary until now such a joint service does not exist, yet progress in forecasting methods in these countries did rapidly grow.

The approaches to forecasting did however change , not only because of the wider knowledge and good will of the scientific and technical personnel in charge of hydrology and meteorology services. The growth of industrialization and urbanization in the vicinity of rivers and in places exposed to severe weather brought a consciousness of the need to increase the mitigation and prevention of disasters of natural and other origins. Thus for example one of the authors of this paper in his studies at the university fifty years ago, was taught of the beneficial effects of flooding in the flood plain, which was, by definition ,reserved for agriculture such as in Egypt where civilization and growth of the state was impossible without the flooding of the Nile.

The professor who was in charge of the subject (deceased since long years) would never believe that in the late twentieth century, it would be possible not only legally to allow the building of factories in the flood plain (as in the Czech Socialist Republic), but to settle hundreds of thousands of poor people in such plains all over the world.

Furthermore, the organization of administrative activities concerning water management at different levels of the Government in many countries has contributed to the increase of the impact of natural disasters on the society.

3. In considering the activities of prevention and mitigation of these above impacts, there are many options (IDNDR,1999). Without any doubt among the most important and cost - effective are the Early Warning Systems (EWS). The core of each such system is the meteorological and hydrological forecast .While the forecast is not technically the simplest part in prevention and mitigation, in most cases it is accessible for the majority of industrialized countries and those in transition to such. The more difficult parts in building the prevention and mitigation system are those depending on the political and administrative organization of the area in question, on the

structure and social levels of the population including its access to education and employment. To give some recent examples in this respect we can consider the prevention and mitigation of consequences of the 1997 and 1998 floods in Central Europe, in particular in the Czech Republic, Poland and Germany. While the level of forecasting and early warning in all three above countries could be considered in general more or less comparable, the social structure and administrative organization has projected itself in the mitigation efforts to a much larger extent. A similar situation presented itself during the recent heavy storms which in the end of 1999 crossed Western and Central Europe and in which the wind attained velocities comparable to tropical hurricanes and caused considerable damages in every respect including losses in human lives. Even in the otherwise very well developed EWS in the USA, during the cold spell in January 2000, sudden snow falls paralyzed part of the country and it was reproached to the National Weather Service that the forecast was not sufficiently precise, which caused large problems in air and road traffic. There were only a few casualties. But the NWS had to check the functioning of its supercomputer, which should permit, together with the excellent data collection system, a timely and more precise forecast and warning.

On the other hand, if these above mentioned natural disasters would be compared with the storms accompanied by torrential rains causing land slides in the coastal regions of Colombia, with the thousands of dead and the forced displacement of dozens of thousands of peoples, the social and economic element of the prevention and mitigation will be amply illustrated.

4. This paper is not however centered on these aspects of the problem but rather on the technical aspect of the EWS and on some aspects of mitigation with the help of a computerized support to the decision making.

With respect to the forecasting part of the system, it should be stressed that a general land surface located weather observing network, with a few sensors with real time transmission to the forecasting center which is equipped with one computer, one rainfall-runoff and one routing model, both dating from twenty or thirty years ago and a telephone connection with some disaster warning authority, is not to be considered either as a real time operation or a system. This does not necessarily mean that all systems must have a multi-sensor real-time tele-transmitting data collection sub-system (including radar and satellite imaging equipment as well access to meteorological forecasts, based also on atmospheric models). Nevertheless, such a data system should be aimed toward in any central forecasting system serving a country or whole parts of a large river basin such as the Danube. In building similar systems, however, several traps and blind alleys exist. To start with, the basic philosophy in the early warning approach is presenting two mutually conflicting aspects:

The first is the lead (advance) time with which the warning is issued. If this time is too short, the value of the warning decreases, eventually to zero. On the other hand, there is the fact that the longer this time is, the smaller the accuracy , both of the geographical location and the intensity of the natural phenomenon able to cause a disaster, and thus the effectiveness of the warning decreases. The psychology of disaster warning indicates also that after a certain period, the longer the time available for mitigation action is, the less urgent and often less effective these actions are. Last but not least ,in case of an inaccurate warning, the “cry wolf” phenomena as false alarms are called, may also reduce the value of the warning to zero.

At first glance, the lead time of the forecast can be increased by accelerating the transmission of data from the network to the forecasting center by using various real-time observation and transmission technologies. The second element of acceleration of the issuance of the warning and thus an increase of the lead time may be by using high performance supercomputers and different software enhancing the forecasting operations, such as the GIS. A distinct addition to the lead time in case of a rainfall-runoff model is the use of a rainfall forecast obtained from an atmospheric model. Sometime however the increased sophistication of the data collection and modeling may, particularly in countries which do not have easy access to the technology spare

parts or the highly specialized technological know-how (the case for some countries of the Danube basin) cause an opposite effect on the issuance of the warnings; it may delay it and even prevent its issuance.

Another element to be considered in building the system is the cost/efficiency ratio achieved by the sophistication of the system. A highly computerized forecasting center without equally performing data collection is a luxury which may not improve the performance of the system as a whole with respect to the efficiency of the warning. In this respect the redundancy in computing and transmission is to be considered first before taking steps toward a more sophisticated system. One of the authors of this paper in his activities of assisting in setting up forecasting systems, in developing countries predominantly, always invited attention to simple problems of maintenance, such as electric power failures, short circuits in electronic equipment etc. A fall -back facility, although adding cost, enhances the efficiency-cost ratio and may save lives.

5. The desirable forecasting system is illustrated in fig 1. (Nemec, 1986). Such a system is

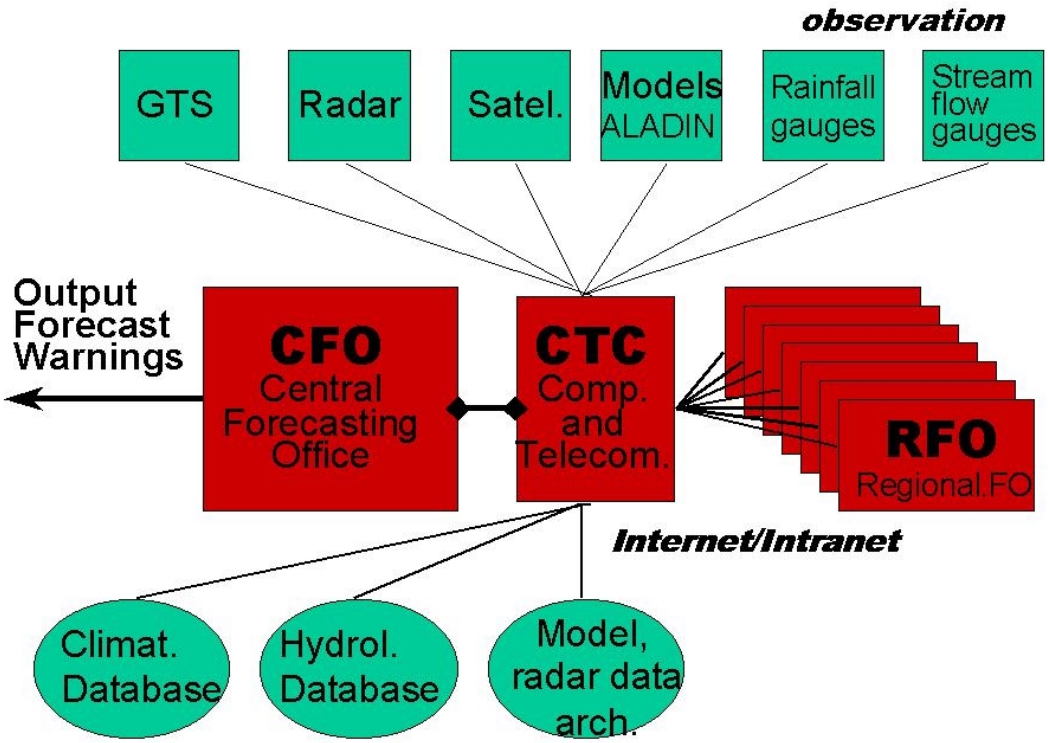

Fig 1 Integrated Flood Forecasting and Warning System in the Czech Hydrometeorological Institute

accessible to most countries in Europe and elsewhere. Good examples are the European Union projects AFORISM (A comprehensive FORecastIng System for flood Mitigation and control) and EFFORTS (European Flood Forecasting Operational Real Time System). In the USA the NOAA NWSRFS (National Weather Service River Forecasting System) has been developed and is being adapted by several countries in the world for their forecasting needs.. (Todini, 1998; Nemec, 1999 ; WMO,1999).

A recent meeting of the users of the NWSRFS from countries outside of the USA, held in the Headquarters of the USA NOAA near Washington DC, and subsequent visit of the participants in the River Forecasting Center in Pennsylvania for the basins of rivers in the Central Eastern Region (including some large rivers like the Susquehanna and Delaware), confirmed the view expressed by the authors of this paper (Nemec,1999) concerning the need of adaptation of each flood forecasting system to the rivers they serve. Thus figure 1 represents the elements of which a system should be built, but does not provide the specification for every part of the system. The above indicated visit at the RFC in Pennsylvania indicated that this center and all the 13 centers that are in the USA are not identically organized and do not use always the same methodology or models .On the other hand, the data collection and processing system, such as the NEXRAD radar network of the US NWS and other observing and transmission systems are standardized and perform identically in all Centers. This is an important principle valid also for European conditions, although not easily achieved.

The Czech Hydrometeorological Institute has six regional offices (Obrusnik, 1999), each of which has forecasting responsibility for larger rivers in the region. The modernization plans of the forecasting systems, started after the 1998 floods, follow a similar strategy as exposed above. A new data processing system based on the ORACLE software will be shared by all regions. The real -time transmitted precipitation data are collected for the time being by different equipment, but a standardization is underway. On the other hand, the hydrological forecasting models in the different larger basins are, with the exception of the basin of the Labe (Elbe), of different origin, although data interfaces permit basic meteorological information to reach the hydrological models from a single basic network including radar data (from 3 radars), satellite information and forecasted meteorological data from three atmospheric LAMs (Local Area Models). The Institute initiated successful cooperation with several meteorological services in the EU and serves as a Central European center for meteorological modeling with one LAM based on the model developed by the Meteorological Service of France and adapted to Central European needs by specialists from the Czech Institute. The Institute also cooperates with the USA NOAA National Weather service and has transferred in particular a multisensor precipitation data field processing method for use in hydrological forecasts. This cooperation is continuing and transfers of technology by mutual visits of specialists are underway.

A study by the Department of Water Resources of the Czech Agricultural University in Prague analyzed in 1999 the hydrological forecasting needs of the Institute and recommended that a standardized system be introduced in the near future based on the system already used in the Labe (Elbe) basin. The system, called “AQUALOG”, originated in the Czech Republic and allows the use of several types of snowmelt/rainfall- runoff and routing models, according to the needs of each river basin .

6. After the floods in 1997-98, international cooperation was initiated by the Czech institutions involved in disaster mitigation and prevention, under the leadership of the Czech National Committee for the IDNDR. In the first consultation in 1998 held in Prague, National Committees or equivalent bodies from Austria, Germany, Hungary, Poland and Slovakia took part. Also participating In the consultations were representatives of the UN Secretariat in Geneva and the UN Economic Commission. In the following consultation, this cooperation was institutionalized as the “Central European Forum for Disaster Prevention” (CEUDIP), by establishing a secretariat and annual consultations rotating in all participating countries. Thus the consultation 2000 will take place in Warsaw. As the first three subjects of consultations and technical cooperation were selected methods of early warning, training in disaster mitigation and cooperation with media.

6. The CEUDIP will no doubt also concentrate its attention on the Decision Support System (DSS), which may be built in computerized form as a continuation of the forecasting and early warning system and connected to it in real time. A type of such a system has been presented in

the above mentioned meeting in Washington. It has been built for the basin of the River Tennessee with the cooperation of four US agencies involved with the EWS, water management and disaster mitigation in the basin.

Further information on CEUDIP activities, including activities in the field of disaster prevention in the participating countries will be available on the INTERNET. The address of the CEUDIP WEB page will be having a link on http://www.chmi.cz.

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The Review of Meteorological Products for Utilization in Hydrological Forecasting

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Abstract: This paper deals with the meteorological aspects of floods, defining four groups of causes meteorological of floods. Following are introduced meteorological aspects of flood risk and flood hazard assessment and steps taken in assessment of flood related meteorological hazard. Presented are meteorological data needed for flood forecasting and warning, with a detailed specification of data sources for three most crucial ones – precipitation, soil moisture and snow. Finally outline of basic meteorological products used at SHMI's practice for flood forecasting and warning is discussed.

Key words: Floods, flood risk, flood hazard, flood forecasting, flood warning

Der Überblick der meteorologisehen Produkten, die für hydrologische Vorhersagen benutzbar sind

Zusammenfassung: Dieser Artikel befasst sich mit den meteorologischen Aspekten des Hochwassers und definiert 4 Gruppen der Ursachen. In zu Folge sind die Risiken und Gefahren der meteorologischen Aspekten bezeichnet, die mit den Fluten verbunden sind. Hier sind die meteorologischen Daten, die für die Wettervorhersage und Vorwarnung des Hochwassers mit der detailirter Spezifikation der drei am bedeutensten Quellen - die Niederschlägen, die Bodenfeuchtigkeit und Schnee gebrauchbar sind, präsentiert. Folgend ist der Übersicht der Grundprodukten eingefürt, die man in der Praxis des SHMI für die Flutvorhersagen und -vorwarnungen benuzt.

Schlüsselworte: Hochwasser, das Hochwasserrisiko, die Hochwassergefahr, die Hochwasservorhersage, die Hochwasservorwarnungen

1 Introduction

Despite the tremendous progress in science and technology, weather is still the custodian of all areas pf life on the earth. Thus too much rain causes flooding, damages to life and properties, destroying cities, washing away crops, drowning livestock, and giving rise to waterborne diseases. Flooding and flood damages were and remain problem for most of the people round the world. It is well known that man has increased the risk of river flooding due to man intervention, like hydraulic interventions, intensive building activities and the use of all areas in the vicinity of rivers that altered the river regime. To make it worse, today's knowledge on the effects of climatic changes shows that there will be a general rise of risk from flooding.

It is particularly difficult to predict the changes in regional precipitation patterns, flood-producing rainfall and snowmelt rates that may be associated with possible global warming. However, two effects can be deducted from basic principles. First, global warming may produce earlier melting of seasonal snowpacks in certain areas. Second, the incidence and severity of extreme rainfall may increase because higher temperatures may produce more vigorous hydrological cycle and because the precipitable water content of the atmosphere increases with temperature.

It should be noted that flood-related disasters do not confine themselves exclusively or even primarily to riverine floods. From a natural hazard perspective, there are important similarities between river flooding, lake flooding, flooding resulted from poor drainage in areas of low relief and flash flooding caused by very intensive convective storms.

Flooding is natural phenomenon. The natural variation of water levels is a part of the feature of rivers. Extreme river flooding occur when intensive precipitation falls on soils, which are already saturated due to the previous precipitation or on soils, which are frozen and cannot absorb any more water. Extreme inland flooding occur when very intensive stationary rainfall patterns cover relatively small area. The intensity of such a phenomenon normally exceeds 90 mmh^{-1}. The other precursors are local physical, geographical and hydrological conditions and sensitivity to flash floods that point out the so-called Flood-prone areas.

Improved flood prevention and protection remain indispensable and will in future be more and more in demand than ever before. It will require building of the proper Framework for risk assessment. One of the most important factors to be considered in making assessment of hazards[1] and risks[2] is the purpose for which the assessment is being made. Comprehensive risk assessment starts with the Natural system observations continue with Hazard potential, Vulnerability[3] Risk assessment and Risk acceptance and ends with Planning measures. Meteorological aspect are linked to this process in every step, however the Forecasting and warning system is basically a Planning measure and it is applied as a measure in its Risk mitigation that provides the best possible practice for minimization of risks.

2 Meteorological aspects of floods

There are four main groups of meteorological causes that are linked to floods and flash floods:

- Small-scale convective storms causing flash-floods;
- Large and mostly stationary frontal systems or widespread storms causing flooding on a regional scale;
- Favorable meteorological conditions leading to snowmelt;
- Riverine floods resulting from ice jam;
- Soil moisture levels prior the heavy rainfall event.

There is a general correlation among frontal system/storm duration, frontal system/storm areal extent, the size of the watershed associated with the flood, the duration of flooding, and the time from the beginning of the frontal system/storm to the floods peak.

Flash floods are typically caused by convective precipitation of extreme intensity of short duration (less than 2 to 6 hours) and limited areal extent (less than 1000 km^2. The most local events are associated with isolated thunderstorms, super-cells and squall lines. On the other hand mesoscale events are mostly associated with the multiple squall lines and short-wave troughs. Flash floods can be sometimes associated with the larger meteorological pattern if convective cells are embedded within the regional frontal system.

Regional flooding (1 000 to 10 000) in Europe used to be associated with major frontal systems and snowmelt, in other regions also with tropical and extratropical storms and monsoonal rainfall. Rainfall causing floods in large watersheds tends to be less intense and of longer duration than rainfall causing flash floods.

Snowmelt floods are basically the result of 3 factors:

- The existence of the snowpack with substantial areal extent and depth,
- Favorable temperature and water content conditions,
- Availability of energy for snow melting.

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[1] A threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area.

[2] Expected losses (of life, persons injured, property damaged and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of a hazard and vulnerability.

[3] Degree of loss (from 0 to 100 %) resulting from a potentially damaging phenomenon.

Snowmelt occurs when energy is added to a snowpack at 0 ^{o}C. Some of the largest floods are caused by a combination of precursors and warm rain falling onto a snowpack can make a significant contribution. In large snow-dominated watersheds, the annual peak flow is nearly always caused by snowmelt.

In cold regions, extreme high water stage can be caused by snow obstructing very small channels or ice jams in large rivers.

In many watersheds flooding is related to large rainfall amount in conjunction with high levels of initial soil moisture. In contrast, flash floods in arid or urbanized watersheds are associated with rainfall intensities that are greater than surface infiltration rate. In general, soil moisture, the total amount of rain (or snowmelt) and the rainfall intensity (or snowmelt rate) are important in generating flooding. However, the relative importance of these factors varies from watershed to watershed and even from storm to storm.

3 Meteorological aspects of floods risk and flood hazard assessment

Many studies approached the Flood hazard assessment, as far as the Meteorological phenomena are concerned, primarily from the point of view of economic terms. As a result, justification for preparedness measures is frequently formulated in some kind of cost-benefit analysis of relief. Programmes to mitigate damage resulting from meteorological hazards are, therefore, given a dollar connotation. “A propos” what is the cost of human life?

Flood risk should be evaluated in terms of consequences of a disaster including live lost, persons injured, property damage and also economic activity disrupted. Risk is the product of both hazard and vulnerability. Therefore, flood risk assessment combines meteorological hazard assessment with the vulnerability of people and infrastructure. Assessment of flood related meteorological hazards should go through the following steps:

1. Forecasting and warning needs:
   - Location of area at risk;
   - Type of forecast or warning;
   - Required lead time;
   - Required accuracy.
2. Data collection:
   - Availability of all types of data, mainly surface and upper-air measurements and observations and remote sensing measurements;
   - Manner and timeliness of data collection.
3. Data processing:
   - Fast and comprehensive data processing;
   - Numerical modeling of actual data;
   - Numerical weather prediction;
   - Fast and comprehensive automatic and/or interactive analysis using conceptual models.
4. Data transmission:
   - Availability and types of transmission systems;
   - Reliability;
   - Timeliness.
5. Accuracy of forecast and warning
   - Splitted accuracy system that enables to provide immediate forecast and warning, mostly automatically or semi-automatically, with lower accuracy and delayed forecast and warning, mostly manually or semi-manually, with higher accuracy.

4 Meteorological data for flood forecasting and warning

The following meteorological parameters, either actual or forecasted, are basically used in hydrological forecasting of riverine and/or flash floods:

- Precipitation;
- Air temperature;
- Air Humidity;
- Wind speed and direction;
- Snow depth and snow water equivalent;
- Evaporation;
- Evapotranspiration;
- Radiation balance;
- Soil moisture;
- Significant weather associated with precipitation pattern.

Actual data are extracted from the operational databases or are provided directly from the meteorological observing networks. Observing networks are continuously developing from the manual and isolated ones to composite integrated automatic networks that encompasses surface upper-air manual and automatic meteorological stations together with remote sensing stations like, meteorological radars, profilers, lightning detection systems, geostationary and polar orbiting meteorological satellites.

Among the above mentioned meteorological parameters the precipitation, soil moisture and snow data have a special importance.

Precipitation

Precipitation is the most crucial input parameter for the hydrological models as one of the most important steps in the process of making hydrological forecasts is an accurate precipitation analysis.

At present, for the purpose of the hydrological models, mostly discrete values (either actual values or forecasted ones) from the surface rain gauge network are provided. Rain gauge networks provide accurate point data measurements, but without high grid density and lack the spatial resolution to accurately describe the rainfall within reasonable area. Therefore rain gauge network, even the fairly one, can miss significant rainfall, especially associated with the intense convective storms. Another significant problem with the rain gauge networks is the inability to determine patterns of precipitation or to identify the heaviest amounts. Thus, there is a strong need for real-time precipitation analysis that is not totally dependent upon traditional rain gauge networks.

Weather radars can provide can provide, among others, rain intensity and N-hourly accumulation on a temporal and space distribution basis. The recent introduction of Doppler radars techniques has provided increased confidence in the basic measurements while providing significant reductions in ground clutter removal and additional information regarding storm movement and rainfall velocity. There are instances, however, where radars encounter difficulties in estimating extreme rainfall, especially in isolated convective cells, which might hide each other. Although what radar measures, namely return power, is related to the sixth power of the raindrop diameters, known as radar reflectivity, Z, the interpretation of this parameter as rainfall is not straightforward. There are several sources of errors that contribute to the effect of radar reflectivity, however the most significant one is the assumption made in the Marshal – Palmer relationship, the relationship of radar reflectivity and rain rate.

Present space born measuring equipment use electromagnetic radiation, which have proven to be of special value. Those ranges from ultra-violet through the visible, thermal infrared to microwave. There are no routine outputs from direct remote sensing measurements from present meteorological satellites as far as the precipitation is concerned. Numbers of post-processed

techniques are used to improve precipitation data gained from other sources. The next generation of satellites, due at the end of 2000, are expected to provide information on precipitation clouds, convective rainfall rate, total precipitable water, integrated cloud water and layer precipitable water. Again one cannot expect the output in a sense of "ground truth".

The third remote sensing system, complementary to the meteorological radars and satellites are the lightning localization and lightning characterization systems based on VHF interferometric principle. As the thunderstorm electrical activity results from the simultaneous occurrence of intense convection and high densities of hydrometeors (graupels, ice crystals and water droplets), which are the origin of all storm hazards, data on precipitation can be derived from storm electrical activity.

As a result none of all of above mentioned direct or indirect precipitation measurement systems cannot satisfy the hydrological needs. Precipitation should be therefore provided as one areal parameter for the defined basin / catchment area or should be in a form of a gridded field for the whole required area. It should be computed as a completely new parameter from all the available sources, namely those mentioned above. Methods (models) should be developed how to do it in a way so that physics of the atmosphere and orography is taken into account in the areal precipitation computation rather than simple statistics. One of the possible approaches is to use present Mesoscale or LAM models with the assimilation of all data including radar, satellite, lightning and rain gauge data. A first guess of the run of such a model can produce the areal precipitation data to be used as analysis and next runs can produce the forecasted areal precipitation data for the direct input into the hydrological models.

Soil moisture

The subsurface component of the hydrological cycle comprises two zones. One is the zone of aeration and the second is the zone of saturation. Water in the zone of aeration is called soil moisture. Soil moisture is an essential input to a range of hydrological models that determine catchment runoff.

Soil moisture measurement networks provide direct or indirect point measurement normally in a poor grid density and lack the spatial resolution to accurately describe the rainfall within reasonable area. Direct measurements, normally made by gravimetric method, required manpower and are time consuming. Therefore measurements of soil moisture are scarce. In addition direct measurements bear an error associated with the removal of the soil sample. Indirect methods (radiological, neutron attenuation, pulsed nuclear magnetic resonance, etc.) could be automated, are more accurate, however not much suitable for the meteorological observing systems. The basic problem is the lack of spatial data of soil moisture and all those negative aspect of point measurements as mentioned in case of precipitation.

Remote sensing techniques are currently used to estimate soil moisture properties at or near the surface down up to several meters. Especially microwave techniques[4] have shown a lot of potential for measuring soil moisture because only in the microwave spectrum is the direct physical relationship between soil moisture and the reflection or emission of radiation. Both active and passive microwave methods will become fully operation on MSG satellite due to launched by the end of 2000.

Remote sensing data cannot provide the "ground truth" as point data and point data cannot provide areal and spatial distribution with the required accuracy. For this reason models that take inputs of soil moisture from both source and produce newly recomputed parameter should be applied.

[4] The same technique is used for estimation of evapotranspiration rates, another required meteorological parameter for hydrological purposes.

Snow

The water stored in snow is held in cold storage on a basin for an extended period of time before it enters into the runoff process. During this varying period, the snow in storage can be augmented by additional snow accumulation, redistributed by wind, changed in its internal structure and affected by number of meteorological factors. The snowpack is removed from the water basin by ablation process usually lasting several weeks to several months depending on the amount of snow, location and region. The snowmelt process takes place at various rates depending on meteorological aspects as well as other aspects like, slope, elevation and vegetation cover. Prediction snowmelt runoff is required for many hydrological purposes including flood forecasting and warning.

Surface meteorological networks provide reliable point data of snow depth cover, either manually or automatically, using number of method, starting from the inexpensive ultrasonic ranging devices. However standard measurement of snow water equivalent uses gravimetric method that requires manpower. The other methods that could be easily automated (radioisotope snow-gauges, natural gamma radiation) are expensive. The main obstacle with the widespread use of point measurement, even siting in a representative location is an interpretation of point data as areal indices.

Remote sensing of snow can be accomplished using gamma rays, visible and near infrared and microwaves. The microwave band has the greatest potential. The potential of satellite to provide useable information on snowpack dynamics is now widely recognized and today many schemes exists which employ satellite derived snow measurements for snowmelt-runoff prediction. The situation is going to be significantly improved by new MSG satellites. One important aspect, apart of the areal data, where satellites can significantly help is the monitoring of snow metamorphism. The process of metamorphism occurs continually during the snow accumulation and ablation season. Important snow properties associated with metamorphism include grain size, albedo, layering and surface and snowpack temperatures. Remote sensing of these changes can be accomplished by combination of appropriate wavelength bands. This should allow a good estimate of the time when the snowpack is ready to transmit melt water from the surface to lower layers and eventually produce runoff.

Again modeling of snow depth cover and snow water equivalent is the best way how to combine point data and remote sensed data in order to provide the best input for the hydrological snow models.

5 Basic meteorological productsfor flood forecasting and warning used at SHMI

Previously a personal contact between forecasters and hydrologists was the main way in which the meteorological information was transferred to the hydrologists. Nowadays a very effective tool INTRANET is mainly used for this purpose at SHMI, however the personal communication still plays an important role.

A brief review of the meteorological data and products available on INTRANET WWW pages is as follows:

- Operational meteorological observations, including the rate of precipitation, from the SHMI's observing network, that contains 28 fully automated weather stations, is update every 10 minutes.
- Estimation of the intensity of precipitation from the radar measurement is updated every 15 minutes at the site Malý Javorník and every 30 minutes at Kojšovská hoľa. Information is presented in a map form. The sums of precipitation, derived from radar data (Malý Javorník), are computed for 1, 3, 6 and 24 hours. Also they are presented in a map form. Thunderstorm tracking is offered as well. In addition the intensity of precipitation from Central European Radar Network (CERAD) is available.

- Model outputs of the LAM RC LACE model, especially the prediction of the precipitation amount are processed into a map form. The RC LACE model is an application of ALADIN model. It is a spectral model with a horizontal resolution 12,2 km and 31 vertical levels. Sophisticated physical parameterizations are incorporated; mainly those concerning the deep convection are physically very realistic. The model is integrated in dynamic mode twice a day up to 48 hours. Three-hour totals and cumulated totals are automatically processed.
- Text weather forecasts up to 5 days.

There is a wide range of meteorological products, which are available in the Central Forecasting Office of SHMI, but they are not put on INTRANET WWW pages. Some of them because of technical reasons, other are a subject of a subjective evaluation and interpretation of the forecaster and the results of such evaluation must be personally explained to the user including the estimation of reliability. An example of this kind of information:

- Satellite images (VIS, IF, WV and multichannel composition) - every 30 minutes.
- Outputs from SAFIR (lightning detection system) - almost on line.
- Column water content (derived from radar data at site Malý Javorník)
- Data from climatological observing network (approximately 50 stations) - once a day.
- Data from rain gauge network (approximately 700 stations, 24-hour totals of precipitation) once a month.
- Weather forecasts, or outlooks beyond 5 days.

Two examples of the radar and satellite images are included, to illustrate above-mentioned products. Destructive flash flood events occurred at that time in the eastern part of Slovakia.

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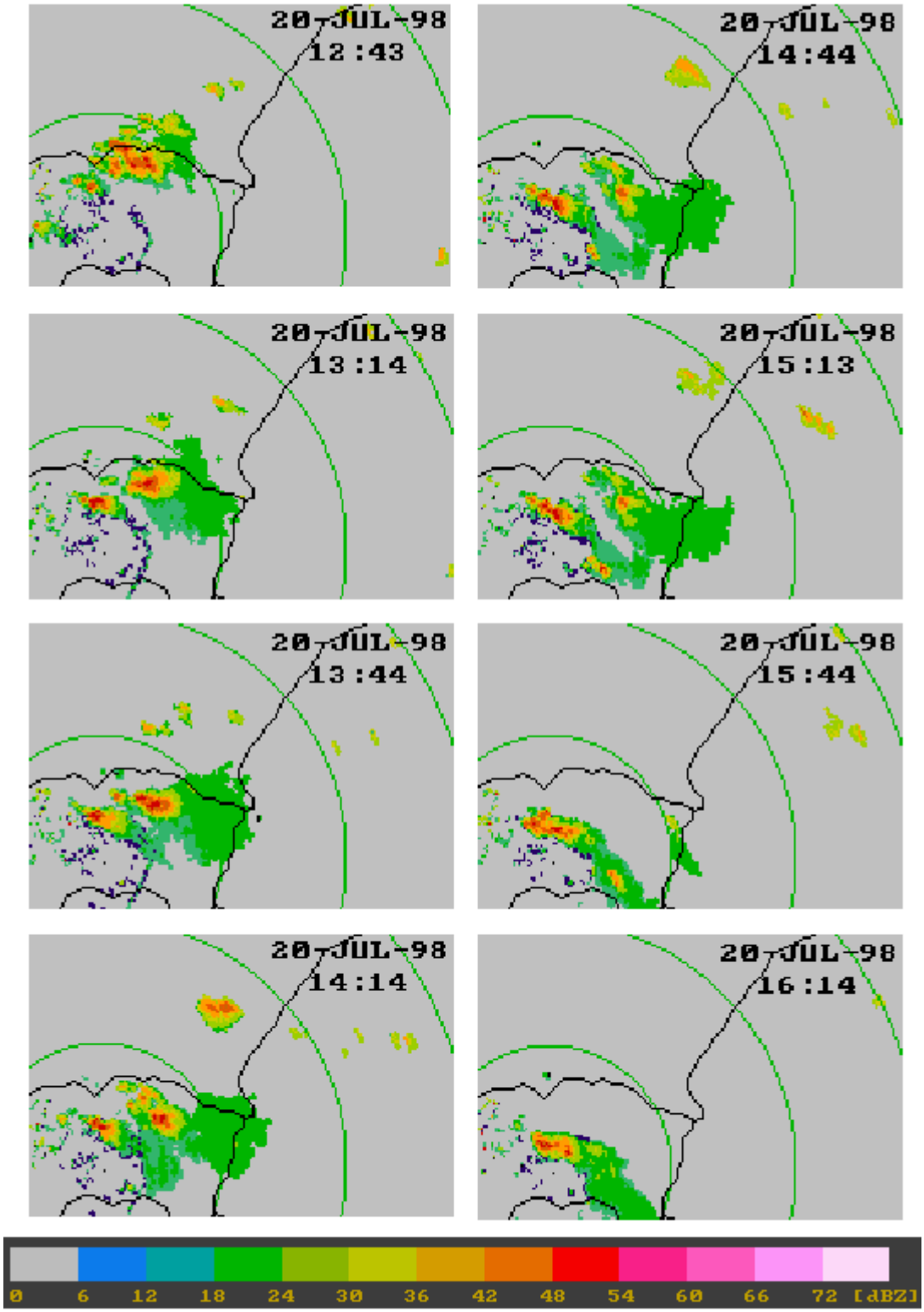
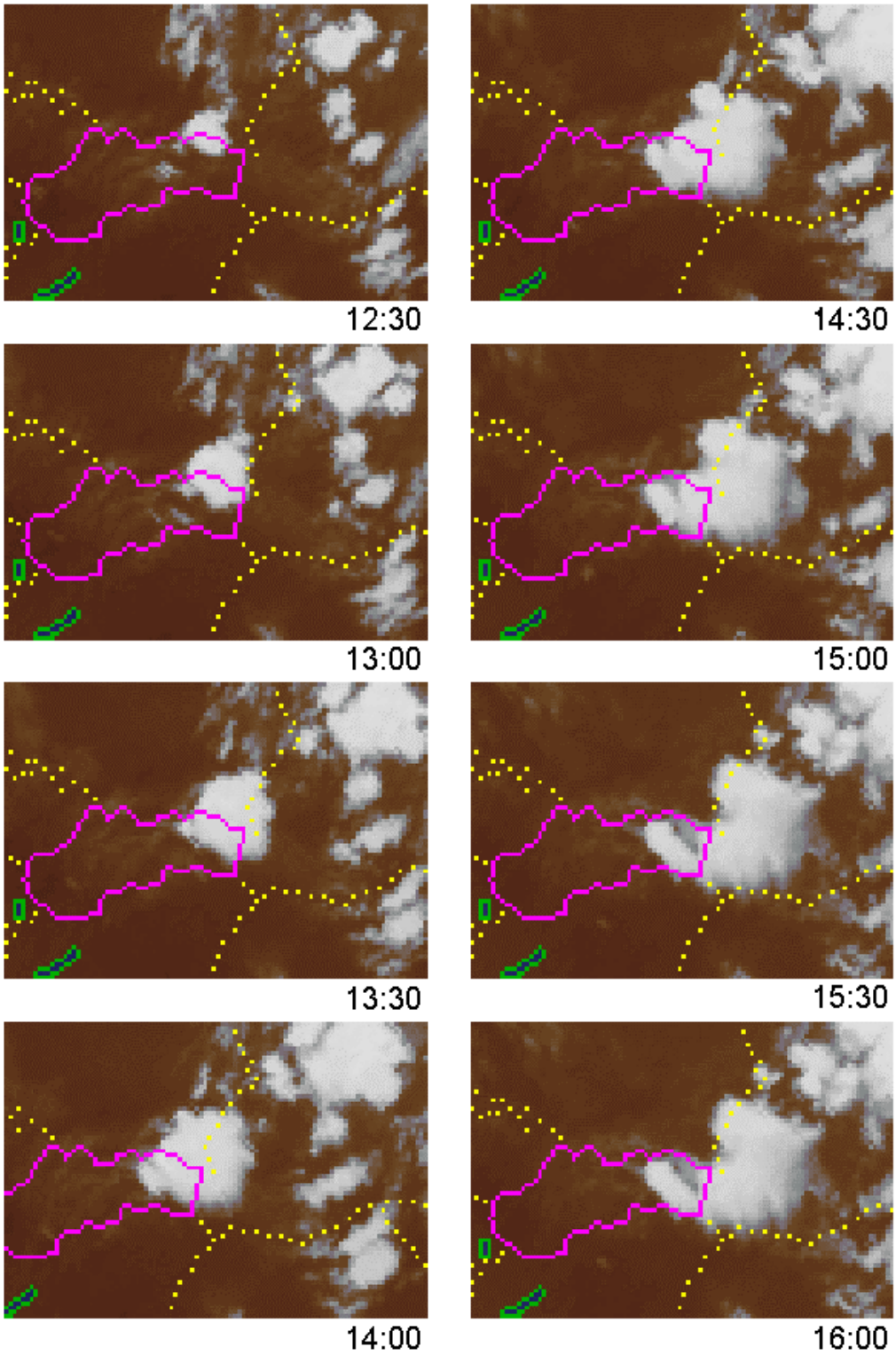
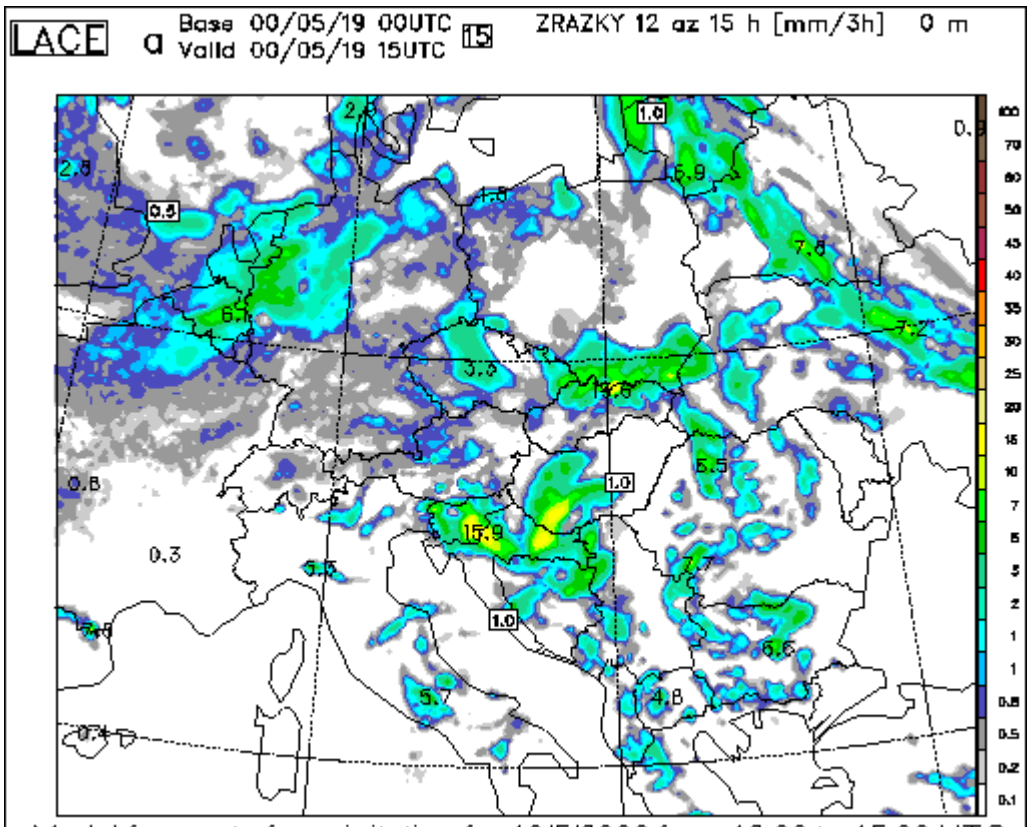


Weather radar maximum reflectivity, 20/07/1998 from 12:43 to 16:14 UTC



METEOSAT - infrared channel, 20/07/1998 from 12:30 to 16:00 UTC



Model forecast of precipitation for 19/5/2000 from 12:00 to 15:00 UTC

Erfahrungenmit der Schusspolderwasser-Vorhesage in Ungarn

Imre Pálfai, Tamás László Boga, Judit Sebesvári

Zusammenfassung: Ein Überblick über die hydrologische Erkundung des Entstehens von Schusspolderwassern, von welchen die Flachlandgebiete Ungarns periodisch und schwerwiegend heimgesucht werden. Kurze Beschreibung der Methoden zur Vorhersage der Entstehung des Schusspolderwassers, des Ausmasses der vernässten/überfluteten Flächen und der Entwässerungsverhältnisse. Vorführung der Erfahrungen, die mit der neuesten Methode der Schusspolderwasser-Vorhersage bzw. mit der Einführung und betriebsmässigen Anwendung des sog. Vernässungsindexes gewonnen wurden.

Schlüsselworts: Schusspolderwasser, Überschwemmung durch Schusspolderwasser, Vernässungsindex, Schusspolderwasser-Vorhersage.

Experiences Gained with Excess Water Forecasting in Hungary

Abstract: A survey of the hydrological exploration of the genesis of excess waters, periodically occurring and causing serious damages in the flatland areas of Hungary. A short description of the methods of forecasting the occurrences of excess waters, the extension of inundated areas and the conditions of dewatering. The experiences gained with the most recent method of excess water forecasting, by introduction and operative use of the so-called excess water index.

Key words: Excess water, inundation by excess water, excess water index, excess water forecasting

1 Einleitung

Unter „Schusspolderwasser" wird das in Flachlandeinzugsgebieten, an deren Oberfläche und damit verbundenen Bodenraum anfallände Wasser verstanden. Die Entstehung des Schusspolderwassers ist eine besonders für das Karpatenbecken typische Erscheinung. Die Schusspolderwässer verursachen seit den in der zweiten Hälfte de 19. Jh. durchgeführten grosszügigen Massnahmen für Hochwasserschutz und Flussregulierung immer grössere Schwierigkeiten. Die weitläufigen Überschwimmungen grosser Flachen fügen der Landwirtschaft und den Siedlungen betrachtliche Schaden zu. Unter den zu Schusswasserüberschwemmungen führenden Ursache sollen die ungünstigen Geländeverhältnisse (Bodenvertiefungen), der hohe Grundwasserstand und der überdurchschnittliche Niederschlag an erster Stelle genannt werden. In den Flachlandgebieten kann es während des ganzen Jahres zu Schusspolderwasser-Erscheinungen kommen, wobei sie jedoch mit höchster Wahrscheinlichkeit im Winter und Frühling auftreten.

Zwecks Vorbeugung, bzw. Milderung der Schusswasserpolderschäden wurden in den Flachlandgebieten im Laufe der Zeit Systeme des Schusspolderwasserschutzes ausgebaut. Sie bestehen aus einem Kanalsystem, Bauwerken der Wassersteuerung, Pumpanlage in den Mündungen der Hauptkanäle und eventuell auch an ihrem Lauf (zweck Steigerung des Gefälles) sowie aus Polderwasserspeichern. Wichtige Voraussetzungen für einen effektiven Betrieb dieser Systeme sind eine rechtzeitige Bereitschaft auf die Bekämpfung, die Verrichtung der damit verbundenen technisch-organisatorischen und Koordinationsaufgaben, wozu die Vorhersagen des Schusspolderwassers äusserst nützliche Beihilfe leisten können.

2 Die früheren Methoden der Schusspolderwasser-Vorhersage

Mit den hydrologischen Aspekten der Schusspolderwässer haben sich in Ungarn seit langem zahlreiche Fachleute beschäftigt. Ihre Forschungsergebnisse trugen zur Erschliessung des

Phänomens Schusspolderwasser, zur Klärung seiner hydrologischen und meteorologischen Ursachen, bzw. Zur Begründung der Methoden seiner Vorhersage bei (Salamin 1955, Kienitz 1967 u. 1974, Orlóci-Schlegel 1967, Oroszlány 1981). Der Publikationen, die sich ausgesprochen mit der Schusspolderwasser-Vorhersage befasst hätten, gibt es jedoch recht wenige, von denen – ohne Anspruch auf Vollständigkeit – folgende Arbeiten erwähnt werden sollen.

Unter Verwendung der von 1940 bis 1953 gemessenen Daten der am Flusse Hármas-Körös gelegenen, 245 km^2 grossen Einzugsgebietes „Peres", hat *K. Szesztay (1956)* eine Methode zur Vorhersage des Auftretens des Schusspolderwassers entwickelt. Die Basis dieser Methode bildet eine Kennzahl der Bodenfeuchtigkeit, die als der gewogene Mittelwert – als Summe von Regen und Schneeschmelze definierten – Wasserbelastungen der vorangehenden 6 dekaden ermittelt wird, wobei die Gewichtzahlen mit der Entfernung vom Zeitpunkt der Vorhersage abnehmen.

Das Vorhersage-Verfahren von *F. Fehér (1976)* berechnet, unter Verwendung der von G. Kienitz entwickelten Modelle EXPRE und DRAINAGE, zunächst den sich aus Verdunstung und Einsickerung ergebenden „Verlust", dann das anfallende Schusspolderwasser-Volumen und schliesslich die Parameter der Schusspolderwasserwelle sowie die erwartungsmässig zu überflutende Fläche. Die Methode wurde zur operativen Vorhersage im Jahre 1970 Flachlandeinzugsgebieten eingesetzt: im experimentellen Einzugsgebiet „Mirhó-Gyolcs" (mit etwa 100 km^2 Fläche an der Mittleren Theiss gelegen) und im Eizugsgebiet „Dobai", ähnlichen Aussmasses.

G. Csekő (1979) hat für das Zwischenstromland Donau-Theiss gelegene, 295 km^2 grosse Flachlandeinzugsgebiet „Fehértó-Majsa", unter Verwendung der während der Periode 1963-1977 gemessenen Niederschlags-, Abfluss- und Grundwasser-Daten, Regressionsbeziehungen entwickelt, mit deren Hilfe die täglichen bzw. monatlichen Abflussmaxima vorhergesagt werden können.

Für das 8.200 km^2 grosse, Schusspolderwasser-gefährdete Gebiet der Wasserwirtschaftsdirektion Unteres Theisstal (ATIVÍZIG) wurden, unter Verwendung der Regressionsuntersuchung der hydrometeorologischen und Schusspolderwasser-Daten der Periode 1956-1982, Beziehungen entwickelt, welche – über eine Kennzahl der Wasserbelastung des Bodens sowie eine Kennzahl der Wasserempfänglichkeit – sich zur mittel - und kurzfristigen Vorhersage der imWinter und Frühling zu erwartenden maximalen Überschwemmung sowie zur schätzweisen kurzfristigen Vorhersage der maximalen Sommerüberschwemmung eignet *(Pálfai 1983 und 1984).* Die Kennzahl der Wasserbelastung wird aus den Niederschlags- und Verdunstunghöhen des Monats Januar sowie von der maximalen Mächtigkeit der Schneedecke, die Kennzahl der Wasserempfänglichkeit aber aus dem Grundwasserstand und der – um die Verdunstung reduzierten – Niederschlagssumme der jeweiligen vorangehende zwei Monate ermittelt. In der Gleichung der kurzfristigen Vorhersage ist einer der hauptsächlichen Parameter die sog. kritische Schneemächtigkeit, wobei – aufgrund von Abschätzungen – auch die Zeit der Schneeverdichtung, das Tempo der Schneeschmelze und die Menge des Schmelzregens ebenfalls berücktsichtigt werden müssen. Mit dieser Methode wurde in den 80-er Jahren mehrere Schusspolderwasser-Vorhersagen erstellt, deren Ergebnisse jedoch leider in einem weiten Bereich streuten, so dass sie lediglich zur Erweckung der Aufmerksamkeit bzw. als grobe Informationen betrachtet werden konnten.

3 Ermittlung und Vorhersage des Vernässungsindexes

Der Vernässungsindex (PBI) wurde anhand der Auswertung der katastrophalen Schusspolderwasser-Ereignisse von 1940-42 entwickelt *(Pálfai 1992).* Dieser Index ist eine Verhältniszahl. In deren Zähler die – in Anbetracht der maximalen Schneemächtigkeit gewissermassen korrigierte – Niederschlagssumme des Winterhalbjahrs (Oktober-März) steht, und der Nenner die Abweichung des mittleren Grundwasserstandes im Oktober vom langjährigen Mittelwert

sowie die Eindrangstiefe des Bodenfrostes ausdrückt. Die Werte des Indexes qualifizieren die verschiedenen Vernässungsgrade folgendermassen:

unter 0,5	- vernässungsfrei,
von 0,5 bis 1,0	- geringe Vernässung,
von 1,0 bis 2,0	- mittlere Vernässung,
von 2,0 bis 3,0	- bedeutende Vernässung,
über 3,0	- ausserordentliche Vernässung.

Die „Schusspolderwasser-Vorhersage" besteht darin, dass die zur Zeit der Vorhersage bekannten Werte in die Berechnungsformel des Vernässungsindexes gesetzt werden, die zukünftigen, noch unbekannten Faktoren aber jeweils in drei Varianten – undzwar aus den Niederschlagshöhen 110, 50 und 90%-iger Überschreitungswahrscheinlichkeit ausgehen – geschätzt werden. Die Werte der maximalen Schneemächtigkeit und des Bodenfrostes werden in Abhängigkeit von der Niederschlagshöhe veranschlagt. Wenn z.B. die Voraussage in den ersten Januartagen zusammengestellt wird, so stehen als bekannte Daten folgende Werte zur Verfügung: der Grundwasserstand im Oktober des Vorjahres bzw. dessen Verhältnis zum langjährigen Mittelwert, sowie die dreimonatige Niederschlagssume der Periode Oktober-Dezember. Die übrigen Faktoren werden aufgrund der in drei Varianten veranschlagten Niederschlagshöhen der dreimonatigen Periode Januar-März berüksichtigt.

Das Verfahren selbst ist keine eigentliche Vorhersage, da es die möglichen Varianten der Fortsetzung eines bereits begonnenen, mehr oder weniger bekannten hydrologischen Prozesses liefert, was die Vorbereitungen des Bekämpfungsapparats erleichtern kann sowie eine Grundlage zur Erwägung dessen bildet, mit Schusspolderwässer welchen Grades in den verschiedenen Regionen des Landes gerechnet werden muss.

Die oben beschriebene Methode wurde im Auftrag des Staatsamtes für Wasserwesen (OVF) während der ersten Hälfte der 90er Jahre entwickelt (ATIVÍZIG 1993) und wird seit 1996 auch betriebsmässig angewandt. Anfangs wurden Vorhersagen für 18-20 Flachlandeinzugsgebiete Ungarns herausgegeben. In letzter Zeit werden die Werte des Vernässungsindexes für 47 – mit meteorologischen Stationen ausgerüstete – Einzugsgebiete der Grossen und Kleinen Ungarischen Tiefebene ermittelt, auch wird ihre gebietliche Verteilung kartenmässig dargestellt.

Zwischen dem Vernässungsindex, der vom Schusspolderwasser überschwemmten Fläche sowie der Polderwasserabfluss besteht eine Korrelationsbeziehung, deren Ermittlung, nach Regionen aufgegliedert, z.Z. im Gange ist. Doch werden auch bis zur Erhaltung der Ergebnisse dieser Untersuchungen die regelmässig monatlich herausgegebenen Voraussagen, von der jeweiligen hydrologischen Situationabhängig, immer mit auf die früheren bedeutenderen Schusspolderwässer bezogenen analogischen Analysen ergänzt. Zu dieser Situationsbewertung und Vorhersage ergänzenden Charakters gehört auch eine ausführliche Analyse der räumlichen und zeitlichen Veränderlichkeit der Schneemächtigkeit und das Schneewassergehaltes. Den Schusspolderwasser-Vorhersagen werden auch die kürzer- oder längerfristigen Wettervorhersagen des Meteorologischen Landesdienstes beigelegt, die Eintreffwahrscheinlichkeit der letzteren ist jedoch ziemlich unsicher.

4 Vorhersage des Schusspolderwassers im Winter und Frühling des Jahres 1999

Die erste Vorhersage der während des Winters und Frühjahrs von 1999 zu erwartenden Schusspolderwasser-Situation wurde für Staatsamt für Wasserwesen (OVF) am 2. November 1998 erstellt. Der Vernässungsindex wurde, unter Voraussetzung der fünfmonatigen Niederschlagshöhe (November-März) dreier verschiedener Wahrscheinlichkeiten für 22 Regionen ermittelt. Es wurde festgestellt, dass „die Werte des Indexes bereits im Falle einer fünfmonatigen Niederschlagshöhe 50%iger Wahrscheinlichkeit der Schwellenwert 0,5 überschreiten, doch kann eine bedeutendere Vernässungsgefahr lediglich für die Region Szatmár-Bereg prognostiziert werden, für welche die höchsten Index-Werte erhalten wurden."

Laut der am 10. Dezember 1998 herausgegebenen Vorhersage kann „für die Regionen Szatmár-Bereg und Rétköz eine bedeutende Vernassung prognostiziert werden (der PBI liegt zwischen 2,0 und 3,0), während in den Regionen Bodrogköz, Taktaköz, Jászság, Nagykunság, Körösvidék, Kurca, Donau-Tal und Kleine Schüttinsel eine mittlere, in den übrigen Regionen eine geringe Vernässung zu erwarten ist. In der Region Szatmár-Bereg kann es bei einem Niederschlag 10%iger Überschreitungswahrscheinlichkeit sogar zu einem ausserordentlichen Schusspolderwasser kommen."

Laut der Mitteilungen vom 8. Januar 1999 „kann bei einem Niederschlag 10%iger Überschreitungswahrscheinlichkeit in der Region Szatmár-Bereg zu einer ausserordentlichen, in der Region Rétköz aber zu einer bedeutenden Vernässung kommen. Mit Ausnahme des Rückens in Zwischenstromland Donau-Theiss kann im ganzen Flachlandgebiet Ungarns eine mittlere Schusspolderwasser-Lage erwartet werden. Auch bei einem durchschnittlichen (50%igen) Niederschlag ist eine bedeutende Vernässung in den Regionen der nordöstlichen Landesteiles anderswo sind mittlere Vernässungen zu erwarten. Auch im Falle einer niederschlagsarmen (90%igen) Periode ist in den erwähnten nordöstlichen Regionen mit einer mittleren Vernässung zu rechnen."

Anfang Februar 1999 kam es zu einem flächendeckenden und ausgiebigen Schneefall, woraus auf eine höhere Wahrscheinlichkeit des Eintreffens der 10%igen Situation gefolgert wurde. So wurde, durch das Staatsamt für Wasserwesen (OVF) angeregt, am 12. Februar 1999 eine unfassende hydrometeorologische Information und eine kurzfristige Schusspolderwasser-Vorhersage erstellt. Letztgenannte lautet folgendermassen:

„Schusspolderwasser-Vorhersage: im Schnee ist eine ausserordentlich grosse Wassermenge gespeichert, der Grundwasserspiegel liegt überdurchschnittlich hoch. Daraus folgt die Möglichkeit einer den Durchschnitt wesentzlich übersschreitenden Überflutung durch Schusspolderwasser. Die Aufwärmung kann eine entscheidende Rolle spielen, da das Tempo der Schneeschmelze von ihrer Intenssitat und davon abhängt, ob sie auch von einem Schmelzregen begleitet wird. Sollte sich die plötzliche Aufwärmung vom Februar 1966 wiederholen, so ist sogar eine Schusspolderwasser-Überschwemmung im Ausmass von 200-250 tausend ha nicht ausgeschlossen, wobei die Wasserabführungskapazität der Entwässerungs-systeme erschöpft würde. (Im Jahre 1966 stand eine Fläche von 360 tausend ha unter Wasser). Im Falle einer allmählichen, durch nächtliche Froste unterbrochenen Aufwärmung kann landesweit eine mittlere, sich auf etwa 100 tausend ha erstreckende Übersschwemmungsfläche erwartet weden. Die am meisten gefährdeten Regionen sind die Gegend der Oberen Theiss, die Flachlandgebiete Nord-Ungarns sowie die Gegend der Mittleren Theiss. Beträchtliche Über-schwemmungen sind in den Zuständigkeitsgebieten von den folgende vier Wasserwirschafts Direktionen zu erwarten: WWD Oberes Theissgebiet, WWD Nord-Ungarn, WWD Jenseits der Theiss und WWD Mittlere Theissgegend. Die bis zum 28. Februar gültige Wettervorhersage prognostiziert keine plötzliche und intensive Aufwärmung, nur einen gewissen Niederschlag, bei dessen Eintreffen die Schneeschmelze beschleunigt werden kann. Auf grössere Überschwemmungen durch das Schusspolderwasser kann zuvor (gegen Ende Februar) im südlichen Teil der Grossen Ungarischen Tiefebene gerechnet werden, da hier um einige Grade höhere Temperaturmaxima zu erwarten sind, als im nördlichen-nordöstlichen Teil des Landes, wo die Schusspolderwässer zwar etwas später auftreten aber auch wesentlich grössere Flächen überschwemmen werden."

Aufgrund einer Analyse des Ganges der Niederschlags- und Schneeverhältnisse sowie der bereits bestehenden zerstreuten Überschwemmungsflecken, haben unsere am 18. und später am 26. Februar herausgegebenen Vorhersagen die obere Grenze der Überschwemmungsfläche in 300 tausend ha angegeben. Die tatsächlichen stattgefundene, gleichzeitige maximale Über-schwemmung erstreckte sich – am 8. März – auf 350 tausend ha. Da jedoch die Über-schwemmungsmaxima in den verschiedenen Regionen des Landes zu verschiedenen Zeitpunkten auftraten, wurde im Februar und März 1999 insgesamt eine landwirschaftliche

Fläche von 420 tausend ha vom Schusspolderwasser betroffen. Den meisten Schaden erlitten dabei die nördlichen und mittleren Teile der Grossen Ungarischen Tiefebene.

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The System for Hydrological Forecasting in Serbia

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Abstract: This paper gives an overview of the hydrological forecasting system developed and used in the Republic Hydrometeorological Service of Serbia, Federal Republic of Yugoslavia. Activities in real time include data observation, collection and transmission to communication centers, data processing and forecasting, as well as preparing different types of reports and warnings for users in waterway management organizations, hydropower production plants, flood protection services, public, etc. Special attention is given to transit waters and cooperation with neighboring countries. Some details on the Project of forecasting and early warning system improvement as well as the Weather radar network project that are currently running in the Service are also given.

Key words: hydrological forecasts, flood protection, meteorological radar network.

System der Hydrologischen Vorhersagen in Serbien

Zusammenfassung: Diese Arbeit gibt eine Übersicht des im Hydrometeorologischen Dienst Serbiens, Bundesrepublik Jugoslawien, entwickelten und benutzten Vorhersagesystems. Die Aktivitäten umfassen Beobachtungen, Datensammlung und -übertragung in die Kommunikationszentren, Datenbearbeitung, Erstellung von Vorhersagen ebenso wie die Vorbereitung unterschiedlicher Berichte und Warnungen für Benutzer in den Bereichen der Schiffahrt, Wasserkraftwerke, Hochwasserschutz, Öffentlichkeit etc. Spezielle Aufmerksamkeit wird grenzüberschreitenden Flüssen und der Zusammenarbeit mit den benachbarten Ländern geschenkt. Einige Details zum Projekt zur Vorhersage und Verbesserung des Frühwarnsystems werden ebenso gegeben wie über das Wetterradarprojekt, welches derzeit beim Hydrometeorologischen Dienst läuft.

Schlüsselwörter: hydrologische Vorhersage, Überschwemmungschutz, meteorologisches Radarnetzwerk

1 Introduction

1.1 Hydrological information

Activities in real time include data observation, collection and transmission through communication centers, data processing, forecasting and issuing of reports, bulletins and warnings. Hydrological informations are important for flood protection, reservoir management, water supply, water quality management, navigation, fishery, sport and tourism.

Ice observation and ice run forecasting are important particularly for:

(a) navigation;

(b) protection of structures in the channel;

(c) protection of river flood plains from ice flooding caused by ice accumulation;

(d) making a decision of mechanical disintegration of an ice cover.

Republic Hydrometeorological Service daily processes data from the basic reporting station network and prepares different types of bulletins that are available to users through modem connection.

1.2 Hydrography of the region

The Black Sea drainage basin takes 90% of the territory of the Republic of Serbia. Several large

rivers inflow in the Yugoslavian reach of the river Danube (length: 588 km), draining massifs of the Alps and the Carpatian mountains (Fig.1). On the Yugoslavian - Hungarian border the area of the Danube drainage basin is about 210 000 km^2, but downstream of the dam Iron Gate 2 the drainage basin area is greater than 580 000 km^2.

Fig. 1 Hydrography of the region - the Danube drainage basin upstream of profile Negotin

The river Tisa and its tributaries flow from the Carpatian mountains and Pannonia through Ukraine, Slovakia, Romania and Hungary to Yugoslavia. From the Transylvanian mountains in Romania to Yugoslavia flow Zlatica, Begej, Tamis, Karas and Nera that are collected in the channels of the Multipurpose hydro-system Danube-Tisa-Danube.

The river Drava flows from the Alps in Austria through Hungary and Croatia giving its contribution to Danube from the west. From the Alps in Slovenia flows Sava, collecting major tributaries from the Dinaric Alps and having its confluence with Danube in Belgrade. And finally in Serbia in Danube inflows Velika Morava and a number of tributaries that are flowing from the southeast having their springs in Bulgaria.

1.3 History of meteorology and hydrology in Serbia

At the time when the Meteorological Observatory in Belgrade had been founded in 1887, methods of getting knowledge of the atmosphere by observing, measuring and direct data analyses were in full progress. The Observatory had signified the beginning of the meteorological science in Serbia, the sparkle that had not extinguished as it had happened with the impressive but lonely effort of establishment of 27 stations on 8000 sq. miles in 1852-1862.

It must be mentioned here that the famous scientist Milankovic had started his work on the theory of climate and the Ice Ages studying three papers in this Observatory. From these papers Milankovic concluded that the initial distribution equation of solar heat on the Earth was inadequately formulated and that the whole problem should be clarified (Milosavljevic & Mesinger, 1987).

The first weather forecast was issued in the August 1902, but it was published for the first time in the "Srpske Novine" in the February 1903.

The first hydrological record at Belgrade on the river Sava dates from 1856. From 1918 daily reports of water levels on main streams were transmitted through telegraphs to the Hydrographic bureau of the General water administration. At the end of 1922 on the initiative of the Danube Commission, General water administration had taken part in the international activities on the river Danube.

After catastrophic floods in 1924 and 1926 the Hydrological forecasting department was established in order to prepare proper information and hydrological forecasts. Systematic ice observations were organized after the ice flooding in 1956.

From 1968 the Hydrological forecasting department has issued short-range and middle-range discharge forecasts in the profile Orsova for the needs of constructing of the hydropower production plant Iron Gate. In 1971 the Hydrological forecasting department started to issue middle-range ice forecast bulletins for Danube and its tributaries.

In the work of Department one of the constant ambitions was making progressive improvements of issued forecasts by proving its issues with numerical verification criterion, according to the contemporary knowledge and hydrological researches (Prohaska & Radojicic, 1977).

In close cooperation, specialized hydrological and water management institutions Jaroslav Cerni, Energoprojekt, FHMI of Yugoslavia and RHMS of Serbia had accomplished the improved discharge forecasting model for the needs of the Iron Gate hydropower production plant in 1979 (Petkovic, 1986).

1.4 Water resources and water regime

In Yugoslavia the river Danube gains four large tributaries that makes 60% of the multi-annual mean flow of Danube at the profile of the town Negotin on the Yugoslavian - Romanian - Bulgarian border. The river Danube has nival-fluvial-glacial regime with peaks in late spring. At the Yugoslavian reach the Danube tributaries have the fluvial-nival flow regime with peaks in early spring.

Transit water of Danube represents the significant part of water resources of the Republic of Serbia. On the other hand, Danube can make enormous damages not only by its peaks but also by duration of critical levels, as it was in flooding in 1965 that had lasted for more than three months (Table 1).

Table 1 Seasonal variation of peak flow discharge of Danube

Period 1946 - 1994	DANUBE Hungarian border				DANUBE Belgrade			
	jan-mar	apr-jun	jul-sep	oct-dec	jan-mar	apr-jun	jul-sep	oct-dec
Observed (m^3/s)	6 220	8 360	7 890	4 280	13 910	14 100	13 560	12 350
Mean (m^3/s)	3 780	4 040	4 040	2 410	8 490	9 200	6 670	6 580
Coefficient of variation	0.273	0.261	0.340	0.338	0.250	0.250	0.303	0.297

2 Forecasting department

Non-structural measures for flood damage reduction are flood forecasting and warnings, emergency measures during floods, flood zoning, flood proofing, flood insurance,

indemnification of flood damages, educational activities (Bruk & Babovic, 1988).

Flood forecasting and early warnings are among the most efficient non-structural measures in flood damage mitigation. The importance of hydrological forecasts correlates with a value of protected objects of industry, infrastructure, settlements, agricultural production and also with the possible impact on the regional economy.

Total area of protected land is about 1.6 million hectares. Flood control systems exists along all larger rivers and medium ones. Total length of embankments exceeds 3500 km and more than 30 reservoirs are included in flood control system. In excess situations informations are collected from the flood control system for dissemination to the Water authorities in real time.

2.1 Real time activities

The Department collects and processes real-time information from 56 hydrological and 56 meteorological stations from Serbia and 36 hydrological stations from Europe (Table 2). Most of the observed data in Serbia are collected by radio-link (Kovacevic *et al.*, 1996).

Table 2 Reporting stations from international and national networks

River	International daily reports	National daily reports	Forecasts four days in advance	Forecasts in emergency situation
DANUBE and Drava	11	11	12	all
TISA and tributaries	23	12	2	all
SAVA and tributaries	2	13	3	all
MORAVA	-	20	4	all
Sum	36	56	21	all

The PC system 'Forecast' is developed for data processing and dissemination in real time. It enables interactive and efficient data access and graphical presentation. All activities are automated and easy to use by sub-options of the primary menu through the user-friendly interface. Processing software is developed in the Department (Palmar *et al.*, 1994).

Commercial packages are available for graphical presentation and a number of HOMS components are incorporated. Flow routing models are applied to large river flow forecasting and conceptual moisture accounting models are calibrated for smaller basins (Palmar, 1999).

The PC system 'Forecast' is connected to the World Weather Watch Global Transmission System (WWW GTS) by the front-end computer VAX in the telecommunication center of the Service. The modem connection is used for dissemination of bulletins, reports, flood warnings and the information exchange with the Water management authorities.

Now, the new Windows based 'Forecast' version is under development and implementation. It is built with the application of the advanced capabilities of the communication subsystem. At present, the Internet is used for communication with users and for bilateral exchange of data with the Water management authorities of the lower Tisa river in Hungary.

In the very future the front-end computer will be substituted with Windows NT Server enabling faster communication by the TCP/IP protocol and the Internet based approach for developing of the communication applications. The Web presentation of the Service represents the part of this project.

2.2 Hydrological forecasts

Flood defense plan is enacted every year by the Republic Government, by which the Republic Hydrometeorological Service is obliged to issue flood forecasts during the state of emergency,

which is declared when the river stage exceeds certain limits. This is the case with all large rivers and most of the medium ones. Early warnings for smaller catchments based on weather forecasts and nowcasts are also issued.

It is observed that from the 1996 in Serbia floods have occurred more frequently. The year 1999 is the extreme one in that respect. In the spring of 1999 Danube and Tisa were under the flood protection almost three months. In the July of 1999 extreme rainfall is observed in the central part of Serbia with catastrophic flood in the region of Sumadija. The daily and monthly rainfall exceeded previously observed maximums.

Several hundreds of forecasts, early warnings and other reports were issued during the state of emergency. The Department has carried out detailed analyses of meteorological and hydrological preconditions of these extreme events. At the same time, detailed studies of the flood protection system were carried out by the Water authorities. These studies and analyses serve for improvement of reliability of forecasts as well as for improvement of efficiency of the flood protection system.

2.3 Ice forecasts

The Department started to issue middle-range ice forecasts for Danube and its tributaries in 1971. The forecasting method is based on empirical or statistical dependencies between certain hydrological elements and the total heat loss necessary to form ice cover, ice dam or for ice break-up (Jovanovic *et al.*, 1994).

The problem of ice forecasting has become more important after the hydropower plant Iron Gate was constructed. Ice forecasts are issued for the period of seven, fifteen or thirty days in advance using short- and long-range numerical weather forecasts made by the Meteorological department of the Service (Kovacevic & Jovanovic, 1999).

In the past years, the ice forecast was very important for the ice protection in the severe winter season 1984/1985, while in other years its significance might be considered from the economical aspect of financial savings by planing the engagement of icebreakers.

Unfortunately, the importance of the precise ice forecasting in the winter season 1999/2000 has drastically increased due to unexpected development on Danube in the region of Novi Sad. Three demolished bridge structures could endanger the upstream section by the ice dam formation on the submerged structures and could result therefore in severe ice flooding. Fortunately, temperature conditions were realized as it was forecasted by the Service. In addition to standard procedures of the bilateral hydrological cooperation, ice forecasts issued by the Service were more frequently exchanged with the Hungarian water authorities.

2.4 Water management feedback information

Besides the flood protection, hydrological forecasting enables optimal management in all activities related to water. Close cooperation with hydropower production plants is realized through the exchange of hydrological data, forecasts and release plans from main reservoirs such as Iron Gate, etc.

The multipurpose system Danube-Tisa-Danube (abbr. DTD, purposes: flood protection, water supply, navigation, irrigation, drainage, hydropower production) is one of the main users of the hydrological information and forecasts (Milovanov, 1977). Feedback informations from important water management systems are used for further analyses and forecasts.

3 New projects

3.1 Weather radar network project

Successful forecasting of flush floods on torrential basins and other basins with time of

concentration less then 24 hours, can be performed only with precise quantitative precipitation forecasts (Radic, 1997). In moderate climate condition, heavy rain frequently occurres with hail. In the RHMS the weather radar forecasting system started to develop in 1970s.

In the Hail suppression department of the Service, the weather radar network consists of 10 weather radars Mitsubishi RC-34A, as S-band weather radar. This weather radar network covers the territory of the Republic.

The system for processing, presentation and analysis of weather radar signals has been developed in order to get quantitative data from the existing network and to accomplish successful hail suppression activities. The processing system generates the composite image obtained from several weather radars, with a goal of improving the quality of issued information. As a consequence, increasing of the forecast accuracy of precipitation distribution in time and space, is expected.

The radar image of the rain storm event above the hill Kosmaj at about 50 km south from Belgrade, created by the weather radar monitoring system is shown in Fig. 1. The weather radar network system will incorporate three new weather radars Gematronik Meteor 400AS in Vojvodina this year.

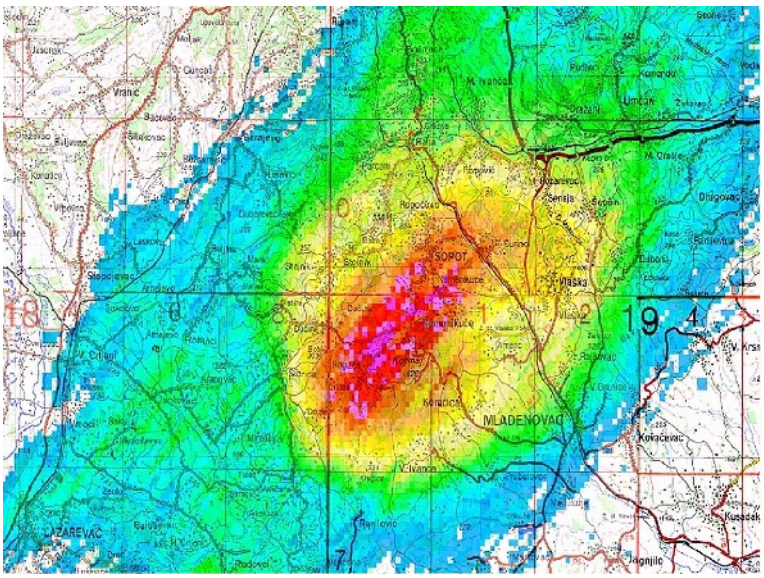

Fig. 2 Weather radar image of the rain storm event above the hill Kosmaj in June 1998

It is planned that the weather radar network will also include dual X and S band MRL5 weather radar situated in Belgrade. The MRL5 radar serves the Weather forecast center of the Service, and it is also used for nowcasting especially for the urban area. Linkage of weather radars will enable application of numerical radar information in hydrological forecasting.

3.2 Forecasting and early warning system improvement project

In the 1998 Project of the forecasting and early warning system improvement started in cooperation with the specialized Water management institute Jaroslav Cerni. The project is financed by the Water authorities of Serbia. Objectives of this project are to:

(a) detect information needs in respect to users in flood protection system;

(b) define concept of the improvement of the system;

(c) introduce new measurement techniques, remote sensing and automated stations;

(d) introduce new efficient communication techniques;

(e) improve data processing and dissemination system;

(f) define forecasting modules for limited regions, reservoirs included in flood protection

system and torrential basins.

This objectives should be achieved trough several fazes:

(a) Analysis of the present state of the system.

(b) Design of the optimal network of meteorological and hydrological reporting stations.

(c) Design of the model of the weather radar observation.

(d) Design of quantitative precipitation forecast (QPF) model.

(e) Design of hydrological forecasting procedures.

Some of the fazes denoted are currently in design, while the main precondition for the implementation will be the availability of investment funds.

4 Conclusions

Nowadays, efforts of the Service are concentrated on the development of the meso-scale model capable to model convective storm cells as well as the implementation of the weather radars and other remote sensing methods in precipitation forecasts and measurements. Development of methods for forecasting and measuring of precipitation by weather radar that is currently running in the Service, will result in more reliable input data for hydrological forecasts. Spatially precise precipitation forecasts will affect the accuracy of hydrological forecasts and flush flood early warnings, resulting in increased efficiency in flood control on small basins.

Yugoslavia has the long tradition of bilateral water management cooperation with neighboring countries. The cooperation with the water management authorities of Hungary is in the line of this tradition. In addition to multilateral cooperation in the frame of Danube Commission, additional activities are realized to increase the reliability and availability of observed and forecasted data according to adopted hydrological cooperation plan. Special attention in the cooperation is given to flood protection and in that course to the exchange of hydrological informations and forecasts.

It must be stressed that the multilateral hydrological and water management cooperation on the large rivers Danube, Drava, Tisa, Sava, is urgently needed in measurement, forecasting and flood control system operations. Variety of observed and forecasted data that have to be internationally exchanged, is expected to increase in relation to measurement and communication techniques development.

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Secondary Network of Hydrological Stations in Serbia

Borjanka Palmar, Bojan Palmar

Abstract: The secondary network is established on the additional specific demand of water management authorities, flood protection services and public utilities. The Republic Hydrometeorological Service of Serbia (RHMS) is one of the organizations in Serbia that establishes and operates the network of secondary hydrological stations. Secondary stations have been established for the purpose of the ecological protection, too. There are also a number of hydrological pilot basins. In the hydrometric field work it is essential to implement all clauses of the ISO technical standards in the matter of the liquid flow measurements in open channels. In the paper it is stressed that in contrast to the past, the number of large-scale projects and investments in hydrological investigation has decreased, but variety of users that needs hydrological and meteorological data for private enterprises, farms, fisheries and other small-scale projects has increased in number.

Key words: network, technical standard, pilot basins, freshwater supply, ecological protection

Das sekundäre hydrologische Netz in Serbien

Zusammenfassung: Das sekundäre Netz von hydrologischen Stationen (Ergänzungsnetzwerk) wird an Hand zusätzlicher, spezifischer Forderungen von Wasserwirtschaftsbehörden, des Hochwasserschutzdienstes und öffentlicher kommunaler Einrichtungen erstellt. Der Hydrometeorologische Dienst Serbiens (RHMS) ist eine der Organisationen in Serbien, die das Ergänzungsnetzwerk der hydrologischen Stationen aufbaut und betreut. Auch wurden Stationen dieses Netzes zum Zweck des Umweltschutzes errichtet. Ebenso gibt es eine Anzahl hydrologischer Versuchsgebiete. Im Zusammenhang mit hydrometrischen Feldarbeiten ist die Einarbeitung aller Vorschriften der ISO-Normen für Abflussmessungen in offenen Gerinnen von größter Wichtigkeit.

In diesem Artikel wird betont, dass, im Gegensatz zur Vergangenheit, die Zahl der großen Projekte und Investitionen in den hydrologischen Forschungen immer kleiner wird, während gleichzeitig die Zahl der verschiedensten Benutzer, die die hydrologischen und meteorologischen Angaben für private Unternehmen, landwirtschaftliche Betriebe, Fischereiwesen und ähnliche kleinere Projekte erfordern, ständig zunimmt.

Schlüsselwörter: Netzwerk, technische Normen, experimentelle Einzugsgebiete, Wasserversorgung, Umweltschutz

1 Monitoring of water regime elements

Concerning the WMO Technical regulations in Hydrology, there are several preconditions that must be achieved in a successful operation of a national hydrological service:

(a) density of the basic network of hydrological and meteorological principal stations should be sufficient to make possible the appropriate assessment of hydrological cycle elements;

(b) observation stations should be located at sites with adequate flow conditions that enables proper functioning of instruments and satisfactory observation and measurement of water regime elements;

(c) each hydrological surface water or groundwater station should be established with the assumption of continued operation for at least ten years, unless it serves for a specific purpose which justifies its functioning for a shorter period.

In reference to definition, the secondary hydrometric station is a station which is established to operate only for a limited number of years, with the aim to supplement the basic network of principal hydrometric stations.

The secondary network is established on specific additional demands of water management authorities, such as flood protection services or waterway management organizations. Another class of demands comes from public services and utilities for covering the collection of hydrological and meteorological data in a particular site, needed in a freshwater supply facility design, ecological protection and hydropower production (Palmar *et al*, 1999).

The RHMS is one of the organizations in Serbia having a license for establishment and operation of the secondary hydrological network. Energoprojekt is the other specialized institution with performed dam constructions all over the world from Latin America to Africa and Asia. There is also the Water management institute Jaroslav Cerni that carried out a great number of hydrological engineering projects in the former Yugoslavia, having the advantage of the rating tank with the current-meter calibration license. Besides, there are smaller project organizations, too.

There is a distinction between two reasons for the secondary station establishment. Most of them have been established for the purpose of collecting hydrological information on the specific site, with the primary goal to verify estimates based on regional and time series analyses of long records. The others are needed chiefly for the real-time water management requirements, such as flood protection or navigation.

2 Hydrometric field work and technical standards

The essential thing in hydrometric field work is the implementation of clauses of the WMO regulations in hydrology namely the ISO technical standards in the matter of the liquid flow measurements in open channels. It is assumed that the establishment and operation of a secondary station must be consistent with the basic network standards.

Yugoslavian standards (JUS) on the liquid flow measurements in open channels are under authority of the federal commission for hydrometric determinations. In the 1970s Yugoslavia had cast a vote for the international standards on water-level measurement devices, velocity - area methods and the most recent issues of these standards are under study of the commission now.

3 Secondary network in Serbia

3.1 Water supply, hydropower production and ecological requirements

As it is previously said, the RHMS is one of the organizations having the right to legally establish and operate the hydrological secondary station network. In organizational and functional sense, these stations belong to one of the six hydrological district offices covering parts of the territory of the Republic, and this fact has always been a comparative advantage of the Service.

There are two main groups of questions on water demand. The first is water supply for the industry and communities, the other is power production. Possible solution for both is the same: dam construction with vast reservoirs. With the exception of the large dams on Danube, Tisa and Drina there is a great number of medium and small reservoirs in mountains especially in the southwest and the southeast. For most of them hydrological groundwork has been practically laid by the hydrological department of the Service and its chief Ing. Savic.

The Service has been successfully included in determination and solving the freshwater supply problems in several towns and districts, covering with additional hydrological investigations the

river basins of Jablanica, Kladnica, Turija, Dobrava, Kacer, Dulenka, Kalenicka, Gruza, Studenica, Dicina, Nisava, Golema reka, etc., as well as the river Toplica where the freshwater supply reservoir is under construction now.

There are some ecological aspects that have always been important to the water management authorities:

(a) secondary network of groundwater stations has been established for subsurface water level monitoring of depletion as well as artificial raising caused by river dam construction;

(b) secondary network of water quality stations has been established for the purpose of making regression analyses of the river discharge versus sampled water quality data at the specific site of the watercourse;

(c) secondary network of suspended load sampling stations has been established for the needs of the erosion processes assessment in the drainage basin, and consequently land use change and soil conservation;

(d) secondary network of meteorological stations has been established at specific sites for monitoring of hydrological cycle elements such as precipitation, air temperature, wind, relative humidity etc. that are needed in designing and managing as well as in evaluation of the impact of some large water body on the environment.

At present, in respect to hydrological secondary network design and operation, hydrometric field work (discharge measurements) is requested rather than the establishment of a new secondary station on the specific site. Variety of users that requires hydrological and meteorological data for design of private enterprises, farms, fisheries, ecological projects and other small-scale projects has increased in number.

3.2 Pilot basins

In cooperation with the Federal Hydrometeorological Institute of Yugoslavia, in the 1970s several hydrological pilot basins were equipped with proper instruments by the Service, according to counseling of the Yugoslavian National Committee for International Hydrological Program of UNESCO (Jovanovic *et al.*, 1977). The payment of expenses was on the annual rate.

The part of this project failed because of the shortage of investing money, but observation and measurement have continued on several experimental stations, for example in the Gradnja basin with the area of 28 km^2. For many years the extensive hydrometric investigations were performed in the Gornja Toplica pilot basin (Ocokoljic & Mitrovic, 1985).

Although the project EHSIH represents the different field of hydrological investigations, this experimental hydrological laboratorial system of the FCE hydrological institute has to be mentioned here (Radic, 1992). As a result of hydrological physical model investigations, the ILR model was accomplished. One of the ILR model applications was the hydrological investigation and parameter calibration for the Gornja Toplica pilot basin (Palmar, 1983).

In 1987 at the FCE in Belgrade it was established the International research and training center for urban drainage (IRTCUD) on behalf of UNESCO (Maksimovic, 1994). The scopes of the center are operational rainfall - runoff researches in urban conditions, engineering design and international educational courses. The center maintains its own pilot basins with the experimental hydrological and meteorological secondary stations.

In the frame of suburban watershed investigations, one of projects held by the Institute Jaroslav Cerni needs to be cited (Prohaska *et al.*, 1979). The watershed under consideration has represented the interesting combination of inconsistent physiographic factors, from the agricultural watershed conditions in the upper course to the densely inhabited industrial zone in the lower course in the southern part of Belgrade.

There were also the significant number of the experimental mountain basin investigations that were performed by foresters and the specialized institutions in Serbia. Their field of investigation covers the pluvial erosion mitigation, soil conservation projects, afforestation studies, analyses of the deforestation impact on runoff, as well as torrential engineering and fluvial erosion mitigation.

3.3 Multipurpose Hydro-System Danube-Tisa-Danube in Vojvodina

There was the pertinent problem of flooding in the southern part of the broad Pannonia plain in last centuries. The people had suffered great devastation not only from destructive waters of large rivers such as Danube or Tisa, but also from Begej and Tamis. In despite of great efforts and hard labor, some of the past water management projects was not completely successful (Milovanov, 1987).

In the mid-1970s, all of rivers, waterways and canals in Vojvodina were included in the multipurpose system Danube-Tisa-Danube (Milovanov, 1972). The DTD system has the great significance for water supply, drainage and irrigation as well as for navigation and flood protection of the region.

There are the basic network on main streams and the secondary network on other channels, that make the part of the hydrological operating system of the RHMS and public services.

3.4 Water management cooperation with the neighboring countries

The RHMS has the appointment of the Yugoslavian Water Management Commission for the flow measurement performing and the curve fitting based on mutual flow measurements, as well as the data exchange with the hydrological services of neighboring countries.

At the Hungarian - Yugoslavian border, beside principal stations on Danube and Tisa, there are secondary stations established on two small channels. One of these watercourses is the meandering channel Plazovic with several border intersections, having the source near Baja on Danube and the mouth in the artificial Great Waterway in Backa. The other gauge is located on the barrage of the Baja - Bezdan lateral channel. In the border zone there are mutual discharge measurements in the frame of the bilateral water management cooperation.

At the Romanian - Yugoslavian border in Vojvodina, there are rivers with the frontier intersections, having the sources in the high Transylvania mountains but very small longitudinal slopes in the lower courses in Yugoslavia. All of them have the intersections with the artificial Great Waterway in Banat and the confluence in Tisa or Danube. In 1979 on demand of the flood protection and the ecological authorities, hydrometric secondary station was established on each natural or artificial channel at the very border. Now there are mutual flow regime measurements in the border zone in the frame of the bilateral water quality management cooperation on Tamis, Karas, Nera and other smaller rivers and canals.

The long reach of the river Danube represents the border with Romania, with the great number of water level staff gauges for the needs of navigation. The large hydropower production plants Iron Gate 1 and Iron Gate 2 have operated the inflow and outflow data network of their own for management and making production plans. The RHMS hydrological data reports and forecasts are available to the Iron Gate experts in real time.

At the Yugoslavian - Albanian border there was a pertinent problem of high-water conditions of the Fierza dam. Because of the problem, for the purpose of monitoring surface water, groundwater and meteorological elements on the Beli Drim river basin, a dense secondary network had been established in addition to basic network. Nowadays the most of the network is out of function, but more than 20 years the Service prepared annual summary publications on the Beli Drim water regime analyzing the backwater effects of the downstream dam, according to demands of the Federal Government.

About the Yugoslavian - Bulgarian border watersheds, there was a water management agreement in the past on two river basins. Rivers that flow from Bulgaria to Yugoslavia belong to the Black Sea basin, but rivers that flow from Yugoslavia to Bulgaria belong to the Aegean Sea basin. This compact secondary network is the part of the basic network now.

At the border rivers with the former Yugoslavian Republics, there is the dense basic hydrological network in counterclockwise order Danube, Bosut, Studva, Sava, Drina, Lim, Lepenac and Pcinja, having long observation data series.

4 Annual publications

According to the WMO recommended and standard procedures, each Member has to maintain the basic network and:

(a) to collect the hydrological records;

(b) to maintain archives with the up-to-date inventory;

(c) to facilitate data retrieval and data analysis by an automatic data processing equipment;

(d) to issue annual publications of hydrological data in the appropriate form.

The RHMS issues its hydrological year-book in three volumes as Surface water data, Groundwater data and Water quality data. The year-book includes data collected from the basic hydrometric network on the territory of Republic in the past year.

Collecting reliable information on the water regime and its trend in large scale is the primary goal of the basic network. Data collected from the basic network make the basis for deterministic and stochastic hydrological studies such as regional multiple regression analyses, time series systematic pattern analyses, distribution fitting, etc. (Jevdjevic, 1977).

As it is previously said, the secondary station is established for a limited number of years to supplement the basic network information. An annual publication of secondary station data includes watershed map, standard basic statistics tables and graphs, hydrographs, rating curves, duration curves, as well as additional water management information that are relevant to the financial investor.

5 Conclusions

It is important to notice that in contrast to the past, the number of large-scale projects such as regional water management systems has decreased. On the other hand, variety of users that requires hydrological and meteorological data for design of private enterprises, farms, fisheries and other small-scale projects has increased in number. Nowadays one of the most important programs is the freshwater supply system Rzav in the western Serbia, which is conducted with the assistance of our Service. The other project of great significance is the Prvonek dam in the industrial Vranje region on the very south.

In the 1990s there were no size reducing of the basic hydrological network, but the clients' investments into the secondary network have become less. In such situation, it was decided not to remove gauges and recording instruments but to carry on with observations and measurements. Although there were chances that clients would change their mind and pay their expenses, it was a burden to the Service. On the other hand, it was understood that in Serbia the hydrological network density was about the middle of the WMO scale. It was concluded therefore that continuation would produce positive effects on the regional water resources assessment in future.

In hydrology one can distinguish three basic hydrological techniques such as descriptive, utilitarian (applied) and scientific (Jevdjevic, 1991). It is realized that hydrology touches frontiers of other basic sciences such as geography, hydrogeology, pedology, ecology, meteorology, and particularly fluid mechanics and statistics. As applied discipline, hydrology is

in relationship with the water management practical questions, dealing with water utilization for water supply, energy production and infrastructure. Consequently, an estimation guideline for the future courses of needs for hydrological secondary station data, is the water management development trend in the region.

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Monitoring the Spreading of the Drava River Flood Waves in Croatia

Irena Pavić, Danko Biondić, Mladen Petričec, Đuro Hatić

Abstract: This paper describes comprehensive monitorings of the Drava River flood waves propagation in Croatia. Besides of the water level and flow measurements at permanent gauging locations, these monitorings also included observations of water level at an extra temporary water level gauging rods and numerous additonal great flow measurements. These monitorings took place in the autumn of 1993 at the Drava River section between Slovenian state border and Kingovo and in the autumn of 1998 at the river section between Botovo and Belišće. Attained results were important basis for improvements of the hydroelectric power plants control system, for improvements of the flood control system, and for planning and designing of various structures on the Drava River.

Key words: the Drava River, Flood wave propagation, Comprehensive monitoring, Flow measurement, Water level observing

Beobachtungen der Wellenfortpflanzung am Fluß Drava (Drau) in Kroatien

Zusammenfassung: Beschrieben werden umfangreiche Beobachtungen über die Fortpflanzung der Hochwasserwellen an der Drau in Kroatien. Neben Messungen der Wasserspiegel und Durchflüsse an permanenten Pegelmeßstellen beinhalten diese Beobachtungen Wasserspiegelmessungen an eigens eingerichteten temporären Pegeln und zahlreichen zusätzlichen Messungen von Hochwasserabflüssen. Diese Beobachtungen erfolgten an der Drau im Herbst 1993 im Abschnitt zwischen der slowenischen Grenze und der Ortschaft Kingovo und im Herbst 1998 im Abschnitt zwischen Botovo und Belisce. Die gewonnenen Ergebnisse bildeten eine wichtige Grundlage für die Verbesserung des Kontrollsystems der Wasserkraftwerke, die Verbesserung des Hochwasserkontrollsystems und für die Planung und den Entwurf unterschiedlicher Wasserbauten an der Drau.

Schlüsselwörter: Drava (Drau), Wasserwellenfortpflanzung, umfangreiche Beobachtungen, Durchflussmessung, Wasserstandvermarkung.

1 Introduction

From its spring in the South Tyrol up to the place it joins the Danube, the Drava runs through Italy, Austria, Slovenia, Croatia and Hungary. In the area of Croatia, the Drava River takes its the biggest tributary, the Mura River, and runs further towards the Danube River, through the wide alluvium valley. The lowland course of the Drava River forms the Croatian-Hungarian state border and it is characterised by numerous meanders and wide floodplains (Fig. 1).

The Drava River basin covers an area of total 43200 km^2. The biggest part of the basin is in Austria (52.3%), and smaller parts are in Hungary (19.5%), Croatia (16.5%), Slovenia (11.5%) and Italy (0.2%). The average annual height of precipitation at the basin is approximately 990 mm, with regard to the greatest portion of the rainfall in the alpine part of the basin, decreasing gradually going eastward. The water regime of the Drava River is rain-glacier and it is characterised by lower mean monthly discharges in the winter and by higher in the second half of the spring and in the summer. Average annual discharges are quite uniform, which is due to increased melting of the alpine glaciers during dry differing from rainy years (Biondić, D. et al., 1998). Floods usually occur during the late spring as a result of snow melting in the Alps and heavy rains at the same time, and during the autumn only as a result of heavy rains. Charactertistical discharges of the Drava and the Mura Rivers in Croatia that have been recorded at gauging stations of the Meteorological and Hydrological Service are shown in table 1.

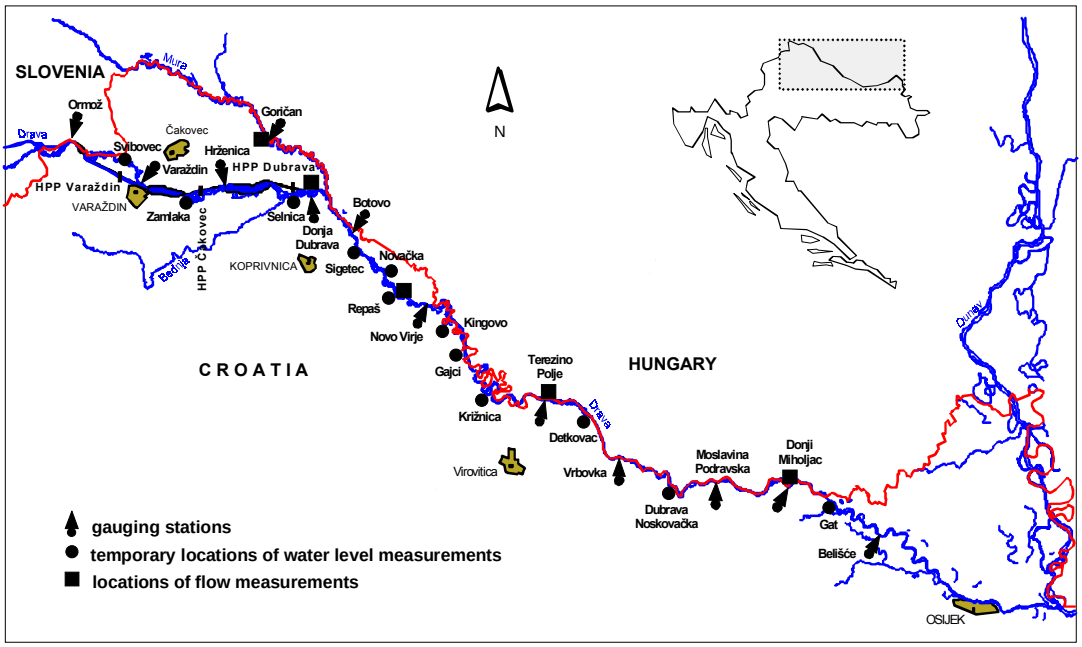

Fig. 1 Overview map of the Drava and Mura Rivers in Croatia

Table 1 Characteristical discharges recorded at gauging stations of the Drava and Mura Rivers in Croatia

River	Station	Period	Minimum recorded discharge[1] (year of occurence) (m^3/s)	Average minimum annual discharge (m^3/s)	Mean discharge (m^3/s)	Average maximum annual discharge (m^3/s)	Maximum recorded discharge (year of occurance) (m^3/s)
Drava	Ormož[(2)] (Slovenija)	1954-1974	40,0 (1974.)	72,0	337	1417	2679 (1966.)
Drava	Varaždin[(3)]	1951-1981	22,1 (1977.)	71,7	341	1286	2843 (1966.)
Drava	Donja Dubrava	1983-1997	32,9 (1987.)	60,6	291	1148	1850 (1995.)
Mura	Goričan	1926-1997	30,5 (1943.)	65,6	161	642	1447 (1972.)
Drava	Botovo	1926-1997	80,1 (1985.)	193	517	1450	2652 (1972.)
Drava	Novo Virje	1977-1997	120 (1978.)	157	494	1413	2250 (1993.)
Drava	Terezino Polje	1961-1997	134 (1972.)	193	527	1497	2889 (1972.)
Drava	Donji Miholjac	1926-1997	152 (1987.)	232	543	1357	2288 (1972.)
Drava	Belišće	1962-1993	160 (1987.)	233	556	1405	2232 (1972.)

Notes:

The Drava's minimum discharges depend on releases from upstream HPP's.

The Ormož g.s. is located at the Varaždin HPP reservoir since 1975.

The Varaždin's g.s. is located at the Čakovec HPP reservoir since1982.

Frequent flooding of wide areas and very unstable riverbed which always significantly changed during floods, induced a complex river training works at the Drava River in Croatia and

Hungary at the beginning of the 19th century. To this day many meanders were cut and numerous open channel structures and flood protection embankments were built. Those activities contributed to the stability of river banks and significantly reduced flooding risks (Biondić, D. and Petričec, M., 2000). Varaždin, Čakovec and Dubrava diversion type hydropower plants, which were built during the last twenty-five years at the Drava River section upstream of the Mura's mouth also significantly contribute to the safety of the flood protection system of the Drava River (Franković, B. et al., 2000, Gereš, D. and Beraković, B., 2000).

Intensive economic growth in Croatia and Hungary in the second half of the 20th century, induced complex investigations of the possibilities for arrangement and multipurpose usage of the downstream part of the Drava River, which resulted in common projects that were finished during the eighties. Realisation of these projects would result in full energy utilisation of the downstream part of the Drava River, in the opening of an important international navigation waterway, in enabling of the gravity irrigation of a number of agricultural areas and in attainment of complete flood protection. Hungarian partners withdrawing from the project of construction the upstreammost planned Đurđevac HPP, effected the launch of the alternative Novo Virje HPP project which would involve only structures built on the territory of Croatia (Franković, B. et al., 2000).

Hydrological characteristics of the Drava River in Croatia are continuously monitored at several gauging stations of the Meteorological and Hydrological Service and also by special equipment located at dams and powerhouses of the Drava's hydropower plants. Despite many gauging locations, the available hydrological data found insufficient for the further planning and designing of various structures on the Drava River, and for the quality calibration of various hydrological forecasting models used for flood control and energy production purposes. Reasons for that were unrealible discharge curves for great flows because of insufficient number of great flow measurements and large distances between permanent gauging stations.

In order to improve the condition of the hydrological data, comprehensive monitorings of flood waves propagation were organized on two occasions. Besides of the water level and flow measurements at permanent gauging locations, these monitorings also included observations of water level at an extra seven temporary water level gauging rods and numerous additional great flow measurements. Monitorings took place in the autumn of 1993 at the Drava River section between Slovenian state border and Kingovo (Pavić. I. et al., 1994) and in the autumn of 1998, at the river section between Botovo and Belišće (Pavić. I. et al., 1999) (Fig. 1). The aim of this paper is to present achieved results and to emphasize their importance for the water management of the Drava River.

2 Flood wave from October 1993

In the first half of October 1993 heavy rains were recorded at the whole basin of the Drava River and they caused the full saturation of the soil. After a short halt, on 21st of October heavy rains started again, so water levels of the Drava and Mura Rivers along whole courses promptly increased. At the upstream parts of the Drava's basin in Austria and Slovenia the flood wave was formed. The maximum discharge of this wave occurred at the Croatian-Slovenian state border on 24th October around 08.00 p.m. and it was 2064 m^3/s. By the transformation through reservoirs and abandoned riverbeds of hydropower plants, the maximum discharge of the wave decreased to 1810 m^3/s and at the location of Donja Dubrava g.s. (around 5 km upstream of the Mura's mouth) it occurred on 25th October around 06.00 p.m. The maximum discharge of the Mura's flood wave was 1040 m^3/s at Goričan g.s. (Letenye in Hungary) and on the mouth it occurred on 27th October, which was a day and the half later from the maximum discharge of the Drava River at the same location. In this way at the Drava River section downstream of the Mura's mouth, the flood wave with two separate peaks was formed. By the propagation through

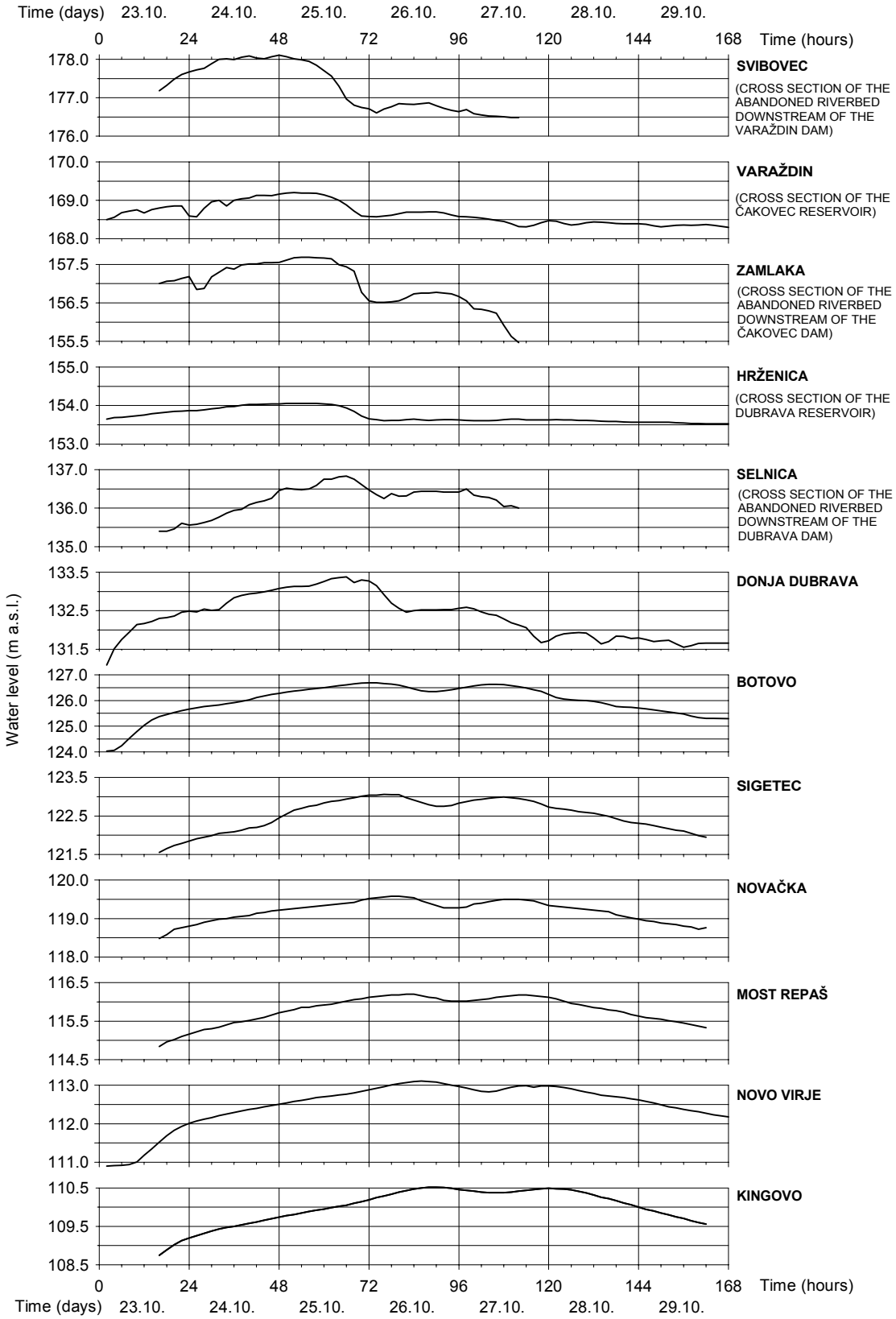

Fig. 2 Water levels at locations of gauging stations and temporary measurement places during monitoring of the Drava River flood wave propagation in October 1993

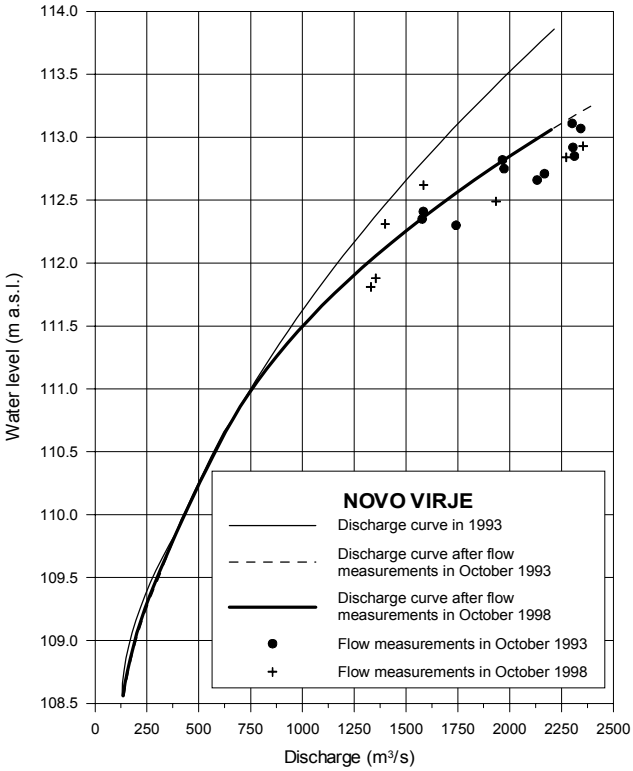

Fig. 3 Discharge curves at Novo Virje gauging station

wide floodplains and without some important tributaries maximum discharges of this flood wave decreased along the river course. They were 2302 m^3/s at Botovo, 2250 m^3/s at Novo Virje, 2120 m^3/s at Terezino Polje (Barcs in Hungary) and 1897 m^3/s at Donji Miholjac (Dravaszabolcs in Hungary). Based on results of probability analysis of early recorded maximum annual discharges, the maximum discharge of the Drava's flood wave in October 1993 was around 20-years return period upstream of Botovo and around 10-years return period at downstream river course. Maximum discharge of the Mura's flood wave at its mouth was around 10-years return period. Flood wave was successfully evacuated without seriously damages at floodplains, except at some insufficiently protected areas near abandoned riverbeds of hydropower plants.

Besides of permanent water level measurements at gauging stations of the Meteorological and Hydrological Service, and water level and flow measurements by special equipment located at dams and powerhouses of hydropower plants, during this occurrence the additional hydrological measurements were performed. These measurements consisted of two-hourly water level obsrevations at an extra seven temporary water level gauging rods located upstream of Kingovo (Fig. 2) and of numerous great flow measurements at the Drava River near Donja Dubrava (19) and Repaš (11), also at the Mura River near Goričan (6). Water level observations at temporary rods started on 23rd October at 04.00 p.m. and it finished on 29th October at 06.00 p.m. Flow measurements were performed from 24th to 29th October, and that was at the Drava River near Donja Dubrava in the range from 669 to 1606 m^3/s, at the Drava River near Repaš in the range from 1578 to 2343 m^3/s and at the Mura River near Goričan in the range from 456 to 1032 m^3/s. Based on attained results of flow measurements, significant corrections of earlier defined discharge curves of the Drava River at Donja Dubrava g.s. and Novo Virje g.s. were obtained (Fig. 3). Flow measurements at the Mura River near Goričan confirmed reliability of the earlier defined discharge curve at Goričan g.s.

Since the great flow measurements at the Novo Virje g.s. was impossible to perform due to technical reasons, in order to make corrections of the discharge curve, the results of flow measurements at some kilometers upstream Repaš were used. Flow measurements at all locations were performed both during the rise and during the fall of water levels, therefore measured Q-H relations make clearly formed loops.

3 Flood wave from October 1998

At the end of September and beginning of October 1998, heavy rains were recorded at upstream parts of Drava's and Mura's basins in Austria and Slovenia and flood waves on these rivers

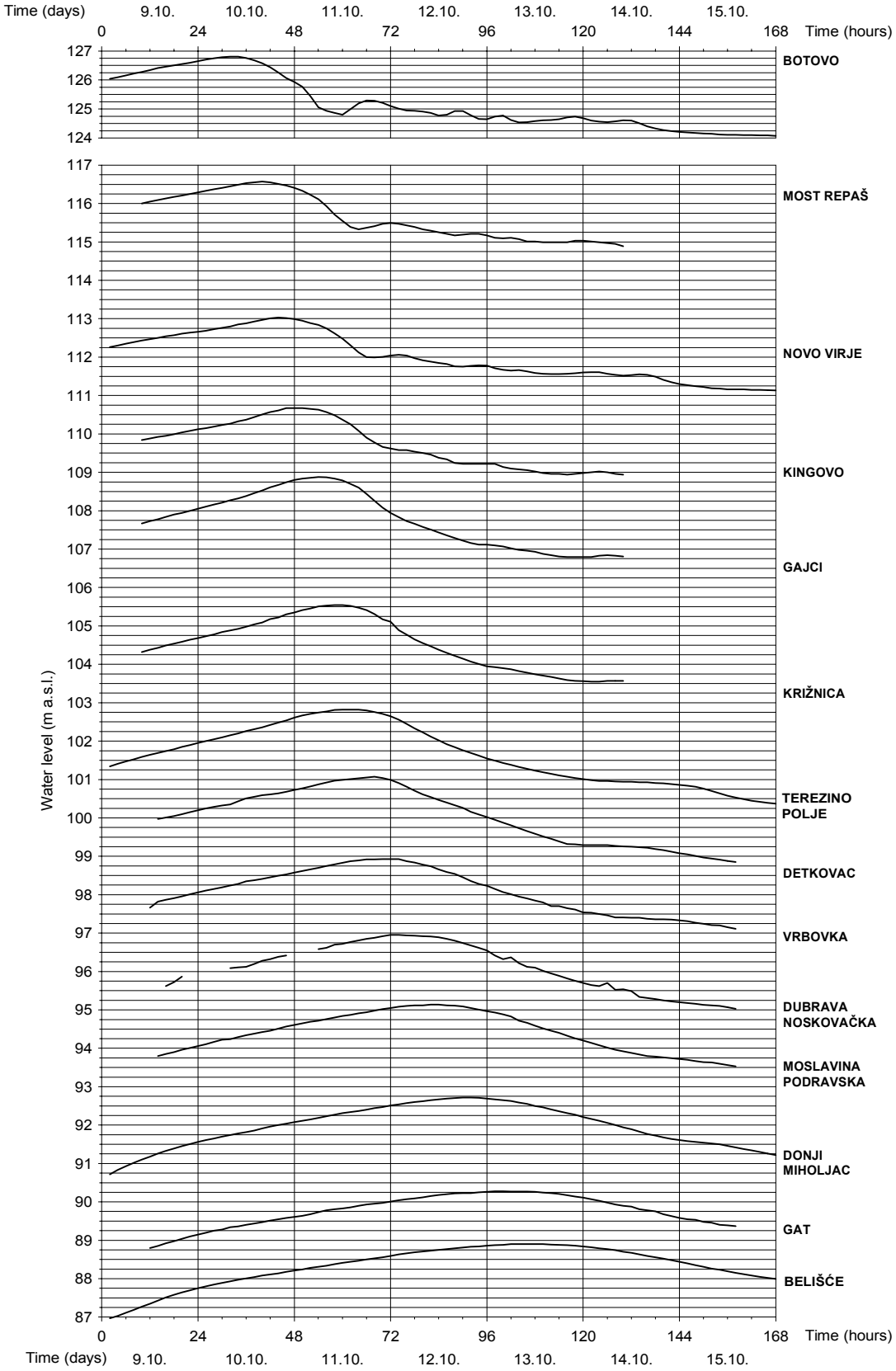

Fig 4 Water levels at locations of gauging stations and temporary measurement places during monitoring of the Drava River flood wave propagation in October 1998

were formed again. The maximum discharge of the Drava's flood wave occurred at the Croatian-Slovenian state border on 8th October around 10.00 p.m. and it was 2200 m^3/s. By the transformation through reservoirs and abandoned riverbeds of hydropower plants, the maximum discharge of the wave decreased to 1884 m^3/s and it occurred at the location of Donja Dubrava g.s. on 9th October around 11.00 p.m. The maximum discharge of the Mura's flood wave was 800 m^3/s at Goričan g.s. and on the mouth it again occurred one and the half days later from the maximum discharge of the Drava River at the same location. Downstream of the Mura's mouth maximum discharges of this flood wave decreased along the river course again. They were 2398 m^3/s at Botovo, 2171 m^3/s at Novo Virje, 1830 m^3/s at Terezino Polje and 1556 m^3/s at Donji Miholjac. Based on results of probability analysis of early recorded maximum annual discharges, the maximum discharge of the Drava's flood wave in October 1998 again was around 20-years return period upstream of Botovo and around 5-years return period at downstream river course. Flood wave was again successfully evacuated without seriously damages at floodplains, except at some insufficiently protected areas near abandoned riverbeds of hydropower plants.

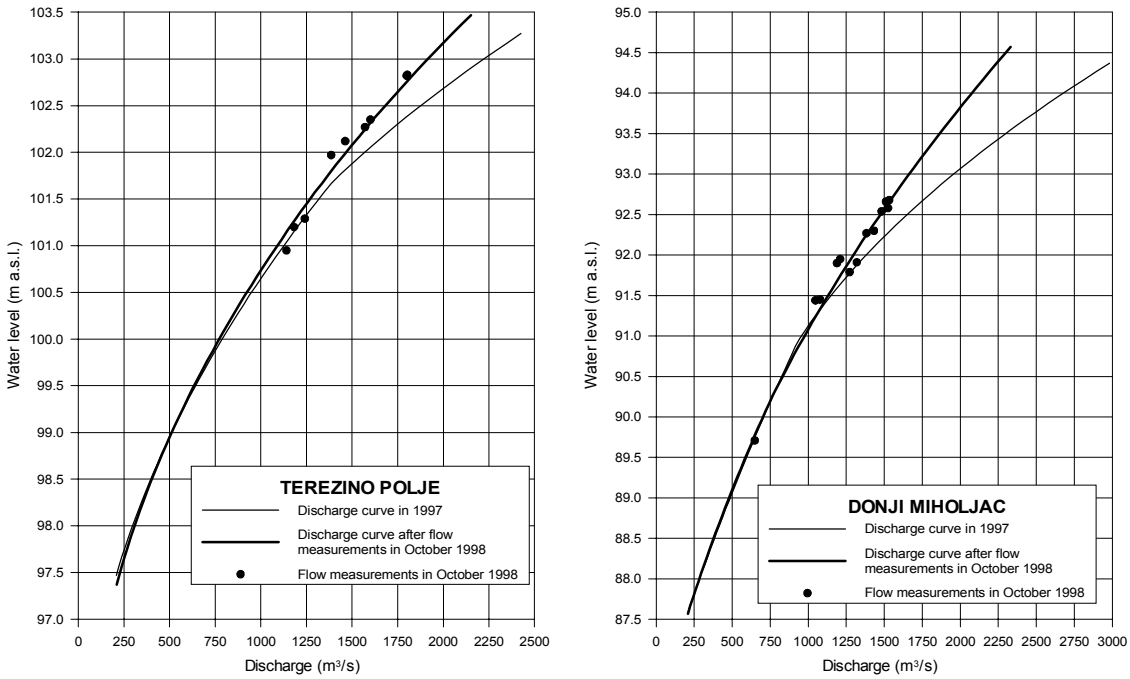

Fig. 5 Discharge curves at Terezino Polje and Donji Miholjac gauging stations

Besides of permanent water level measurements at gauging stations of the Meteorological and Hydrological Service, and water level and flow measurements by special equipment located at dams and powerhouses of hydropower plants, even during this occurrence the additional hydrological measurements were performed. These measurements consisted of two-hourly water level obsrevations at an extra seven temporary water level gauging rods located downstream of Botovo (Fig. 4) and of numerous great flow measurements at the Drava River near Repaš (7), Terezino Polje (8) and Donji Miholjac (13). Water level observations at temporary rods started on 9th October at 10.00 a.m. and it finished on 15th October at 02.00 p.m. Flow measurements were performed from 9th to 15th October, and that was at Repaš in the range from 1300 to 2354 m^3/s, at Terezino Polje in the range from 1140 to 1802 m^3/s and at Donji Miholjac in the range from 1047 to 1532 m^3/s. Based on attained results of flow measurements, significant corrections of earlier defined discharge curves at Terezino Polje g.s. and Donji Miholjac g.s. were obtained (Fig. 5). Flow measurements at Repaš confirmed reliability of the

discharge curve at Novo Virje g.s. which was defined after measurements performed in October 1993 (Fig. 2). Flow measurements at all locations were again performed both during the rise and during the fall of water levels, therefore measured Q-H relations make clearly formed loops.

4 Conclusion

Attained results during monitorings of flood waves propagation at the Drava River in Croatia enabled significant revisions of some earlier defined discharge curves for great flows and also enabled collection of measurement data of high water levels at numerous locations where measurements had never been performed before. These results made possible quality calibration of various mathematical models for the planning and designing structures on the Drava River, and for flood control and energy production purposes (Petričec, M. et al., 1994, Biondić, D. et al., 1997). Proved importance of performed measurements for improving the efficiency of the water management of the Drava River efficiency justifies the performing similar actions at other watercourses.

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System For Short-Term Forecasting of Discharge (Water Level) at the Yugoslav Section of the Danube

Tioslav Petkovic, Mihajlo Gavric, Gordana Spegar

Abstract: This paper presents the short description of the system for short-term forecast of discharge at the Yugoslav section of the Danube. The Prognostic system is based on transformational functions, which parameters, starting from its probabilistic characteristic have been defined by the method of moments using the optimisation procedure. With the aim of improvement of issued forecasts the initial conditions and current corrections of forecasts have been included in the model. As a result, the graphical and numerical indicators of the issued forecasts for the gauge stations Bezdan, Bogojevo and Novi Sad have been presented.

Key words: short-term forecast of discharge, forecasting model, transformation function, correction of forecasts

System für kurzfristige Vorhersagen des Durchflusses (Wasserstandes) an der Jugoslawischen Donau

Zusammenfassung: Dieses Papier präsentiert eine kurze Beschreibung des Systems für die kurzfristige Vorhersage des Abflusses im jugoslawischen Teil der Donau. Das Vorhersagesystem basiert auf Transformationsfunktionen, deren Parameter, ausgehend von ihrer Wahrscheinlichkeit, durch die Momentenmethode unter Anwendung von Optimierungsverfahren definiert werden. Mit dem Ziel der Verbesserung der erhaltenen Vorhersage sind die Anfangsbedingungen und laufenden Korrekturen/Adaptierungen im Modell enthalten. Als Ergebnis werden die graphischen und numerischen Kennwerte der erhaltenen Vorhersagen für die Meßstationen Bezdan, Bogojevo und Novi Sad vorgelegt.

Schlüsselwörter: kurzfristige Vorhersage, Vorhersagemodel, Umwandlungsfunktionen, Korrekturen von Vorhersagen

1 Introductory remarks

Models for water level (discharge) forecast at a particular section of the river stream, based on the approximate equations of waves transformation, have been applied more frequent in recent hydrological operational practice. The use of approaches depends on the available hydrological data at the observed part of water flow, time of travelling, number and size of tributaries and the applied forms of the transformational functions.

This makes a short presentation of the developed system for short-term forecast of discharge (water level) at the Yugoslav section of the Danube, which is not in the range of influence of the dam "Djerdap" for the period from one to five days in advance. The prognostic system is based on the linear model of transformation, when the transformation is the function approximated by the modified Gamma distribution. The distribution parameters, starting from its probabilistic characteristic - as the density of time distribution of water yield of elementary quantities at the section, have been defined by the method of moments using the optimisation procedure /1,5/.

2 Computation of water discharge transformation at river sections

The expression (1) /3,5,6/ has been used for computation of flood wave transformation at particular river sections during concentrated lateral water yield:

$$Q_t = \sum_{i=1}^{m} K_i \int_0^t P_i(t-\tau) \cdot q_i \cdot d\tau \qquad (1)$$

where *m* is number of entry profiles at the section; K_i balance coefficient for each entry profile, respectively; P_i transformational functions ordinates; q_i water discharge at entry profiles.

Coefficients K_i characterising lateral water yield from the surfaces which are not covered with hydrological observations have been determined by the conditions for water balance preservation at the river section and they are proportional to the discharge values at entry profiles and belonging catchments of these profiles /3,6/

$$K_i = K_{f_i} \cdot \overline{K}_w \qquad (2)$$

where $\overline{K}_w$ is mean value of not co-ordinated water balance at the section and K_f is coefficient proportional to the relationship of catchment surfaces which are under control, i.e., they are not covered by the systematic discharge observations.

The choice of disagreement coefficient also takes into account the criterion:

$$Q_{max,j} \le \sum_{i=1}^{m} K_i \cdot Q_{max,j,i} \qquad (3)$$

where $Q_{max,j}$ and $Q_{max,j,i}$ are maximum discharges at exit and entry profiles for j-th flood wave, respectively. Transformation model parameters have been defined by the optimisation model, starting from minimum function conditions

$$S = \sum_{i=1}^{N} \sum_{j=1}^{M_i} (Q_{o,ij} - Q_{r,ij})^2 \rightarrow \min \qquad (4)$$

where N is the number of years included in optimisation M_i number of ordinates of the i-th year, $Q_{o,ij}$, $Q_{r,ij}$ observed and computed discharges at exit profile.

When there was no discharge curve, model parameters were defined by direct way /4/, namely, a conditional discharge curve was constructed in the form:

$$Q = b \cdot H^2 + c \cdot H + d \qquad (5)$$

where *b*, *c* and *d* are discharge curve parameters obtained from the minimum of mean square error of water level definition by the following equation (5).

3 Possibility of trnasformational functions use for water discharge forecast

There were a sequence of complications in the process of developing the water forecast numerical model based on transformational functions, which refer to taking into account the information of river state in real time. These information include the data on forecasted value at the moment of forecast issuing (the initial conditions) and entry data in the period of anticipation.

The general prognostic dependence based on transformational functions may be expressed in the following way:

$$\tilde{Q}_{t+\delta} = \sum_{i=1}^{m} K_i \cdot \left\{ \sum_{j=\delta+1}^{r_1} P_{i,j} \cdot q_{i,t+\delta-j+1} + \sum_{j=1}^{\delta} P_{i,j} \cdot \tilde{q}_{i,t+\delta-j+1} \right\} + \Phi_t(Q,\delta) \qquad (6)$$

where t is the moment of forecast issuing ; m - the number of entry profiles for which the transformational functions are known; δ - time of anticipation (timely forecast); K_i is balance coefficient; r_i - the number if significant ordinates of transformational functions; $P_{i,j}$ - transformational function ordinates; $q_{i,j}$ - ordinates of i-th entry at j-th moment of time which are known at the time of forecast issuing; $q_{i,j}$ - ordinates of i-th entry at j-th moment of time which are unknown at the time of forecast issuing; $\Phi_t(Q,\delta)$ - correction operator which include the data on observed discharges at the exit profile at the time of forecast issuing.

The transformational function ordinates $P_{i,j}$ are calculated with use of modified Gamma distribution i.e.,

$$P(\tau) = \frac{\alpha^{\alpha}}{m_1 \Gamma(\alpha)} \left(\frac{\tau}{m_1} \right)^{\alpha-1} \cdot e^{\left(-\frac{\tau}{m_1}\right)} \cdot B(\tau) \qquad (7)$$

where: α, m_1, Γ, B are functions of basic parameters of the model *a*, $\bar{v}$ and *k* /1, 5/.

The result of consideration of general prognostic dependence (6) is that it is indispensable to solve the following problems related to operational forecast issuing:

development of the efficient algorithm for forecasted value current information inclusion into forecast (up-to-date correction);

choice of the method for assessment (forecast) of entry data for the forecasting period.

Naturally, the efficiency of issued forecasts depends, to a great degree, on the way of use of the information concerned.

The data on discharges (water levels) at exit profiles, available at the moment of forecast issuing are not used for transformation linear model which leads to forecast inaccuracies. Therefore, the initial conditions must be included in prognostic model with the aim of avoiding the inaccuracies.

This problem has been solved by use of modified procedure based on current forecast errors correction at the time of forecast issuing /2/. Namely, transformational curve P_i is presented in the form of convolution of two curves P_{1i} and P_{2i} which entry discharge is transformed, while correction operator is given in the following way, in this case:

$$\Phi_t(Q,\delta) = \left(\frac{\Delta Q_t}{P_{2i,max}} \right) \cdot P_{2i,max+1+\delta} \qquad (8)$$

where $\Delta Q_t = Q_t - \bar{Q}_t$; Q_t - observed discharge; $\bar{Q}_t$ - computed discharge without corrections on the day of forecast issuing; $P_{2i,max}$ - transformational function $P_{2,i}$ maximum ordinate value.

The operational forecast issuing requests, except current information on forecasted value, the entry data ($\tilde{q}$) in the period of forecast anticipation (δ). The influence of these data, as well as their reliability related to the forecast accuracy, is defined by a form of transformational function; the less the first transformational functions ordinates, the less the influence of these data and vice versa.

In case that the prognostic models are not developed for entry profiles, a few principles of extrapolation can be used for solution of this problem, both in the phase of dropdown and accretion, or a recurrent expression is used /6/

$$\tilde{q}_{t+\delta} = q_{t+\delta-1} + r^{\delta}(q_t - q_{t-1}) \qquad (9)$$

where r is correlation coefficient of water discharge yield with a shift for a time unit. The above procedure gives better results than linear interpolation, especially when $r \geq 0{,}6$.

4The application of short-term discharge (water stage) forecast model in the Yugoslav section of the Danube)

The above theoretical assumptions have been used as a basis for developing, primarily, a transformational model for the Yugoslav section of the Danube (Bezdan-Novi Sad) Fig. 1, and afterwards a prognostic model for discharge forecast at the gauge stations Bezdan ($\delta = 1 \div 3$ days), Bogojevo ($\delta = 1 \div 4$ days) and Novi Sad ($\delta = 1 \div 5$ days).

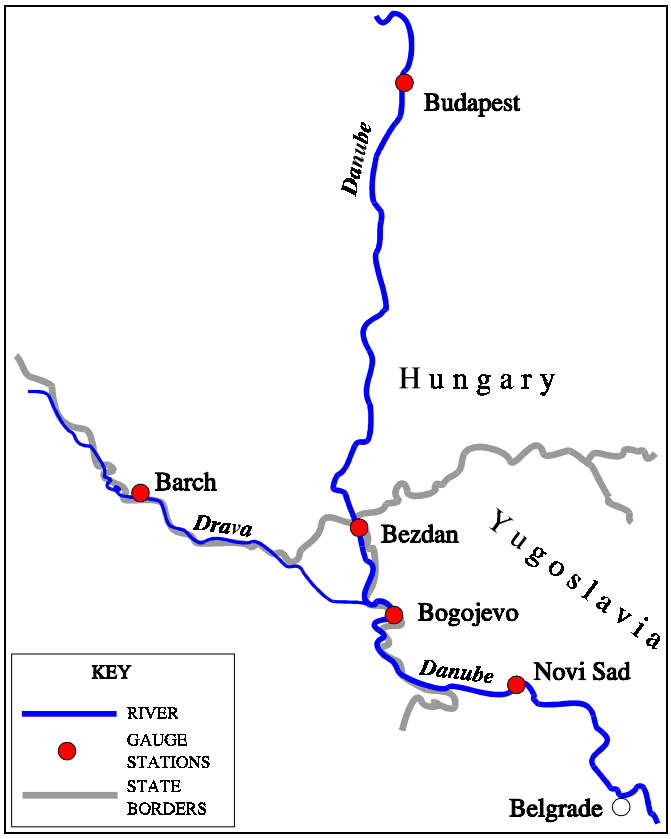

Fig 1 River section scheme at the Danube

Prognostic package is anticipated in a way, so that, using historical data from the gauge stations Budapest, Bezdan, Barch, Bogojevo, Novi Sad, it defines the optimum parameters of transformational functions including balance coefficients as well, and then makes forecasts for $\delta = 1$ to 5 days, updating them permanently. It must be noted that water level forecast has been issued at Novi Sad following the equation (5) and that the forecasted values at upstream profile make the entry values at downstream profile. At the gauge station Barch, the assessment of discharge in anticipation period was defined following the equation (9) and at the gauge station Budapest the forecasts of the Institute "Vituki" were used. The scheme presentation of developed programme package is given in Fig 2.

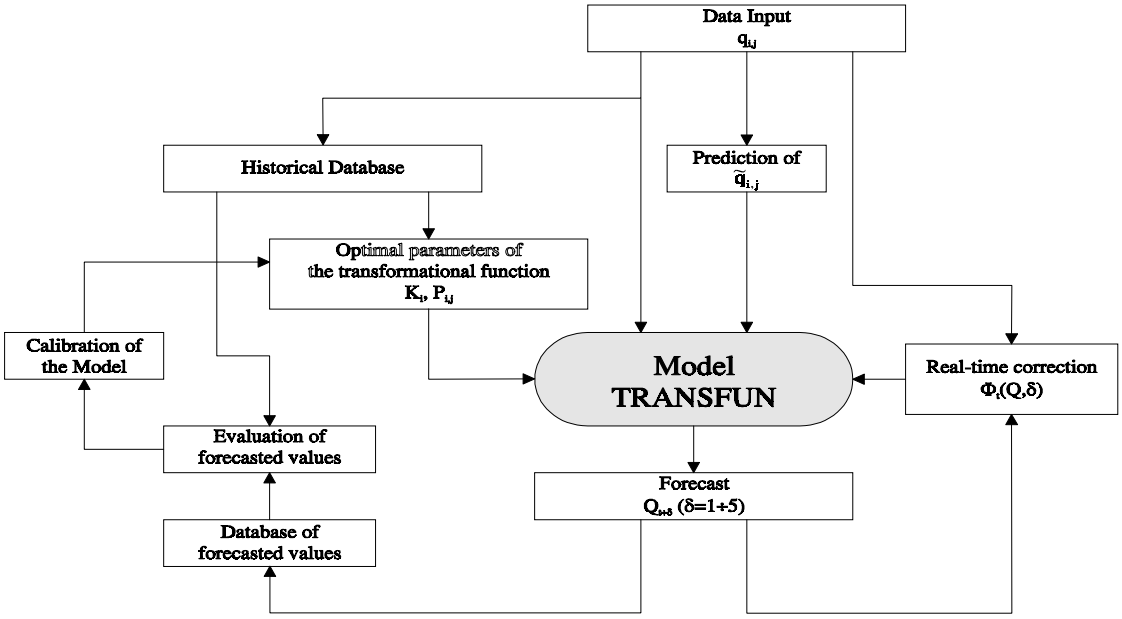

Fig 2 Programme Model "TRANSFUN" scheme

Table 1 presents the values of the optimum parameters of transformational functions and balance coefficients.

Table 1 Optimum Parameters values

Flow section	Output profile	L [km]	Model parameters			K_i	Parameters Q=*f* (H)		
			a [day]	$\overline{v}$ [km/day]	k		b	c	d
Budapest-Bezdan	Bezdan	222	0.70	56.9	1.70	1.13 for $Q^{bez.}$>1900 1.04 for $Q^{bez.}$<1900	-	-	-
Bezdan-Bogojevo	Bogojevo	58	2.64	26.7	-1.50	0.99 for $Q^{bog.}$>2300 1.04 for $Q^{bog.}$<2300	-	-	-
Barch-Bogojevo	Bogojevo	167	0.60	50.4	-1.00	1.20	-	-	-
Bogojevo-Novi Sad	Novi Sad	112	0.84	68.1	2.00	-	0.0098	2.91	1084

The graphical presentations of observed and forecasted discharges at the gauge stations Bezdan (δ=3 days), Bogojevo (δ=4 days) and Novi Sad (δ=5 days) in 1996, are given in figures 3, 4 and 5. Numerical and graphical presentations impose the conclusion that the issued forecasts are satisfactory. It must be noted that the forecasts at these profiles for minor period of anticipation (b=1÷4) are significantly better.

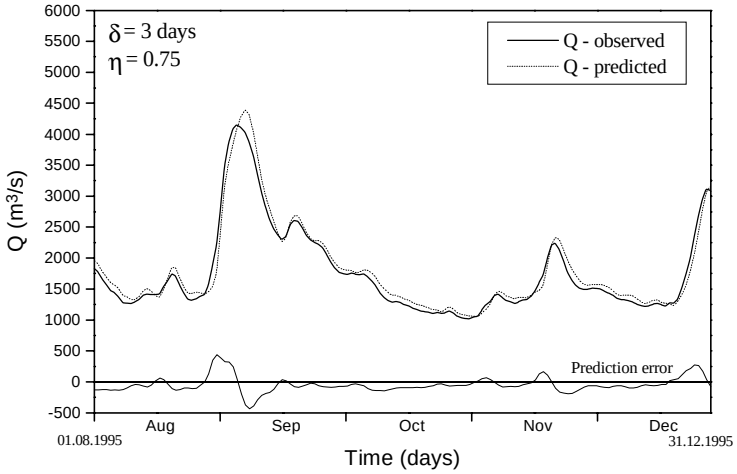

Fig. 3 Graphical Presentation of Observed and Forecasted Discharges at the Gauge Station Bezdan

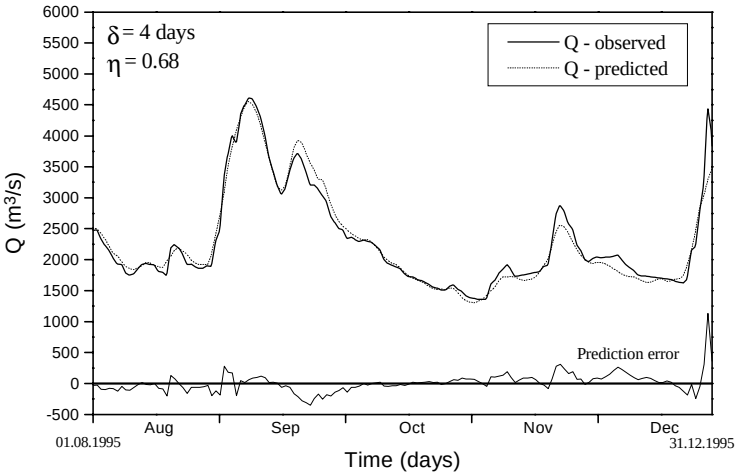

Fig. 4 Graphical Presentation of Observed and Forecasted Discharges at the Gauge Station Bogojevo

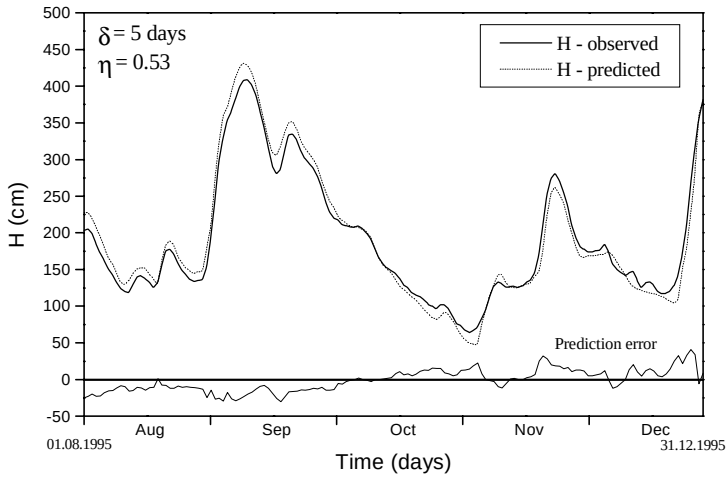

Fig. 5 Graphical Presentation of Observed and Forecasted Water Levels at the Gauge Station Novi Sad

5 Conclusion

The developed prognostic system for short-term discharge forecast at the Yugoslav section of the Danube is used operationally in the Water Forecast Division of the Federal Hydrometeorological Institute.

Further investigation of this model application has been directed to downstream profiles at the Danube up to the entry of the "Djerdap" accumulation, which will result in the period to follow in the complete definition of automatic prognostic hydrological system of the Yugoslav section of the Danube. Some research has also been directed to the definition of model parameters for different water regimes as well as to introduction of other procedures which can describe better the initial conditions of the model.

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Hochwasservorhersagesysteme in Baden-Württemberg für die obere Donau

Werner Schulz

Zusammenfassung: Die Donau in Baden - Württemberg hat ein Einzugsgebiet von etwa 4000 km2 (Pegel Berg). Die Hochwasser-Vorhersage-Zentrale Baden-Württemberg berechnet bei Hochwasser stündlich Vorhersagen für verschiedene Pegel entlang des Flusses. Für den obersten Teil des Einzugsgebietes wird operationell ein Niederschlags-Abflussmodell eingesetzt. Dessen Vorhersagen basieren auch auf den Mess- und Vorhersagedaten des Niederschlags und des Schneedeckenausflusses. Sie dienen zudem als Eingangsdaten für das Kalman-Filter Modell zur Hochwasservorhersage bis zum Pegel Berg. In absehbarer Zeit sollen sowohl ein Wasserhaushaltsmodell als auch Niederschlagsdaten aus Radar zur Verbesserung der Hochwasservorhersagen beitragen.

Schlüsselwörter: operationelle Hochwasservorhersage, Flussgebietsmodell, Kalman-Filter.

Flood-Forecasting Systems in Baden-Württemberg for the Upper Danube

Abstract: The Danube in Baden - Württemberg has a catchment area of about 4000 km2 (gauge Berg). If there is a flood, the Flood Forecasting Centre Baden-Württemberg calculates hourly forecasts for different gauges along the river. For the highest part of the catchment, a rainfall-runoff model is used operationally. Its forecasts are based also on the measuring and forecast data of the precipitation and snowmelt. They serve besides as input data for the Kalman filter model which is used to calculate the flood forecasts at gauge Berg. In the near future a water balance model and also precipitation data from radar will be used to contribute to the improvement of the flood forecasts.

Key words: Rainfall-runoff model, operational flood forecast, Kalman filter, Radar, snowmelt.

1 Hochwasser an der Donau in Baden-Württemberg

Die Quellzuflüsse der oberen Donau entspringen im Schwarzwald, sie liegen in einer Höhe von 600 bis 1000 m (Brigachquelle: 1078 m). Ihr oberes Einzugsgebiet erhält Jahresniederschläge von bis zu 1600 mm. Die meisten in der Donau bis Berg ablaufenden Hochwasser entstehen im Bereich des Schwarzwaldes [LfU 1991]. Dies verdeutlicht schon die Betrachtung der mittleren Hochwasserabflüsse, die zwischen Kirchen – Hausen und Berg nur wenig zu nehmen:

Tabelle 1: Mittlere Hochwasserabflüsse und –spenden im Bereich der oberen Donau und Scheitelabfluss des Hochwassers Februar 1990 [Deutsches Gewässerkundliches Jahrbuch 1995].

Pegel	Einzugsgebietsfläche	MHQ	Scheitelabfluss 1990
Kirchen-Hausen	758 km^2	133 m^3/s	359 m^3/s
Berg	4047 km^2	201 m^3/s	445 m^3/s
Neu-Ulm	7578 km^2	580 m^3/s	800 m^3/s

Auch das bisher größte aufgezeichnete Hochwasser vom 15.02 - 17.02.1990 entstand im Bereich des Schwarzwaldes. Die vergleichsweise hohen Abflüsse am Pegel Neu-Ulm (Bayern) sind auf dem Zufluss der Iller, die ihren Ursprung in den Alpen hat, zurückzuführen.

Diese Situation wurde beim Aufbau der operationellen Hochwasser-Vorhersage für die Donau durch einen entsprechenden Aufbau der Messnetze und der Modelle berücksichtigt.

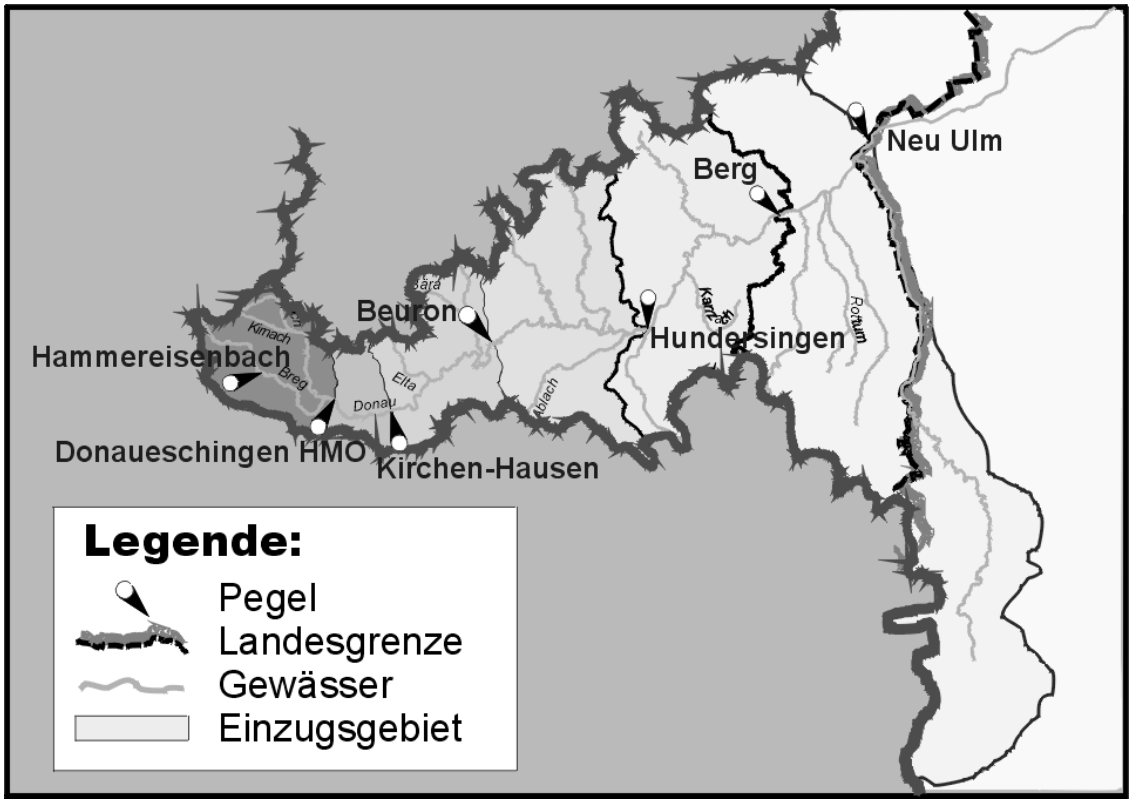

Abb. 1 Das Einzugsgebiet der Donau bis zum Pegel Neu –Ulm

2 Operationelle Hochwasservorhersagen für die Donau

2.1 *Anforderungen und Voraussetzungen*

Um bei einem aufkommenden Hochwasser die Zeit bis zum Eintreten kritischer Wasserstände erfolgreich für Schutzmaßnahmen vor Ort nutzen zu können ist eine Warnung vor dem eintreffenden Hochwasser und Kenntnisse über den in nächster Zeit zu erwartenden Verlauf erforderlich [Homagk 1996a]. Hochwasservorhersagen können hier wertvolle Dienste leisten, wenn sie eine Dauer von mehreren Stunden aufweisen, hinreichend verläßlich sind und zudem regelmäßig und zuverlässig erstellt werden.

Die Vorhersagemodelle müssen auch unter operationellen Bedingungen (z.B. Pegelausfall) lauffähig sein. Die erforderlichen Eingangsdaten werden zeitnah und in digitaler Form benötigt..

Für die Modellkalibrierung werden zudem Ereignisdaten historischer Ereignisse benötigt. Der Aufbau eines Flussgebietsmodells erfordert weiterhin Systemdaten, z.B. zum Gefälle, zur Geometrie der Gewässerteilstrecken, Speicherinhaltslinien und hydrologische Parameter wie Retentionskonstanten für Teileinzugsgebiete [Homagk 1998].

2.2 *Operationelle Erstellung der Hochwasservorhersagen*

2.2.1 Erfassung der Eingangsdaten

Die Hochwasser-Vorhersage-Zentrale Baden-Württemberg (HVZ) ruft bei Hochwasser alleine im Einzugsgebiet der Donau stündlich 21 Pegel online ab. Weiterhin stehen ihr die stündlich aktualisierten Niederschlagsmesswerte von ca. 40 Stationen im Bereich der Donau, sowie mehrmals täglich aktualisierte Niederschlags- und Schneeschmelzvorhersagen zur Verfügung. Zur Berechnung des Schneedeckenausflusses mit dem Modell SNOW werden Vorhersagen und Messwerte von Lufttemperatur, Luftfeuchte, Globalstrahlung bzw. Sonnenscheindauer und Nie-

derschlagshöhe verwendet. Die dreimal wöchentlich an 38 Stationen im Bereich der Donau gemessenen Werte von Schneehöhe und Wasseräquivalent werden zur Stützung der Berechnungen herangezogen [Rachner 1997]. Die Vorhersagen werden vom DWD auf einem Rechner bereit gestellt und von der HVZ abgeholt.

2.2.2 Modellierung des Hochwasserabflusses

Das flächendetaillierte Hochwasser-Flußgebietsmodell FGMOD [Ludwig 1978, Holle 1983], das als Konzeptmodell die gemessenen Abflüsse und Niederschläge und die Vorhersagen von Niederschlag und Schneedeckenausfluss in die Vorhersage einbezieht, wird zur Modellierung der Hochwasserabflüsse von Brigach und Breg eingesetzt. Zielpegel der Vorhersagen ist Donaueschingen-HMO.

Das 487 km^2 große Einzugsgebiet wird durch Teileinzugsgebiete von durchschnittlich 44 km^2 erfaßt. Für die Teileinzugsgebiete ermittelt FGMOD über ein Interpolationsverfahren die Niederschlagshöhe für jeden Zeitschritt. Der abflusswirksame Niederschlag wird über einen Abflussbeiwert ermittelt, welcher sich über die Dauer der Vorhersage in Abhängigkeit vom Niederschlag ändert. Der so berechnete Effektivniederschlag wird auf einem Speicher mit geringer Retention (schneller Speicher) und einem Speicher mit großer Retention (langsamer Speicher) aufgeteilt. Aus deren Abfluß und den konstanten Basisabfluss ergibt sich der Abfluß aus einem Teilgebiet. Über eine Folge von Niederschlags-Abfluss Modellen (für die einzelnen Teilgebiete) und über die Verformung der Hochwasserwelle in den Gewässerteilstrecken wird der Abfluß aus dem Einzugsgebiet berechnet [Homagk 1998]. In FGMOD erfolgt eine Optimierung der Abflussbeiwerte der einzelnen Pegelkontrollbereiche für jede Vorhersage. Durch diesen, über die Niederschlags-Abfluss Simulation vorgenommenen, modellinternen Abgleich zwischen Niederschlag und Abfluss werden z.B. zeitweilig vorliegende Unsicherheiten in den Eingangsdaten (z.B. durch Stationsausfall) ebenso berücksichtigt wie die aktuellen Abflussverhältnisse im Teileinzugsgebiet.

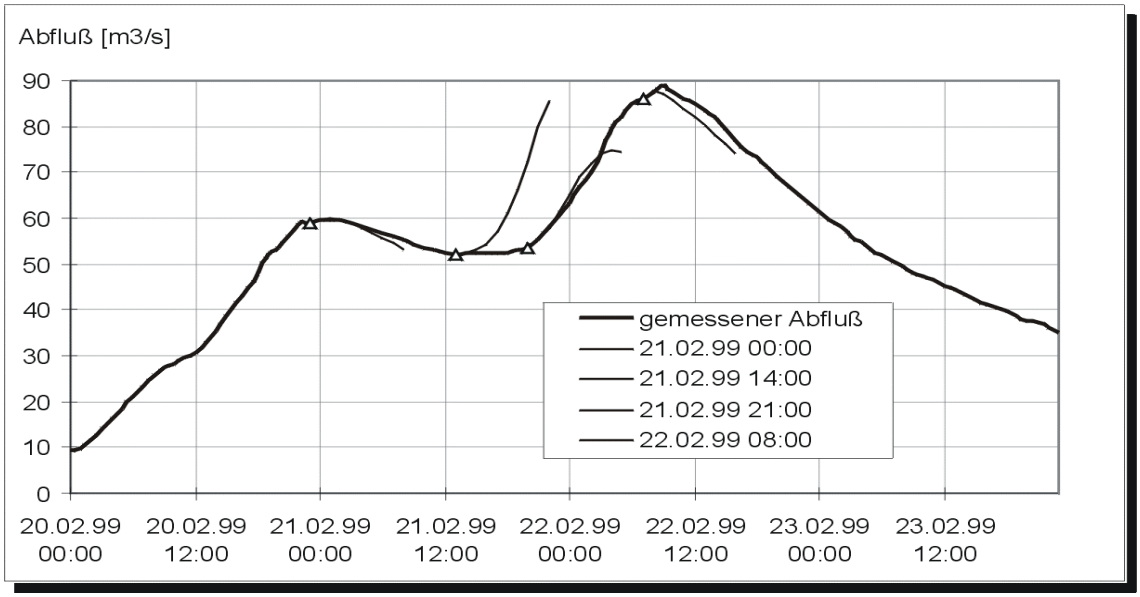

Abb. 2 Verschiedene Hochwasservorhersagen für den Pegel Donaueschingen-HMO vom Hochwasser Februar 1999, erstellt mit dem FGMOD-Hochwasservorhersagemodell

Unterhalb von Donaueschingen – HMO werden die Vorhersagen mit einem Kalman-Filter Modell berechnet. Der Kalman-Filter [Barth 1991] dient prinzipiell der Anpassung mathematischer Modelle an einen anhand von Messungen beschriebenen Prozess. Dieses System wurde für die Erstellung von Hochwasservorhersagemodellen auf hydrologischer Grundlage genutzt. Das Modell verwendet als Input ausschließlich die Abflüsse an den Pegeln, die über Wasserstands-

Abfluss Beziehungen ermittelt werden. In den einzelnen Teilgebieten und Gewässerstrecken werden die hydrologischen Prozesse anhand eines statistischen Ansatzes modelliert. Es benutzt keine Gerinnedaten, sondern Übertragungsfunktionen bzw. Optimierungsverfahren zur Simulation des Hochwassers in den einzelnen Gewässerabschnitten zwischen den Pegeln [Homagk 1998]. Sein Vorteil liegt im relativ niedrigen Aufwand für die Modellerstellung und den operationellen Betrieb.

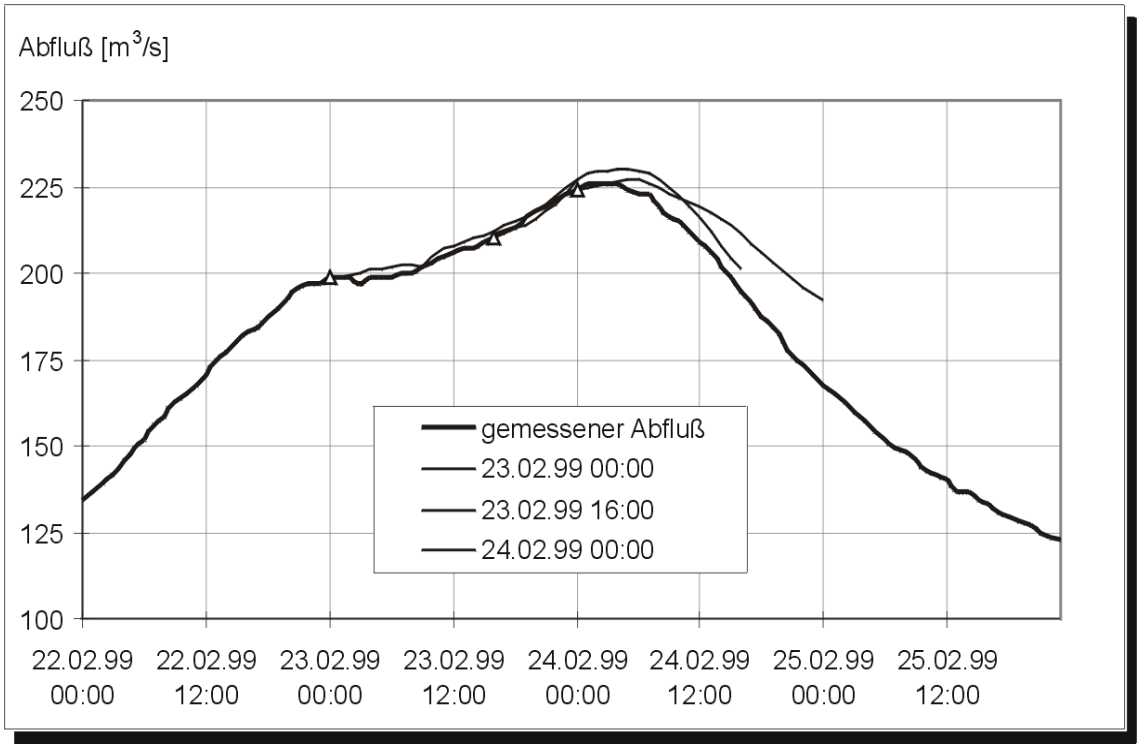

Abb. 3: Verschiedene Hochwasservorhersagen für den Pegel Berg, Hochwasser Februar 1999, erstellt mit dem Kalman-Filter Modell

Die oben abgebildeten Vorhersagen wurden operationell während des Hochwassers erstellt. Nachträglich wurden die Messwerte eingezeichnet. Während des Hochwassers Februar 1998, das an Brigach und Breg stark von der Schneeschmelze geprägt war, konnte erstmals die Schneeschmelzvorhersage für die obere Donau genutzt werden. Die fehlerhafte Vorhersage vom 21.02., 13:00 Uhr am Pegel Donaueschingen-HMO ist auf eine zu hohe Schneedeckenausflussvorhersage auf Grund einer zu hohen Niederschlagsvorhersage zurückzuführen. Flussabwärts weisen die Vorhersagen wieder eine gute Qualität auf (vgl. Abbildung 7).

3 Bereitstellung der Vorhersagen

Für Entscheidungen vor Ort sind neben der Qualität der Vorhersagen auch deren rasche und zuverlässige Verfügbarkeit wichtig. Bei überregionalen Hochwasser arbeitet die HVZ rund um die Uhr und stellt, stündlich aktualisiert, die Daten und Vorhersagen über unterschiedliche Medien bereit [vgl. Homagk 1996b]. Die aktuellen Wasserstände können über eine automatische Telefonansage und Btx erfragt werden. Über Faxabruf, T-online und Internet (http://www.uvm.baden-wuerttemberg.de/lfu/hvz/) stellt die HVZ allen Interessenten zusätzlich ihre Vorhersagen in Form von Ganglinien zur Verfügung. Das Internet bietet zusätzlich Informationen über den gefallenen Niederschlag und die Niederschlagsvorhersagen des Deutschen Wetterdienstes (DWD).

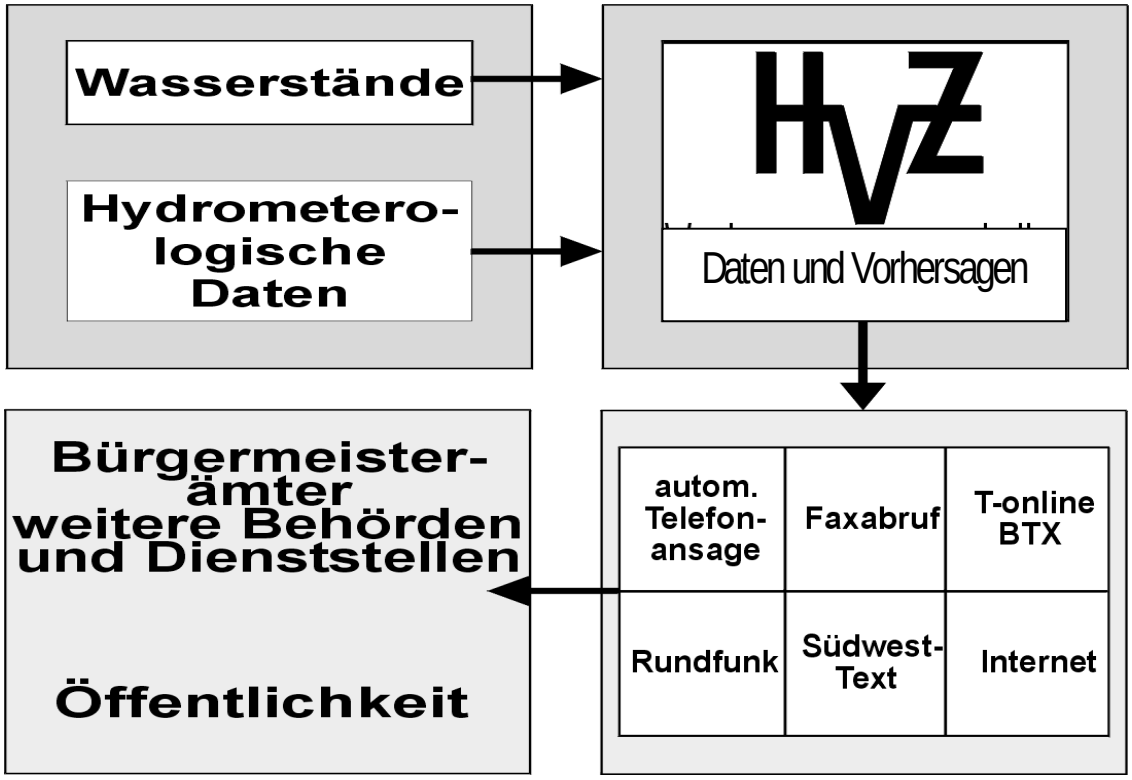

Abb. 4 Informationsverteilung durch die HVZ

Aktuelle Informationen werden in einem Lagebericht zusammengefaßt und bereit gestellt. Auch Interviews mit unterschiedlichen Radio-Sendern werden genutzt um die Bevölkerung zu informieren.

4 Fortschreibung der Systeme

4.1 *Ziele*

Die Systeme werden laufend mit folgenden Zielen fortgeschrieben:

- Einbeziehung weiterer Pegel in die Vorhersage. Dies gilt insbesondere für den Pegel Neu-Ulm Bad Held, welcher direkt unterhalb der Einmündung der Iller liegt.
- Eine hohe Zuverlässigkeit der Vorhersagen auch bei aussergewöhnlichen Ereignissen.
- Eine Abschätzung über die zu erwartende Höhe des Hochwassers zu einem möglichst frühen Zeitpunkt.

4.2 *Maßnahmen zur Fortschreibung der Systeme*

4.2.2 Aufbau eines Wasserhaushaltmodelles für die Donau

Das Land Baden-Württemberg baut sukzessive ein flächendeckendes Wasserhaushaltsmodell für die routinemäßige Vorhersage von Mittel- und Niedrigwasserabflüssen auf. 1999 wurde das Wasserhaushaltsmodell Neckar erstellt, derzeit ist das Wasserhaushaltsmodell Donau im Aufbau. Die Modelle basieren auf dem Programmsystem LARSIM [Bremicker 1998], eine Fortschreibung von FGMOD.

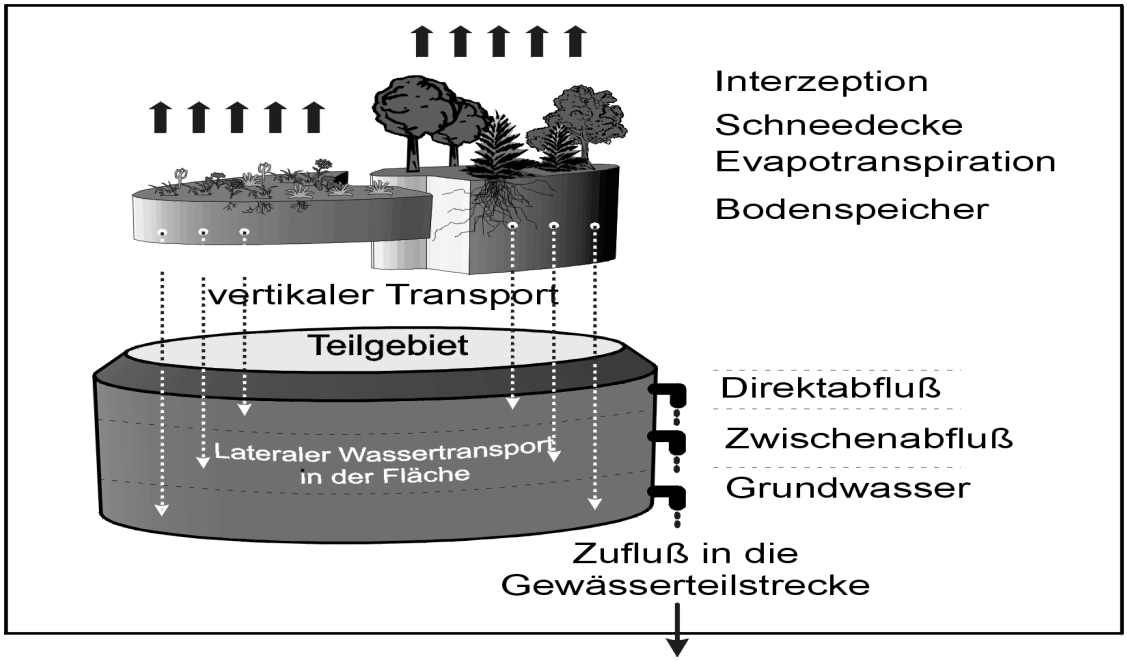

Abb. 5 Schematische Darstellung eines Teilgebietmodells zur Abflussbildung aus Niederschlag in LARSIM.

Der Modellaufbau entspricht dem von FGMOD, jedoch bietet LARSIM zusätzliche Möglichkeiten, z.B. eine Berechnungsoption zur kontinuierlichen Simulation. Die Modelle werden für die Einzugsgebiete als Rastermodelle mit einer Maschenweite von 1 km aufgebaut.

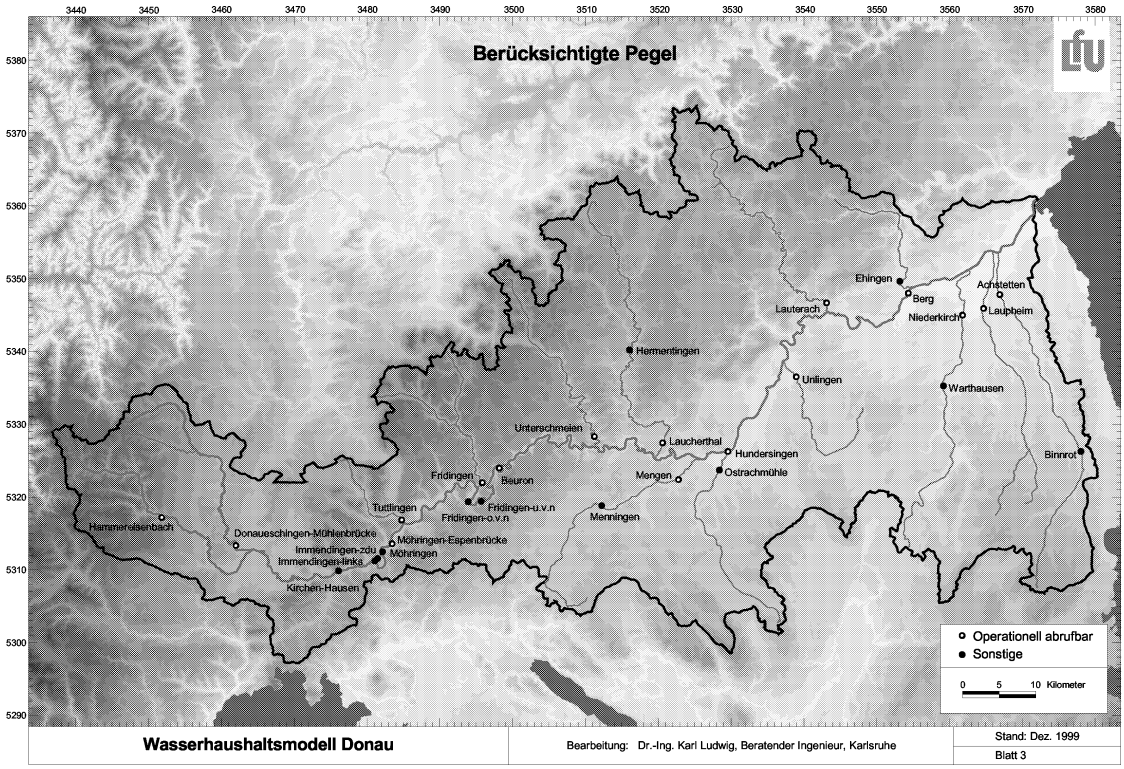

Abb. 6 Gebiet des Wasserhaushaltsmodell Donau mit den berücksichtigten Pegeln

Die obenstehende Abbildung verdeutlicht die Abflussbildung eines Teilgebietes aus dem Niederschlag:Die bei den täglichen Berechnungen gewonnenen Modellparameter (aktuelle Boden-

feuchte, Speicherparameter) können für das Hochwasservorhersagemodell genutzt werden, um so schon zu Beginn eines Hochwassers die momentanen Abflusseigenschaften eines Einzugsgebietes zu erfassen. Dies dürfte zu zuverlässigeren ersten Vorhersagen über den zu erwartenden Anstieg führen.

4.2.3 Gewinnung quantitaitver, flächendeckender Niederschläge aus Radar

Im letzten Jahr wurde das Radarverbundnetz des DWD fertiggestellt. Derzeit werden Verfahren zur kontinuierlichen Aneichung der Radardaten anhand der online übertragenen Messungen der Niederschlagsstationen entwickelt und umfangreiche statistische Auswertungen an einzelnen Standorten vorgenommen. Nach Abschluss des Projektes im Jahr 2002 werden räumlich und zeitlich hoch aufgelöste Niederschlagsverteilungen in Echtzeit zur Verfügung stehen [Bartels 1998].

4.2.4 Verbesserungen der operationellen Schneeschmelzvorhersage

Während des Hochwassers Februar 1999 wurde das Modell SNOW erstmals operationell für das Donaugebiet eingesetzt. Der Hochwasserscheitel konnte mit den daraus gewonnen Vorhersagen gut berechnet werden. Es zeigte sich jedoch auch, dass im operationellen Betrieb noch Verbesserungen notwendig sind. So werden künftig die Berechnungen häufiger (viermal statt einmal täglich) durchgeführt und die Daten von mehr Messstationen berücksichtigt. Selbstverständlich werden dann auch die aktuellen Vorhersagen des Wetter-Vorhersage Modelles des DWD (Niederschlag, Temperatur etc.) einbezogen.

Zusätzlich werden Fortschreibungen des Modelles geprüft. Insgesamt sind aktuellere und genauere Vorhersagen des Schneedeckenausflusses zu erwarten.

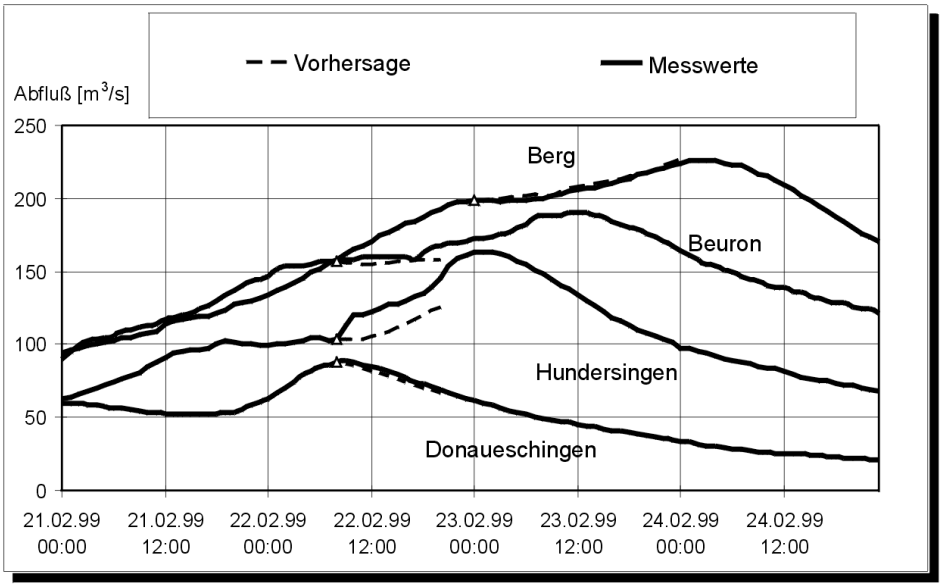

Abb. 7 Verschiedene Hochwasservorhersagen für die Donau, Hochwasser Februar 1999

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A Seasonally Varying Weighted Average Method for the Combination of River Flow Forecasts

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Abstract: A modification of the Weighted Average Method (WAM) is used in the context of the combination of river flow forecasts. The essence of this concept is that the synchronous outputs (i.e. the discharge forecasts) of a number of structurally different river flow forecasting models are combined to provide an overall 'consensus' discharge forecast that would be more accurate and reliable than that of the best of the individual models. In the standard WAM, the combined discharge forecast is the weighted sum of the discharge forecasts of the individual river flow forecasting models, where the weights are taken as being time-invariant. In the present study, a Seasonally Varying Weighted Average Method (SVWAM) for forecast combination is developed which is based on the postulate that each weight of the WAM has a simple periodic variation throughout the year. The SVWAM is applied to the data of six catchments from different geographical locations. The performance of this modified WAM is compared with that of the standard WAM, considering also the corresponding forecast efficiencies of the discharge forecasts of the individual models included in the combination process.

Keywords: river flow forecasting, forecast combination, weighted average method, seasonally varying weighted average method)

Eine saisonal variierende Methode des gewogenen Mittels für die Erstellung von hydrologischen Prognosen für Fließgewässer

Zusammenfassung: Eine Modifikation der Methode der gewichteten Mittel (MGM) wird für die Kombination von Abflussvorhersagen verwendet. Das Wesen dieses Konzepts beruht auf der Kombination der gleichartigen Outputs (d.h. die Durchflussprognosen) einer Anzahl von strukturell verschiedenen hydrologischen Abflussprognosemethoden, um so eine insgesamt "allgemein übereinstimmende" Strömungsprognose erstellen zu können, welche genauer und verlässlicher ist als die des besten Einzelmodells. In der Standard-MGM ist die kombinierte Abflussprognose die gewichtete Summe der Abflüsse der einzelnen hydrologischen Prognosemodelle, in der die Gewichte als zeit-invariabel angesehen werden. In der vorliegenden Studie wird eine saisonal variierende Methode der gewichteten Mittelwerte (SVMGM) zur Prognosekombination entwickelt, die auf der Annahme beruht, dass jedes Gewicht der MGM durch das Jahr hindurch eine einfache periodische Abweichung verzeichnet. Die SVMGM wird auf die Daten von sechs Einzugsgebieten in unterschiedlichen geographischen Lagen angewandt. Die Ergebnisse dieser abgewandelten MGM werden mit jenen der Standard-MGM verglichen, wobei auch die jeweilige Prognose-Effizienz der Abflussprognosen der individuellen, im kombinierten Prozess inkludierten Modelle berücksichtigt wird.

Schlüsselwörter: Hydrologische Prognosen für Fließgewässer, Prognosekombination, Methode der gewogenen Mittel, saisonal variierende Methode.

1 Introduction

A modification of the concept of river flow forecast combination, originally introduced in the context of river flow forecasting by Shamseldin (1996) and Shamseldin et al. (1997), is presented. This concept advocates the synchronous use of the discharge forecasts of a number of different river flow forecasting models in order to provide an overall combined discharge forecast that would be more accurate than those of the individual models. Such a procedure may

be perceived as being a rather simple alternative to the iterative method of systematic model refinement for improving the accuracy of river flow forecasts for a particular catchment. In the combination concept, the discharge forecast of each selected model is viewed as representing an 'expert opinion' and, as the opinions of experts generally differ in emphasis, if not in substance, the combined forecast is viewed as representing the 'consensus' opinion of the selected group of 'experts'.

The justification of using the combination concept in the context of river flow forecasting is that, at the present time, there is no near-perfect super-model available to truly define the rainfall-runoff transformation. Yet the forecast results available from each individual model may well accurately reflect certain (but different) aspects or characteristics of the true nature of the real relation and so the judicious combination of these results would be expected to provide more reliable forecasts.

Shamseldin et al. (1997) tested the performance of three model-output combination methods, namely, *the Simple Average Method* (SAM), *the Weighted Average Method* (WAM), and *the Neural Network Method* (NNM) using the discharge forecasts of five rainfall-runoff models in eleven catchments from different parts of the world. The first two of these combination methods are linear techniques, the third one being non-linear. The results of the study by Shamseldin et al. (1997) indicated that the combined discharge forecasts are indeed superior to those of the best of the models involved in the combination. Pursuing this theme, the present work addresses the time-variance of the natural catchment system as a further development of the WAM.

In the standard Weighted Average Method (WAM), the combined discharge forecast is obtained as the weighted sum of the discharge forecasts of the individual models, where the weights assigned to the different models are assumed to be constant (i.e. time-invariant). In the proposed Seasonally Varying Weighted Average Method (SVWAM), however, each individual weight is assumed to have a seasonal variation throughout the year.

This Seasonally Varying Weighted Average Method (SVWAM) is tested using the daily discharge forecasts of five rainfall-runoff models operating on the data sets of six catchments. The five selected models are; the Simple Linear (Total Response) Model (SLM) (Nash and Foley, 1982; Kachroo and Liang, 1992), the seasonally-based Linear Perturbation Model (LPM) (Nash and Barsi, 1983), the Linearly-Varying Variable Gain Factor Model (LVGFM) (Ahsan and O'Connor, 1994), the Constrained Linear Systems with a Single Threshold (CLS-Ts) (Todini and Wallis, 1977; Xia, 1989) and the Soil Moisture Accounting and Routing Procedure (SMAR) (O'Connell et al., 1970; Kachroo, 1992; Khan, 1986; Liang, 1992). These are all relatively unsophisticated lumped models, the first four being of the system-theoretic (black-box) variety and the fifth being a lumped quasi-physical conceptual model. These models are described in considerable detail by Shamseldin et al. (1997). The six chosen test catchments have different geographical locations in the world, having various sizes and climatic conditions. A brief summary description of these catchments is presented in table 1. The efficiency of the discharge forecast results obtained for the SVWAM are compared with the corresponding results of the standard WAM and also with those of the individual models included in these two variations of the combination procedure.

2 The Seasonally Varying Weighted Average Method (SVWAM)

According to the Weighted Average Method (WAM), the combined output (i.e. the discharge forecast) Qc_i is a weighted sum of the corresponding outputs of the individual models, that is;

$$Qc_i = \sum_{j=1}^{N} w_j \, \hat{Q}_{i,j} \qquad (1)$$

where w_j is the weight assigned to the output of the *j-th* model, N is the number of models used in the combination and $\hat{Q}_{i,j}$ is the estimated discharge of the *j-th* model for the *i-th* time period, the weights w_j being considered as time-invariant. It is quite plausible that some models would perform better than the other models during certain periods of the year. In such cases, it would seem appropriate that the weights would also vary throughout the year, as the adoption of constant weights would adversely affect the performance of the WAM method. This concept is similar to that of the seasonally varying runoff coefficient tested in the context of the SLM by Kachroo et al. (1992).

In the Seasonally Varying Weighted Average Method (SVWAM), each individual weight is assumed to vary throughout the year in a periodic fashion, according to the equation;

$$w_{i,j} = \eta_j + \sum_{k=1}^{p} \left\{ A_{k,j} \cos\left(\tfrac{2\pi ki}{n}\right) + B_{k,j} \sin\left(\tfrac{2\pi ki}{n}\right) \right\} \quad (2)$$

where η_j is constant, $w_{i,j}$ is the weight assigned to the j-th model for the i-th time period, $A_{k,j}$ and $B_{k,j}$ are coefficients, p is the number of harmonics and n has the value of 365 for the case of daily data (as used in the present study). In the above equation, if p is equal to zero or the coefficients $A_{k,j}$ and $B_{k,j}$ all have zero values, then the SVWAM structure collapses back to that of the standard WAM.

Substituting equation (2) into equation (1) and including an output error term e_i, the relationship between the observed discharge Q_i and the corresponding forecast values of the individual models can be expressed as

$$Q_i = \sum_{j=1}^{N} \eta_j \hat{Q}_{i,j} + \sum_{j=1}^{N} \sum_{k=1}^{p} \left\{ \hat{Q}_{i,j} A_{k,j} \cos\left(\tfrac{2\pi ki}{n}\right) + \hat{Q}_{i,j} B_{k,j} \sin\left(\tfrac{2\pi ki}{n}\right) \right\} + e_i \qquad (3)$$

By letting $Y_{i,(j-1)p+k} = \hat{Q}_{i,j} \cos\left(\tfrac{2\pi ki}{n}\right)$ and $Z_{i,(j-1)p+k} = \hat{Q}_{i,j} \sin\left(\tfrac{2\pi ki}{n}\right)$, equation (3) can be expressed as

$$Q_i = \sum_{j=1}^{N} \eta_j \hat{Q}_{i,j} + \sum_{j=1}^{N} \sum_{k=1}^{p} \left\{ Y_{i,(j-1)p+k} A_{k,j} + Z_{i,(j-1)p+k} B_{k,j} \right\} + e_i \qquad (4)$$

Equation (4) can also be expressed in matrix/vector notation as;

$$\mathbf{Q} = \mathbf{XH} + \mathbf{E} \quad (5)$$

where $Q = (Q_1, Q_2, Q_3, \wedge\wedge, Q_{K-1}, Q_K)^T$ is the output column vector, T denoting the transpose of the vector, *K* is the total number of observations, H is the parameter column vector defined by

$$\mathbf{H} = (\eta_1, .., \eta_N, A_{1,1}, A_{2,1}, .., A_{p,1}, .., A_{1,2}, .., A_{p,2}, .., A_{p,N}, B_{1,1}, B_{2,1}, .., B_{p,1}, .., B_{1,2}, .., B_{p,2}, .., B_{p,N})^{\mathrm{T}}$$

$\mathbf{E} = (e_1, e_2, e_3, \wedge\wedge, e_{K-1}, e_K)^T$ is the combination error column vector and **X** is the input matrix which is defined as

$$\mathbf{X} = \begin{bmatrix} \hat{Q}_{1,1} & \Lambda & \hat{Q}_{1,N} & Y_{1,1} & \Lambda & Y_{1,p} & \Lambda & Y_{1,Np} & Z_{1,1} & \Lambda & Z_{1,p} & \Lambda & Z_{1,Np} \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} \\ \hat{Q}_{i,1} & \Lambda & \hat{Q}_{i,N} & Y_{i,1} & \Lambda & Y_{i,p} & \Lambda & Y_{i,Np} & Z_{i,1} & \Lambda & Z_{i,p} & \Lambda & Z_{i,Np} \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} \\ \hat{Q}_{K,1} & \Lambda & \hat{Q}_{K,N} & Y_{K,1} & \Lambda & Y_{K,p} & \Lambda & Y_{K,Np} & Z_{K,1} & \Lambda & Z_{K,p} & \Lambda & Z_{K,Np} \end{bmatrix}$$

Equation (5) may be regarded as a multiple regression model and the unknown parameter vector **H** may be estimated using the method of ordinary least squares, i.e. by minimising the sum of the squares of the differences between the observed discharges and the corresponding combined estimated discharges. The ordinary least squares estimate of the parameter vector $\hat{\mathbf{H}}$ is then given by

$$\hat{\mathbf{H}} = (\mathbf{X}^{\mathbf{T}}\mathbf{X})^{-1}\mathbf{X}^{\mathbf{T}}\mathbf{Q} \qquad (6)$$

3 Application of the Seasonally Varying Weighted Average Method

The Seasonally Varying Weighted Average Method (SVWAM) is tested using the daily discharge forecasts of the five selected rainfall-runoff models (i.e. SLM, LPM, LVGFM, CLS-Ts and SMAR) for the six test catchments. The available data record is split into two parts (i.e. split sampling), one part being used for model calibration, the remaining part being used for verification of the model. Table 1 shows the lengths of the calibration and the verification periods for the test catchments. The SVWAM is calibrated by the method of ordinary least squares, using equation (6), with the number of harmonics p taken as one. Preliminary tests carried out by the authors indicated that there is no substantial improvement in the performance of the SVWAM by increasing the number of harmonics beyond one.

Table 2 shows the Nash-Sutcliffe R^2 model efficiency values for the forecasts of the five selected rainfall-runoff models and also for the WAM and the SVWAM combination forecasts. The R^2 model efficiency criterion (Nash and Sutcliffe, 1970) is calculated using the following equation

$$R^2 = 1 - \frac{F}{F_o} \qquad (7)$$

where F is defined as the sum of the squares of the differences between the estimated discharges $\hat{Q}_i$ and the corresponding observed discharges Q_i and F_o is the 'initial variance', which is defined as the sum squares of differences between the observed discharges and the mean discharge of the calibration period.

Table 1 Summary description of the six test catchments.

Catchments	Sunkosi-1	Yanbian	Brosna	Halda	Shiquan-3	Baihe
Country	Nepal	China	Ireland	Bangladesh	China	China
Area (km^2)	18000	2350	1207	779	3092	61780
Average Rainfall (mm/day)	4.65	3.28	2.2	6.75	2.3	2.59
Average Evaporation (mm/day)	3.3	5.79	1.31	2.77	2.41	2.89
Average Discharge (mm/day)	3.63	2.55	0.98	4.84	0.98	1.04
Calibration Period (years)	6	6	8	5	6	6
Verification period (years)	2	2	2	2	2	2
Data Starting date	1 Jan. 1975	1 Jan. 1978	1 Jan. 1969	1 Apr. 1980	1 Jan. 1973	1 Jan. 1972

Examination of table 2 shows that, in the calibration periods, both the WAM and the SVWAM have better (i.e. higher) R^2 values than those of the individual rainfall-runoff models, the

performance of the SVWAM being consistently better, in terms of R^2, than the WAM for each of the six test catchments.

For the verification periods, in the case of two catchments (Yanbian and Brosna), the standard WAM has higher R^2 values than those of the five individual rainfall-runoff models. In the case of three of the remaining four catchments, namely, Sunkosi-1, Halda and Shiquan-3, the R^2 values of the WAM are greater than those of the worst four of the individual models. In the case of the Baihe catchment, however, the WAM outperforms only two of the individual models, namely, the LVGFM and the CLS model. Referring still to the verification periods, in the case of four of the catchments, (Yanbian, Brosna, Halda and Baihe), the SVWAM is seen to perform better than the five individual models, while in the case of the two remaining catchments (Sunkosi-1 and Shiquan-3) it performs better than the four worst models.

Table 2 The R^2 efficiency results of the Five Models, the WAM, and the SVWAM.
Calibration period

Model	Sunkosi-1	Yanbian	Brosna	Halda	Shiquan-3	Baihe
			R^2 (%) values			
SLM	85.8	73.7	40.1	81.7	72.0	70.40
LPM	92.0	83.0	70.3	84.6	76.9	74.3
LVGFM	88.6	78.1	41.4	83.6	87.6	87.2
CLS	90.5	81.6	47.0	84.0	75.8	83.3
SMAR	89.8	85.9	85.8	85.5	89.7	83.3
WAM	92.9	87.7	89.0	87.2	91.8	90.0
SVWAM	**93.4**	**89.8**	**91.2**	**88.6**	**92.5**	**91.4**

Table 2 contd.

Verification period

Model	Sunkosi-1	Yanbian	Brosna	Halda	Shiquan-3	Baihe
			R^2 (%) values			
SLM	83.4	75.7	45.7	72.4	54.0	70.5
LPM	**90.5**	79.2	77.5	77.2	56.2	73.2
LVGFM	83.6	76.4	48.1	75.3	**79.0**	61.5
CLS	84.6	81.1	60.3	66.5	57.3	65.5
SMAR	85.2	83.9	85.4	84.6	68.2	72.8
WAM	89.0	86.1	88.2	82.3	77.1	66.5
SVWAM	87.6	**86.7**	**90.6**	**85.5**	72.8	**74.9**

Comparison of the results of the SVWAM with the WAM, for the verification periods, shows that the SVWAM has higher R^2 values than the WAM in the case of four of the catchments, namely, Yanbian, Brosna, Halda and Baihe. In one the remaining catchments (Sunkosi-1), the R^2 values of the WAM and the SVWAM are 89.0 % and 87.6 % respectively, while in the other remaining catchment (Shiquan-3), the R^2 values of the WAM and the SVWAM are 77.1 % and 72.8 %, respectively.

4 Conclusions

In the present study, a Seasonally Varying Weighted Average Method (SVWAM) for river flow forecast combination is presented and applied. The SVWAM is based on the assumption that weights assigned to the different individual model forecasts vary throughout the year and that such variation can be represented by a simple periodic function.

The SVWAM is tested using the discharge forecasts of five rainfall-runoff models applied to six catchments and the R^2 model efficiency values so obtained are compared with those of the individual models included in the combination. The performance of the SVWAM is also compared with that of the standard Weighted Average Method (WAM) in which the weights assigned to the different models are assumed to be constants. The results presented in the present paper indicate that the combined discharge forecasts are generally more accurate and reliable than those of the individual models. These results are in general agreement with those of the previous river flow forecast combination studies of Shamseldin (1996), Shamseldin et al. (1997) and Shamseldin and O'Connor (1999). Comparison of the R^2 model efficiency values of the SVWAM with those of the WAM suggests that the performance of the SVWAM is generally better than that of the WAM. Overall, the conclusion is that the combination of individual model forecasts using the simple SVWAM is justified and should be seriously considered when such forecasts are readily available.

In future applications of the SVWAM, consideration should be given to the on-line adjustment of the parameters of the SVWAM and the further modification of the procedure to enable its application in updating non-simulation mode and thereby to facilitate the use of the SVWAM for real-time river flow forecasting. Such considerations are currently under investigation by the present authors.

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Die Karpaten - die hochwassergefährlichste Region in der Ukraine

Mykhaylo Sosyedko, Olga Luk`yanetz

Zusammenfassung: Die Gebiergsketten von den Karpaten bilden orographische Hindernisse für die Versetzung der Luftmassen, die vom Atlantik herankommen. Infolgedessen erreichen Sturzregen 150-250 mm in den 24 Stunden und umfassen gleichzeitig 15-30 Tsd. km^2. Hochwässer verschiedener Höhen wiederholen sich an den Karpatischen Flüssen 3-8 Male pro Jahr. Besonders grohende Hochwässer ereignen sich während der Perioden mit hoher Wasserführung. Hochwässer in den Karpaten sind gewöhnliche Naturerscheinungen für dieser Region.

Schlüsselworte: Hochwässer, Sturzregen, Hochwasserhäufigkeit, Hochwassermengen

The Carpathians are the Most Dangerous Region in the Ukraine about Floods

Abstract: Mountain ridge of the Carpathians makes an orographic obstacle for transforence of the Atlantic air masses. On accout of that continuous heavy rains reach 150-250 mm during 24 hours and evelop simultaneously about 15-30 thousand km^2. The floods of different heigt be repeated on Carpathians rivers 3-8 times per year. Unusually menacing floods happen at the higt stream-flow periods. The floods in the Carphatians are common natural occurrences for that Region.

Key words: floods, heavy rains, flood frequency, maximum discharges

1 Einleitung

Hochwasserereignisse in den Karpaten (Theiβ-, Dnister- und Prut-Fluβbecken) zeichnen sich durch Häufigkeit, Entstehungsintensität und gleichzeitige Verbreitung auf beträchlichen Gebiete aus. Ofters nehmen die Hochwässer gefährliche Erscheinungen an, die zerstörende Folgen haben.

Erforschungen und Erkennungen an diesen Naturereignissen, insbesondere von ihrer Häufigkeit, sind von groβem Wert über die Lösung verschiedener wirtschaftlicher Probleme. Solche Angaben werden auch für die Hochwasservorgesagen gedint.

In diesem Vortrag werden sich an einige Einzugsgebiete erinnert, die in der Tabelle 1 vorgestellt sind.

Tabelle 1 Ausgewählte Abfluβmeβstellen an den Karpaten-Flüssen

Gewässer	Meβstelle	Einzugsgebietsgröβe, km^2	Mehrjärige Abfluβmittelwert, m^3/s
Theiβ	Rachiw	1070	24.7
Theiβ	Wylok	9140	209
Rika	Mishgirja	550	13.6
Borshawa	Schalanky	1100	20.8
Latoryzja	Mukaceve	1360	25.5
Latoryzja	Tschop	2870	34.9

Ush	Ushgorod	1970	29.2
Dnister	Zalistschyky	24600	230
Prut	Tscherniwzi	6890	77.6

2 Besonderheiten der Hochwasserentstehung in den Karpaten

Zu den Hauptumständen, welche Hochwassererscheinungen hervorrufen, gehören intensive Regenfälle und Gegendorographie.

Die Gebirgsrücken von den Karpaten bilden orographische Hindernisse für die Versetzung der Luftmassen, die vom Atlantik während der Zyklonentätigkeit ankommen. Infolgedessen werden atmosphärische Prozesse gestört. Dabei halten sich feuchte Luftmassen unter den Einfluβ der Gebirge auf und befinden sich verhältnismäβig lange Zeit in der Zone der aufsteigenden Strömungen [1]. Solcherweise geschieht eine Intensifikation der Sturzregenfälle. Gegebenenfalls können die Niederschläge von 70-150 mm pro 12 Stunden und von 150-250 mm während der 24 Stunden erreichen. Solche strömende Regen verbreiten sich während der Durchgänge der atmosphärischen Fronten fast gleichzeitig auf die Territorien bis zur 15-30 Tsd. km^2 [2-4,7].

Insorfern Landschaftsgefälle im Gebirge 200-500 m/km übertreffen, ereignen sich Abfluβbildungsprozesse im Laufe von Sturzregen sehr intensiv. Die Vorstellungen über Intensität dieser Prozesse können folgende Angaben von maximalen Abfluβspenden machen. In den Karpaten gelangen diese Kennzifern aus Einzugsgebieten mit 100-200 km^2 bis zu 2500-3100 l/s. km^2. In den Flüssen mit den Einzugsgebietsflächen von 300-500 km^2 stellen sich maximale Abfluβspenden nicht selten um 1000-2000 l/s. km^2 gleich, wogegen Abfluβspenden solcher Wahrscheinlichkeit an Flachlandflüssen von der Ukraine 50-200 l/s.km^2 nicht übertreffen.

Obergenannte Fluβbecken befinden sich in den Grenzen zweier Orographiegebiete (im Gebirge und auf dem Flachland). Diese Besonderheit ist sehr gut im Theiβ- und Dnistereinzugsgebiete zu erkennen. Derer gröβte Teile liegen in den Gebirgen und Vorgebirgen, und die übrigen - auf den Ebenen. Mit diesen orographischen Eigenheiten sind gröβerenteils Wasserregime der Flüsse während der Hochwasserereignisse verbunden. Beträchtliche Landschaftsgefälle werden im Oberlauf und Mittellauf der Gebirgsflüsse schnelllaufende Hochwasserereignisse hervorrufen, während derer Wasseranstiege von 1.5-2.5 m pro 3-4 Stunden erreichen. Gleichzeitig geschehen schnelle Wasserableitung aus Gebirgsströmen bis zu Fluβtäler der Theiβ oder des Dnisters und ihren Nebenfluβmündungen. Weil ebene Fluβstrecken kleine Gefälle (0.1-0.5 m/km), haben treten zufließende Wassermassen über die Ufer und überschwemmen groβe Fläche, wenn nur die Wasserabführung nicht rechtzeitig gewährleistet wird [4].

Über die Verflachung der Hochwasserwellen an ebenen Fluβstrecken kann man nach folgenden Angaben zu schließen. Zum Beispiel, maximale Hochwasserspenden in Latoryzja an der Strecke von Mukaceve bis Tschop werden solcherweise herabgesetzt (Tab.2).

Tabelle 2 Maximale Abfluβspenden an der Fluβstrecke von Latoryzja

Hochwasser (Monat, Jahr)	**Maximale Abfluβspende, l/s.km^2**	
	bei Mukaceve	**bei Tschop**
Apr. 1962	490	112

Juli 1980	1200	220
Dez. 1981	960	176
Nov. 1998	970	165

3 Hochwasserhäufigkeit

Hochwässer verschiedener Höhen wiederholen sich an den Karpatenflüssen 3-8 Male pro Jahr. Aber besonders drohende Hochwasserereignisse kommen in den Perioden hoher Wasserführung vor, welche durch groβräumige atmosphärische Vorgänge bedingt [9, 10].

Die Erforschungen der mehrjährigen Abfluβschwankungen in den obengenannten Fluβgebieten mit Benutzung der Beobachtungsreihen von 90-120 Jahren zeugen von folgender Gezetzmäβigkeit in den Karpaten. Hier zeigen sich Aufeinanderfolgen von Zeitabschnitten mit hoheren und niedrigen Wasserführungen genügend stabil. Durchschnittliche Zeitdauern dieser Perioden machen 13-17 Jahre aus (Abb.1).

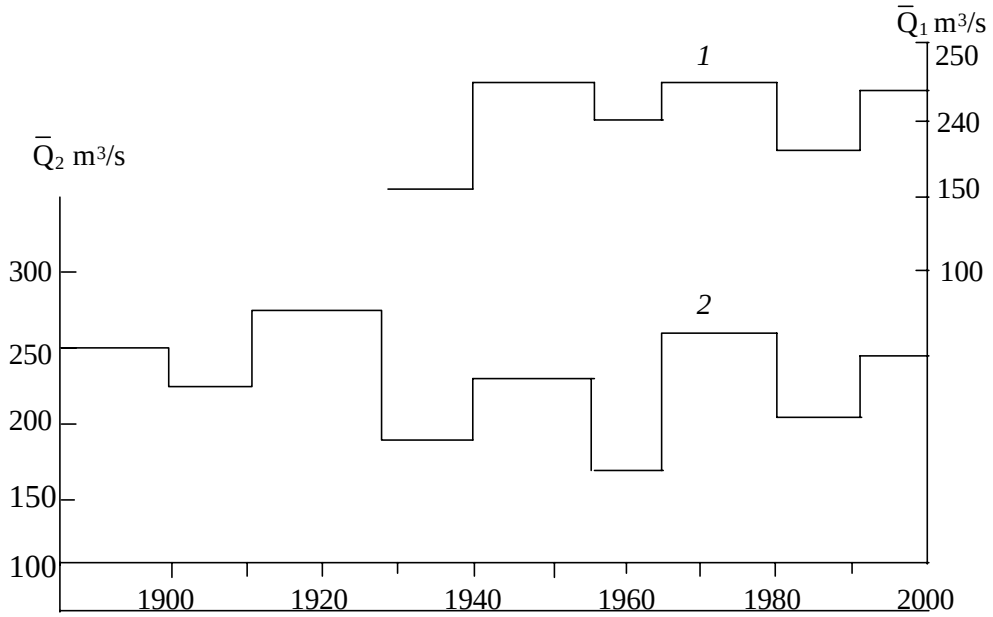

Abb. 1 Abfluβgänge nach den Wasserführungsperioden

1) Theiβ - Wylok
2) Dnister - Zalistschyky

Erste Erinnerungen über bedeutende Hochwasserereignisse in den Karpaten sind zu uns aus Literaturquellen gekommen, die zum XII. Jahrhundert gehören [8]. Einige Beschreibungen ihrer zerstörenden Folgen zeugen, daβ diese Naturgewalten von Murgangerscheinungen begleitet wurden.

Im XX. Jahrhundert wurden hohe Wasserführungen mit häufigen Hochwasserereignissen in den Jahren 1912-1927, 1940-1955 und 1965-1981 vermerkt (Tab.3). Die bedeutendsten Hochwässer in diesen Perioden, die auβerdem von Murerscheinungen begleitet wurden, haben auf etlichen Karpaten-Gebiete übergegriffen (1927, 1941, 1969, 1970). Diese Naturgewalten haben zu groβen Schaden, Zerstörungen und Überschwemmungen geführt.

Die Perioden der hohen Wasserführung sind durch beträchtliche Niederschläge bezeichnend, die öfters für einige Jahre und viele Monate um 2-3 Male mehrjährige Mittelwerte überstiegen wurden. Im XX. Jahrhundert werden die Jahre 1902, 1912, 1941, 1970, 1980, 1998 im Theiß-Flußgebiet besonders ausgezeichnet, wenn 1600-2400 mm in einem Jahr und 250-400 mm in einigen Monaten (bei normalen Werten 1000-1100 mm und 70-120 mm entsprechend) gefallen sind.

Tabelle 3 Maximale Hochwassermengen für die verschiedenen Wasserführungsperioden

Periode	**Wasser-führung**	**Maximale Hochwassermengen, m^3/s**		
		Theiß - Wylok	**Dnister - Zalistschyky**	**Prut - Tscherniwzi**
1883-1898	h	-	1880, 2300, 4440	-
1899-1911	n	-	2110, 3070, 3730	-
1912-1927	h	-	2860, 4070, 4120	-
1928-1939	n	-	1040, 2460, 2880	-
1940-1955	h	2070, 2270, 2920	3180, 3420, 8040	1220, 2710, 2820
1956-1964	n	1460, 1520, 2010	1220, 1630, 1740	1180, 1510, 2280
1965-1981	h	2720, 3060, 3650	3300, 3910, 5970	3050, 3880, 5200
1982-1991	n	1780, 1980, 2550	2010, 2250, 2700	1370, 1610, 1950
1992-1998	h	2390, 2910, 3150	1940, 2810, 4080	1440, 1750, 1940

Anmerkung. Die Wasserführungen: h - hohe, n - niedrige.

So, am Ende vom August und am Anfang des Septembers 1941 waren außerordentlich hohe Hochwässer mit zerstörenden Folgen in ganzem Karpaten-Gebiet stattgefunden. In dieser Periode waren Wasserstände an der Dnister-Flußstrecke bei Zalistschyky und oberhalb auf 8-10 m angestiegen. Es war das höchsten Hochwasser für 120-150 Jahre im Dnister-Flußbecken. Einige Forscher meinen, daß die Wahrscheinlichkeit dieser Hochwässer gilt einmal in 250-300 Jahren [8].

Im allgemeinen war das Jahr 1941 von auserordentlicher Bedeutung in der ganzen Karpaten-Region (einschließlich im Rumanien und Ungarn). Dieses Jahr war im XX. Jahrhundert äußerst wasserreiches - die Abflußjahresmittel wurden in 1.7-2.3 Male mehrjährigen Werte übertroffen [11].

Im Juni 1969 waren Dnister- , Prut- und teilweise Theiß-Flußgebiete über Hochwasserereignisse gelitten. Damals wurden Starkregen 20-30 Tsd.km^2 umfasst, wo 150-250 mm während der 24 Stunden gefallen waren. Die Wasserstände an den Dnister und seinen Nebenflüssen wurden in 4-7.5 m im Vergleich zu gewöhnlich niedrigem Wasser angestiegen.

In dieser Zeit war maximaler Wasserstand an der Theiβ bei Rachiw seit dem Jahre 1946 am höhsten.

Im Mai 1970 wurden bedeutende gleichzeitige Hochwasserereignisse im Theiβ-Becken in den Grenzen von der Ukraine und dem Rumanien beobachtet. Die Regenfälle wurden damals auf die Fläche um 50 Tsd. km^2 . verbreitet. Dabei wurden100-150 mm während der 48 Stunden gefallen. In dieser Zeit waren sich die Wasserstände in der Theiβ um 5-6 m erhöht.

Mit nachfolgender hoher Wasserführungsperiode, die in Jahren 1992-1993 begann, wurden sich bedentende Hochwässer in den letzten Jahren in allen Karpaten-Fluβbecken und auch im Mitteleuropa ereignet.

Besonders heftige Hochwassersituation mit raumausgedehnten Hochwässer seltener Wahrscheinlichkeit waren im November 1998 an den Flüssen von Theiβ-Fluβbecken geschehen. Im 1998 reichliche Niederschläge haben mehrmalige Hochwasserereignisse von April bis Oktober verursacht. Extreme Regenfälle am 4-5. November führten zum beträchtlichen Hochwässer. In diesen Tagen wurden die Niederschlagssummen meistens 100-230 mm erreicht. Dieses Hochwasser gehört zu den Ereignissen seltener Häufigkeit. Maximale Abfluβmengen und Wasserstände waren im Vergleich mit allen während der letzten 60 Jahre registrierten Werten auβergewöhnlich (Überschreitungswahrscheinlichkeit ist 1.5-5 % gleich).

Für das Theiβ-Einzugsgebiet sind warme Wettergeschehen mit häufigen Regenfällen im Herbst und am Winteranfang eigen. Darum ereignen sich hier im November und Dezember etwa 20-30 % von allen Hochwässer, die im Laufe eines Jahres geschehen (Tab.4). D.h., Regenhochwässer von diesen Monaten sind in 40-70 % Jahren beobachtet. Dabei können maximale Wasserstände in 15-30 % Fällen die Höchstwerte anderer Hochwässer entsprechendes Jahres übertreffen.

Tabelle 4 Anzahl und Häufigkeit der Hochwassergeschehen in den Jahren 1947-1998 (Theiβ-Fluβbecken)

Gewässer-Pegel	**Ganze Anzahl der Hochwässer**	**Hochwasserhäufigkeit im November und Dezember, %**	
		den allen Jahren gegenüber	**den allen Hochwässer gegenüber**
Theiβ - Rachiw	117	48	21
Theiβ - Wylok	91	56	22
Rika - Mishgirja	132	71	26
Borshawa - Schalanky	140	65	24
Latoryzja - Mukaceve	82	60	30
Ush - Ushgorod	88	72	25

Anmerkung. Dabei werden jene Hochwässer in Betracht gezogen, welche minimale jährliche Höchstwassermengen für mehrjährige Periode übertreffen.

4 Abschließende Bemerkungen

Solcherweise, Hochwasserereignisse in den Karpaten sind gewöhnliche für diese Region Naturerscheinungen. Sie werden durch Lage der Gebirgsrücken, die auf dem Wege der aus dem Atlantik versetzenden Luftmassen liegen, und Landschaftsbesonderheiten der Flußeinzugsgebiete bedingt.

Die Wassernaturkräfte haben den Karpaten immer Sorgen gemacht und werden im weiterem beunruhigen. Darum braucht die Karpaten-Region entspechende stetige Aufmerksamkeit und sie soll in hohen Ansehen stehen.

Für den Schutz gegen Hochwässer ist es unumgändlich notwentig entspechende Maßnahmen zu verfügen. Aber sie müssen unaufschieblich, ständig, ernst und dringend verwirklichen.

Dringende Entscheidung braucht auch die Tätigkeitsverbesserung des hydrometeorologischen Nachrichtendienstes.

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Estimation of Flooding Risk Indices Using the Geographic Information System and Remotely Sensed Data

Gheorghe Stancalie, Corina Alecu, Simona Catana, Marinela Simota

Abstract: Floodings are an important risk in many areas around the globe and especially in Romania. In the latest years floodings occurred quite frequently in Romania, some of which isolated, others were affecting wide areas of the country's territory. The paper assumes a modern approach for the flooding risk indices, associated to the physic-geographical, morpho-hydrographical and vulnerability characteristics of a region, in view to establish a methodology which should further allow to determine the flooding risk, using representatives indices at a scale compatible with a synthetic representation of the territory. There are stressed the facilities supplied by the Geographic Information System (GIS) and the remotely sensed data to manage flooding during their characteristic phases: before, during and after flooding. Accent is laid on the pre and post-crisis phases. The application was developed for the Arges hydrographic basin in Romania, a critical area, keeping in mind that it withholds many localities, including the capital and also important economic centres.

Key words: flooding, remote sensing, risk indices, Geographic Information System

Einschätzung der Überflutungsrisikoindikatoren unter Anwendung eines Geographischen Informationssystems und Fernerfasster Daten

Zusammenfassung: Überschwemmungen sind ein großes Risiko in vielen Gegenden weltweit und insbesonders in Rumänien. In den letzten Jahren traten häufig Überschwemmungen in Rumänien auf, von denen manche isoliert, andere große Gebiete des Landes betrafen. Dieses Papier stellt einen neuen und modernen Ansatz zur Risikobewertung anhand von Indices dar, welche mit den räumlich-geographischen und morpho-hydrographischen Charakteristiken sowie der Schadensanfälligkeit einer Region zusammenhängen, im Hinblick auf die Einführung eines Verfahrens, welches die Bestimmung des Überflutungsrisikos anhand repräsentativer Indikatoren in einem mit der synthetischen Wiedergabe des Gebietes vergleichbaren Maßstab erlaubt. Aufgezeigt werden die Möglichkeiten eines geographischen Informationssystem (GIS) in Verbindung mit fernerfassten Daten hinsichtlich Überflutungsmanagement in den charakteristischen Phasen: vor, während und nach der Überflutung. Hervorgehoben werden die Vor- und Nachkrisenphasen. Die Anwendung wurde für das hydrographische Becken Arges in Rumänien entwickelt, ein kritisches Gebiet, da sich hier viele Ortschaften, die Hauptstadt und bedeutende wirtschaftliche Zentren befinden.

Schlüsselwörter: Hochwässer, Fernerkundung, geographische Informationssysteme, Risikoindikatoren.

1 Introduction

Floodings and the accompanying landslides (mainly caused by abundant precipitation) affect and destroy houses and households, bridges, roads, railroads, telephone and power network, crops, water supply systems, hydrometric installations, leading to dysfunction in the warning and hydrological forecast activity.

Eversince the first satellite observations of the Earth, numerous studies have been achieved using information from the satellite systems and the facilities of GIS technology in the topic of managing flooding connected phenomena. Satellite images are objective information sources, available in time and relatively cheap, for the determination of parameters necessary to monitor and assess floodings and their consequences. Based at the beginning on the use of LANDSAT

data, this activity gained peculiar interest once the possibility yielded for a combined use of remote sensing data from the optic and microwave domain respectively.

The management of data helping to monitor the generated high floods largely relies on the functional facilities supplied by the GIS systems, combined with satellite image-data and the hydrological models. This approach may be used in the differential phases of establishing the sensitive areas, such as: management of the database built up from the ensemble of the spatially geo-referenced information; elaboration of the risk indices on the ground of the morpho-hydrometrical, meteorological and hydrological data; interfacing with the models in view to improve them into what concerns compatibility with input data, recovery of results and the possibility to work out scenarios; presentation of results as synthesis maps easy to access and interpret, additionally adequate to be combined with other information layouts resulted from the database.

2 Study area – Arges basin

The study area represented by the Arges hydrographic basin is affected by flooding as ascertained by the frequency of these phenomena: 1972 – 1973, 1975, 1979, 1983, 1991, 1997, 1998. This area is so much the more critical one, considering that it comprises the capital, as well as several other important economic centres. As regards the results damages, the high flood of March 29 - April 10 1997, alone affected nearly 600 households and annexes, over 4000 ha of arable land, 4 bridges, more than 40 footbridges and 40 Km of roads, along with important hydrotechnical constructions.

Situated in the south of the country, the Arges river, its tributaries included, constitutes one of the most important hydrographic basin in the country with respect to its hydro-energetic potential and the water supplies of the industrial centres and crop lands. Through the position it occupies in a physico-geographic ensemble with specified characters, with a moderate continental climate, sufficiently humid in the mountain areas and drier in the plain, is playing a large variety of the relief and lithology, the Arges river hydrographic basin has a complex hydrological regime.

3 Working method

Forecasting and monitoring phenomena associated to torrential precipitation is very difficult, one hand because of the nature of these phenomena, characterised through violence and spontaneity and on the other – because of the basins' characteristics (size, geomorphology) which make the propagation time, i.e. the reaction interval, generally very short. In this context, prevention and forecast activities must be based on prior identification and localisation of the sensitive areas.

Approaching the previously formulated issue was made at two levels:

- that of the risk degree vis-à-vis the various parameters causing or not floodings;
- that which takes into account the human presence in the sensitive areas. This implies to establish the vulnerability degree, defined function of the human and material costs that flooding may induce.

Integrating the notion of risk in quantifying the potential damages proves to be an absolute necessity, determined by the proportion of the human and economic consequences of the phenomenon.

Given the spatial length of the Arges hydrographic basin the work scale was chosen 1:200 000. The elaboration of digital maps concerning the elements of interest to monitoring and assessing floodings and their consequences aimed at answering self evident small scale forecast necessities, but also to supply documents presumed to bring forth a certain number of answering elements, so as to use information regarding soil occupation and territory management.

Having in view the sizes of the Arges basin and its physico-geographical characteristics, as well as the practical and lucrative constraints, the basin was divided into three areas: upper, middle and mower. The acquisition of the cartographic data and elaboration of thematic layouts as part of the GIS system under ARC/INFO software environment, was made corresponding to these three sectors. The system's facilities allow unifying the layouts of the mentioned basin sectors for ensemble representations as well as to combine the different thematic layouts.

The basic entity in hydrology is the sub-basin defined as the geographic environment, which supplies a water flow. The induced hydrological activity depends on its surfaces geological structure and disposition of the hydrographic network, as well as on the climatic and topoclimatic characteristics. In this sense, there was performed the division of Arges basin in its belonging sub-basins.

4 Structure, attributes and functions of geo - referenced database

The database was structured as an ensemble of file-distributed quantitative and qualitative data. Organising the files was focused on a relational structure as information thematic layouts. With this approach, spatial objects may be described through three main property classes: those determining the objects position on the Earth surface, those establishing spatial relations with other objects and those referring to the spatial objects attributes.

Coding the existing relationships between spatial entities was performed with the help of facilities supplied by the complete topology of the PC ARC/INFO software. The achievement was viewed of a database apt to allow elaborating indices of hydrological risk to flooding, made up of information associated to three main criteria:

- morphology and topography: hydrographic network, dams and channels network, sub-basins, confluence order; hydrographic and/or drainage network density; mean slopes of the sub-basins; mean slopes in different river sections;
- land cove/land use: land impermeability, in-soil water resilience to infiltration;
- vulnerability to flooding: communication ways network (highways, railroads), localities, meteorological, hydrometric stations network and rain measurement points network.

The first information group allows describing the basin and sub-basins from the viewpoint of the physico-hydrographical characteristics. Classifications and hierarchizations may be made, function of the mountainside and riverbed slopes, of the confluence orders and network or draining density. Such analysis, vis-à-vis the risk degree associated to one parameter or combination of parameters (risks accumulation) may be performed for each sub-basin, basin sections or at whole basin scale.

As regard the notion of confluence order associated to a sub-basin, this can be defined function of the number of sub-basins it supplies directly or of the ensemble of sub-basins it supplies from upstream. Since the mean slope of a waterflow is generally incorrectly correlated with the mean slope of the mountainsides belonging to the associated sub-basin, both parameters concerning the slope were taken into- account as risk factors.

The second group is useful to classify the sub-basins function of the main types of vegetation cove and land use, thus allowing their characterisation function of the land impermeability degree, of their absorption capacity or resilience to in-soil water infiltration. The notion of soil impermeability was connected to the necessity to determine the absorption capacity and resistance to in-soil water infiltration. It must be mentioned that these parameters represent "potential capacities", having in view that the dry soil hypothesis is considered. Certainly, results differ sensibly if the soil is already water saturated at the beginning of the period with precipitation; in this case, coefficients must be modified.

The third group characterises the degree of vulnerability to flooding, being mainly determined by the human presence (associated to localities) in the high-risk areas. It is thought that the

vulnerability aspect may be evaluated taking into consideration the existence of inhabited areas in the vicinity of water flows, of dams and other protection hydrotehnical works, of the potential degree of afflicting the communication ways network, etc.

The database was connected so as to allow obtaining synthetic representations of the hydrological risk for the Arges basin, through using the risk parameters separately or combined. For instance, there can be considered the mean slopes of the mountainsides, the in-soil water absorption, the water resilience to infiltration and the vulnerability degree. The advantage consists in that the system allows greater parameters combination diversity, allotted with various weights, associated to the mentioned three main criteria.

The layout of the hydrographic network encompasses the network properly (including the temporary flows), as well as the existing lakes and storages. The basin was divided in 168 sub-basins, along with the basin rests belonging to a confluence or storage. The layout of the communication ways comprises the roads network (motor highways, state highroads, and modernised and local roads), along with the railroad network. A separate layout was allocated to the locality network, comprising the capital, municipalities, cities, communes and villages. For example, figure 1 displays the thematic layout with the localities and communication ways network. According to the structure of the hydro-meteorological data-collecting network, separate layouts were created, comprising the meteorological, precipitation and hydrometric measuring points.

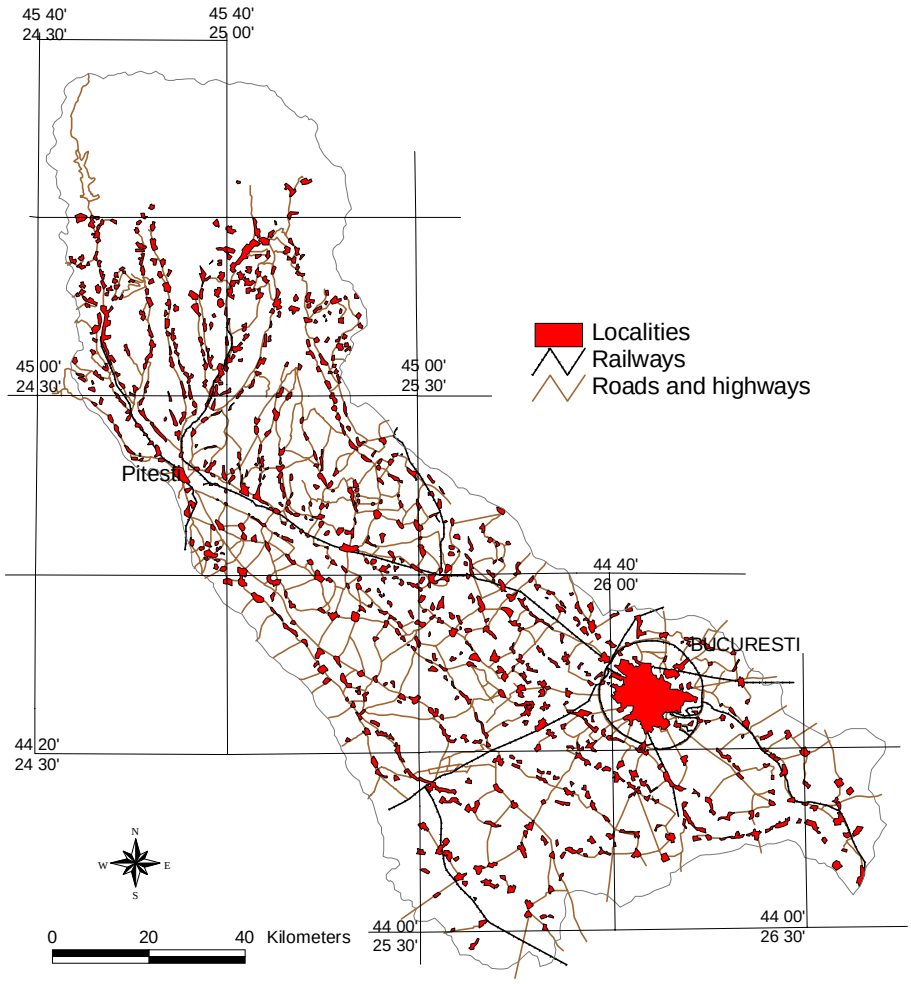


Fig.1 GIS thematic layout with localities and communication ways network in Arges basin

5 Flooding risk indices based on parameters extracted from satellite images

Although satellite sensors cannot measure the hydrological parameters directly, remote sensing can supply information and adequate parameters to contribute to identify and map the hydrological risk at the basin level. Of the numerous information deriving from analysing high spatial resolution satellite images (e.g. SPOT, LANDSAT), a series of criteria were determined from the radiometric information contained in image-data concerning the biophysical and anthropical parameters of basins. The morphological characteristics were extracted by image processing and from the Digital Terrain Model (DTM). The nature of this information, through the spatial and temporal coverage attributes may contribute to build complete databases suitable to allow simulations or scenarios. The following parameters were organised in hierarchical form by classes, in order to produce a synthetic and representative information:

- hydrographic network density – defined as the ratio between the length of the water flows over a surface and the respective surface (sub-basin). The water accumulation as a risk factor may be estimated function of the hierarchically categories for the network density: the denser the network, the faster the access speed to this network and thus the occurrence of high floods is more likely.
- water accumulation (usually associated to high flows) defined by the water amount captured by the hydrographic network; thus the larger the capturing area, the more important the water amount reaching the bed.
- size of potential flooded surface – the larger the surface, the higher the risk..
- soils impermeability degree – revealing the areas (sub-basin) with poorer vegetation coverage. These data are weighted through the slope and reported to basin surface.

These four parameters are weakly correlated: this explains through the complexity of the phenomenon and the parameters spatial extension used to define the hydrological risk.

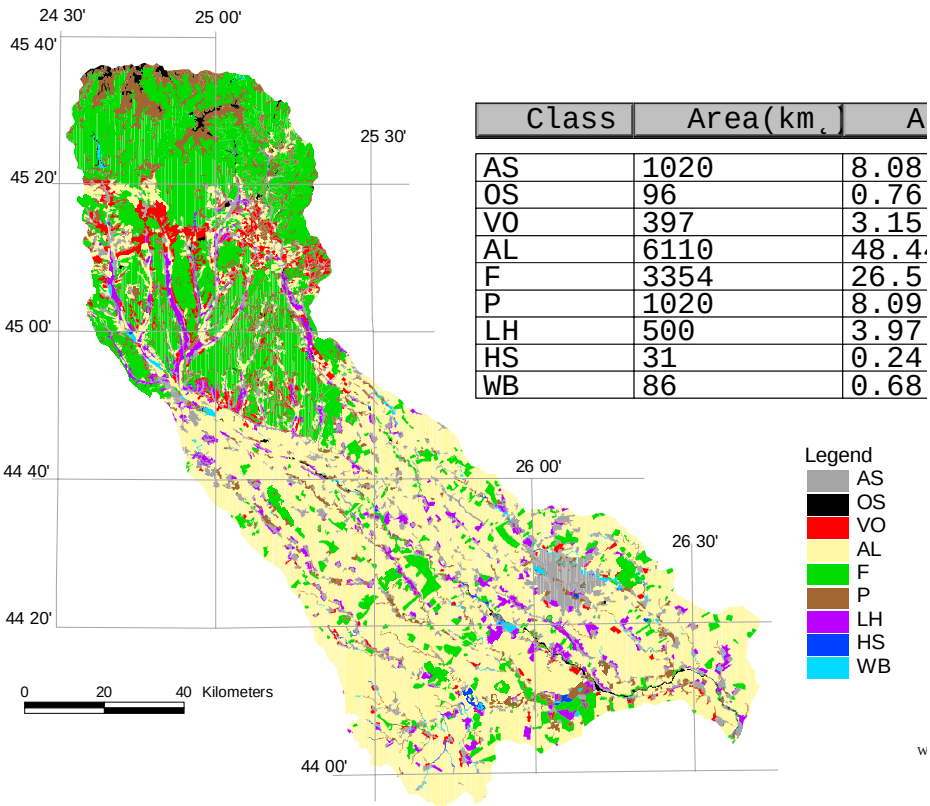
Data resulted from LANDSAT-TM and SPOT-XS satellite images processing, by ERDAS Imagine Professional software, were used to compute the risk parameters. Also, the CORINE LAND COVER database obtained through computer assisted photointerpretation constituted a valuable source of information. Classification of land cover/land use was performed according to EUROSTAT catalogue in 44 classes.

Taking into account the necessity to obtain information concerning the parameters useful to quantify the flooding risk degree (impermeability degree, resilience in-soil water infiltration) there were performed regrouping of the land cover/use classes by 9 main types: artificial (built) surfaces (AS), open spaces with little or no vegetation (OS), vineyards and orchards (VO), agricultural lands (AL), forests (F), pastures and natural grasslands (P), heterogeneous lands belonging to households (LH), humid surfaces (HS), lakes and water bodies (WB). The obtained results for the Arges basin are presented in figure 2. These are useful information for the determination of the impermeability degree, function of the identified classes that may be assigned with impermeability coefficients, within a scale ranging from 0 to 1, as exemplified in the table below:

Table 1 Impermeability coefficients associated to the main land cover and use classes in the Arges basin:

Class	F	AL	VO	LH+P	OS	HS	AS
Impermeability coefficient	0.4	0.5	0.7	0.75	0.8	0.9	1.0

These coefficients allow determining the mean impermeability coefficient by sub-basin, weighted with their mean slopes.



Class	Area(km	A
AS	1020	8.08
OS	96	0.76
VO	397	3.15
AL	6110	48.4
F	3354	26.5
P	1020	8.09
LH	500	3.97
HS	31	0.24
WB	86	0.68

Fig. 2 Main land cover/land use classes of the Arges basin obtained from LANDSAT-TM data

In view to establish the water absorption capacity over the basin surface, the land cover and use classes were regrouped by a number of four classes, to which the specific coefficients were assigned (table 2): artificial surfaces (AS), agricultural lands (AL), vineyards and orchards (VO), pastures and grass lands (P), lands belonging to households (LH).

Table 2 Water absorption capacity values associated to the main land cover and use classes in the Arges basin:

Class	AS	AL	VO	LH + P
Water absorption capacity (mm)	60	300	280	360

The allotted coefficients represent the precipitation amount, which a field is able to absorb. These coefficients are related with a runoff delay factor: the higher the coefficient, the higher the soil capacity to absorb water; also, the higher the water absorption capacity at the level of a spatial unit, the higher the precipitation necessary in a time unit for runoff occurrence.

The analysis concerning the water absorption capacity at the sub-basin level has allowed establishing a hierarchy of the basins function of their capacity to retain the water before the occurrence of the surface runoff.

Another parameter connected to the land cover and use is the resilience to the in-soil water infiltration. The respective coefficients represent the considered area capacity to retain water at the beginning of the precipitation episode, before surface runoff start. Coefficients are expressed as precipitation amount (in mm) necessary for runoff start on slope, assuming water saturated soil. Actually this the water amount that the soil surface can retain, function of the various coverage, such vegetation, built areas, etc. the notion of flooding risk is in this case directly

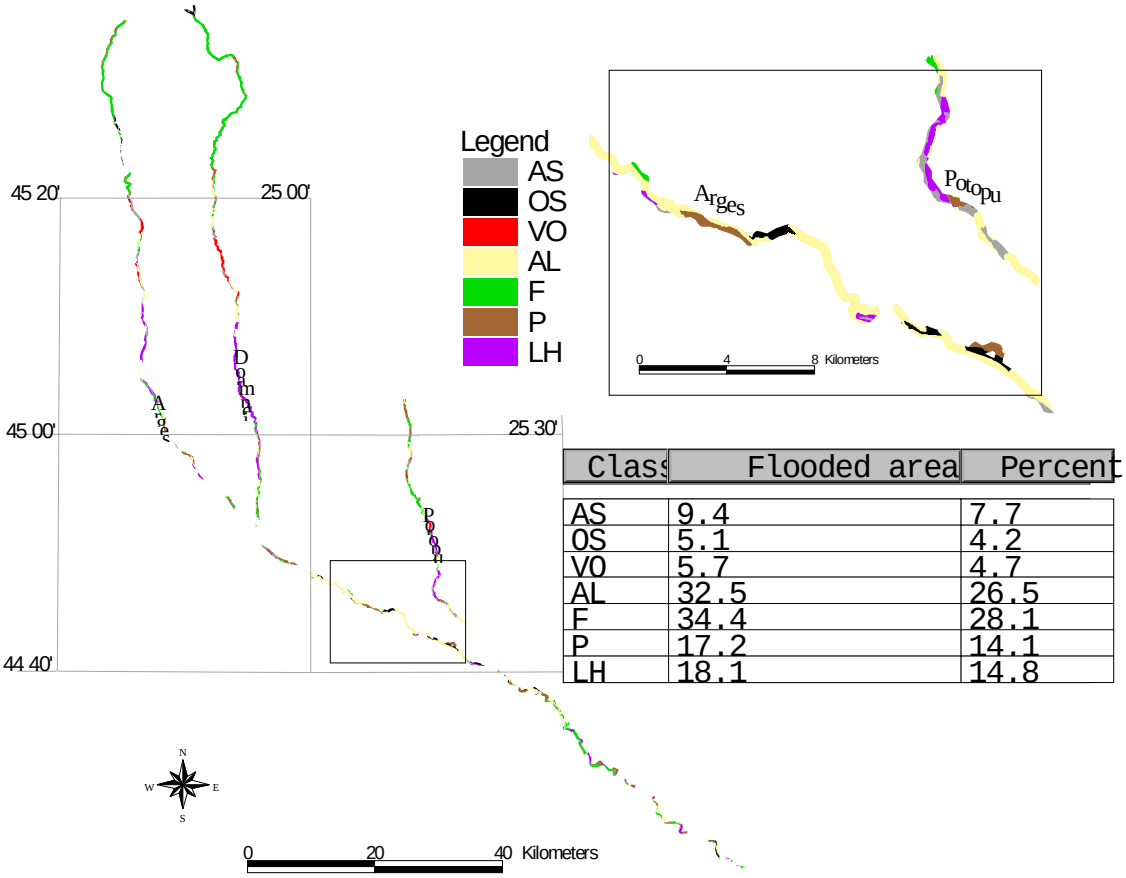
connected to the water runoff on slopes, known that the more intense the runoff, the higher the flooding risk.

In view to establish the resilience to in-soil water infiltration, the land cover and land use classes were regrouped by a number of four classes, to which the specific coefficients were assigned (table 3):

Table 3 Resilience to in-soil water infiltration values associated to the main land cover and use classes in the Arges basin:

Class	AS	AL	VO	LH + P
Resilience to in-soil water infiltration (mm)	10-20	3-7	3-5	8-15

On the basis of the mentioned risk parameters, as well as on the vulnerability degree expressed by the human presence (localities) seven classes were defined a qualitative scale (high – low degree). Given the water levels in the river, the terrain elevation, the flooding sensitivity information allows an accurate location of the zones affected by flooding and inventory of the damages. For example figure 3 reproduces the distribution of the land use categories reached by a 200 meters width buffering zone for flood simulation, along the rivers Arges, Doamnei and Potopu.



Class	Flooded area	Percent
AS	9.4	7.7
OS	5.1	4.2
VO	5.7	4.7
AL	32.5	26.5
F	34.4	28.1
P	17.2	14.1
LH	18.1	14.8

Fig. 3 Inventory of land use categories in the area reached by flood for a 200 m width bufferi zone along the rivers Arges, Doamnei and Potopu.

6 Conclusions

Considering the necessity to improve the means and methods to assess and monitor flooding, the paper presents the capabilities offered by remotely sensed data and GIS techniques to manage flooding and the related risk in a basin-test of Romania.

High satellite images proved to be a very important tool, through the synoptic vision of the territory and the geomorphological data they represent.

The analysis of the hydrological risk indices was associated to the topographic, morpho-hydrographic, physiographic and vulnerability characteristics within the Arges basin. The study encompassed both the risk degree levels associated with various parameters that condition and determine flooding, and the one, which takes into account the human presence in sensitive areas. This approach implies establishing the vulnerability degree defined function of the costs of human and material nature which floodings may determine.

It was planned to design and build a database, which will help to elaborate the flooding hydrological risk indices. This database contains information associated to three main criteria: morphology-hydrology (hydrographic network, sub-basins, confluence order, density of hydrographic network and/or the drainage, the mean slopes by sub-basin, the mean slopes by river sections, land cover/land use (land impermeability, in-soil water absorption capacity, resilience to in-soil water infiltration) and vulnerability to flooding.

The database allows obtaining synthetic representations of the hydrologic risk for the Arges basin, through separate or combine use of the risk parameters, as well as for interfacing with the hydrological models in view to improve them as regards compatibility with input data, recovering results and the possibility to achieve scenarios.

Information extracted from satellite images of high spatial resolution represents useful data for the determination of certain parameters necessary to administrate floodings: hydrological network, water accumulation (usually associated to high discharges), size of potential flooded surfaces, land impermeability degree, etc.

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Operationelle Wasserstandsvorhersagen für die Schifffahrt auf der deutschen frei fließenden Donaustrecke Straubing-Vilshofen

Gerd Steinebach

Zusammenfassung: Die schiffbare Donau ist in Deutschland weitgehend mit Staustufen ausgebaut. Zwischen Straubing und Vilshofen verbleibt jedoch eine ca. 75 km lange, frei fließende Strecke, die bei Wasserständen unterhalb von Mittelwasser erhebliche Beeinträchtigungen für die Schifffahrt verursacht. Durch zuverlässige Informationen über aktuelle und zukünftig verfügbare Wasserstände kann die Schifffahrt bei der optimalen Ausnutzung ihrer Ladekapazitäten unterstützt werden.

Das hierzu entwickelte Wasserstandsvorhersagemodell basiert, analog dem am Rhein seit 1996 eingesetzten Verfahren, auf einem hydrodynamischen Basismodell, gekoppelt mit statistischen Verfahren zur Vorhersage der Abflüsse der wichtigsten Zuflüsse.

Die im 1999 durchgeführten Probebetrieb erzielten Vorhersageergebnisse waren noch nicht voll zufriedenstellend. Besondere Schwierigkeiten bereiten die durch die Steuerungen der Kraftwerke und die kurzen Reaktionszeiten der Nebenflüsse auf Niederschlagsereignisse verursachten Durchflussschwankungen.

Durch die Implementierung geeigneter Ansätze zur Modellnachführung sowie durch die vorgesehene Ankopplung von Niederschlag-Abflussmodellen können ausreichend genaue Vorhersagen erzielt werden.

Schlüsselwörter: Schifffahrt, Donauabschnitt Straubing-Vilshofen, operationelle Wasserstandsvorhersage, hydrodynamisches Modell, Mehrkanalfiltermodell

Operational Water-Level Forecasts for Navigation on the German Free Flowing Danube between Straubing and Vilshofen

Abstract: For navigation, the German Danube is widely regulated by weirs. Between Straubing and Vilshofen remains a free flowing river-reach of about 75 km lenght. In case of lower water levels, navigation suffers from severe restrictions on this river-reach. Reliable information on present and future water-levels may help to obtain optimal loading rates of the ships.

For that purpose, a water-level forecast model was developed. The model concept is similar to the model of the river Rhine, which is in use since 1996. It consists of a hydrodynamic model coupled with statistical methods for flow-forecasts of important tributaries.

The forecast results within the first phase of model operation in 1999 were not fully satisfying. Main difficulties arise from variations of the flow due to the operation of power plants and the fast influence of the tributaries due to rainfall.

By implementing suitable model extentions and through the planed coupling with precipitation-runoff models, sufficiently accurate results can be obtained.

Key words: Navigation, Danube, river-reach Straubing-Vilshofen, operational water-level forecasts, hydrodynamic model, multi channel filter model

1 Einleitung

Ein erheblicher Engpass für die Schifffahrt auf der West-Ost Verbindung Rhein-Main-Donau befindet sich im Bereich Straubing-Vilshofen. Diese ca. 75 km lange, frei fließende Strecke verursacht bei Wasserständen unterhalb von Mittelwasser große Beeinträchtigungen hinsichtlich der zu erzielenden Ladekapazitäten und bildet zudem ein erhöhtes Havarierisiko. Derzeit

werden unterschiedliche Varianten des Streckenausbaus untersucht [BAW99]. Parallel dazu wurde ein Wasserstandsvorhersagemodell für die Belange der Schifffahrt entwickelt.
Über ein analoges Modell für den Rhein wurde bereits in [Stei96] und für die Elbe in [FrHe98] berichtet. Das Rheinmodell hat sich als zuverlässig und praktikabel erwiesen. Es ist seit 1996 im operationellen Einsatz und wird in jüngster Zeit auch zur Hochwasservorhersage angewendet [StWi00]. Aufbauend auf den am Rhein gewonnenen Erfahrungen und dem dort eingesetzten Modellkonzept wurde das Donaumodell implementiert. Es setzt sich zusammen aus einem hydrodynamischen Modellansatz der 350 km langen Donaustrecke zwischen dem Pegel Neu-Ulm und dem Wehr Kachlet, gekoppelt mit einem statistischen Modellansatz [Wi88] für die wichtigsten Zubringer Iller, Lech, Naab, Regen und Isar.
Die Abbildung 1 zeigt das deutsche Donaueinzugsgebiet und die Pegel, deren Daten im Modell berücksichtigt werden. Vorhersagen werden derzeit bis zu 48 Stunden berechnet.

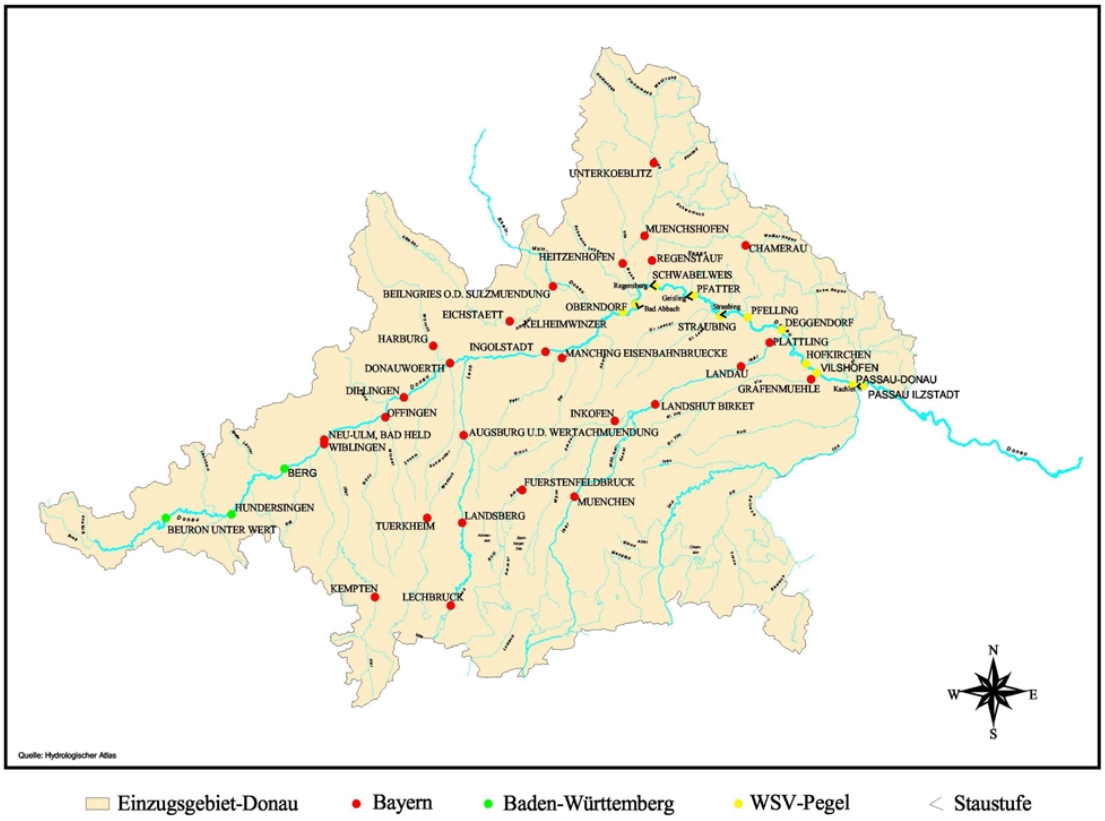


Abb. 1 Deutsches Donaueinzugsgebiet mit den zum Modellbetrieb verwendeten Pegeln

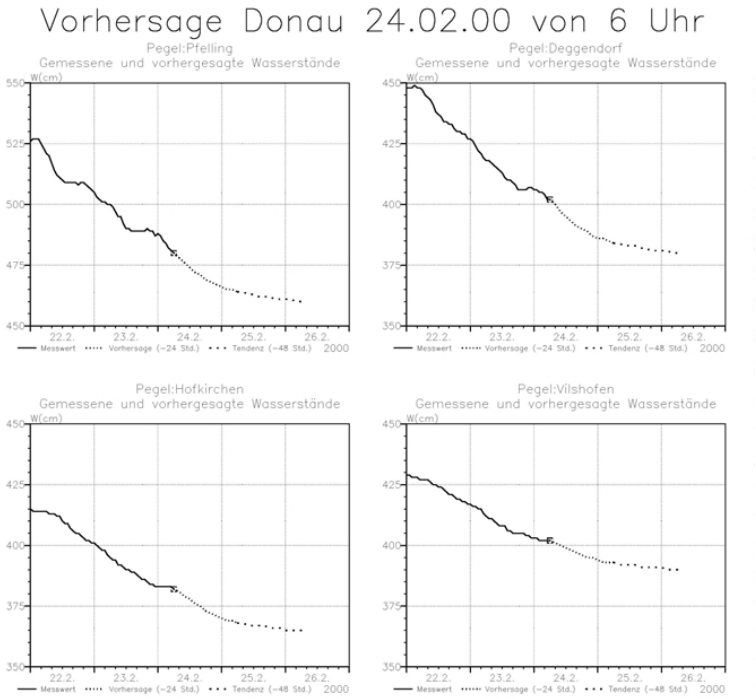
2 Modellkonzept

Basisbaustein des Vorhersagemodells für die Donau ist ein hydrodynamischer Modellansatz. Dieser beruht auf den physikalischen Gesetzen der Massen- und Impulserhaltung. Zusammen mit einigen Vereinfachungen ergeben sich hieraus die Saint-Venant Gleichungen für die Unbekannten durchflossener Querschnitt A(x,t) und Durchfluss Q(x,t) in Abhängigkeit der Ortsvariablen x und der Zeit t [Stei99].
Zur Lösung der Gleichungen sind geeignete Anfangswerte und Randbedingungen vorzugeben. Gewöhnlich wird am oberstrom gelegenen Rand der gemessene Durchfluss (hier am Pegel Neu-Ulm) verwendet. Am unterstrom gelegenen Rand wird die Einhaltung einer gültigen

Wasserstands-Durchflussbeziehung gefordert oder wie im vorliegenden Fall ein Wasserstand vorgegeben (Normalstau am Wehr Kachlet). Seitliche Zuflüsse werden durch Quellterme berücksichtigt.
Der Austausch zwischen Wasser im Hauptstrom und in Stillwasserzonen oder Grundwasser wird pauschal über eine zusätzliche Gleichung für seitlichen Retentionsraum modelliert [Stei99]. Das Volumen dieses Retentionsraumes sowie die Austauschraten können als zusätzliche Parameter zur Modellkalibrierung herangezogen werden.
Zum Modellbetrieb müssen die Zuflüsse und die Duchflüsse am Einströmrand im Simulationszeitraum (Vergangenheit) bekannt sein. Der einfachste Ansatz nimmt im Vorhersagezeitraum (Zukunft) konstante Zuflüsse an. Wesentlich verbesserte Vorhersageresultate sind zu erwarten, wenn für die Zuflüsse selbst Vorhersagen vorliegen. Diese Vorhersagen werden für die wichtigsten Pegel Neu-Ulm/Donau (Einströmrand), Augsburg/Lech, Heitzenhofen/Naab, Regenstauf/Regen und Plattling/Isar mit Hilfe statistischer Verfahren berechnet. Zum Einsatz kommt hier das Mehrkanalfiltermodell MKF [Wi88], das sich in der Praxis als sehr zuverlässig erwiesen hat. Mit dem MKF-Modell werden Wasserstandsvorhersagen aufgrund der Beobachtungen an im Einzugsgebiet oberhalb gelegenen Pegeln geschätzt. Die Wellenlaufzeiten von diesen Pegeln bis zum Vorhersagepegel bestimmen prinzipiell die maximale Vorhersagezeit. Diese wurde hier einheitlich auf neun Stunden festgelegt, d.h. im Vorhersagezeitraum von neun bis 48 Stunden werden die Zuflüsse wieder als konstant angenommen.
Zum operationellen Betrieb müssen zeitnah die gemessenen Wasserstände zur Verfügung stehen. Diese werden automatisch abgerufen und per Datenfernübertragung zum Zielrechner übertragen oder per FTP von anderen Abrufzentralen zur Verfügung gestellt.
Sämtliche Berechnungsroutinen des Modells sind in Fortran77/90 implementiert, die Benutzeroberfläche wurde mit Delphi realisiert.

3 Ausgewählte Vorhersageergebnisse

Im Jahr 1990 wurde ein Probebetrieb des Modells durchgeführt. Täglich wurde eine Vorhersage basierend auf den bis 6.00 Uhr gemessenen Wasserständen berechnet. Die Abbildung 2 zeigt das Ergebnis einer solchen Vorhersage.
In der Abbildung 3 sind die in 1999 am Pegel Hofkirchen gemessenen Wasserstände dargestellt. Eine ausgeprägte Niedrigwasserperiode erstreckte sich von August bis September sowie von Mitte Oktober bis Mitte November.
In der Abbildung 4 sind beispielhaft einige Vorhersageresultate für den Pegel Hofkirchen dargestellt. Eine statistische Auswertung der Vorhersageergebnisse im Zeitraum 1.8. bis 31.10.1999 zeigt die Tabelle 1. Es ergibt sich, dass besonders im Vorhersagezeitraum von 24 bis 48 Stunden weitere Modellverbesserungen notwendig sind.



	Pfel-ling	Deggen-dorf	Hof-kirchen	Vils-hofen
24. 2.2000, 6. 0 Uhr	480	402	382	402
24. 2.2000,10. 0 Uhr	476	397	379	400
24. 2.2000,14. 0 Uhr	472	393	376	398
24. 2.2000,18. 0 Uhr	469	390	373	396
24. 2.2000,22. 0 Uhr	467	387	371	395
25. 2.2000, 2. 0 Uhr	465	386	369	393
25. 2.2000, 6. 0 Uhr	464	384	368	393
25. 2.2000,10. 0 Uhr	463	383	367	392
25. 2.2000,14. 0 Uhr	462	383	367	392
25. 2.2000,18. 0 Uhr	462	382	366	391
25. 2.2000,22. 0 Uhr	461	381	366	391
26. 2.2000, 2. 0 Uhr	461	381	365	390

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Abb. 2 Tägliche Donauvorhersage für die Schifffahrt

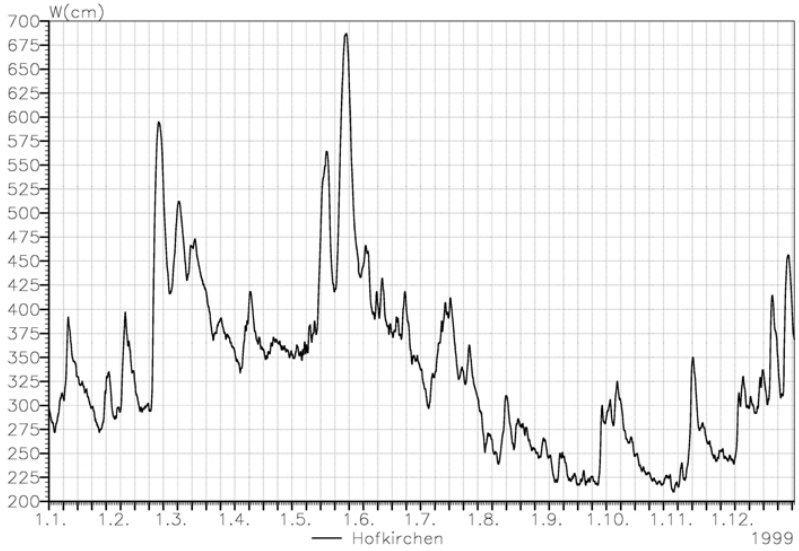

Abb. 3 Gemessene Wasserstände des Jahres 1999 am Pegel Hofkirchen

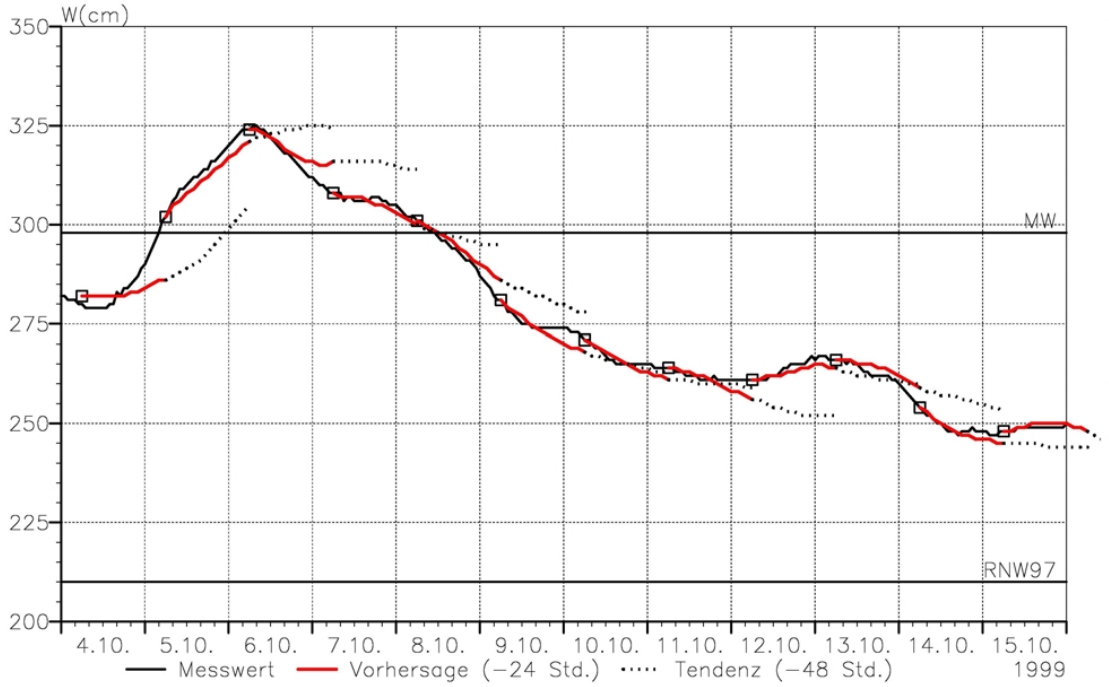

Abb. 4 Ausgewählte Vorhersageergebnisse am Pegel Hofkirchen

Pegel	Vorhersage in h	Fehler <= +/-10 cm	Fehler <=+/-25 cm
Pfelling	12	92,4 %	100 %
	24	78,3 %	98,9 %
	36	64,8 %	94,5 %
	48	56,0 %	89,0 %
Deggendorf	12	97,8 %	100 %
	24	76,1 %	100 %
	36	59,3 %	97,8 %
	48	40,7 %	87,9 %
Hofkirchen	12	98,9 %	100 %
	24	92,4 %	98,9 %
	36	79,1 %	98,9 %
	48	67,0 %	96,7 %
Vilshofen	12	97,8 %	98,9 %
	24	97,8 %	100 %
	36	93,4 %	98,9 %
	48	92,3 %	100 %

Tabelle 1 Statistische Auswertung der Vorhersageergebnisse im Zeitraum 1.8. bis 31.10.1999

4 Modellerweiterungen

Besonderen Einfluss auf die Wasserstände in der Donau haben Steuermaßnahmen an den Kraftwerken. Dieser Einfluss ist beispielhaft für den Pegel Oberndorf in der Abbildung 5 dargestellt. Zum Vergleich sind die im gleichen Zeitraum gemessenen Wasserstände am Rheinpegel Kaub eingezeichnet. Aufgrund dieser speziellen Situation an der Donau wird eine vergleichbare Güte der Vorhersageergebnisse wie am Rhein nicht zu erzielen sein.
Da die Schifffahrt die etwa im Tagesrythmus auftretenden Schwankungen in die Kalkulation der Abladetiefen einbeziehen muss, ist es Ziel, den geglätteten Verlauf der Ganglinie vorherzusagen. Hierzu wurde ein gleitendes Mittel in Abhängigkeit vom Durchfluss und dem Wasserstandsanstieg eingeführt, das in der Abbildung 6 gezeigt ist. Durch Angleichung der im Simulationszeitraum berechneten an die geglätteten Wasserstände mittels künstlicher Wasserzufuhr oder –entnahme am Pegel läßt sich die Vorhersagegüte des Modells verbessern. In der Tabelle 2 sind beispielhaft für den Pegel Pfelling die mit dieser Erweiterung erzielten Ergebnisse aufgelistet.

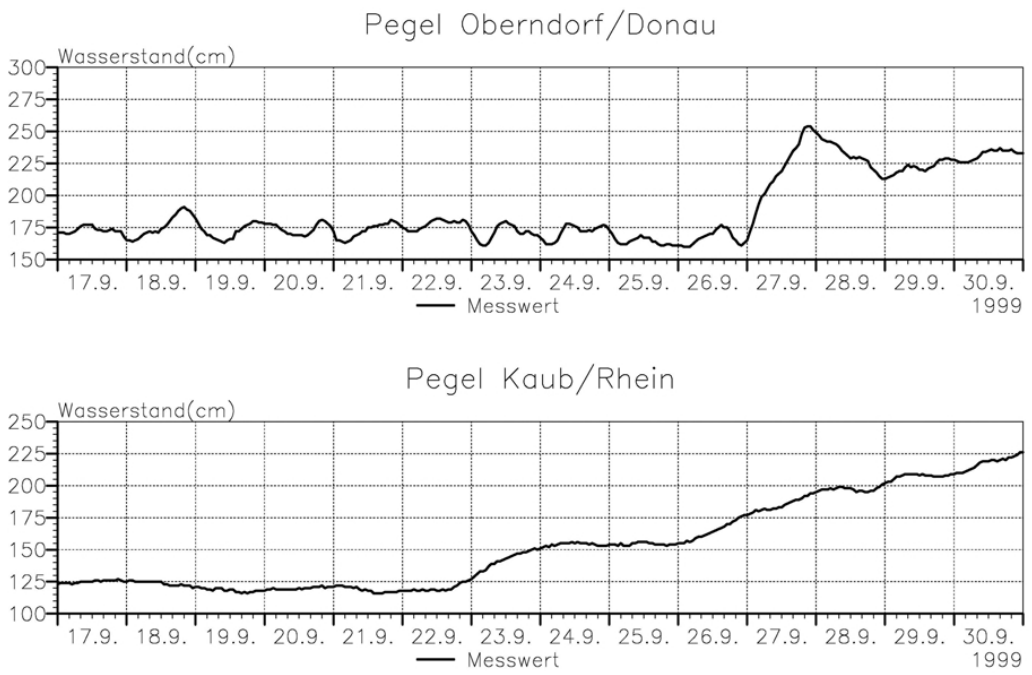

Abb. 5 Vergleich des Verlaufs gemessener Wasserstände an Donau und Rhein

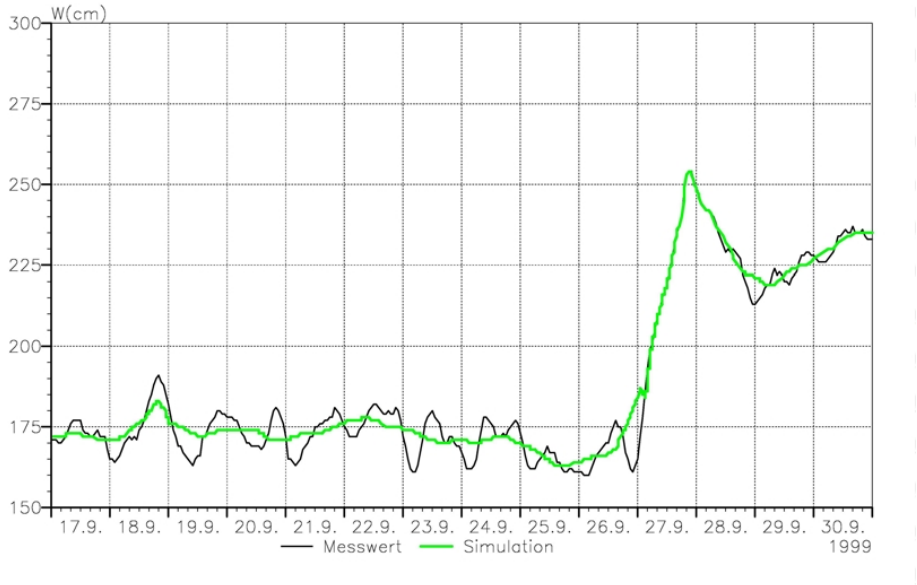

Abb. 6 Beobachtete und geglättete (= simulierte) Wasserstände am Pegel Oberndorf

Pegel	Vorhersage in h	Fehler <= +/-10 cm	Fehler <=+/-25 cm
Pfelling	12	96,7 %	100 %
	24	84,8 %	98,9 %
	36	70,3 %	95,6 %
	48	60,4 %	90,1 %

Tabelle 2 Verbesserte Vorhersageergebnisse nach Modellerweiterung durch Glättung

Schließlich ist es notwendig, die Zuflüsse über die bisher realisierten neun Stunden hinaus auf bis zu 48 Stunden vorherzusagen. Dies wird nur durch eine Ankopplung von Niederschlag-Abflussmodellen gelingen. Analoge Entwicklungen werden derzeit im Rheingebiet zur Verlängerung der Vorhersagezeiten verfolgt. Als Modellansatz kommt hier das schwedische HBV-Modell zum Einsatz, mit dem gute Erfahrungen erzielt wurden [Kra98]. Die mit dem Lokalmodell des Deutschen Wetterdienstes vorhergesagten Niederschläge und Temperaturen dienen als Eingangsdaten der Niederschlag-Abflussmodelle.
Unter der Annahme, dass die wichtigsten Zuflüsse der Donau auch im Vorhersagezeitraum bekannt (optimale Vorhersage) sind, verbessern sich die Vorhersagegenauigkeiten weiter wie in der Tabelle 3 aufgezeigt.

Pegel	Vorhersage in h	Fehler <= +/-10 cm	Fehler <=+/-25 cm
Pfelling	12	96,7 %	100 %
	24	85,9 %	98,9 %
	36	73,6 %	96,7 %
	48	70,3 %	94,5 %

Tabelle 3 Vorhersagegenauigkeiten unter der Annahme, dass die Zuflüsse optimal vorhergesagt sind.

5 Fazit und Ausblick

Zur schifffahrtsbezogenen Wasserstandsvorhersage an der Donau wurde ein operationell einsatzfähiges mathematisches Modell entwickelt und angewendet. Das sich am Rhein bewährte Modellkonzept konnte hierzu erfolgreich übertragen werden.
Aufgrund von Steuerungseinflüssen auf dem staugeregelten Donauabschnitt wird die Genauigkeit der Vorhersageergebnisse erheblich beeinflusst. Durch die Einführung geeigneter Glättungsverfahren konnten die Vorhersageresultate verbessert werden.
Zukünftig wird eine weitere Verbesserung der Zuflussvorhersagen angestrebt. Hierzu sollen geeignete Niederschlag-Abflussmodelle für die wichtigsten Teileinzugsgebiete entwickelt werden.

6 Danksagung
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GIS Database of Physical-Geographical Characteristics of Small Catchments in Slovakia: A Basic Tool for Water Resources Management

Marcel Šúri, Tomáš Cebecauer

Abstract: The paper presents the methodology and results of creation the GIS database of 4 587 autochtonous small catchments with area less then ca. 150 km^2. The physical-geographical attributes of the database represent the relevant characteristics of relief, climate, soil-substratum complex and land cover at regional scale. The presented GIS database is inevitable assumption for exact hydrogeographical classification of the catchments in Slovakia as well as inventarisation of their physical-geographical characteristics.

Key words: Hydrological databases, GIS, relief, rainfall, geological transmisivity, land cover.

GIS-Datenbank der physisch-geographischen Charakteristiken der kleinen Einzugsgebiete in der Slowakei: ein grundlegendes Mittel zur Wasserressourcenbewirtschaftung

Zusammenfassung: Der Beitrag zeigt die Methodologie und die Ergebnisse des Aufbaus einer GIS-Datenbank von 4.587 unabhängigen kleinen Einzugsgebieten mit Flächen kleiner als ca. 150 km^2. Die physisch-geographischen Attribute der Datenbank repräsentieren die relevanten Charakteristiken des Reliefs, des Klimas, der Boden- und Gesteinszone sowie der Landnutzung auf regionaler Ebene. Diese GIS-Datenbank ist eine unverzichtbare Voraussetzung für die exakte hydrogeographische Klassifikation der kleinen Einzugsgebiete der Slowakei ebenso wie ein Verzeichnis ihrer physisch-geographischen Charakteristiken.

Schlüsselwörter: hydrologische Datenbank, GIS, Relief, Niederschläge, Transmissivität, Landnutzung.

1 Introduction

Systematic hydrological observation is organised on a selected number of catchments due to limited financial and personal resources. The estimation of hydrological characteristics on ungauged catchments is done by application of extrapolation and interpolation procedures. On the regional scale the extrapolation procedures are usually based on the application of analogy that catchment with similar physical–geographical characteristics have similar hydrological response.

The prerequisite of reliable estimation the hydrological characteristics is the exact zoning of catchments using regional typifying methods. These are first applied to a set of gauged catchments clustered on the basis of their physical-geographical characteristics to larger spatial units even though geographically discontinuous. Hydrological homogeneity within a regional type or heterogeneity between the types with regard to selected hydrological characteristics is then tested by mathematical and statistical methods. The rest of ungauged catchments are included in the identified regional types that comply with the condition of hydrological homogeneity and heterogeneity according to their physical-geographical characteristics.

Creation of a network of small catchments fulfilling the function of classified objects along with the database of their physical-geographical characteristics is then a basic prerequisite for

application of regional-typifying procedures and the estimation of the values of hydrological characteristics for the ungauged catchments (Solín 1993).

This contribution outlines the methodological aspects of creation the database of physical–geographical characteristics using the network of small catchments and briefly describes the resulting database.

2 Digital network of the basic small catchments

The digital network of small catchments was identified with the aim to fulfil the formal requirements (spatial continuity of the units of approximately the same size) and the criterion of natural closeness of hydrological cycle and autochtony of their hydrological response (Solín and Grešková 1999). This means that each catchment has only one input (precipitation) and only one outlet (discharge in the final profile), and the hydrological response is the product of its physical-geographical characteristics. The data layer consists of 4 587 small catchments at scale 1:50 000.

Digital network of small catchments in the territory of Slovakia was created by an extensive adaptation (generalisation, pre-digitising) of the digital network of detailed catchments defined by the Slovak Hydro–meteorological Institute and digitised by the Slovak Environmental Agency (SEA) from maps at scale 1:50 000. The adaptation removed the biggest drawback of this network, i.e. presence of catchments with alochtonous hydrological response. The hydrological numbering of streams was based on that published in Hydrologické poměry ČSSR (1965). The generalisation observed the following rule: The catchments of the basic network were identified so as to fulfil the condition of closeness of the natural hydrological cycle in the framework of hierarchic 3rd, 4th, 5th, or any following order, their heterogeneity from the point of view of physical-geographical attributes was not too high and the area not exceeding the size of about 100 km^2. Allochtony of hydrological response of catchments which was not removed by generalisation was cleared out by their pre-digitising with help of digital layers of elevation contour lines and river network vectorised from the topographic maps at scale 1:50 000.

3 Data-base of physical-geographical characteristics of small catchment network

The created GIS database of physical-geographical characteristics of small catchments consists of the four groups of characteristics, representing: **a)** morphometry of relief, **b)** climate, **c)** substrate and soil and **d)** land cover. The characteristics were derived from presently available analytical data sources digitally integrated into the cartographic co–ordinate system S–JTSK. The continuous and ordinal data (relief, rainfall, soil–substratum complex) were used to derive selected statistical characteristics, qualitative data (land cover, aspect) were used to compute percentage cover within the catchments (see Fig. 1).

Morphometric characteristics of relief

The set of morphometric characteristics of relief was derived from a digital model of relief (DMR). The DMR of the whole territory of Slovakia in a form and quality complying also with the most demanding criteria of all its users was not processed as yet. In spite of the fact that there exist at least three all-national DMR's in raster formats with a pixel resolution 100 metres, their low quality, inconsistency of input data, and the used methods made them useless for our needs (see Šúri et al. 1997). This was why it was decided to create a new generation DMR with pixel resolution 50 m (DMR50-SK).

DMR50-SK was processed by GeoModel s.r.o. company that provided it for the purpose of derivation of database characteristics. The input data set for the calculation consists of more then 16 million points derived from vectorised contour lines of 137 topographic maps at scale

1:50 000 covering the whole Slovak territory. For interpolation it was used a method of regularised spline with tension controlled by the tension parameters and smoothing with a possibility of direct calculation of morphometric characteristics of relief (Mitášová and Mitáš 1993).

DMR50-SK consists of rasters of elevation, slope, aspect, normal and tangential curvature of relief (the last two characteristics define the shape of relief in a given point). Using DMR50-SK for each small catchment we have derived the following morphometric characteristics:

- **maximum elevation - ele_max** [m a.s.l.];
- **minimum elevation - ele_min** [m a.s.l.];
- **difference in maximum and minimum elevation (ele_max – ele_min) - ele_rang** [m];
- **average elevation - ele_avg** [m a.s.l.];
- **standard deviation of elevation - ele_std** [m];
- **maximum slope - slop_max** [º];
- **average slope - slop_avg** [º];
- **prevailing aspect**; the original data (in degrees) were reclassified into 8 and 4 categories respectively. The resulting fields in tables represent percentage of slopes area with the prevailing of the individual categories as follows:
  - **asp_N45** - for aspect 338-360º and 0-22º [%];
  - **asp_NE45** - for aspect 23-68º [%];
  - **asp_E45** - for aspect 69-112º [%];
  - **asp_SE45** - for aspect 113-157º [%];
  - **asp_S45** - for aspect 158-202º [%];
  - **asp_SW45** - for aspect 203-247º [%];
  - **asp_W45** - for aspect 248-292º [%];
  - **asp_NW45** - for aspect 293-337º [%];

resp.:

  - **asp_N90** - for aspect 316-360º a 0-45º [%];
  - **asp_E90** - for aspect 46-135º [%];
  - **asp_S90** - for aspect 136-225º [%];
  - **asp_W90** - for aspect 226-315º [%].

Climatic characteristics

Out of climatic characteristics we have used mean annual precipitation total as one of the most important indices characterising the input into hydrological cycle. The input data were derived from isohyets (representing the period 1931-80) vectorised from the map at scale 1:750 000 (Faško 1999). The raster data layer with pixel resolution 100 metres was computed in a similar way as DMR by method of regularised spline with tension. For each small catchment of the database the following characteristic was derived:

- **mean annual precipitation totals – rain_31-80** [mm.year^{-1}].

Substrate and soil characteristics

Influence of geological substrate and soil on the character of hydrological response of catchment is characterised by means of transmissivity and permeability. Transmissivity (or discharge) is a property of acquiferous layer to transmit water. Co-efficient of transmissivity **T**

(m^2. s^{-1}) is a result of two directly stipulated values: co-efficient of filtration **k** [m .s^{-1}] and thickness of acquiferous layer **M** [m]. The basic information source used for the creation of digital map of transmissivity (Grešková 1997) was the hydrogeological map of ČSSR in scale 1:200 000 (Melioris et al. 1986) which still provides the most complete information on geological and hydrogeological attributes of the whole territory of Slovakia The thematic layer of transmisivity consist of four values (1 – the highest transmisivity, 4 - the lowest).

Hydrogeological classification of the generalised geological map at scale 1:500 000 (Porubský 1980) was used for creation of the digital GIS database characterising permeability of geological complex. The original classification by Porubský (that is based on the assessment of porosity and density of cracks of geological substratum) were reclassified into 7 classes. The permeability of geological complex was characterised by seven ordinal classes (1 – the most permeable, 7 – the least). The permeability of soil-weathered mantle complex was characterised in the similar way by seven classes, but the classification was based on the assessment of permeability of texture of soil-weathered mantle complex. The texture for individual rocks was set according to Šály (1962, 1986). For each catchment the following attributes were derived:

- **average transmisivity** – **transm** [class];
- **average permeability of substratum complex** – **trans_g** [class];
- **average permeability of soil-weathered mantle** – **trans_s** [class].

Characteristics of land cover

Characteristics of land cover for each catchment were derived from the CORINE Land Cover database. The Project CORINE Land Cover is a part of the EU programme and it was carried out in Slovakia in the years 1994-1996 (Feranec et al. 1996) and revised in 1998 (Feranec et al. 1998). Its aim is to create a consistent and compatible database concerning land cover of Europe in scale 1:100 000. Methodologically the project is based on visual interpretation of satellite image maps created from the Landsat TM data. Digital spatial database of Slovakia represents the actual state of land cover in the years 1989-1992. In the sense of the defined legend (Heyman et al. 1994) it contains in total 44 classes (31 out of them were identified in Slovakia) hierarchically arranged to three levels. There are 5 basic classes at the first level: artificial areas, agricultural areas, forest and semi-natural areas, wetlands and waters. For our purposes several of the classes were amalgamated at the third level and using GIS we computed the percentage of their extent within the catchments:

- **urbanised and technised areas – LC_urban** [%] (CLC classes 1xx);
- **arable land – LC_agric** [%] (CLC classes 211, 242, 243);
- **vineyards and fruit plantations – LC_wine** [%] (CLC classes 221, 222);
- **grasslands – LC_grass** [%] (CLC classes 231);
- **deciduous forests – LC_decid** [%] (CLC classes 311);
- **coniferous forests – LC_conif** [%] (CLC classes 312);
- **mixed forests – LC_mixf** [%] (CLC classes 313);
- **forests and shrubs – LC_fshrub** [%] (CLC classes 311, 312, 313, 322, 324, 334);
- **alpine grasslands and rocks – LC_rocks** [%] (CLC classes 321, 332, 333).

4 Conclusions

When compared the previously available data, the presented digital network of small catchments together with its attribute database enables to gain new and more precise knowledge

of physical-geographical characteristics of catchments in Slovakia and to improve regional typification studies with aim to estimate hydrological characteristics.

The presented work is one of the outputs of the scientific project of the VEGA grant agency No. 2/7050/20 „Hydrogeographic regional types of SR – problems of extrapolation the hydrologic response and rational use of water resources“.

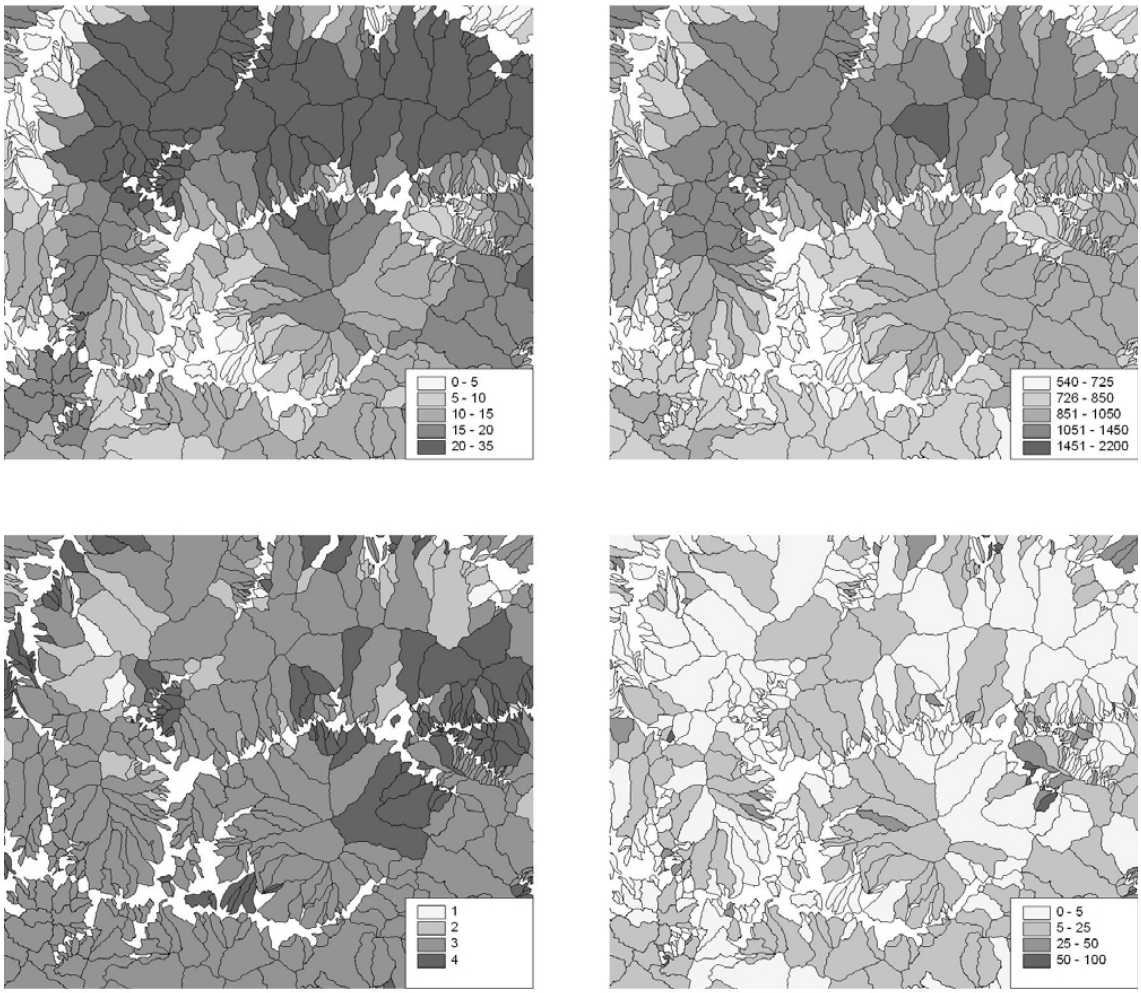

Fig. 1 Four examples of the characteristics derived for the individual small catchments (Central Slovakia): 1. average slope [degrees], 2. mean annual precipitation total [mm], 3. average transmisivity [classes], 4. grasslands [%].

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The use of Geostatistics and Satellite Rainfall Estimation for Hydrological Modelling: A case study of Upper Awash River Catchment, Ethiopia

Alemu Tadesse

Abstract- The National Meteorological Services Agency (NMSA) of Ethiopia has got both Meteosat and NOAA satellites reception and processing facilities. The TAMSAT (Tropical Applications of Meteorology Using SATellite and other data) method of rainfall estimation has been operational at NMSA for more than 9 years. However, attempt has never been made to make use of the satellite rainfall estimates for hydrological purposes.

The aim of this study is to make use of TAMSAT rainfall estimate for hydrological modelling for the Upper Awash catchment. The method makes use of the integration of Geostatistics and GIS (Geographic Information System) for rainfall estimation and using the estimated rainfall in hydrological models.

In this study 14 stations in the upper Awash catchment are considered. Three of these stations collect meteorological parameters necessary for the calculation of Potential Evapotranspiration. The potential evapotranspiration for the catchment has been estimated from two stations (taking all shortcomings into consideration) and fourteen stations are used for variogram parameter calculation.

The satellite estimate of rainfall occurrence was calculated for different threshold temperatures (-30^{0}C,-40^{0}C,-50^{0}C and -60^{0}C). Using the results of variogram models the rainfall was estimated using block kriging. Mean rainfall, fraction of cover and mean CCD (Cold Cloud Duration) have been computed for each year (1990/1995) for the catchment. The Upper Awash river flow simulation have been done using Potentialevaporation and , krigged rainfall, and satellite estimate rainfall. The Awash flow simulation has been done with a very good accuracy.

Introduction

Water is one of the most prevalent substances in the Earth-atmosphere system and it is one of the most fundamental to the existence of life. Shortages of fresh water for domestic consumption, as well as suitable water for agriculture and industry have been a critical problem in most parts of the world. Water supply problems already restrict significantly the life of men and the economics of the entire globe.

The study of the water resource and its movement on the Earth is of very practical importance for life on the planet.

Rainfall is one of the most important part of the water resource. It is vitally important to quantify it accurately. Determining the spatial and temporal depth of rainfall input to the Earth is necessary for everyday management of water resources such as rivers and reservoirs, irrigation, and weather forecasting. It is also an essential component of scientific investigation of the hydrologic cycle, the global water balance and large-scale global atmospheric modeling.

The Awash river basin, for which this case study has been conducted, is mostly located in the arid lowlands of Afar Region in the north eastern part of Ethiopia. It frequently floods in August/September following heavy rains in the eastern highland and escarpment areas. A number of tributary rivers draining the highlands eastwards can increase the water level of the Awash river in a short period of time and cause flooding in the low-lying alluvial plains along the river course. Certain areas which frequently, almost seasonally, get inundated are marshlands such as the area between the towns of Debel and Gewane in the vicinity of Lake Yardi and the lower plains around Dubti down to Lake Abe in the administrative Zone 1 of Afar Region. The third area which often floods is the southern part of administrative Zone 3, about 30 kilometres north of Awash town in the vicinity of Melka Werer.

Afar Region, predominately populated by nomadic and semi-nomadic pastoralists, is generally not known for settled agriculture. But the riverside land, especially the flat lowlands, is fertile and in parts intensively cultivated and relatively densely populated.

The lowlands around Wonji, about 10 kilometres south west of Nazareth town and further down the river around Metehara were flooded and state and private owned agricultural plantations were put at risk. In this upper section of Awash river the flooding was usually caused by the release of water from the Koka dam's flood gates which is necessary when the reservoir reaches its maximum capacity.

TAMSAT Method of Rainfall Estimation

The Reading Method or (TAMSAT) is an example of an infrared-based cloud-top temperature thresholding technique.

The assumptions inherent in the TAMSAT rainfall estimation are:

Rainfall comes mainly from convective storm clouds.

These clouds only rain when their tops have reached a certain minimum height(the height threshold).

The cloud top height can be identified by its temperature on the infra-red image. This temperature is referred to as the threshold temperature T_t.

At a given location, the quantity of rainfall can be calculated from the length of time the cloud top has been above the height threshold (or colder than the corresponding temperature thershold T_t). This length of time is the **Cold Cloud Duration or CCD**.

A further assumption is that the relationship between rainfall quantity R and CCD is linear provided there is adequate averaging of the data either in space or in time.

The offset and the slope (a_0 and a_1) depend on local climatic conditions and hence vary both in space

$$\left.\begin{array}{l} R = a_0 + a_1 CCD .....CCD > 0 \\ R = 0 .....CCD = 0 \end{array}\right\} .....(1)$$

and time. In order to account for spatial variability, Africa has been divided into a number of calibration zones. The zone definition is a compromise between areas small enough to be climatically homogeneous but large enough to contain sufficient raingauges for calibration purposes. For each zone the temperature threshold and calibration parameters are defined by comparison with available raingauge data. In recognition of the temporal variability to be expected with the progression of rainy season, a separate calibration is usually used for each calendar month in each zone.

Geostatistics

Geostatistics involves the analysis and prediction of spatial or temporal phenomena. It is just a name associated with a class of techniques used to analyze and predict values of a variable distributed in space or time. Such values are implicitly assumed to be correlated with each other, and the study of such a correlation is usually called a "structural analysis" or "variogram modeling." After structural analysis, predictions at unsampled locations are made using "kriging".

Briefly, the steps in a geostatistical study include: (a) exploratory data analysis (b) structural analysis (calculation and modeling of variograms) (c) making estimates (kriging or simulations)

Kriging is a geostatistical tool for the optimum sampling design and interpolation of unsampled locations or areas; taking into account the spatial structure of the data based on the semi-variance. This procedure is optimal in the sense that estimates are unbiased and the estimation variance is a minimum. A variant called *block kriging* estimates average values over areas (blocks) rather than points.

Description of Spatial structure

Here we look at a way to describe the spatial structure of two-dimensional data. It is called the variogram, which is a plot of spatial variation as a function of distance.

Semivariance is defined as

$$\gamma(h) = \frac{1}{2N(h)} \sum (Z_i - Z_{i+h})^2 \text{.....(2)}$$

Where :

γ(h): Semivariance for lag distance class h.

Zi : pixel value at point i;

Zi+h : pixel value at point i+h;

N(h) : total number of sample couples for the lag interval h

Semivariance is a measure of the degree of similarity between points at a given distance h. At some distance, called the range, the semivariance will become approximately equal to the variance of the surface itself. This is the greatest distance over which the value at a point on the surface is related to the value at another point.

The experimental semivariogram is a plot of semivariance as a function of distance between the observations, and is the source of information used in kriging to achieve optimal weighting functions for mapping. Kriging uses the semivariogram, or rather a mathematical model of the semivariogram, in calculating estimates to points or over an area.

Having calculated the experimental semi-variograms, an equation that best describes the values is found by fitting a curve to these experimental values. This curve is a model variogram. The exponential model has been found the best among the models used in this study.

Exponential model

$$\gamma(h) = \begin{cases} 0 \text{.....} \text{.....} \text{.....} \text{.....} \text{.....} \; if \;\; |h| = 0 \\ \\ C_0 + C_1\left(1 - \exp(-\frac{|h|}{a})\right) \text{.....} \; if \;\; |h| > 0 \end{cases} \text{.....} \text{.....} \text{.....} \text{.....} \; (3)$$

Climatological Variograms

Often it is very difficult to compute the variogram coefficients (and hence the kriging weights λi) at each time index. If data is sparse the experimental variograms estimated at each time step may be very noisy and the theoretical model poorly estimated. To avoid this, Lebel et al (1987)[2] propose the climatological variogram γ*(h).

The climatological variogram is the average variogram over *k* time steps of the standardised data, i.e.:

$$\gamma^*(h) = \frac{1}{2N(h)Nk} \sum_{Nk} \sum_{N(h)} (Z'_i - Z'_{i+h})^2 \text{.....(4)}$$

where Z' are the standardised data values with respect to the spatial mean and variance. Note that the climatological variogram γ*(h) is computed over the whole period and therefore, the λ_is are computed once and for all. This allows an easy verification of the weights assigned to each gauge and hence to their importance in contributing to the estimation of the catchment means.

Kriging interpolation

Kriging is an interpolation technique, which gives an estimated value at a point or over an area from scattered point data over a defined region and also provides an estimation error (variance). Estimation over an area is called block kriging [1] and [2].

$$\hat{P} = \sum_{i=1}^{N} \lambda_i P_i \text{.....(5)}$$

Block Kriging System

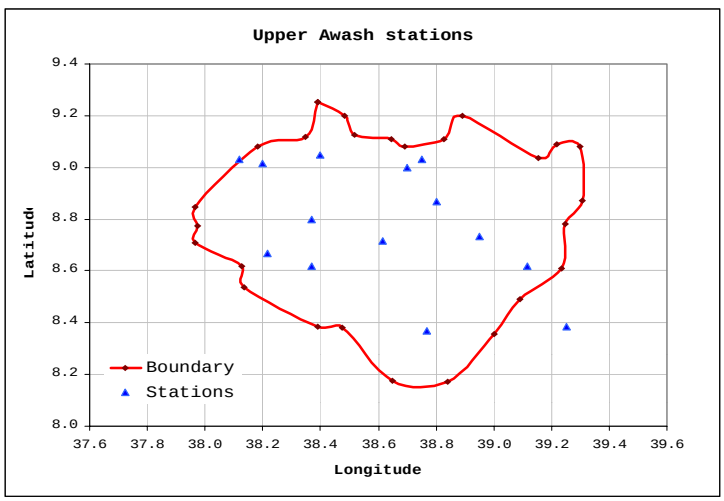
Considering the estimation target to be an area

$$\begin{cases} \sum \lambda_j \gamma(r_i, r_j) + \mu = \frac{1}{A} \int \gamma(r_i, r) dr \text{.....(6)} \\ \sum \lambda_j = 1 \end{cases}$$

Data

The rainfall data used in this study was on daily basis and obtained from the National Meteorological Services Agency. The period of the data is for May-September (the main rainy season for Ethiopia) from 1990 to 1996.

The daily rainfall data was from fourteen stations in the upper Awash catchment. The distribution of these stations in the catchment is shown in the figure below.



Three of the above stations collect parameters used in the calculation of PET. One of these three stations has no wind data. Hence, PET calculation was done from the stations only. These two stations are very close to each other. The information that is obtained from these two stations might not be very different. However, PET is expected to be smooth over the catchment and the PET calculated from these two stations is assumed to be representative and hence used in the Pitman flow simulation.

Daily flow data was obtained from the Hydrological Department of Ministry of Water Resources. The data was from 1990 to 1996 for the months of May-September. The daily CCD data from the TAMSAT archive has been used. The CCDs were at five different thresholds (-30^{0}C to -60^{0}C).

Methodology

The experimental (or empirical) variograms were plotted and theoretical models (exponential, spherical) were fitted to the empirical variogram.

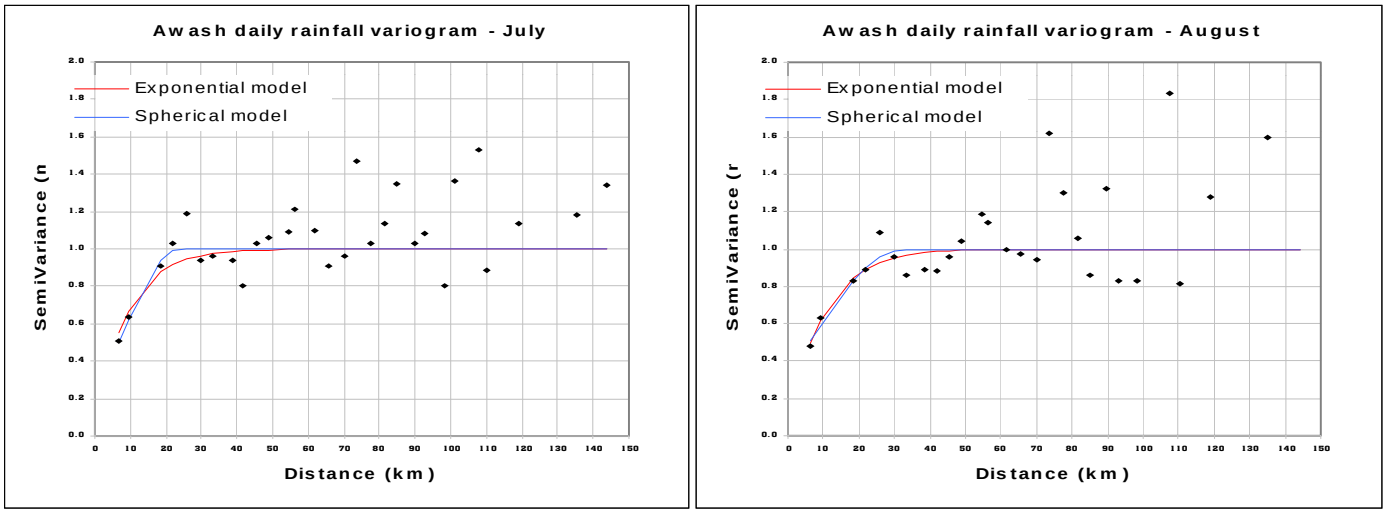
The model chosen throughout was the exponential model with a nugget effect, which provided the best fit both visually and from the Generalized Least Square (GLS) criteria. All models chosen were plotted over the experimental variogram to provide visual confirmation.

I. Awash monthly climatological variograms

The table of exponential variogram model ranges and nugget/sill is presented below. Five seasons of daily rainfall (1990 to 1996) were used for 14 stations in the Awash catchment.

	May	June	July	August	September
Nugget	0.72	0.36	0.07	0.02	0.34
Sill	0.28	0.64	0.93	0.98	0.66
Range (km)	6	9	9	10	13

Variogram Plots



Plot of the climatological variogram for daily rainfall for the Upper Awash catchment, month of July and August for years 1990-1996.

Higher nuggets have been have observed at the beginning and end of the rainy season and the patterns are more noisy. This is attributed to the fact that at the beginning and end of the rainy season the rain is from smaller cloud patches resulting in higher spatial variability. For the months of July and August the rain bearing systems are more established and are wider in size and as a result there is less variability of the rainfall over the stations in the catchment.

II. Rainfall occurrence evaluation from CCD

CCD has been evaluated as to how well it can depict the occurrence of rainfall (Rain/NoRain). The following statistical concepts were used for CCD performance evaluation.

Accuracy, ACC

$$ACC = \frac{n_{oo} + n_{11}}{n_{00} + n_{01} + n_{10} + n_{11}} \text{.....(7)}$$

is just the fraction of correct determinations by the CCD data. Varies between 0 (bad) and 1 (good).

Hit rate, HR

$$HR = n_{11} / (n_{11} + n_{01}) \text{.....(8)}$$

This gives the fraction of actual rainy days that were identified by the CCD. The higher the value the better the discrimination by the CCD.

False alarm rate, FAR

$$FAR = n_{10} / (n_{00} + n_{10}) \text{.....(10)}$$

This gives the fraction of actual dry days that were identified as rainy by the CCD. The lower the value the better the discrimination by the CCD.

Kuipers skill score, KSS

$$KSS = \frac{n_{00} * n_{11} - n_{10} * n_{01}}{(n_{00} + n_{10}) * (n_{01} + n_{11})} \text{.....(11)}$$

This varies between –1 and +1. The worse the estimate the closest it is to 0. Negative values are obtained by "perverse" estimates. Perfect estimates tend to 1. Note the KS is just the difference between the HR and the FAR We also derived probability of R being above 0 when CCD > 0 and CCD = 0.

The parameters values obtained from CCD at different threshold temperatures in estimating rainfall occurance are shown below.

-30^0C

Time step/ measures	ACC	HR	FAR	KS	P(R>0|CCD>0)	P(R=0|CCD>0)
Global (all months)	0.67	0.79	0.48	0.30	0.68	0.65
May	0.70	0.75	0.33	0.43	0.51	0.86
June	0.65	0.74	0.49	0.25	0.69	0.57
July	0.68	0.87	0.80	0.07	0.73	0.39
August	0.67	0.83	0.72	0.11	0.74	0.40
September	0.71	0.74	0.32	0.42	0.76	0.65

-40^{0}C

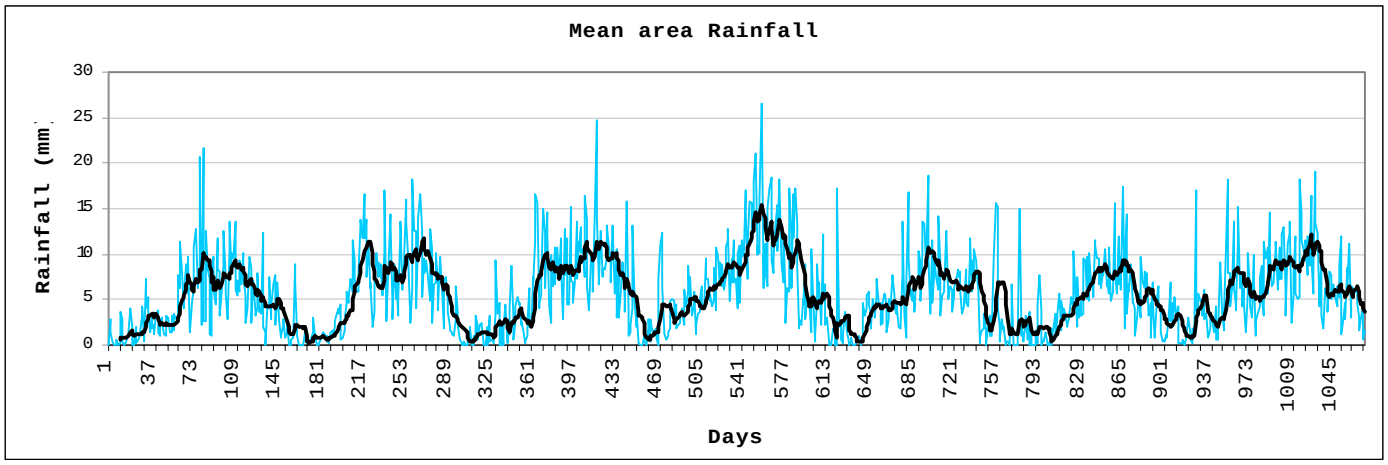
Time step/ measures	ACC	HR	FAR	KS	P(R>0|CCD>0)	P(R=0|CCD>0)
Global (all months)	0.64	0.62	0.34	0.28	0.72	0.55
May	0.72	0.47	0.17	0.30	0.54	0.78
June	0.60	0.53	0.32	0.21	0.69	0.52
July	0.61	0.70	0.59	0.11	0.75	0.36
August	0.63	0.70	0.57	0.13	0.79	0.32
September	0.63	0.53	0.26	0.28	0.69	0.60

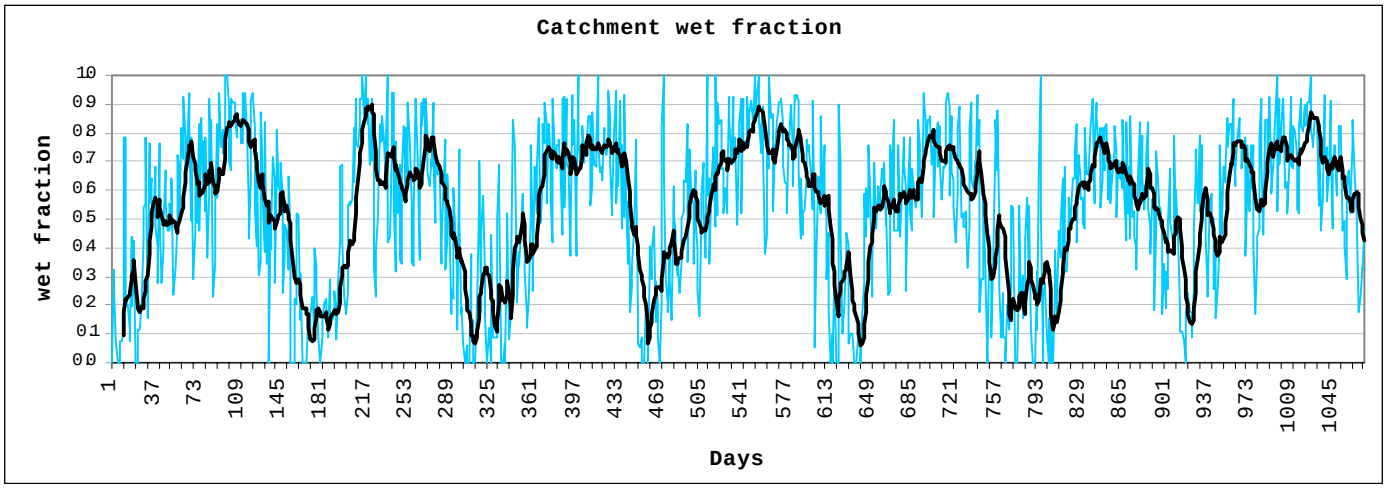
Comments

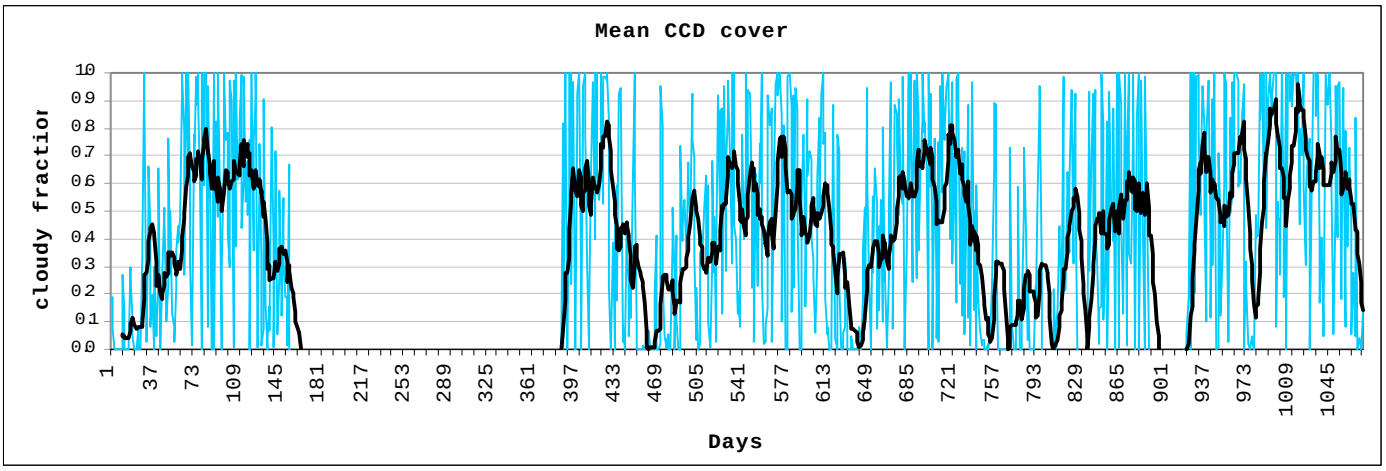
It was observed that -30^{0}C is found to be the best threshold after comparing it to other CCDs of different thershold temperature (-40 to –60). The estimation of rainfall occurecnce for all thresholds was found to be better -for the months of May and September. These months are beginning and end of main rainy season where by an isolated Cumulonimbus Clouds (CBs) are formed. The false alarm rate is maximum for July and August for all thersholds (but minimum for the -30^{0}C). This might be due to the effect of cirrus clouds, which seem to be cold but not rain giving.

The knowledge of the CCD amount is very important in that it gives a clue about the amount of the rainfall in the catchment. The fraction of cloud cover and the mean CCD have been computed for Upper Awash catchment. The results seen show that the CCD is good enough in showing the fraction of cover. The analysis done will be explained in the subsequent sections.

General catchment behaviour description







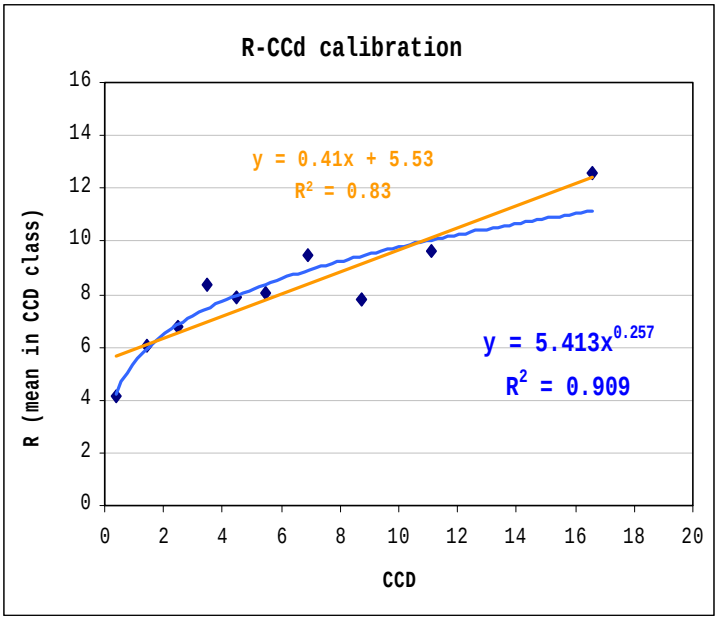
Comment: The window which appears in the CCD plots is due to missing data. All plots are for the CCD -40. On daily basis, CCD can act as an indicator of rainfall even if no reliable estimates of actual rainfall ammounts can be made. In particular, it follows from the causal link between occurrence of

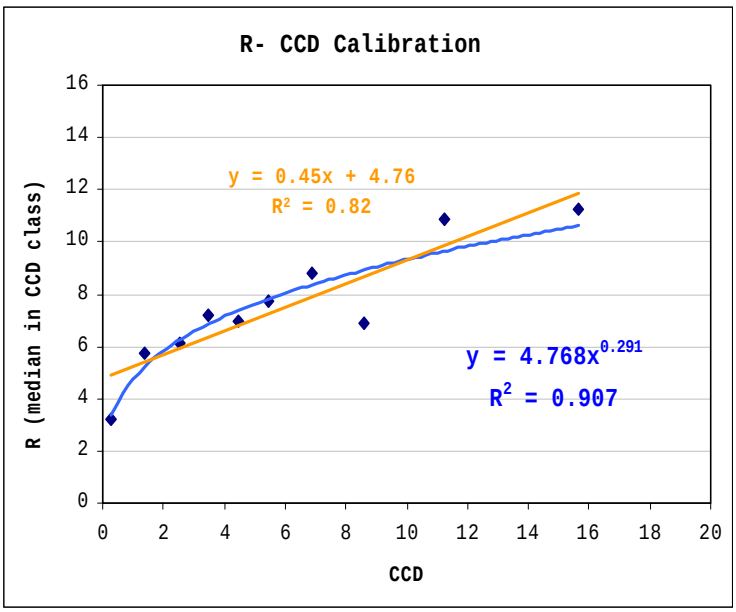
It can be seen in the graphs that CCD-40 can show all the peaks in the rainfall plots. Which shows that CCD approach is a very good technique to estimate the wetness of the catchments and also to estimate the mean rainfall over the catchment. However, the catchment is too small to be conveniently monitored by satellite on daily basis. It could be better for larger catchments and the noisy condition which is seen on the CCD fraction of cover will be smoothed out.The CCD couldn't peak the variability over smaller catchments.

Estimation of catchment rainfall from satellite data

The ordinary regression analysis did not show good relation between CCD and krigged rainfall. A different approach has been tried. The CCD data has been divided into classes. The mean and median of kriged rainfall (for rainfall values greater than zero) and CCD, the probability of rainfall greater than zero, and the expected rainfall (the prduct of mean Krigged rainfall and the probability) for each class of CCD have been computed. The expected rainfall was plotted against mean/median of CCD in each class. Linear and power functions were fitted, and the power function was found to be better.

Plots of the kriged rainfall against CCD.

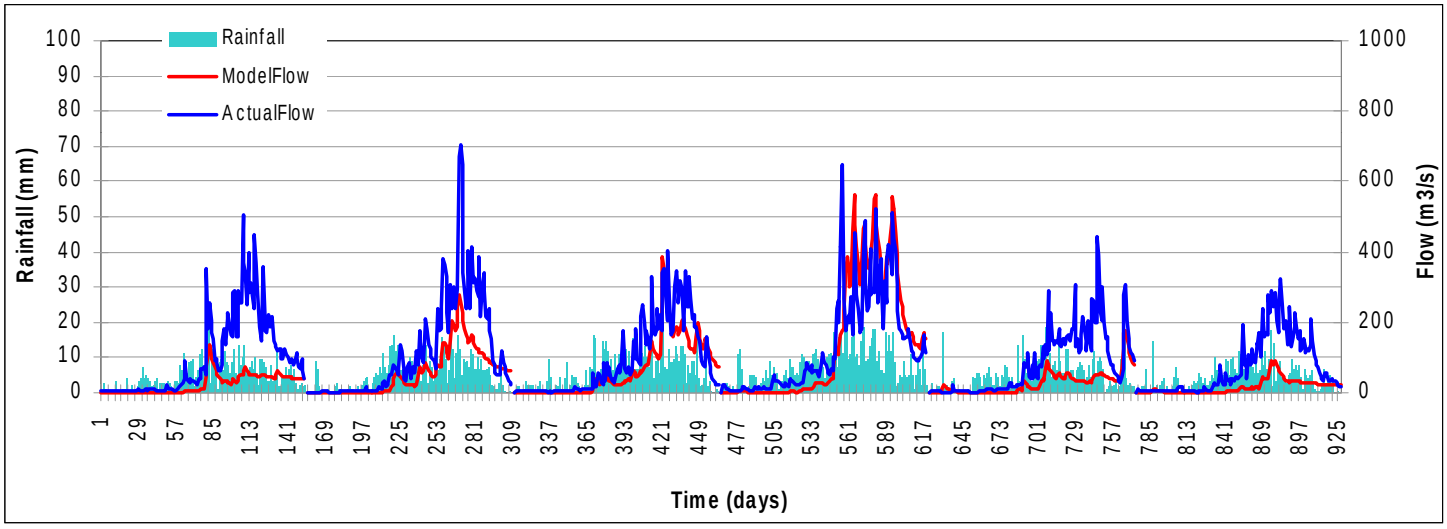




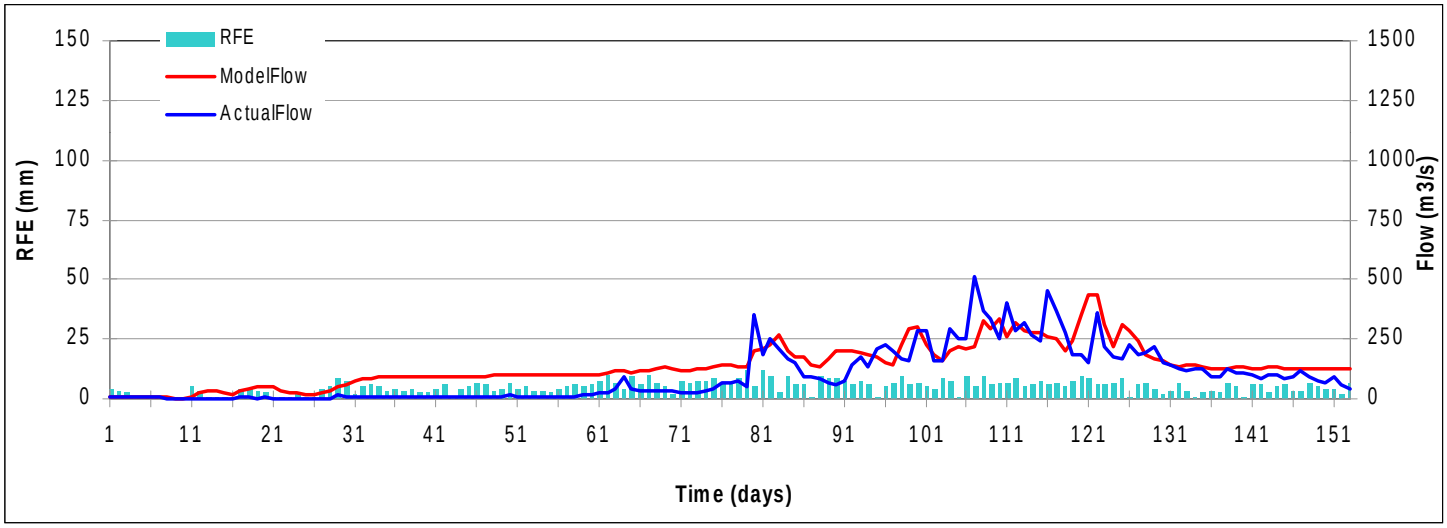
Rainfall has been estimated using parameters from both functions (power and straight line). The two rainfalls were compared. The rainfall estimated using the parameters from the power function for the median of kriged rainfall and CCD have been used in the Pitman model (Mariane DIOP [4] and W.V.Pitman (1973) [5]) for Awash River flow simulation.

The simulations are performed using kriged gauge rainfall and TAMSAT satellite estimates with PET data as input

Pitman Model using Kriged rainfall



Pitman model Using Satellite Estimated Rainfall



Conclusion

It can be concluded that the TAMSAT method of hydrological modeling is good for the larger catchments not for smaller catchments like the Upper Awash catchment. However, further research has to be conducted for the whole Awash Catchment including the middle and lower awash. Warmer

CCDs are found to be performing well in discriminating occurrence and non-occurrence of rainfall. It is worthwhile to use warmer thresholds for Awash catchment. It is also very important to find way of filling the gap for PET and further research is necessary to find the way to make use of satellite data to map potential evapotranspiration over the catchment. Rainfall estimate from CCD -40 seems to perform better in following the pattern of actual flow and picking the peaks in the Upper Wash flow simulation using the Pitman model.

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Online-angeeichte Radarniederschlagsprodukte als zukünftige Komponente für die Hochwasservorhersage

Elmar Weigl

Zusammenfassung: Am Beispiel eines extremen Niederschlagsereignisses wird das Verfahren der Offline-Aneichung quantitativer Radarniederschlagsdaten dargestellt. Dieses Verfahren soll im Rahmen des von der Länderarbeitsgemeinschaft Wasser geförderten Projekts RADOLAN (Routineverfahren zur Online-Aneichung der Radarniederschlagsdaten mit Hilfe von automatischen Bodenniederschlagsstationen (Ombrometer)) in den Echtzeitbetrieb überführt werden. Hierfür sind mehrere grundlegende Entwicklungsarbeiten mit schrittweiser Verkürzung des Meßintervalls für den Niederschlag von einem Tag auf eine Stunde bis hinunter auf Kurzzeit-Dauerstufen unter einer Stunde notwendig.

Schlüsselworte: Aneichung, Niederschlag, Offline, Online, Radar

Online Calibrated Radar Precipitation Products as Future Component for Flood Forecasting

Abstract: The radar data processing in the offline operation will be presented by an example of extreme precipitation. This procedure should be transferred into real-time application within the project RADOLAN (routine procedure for an online calibration of radar precipitation data by means of automatic surface precipitation stations (ombrometers)), which is sponsored by the Länderarbeitsgemeinschaft Wasser. Therefore some fundamental steps in the development with a gradual shortening of the measuring interval for precipitation from day to hour up to short-term intervals of less than an hour are necessary.

Key words: Calibration, non real-time, precipitation, radar, real-time

1 Einführung

Neben der herkömmlichen punktuellen Messung der Niederschlagshöhe mit Niederschlagsmessern, -sammlern und schreibern besteht die Möglichkeit der indirekten Messung durch Radar. Die vom Radar ausgestrahlten elektromagnetischen Impulse werden von den Niederschlagsteilchen zurückgestreut und zu einem Bruchteil wieder vom Radar empfangen. Durch eine Umrechnung der Radarreflektivitäten erhält man Niederschlagsintensitäten.

Der Deutsche Wetterdienst (DWD) wird in diesem Jahr den Aufbau des Radarverbundnetzes mit insgesamt 16 Standorten abschließen, so daß die Bundesrepublik Deutschland möglichst flächendeckend mit quantitativen Radarniederschlagsinformationen versorgt werden kann. Qualitative Niederschlagsinformationen sind von den C-Band-Radargeräten bis 200 km, quantitative Niederschlagsinformationen bis 100 km Radius vom jeweiligen Standort verfügbar.

Der größte Vorteil der Radarniederschlagsmessung ist die flächendeckende Darstellung der Niederschlagsverteilung in einer räumlichen Auflösung von zwei mal zwei Kilometern (qualitativ) bzw. von einem Quadratkilometer (quantitativ). Die Qualität der Radarniederschlagsdaten ist allerdings insbesondere für wasserwirtschaftliche Anwendungen wegen verschiedener Ursachen noch so unbefriedigend, daß umfangreiche statistische Aufbereitungen durchgeführt werden müssen. Erst dann erhält man eine realistische Verteilung der täglichen und stündlichen Niederschlagshöhen für jeden Quadratkilometer im Umkreis von 100 km Radius des Radarstandortes. Dieser beim DWD als „Aneichung“ bezeichnete Prozeß nutzt die vom Radar mehr oder minder unkorrigierten Rohdaten des alle fünf Minuten durchgeführten „precipitation scan“.

2 Offline-Aneichung

Am Beispiel des vom Frankfurter Radar erfaßten extremen Niederschlagsereignisses im Kraichgau am 27. Juni 1994 wird die Radardatenaufbereitung im Offline-Betrieb vorgestellt. Während die synoptisch-klimatologischen Stationen Karlsruhe und Mannheim als nächste online verfügbaren Niederschlagsstationen des DWD (zumindest vor der Einführung Ende 1996 des gemeinsam mit dem Land Baden-Württemberg betriebenen OMBRO-BW-Meßnetzes) maximale Niederschlagshöhen von 45 bzw. 40 mm erreichten, liefern Neckarbischofsheim (DWD) 120 mm und Helmstadt (Land Baden-Württemberg) 180 mm Niederschlag für den gesamten Tag. Diese Informationen sind allerdings nicht in Echtzeit verfügbar gewesen.

Das Original-Radarbild (s. Abb. 1) aus den quantitativen Radarniederschlagsmessungen für diesen Termin zeigt bereits die räumlich sehr stark differenzierte Niederschlagsstruktur des

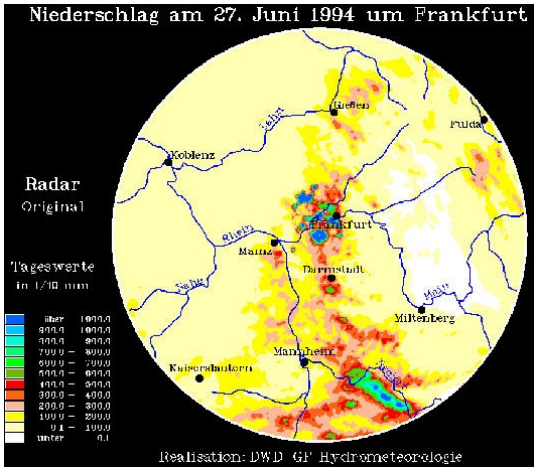

Abb. 1 Niederschlagsverteilung um den Radarstandort Frankfurt am 27. Juni 1994, nicht-angeeichte "Rohdaten" der quantitativen Radarniederschlagsmessung

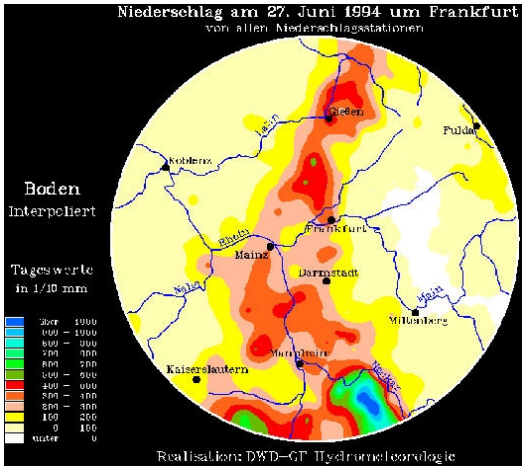

Abb. 2 Niederschlagsverteilung um den Radarstandort Frankfurt am 27. Juni 1994, abgeleitet aus den konventionellen Bodenniederschlagsmeßnetzen des DWD

Ereignisses. Ein erster Vergleich mit den „Boden“-Niederschlagsmessungen (s. Abb. 2) des nebenamtlichen Niederschlagsmeßnetzes des DWD zeigt aber bereits, daß die quantitativen Angaben des Original-Radarbildes einer Korrektur bedürfen. So sind radarseitig sowohl Unterschätzungen des Niederschlages, insbesondere im radarfernen Bereich, als auch Überschätzungen des Niederschlages, insbesondere im radarnahen Bereich, festzustellen.

Die Korrektur erfolgt in einem ersten Schritt dadurch, daß die als Hauptverursacher der Radarüberschätzung anzusehenden Boden- und Festzielechos möglichst umfassend unterdrückt werden. Hierzu werden auch Radarniederschlagsdaten vor dem anzueichenden Termin zur Erstellung einer laufend aktualisierten Cluttermap (Referenzkarte mit den Falschechos) herangezogen. Die als Clutter erkannten Radarpixel werden mit Hilfe der umliegenden Radarniederschlagswerte interpoliert. Somit sind Radarbilder mit einem großen zusammenhängenden Cluttergebiet besonders schwierig zu korrigieren. Insbesondere hierfür werden die Niederschlagsdaten des konventionellen Meßnetzes bereits in dieser Phase mit ihren Maximalwerten der Niederschlagshöhe und deren Gradienten als Voraneichung des Radarniederschlagsbildes genutzt. Dieser Abgleich mit den Bodenniederschlagsparametern führt dazu, daß zu hohe, unrealistisch wirkende Niederschlagsstrukturen als auch allgemeine Über- oder Unterschätzungen des Niederschlags schon vor der eigentlichen Aneichung weitgehend beseitigt werden.

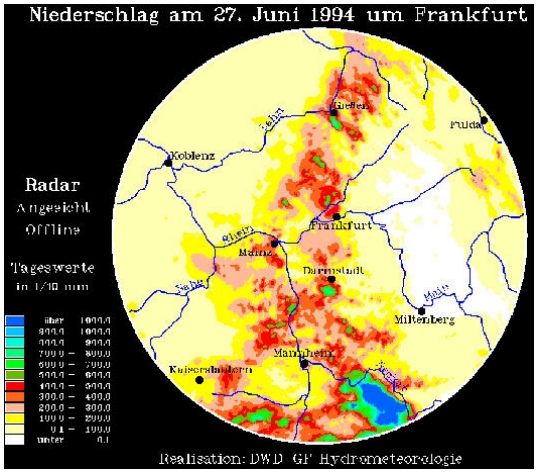

Abb. 3 Niederschlagsverteilung um den Radarstandort Frankfurt am 27. Juni 1994, abgeleitet aus angeeichten quantitativen Radarniederschlagsmessungen

Der zweite Korrekturschritt erfolgt über eine Anpassung der Radarniederschlagsdaten an die Messungen des konventionellen Niederschlagsmeßnetzes (Aneichung). Dabei wird für jede Niederschlagsstation eine Boden-Radar-Aneichgröße bestimmt. Das zugehörige Radarpixel wird aus dem Neunerfeld (zentraler und dessen acht benachbarte Radarpixel) ausgewählt, so daß dessen Niederschlagswert die geringste Differenz zum Stationswert aufweist. Die Aneichgrößen werden auf die Fläche des 100km-Radarkreises interpoliert. Die mathematische Verknüpfung dieser Aneichgrößen mit den entsprechenden bodenechounterdrückten Radardaten ergibt das angeeichte Radarbild (s. Abb. 3; Ausschnitt Kraichgau s. Abb. 4), welches einige bedeutende Verbesserungen gegenüber dem Original-Radarbild und den Bodenniederschlagsmessungen herkömmlicher Art zeigt.

Die Ergebnisse werden aufgrund mehrerer Gütekriterien auf deren fachliche Plausibiltät und Qualität hin überprüft. Hierzu gehören sowohl die Originalmessungen des Radars und des konventionellen Niederschlagsmeßnetzes als auch einige statistische Boden-Radar-Vergleichsgrößen.

Ein wesentliches Gütekriterium ist über die Flächenmittel des Niederschlags auf der Grundlage der verschiedenen Messungen bzw. Aneichschritten abzuleiten. So sollten in erster Näherung

die absoluten Differenzen über einzelne Flächen und über den gesamten Radarkreis zwischen den Radargebietsmitteln und den Bodengebietsmitteln mit fortschreitender Aneichung geringer werden. Die Tabelle 1 zeigt die Flächenmittel für die interpolierten Bodenniederschlagsmessungen (s.a. Abb. 2), die Original-Radarniederschlagsmessungen (s.a. Abb.1), die bodenechounterdrückten Radarniederschlagsmessungen nach dem ersten Aneichschritt und die angeeichten Radarniederschlagsdaten (s.a. Abb. 3). Dabei ist der Radarkreis in äquidistante (20 km) und äquiazimuthale (45 Grad) Sektoren eingeteilt worden. Hier zeigt sich besonders der vom Original-Radarbild im radarnahen Bereich (Distanz bis ca. 20 km) deutlich überschätzte Niederschlag im Vergleich zu den Bodenniederschlagsmessungen (bis über zweifache Überschätzung). In allen Segmenten des radarnahen Bereiches liefert die Aneichung hervorragende Ergebnisse. Im radarfernen Sektor des Azimuthbereiches von 135 bis 180 Grad, in welchem sich der Kraichgau befindet, wird das ursprünglich vom Radar unterschätzte Gebietsmittel durch die Aneichung auf den maximalen Sektorwert von fast 45 mm angehoben.

Tabelle 1 Flächenmittel des Niederschlags (in mm) aus Boden- und Radarniederschlagsmessungen für 40 Sektoren des 100km-Radarkreises von Frankfurt am 27. Juni 1994

Winkel (Grad)	Distanz (km)	Boden	Radar, Original		Radar, boden-echounterdrückt		Radar, angeeicht	
0-44	1-19	30.9	64.0	(33.0)	32.2	(1.3)	30.7	(-0.2)
0-44	20-39	23.9	16.1	(-7.8)	15.2	(-8.7)	23.0	(-0.9)
0-44	40-59	15.7	8.1	(-7.6)	7.9	(-7.8)	15.2	(-0.5)
0-44	60-79	22.9	10.3	(-12.6)	10.0	(-12.9)	18.9	(-4.0)
0-44	80-100	16.0	7.0	(-8.9)	6.9	(-9.1)	13.2	(-2.8)
45-89	1-19	19.3	52.9	(33.6)	21.1	(1.8)	18.5	(-0.8)
45-89	20-39	2.0	3.5	(1.5)	3.3	(1.3)	2.2	(0.1)
45-89	40-59	0.1	0.5	(0.4)	0.4	(0.3)	0.4	(0.3)
45-89	60-79	2.7	2.8	(0.1)	2.7	(0.0)	2.6	(-0.1)
45-89	80-100	8.5	10.2	(1.6)	9.9	(1.4)	9.8	(1.2)
90-134	1-19	22.9	46.3	(23.5)	20.9	(-2.0)	22.6	(-0.3)
90-134	20-39	5.3	3.4	(-2.0)	3.2	(-2.1)	3.8	(-1.5)
90-134	40-59	3.4	1.0	(-2.4)	1.0	(-2.4)	2.0	(-1.4)
90-134	60-79	0.5	0.8	(0.3)	0.8	(0.3)	0.7	(0.2)
90-134	80-100	1.2	2.1	(0.9)	2.0	(0.8)	1.8	(0.6)
135-179	1-19	27.8	50.4	(22.6)	23.3	(-4.5)	25.9	(-1.9)
135-179	20-39	20.2	18.5	(-1.7)	17.6	(-2.6)	20.7	(0.5)
135-179	40-59	25.1	20.8	(-4.4)	20.2	(-4.9)	24.5	(-0.6)
135-179	60-79	31.8	25.3	(-6.4)	24.7	(-7.1)	29.6	(-2.2)
135-179	80-100	36.4	27.4	(-9.0)	26.6	(-9.7)	44.6	(8.2)
180-224	1-19	23.3	40.5	(17.2)	20.4	(-2.8)	22.8	(-0.5)
180-224	20-39	32.4	16.3	(-16.1)	15.6	(-16.8)	26.8	(-5.6)
180-224	40-59	32.5	15.2	(-17.3)	14.8	(-17.7)	26.5	(-6.0)
180-224	60-79	20.1	8.9	(-11.3)	8.6	(-11.5)	16.3	(-3.8)
180-224	80-100	30.6	16.2	(-14.4)	15.8	(-14.8)	29.6	(-1.0)
225-269	1-19	22.1	38.7	(16.7)	14.0	(-8.0)	19.1	(-3.0)
225-269	20-39	28.1	14.4	(-13.7)	12.3	(-15.8)	27.1	(-0.9)
225-269	40-59	20.8	2.9	(-17.9)	2.8	(-18.0)	19.4	(-1.4)
225-269	60-79	6.6	3.2	(-3.3)	3.1	(-3.4)	6.7	(0.2)
225-269	80-100	4.4	5.2	(0.9)	5.1	(0.8)	4.8	(0.5)
270-314	1-19	20.5	43.3	(22.8)	14.4	(-6.2)	17.6	(-2.9)
270-314	20-39	20.3	5.1	(-15.2)	4.9	(-15.4)	16.0	(-4.3)
270-314	40-59	7.2	1.9	(-5.3)	1.9	(-5.4)	6.5	(-0.7)
270-314	60-79	6.7	4.3	(-2.4)	4.2	(-2.5)	5.8	(-0.9)
270-314	80-100	3.0	4.5	(1.5)	4.4	(1.4)	3.4	(0.4)
315-359	1-19	23.6	63.3	(39.7)	22.1	(-1.4)	21.7	(-1.8)
315-359	20-39	33.5	17.8	(-15.6)	9.0	(-24.5)	29.2	(-4.3)
315-359	40-59	15.6	6.3	(-9.3)	6.1	(-9.5)	12.4	(-3.1)
315-359	60-79	7.4	4.1	(-3.3)	4.0	(-3.4)	6.0	(-1.4)
315-359	80-100	3.7	2.9	(-0.8)	2.8	(-0.9)	3.2	(-0.5)
Summen der Differenzen:				(425.0)		(261.4)		(71.7)

Angaben in Klammern: Differenzen zwischen Radar-Gebietsmittel und Boden-Gebietsmittel

In der Abb. 4 ist der betreffende Ausschnitt mit den angeeichten Radarniederschlagsdaten und den verfügbaren DWD-Niederschlagsstationen mit zugehöriger täglicher Niederschlagshöhe dargestellt. Die sehr stark räumlich aufgelöste Niederschlagsstruktur des Ereignisses ist sowohl den Werten der Bodenniederschlagsstationen (Spannweite von 12 bis 120 mm in einem ca. 1000 km^2 großen Gebiet) als auch aus der Radarniederschlagsmessung zu entnehmen. Dabei erhält man für ein Radarpixel, welches die Fläche von einem km^2 abdeckt, die tägliche Niederschlagshöhe von 246 mm. Dies ist das Zweifache des nur ca. sechs km entfernt liegenden Wertes der Station Neckarbischofsheim, aber „nur“ ein Drittel mehr als die eingangs erwähnte Niederschlagsstation des Landes, die für die Aneichung nicht benutzt wurde.

Die Aneichung der stündlichen Radarniederschlagsmessungen erfolgt in Ermangelung an ausreichend verfügbaren stündlichen Niederschlagsaufzeichnungen des konventionellen Meßnetzes über die prozentuale Anpassung der angeeichten Tageswerte auf die Original-Stundenwerte des Radars. Dieses Verfahren liefert für den besonders von Bodenechos verseuchten radarnahen Bereich keine angeeichten Stundenwerte. Da der Kraichgau vom Radar Frankfurt genügend weit entfernt ist und das Radar die Niederschlagsverhältnisse gut qualitativ erfaßt hat, kann die stündliche Niederschlagsverteilung aus Radarniederschlagsmessungen gut berechnet werden.

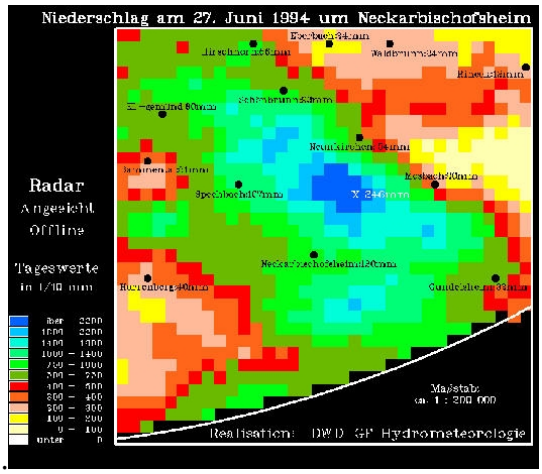

Abb. 4 Niederschlagsverteilung um Neckarbischofsheim am 27. Juni 1994, abgeleitet aus der Radarniederschlagsbestimmung des Standortes Frankfurt, mit Werten der Bodenmeßstationen

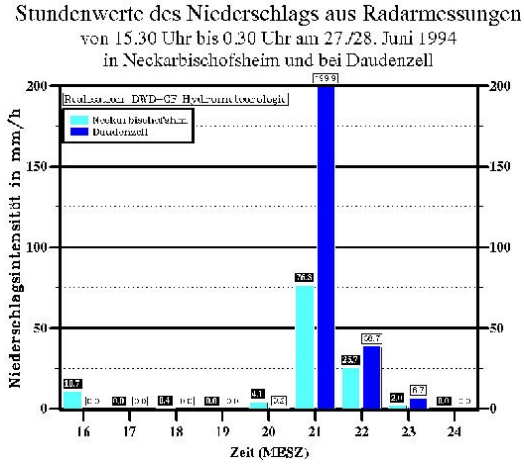

Abb. 5 Stündliche Niederschlagshöhen aus der Radarniederschlagsbestimmung des Standortes Frankfurt für Neckarbischofsheim und Daudenzell von 15.30 bis 0.30 Uhr MESZ am 27./28. Juni 1994

Abb. 5 zeigt für die Station Neckarbischofsheim (bzw. dem zugehörigen Radarpixel) und dem Gebiet „bei Daudenzell“ (bzw. dem Radarpixel mit dem Tageswert von 246 mm) die Stundenwerte des Niederschlags für den betreffenden Nachmittag und Abend des 27. Juni 1994, wie sie aus den angeeichten Radarniederschlagsmessungen berechnet werden. Der für das Gebiet „bei Daudenzell“ erhaltene Wert von ca. 200 mm in einer Stunde erreicht nach den Untersuchungen über maximierte Gebietsniederschlagshöhen (MGN) für Deutschland einen Prozentwert von ca. 85 zum entsprechenden MGN-Wert.

3 Projekt RADOLAN

Mit dem vom Deutschen Verband für Wasserwirtschaft und Kulturbau (DVWK) fachlich begleiteten und von der Länderarbeitsgemeinschaft Wasser (LAWA) geförderten Projekt RADOLAN (Routineverfahren zur Online-Aneichung der Radarniederschlagsdaten mit Hilfe von automatischen Bodenniederschlagsstationen (Ombrometer)) wird das Ziel der quantitativen Niederschlagsbestimmung in Echtzeit mit Radar zum Ende des Jahres 2002 verfolgt. Die grundlegenden Entwicklungsarbeiten zur Online-Aneichung mit schrittweiser Verkürzung des Meßintervalles für Niederschlag von Tag auf Stunde bis hinunter auf Kurzzeit-Dauerstufen

unter einer Stunde und Reduzierung des Bezugsmeßnetzes (Aneichstationen) von maximal 400 Stationen auf weniger als 100 Stationen erfolgen durch folgende Teilarbeiten:

- Optimierung der Clutterkorrektur bei den quantitativen Radarniederschlagsdaten
- Messung von Tropfenspektren und Bestimmung von raum- und zeitabhängigen Z/R-Beziehungen
- Aneichverfahren von Tageswerten (konventionelles Niederschlagsmeßnetz des DWD als dichtes Bodenmeßnetz) bis Stundenwerten (gemeinsames Ombrometermeßnetz des DWD und des Landes Baden-Württemberg)
- Vergleich der angeeichten Werte auf einzugsgebietsbezogene Flächen für Tages- bis Stundenwerte des Niederschlags
- Verkürzung der Abtastrate im precipitation scan der Radarmessung mit flächen- und zeitabhängigen Niederschlagsvergleichen
- Radarniederschlagsabschätzung von Kurzzeit-Dauerstufen unter einer Stunde mit flächen- und zeitabhängigen Niederschlagsvergleichen
- Online-Software für quantitative Radarniederschlagsdaten für hydrometeorologische und wasserwirtschaftliche Zwecke

4 Prüfung des Verfahrens für Online-Aneichstationen

Für die Aneichung in Echtzeit muß mit einer reduzierten Anzahl von verfügbaren Niederschlagsstationen als Aneichstationen ausgegangen werden. Dies bedeutet, daß die Auswahl dieser Aneichstationen von großer Bedeutung ist. Sie müssen einerseits eine relativ große räumliche Repräsentanz haben und andererseits zeitlich in ihrer Güte als Aneichstation konstant bleiben. Beide Kriterien werden aufgrund eines Boden-Radar-Vergleichs über einen längeren Zeitraum hinweg untersucht. Diese Arbeiten fließen direkt in die Meßnetzplanung des DWD ein.

Ein Schwerpunkt liegt daher im Vergleich von angeeichten Radarniederschlagsdaten, die ausschließlich mit den Online-Aneichstationen aufbereitet wurden, mit solchen, die aus der Offline-Aneichung stammen, bei der alle konventionellen Niederschlagsstationen genutzt wurden. Die Arbeiten zur Tageswert-Aneichung wurden mit 17 ausgewählten Niederschlagsereignissen durchgeführt, welche die verschiedenen Niederschlagstypen in ihrer räumlichen und zeitlichen Variation unter hydrometeorologischen und wasserwirtschaftlichen Fachaspekten möglichst umfassend abdecken.

Tabelle 2 Flächenmittel des Niederschlags (in mm); Erläuterung s. Text

Termin (1997)	Radar (Original)	Boden (interpoliert) RR	Boden (interpoliert) OMBRO-BW	Radar (angeeicht) RR	Radar (angeeicht) OMBRO-BW
22.6.	52.3	45.9	46.6	48.1	45.3
24.6.	12.7	11.1	12.8	11.5	11.1
27.6.	16.5	14.5	15.9	14.1	14.1
5.7.	5.1	4.3	4.8	4.4	4.6
11.7.	10.3	4.6	5.0	6.9	6.1
3.9.	6.6	9.6	10.8	9.9	9.9
7.9.	5.4	6.4	6.6	6.5	6.3
13.9.	12.1	17.6	18.0	16.7	16.6
11.10.	14.5	24.8	26.1	23.7	23.8
13.10.	15.0	15.8	16.7	16.1	14.7
6.11.	9.6	4.4	4.4	5.0	5.2
10.11.	2.6	6.1	6.4	6.0	6.5
13.11.	3.5	14.1	13.9	14.5	14.8
20.11.	2.5	4.8	4.1	4.8	4.5
12.12.	13.1	38.9	40.7	39.3	38.1
13.12.	4.9	20.7	19.9	20.9	20.3
17.12.	1.0	0.5	0.3	0.7	0.2

Eine objektive Auswertung ist aus der Gegenüberstellung von Flächenmitteln des Niederschlags aus interpolierten Bodenniederschlagsdaten und aus angeeichten Radarniederschlagsdaten möglich. Tabelle 2 zeigt die Ergebnisse für die innerhalb Deutschlands liegenden Radarsektoren des Radarstandortes Feldberg/Schwarzwald. Größere Abweichungen zwischen Boden- und angeeichten Radarniederschlagswerten sind weder bei der Nutzung aller

Niederschlagsstationen (Offline-verfügare Aneichstationen, Kennung RR) noch bei der Nutzung der Online-Aneichstationen (Kennung OMBRO-BW) zu erkennen. Auch die Ergebnisse der Gebietsmittel aus RR-Werten gegenüber denjenigen aus den OMBRO-BW-Werten sind bei Betrachtung von Tageswerten sehr ähnlich. Die farbig markierten Werte zeigen die Unter- (orange) bzw. die Überschätzung (blau) der Original-Radarmessungen, wie sie bereits in Kapitel 2 erwähnt wurden.

Detailliertere Betrachtungen der Niederschlagsverteilungen durch subjektive Beurteilung der Niederschlagsbilder zeigen bei zwei Terminen einzelne kleinräumige unrealistische Ergebnisse. Diese als „Abrißkanten“ bezeichneten Phänomene konnten auf das bisherige Faktoren-Aneichverfahren mit einem Niederschlags-Schwellenwert von 0,5 mm für die Verwendung des Stationswertes als Aneichstation zurückgeführt werden.

Um das Aneichverfahren hinsichtlich seiner Eignung für kürzere Aneichzeiträume zu untersuchen, wurden für drei ausgewählte Termine Aneichungen durchgeführt, bei denen das Aneichintervall schrittweise verkürzt wurde. Insgesamt sind 18 Teiltermine mit Zeiträumen von zwölf, sechs, drei, zwei und einer Stunde angeeicht worden. Die Auswahl erfolgte mit der Vorgabe, daß insbesondere Intervalle mit möglichst großer Niederschlagshöhe (vom stratiformen und vom konvektiven Niederschlagstyp) untersucht werden sollen.

Die Auswirkungen unterschiedlicher Aneichverfahren treten in erster Linie bei konvektiven Niederschlagsereignissen, die starke räumliche und zeitliche Unterschiede bewirken, und bei geringeren Aneichintervallen auf. Dabei ist eine optimale Aneichung eher mit dem Differenzenverfahren, die die Boden-Radar-Differenzen an den Aneichstationen verwendet, als mit dem Faktorenverfahren möglich. Für nicht mit ihrem Intensitätsmaximum an der Aneichstation getroffene Niederschlagszellen werden zum Teil überhöhte Werte durch die Faktorenaneichung bestimmt. Solche Unterschiede sind allerdings in den untersuchten Fällen nicht aufgetreten. Aus fachlicher Sicht ist somit eine Stundenwert-Aneichung bei weiterer Objektivierung des Aneichverfahrens vertretbar.

5 Ausblick

Die auf den bisherigen Auswertungen basierenden Ideen der Optimierung und Objektivierung des Aneichverfahrens ermöglichen nach deren Umsetzung im Rahmen des Projekts RADOLAN die Bereitstellung von räumlich und zeitlich hoch aufgelösten Bodenniederschlagsverteilungen in Echtzeit für Hochwasservorhersagemodelle.

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Lithodynamic Circumstances in the Ajdemir Lowland (Northeast Bulgaria)

Dora Angelova

Abstract: The Ajdemir lowland that includes the territory of the “Srebarna” Swamp (a biosphere reserve under the protection of UNESCO) represents the most northeastern riparian strip along the Bulgarian bank of the Danube river.
The present work contains an analysis of the paleogeographic and tectonic conditions for the development of the investigated territory. The geodynamic circumstances before the Neogene and during the Neogene and the Quaternary have been distinguished in a regional and local aspect. The reconstruction is made on the basis of the analyses of sediment facies and of the conditions of their formation. The accent is laid on the rearrangement of the basins (marine and continental ones) and on the deformations of the main tectonic structures. The anthropogenic impact and the changes in contemporary lithodynamics related to it have been considered too.

Keywords: Ajdemir lowland, lithodynamics circumstances, "Srebarna" reserve, sediments, tectonics.

Kartierung der Hangstabilität in der Artschar-Orsoja Niederung (Nordwest-Bulgarien)

Zusammenfasung: Die Artschar-Orsoja Niederung (Gesamtfläche 35 km^2) liegt im nordwestlichen Teil der Donau-Ebene. Ihre Entstehung ist mit der Entwicklung der Lom-Depression verknüpft. Die dort zu beobachteten komplexen Hangbildungen sind das Resultat verschiedener Faktoren. Dazu gehören tektonische, erosive, erosiv-akkumulative, gravitative und anthropogene Einflüsse sowie Verkarstungsprozesse. Somit sind endogene, exogene wie auch anthropogene Einwirkungen vorhanden. Auf analytischer Basis wird versucht, die Stabilität des ganzen Ökosystems in einem Bereich abzuschätzen, der durch komplizierte bodenmechanische Verhältnisse und katastrophale geodynamische Prozesse gekennzeichnet ist. Die beigelegte Karte teilt die Hangoberflächen in unterschiedliche Grade der Stabilität bezüglich der komplexen geodynamischen Einwirkungen auf. Grundlage dafür war die Abschätzung der Wirksamkeit der einzelnen Faktoren und die anschließende Summierung der so erhaltenen Grade.

1 Introduction

The investigated region is situated in the northeastern part of the Danubian plain, Bulgaria (Fig. 1). The Ajdemir lowland occupies the strip along the Danube river with an altitude of 10-40 m and width of up to 3 km. The bank of the Danube is high, steep and vertical in the western part, and low and flooded during high waters – in the eastern part. This has brought the necessity of building a dike along the bank. The tectonic swamp “Srebarna” is found in the western part at the confluence of the Kalnezhka and Srebarnenska rivers. The swamp is not only a geological-tectonic phenomenon but is also a biosphere reserve under the protection of UNESCO.

The plain outlook of the relief is disturbed by the development of the Danube river and its tributary valleys which are canyon-like, deeply incised in the loess, Neogene and Cretaceous limestone. The values of the horizontal relief dismembering vary from 0.25 to 1.50 km/km^2. The vertical relief dismembering varies between 0 and 40 m/km^2 for the low and plain relief and between 50 and 120 m/km^2 – for the steep and canyon-like sections of the valleys.

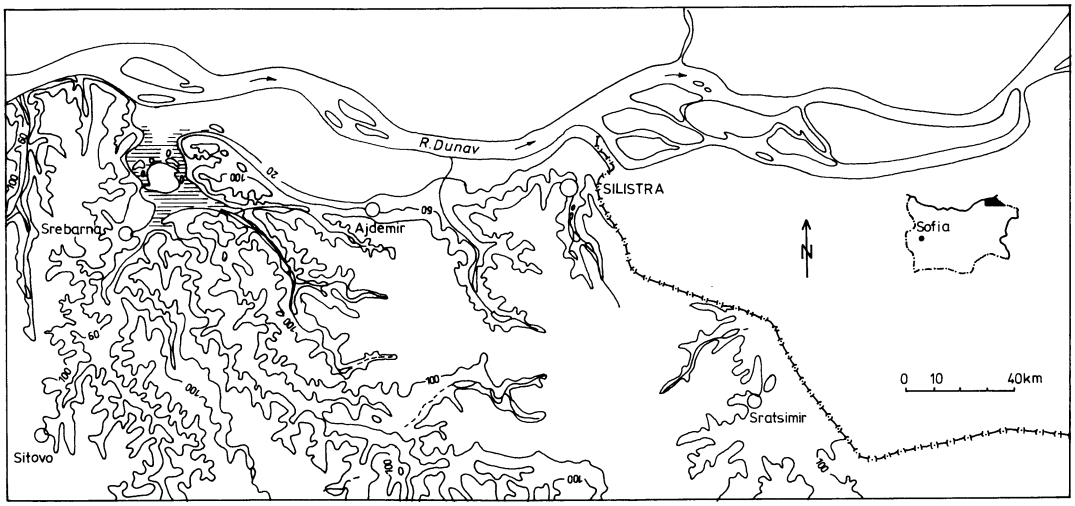

Fig. 1 Hypsometric map of the Ajdemir lowland and its affiliated parts

In a hydrographic aspect the region belongs to the lower reach of the Danube river and its tributaries – the Srebarnenska, Kalnezhka, Kalipetrovska and Silistrenska rivers. These are typical plain rivers. A great part of the surface flowing water is lost in the karstified limestone. The “Srebarna” swamp is fed by several small karst springs and by the Danube water. It has been subjected to an ecological catastrophe during the recent years as a result of its ceased feeding by river water. This imposed the necessity to perform new investigations and to build a channel and engineering facilities for conducting Danubian water.

2 Lithostratigraphic and Tectonic Notes

The karstified limestones of the Rousse Formation and the marls and clayey limestones of the Razgrad Formation from the Lower Cretaceous series are observed at the surface in the investigated territory. The limestones of the Rousse Formation are massive, porcelain-like, oolitic, chalk-like, organogenic, thick-layered. The transition to the Neogene sediments on top of them is transgressive in a normal lithological section. The sediments of the Neogene are found in 3 litho-stratigraphic units: the Sarpovo, Ajdemir and Srebarna Formations. The important lithological varieties are: calciferous and sandy thin-layered clays and fine to medium-grained quartz sands to strongly bound fine-grained sandstone for the Sarpovo Formation; sands for the Ajdemir Formation; clayey limestones and limestones – for the Srebarna Formation. Differing in genesis and age Quaternary sediments and formations lie on top of the Neogene sediments. They are represented by red clays and polygenic gravel of Plio-Pleistocene age, alluvial gravel, sands and clays, and the loess complex with the buried soils and alluvial gravel, sands and clays (the Upper Pliocene ones build the Tarlitsa Formation) and swamp clays (the Todoranka Formation). Triassic sediments are observed in some boreholes (Fig. 2).

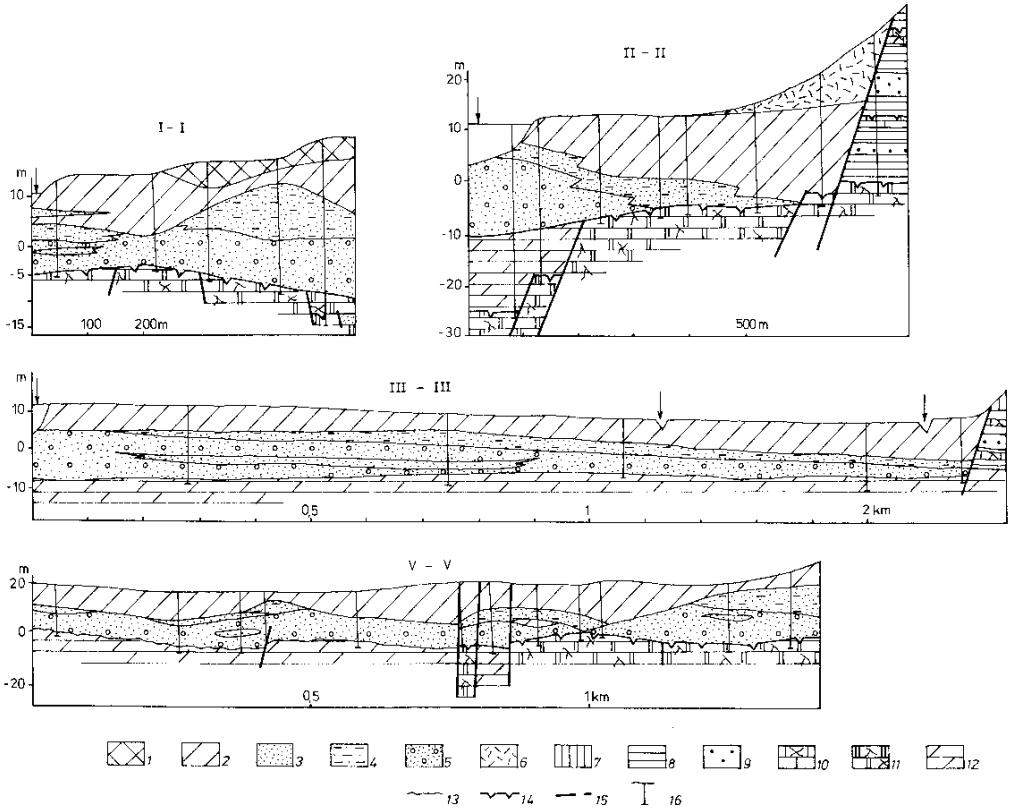

Fig. 2 Geological profiles of the Ajdemir lowland: 1 – contemporary technogenic deposits (embankments); 2-6 – Holocene: 2 – fine clays, 3 – sands, 4 – sandy clays, 5 – gravel and sands, 6 – deluvial formations; 7 – Pleistocene: loess complex with buried soils; 8-10 – Neogene: 8 – clays (Sarpovo Formation), 9 – sandstone (Ajdemir Formation), 10 – karstified limestone (Srebarna Formation); 11-12 – Lower Cretaceous: 11 – karstified porcelain-like limestone (Rousse Formation), 12 – marl (Razgrad Formation); 13 – erosion surface; 14 – karstified surface; 15 – fault; 16 – borehole

3 Geodynamic Circumstances and Main Stages

The reconstruction of the geodynamic circumstances for the development of the NE part of the Moezian platform in Bulgaria is made on the basis of the analysis of sediment facies and the conditions for their formation.

Pre-Neogene Development. An ocean existed in the investigated geographical space till the middle of the Devonian, in which normal ocean lithogenesis took place. Argillites were deposited under the conditions of extension and deepening of the basin. It became shallower during the Silurian when limestones were deposited, and during the Lower Devonian when the deposition of sandstones and argillites occurred. A radical rearrangement of the basins took place during the Middle Devonian as a result of the Caledonian movements. Two zones of marine sedimentation (carbonate and carbonate sulphate one) were delineated. The geodynamic circumstances were substantially changed during the Sudeten tectonic phase due to the following compression. The investigated terrain was a part of the carbonate platform of a shallow epicontinental sea. The withdrawal of marine sedimentation started and then it was replaced by continental sedimentation. The oceanic crust was entirely replaced by a continental one during the Permian. The terrain around Silistra represented a continental dry land, while to the west of Silistra the shallow shelf of the Moezian marine basin was preserved. As a result of the subsequent Hercynian movements (Pfalzian phase) the terrain became completely dry. The

following geological evolution in the investigated region was a part of the Alpine evolution. The geodynamic circumstances were not constant and changed frequently in the course of time. The sedimentation processes had a discontinuous-continuous character with moments of regional transgressions and regressions. Different geodynamic circumstances were combined during the single sedimentation cycles and stages. The global changes in the geological development were accompanied by considerable changes of the geodynamic circumstances. Continental alluvial-lacustrine circumstances existed after the Hercynian orogenesis and during the Lower Triassic and the basal sandstone complex was formed. The following transgression proceeded offensively from east to west and the northern epicontinental internal sea was formed. The circumstances were favourable for the sediment formation of the shallow-marine dolomite-limestone complex (Anisian-Karnian). Total regression started after the Norian age. The carbonate basin was entirely dismembered. Denudation took place everywhere and the regressive breccia-conglomerate-argillite complex was formed. It marked the shallow-marine transgressive-stable and regression stages in the investigated region. The whole Balkan micro-continent was entirely dried and raised at the end of the Triassic (pre-Jurassic discontinuity) and an emersion period began. These continental geodynamic circumstances (Lower Danubian dry land) were preserved till the Bathonian age (the Jurassic). The terrain represented a low comparatively stable land with flat relief forms and local lowerings till the middle of the Jurassic. Transgression from east to west followed then and a shallow internal sea was formed. The marl-limestone geocomplex corresponds to the transgressive stage and the argillite-aleurite one – to the stable stage. The Balkan micro-continent was raised and dried again at the end of the Bathonian age (pre-Callovian regional discontinuity). The terrain was subjected to denudation. The Callovian-Albian sedimentation cycle was represented by three geodynamic circumstances that changed with time for the single stages. The investigated terrain was a part of an internal epicontinental sea in the Balkan micro-continent during all the three stages (Callovian-Kimmeridgian, Tithonian and Early Cretaceous). The Balkan micro-continent was moving to north-east during the Callovian and the trend of lowering had led to the Callovian transgression, to the inrush of Tethys water and to the formation of a new marine basin. The homogeneous carbonate sediments of the limestone geocomplex were deposited during the transgressive-stable stage (Callovian-Tithonian). The shallow-marine marl-limestone sedimentation was typical for the regression stage (Berriasian-Albian). The basin of the internal epicontinental sea became more shallow and smaller in size then. It was preserved during the Albian-Paleocene sedimentation cycle too until the end of the Maastrichtian age. The sedimentation was transgressive shallow-marine psammitic or calciferous (Cenomanian, Turonian), stable calciferous (Coniacian-Maastrichtian), and partially regressive almost shallow-marine (at the end of the Maastrichtian age). The investigated terrain was turned again into a dry land due to the rising during the Paleocene. Then destructive processes took place in the consolidated Balkan micro-continent.

The Neogene development of the investigated territory depended on the development and rearrangements occurring in the Fore-Carpathian and Euxino-Caspian basins. The region represented a low land subjected to denudation, erosion and karstification during the Early Miocene. The beginning of the Middle Miocene (Early Badenian) was a period of global and planetary changes that led to changes in the paleogeomorphological circumstances. The shallow South Dobrudja strait was formed here during the Tarhanian, connecting the Euxine basin with the Fore-Carpathian one. The correlation is the limestone of the Carpathian Formation (Popov, Kojumdgieva, 1987). The direction of the transgression has not been proved. The greater part of the researchers considers that it is from the Fore-Carpathian basin and others assume it to be from the Indian Ocean. The limestone thickness is in the range from 2-3 m to 7-8 m. The strait was dried at the end of the Tarhanian as a result of vertical tectonic movements. A part of the limestone was eroded after the transgression. It is observed only as single spots now. The terrain was a dry land subjected to vast surface denudation during the Chokranian, which continued till the beginning of the Bessarabian sub-age. Then the marine water rushed into the dry land in the

region of the South Dobrudja strait as a result of a local extension. The limestones from the lower part of the Odarska Formation (Popov, Kojumdgieva, 1987) were formed. The South Dobrudja strait was entirely annihilated in the middle of the Bessarabian sub-age. Typical continental emersion was established under warm climatic conditions contributing to the karstification. Low style fold deformations occurred in the Sarmatian sediments during the Atian tectonic phase, at the end of the Sarmatian (11-12 Ma). They marked the main direction of compression from north to southeast. The bank structure playing the role of a watershed between the Fore-Carpathian and Black Sea basins during the subsequent stages was formed then. The main relief form was the Silistra-Rousse bay of the Dacian basin which was tectonically predetermined and represented the last resonance of the overthrust deformations and its formation as a longitudinal depression part in the edge of the Fore-Carpathian (Dacian) basin. The change of the main direction of compression and the rising of the mountain chains after the Volinian contributed to the outlevelling of the main blocks and their rotation. This had led to changes in the development of the karst and gravitation process. The water of the Fore-Carpathian basin transgressed to the south occupying almost the whole territory during the Late Pontain as a result of the rising of the Carpathian-Balkan mountain chain and the compensating sinking of the Moezian plate. The up to 1.6 m thick sediments of the Sarpovo Formation are the correlation ones. The low-thickness sands of the Ajdemir Formation (2-8 m) were deposited during the Dacian due to starting tectonic pulsations. The Rousse-Silistra bay was entirely annihilated during the Roman when the lacustrine limestones of the Srebarna Formation were deposited. They have a thickness of 50-60 m.

During *the Late Pliocene and the Early Quaternary* the terrain was characterised by expressed vertical tectonic deformations resulting from the Wallachian tectonic phase. They had a negative sign in the Sub-Carpathians, exceeding 2000 m, and a positive sign on the Bulgarian territory – about 50 to 100 m (Angelova, 1996). The terrain was subjected to enhanced erosion and accumulation. Levels and river terraces with alluvial and alluvial-proluvial sedimentation were formed. These sediments were represented by well-rounded gravel with sandy-gravel filler and single lenses of unsorted quartz sands. Their thickness exceeds 20 m. Their composition and facies prove that they had undergone a long transport from S to N-NW under conditions of intensive hydrodynamics. The tectonic movements formed the structural capes near Vetren, Ajdemir and Silistra. They played an important role in the formation of the major directions of the Danube river. The main river network of the Srebarnenska, Kalnezhka and Kriva rivers was formed, single sections being tectonically predisposed.

The Pleistocene stage followed the global and planetary climatic changes combined with active tectonics. It started with an abrupt change in the character of the tectonic movements and general rising. Regional rearrangement of the river network took place. As a result the watershed and foothill spaces were disrupted, forming a terrace complex with 4-5 overflood river terraces marked by storied cave levels in the canyon-like sections. The loess complex was formed during the Pleistocene too with the buried soils in it, related to the glacial and stadial epochs, to the lithostructural peculiarities and the Quaternary tectonic movements. The formed soil horizons show 4-5 sediment discontinuities in the investigated region and completed geomorphological cycles. The thickness of the loess is from 30 to 50 m. The origin of the gravitation sedimentation is also connected with the erosion and tectonic development. The total values of the Pleistocene movements are from +55 to +60 m. The tectonic development of the Danubian part is marked by small-amplitude movements (from several to 20-30 m and more seldom – to 100-120 m) along normal faults between the accumulative and destructive part of the plain. Their main directions are equatorial and meridional. Small blocks of different dynamics were formed by these normal faults (Fig. 3).

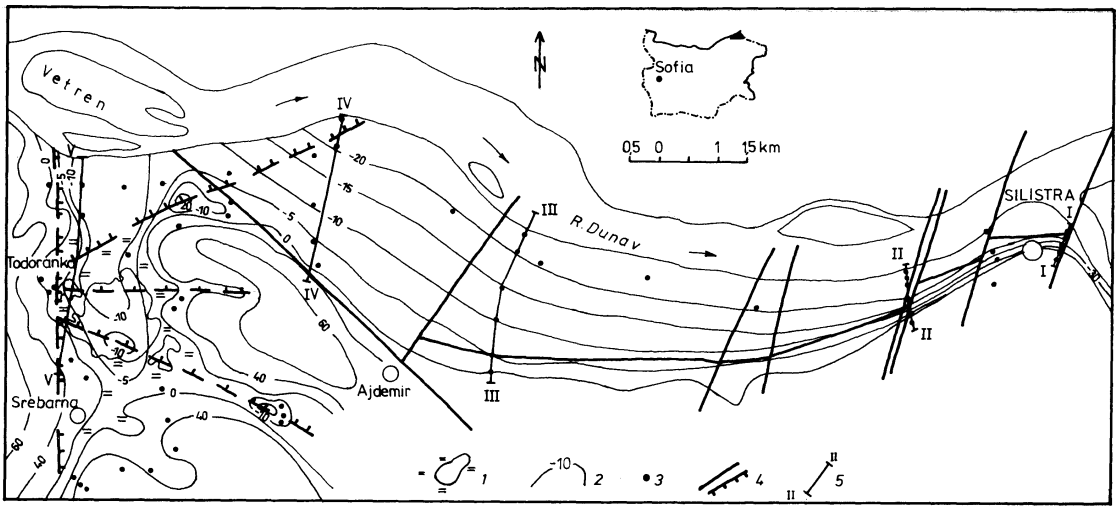

Fig. 3 Pre-Quaternary relief map of the western part of the Ajdemir Lowland: 1 – "Srebarna" swamp area; 2 – isohypses of absolute elevations; 3 – borehole location; 4 – faults and normal faults; 5 – position of the geological profiles.

The formation of a positive morphostructure to the south of the Ajdemir lowland and the display of normal fault movements predetermined the valley divergence in the region. The normal faults observed in the spaces between the blocks marked the orientation of the rivers in W-NW, N and E-NE direction, the changes in the local erosion bases, the asymmetric and canyon-like valleys, incised meanders, etc. The main erosion basis was the Danube river. The river migrated continuously to the south depending on the different dynamics of the single blocks. As a result, its asymmetric profile was shaped – with steep banks and reduced area until the entire destruction of the terraces from the mouth of the Srebarnenska river to the town of Silistra. The thickness of the alluvial deposits of the overflood terraces did not exceed 4 m. The deposits represent the flood and overflood facies of the rivers. The total value of the erosion incision during the Pleistocene was up to 10 m for the Ajdemir lowland and up to 80 m for the rest part (Angelova, 1996, Angelova, 1999).

The Holocene stage was characterised by strongly differentiated vertical tectonic movements and specific climatic circumstances during the post-glacial period. The Ajdemir lowland was formed. As a result of one-act earthquake (8-9 degree, an amplitude of vertical movements 20 m, 10500±250 B.P.), a block was torn off in the western part of the lowland in the region of the Srebarna village. The gravitation block fell in the mouth-part of the Srebarnenska and Kalnezhka rivers, forming a natural barrier for the river water which was deviated in the base of the block and lost in its karst substrate. The swamp sediments of the Todoranka Clayey Formation were deposited in front of the block (Angelova, 1995, 1996). The swamp occupied the local tectonic lowering formed as a result of the earthquake and marked the tectonic node between the regional longitudinal structure and the local transverse structure (Fig. 4).

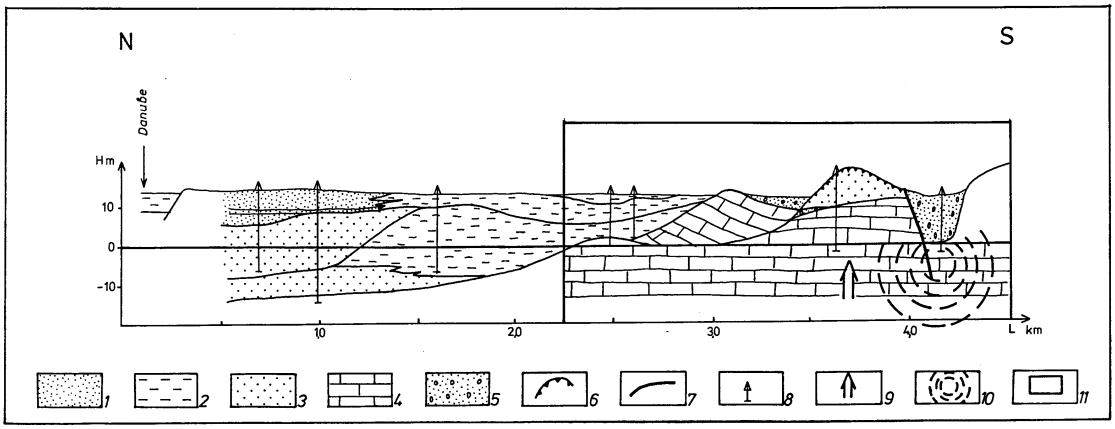

Fig. 4 Geological-geomorphological profile of the "Srebarna" paleoseismic dislocation: 1 – Tarlitsa Gravel-sandy Formation (Upper Holocene); 2 – Todoranka Clayey Formation (Upper-Lower Holocene); 3 – undivided Lower Holocene alluvial deposits; 4 – Rousse Formation (Barremian-Aptian); 5 – accumulative pockets; 6 – relief deformation; 7 – place of the paleoseismic dislocation; 8 – place of the boreholes; 9 – direction of the block movement during the earthquake; 10 – place of the event; 11 – range of the area affected by the earthquake.

The Holocene sediments building the Ajdemir lowland have a river and swamp genesis, their thickness being from 4 to 30 m (Figs. 2, 3, 4). The swamp sediments were formed under conditions of continuous sinking of the tectonic block since the beginning of the Holocene. The Holocene sediments were deposited on small blocks of different dynamics and formed superimposed, interbedded and contiguous discordances. The sedimentation formed clearly expressed cycles in the two lithofacial zones – the alluvial and the swampy ones, due to the occurring climatic and hydrodynamic changes.

The contemporary stage inherited the general character of the morphogenic processes occurring in the Holocene. The development of the river-ravine network and the exodynamic, endodynamic and anthropogenic relief processing continued. The values of the erosion dismembering are within the range of 0.25 to 1.50 km/km^2. The average turbidity value of the river water in the region is high – from 360-1000 g/m^3 and the average quantity of suspended deposits is 2.2 t/s. The accelerated display of the contemporary morphodynamic processes is controlled by the contemporary tectonic and erosion processes, the lithological, hydrodynamic and anthropogenic factors. The local tectonic movements are differentiated for the single blocks (Silistra +0.10 mm/a, Ajdemir +0.80 mm/a). The contemporary swamp formation is an evidence for local tectonic sinking. The exogenic contemporary processes have a risk character and are related to gravitation movements and sedimentation of a sudden origin, active surface and linear erosion, fading or enhancement of the karst process. During the last years the "Srebarna" swamp area has been reduced because of the ceased feeding. The decreased range and depth and the complex geological-tectonic circumstances have led to a biological crisis. The construction of a channel and engineering equipment bringing fresh water from the Danube to the swamp was urgently realised.

5 Conclusions

The investigated region is of strategic importance for the assessment of the geodynamic development of the region. It is a reference for the Holocene history of E Europe. The understanding of the geodynamic predetermination of sediment formation that has not yet been thoroughly described, is of practical value for the assessment and preserving of the environment both in the "Srebarna" International Biosphere Reserve (under the protection of UNESCO) and in the whole regarded territory, from hazardous natural and anthropogenic processes.

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Evolution of the Vegetation Conditions in the Floodplain Region of the Danube

Ján Benetin, Andrej Šoltész

Abstract: The authors selected from a very comprehensive and relatively long-term research program connected with construction of water works in the Slovak-Hungarian section of the Danube river for this contribution a part of results concentrated on future evolution of vegetation conditions in originally annually flooded territory of the Danube river. This territory is covered mostly by floodplain forest and permanent grass growth. Hereby, the results of the former hydrological, hydrophysical and biologic-ecological research, realized in university bodies and in research institutes were utilized.

The mentioned problem was solved using mathematical modeling (MOVOREP-IHH SAS, [1]) for soil water regime analysis including the evaluation of soil water balance components. From obtained data daily EHPI (energy-hydro-plant index) values were evaluated as complex indicator of meteorological and soil moisture conditions for the vegetation evolution. Using this method for evaluation of vegetation conditions for 21 decades in the vegetation period and by determination of trend of trend of given indicator changes was proved the deterioration of vegetation conditions (mainly soil water deficiency) in decades in second half of summer and first half of autumn period.

Key words: potential, actual and optimum evapotranspiration, energy-hydro-plant index, global climatic change

Die Entwicklung der Vegetationsbedingungen im Überschwemmungsgebiet der Donau in Abhängigkeit von ihrer Wasserspiegelabsenkung

Zusammenfassung: Im Zusammenhang mit der Planung und der Ausführung des Wasserkraftwerkes (WKW) Gabčíkovo-Nagymaros im slowakischen und slowakisch-ungarischen Abschnitt der Donau hat man beginnend in den 50er Jahren bis in die 90er eine besondere Aufmerksamkeit auf die Erforschung der ökologischen Bedingungen der angrenzenden Gebiete gewidmet, in denen man vor allem einen Einfluss des geplanten WKW Gabčíkovo-Nagymaros vermutet hat. Es wurde eine systematische biologische und landschaftspflegerische Forschung der Donau und des angrenzenden Gebietes aufgebaut, die seit mehr als 50 Jahren andauert. An dieser Forschung haben intensiv viele zuständige Dienststellen sowie Universitäten, Institute der Slowakischen Akademie der Wissenschaften und Forschungsinstitute der Ressorts mitgewirkt. In Zusammenarbeit der Ungarischen und Slowakischen Akademien der Wissenschaften hat man seit dem Jahr 1981 das integrative Projekt "Geowissenschafliche, hydrologische und biologisch-ökologische Erforschung der Donau- und Theißniederungen und deren Anwendung bei der Lösung der landschaftlichen Probleme" erfolgreich bearbeitet. Im Rahmen dieses Projektes hat das Institut für Hydrologie und Hydraulik der Slowakischen Akademie der Wissenschaften die "Analyse, Prognose und Regulierung des Wasserregimes der Böden im Überschwemmungsgebiet der Donau" gelöst. Die erreichten Ergebnisse wurden stufenweise den Planungs- und Durchführungsorganisationen übergeben und wurden im erheblichen Ausmaß veröffentlicht. Gleichzeitig hat man wertvolles Unterlagenmaterial über die zeitliche Entwicklung der Wasserbilanzelemente der Böden im Überschwemmungsgebiet erworben, einschließlich von Werten der potenziellen und aktuellen Evapotranspiration einer 30-jährigen Reihe der Vegetationsperioden (1955-1984) für dauernde Grasbedeckung auf sechs verschiedenen Böden (sandig, lehm-sandig, sand-lehmig, lehmig, lehm-tonig und tonig).

In den letzten Jahren widmen Klimatologen zusammen mit Hydrologen große Aufmerksamkeit den globalen Veränderungen des Klima und dessen Einfluss auf die hydrologischen Zustände in der Landschaft, auf die Vegetation und besonders auf die Landwirtschaft. In den Veröffentlichungen fehlte aber bisher ein geeigneter Parameter, der die Anforderung der Pflanze an die meteorologischen und Bodenfeuchtebedingungen aufgrund der Auswirkungen des Einflusses der Klimaveränderung beschreiben könnte. In physikalischer und physiologischer Hinsicht ist für den Wachstumsprozess der Pflanzen von den hydrologischen Elementen am ehesten die Evapotranspiration von Bedeutung, wobei man den Verhältniswert der aktuellen (ETA) und potenziellen (ETP) Evapotranspiration (ETA/ETP) oft zur Beschreibung der Bodenwasserversorgung der Pflanzen benutzt. Zu diesem sehr zutreffenden Parameter muss man einen weiteren Parameter hinzunehmen, welcher die Anforderungen der Pflanze in ihrer ontogenetischen Entwicklung an die Wetterbedingungen und meteorologische Situation ausdrücken kann. Dazu eignet sich die sogenannte optimale Evapotranspiration (ETO), die eigentlich die potenzielle Evapotranspiration in Tagen mit optimalem Wetter für das Wachstum der Pflanzen darstellt. Dieses Verfahren wurde für die Auswertung des Einflusses der Klimaveränderungen unter den Vegetationsbedingungen eines dauernden Grasbewuchses in den Gebieten der Überschwemmungsflächen der Donau in der Nähe des WKW Gabčíkovo angewendet.
Schlagworte: Potenzielle, aktuelle und optimale Evapotranspiration, Energo-Hydro-Pflanzen Index, globale Klimaveränderung

1 Introduction

At impact assessment of Gabčíkovo water works on adjacent area of Slovak-Hungarian section of the Danube a very comprehensive geo-scientific, hydrological [5, 6, 7, 8, 9, 10] and bio-ecological research was provided to obtain in the project measures for necessary improvement of ecological conditions of adjacent region. Firstly, it was the floodplain region, partially forested and partially covered with grass growth. Improvement of vegetation conditions in floodplain was a very actual problem when realizing construction of water works on Danube. This was caused consequently by significant decrease of sediment transport in the river of the Danube connected with water level decrease so that in last years before putting Gabčíkovo water works into operation the flooding of the floodplain area was enabled after exceeding 4.000 $m^3.s^{-1}$ discharge in the river. At the same time the minimum contact of ground water level [10] starts after reaching approximately 2.5 times of minimum discharge (1.300 $m^3.s^{-1}$). In period with precipitation deficiency the plants in floodplain did not have sufficient soil water. There occurred an acute requirement for ground water level increase not only in the river zone of the Danube but also in more distant parts of the Rye Island. Even in these consequences the problem of soil water regime in floodplain area of the Danube without any contact of ground water table with cover layers of the soil. The problem was solved using mathematical modeling connected with necessary input data. These were meteorological data (1955-1983) given by SHMI Bratislava and hydrophysical properties of soils measured and determined at IHH SAS [9]. Evaluating values of evapotranspiration (ETP, ETA, ETO) a daily step for calculation from the beginning of the vegetation period until the end (21 decades) of vegetation period was used. Optimum evapotranspiration (ETO) is potential evapotranspiration given for individual ontogenetic periods in a day with optimum weather for the plant development. Therefore it is determined using methods for potential evapotranspiration [2,4].

2 Methodological procedure

Soil water regime course in sandy-loam soil with permanent grass growth without ground water table influence as well as potential (ETP) and actual (ETA) evapotranspiration were calculated for Gabčíkovo site in the vicinity of water works. Daily values of energy-hydro-plant index

EHPI (i.e. complex indicator of meteorological and soil moisture conditions of natural environment with respect to growth and evolution of plants were calculated according to relation:

$$EHPI = \frac{ETA}{ETP^{\beta}.ETO^{\gamma}} \quad , \qquad (1)$$

where ETP, ETA and ETO are potential, actual and optimum evapotranspiration from plant evolution aspect. At the same time for exponent values β and γ considering the constrained range of the EHPI value ($0 \leq EHPI \leq 1$) [2, 3] comes out that $\beta + \gamma = 1$. At low ETP values $\beta \rightarrow 0$, on the contrary, at high ETP values, i.e. ETP > ETO the exponent value $\beta \rightarrow 1$ [4]. In the range of values from $ETPK_2$ to $ETPK_2 + (ETPK_3 - ETPK_2)/2$ it is possible to express β using formula [4]:

$$\beta = 0,5 - 0,5\sqrt{1 - \frac{4(ETP - ETPK_2)^2}{(ETPK_3 - ETPK_2)^2}} \quad , \qquad (2)$$

where $ETPK_2$ corresponds with meteorological conditions at which in given ontogenesis phase the processes of plant growth hold off and $ETPK_3$ characterizes the optimum level of meteorological conditions for plant growth and evolution. At the same time, if $ETP < ETPK_3$ the ETP value is substituted by $ETPK_2$ value, so that $\beta = 0$. Similarly, for interval from $ETPK_3$ to $[ETPK_2 + (ETPK_2 + (ETPK_3 - ETPK_2)]$ the β value can be expressed using:

$$\beta = 0,5 + \sqrt{1 - \frac{4(ETPK_3 - ETP)^2}{(ETPK_3 - ETPK_2)^2}} \quad . \qquad (3)$$

If $ETP > ETPK_3$, ETP value is substituted by related $ETPK_3$ value so that $\beta = 1$. At simplified procedure [2] the EHPI value is calculated in range from $ETPK_3$ to $ETPK_2$ using exponent values $\beta = \gamma = 0,5$ and the relation (1) can be expressed:

$$EHPI = \frac{ETA}{\sqrt{(ETP.ETO)}} \quad . \qquad (4)$$

The course of EHPI values calculated according to Eq.(4) and Eq.(1), (2) and (3) for the vegetation period of the dry year 1983 is illustrated in Fig.1. It is evident that in the beginning of the vegetation period is determination of EHPI values more precise but in the whole period the change tendency of EHPI values preserves (decrease–increase).

3 Tendency of change influence of meteorological and soil moisture conditions on vegetation growth and development in floodplain area of the Danube

The deepening process of the Danube river bed on Slovak-Hungarian reach and with this connected permanent decrease and interruption of ground water table with cover layers of the soil profile as well as interruption of periodical flooding of floodplain area has started in 50-th years consequently with significant decrease of sediment load (gravel and sand) in the river bed in this part of the Danube. The aim of the contribution is to present results of global climate change influence research on vegetation in the floodplain in conditions of decreased ground water table. At influence evaluation of meteorological and soil moisture conditions on vegetation a method of energy-hydro-plant index was used (EHPI as complex indicator). Tendency evaluation of the influence of global climatic changes on meteorological and soil water conditions of vegetation has been provided by regress dependence method of EHPI in individual decades of vegetation periods in 1955–1983 years. These tendencies are illustrated in Fig.2 (decades in late summer period, No.13-15) and Fig.3 (decades in early autumn period, No.16–18). These decades show the most significant influences of climatic changes on vegetation conditions of grass growth. These decades are significant as well for high variability

of precipitation occurrence as for relatively high values of potential evapotranspiration. Decreasing tendency of precipitation (decades No.14 and 15) and increasing tendency of potential evapotranspiration (decades No. 15, 16, 17 and 18) illustrate that the deterioration of soil moisture conditions for vegetation cover is effected by increase of climate extremity, too. This question is necessary to analyze more in more detail in the future.

4 Conclusion

These calculations were performed in conditions of ground water absence. In present time there is an artificial supply of the river branch system of the Danube from upper power channel of Gabčíkovo power plant. This water supply effects as well the ground water table as the soil moisture conditions of cover layers in floodplain region. This influence will be taken into consideration for additional calculations in the future, as well.

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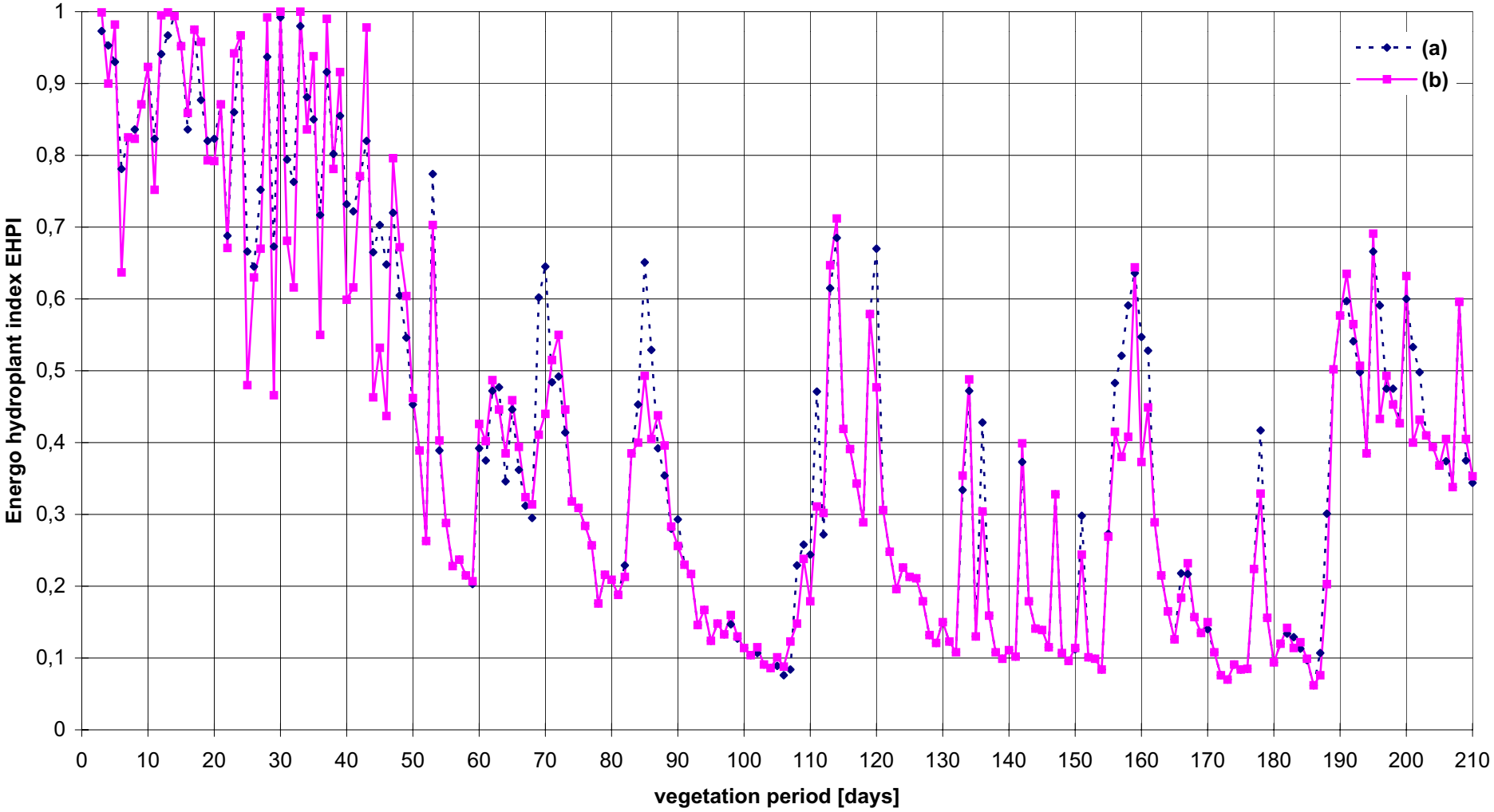

Fig. 1 EHPI values comparison for $\beta = \gamma$ = 0,5 if ETP < ETO **(a)** and β = 1,0 if ETP >= ETO **(b)**

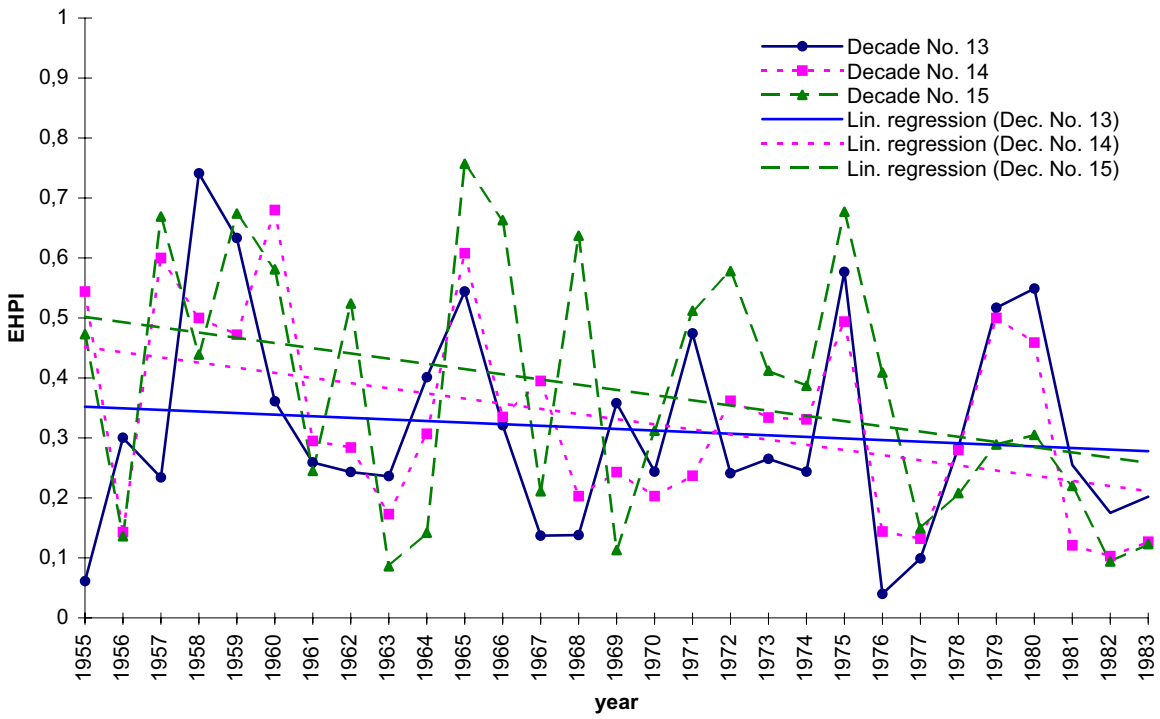

Fig. 2 EHPI value course in decades No. 13-15 of vegetation period in floodplain of the Danube river

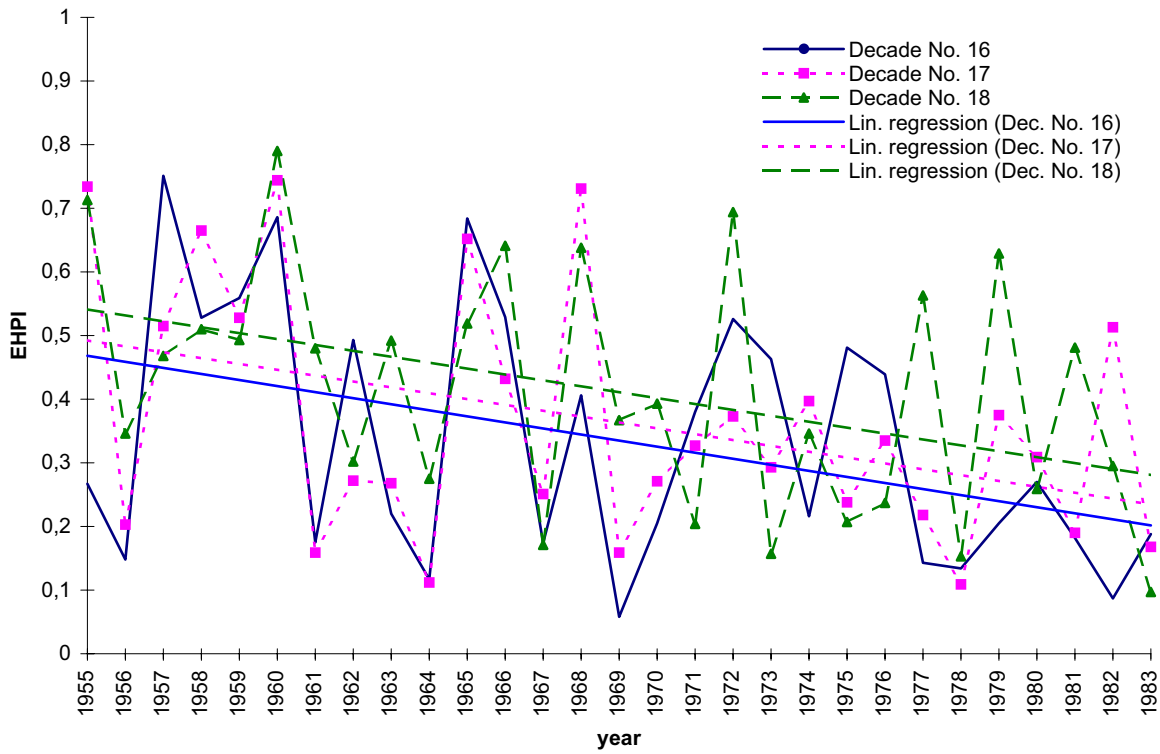

Fig. 3 EHPI value course in decades No. 16-18 of vegetation period in floodplain of the Danube river

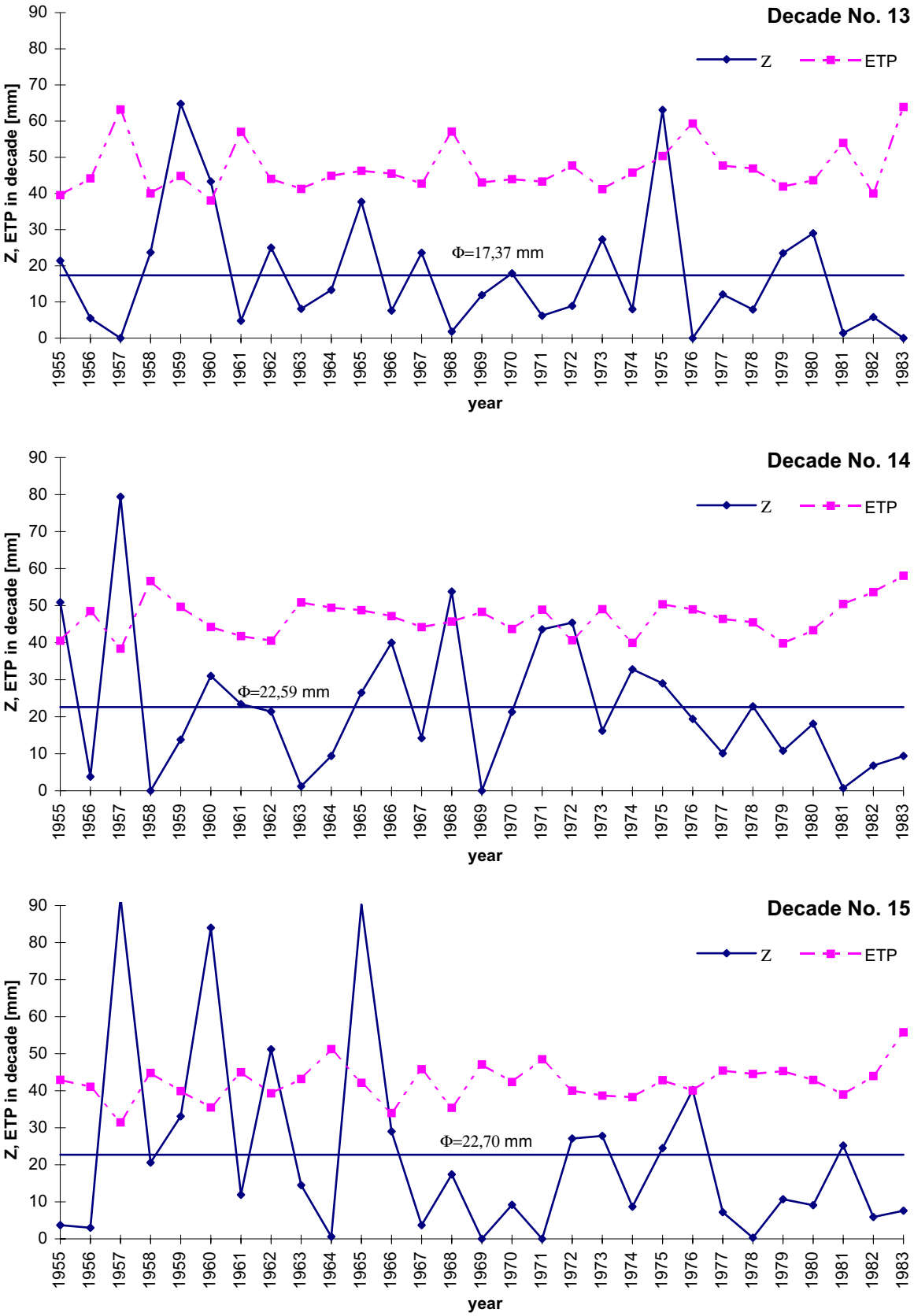

Fig.4 Courses of precipitation and potential evapotranspiration in decades No. 13-15 (1955-83)

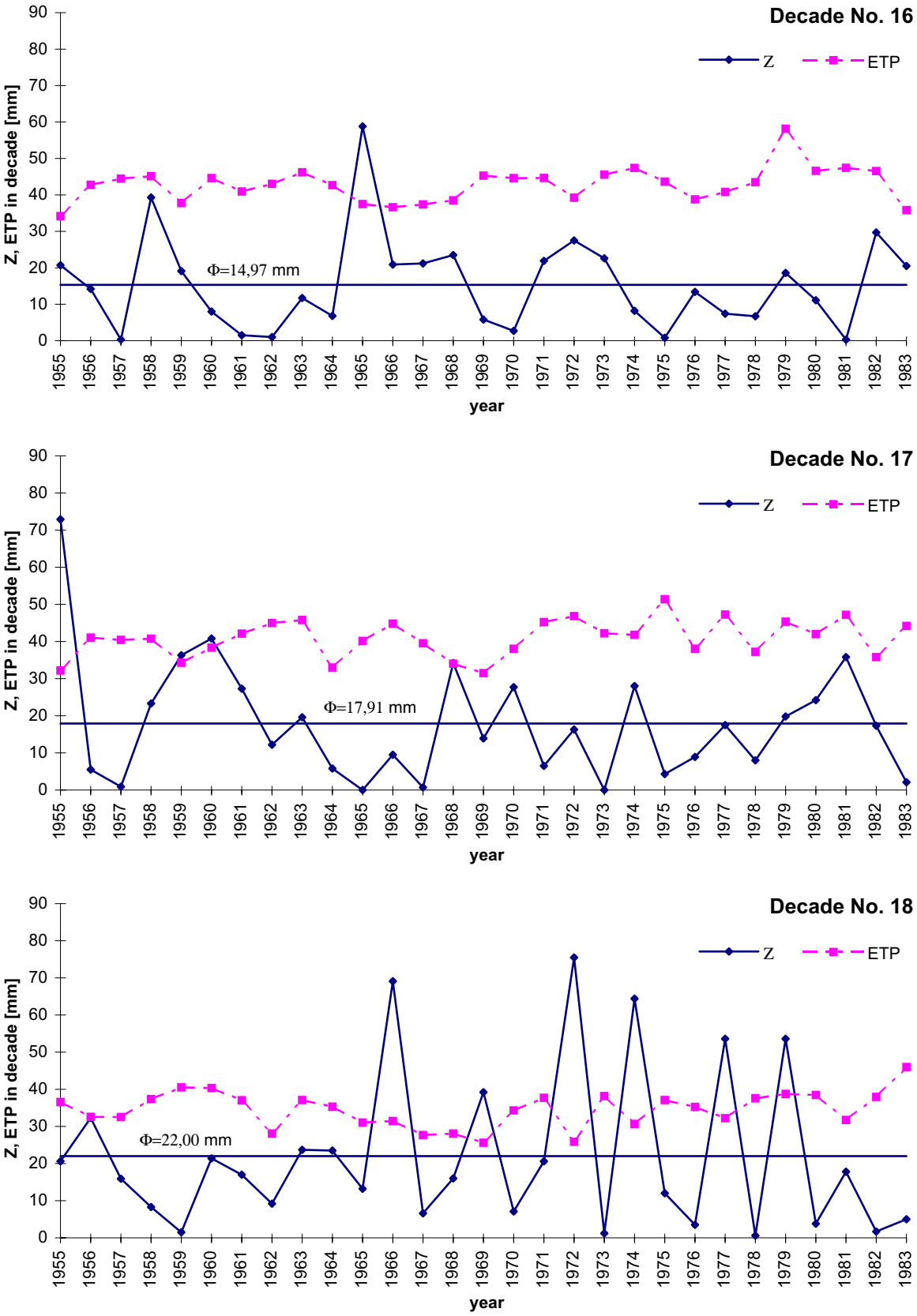

Fig.5 Courses of precipitation and potential evapotranspiration in decades No. 16-18 (1955-83)

Influence of Drought Period of 1982-1994 to the Groundwater Regime in the Danube Hydrological Zone

Einfluss der Trockenperiode 1982 - 1994 auf das Grundwasserregime in der hydrologischen Zone an der Donau

Elena Kirilova Bojilova, Tatiana Vasilevna Orehova

Abstract: Since 1981 in the territory of Bulgaria the continuous decrease of rainfall in combination with increase of air temperature has been registered. As a result of this the depression in the ground water level and decrease in the spring discharges were observed. In the present study, the investigation of groundwater regime was made for the drought period 1982-1994 based on the analysis of the 1960-1996 observation period. Similar tendency in the regime of surface and subsurface water during the drought period has been registered. Some general conclusions concerning the effect of drought on subsurface and surface water are made. The deepest depression for groundwater levels and spring discharges has been observed mainly in 1993 and 1994.

Key words: groundwater regime, spring discharge, water level, drought period

Einfluss der Trockenperiode 1982 - 1994 auf das Grundwasserregime in der hydrologischen Zone an der Donau

Zusammenfassung: Seit dem Jahre 1981 wurde auf dem Territorium Bulgariens eine ständige Abnahme der jährlichen Regenhöhe beobachtet. Parallel dazu wurde auch eine Erhöhung der Lufttemperatur registriert. Als Ergebnis wurde eine Grundwasserspiegelabsenkung und eine Verminderung der Quellschüttungen beobachtet. In der vorliegenden Studie wird eine Untersuchung des Grundwasserregimes für die Trockenperiode 1982 - 1994 unter Berücksichtigung der längeren Beobachtungsperiode 1960 - 1996 vorgestellt. Es wurde für diese Trockenperiode eine gleiche Tendenz sowohl beim Grundwasserregime, als auch beim oberirdischen Wasserregime festgestellt. Über den Effekt der Trockenheit auf das Grundwasser und das Oberflächenwasser werden einige allgemeine Schlussfolgerungen gezogen. Die tiefste Absenkung der Grundwasserspiegel und die geringsten Quellschüttungen wurden vor allem in den Jahren 1993 und 1994 beobachtet.

Schlüsselworte: Grundwasserregime, Quellschüttung, Wasserstand, Trockenperiode

1 Introduction

Since 1981 in the territory of Bulgaria the continuous decrease of rainfall in combination with increase of air temperature has been registereded. As a result the reduction of the river flow has been noticed in the country. The great interest to the event of drought is explained with the conception of global climate change, when water resources will be under threat.

The drought period may be considered as a model of the future global changes. The recent study for water resources of Bulgaria during the drought period (Gerassimov et al., 1999) gives general characteristic of this period for the territory of Bulgaria and for the three main hydrological zones:

(i) zone with direct discharge to the Danube river;
(ii) zone with direct discharge to the Mediterranean sea and
(iii) zone with influence of the Black sea.

In addition to the study of precipitation and river flow some analysis of groundwater variation is applied. In the present study more explicit information is given for the Danube basin, namely for its Western and Central parts.

2 General characteristic of the drought period

The general characteristic of the drought period is given according to (Gerassimov et al., 1999).

2.1 Available data

The sixteen representative hydrological stations for the Danube basin were used in Gerassimov et al., 1999 to lengthen available data series (Table 1, for more comprehensive summary), see Gerassimov et al., 1997.

The water levels for rivers are available since 1909, and river discharges - since 1936.

Table 1 Lengthened data series for the river discharge in Danube watershed

Hydrological station	from
Ogosta river - Mizia	1914
Vit near Teteven	1922
Rosiza - Sevlievo	1922
Jantra - Cholakovzu	1922
Rusensku Lom - Bojichane	1922

Data series for precipitation and air temperature were obtained on the base of all rain gauge and meteorological stations in the territory of Bulgaria. They were lengthened by correlation and regression analysis taking into consideration the altitude of stations (Gerassimov et al., 1999)**.** The number of stations for precipitation and air temperature is given in Table 2.

Table 2 * Number of used data series with annual values for precipitation and air temperature

Basin	Precipitation stations (P), number	Temperature stations (T), number
Danube basin	134	71
Total for Bulgaria	300	169

* after M. Genev, 1999

2.2 Analysis of multi-annual variations of air temperature, precipitation and river flow

As a result of available and lengthened data series, joint chronological graphs for annual values of air temperature, precipitation and river flow for Bulgaria and for the three main hydrological zones were drawn (Gerassimov et al., 1999). Positive trends for air temperature and negative ones for precipitation and runoff were specified for the period 1890 –1995 in the whole country. The strongest decrease of precipitation and runoff was determined in Danube basin. The Fig. 1 presents the chronological graphs for the Danube basin.

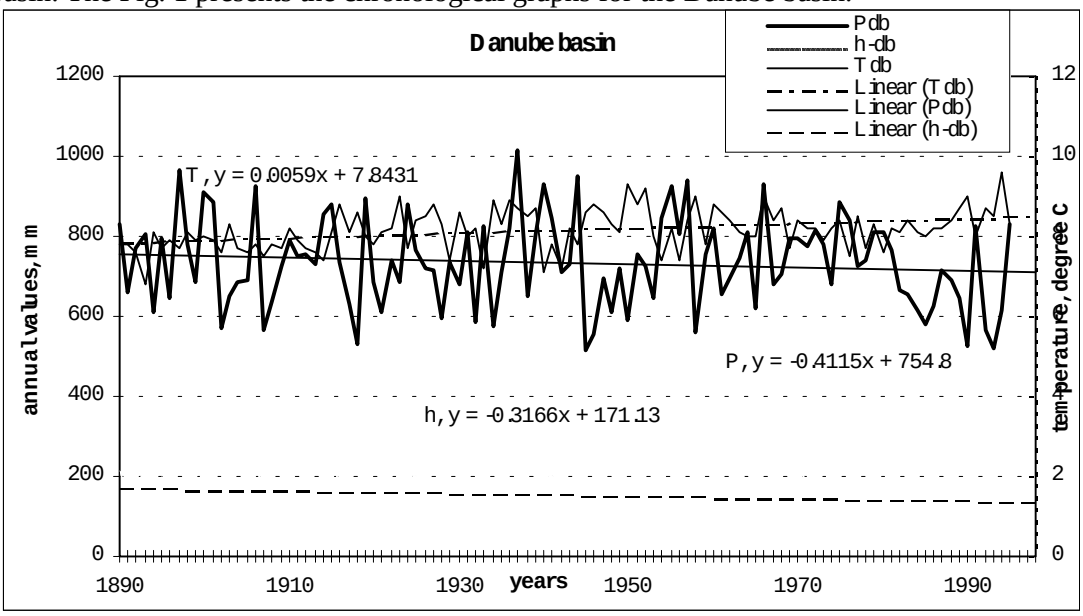

Fig. 1 Joint chronological graphs for annual values of air temperature T, precipitation P and riverflow h (as water layer) for the Danube basin stations (Gerassimov et al., 1999)

2.3 Definition of the drought period for precipitation and river flow

The definition of the drought period for discharges and precipitation is well founded in Gerassimov et al., 1999. The statistical structure of the period represented with two basic parameters - mean value $\overline{X}$ and standard deviation σ_X is presented in Table 3, based on the above mentioned study. The statistical parameters are compared with values from the longest period of data 1890-1995.

The analysis of the Table 3 shows that the chosen estimators ($\overline{X}$ and σ_X) are considerably lower from the values of the 106-year period.

Table 3 Statistical structure of the drought period 1982-1994: $\overline{X}, \sigma_X, Cv$ and their deviation in relation to the period 1890-1995

Area	Element	$\overline{X}_{13}$	$K_X = \frac{\overline{X}_{13}}{\overline{X}_{106}}$	σ_{13}	$K_\sigma = \frac{\sigma_{13}}{\sigma_{106}}$	Cv_{13}	K_{Cv}
Danube basin	h	98.3	0.638	36.1	0.642	0.367	1.005
	P	633.6	0.865	82.2	0.791	0.130	0.844
Bulgaria total	h	138.2	0.695	41.7	0.747	0.302	1.075
	P	640.2	0.877	66.5	0.639	0.104	0.732

The period 1982-1994 is characterized with low depression for river flow and groundwater. Decreasing of the river flow for this period is assessed as 31% in relation to the period 1890-1996 (Gerassimov et al., 1999). The shorter period 1985-1994 gives stronger reduction of the discharge. According to scenarios of Climate change given in Arnell, 1999, the reduction of river flow in Bulgaria with 25-50% is expected. These results are comparable with the effect of the drought period 1982-1994.

3 Analysis of the variation of the spring discharges and groundwater levels

To study the effect of the drought period 1982-1994 to groundwater, the analysis of variations of the spring discharges and groundwater levels was applied.

3.1 Object of study and information base

In the present study we are dealing with the groundwater regime for the drought period 1982-1994 based on the analysis of the 1960-1996 observation period. Time series from National hydrogeological network that starts from 1958-1960 were used. The hydrogeological stations with long period of observation and minimal antropogeneous impact were selected. They are springs and wells. Data series are spring discharges and water levels for the observation wells.

For the purpose of this study the variations of spring discharges and ground water levels in the period 1982-1994 were studied based on the all period of observation. 17 springs and 3 wells were preliminary chosen from river basins located in Western and Central parts of the Danube basin. Deviations for different periods were evaluated: 1960-1981, 1982-1994 and 1985-1994.

Bulgaria is reach in karst springs. In the frames of the Danube basin they are related to elevated massives of Triassic, Jurassic and Cretaceous limestones (Antonov et al., 1980). The most important from them are observed as stations of National hydrogeological network.

3.2 Quantitative assessments of the effect of the drought period to groundwater

The effect of the drought period 1982-1994 on the regime of groundwater was studied. For quantitative assessments the mean values for the periods 1960-1996, 1960-1981, 1982-1994 and 1985-1994 were obtained. The results for 14 hydrogeological stations are presented in Table 4.

For this purpose, the deviations of average values for discharges and water levels for some periods. The per cent deviation is calculated by (where n refers to the short period and N - for the whole period):

$$\varepsilon = \left(\frac{\overline{X}_n}{\overline{X}_N} - 1 \right) 100\%$$

The per cent deviations for shorter periods in comparison to the longest one are presented in Table 4, as well as data for Danube basin and total river discharge for Bulgaria.

Table 4 Deviation of average values for discharges and water levels for the periods: 1960-1981, 1982-1994 and 1985-1994 from the mean values for the 37 years period of observation

River basin	Station	1960-1996	1960-1981	1982-1994	1985-1994
		ε, %*	ε, %	ε, %	ε, %
Lom	karstic spring - 341		10.9	-17.9	-28.2
Ogosta	karstic spring - 340		-3.9	5.4	2.0

	well - 423		5.8	-5.7	-8.0
Scat	well - 442**		1.9	-1.9	-3.4
Iskar	karstic spring - 30		23.0	-37.7	-45.8
	spring - 58**		-0.5	-1.8	3.2
	karstic spring - 446**		16.3	-16.1	-18.1
Iskar / Vit	karstic spring - 25		13.3	-21.4	-21.8
Vit	karstic spring - 379		2.3	-10.7	-9.9
	well - 418		4.5	-5.6	-7.5
Osam	karstic spring - 450**		15.8	-31.0	-35.8
Jantra	karstic spring - 437**		3.5	-3.6	-8.3
	karstic spring - 394**		17.5	-25.2	-32.8
	karstic spring - 396		16.3	-27.1	-43.7
Danube	Danube drainage basin	-6.0	20.5	-32.3	-39.0
Bulgaria	Total river discharge	-3.9	17.0	-27.7	-35.8

* For the period 1890-1995

** The observation period for stations 450, 437 and 394 begins from 1961; for stations 58 and 442 - from 1962; for station 446 from 1963

3.3 Chronological structure

The chronological structure of the investigated periods is presented in Figures 2-7. The deviations for the figures are calculated using annual discharge for springs and annual water level for wells in deviations:

$$\psi = \frac{X - \overline{X}}{\sigma_X}.$$

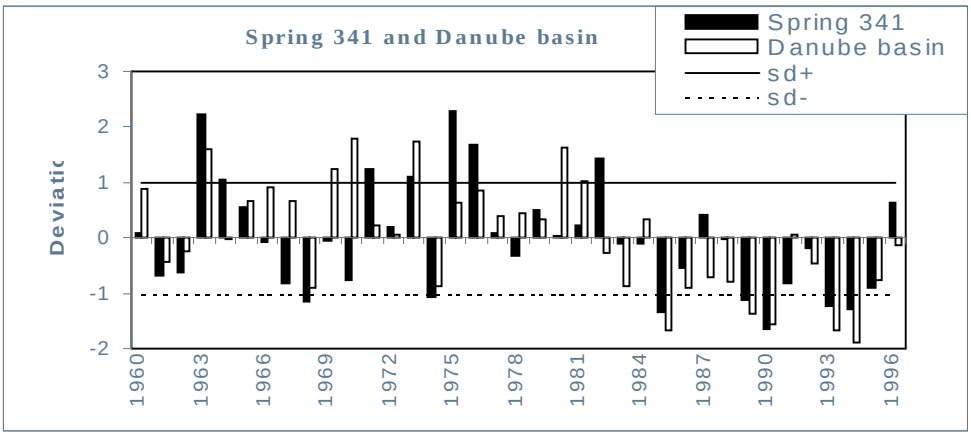

Fig. 2 Discharge for spring 341 and Danube basin in deviations ψ.

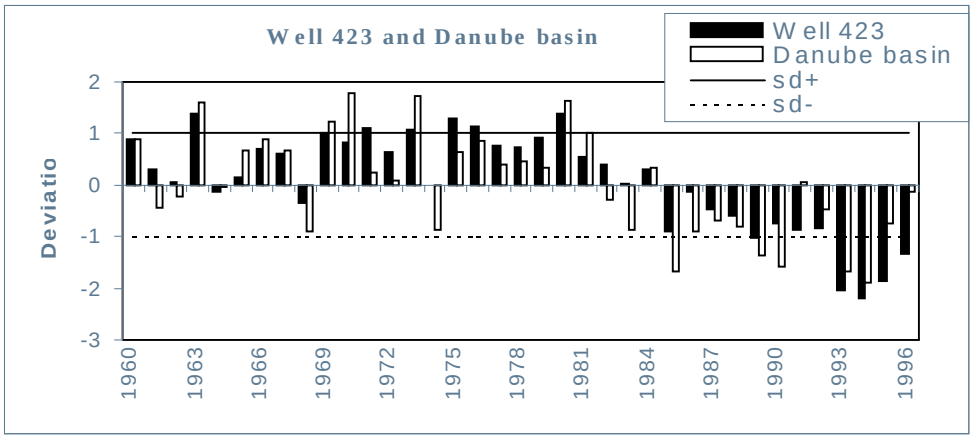

Fig. 3 Water level for well 423 and discharge for Danube basin in deviations ψ.

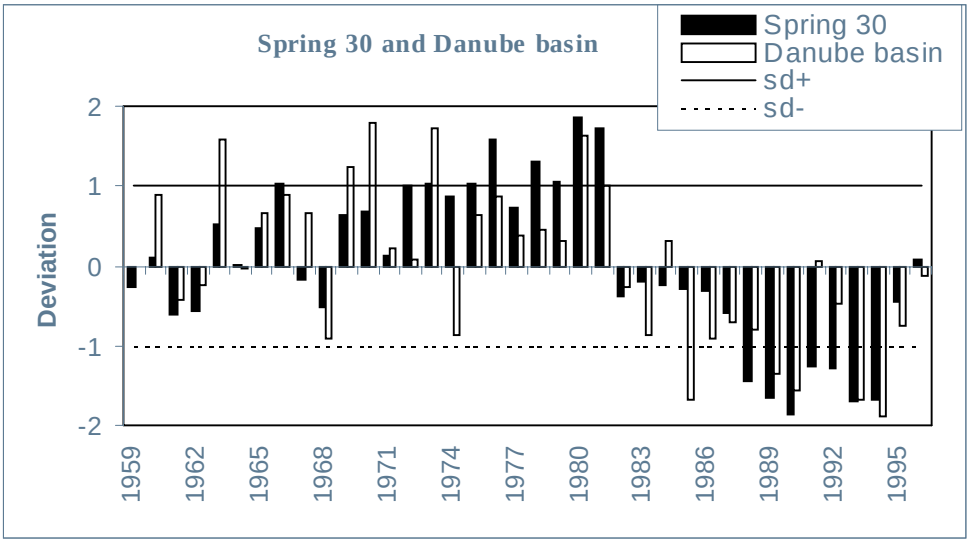

Fig. 4 Discharge for spring 30 and Danube basin in deviations ψ.

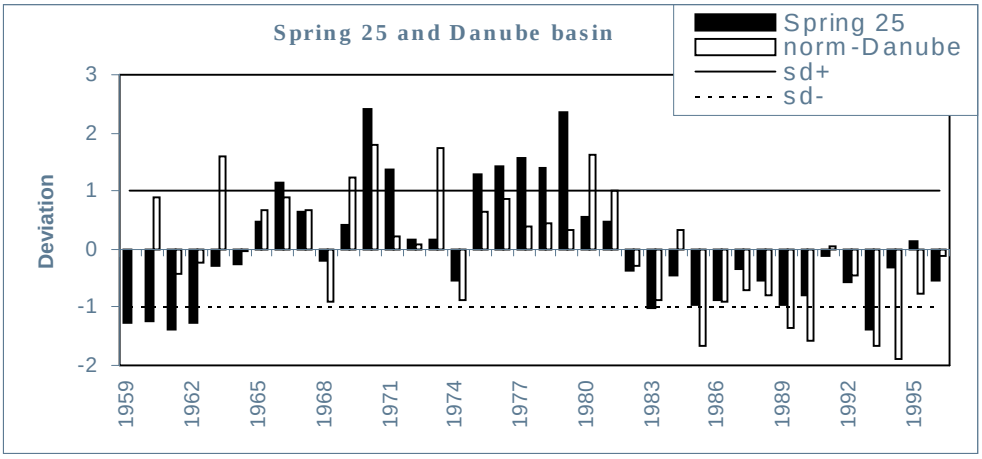

Fig. 5 Discharge for spring 25 and Danube basin in deviations ψ.

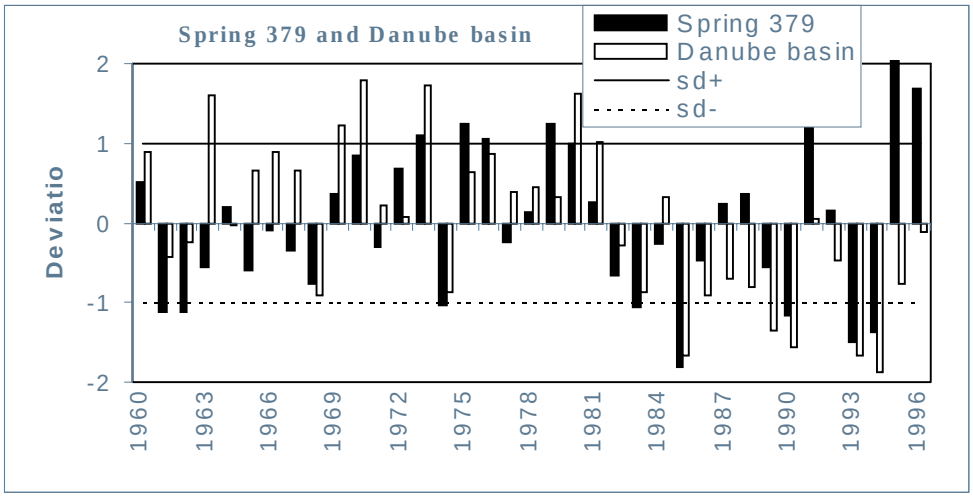

Fig. 6 Discharge for spring 379 and Danube basin in deviations ψ.

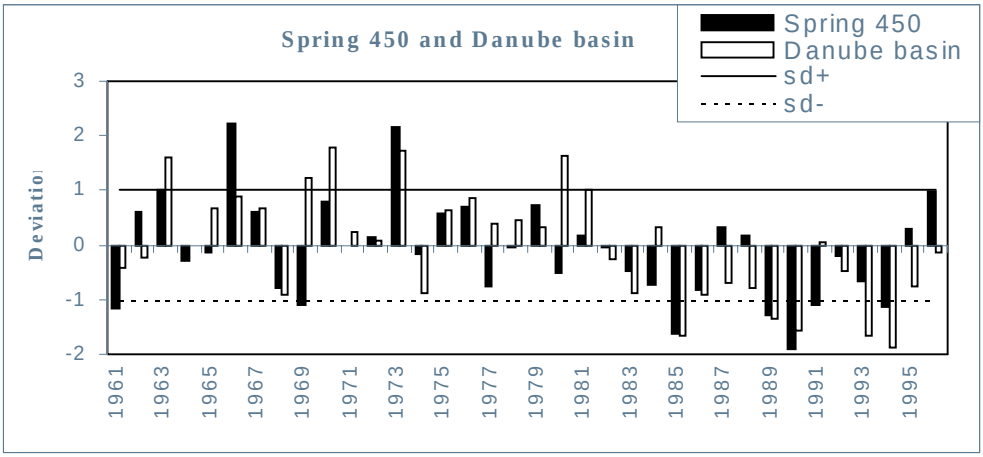

Fig. 7 Discharge for spring 450 and Danube basin in deviations ψ.

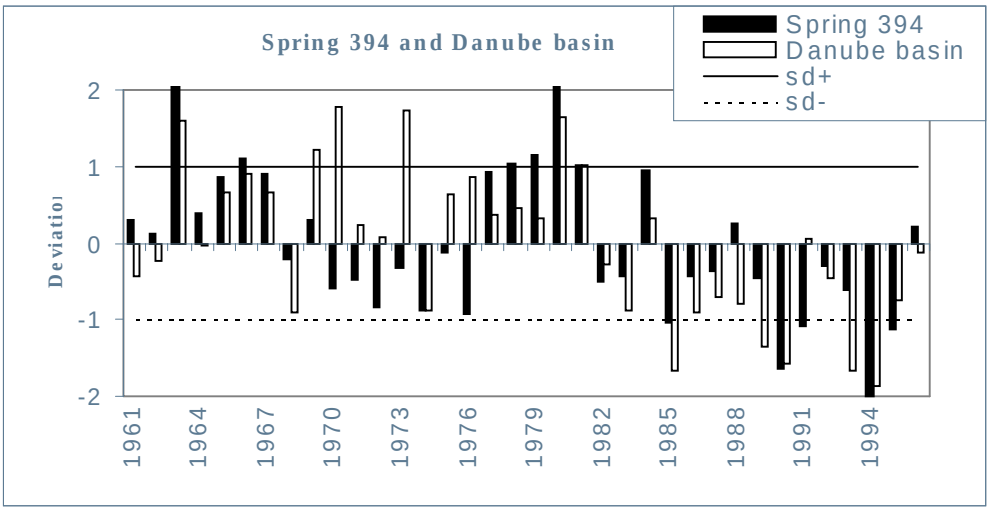

Fig. 8 Discharge for spring 394 and Danube basin in deviations ψ.

The information given in Table 5 and Figures 2÷8 allows to make the following conclusions:

- the drought period 1982-1994 and especially the short one 1985-1994 are characterized with low depression for the groundwater;
- the deviations for the groundwater are in similar range as for river discharges;
- the chronological structure of the drought is similar to this of the river discharge in the Danube zone with minimal values for spring discharges and water levels for wells for 1993 and/or 1994.

4 Conclusions

The drought of 1982-1994 reflected considerably on groundwater in Danube basin. Most of spring was with reduced discharge and wells showed lower water levels. The reduction of spring discharge was determined to be up to 20-30% as a whole. The shorter period 1985-1994 is characterized with lower depression

The chronological structure of the drought is similar to this of the river discharge in the Danube zone with minimal values for spring discharges and water levels for wells for 1993 and/or 1994.

5 Acknowledgments

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A Hydrological Analysis of a Catasrophic Flood in the Tysa River Basin in November 1998

Viktoria Bojko

Abstract: The analysis of hydrometeorological conditions of a catastrophic flood formation over Upper Tysa River basin in boundaries of Ukraine (Transcarpathian region) in November 1998 is considered. The prior conditions are described, the brief presentation of a synoptic situation is given. The characteristic of rainfall regime, flood development and its consequences are presented.

Key words. Flood formation, precipitations, Transcarpathian region, water level, water content, hydrometerogical factor, isohyet card, flood consequence, catastrophic destructions.

Die hydrologische Analyse eines Katastrophenhochwassers im Einzugsgebiet der Theiß im November 1998

Zusammenfassung: Es werden die hydrometeorologischen Bedingungen der Hochwasserentstehung im ukrainischen Einzugsgebiet der Theiß (Transkarpatische Region) im November 1998 analysiert. Die Bedingungen vor dem Hochwasser, werden beschrieben und es wird eine kurze Präsentation der synoptischen Situation gegeben. Schließlich werden das Niederschlagsregime, die Hochwasserentwicklung und seine Folgen vorgestellt.

Schlüsselwörter: Hochwasserbildung, Niederschläge, Transkarpatische Region, Wasserspiegel, Feuchtigkeit, hydrologischer Faktor, Isohyetenkarte, Hochwasserfolgen, katastrophenartige Hochwasserschäden

Total characteristic of conditions of floods formation

The Tysa basin in boundaries of Ukraine (Transcarpathian region) on its geographical situation and climatic conditions concerns to a zone of active storm activity and to one of most flood-dangerous regions of the Europe. Orography of Carpathians, the curve-liked layout of mountain ridges promotes of moist Atlantic air masses retardation, causes of intensification of storm precipitations.

The Transcarpathian territory is located in two orographic regions: 75 % of territory are situated in mountains and foothills of Carpathians, other part (almost 2,500 km^2) on the Hungarian plain. Such orographic features cause character of a water regime of rivers during flood. Significant gradients of mountainous country determine fast development of floods, rises of levels reach to 1.5-2.5 m for 3-4 hours. Flood waters fast reach to Tysa valley and its lower inflows, which are connected by meliorative channels on the plain. Rivers have small stream gradients on the plain and flood waters can submerge significant areas, if their interbasin diversion are not duly provided. This, in turn, results in large damages on the plain part of Transcarpathians.

Floods over Transcarpathians rivers repeat 3-8 times in one year. 20-30 % of all floods in one year on Transcarpathians passes in November - December. For the last 60 years the highest floods in this period of year were observed on many Transcarpathians rivers in 1941, 1947, 1957, 1974, 1978, 1979, 1992, 1993, 1995 years.

In a long-term context the frequency of flood formation is increased during raised of water content, stipulated by global atmospheric circulation.

The catastrophic flood of November 1998 was generated just in such period common raised of water content, which beginnings in the beginning of the last decade 20 centuries. This decade

high floods have been passed not only on rivers of the Ukrainian Carpathians, but also in Germany, Poland, Slovakia, Czechia, on lowland rivers of Ukraine.

Prior hidrometeorogical conditions of flood formation

High on hydrological parameters and disastrous on consequences the flood of November 1998 was simultaneously generated on all Transcarpathians rivers on November 4-8. This was very infrequent combination.

The whole complex prior hydrometeorogical factors was promoted catastrophic development of a flood, together with antropogeneous (not always reasonable and competent) activity in water intake territory and especially in zone of runoff formation.

The flood have been specified prior favorable hydrometeorogical conditions (high water content, good humidification of a water scoops surface), it has stipulated close to 1.0 runoff coefficients:

1. High moisture and partially overmoisture content of drainage basins in the summer and autumn. In April - October 1200-1400 mm (160-170 % of normal) precipitation have dropped out in mountains and 750 - 950 mm (140-180 % of normal) on the plain. The repeatability of such long anomaly of precipitation is estimated as 1-2 times for 100 years. Only for August - October their amount has made 1.3 – 1.5 norms.

2. High standing of ground waters (on 0.5-1.6 over of normal). The observations of meteorogical stations were registering of rise their level in comparison with long-term data, and also from one month by month of warm period of year.

3. High water content of all rivers of region during summer-autumn season, which on the eve of a flood has increased up to 3-6 norms. It was a consequence:

· - of formation floods in different parts of basin in July - October 8, the levels of August flood on small Ug and Latorica inflows were above historical;

· - of development of high rain flood on October 28 - November 2, its levels were only on 1-1.5 meters below historical.

4. To the beginning of November the levels of water were above than low-water stage on 0.5 – 2.5 m in headrivers and on 2.5-6.0 m on their plain parts. The water discharges were exceeded at 10-15 time of low-water stage. It has generated a high ground component of the rivers runoff.

Thus, to the beginning of November all conditions for a new flood were created in theTysa drainage basin.

Synoptic situation on November 3-5, 1998. Character of sprinkler irrigation of territory.

The flood directly was formed by strong, intensive and long precipitation on November 3-5. By characteristic and defining feature of the flood is long strong rainfall coverage of all Transcarpathians territory simultaneously.

The rains have begun in the afternoon on 3rd November at moving of warm front through Transcarpathians. At the night of 4th November a polar front have passed, the intensity of precipitation had increased. In the afternoon of 4th November some active microcyclones was derivated on it. All day Transcarpathians heve been in an operative range of atmospheric processes , the most active on all extent of cold front. And even after its passing through

Transcarpathians territory on November 5 the rains were proceeding, that is stipulated by orographic features of region.

Thus, very strong rains were stipulated by influence of low baric ground formations as active waves on cold front at southwest carry of warm damp air weights at heights of 3-5 km.

The total precipitation isohyet card for November 3-5 (Fig. 1) testifies, that the greatest precipitation are dated to Teresva, Kosovskaja, Black Tysa, Tereblja, and Rika riverheads, i.e. for a zone of Tysa runoff formation. 150-277 mm of precipitation (2-3 of November norms) have dropped out there, in other mountain territory - 70-120 mm, on plain - 35-80 mm. The daily precipitation have reached and in 1.5 time exceeded monthly norm of November. Precipitation were characterized by significant intensity till 8-10 mm/hour.

The precipitation regime is represented on Fig. 2.

Development of a November flood, it parameters and consequences

Rains of such intensity and amounts have stipulated on November 4 formation on the rivers, which headwaters are in "epicentre of a rain", catastrophic high floods. There flood was formed very fast, the rate of water on channel flow reached to 4.5-5 m/s and maximums of levels have exceeded historical on 57-90 cm.

The antropogeneous factor was promoted a destructive force of flows, in particular constraint and clogging of beds, formation of artificial barriers and backwaters. As a result of it there were significant scheduled and high-altitude bed deformations of Tysa inflows during the flood. And the simultaneous accession of floodwaves from inflows to Tysa bed has formed a historical flood with disastrous consequences on plain of the Transcarpathian region. It is possible to explain, in particular, water overflows through protection embankments and their flush in several localities.

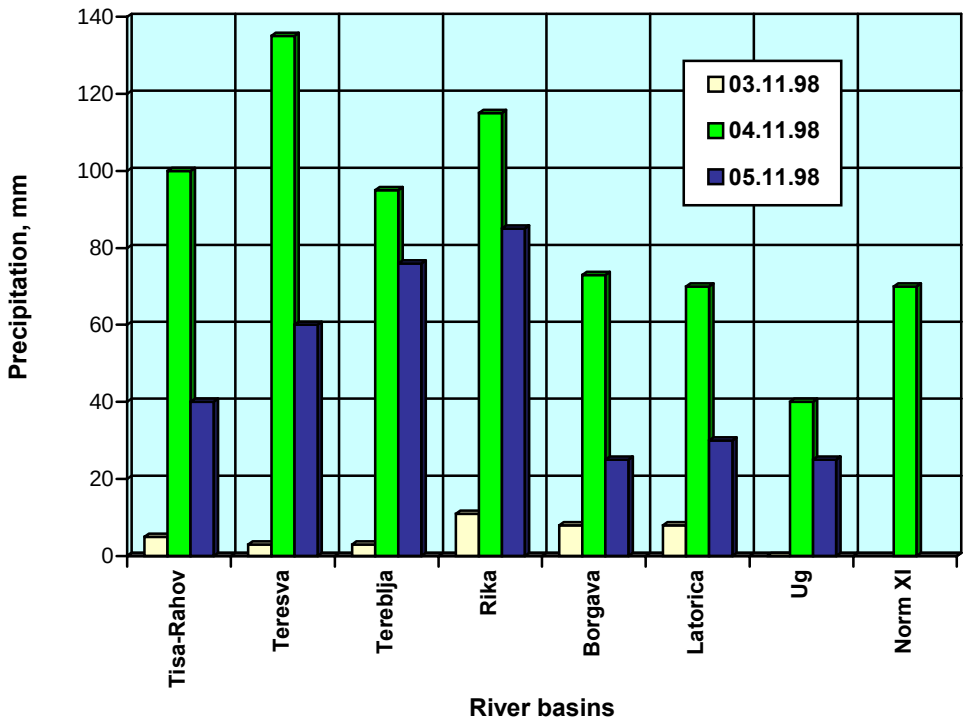

Fig.2 Distribution of precipitation on river basins, November 3-5,1988, mm.

On consequences the flood on Latorica at Mukachevo was fatal. There formation of maximum stages were passing in conditions of significant backwater from water protection embankments. During of 10 hours the level had been exceeding of a crest dam marks, the most part of city was flooded completely.

The feature of formation of November 1998 flood in Upper Tysa basin is placement the main dangerous zone within limits of the Ukrainian part of basin.

In line gauges of 17 hydrological stations (half of the operating hydrological network) the highest levels have reached and exceeded historical maximums of previous years (Fig.3). On Tysa the exceeding was 1-52 cm, on it inflows - 33-90 cm, on Latorica - 2-37 cm. On Ug the flood was not extremally high, the maximums did not reach historical.

The amplitude of levels growth over low-water stage was close and above the greatest values for all period of observations. On data of observations of two hydrological posts the marks of protection embankment crests were exceeded on 31-56 cm.

The flood is estimated on maximum levels and discharges to be close to floods probability 1.5-5 % (Tysa), 2.5 – 6.5 % (Latorica), 3,0 - 13 % (Ug).

During the flood on the territory of region about 2000 houses were destroyed, 40,800 houses flooded, 21,256 men evacuated. Significant parts of transport trunks, protection embankments, electrotransmissions lines etc were destroyed. Some hydrological stations were completely demolished.

The carried out hydrometeorological analysis of conditions of flood formation and development on November 1998, it parameters and the consequences testify that it is necessary to consider it as outstanding, rare repeatability, most extensive on territory coverage.

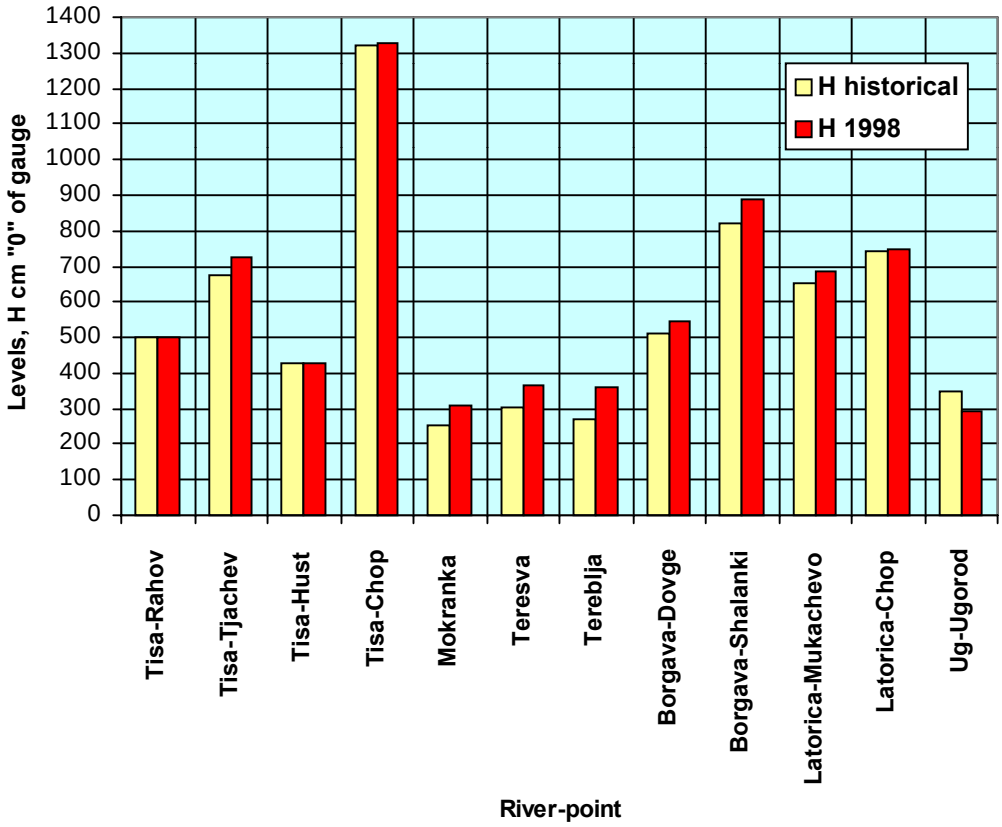

Fig.3 Comparison of flood maximums in 1998 with historical.

After the flood the competent commission created by Government of Ukraine, has analyzed flood reasons, its consequences and a complex economic-organizing, technical, and guidance actions has offered. Their full implementation will be promote both warning of floods, and minimization of its consequences.

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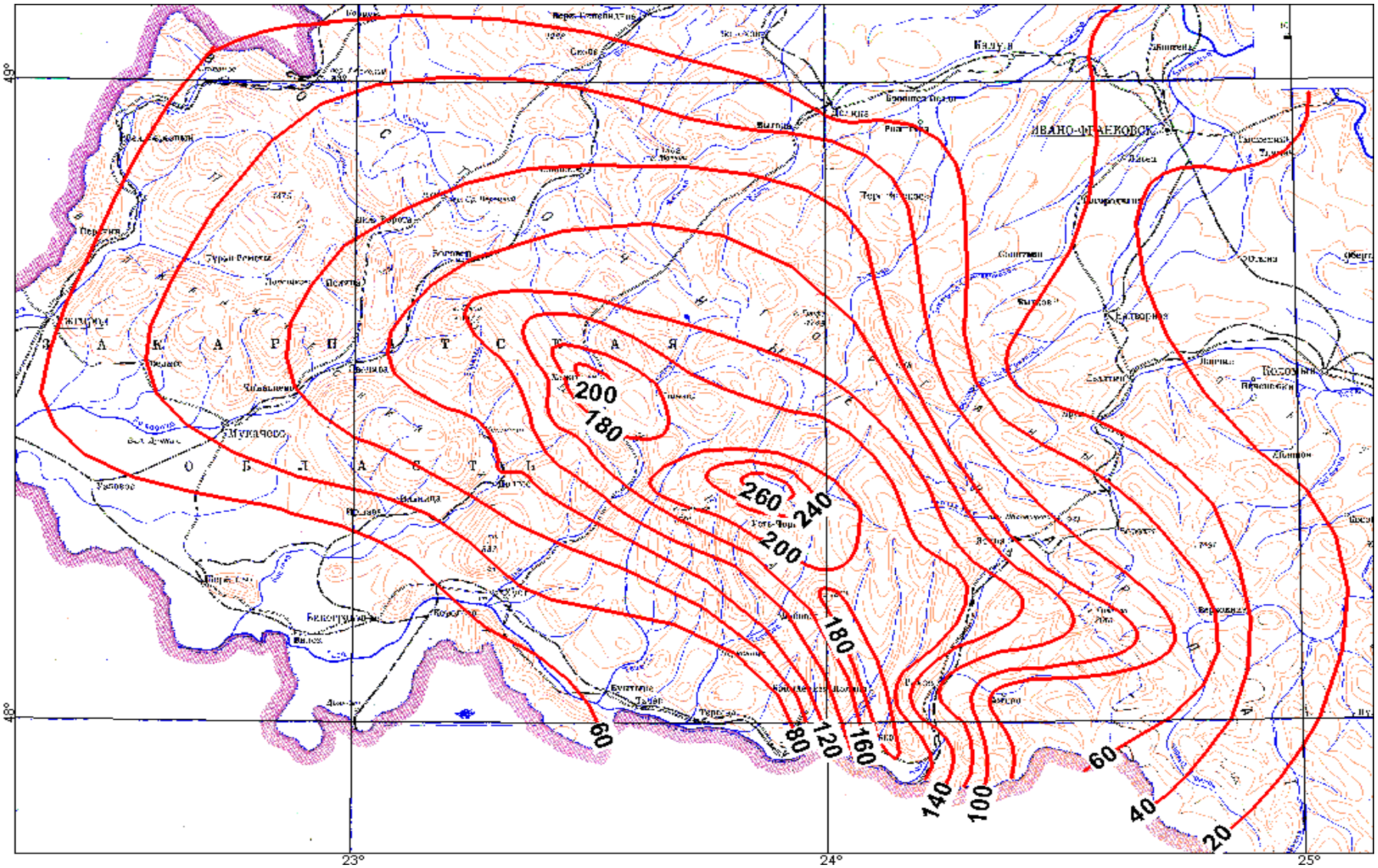

Fig.1 Total depth of rainfall on November 3-5, 1998 (mm)

Ecologically Acceptable Flows Definition by Wetted Perimeter Method

Ognjen Bonacci

Abstract: The paper analyses the problems of determining the ecologically acceptable flows (EAF) in open watercourses. The introductory part describes the reasons of the phenomenon and the need for determining of EAF. A determination of a EAF by the wetted perimeter method is given. The method was applied for the first time about twenty years ago, and at the present it is frequently used in practice due to its comparative simplicity, but also due to ecological-biological soundness. It belongs to the group of methods using a single criterion analysed in detail. In this case it is the parameter of the wetted perimeter of the watercourse topography, flow dynamics, as well as ecological properties essential for habitat development and fish migration. In the closing part of the paper, the wetted perimeter method has been applied to three cross-sections on the Kupa River, showing certain problems that may occur during its application in practice.

Key words: hydrology, ecologically acceptable flows, wetted perimeter, open watercourse

Die Bestimmung ökologisch tragbarer Durchflüsse mittels der Methode der benetzten Gewässerbreite

Zusammenfassung: Im Artikel wird die Problematik der Bestimmung ökologisch tragbarer Durchflüsse (ÖTD) in offenen Wasserläufen analysiert. In den einleitenden Ausführungen werden die Gründe für die Notwendigkeit einer Bestimmung der öTD beschrieben. Es erfolgt eine detaillierte Beschreibung der Theorie der Bestimmung der ÖTD mittels der Methode der benetzten Gewässerbreite. Diese Methode kam erstmals vor zwanzig Jahren zur Anwendung und wird heute in der Praxis wegen ihrer relativen Einfachheit, aber auch der teilweisen ökologisch-biologischen Begründetheit, häufig angewandt. Sie zählt zur Gruppe der Methoden, die sich eines detailliert analysierten Kriteriums bedienen. In diesem Falle handelt es sich um einen Parameter der benetzten Gewässerbreite im offenen Wasserlauf, der die Eigenschaften der Morphologie des Wasserlaufes und der Dynamik des Fließens wie auch ökologische Eigenschaften beinhaltet, die für die Entwicklung der Biotope und die Migration der Fische von Wichtigkeit sind. Abschließend wird die Methode der benetzten Gewässerbreite an drei Querschnitten des Kupa-Flusses angewandt, wo bestimmte Probleme aufgezeigt werden, die bei ihrer Anwendung in der Praxis auftreten können.

Schlüsselwörter: Hydrologie, ökologisch tragbarer Durchfluss, benetzte Gewässerbreite, offener Wasserlauf

1 Introduction

One of the key practical engineering, but also theoretical and ecological problems is providing of healthy and potable water, not only for present generations, but also for future ones. In that context, an important segment is providing of ecologically acceptable flows (EAF). Open watercourses and freshwater lakes as well as appurtenant groundwater aquifers have been aggressively attacked on the entire Earth. They are either over-pumped and/or polluted thus becoming less and less available to people who use, but also ruin them. On the other hand, the consequences are felt in nature by all the elements of the nutrition chain. Therefore, positive human ambitions should be in better co-ordination with the environmental possibilities. In order to achieve that, it is necessary to deeply understanding the functioning of the ecosystem. Studies of this kind are part of modern multi- and inter-disciplinary scientific trends.

From naturalist-scientific point of view, EAF should protect and preserve the existing natural ecological equilibrium of the watercourse in somewhat deteriorated hydrological conditions, i.e. taking into account irreversibly abstracted water quantities. This can be described with the requirement that rare and endangered flora and fauna species shall survive in new conditions, which also means that

natural or met relationships between flora and fauna species shall be preserved as well bio-production and inflow of energy. In order to fulfil these requirements, numerous and long-term measurements are needed.

Each watercourse, spring or lake represents individual hydrological as well as ecological system and therefore shall be analysed and solved separately. Experience obtained in other cases can be useful but can not be applied automatically.

Structure and functioning of the riverine system can be studied and understood only when all elements of the space, with which the river is in a longer or shorter contact during time, are taken into account. It primary refers to the bed, wider coastal area, floodplain and aquifer. It is a four-dimensional system strongly affected by longitudinal processes. The influence of transversal and vertical components and significant variations in time can not be disregarded.

Each human intervention in the watercourse or any water body must ensure the integral structure of nutrition chain as well as biological diversity existing in the area considered. If any link is missing, members of the upper part of the chain will feel it first because they are the most sensitive and thus, the most vulnerable ones. Natural watercourses created an adequate ecosystem that has functioned in a stable way until human, artificially caused changes, rapidly and roughly disturbed the natural equilibrium. The first to be disturbed is geomorphologic structure of a natural flow. Therefore, changes in sediment transport occur as well as erosion and material depositing. Sediment consists not only of stone and earth material but also of nutrients and microorganisms, i.e. base of the nutrition chain. Redistribution of sediments along the watercourse, and especially stopping of their flow, which is a very common consequence of human interventions in rivers, significantly change the ecosystem and survival conditions of some species. It shall be stressed that not every human intervention in nature is a rough attack on the ecosystem, but it is certain that every intervention besides positive also has negative consequences.

Hydrological properties of a watercourse significantly influence the development of the organisms, i.e. increase and decrease in their habitat in dependence of water quantity, velocity and depth, and the flooded areas. By changes in composition and topography of the bed, shelters inhabited by fish, also used for rearing, are either formed or destroyed. Movements of the bed, its carrying of or depositing, change and endanger the existence of local water organisms and also disturb the nutrition chain and destabilise the entire ecosystem. It is therefore obvious that watercourse regulation as well as irreversible water abstraction can significantly change natural hydrological regime thus causing great and negative changes in water organisms habitat.

Habitat in the watercourse must be biologically adequate. Discharge must be sufficient to enable changes in nutrients and oxygen as well as detrimental products of organisms' decay. It must also enable migrating of the largest fish species along the watercourse.

This paper describes one of recent methods of EAF determining which is increasingly used worldwide.

It shall be stresses that a hydrologist wrote this paper, therefore emphasis is given to hydrological point of view of the problem described. A critical reviews and contributions are expected from the colleagues biologists and ecologists for purposes of more complete and better application of the proposed method.

2 Wetted perimeter method for EAF definition

Wetted perimeter, O, is a parameter of an open watercourse which has several significant properties. As the first, it represents geometrical, i.e. morphologic property of a cross-section.

In hydraulic and dynamic sense, its value gives an information on the contact of watercourse bed with the moving water. In the entire length of wetted perimeter, the bed influences water flow dynamics causing pulsation processes in the water mass, which are characteristic for turbulent flow. It is an area in which the roughness of the bed directly influences water velocity. Multiplicity and significance of this parameter are not yet exhausted. It bears information significant from the point of ecology. In its essence, the wetted perimeter directly represents the area of river flora and fauna habitat.

The wetted perimeter method is one of the simplest among numerous and commonly used techniques for determining of EAF. Its positive characteristic is that it is based on natural conditions while its main disadvantage is that it has no explicit representation of aquatic habitat in analysed watercourse. Regardless of it, this method can be used for determining the first approximation of EAF value.

As the first step in application of this method, it is necessary to obtain graphical and subsequent analytical relationship between the wetted perimeter, O, (as an independent variable) and discharge, Q, (as dependent variable). Since EAF value shall be determined based on this analyses, biologists recommend to select the cross-section located above riffle sites or at sites where fish passage is likely to be limited at low stage and/or discharge.

Theoretical analyses and subsequent numerous applications in practice (Gippel and Stewardson, 1998) showed that the lowest breakpoint in the O-Q curve represents a critical discharge below which habitat conditions for aquatic organisms (usually fish and invertebrates) rapidly become unfavourable. In morphological terms, the breakpoint indicates where small decreases in flow result in increasingly greater decrease in wetted perimeter causing the loss of contact between water and the greater part of the habitat.

In the procedure of the breakpoint determining on O-Q curve, it is recommended to apply relative scaling of ordinate and abscissa axes. By relative scaling, values of wetted perimeter and discharge given in m and m^3/s are transformed into dimensionless values. In order to achieve that, it is necessary to select values for relative scaling. A commonly used value in practice is the mean annual discharge. Another possibility is to select the area of the main bed and determine the discharge and wetted perimeter based on which the relative scaling is performed (Bonacci and Roje-Bonacci, 1999).

The breakpoint is determined in a way to select the point on a curve where slope $S=\Delta O/\Delta Q$ (first derivative dy/dx) adopts the selected value. In practice, it is common to adopt the point where the slope of the curve is unity, i.e. S=1. At that point, a small change in discharge (as a percentage of the value considered) will produce the same change in wetted perimeter (as a percentage of the value considered). At higher discharges where the slope, S, is greater than 1, a large increase in discharge will produce a small increase in wetted perimeter. In the aforementioned explanations there is an essential, but also biologically based reason for which the use of slope S=1 is commonly accepted in practice. This value clearly represents the relationship between the discharge and habitat, and gives a rational criterion for selection of EAF values.

3 Case study

Three measuring stations on the Kupa River, with high quality and long-term records, i.e. reliable discharge curves, will be considered. Characteristic data for three stations are given in Table 1 while cross-sections are given in Figure 1.

Figure 2a gives O-Q relationship for the Kupari station. As the first approximation, the breakpoint is determined subjectively by eye from the graph. The breakpoint occurs between the discharges of 4.22 m^3/s and 5.30 m^3/s. Figure 2b gives O-Q relationship in relative coordinates. For its integral use, it shall be stressed that the mean long-term discharge of 13.5 m^3/s at the Kupari station has been used for relative scaling. It will be very unreliable to estimate the breakpoint from Figure 2b. If dy/dx=1 is adopted, the breakpoint occurs between discharge values in relative scales 0.09Q and 0.2Q, i.e. from 1.29 m^3/s to 2.7 m^3/s. For the Kupari station, it is recommended to adopt discharge Q = 4.5 m^3/s as the first approximation of EAF value.

Table 1 Characteristic data for three measuring stations on the Kupa River

No	Station name	Datum plane "O" (m a.s.l.)	Catchment area A (km^2)	Discharge – Q (m^3/s)		
				Minimum Qmin	Average Q	Maximum Qmax
1.	Kupari	304.43	209	0.525	13.5	195
2.	Hrvatsko	285.28	355	0.739	20.1	271
3.	Kamanje	123.83	2178	4.07	73.5	1145

Figure 3a gives the relationship between wetted perimeter, O, and discharge, Q, for the cross-section Hrvatsko (Figure 1b). In this case, the breakpoint is clearly pronounced at Q=3.62 m^3/s. Figure 3b gives O-Q relationship, with relative scaling using the mean annual discharge of Kupa near Hrvatsko of Q=20.1 m^3/s that occurred at stage H=81 cm. By application of this procedure, complete with the criterion dy/dx=1, an EAF value of Q=3.62 m^3/s is obtained.

Based on the conducted analyses, it is recommended to adopt an EAF value of Q=3.62 m^3/s. It shall be noticed that at the cross-section Hrvatsko, located downstream Kupari, with the mean annual discharge greater than mean annual discharge of Kupa near Kupari by 6.6 m^3/s, the value of EAF is lower. This fact clearly points that EAF can not be determined based on one cross-section only. Instead, the entire reach shall taken into account.

Figure 1c gives a cross-section of the Kamanje station on Kupa. It can be noticed on the graph that in the Kamanje section there is a large dead water area. It is a situation when it is not possible to determine EAF by wetted perimeter method. Instead, the mean cross-section of a longer reach, in which there is not dead water, shall be determined.

4 Conclusion

For application of the described method in practice, parallel and coordinated work of biologists and hydrologists is recommended. Hydrologists must present their results to biologists, who shall be dominant in final decision making, i.e. EAF selection. As shown in case of Kupa River cross-sections, the selection can not be made based on properties of one cross-section only, i.e. the entire reach shall be taken into consideration.

A conclusion is imposed that not every cross-section can be taken in consideration. The selection of a cross-section shall be connected with biological and ecological properties of a watercourse because the applied method is not only hydrological-morphological one, but, on the contrary, it shall be also ecological, i.e. multi- and inter-disciplinary method. In order to achieve that, a cross-section, or better, mean cross-section of the reach shall be selected based on a joint field survey by hydrologists and biologists. During field survey, biologists shall determine properties of the bed habitat and productivity of the bottom for bio-organisms. Hydrologists shall determine hydrological and morphological properties of the bed as well as its topography (riffles, dunes etc). They must agree upon relationship between hydrological and biological properties. In that sense, it is important to take into consideration location and provision of fish passages. Water depth over at least 50% of the bed must enable free passage of the largest fish species commonly inhabiting the analysed watercourse.

For purposes of EAF determining, it is recommended to use several methods out of which the wetted perimeter method shall be used as obligatory. The wetted perimeter method has been applied to three cross-sections on the Kupa River, showing the complexity and certain problems that may occur during its application in practice. Regardless of that, its theoretical and practical value has not been put in question.

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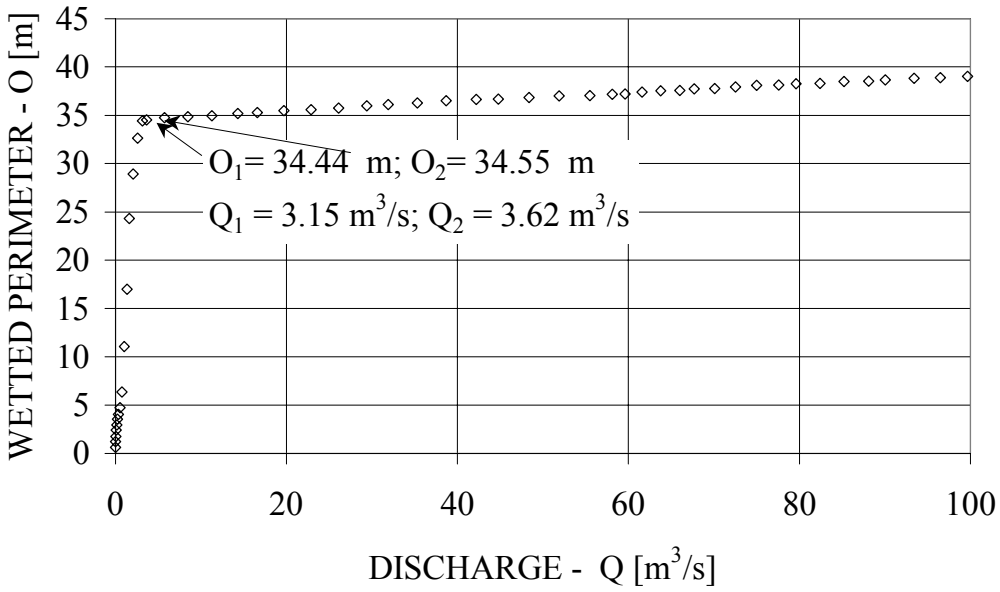
(a)



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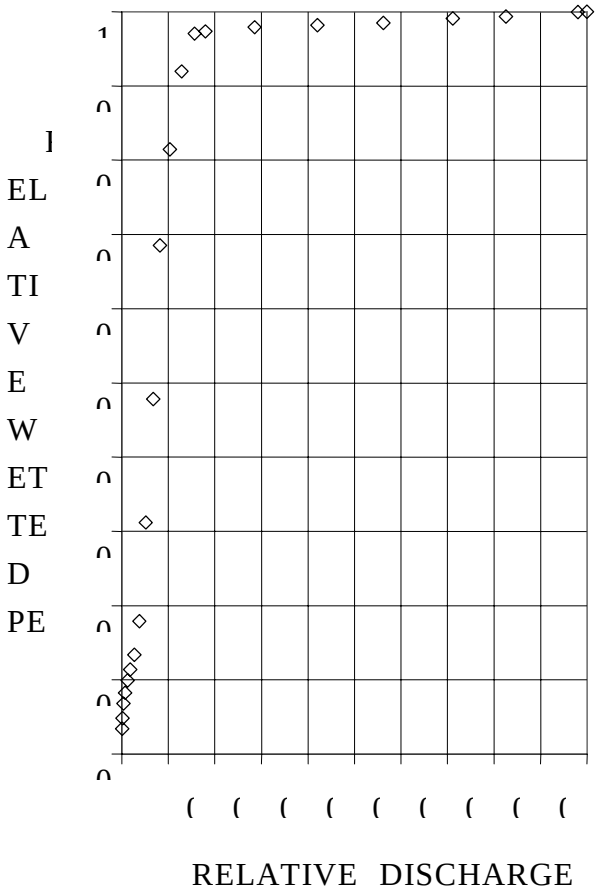
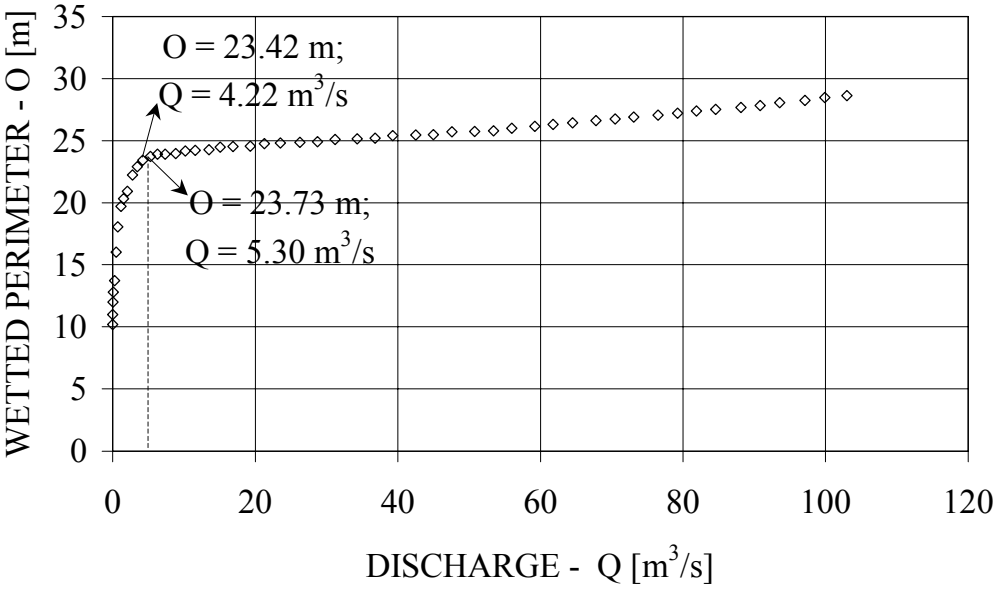
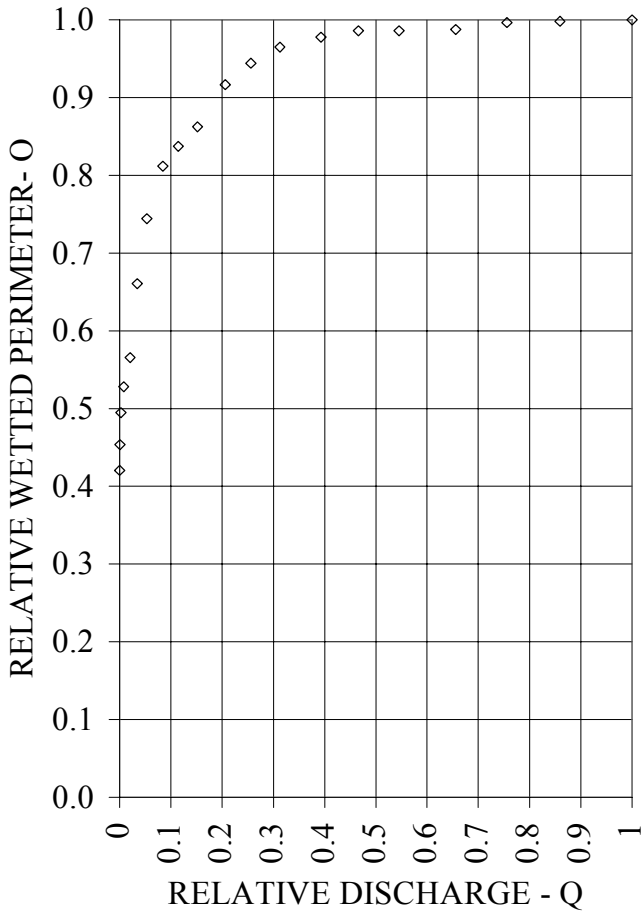


Fig. 3 Relationship between wetted perimeter, O, and discharge, Q, for the profile Hrvatsko at the River Kupa in: (a) normal and (b) relative scale

(a)





(b)

Fig. 2 Relationship between wetted perimeter, O, and discharge, Q, for the profile Kupari at the River Kupa in: (a) normal and (b) relative scale

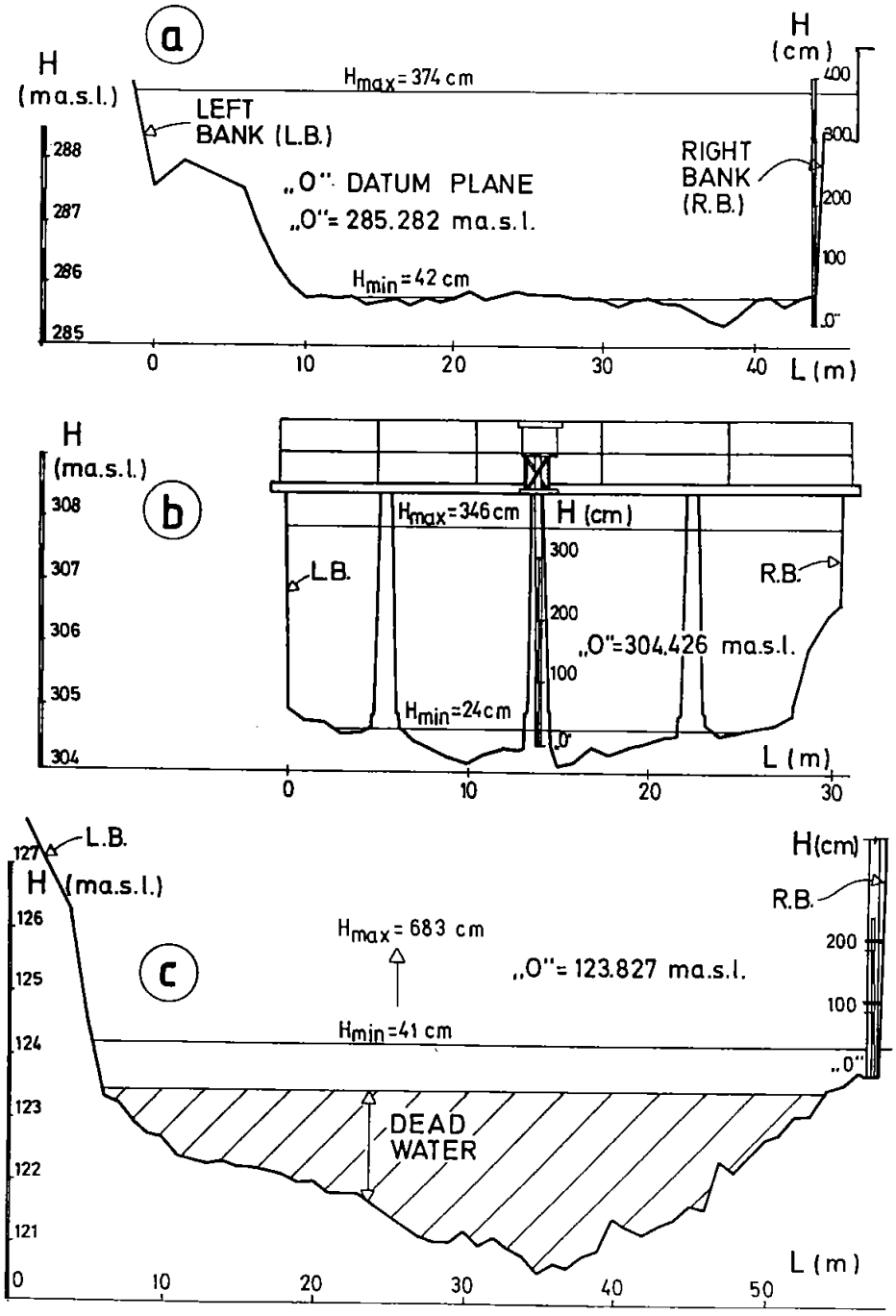


Figure 1 Cross-sections of three Kupa River profiles: (a) Kupari, (b) Hrvatsko, (c) Kamanje

Langzeitkorrelationen in hydrologischen Zeitreihen

Peter Braun

Zusammenfassung: Es wurde die Korrelationsstruktur von nahezu 60 Durchfluß - Zeitreihen (tägliche Werte) in Bayern und Baden-Würtemberg untersucht. Dabei wurde eine ausgeprägte Langzeitkorrelation festgestellt, die durch den sog. HURST - Koeffizienten parametrisiert wird. Der HURST - Koeffizient lag im Mittel bei H ≈ 0,83. Dies weicht deutlich von einem reinen Zufallsprozeß ohne Langzeitkorrelation (dem sog. „random walk“) ab, für den H = 0,5 gilt. Es scheint darüber hinaus eine schwache Multiskalität vorzuliegen. Diese Befunde deuten auf das Vorliegen selbstähnlicher Zeitstrukturen in Abflußzeitreihen. Diese Befunde sind im Hinblick auf Trendanalysen und Wahrscheinlichkeitsverteilungen von Extremereignissen von fundamentaler Bedeutung.

Schlüsselworte: Selbstähnlichkeit, Multiskalige Prozesse, Verallgemeinerter HURST - Koeffizient, Langzeit-Gedächtnis von Zeitreihen, Simulation von Zeitreihen

Long-term Correlations in hydrological Time Series

Abstract: Long-term correlation in nearly 60 daily time-series of discharge in Bavaria and Baden-Württemberg has been investigated. A considerable degree of long-term correlation has been detected, expressed in terms of the so called HURST - coefficient. The mean of this coefficient is H ≈ 0.83. It is a considerable difference to the model of pure random walk (H = 0.5). It seems, that the underlying time series exhibit a weak multiscaling behaviour. This findings are important in respect to trend analysis, simulation of discharge time series and assumptions in subject to probability density functions (pdf).

Keywords: Self-similarity, Multiscaling processes, Generalized HURST - coefficients, Long - memory, Simulation of Time series

1 Einführung

Im Zusammenhang mit der Frage nach der Evidenz einer Klimaänderung sieht sich die Hydrologie in wachsendem Maße mit der Aufgabe konfrontiert, die Dynamik von Abflußzeitreihen daraufhin zu prüfen, ob im Lauf der letzten Jahrzehnte etwa systematische Verschiebungen hin zu höheren Abflüssen stattgefunden haben und noch stattfinden. Dies ist aber keine triviale Aufgabe, denn die beobachteten hydrologisch relevanten Zeitreihen sind Ergebnisse von Zufallsprozessen, d.h. sie enthalten zufällige Variationen, sie sind also „verrauscht“. Es stellt sich damit die zentrale Frage: Wenn ein „Klima-Signal“ - statistisch betrachtet, eine Instationarität in der Zeitreihe - tatsächlich vorhanden sein sollte, wie kann man dieses Signal aus dem „Rauschen“ herausfiltern?

Um diesen wichtigen Fragen nachzugehen, haben die Länder Bayern (BY) und Baden - Württemberg (BW) gemeinsam mit dem Deutschen Wetterdienst (DWD) ein arbeitsteiliges Untersuchungsprogramm aufgelegt ("KLIWA"), das zahlreiche Einzelaktivitäten umfaßt. Zwei der genannten Aktivitäten beziehen sich auf die Frage, ob die vorhandenen Zeitreihen des Abflusses in beiden Ländern *spezielle Langzeitkorrelationen enthalten.* Zu diesem Thema ist vom Bayerischen Landesamt für Wasserwirtschaft München und der Universität Giessen, Inst. für Theoretische Physik III, ein Abschlußbericht erarbeitet worden (Braun & Kantelhardt, 1999), dessen wesentliche Ergebnisse im folgenden kurz zusammengefaßt werden.

In der Technik ist man schon seit Jahrzehnten daran gewohnt, „Signale“ von „Rauschanteilen“ mittels geeigneter Filter zu trennen. Leider sind die Probleme, die bei der Analyse von hydrolgischen Zeitreihen auftreten, wesentlich komplizierter als in der Technik. Denn im Unterschied zu dortigen Anwendungen, wo das „Signal“ meist bekannt ist, besteht im Falle

natürlicher Prozesse zunächst die Aufgabe darin, zu definieren, wonach man eigentlich sucht, d.h. welche zeitliche Variation als „Signal“, als Trend, zu interpretieren ist, ehe man an „Filterung“ denken kann.

Ein bisher in der Hydrologie üblicherweise verwendetes Werkzeug bei der Untersuchung von Abflußzeitreihen auf „Klimasignale“ ist die klassische lineare Trendanalyse. Sie wurde in den letzten Jahren häufig für derartige Überprüfungen in Deutschland eingesetzt. In der internationalen Literatur gibt es aber Hinweise, daß Abflußzeitreihen bezüglich der ihnen inhärenten Zufallsfluktuationen eine ganz spezielle dynamische Struktur aufweisen, die mit dem Selbstähnlichkeitsverhalten der beteiligten zeitlichen und räumlichen (Zufalls-) Prozesse zusammenhängen (Mandelbrot & Wallis, 1969; Braun u.a., 1998).

Selbstähnlich (selbstaffin) ist ein Prozeß dann, wenn bestimmte charakteristische Eigenschaften (wie z.B. Verteilungsfunktionen bzw. deren Momente) auf allen Skalen in gleicher Weise auftreten. Dabei ist der Begriff der Skala wesentlich: Damit kann sowohl (bei räumlichen Zufallsprozessen) die betrachtete räumliche Auflösung, als auch (bei Zeitreihen) die zeitliche Auflösung gemeint sein. Man stelle sich z.B. vor, daß man Tageswerte von Abflußdaten dadurch aggregiert (also die *Auflösung* der Daten reduziert), daß man Dekaden-, Monats-, Jahresmittel (oder Mittel auf noch längeren Zeitskalen) bildet.

Dann betrachtet man z.B. die Momente dieser unterschiedlich aggregierten (aufgelösten) Zeitskalen. ***Verhalten sich diese Momente für alle Zeitskalen in gleicher Weise, so ist der Prozeß selbstähnlich***. Im Falle selbstähnlicher bzw. selbstaffiner Prozesse (der Unterschied in den gebrauchten Begriffen ist technischer Natur und wird hier nur der Vollständigkeit halber erwähnt) wird man ein charakteristisches *Skalengesetz* finden: Trägt man das betrachtete Moment (gewöhnlich steht das zweite Moment, die Varianz, im Mittelpunkt) doppeltlogarithmisch gegen die unterschiedlichen Skalen (Auflösungen) auf, stößt man im Falle selbstaffiner Prozesse auf ein *Potenzgesetz.* Der entscheidende Parameter dieses Potenzgesetzes ist der sog. *HURST – Koeffizient H.*

Diese Potenzgesetze sind für selbstaffine Prozesse charakteristisch. Wenn man von Potenzgesetzen im Skalenverhalten spricht, steht dies synonym für ein *fraktales Skalenverhalten.* Fraktale zeichnen sich anschaulich dadurch aus, daß das „Ganze“ in seinen „Teilen“ wiederkehrt: Die „Teile“ sind dem „Ganzen“ in einem definierten Sinne „ähnlich“. Bei geometrisch darstellbaren fraktalen Mengen ist dies unmittelbar sinnlich nachvollziehbar: Wird eine frakale Menge „vergrößert“, dann kehren auf diesem veränderten Skalenniveau charakteristische Figuren oder Lagebeziehungen wieder. Im Falle von Zeitreihen ist die Operation der „Vergrößerung“ (oder Verkleinerung) durch die Festlegung der *zeitlichen Aggregierungsvorschrift (Auflösung)* gegeben.

Es ist wichtig zu betonen, daß die Identifikation selbstaffinen Verhaltens in Meßwertreihen i.allg. nicht das Resultat strenger theoretischer Herleitung ist, sondern empirisch dadurch abgesichert werden muß, daß man die Existenz o.g. Potenzgesetze statistisch signifikant nachweist. Selbstaffine Prozesse sind dann in dem Sinne *skalenfrei* oder *skaleninvariant*, als daß *die genannten statistischen Charakteristiken skalenunabhängig immer durch das gleiche Potenzgesetz mit demselben Exponenten H beschrieben werden.* Praktisch ist der Skalenbereich, für den Skaleninvarianz festgestellt werden kann, natürlich endlich (obwohl theoretisch auch unendliche Skalenbereiche zugelassen sind).

Dieses selbstähnliche (selbstaffine) Verhalten der Zufallsprozesse (der Abflußzeitreihen) bringt nun eine ganz spezifische Korrelationsstruktur der Zeitreihe (bzw. der zugehörigen Zufallsfluktuationen, z.B. der Abweichungen von einem Mittelwert) hervor. Man ging bisher üblicherweise von der Vorstellung aus, daß die den Zeitreihen aufgeprägten Zufallsfluktuationen lediglich zeitlich *lokal* korreliert sind (was dem Gedankenmodell der MARKOV – Prozesse entspricht). Unter zeitlich lokal versteht man die Eigenschaft, daß ein Abflußmeßwert zu einem beliebigen Zeitpunkt t höchstens von zeitlich unmittelbar benachbarten Werten der Vergangenheit beeinflußt wird. *Eine solche Beschränkung ist aber*

nicht mit der Selbstaffinität vereinbar, denn wenn das gleiche Potenzgesetz für alle Zeitskalen gilt, so wird auch ein Zusammenhang zeitlich weit auseinander liegender Meßwerte in der Reihe R(t) festgelegt.

Es erweist sich im Rahmen der hier vorgenommenen Untersuchungen zum Skalenverhalten von Abflußreihen, daß die Prämisse ausschließlich lokaler Korrelationen nicht aufrecht erhalten werden kann. Vielmehr muß man auf Grund der hier vorgelegten Untersuchungen davon ausgehen, daß die Fluktuationen sehr *beachtliche Langzeitkorrelationen aufweisen.* D.h., ein Meßwert zum Zeitpunkt t wird nicht nur durch die zeitlich unmittelbar voraufgehenden Meßwerte beeinflußt, sondern auch durch Meßwerte, die bereits lange vor dem herausgegriffenen Zeitpunkt t realisiert wurden. Bekanntlich wird das „Gedächtnis“ von Zeitreihen im statistischen Sinne durch das Verhalten der Autokorrelationsfunktion (AKF) bei wachsender Zeitverschiebung τ definiert. Oftmals stellt man fest, daß die AKF mit wachsender Zahl der Zeitverschiebungen τ gegen Null geht.

Sei m der Wert von τ, für den die AKF erstmals verschwindet, so sagt man, der Prozeß habe ein Gedächtnis der Länge m. Ohne hier auf Einzelheiten eingehen zu können, sei betont, daß bei selbstaffinen Prozessen die AKF nach einem Potenzgesetz mit τ gegen Null strebt, wobei die Konvergenzgeschwindigkeit wesentlich langsamer ist als z.B. bei einem „roten Rauschen“. Letzteres gehört zur Klasse der MARKOV – Prozesse (m ist vergleichsweise klein, da die AKF *exponentiell* gegen Null abfällt). Der wesentlich langsamere Abfall der AKF selbstaffiner Prozesse im Vergleich zu gewöhnlichen MARKOV – Prozessen ist der Grund für die Rede von der „Langzeitkorrelation“ in solchen Reihen (m kann u.U. sehr groß werden, da die AKF auch für große τ nie echt „NULL“ wird).

Da bei „Trendanalysen“ die Frage nach den langfristigen zeitlichen Änderungen der Prozeßstatistiken (den Momenten) im Mittelpunkt des Interesses stehen, ist unmittelbar einsichtig, daß die empirisch gefundenen Skalengesetze der Momente in diesem Zusammenhang besonders bedeutsam sind. Dies vor allem deshalb, weil die „trendbedingten“ Veränderungen der Zeitreihen u.U. in der gleichen Größenordnung vermutet werden müssen wie die durch Langzeitkorrelationen induzierten Fluktuationen. Durch die Langzeitkorrelation ist es eben (je nach Stärke dieser Korrelation bzw. dem Grad der Selbstähnlichkeit) im Mittel wahrscheinlicher, daß auf einen positiven Zuwachs der Zeitreihe wieder eine (positive) Änderung der Zeitreihe erfolgt: Dies ist genau der Mechanismus, den wir i.allg auch bei einer „trendhaften“ Entwicklung der Zeitreihe erwarten würden (z.B. bei einem linearen Trend).

Ist nun das Gedächtnis m wegen der gefundenen (selbstaffinen) Langzeitkorrelationen sehr lang (theoretisch unendlich), dann folgt daraus anschaulich, daß dieser Effekt bei der Analyse etwaiger Trends unbedingt beachtet werden muß. Wie dies im Einzelnen zu geschehen hat, ist eine sehr schwierige Frage und gegenwärtig Gegenstand intensiver Forschungstätigkeit im Projekt KLIWA.

2 Datengrundlagen

Bei der Datenauswahl wurde darauf geachtet, daß möglichst lange Reihen zur Verfügung standen. Aus Bayern wurden insgesamt 38 Pegel, aus Baden – Württemberg 29 Pegel ausgewählt. Das entspricht einer statistischen Basis von 4448 Pegeljahren, wobei die mittlere Länge der Reihen in BW 69 und in BY 64 Jahre umfaßt. Von diesen Gesamtdaten wurden aber im Zuge der Auswertung 6 Pegel ausgeschieden, weil sie den Datenanforderungen nicht genügten.

3 Methodische Grundlagen

Die besprochenen Skalengesetze selbstaffiner Zeitreihen werden im *monoaffinen Fall* durch den Parameter H festgelegt. Für stationäre Reihen liegt dieser Koeffizient in dem Intervall $0 < H < 1$, wobei es einige wichtige Fallunterscheidungen gibt. Der wichtigste Fall liegt dann vor, wenn $H > 0{,}5$ ist: Wir sprechen dann von einem *persistenten, selbstaffinen Zufallsprozeß*. In dem Begriff „persistent“ kommt die grundlegende Eigenschaft der bereits besprochenen Langzeitkorrelation zum Ausdruck. Für einen unkorrelierter Zufallsprozeß (das Idealmodell des „weißen Rauschens“) nimmt H den Wert $H = 0{,}5$ an.

Es gibt mehrere Methoden, um den grundlegenden Skalenparameter H auf statistischem Wege zu bestimmen. Eine der ältesten Methoden beruht darauf, daß man die Eigenschaft selbstaffiner Prozesse ausnutzt, einen ganz spezifischen Verlauf des Varianzspektrums zu erzeugen. Sofern die Spektraldichte – doppeltlogarithmisch über der Frequenz aufgetragen – eine Gerade ausbildet, kann der HURST – Koeffizient aus dem Anstieg dieser Geraden durch lineare Regression ermittelt werden.

Die *Detrended Fluctuation Analysis (DFA)* ist eine neue Methode zur Bestimmung von H (Buldyrev, 1995). Sie vermeidet den Nachteil der Spektralmethode, die dann verzerrte Schätzungen von H liefert, wenn signifikante Instationaritäten in den Daten enthalten sind. Bei der DFA werden Trends in den Daten hingegen während der Analyse implizit beseitigt.

Ein weiterer Vorteil liegt aber darin, daß diese Methode auch auf *multiaffine Prozesse* anwendbar ist. Unter einem multiaffinen Prozeß (dessen mathematische Struktur kompliziert ist) versteht man einen Prozeß, dessen Skalenparameter H nicht mehr konstant ist (wie im einfachen monoaffinen Fall, dem sog. „simple scaling“). Insbesondere zeichnet sich eine multiaffine Reihe durch eine wesentlich komplexere Struktur des Skalenverhaltens aus.

Zwar gilt für jedes Moment der zu Grunde liegenden Verteilung nach wie vor ein Potenzgesetz (also das Gesetz der Selbstähnlichkeit), allerdings entartet der wichtige Skalenparameter H zu einer nichtlinearen Skalenfunktion H(q) (mit q = Ordnung des betrachteten Momentes). Grob gesprochen hängt das Skalenverhalten nunmehr explizit von der Größe des Abflußwertes ab: „kleine“ Abflußwerte führen auf ein anderes Skalengesetz als „große“. Formal läßt sich der geschilderte Zusammenhang folgendermaßen darstellen:

Betrachten wir eine (zufällige) Zeitreihe R(t), die in dem Beobachtungsfenster $0 < t < T$ gemessen wurde. $R_\lambda(t)$ bezeichne den Mittelwert von R(t) über ein Intervall der Breite λ. Dabei ist λ die zeitliche Auflösung (das Meßintervall), und t die neue Zeitkoordinate im Zentrum jedes Meßintervalls.

Wenn die Zufallvariable R(t) stationär von zweiter Ordnung ist, dann gilt für $| R_\lambda(t) |^q$ mit einem Exponenten q die multiaffine Skalenbeziehung:

$$\{ | R_\lambda(t) |^q \} \propto \lambda^{K(q) - q}, \quad (1)$$

wobei {...} das Zeichen für das Ensemble - Mittel über alle t darstellt. K(q) ist eine nichtlineare Funktion von q. Aus dieser Funktion kann man H(q) ableiten:

$$H(q) = K(q)/q \qquad (2)$$

H(q) wird auch als *verallgemeinerter (multiaffiner) HURST – Koeffizient* bezeichnet. H(q) hängt damit im multiaffinen Fall explizit von q ab. Im Falle eines Monofraktals gilt der Zusammenhang mit dem HURST – Koeffizienten H gemäß:

$$K(q) = q\,H \qquad (3).$$

Das Spektrum eines Zufallsprozesses hängt eng mit dem zweiten Moment (q = 2; der Varianz) zusammen. Im multiaffinen Fall gilt der Zusammenhang zum Skalenexponenten β des Spektrums:

$$\beta = K(2) - 1 \qquad (4),$$

wobei $K(2) \neq 2\,K(1)$ ist (im Gegensatz zum monofraktalen Fall, für den gemäß Gl. (3) $K(2)/2 = H$ bzw. $\beta = 2H - 1$ gilt). Mit der Spektralmethode allein können die multiaffinen Charakteristika $K(q)$ oder $H(q)$ also nicht ermittelt werden.

Es ist klar, daß der besondere Charme der Einfachheit monoaffiner Skalengesetze hierdurch verloren geht. Die DFA – Methode liefert aber bei vertretbarem Aufwand eine konsistente Schätzung für die Skalenfunktion $K(q)$, was hier aus Platzgründen nicht behandelt werden kann.

4 Ergebnisse

Die wesentlichen Ergebnisse lassen sich wie folgt zusammenfassen:

- Die untersuchten Zeitreihen aus beiden Ländern zeigen selbstaffines Verhalten, was ein Langzeitgedächtnis (Langzeitkorrelation) zur Folge hat. Die Struktur des Skalenverhaltens ist schwach *multiskalig (multiaffin).*
- Der mit den oben besprochenen zwei Methoden abgeleitete HURST – Koeffizient H für das zweite Moment (H(2)) liegt im Mittel bei $H = 0{,}83$, was etwas niedriger ist als entsprechende Literaturwerte ($H \approx 0{,}85$). Es konnte gezeigt werden, daß diese (marginale) Differenz methodisch bedingt ist, da früher so leistungsfähige Methoden wie die DFA noch nicht zur Verfügung standen.
- Die räumliche Ausprägung des Skalenverhaltens in beiden Ländern ist dadurch gekennzeichnet, daß in praktisch allen Gebieten ein ausgeprägt selbstaffinens Verhalten diagnostiziert werden konnte, wobei allerdings eine beträchtliche Streuung der HURST – Koeffizienten H(2) festzustellen ist. Im Bericht wird gezeigt, welche Ursachen für diese Streuung in Betracht kommen könnten. Insbesondere erwies sich, daß bei „kleinen“ Gebieten (das sind im Sinne dieser Definition Gebiete mit < 2.000 km²) diese Streuung besonders stark ausgeprägt ist. Der Grund scheint eine Überlagerung verschiedener (lokal generierter) Zufallsprozesse zu sein, die bei kleinen Gebieten die Dynamik der Langzeitkorrelation stark modifizieren. Die Koeffizienten genügen einer Normalverteilung, was den behaupteten Zufallscharakter der Störung belegt.
- Für „große“ Gebiete (>2.000 km²) wurden hingegen praktisch überall gleiche HURST – Koeffizienten gefunden. Da in diese Analyse auch „große“ Gebiete außerhalb der beiden Länder einbezogen wurden (Rhein bei Köln, Elbe bei Neudarchau) und die Donau bei Hofkirchen, sind fast alle bedeutenden Ströme Deutschlands vertreten. Die abgeleiteten Aussagen dürften insoweit repräsentativ für „große“ Flussgebiete sein.
- Die untersuchten Zeitreihen weisen alle ein deutliches *crossover – Verhalten* im Kurzzeitbereich auf: Die Dynamik ist ein Kompositum mindestens zweier Dynamikbereiche (Frequenzbereiche): Der niederfrequente (langperiodische) Teil mit Periodenlängen größer als ≈ 100 Tage, und der höherfrequente Teil mit Periodenlängen unter 100 Tagen. Der langperiodische Teil erweist sich bis hin zu den längsten noch statistisch zuverlässig zu untersuchenden Perioden (bis zu ≈ 30 Jahren) als die Realisierung eines *stationären* und *persistenten selbstaffinen Prozesses.* D.,h., auf der Basis der hier vorgenommenen Analyse sind keine Anhaltspunkte für eine drastische systematische (instationäre) Änderung des statistischen Bedingungskomplexes zu finden (in diesem Falle wäre mit einem $H > 1$ zu rechnen). D.h., für einen eindeutigen Trend in den untersuchten Reihen gibt es beim jetzigen Erkenntnisstand keine Anhaltspunkte, wobei aber ausdrücklich auf die folgende Diskussion hingewiesen sei. Eines muß aber bereits jetzt festgehalten werden: Die bisherige Praxis der Trendanalyse ist im Lichte der jetzt vorliegenden Erkenntnisse zum selbstaffinen Charakter der Zeitreihen wohl nicht mehr als sachgerecht einzustufen

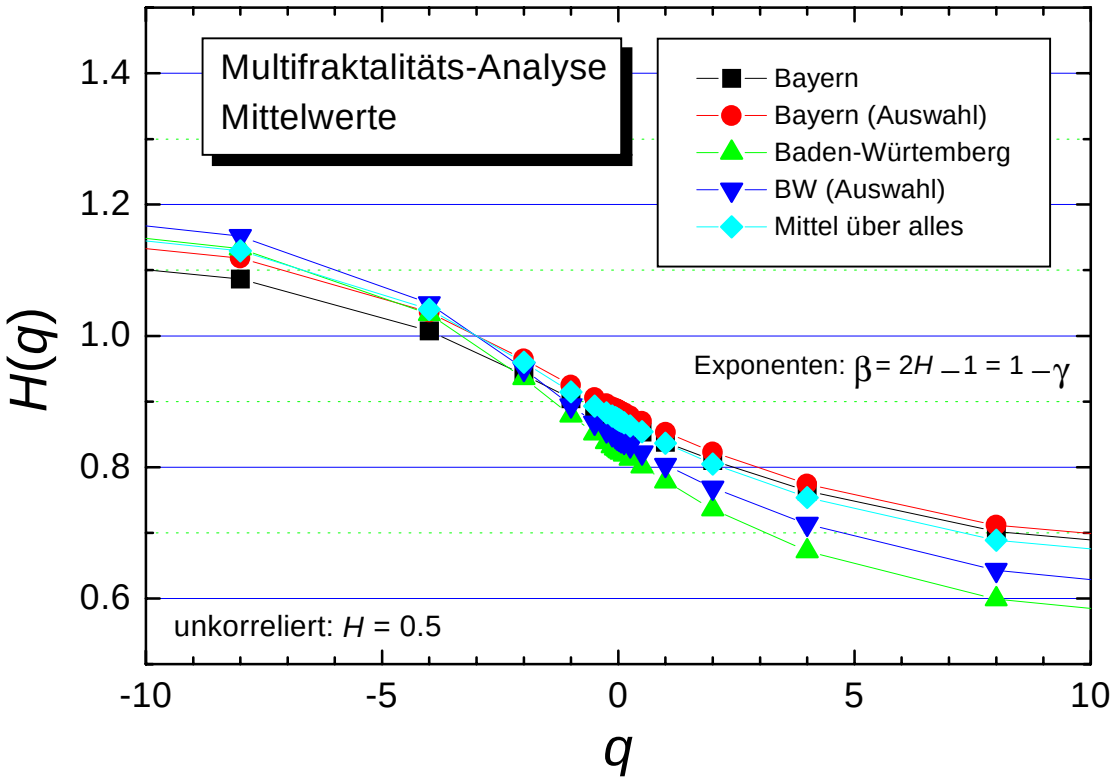


Fig. 1 Gemittelte Funktionsverläufe des verallgemeinerten HURST - Koeffizienten H(q) für Bayern und Baden-Württemberg (BW). Der Fall eines (unkorrelierten) „random walk“ ist durch H = 0,5 gegeben. Die Funktionsverläufe zeigen, daß das Skalenverhalten multiskalig ist (andernfalls wären die H(q) = const.). Man beachte den H - Wert für das zweite Moment (q = 2), was im Mittel bei H(2) ≈ 0,83 liegt.

5 Ausblick

Die bisher erhaltenen Ergebnisse zur selbstaffinen Struktur von Abflußzeitreihen enthüllen eine komplexe dynamische Struktur der untersuchten Reihen. Es ist evident, daß der Nachweis von Langzeitkorrelationen für die in KLIWA beabsichtigten Trendanalysen von ganz grundsätzlicher Bedeutung ist. Es muß allerdings darauf hingewiesen werden, daß – auch in der internationalen Literatur – dieser spezielle Problemkreis als nicht gelöst betrachtet werden muß. Insoweit bewegen sich die mit den Kooperationspartnern in KLIWA vereinbarten Untersuchungen zur Trendextraktion in multiaffinen Zeitreihen im Bereich der Grundlagenforschung. Da es wahrscheinlich in diesem Jahr noch nicht gelingen wird, einen analytisch faßbaren Trend quantitativ aus den Reihen herauszufiltern, wird eine heuristische Vorgehensweise praktiziert werden.

Dabei wird die selbstaffine Korrelationsstruktur der Abflußreihen als Grundlage für einen (iterativen) Suchprozeß genommen. Speziell werden künstliche Reihen der (multiaffinen) Fluktuation erzeugt (die der Korrelationsstruktur der gemessenen entsprechen), um diese mit „Trends“ unterschiedlicher Ordnung (also auch nichtlinearen) zu überlagern. Dabei wird geprüft, wie stark ein „Trend“ sein darf, um bei verschiedenen Stufen der Analyse (d.h. bei

verschiedenen Graden der trendbeseitigenden Fluktuationsanalyse DFA) nicht größere Abweichungen vom idealen selbstaffinen Skalenverhalten zu verursachen, als an den empirischen Daten beobachtet werden. Diese Methode erscheint geeignet, bei voller Beachtung des multiaffinen Charakters der Fluktuationen, einen „Maximaltrend“ herauszufiltern, der gerade noch mit dem gefundenen multiaffinen Charakter der Fluktuationen verträglich ist.

Naturgemäß ist die Schlüssigkeit dieses so definierten „Trends“ nicht völlig befriedigend. Andererseits ist das hier ins Auge gefaßte schrittweise Vorgehen angesichts der bereits erwähnten theoretischen Probleme bei der nichtlinearen Filterung selbstaffiner Reihen das einzig mögliche, was in einem überschaubaren Zeitrahmen zu einem Teilerfolg führen wird.

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Iterative Regionalization Search Based on L-Moments and Its Application to Indirect Flood Estimation

Juraj Čunderlík

Abstract: Regional flood frequency analysis is currently one of the most often applied methodology for flood frequency estimation at ungauged sites worldwide. This paper presents an alternative approach to flood flow regionalization procedure, which is based on iterative search technique. The technique pools river catchments into flood regions according to similarity in physiographic characteristics, but the division values are identified iteratively as the values with minimum within and maximum between regional variance of certain probability distribution parameters of annual maximum discharges (Q_{max}^{AN}). The rationale behind this approach is that both physiographic characteristics and at-site statistics are involved in the regionalization process and hence the reliability of such regions is increased. Probability distribution parameters of Q_{max}^{AN} are defined by the method of linear moments, which is due to its statistical properties (robustness, relative unbiasness) superior to the classical method of moments. The method of regional L-shape estimation in combination with the proposed regionalization is applied on 266 river catchments, and tested for indirect quantile estimation on the set of ten catchments, which are excluded from the analysis. The proposed approach showes promising results and seems to be reliable method for indirect flood estimation. Therefore, the method is recommended for use instead of in our practice long-lived classical empirical formulas.

Key words: iterative search regionalization, regional homogeneity, L-moments, regional shape estimation, N-year flood

Hochwasser-Regionalisierung durch iterative Auswahl, basierend auf L-Momenten und ihre Anwendung bei der indirekten Hochwasserschätzung

Zusammenfassung: Die regionale Analyse ist zur Zeit eine der meist angewendeten Methoden zur Bestimmung von Hochwasserjährlichkeiten in unbeobachteten Einzugsgebieten. In dieser Arbeit wird eine alternative Methode der Hochwasserregionalisierung dargestellt, die auf der „Iterative search Method" aufbaut. Die Vorgehensweise ordnet Einzugsgebiete solchen Flussregionen zu, die ähnliche Gebietswerte aufweisen. Dabei werden die Verteilungswerte näherungsweise als Werte mit dem Minimum innerhalb und dem Maximum zwischen der regionalen Varianz der Parameter einer bestimmten Wahrscheinlichkeitsverteilung jährlicher Maximalabflüsse (Q_{max}^{AN}) festgelegt. Die wissenschaftliche Erklärung für diese Vorgehensweise ist, dass sowohl die physiographischen Charakteristiken wie auch die ortsbezogenen Statistiken in den Regionalisierungsprozess einbezogen sind und dadurch die Zuverlässigkeit solcher Regionen zunimmt. Die Wahrscheinlichkeitsverteilungs-Parameter Q_{max}^{AN} werden definiert über die Methode der linearen Momente, die wegen ihrer statistischen Eigenheiten (Robustheit, relative Unbeeinflussbarkeit) der klassischen Momenten-Methode überlegen ist. Zur Bestimmung von Verteilungsparametern wurden die L-Momente herangezogen, welche geeigneter sind als übliche Momente. Die Methode wurde auf 266 Einzugsgebiete der Slowakei, die verschiedene physiogeographische Regionen repräsentieren, angewendet und in zehn Testgebieten, die nicht in die Analyse eingeschlossen waren, getestet. Die vorgestellte Methode zeigte vielversprechende Resultate und scheint verlässlich zu sein für die indirekte Hochwasserabschätzung. Diese Methode wurde deswegen für die praktische Anwendung statt der bisher verwendeten empirischen Formeln empfohlen.

Schlüsselwörter: Regionalisierung durch iterative Auswahl, regionale Homogenität, L-Momente, n-jährliches Hochwasser

1 Introduction

Research on flood frequency analysis undoubtedly takes one of the highest positions of interest in contemporary hydrology due to the large economic and environmental impact of floods. The recent run of extreme floods in the world is translated into scientific and societal concerns as a question of risk and reliability of flood frequency estimates. As a consequence, current flood estimation methods are reevaluated in many countries worldwide.

Several novel methods of regional flood frequency analysis have appeared during the last couple of years. Undoubtedly, some of the most often applied are the Index Flood method developed by Dalrymple (1960), American Bulletin 17B (US WRC 1981), the Region of Influence method proposed by Burn (1990) or the new British FEH (IH 1999). The performance of all these methods strongly depends on regionalization - which is clearly the most important step in a regional flood frequency analysis. Nowadays, prevailing regionalizations usually base the formation of flood regions on the similarity of river catchments in physiographic characteristics. This approach is derived from the conception that catchments similar in physiographic characteristics have consequently similar flood response. Possible dispersion of the sample at-site statistics in such regions can be explained by their sampling variability.

Flood flow regions are usually defined by cluster analysis, principal component or factor analyses. Such multivariate analyses are very sensitive to the scaling of the data and first of all reflect the distribution of gaps in the data space rather than any hydrological relationships. The iterative search technique developed by Wiltshire (1985) avoids some difficulties of multivariate analysis. The objective of this paper is to describe modified iterative search procedure and its application in selected catchments in Slovakia.

2 Method

1.1 Formation of flood flow regions

The iterative search method of flood flow regionalization was first proposed by Wiltshire (1985, 1986). The method presented here is based on hierarchical step by step partitions of the set of catchments into two groups according to the values of the *F* test statistic. In this work the *F* statistic is defined in terms of L-moments as:

$$F = \frac{BvLcx}{WvLcx} \tag{1}$$

where *BvLcx* is the between group variance of L-moment ratios *L-Cv* (coefficient of linear variation), *L-Cs* (coefficient of linear assymetry) and *L-Ck* (coefficient of linear kurtosis):

$$BvLcx = \sum_{i=1}^{N} \left[\frac{\left(W_{LCv^i} - \overline{W}_{LCv}\right)^2}{\sum_{j=1}^{n_i} SCv_{i,j}} + \frac{\left(W_{LCs^i} - \overline{W}_{LCs}\right)^2}{\sum_{j=1}^{n_i} SCs_{i,j}} + \frac{\left(W_{LCk^i} - \overline{W}_{LCk}\right)^2}{\sum_{j=1}^{n_i} SCk_{i,j}} \right] \tag{2}$$

and *WvLcx* is the within group variance of L-moment ratios *L-Cv*, *L-Cs* and *L-Ck* quantified by:

$$WvLcx = \sum_{i=1}^{N} \sum_{j=1}^{n_i} \left[\frac{\left(LCv_{i,j} - W_{LCv^i}\right)^2}{SCv_{i,j}} + \frac{\left(LCs_{i,j} - W_{LCs^i}\right)^2}{SCs_{i,j}} + \frac{\left(LCk_{i,j} - W_{LCk^i}\right)^2}{SCk_{i,j}} \right] \tag{3}$$

where W_{LCvi}, W_{LCsi} and W_{LCki} are the regional averages of L-moment ratios in *i*-th group, $\overline{W}_{LCx}$ are the total averages of W_{LCvi}, W_{LCsi} and W_{LCki}, $SCv_{i,j}$, $SCs_{i,j}$, $SCk_{i,j}$ are sampling variances of L-moment ratios, *N* is the number of groups (regions) and n_i the number of sites in *i*-th group. Such definition of F statistic takes into account all probability distribution parameters, which

should in a homogeneous region remain constant. The regionalization procedure proposed here involves the following steps:

1. Identification of a set of regionalization characteristics, for example catchment area (*AREA*), average catchment slope (*SLC*) and annual average precipitation (*AAR*).
2. Selection of division values (partition step) for each characteristic and division the total set of catchments into two groups starting with the first characteristic (*AREA*). The first group will include catchments with *AREA* values less than or equal to the first *AREA* division value, the latter group catchments with *AREA* greater than the first *AREA* division value.
3. Calculation of the *F* statistics for all division values. The optimal result of any regionalization is such that minimizes the within-regional variance of used regionalization's parameters and maximizes their between regional variance. The most approapriate division should be therefore the one with the highest value of *F* statistic (F_{max}).
4. Splitting the total set of catchments into two groups according to F_{max}. Repeating steps 2-3 for each group separately. The number of total divisions depends on the number of catchments, on the number of regionalization characteristics and on their impact on the magnitude of the variance *F*. The division process should stop when no further significant increase of *F* statistics occurs.
5. Repetition of steps 2-4 for the rest of regionalization characteristics (*SLC* and *AAR*) as shown in figure 1.

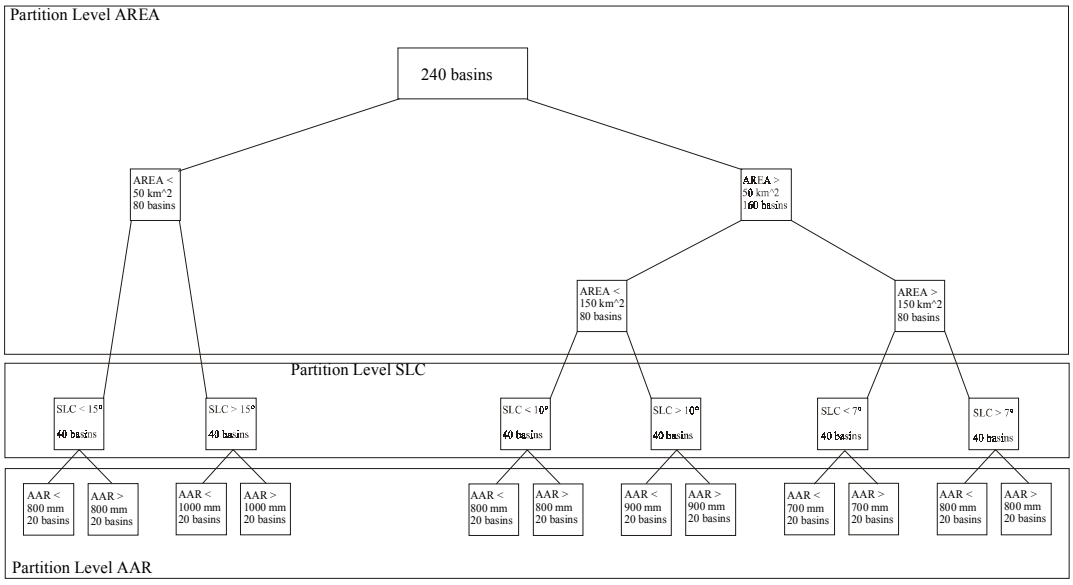

Fig. 1 An example for hierarchical step by step iterative partition.

1.2 Testing regional heterogeneity

Regional heterogeneity of identified regions is often tested by Hosking's test of regional heterogeneity (Hosking a Wallis (1997)). This test is based on the comparison of the regional variance of L-moment ratios in a certain region with the average variance of the L-moment ratios given from N_{sim} simulations of homogeneous regions influenced only sampling variability. The heterogeneity measure *H* is defined as:

$$H = \frac{(V - \mu_v)}{\sigma_v} \tag{4}$$

where *V* is the standard deviation of the at-site sample L-moment ratios ($t^{(i)}$) weighted by the record length (n_i) in a given catchment *i*:

$$V = \sqrt{\frac{\sum_{i=1}^{N} n_i \left(t^{(i)} - t^R\right)^2}{\sum_{i=1}^{N} n_i}} \tag{5}$$

t^R is the regional average L-moment ratio ($t^{(i)}$), μ_v, σ_v are the mean and standard deviation of the N_{sim} values of V simulated according to kappa frequency distribution. Simulated regions have the same number of catchments and the catchments have the same record lengths as the original ones. Depending on which L-moment ratio is used, we can define three test statistics - H_1 if *L-Cv* is used, H_2 if *L-Cs* and H_3 if *L-Ck*. The region should be regarded as "acceptably homogeneous" if $H < 1$, "possibly heterogeneous" if $1 \leq H \leq 2$ and "definitely heterogeneous" if H > 2 (Hosking and Wallis (1997)).

1.3 Selection of a regional distribution of Qmax

The most appropriate regional distribution can be determined by means of the L-moment ratio diagram and the Hosking's goodness of fit test. The L-moment diagram is a widely used tool for graphical interpretation and comparison of L-moment ratios *L-Cs*, *L-Ck* of various probability distributions with the estimated sample L-moment ratios. Regional averages *L-Cs* and *L-Ck* are weighted proportionally to the sites' record length and plotted on the diagram. The distribution which is closest to the regional average value is chosen. In this decision procedure the scatter of individual sites' L-moment ratios in a given region is also taken into account.

Hosking's goodness of fit test (Hosking a Wallis (1997)) is based on the judgment of the quality of a distribution fit by the difference between the L-kurtosis *L-Ck* of the fitted distribution (τ_4^{DIST}) and the regional average *L-Ck* (t_4^R). To assess the significance of this difference Hosking suggests to compare it with the sampling variability of t_4^R. The goodness of fit measure Z^{DIST} is then:

$$Z^{DIST} = \frac{\left(\tau_4^{DIST} - t_4^R + B_4\right)}{\sigma_4} \tag{6}$$

where B_4 is the bias of t_4^R and σ_4 is the standard deviation of t_4^R calculated as:

$$B_4 = \frac{1}{N_{sim}} \sum_{m=1}^{Nsim} (t_4^{[m]} - t_4^R) \qquad \sigma_4 = \sqrt{\frac{\sum_{m=1}^{Nsim} \left(t_4^{[m]} - t_4^R\right)^2 - N_{sim} B_4^2}{N_{sim} - 1}} \tag{7}$$

where $t_4^{[m]}$ is the regional average *L-Ck* of the *m*-th simulated region and *Nsim* is the number of simulations of the original region with the same number of sites and the same sites' record lengths. Simulated regions have kappa distribution as their frequency distribution. The fit is adequate if $|Z^{DIST}| \leq 1{,}64$.

1.4 Estimation of N-year floods

In this study the regional L-shape estimation method (RLSM) was employed for indirect quantile (Q_N) estimation. The key assumption of the RLSM method is that the sites form a homogeneous region and that the frequency distributions of the sites are identical apart from location and scale parameters. These parameters have to be estimated from at-site statistics, the shape parameter is in a given region constant and is estimated by the regional average. The location parameter is estimated by the sample mean of the $Q_{\max}^{AN}$ ($\overline{Q}_{\max}^{AN}$). In the case of ungauged sites, the sample mean is usually estimated from catchment characteristics using regression model. Since the correlations between the scale parameter *L-Cv* and catchment characteristics is not significant, estimates of *L-Cv* can be inferred from a contour map. The map

is shown on picture 2. The map was drawn from at-site values of *L-Cv* attributed to the gravity centers of 240 small catchments using kriging interpolation method. More details can be found in Čunderlík (1999a).

Fig. 2 Contour map of the *L-Cv*

3 Study catchments

For the purpose of this analysis only catchments with area less then 400 km^2 were selected. Sites influenced by dams were excluded from the analysis. All sites have at least 15 years of continuous records of annual maximum discharges. The average record length is 33 years, the longest 77 years. Totally 266 river catchments representing all physiographic regions of Slovakia were included to the database. Another 10 selected catchments which were not included into analysis were left for testing purposes. Table 1 gives a short summary of catchments according to their area and record length. Catchment physiographic characteristics were derived by GIS using 100x100 m. DEM.

Table 1 Summary of 266 selected river catchments (1) and 10 testing catchments (2).

Data	**Catchment area [km^2]**				**Record length [years]**							**Sum**
	0-100	100-200	200-300	300-400	15	15-20	20-30	30-40	40-50	50-60	> 60	
1	181	47	24	14	3	24	118	70	19	7	25	266
2	2	2	2	4	1	0	2	3	0	2	2	10

3 Results

The choice of regional characteristics was based on their impact on the magnitude of the *F* statistic. Figure 3 shows the *F* statistic described by the L-moment ratios *L-Cv*, *L-Cs* a *L-Ck* for the division values of catchment area (*AREA*), average slope (*SLC*) and average annual precipitation (*AAR*). Other catchment characteristics did not show significant impact on changes of *F*. The chosen characteristics are correlated to other characteristics important in the flood formation process. *AREA* is strongly correlated to the mean river length, and river network density, *SLC* with main river slope and with catchment elevation range. *AAR* is correlated with one-day extreme precipitation.

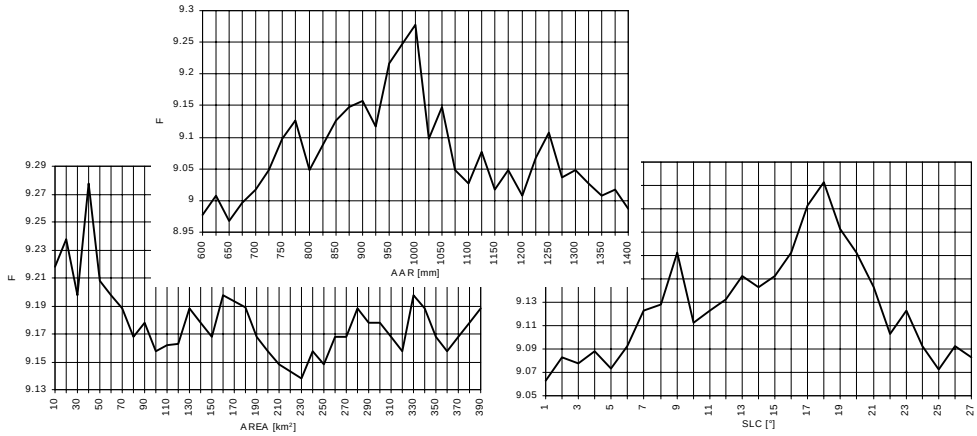

Fig 3 Dependance of the F statistic on AREA, SLC and AAR.

Table 2 shows the definition of identified regions in terms of the intervals (division values) of the regionalization characteristics. The mark "-" means that there was no need for further division of the current region since the region is already homogeneous in terms of that characteristics (e.g. in the region 7 all catchments have similar annual rainfall - slightly around 1300 mm).

Table 2 Identified regions characterized by the intervals of regionalization parameters.

Region	AREA [km^2]	SLC [°]	AAR [mm]
1	< 0 - 40)	< 0 - 9)	< 780
2	< 0 - 40)	< 0 - 9)	≥ 780
3	< 0 - 40)	< 9 - 15)	< 860
4	< 0 - 40)	< 9 - 15)	≥ 860
5	< 0 - 40)	< 15 - 21)	< 980
6	< 0 - 40)	< 15 - 21)	≥ 980
7	< 0 - 40)	≥ 21	-
8	< 40 - 120)	< 0 - 7)	-
9	< 40 - 120)	< 7 - 12)	< 775
10	< 40 - 120)	< 7 - 12)	≥ 775
11	< 40 - 120)	< 12 - 16)	< 980
12	< 40 - 120)	< 12 - 16)	≥ 980
13	< 40 - 120)	≥ 16	< 1020
14	< 40 - 120)	≥ 16	≥ 1020
15	< 120 - 400)	< 0 - 7)	-
16	< 120 - 400)	< 7 - 12)	< 780
17	< 120 - 400)	< 7 - 12)	< 780 - 880)
18	< 120 - 400)	< 7 - 12)	≥ 880
19	< 120 - 400)	≥ 12	< 950
20	< 120 - 400)	≥ 12	≥ 950

The results of the Hosking's tests of regional heterogeneity are summarized in table 3.

Table 3 Hosking's tests of regional heterogeneity for identified regions (shaded numbers are above the threshold). Regional distributions of Q_{max}^{AN} chosen by: Dist-Ldiag = L-moment diagram, Dist-test = Hosking's goodness of fit test, Test = values of Hosking's test statistics, Reg-dist = final choice and parameters of regional dimensionless growth curves.

Reg ID	Number of catchments	Heterogeneity measures H1	H2	H3	Regional distribution Dist-Ldiag	Dist-test	Test	Reg-dist
1	10	0,39	-0,70	-0,46	LN3/GEV	GLO/GEV	-0,68/-1,47	GEV
2	20	-0,58	-0,68	0,27	LN3/GEV	GLO/GEV	0,10/-1,04	GEV
3	16	**2,67**	1,74	0,94	LN3/PE3	LN3/GEV	-0,20/0,75	LN3
4	9	0,05	1,18	1,97	GEV	GLO	-0,69	GEV
5	16	0,84	0,15	0,55	GEV	**GLO**	**-2,29**	GEV
6	15	-0,22	0,46	0,71	GLO/GEV	**GLO**	**-2,29**	GLO
7	13	0,83	0,29	0,28	GEV/LN3	GEV/GLO	-0,75/1,06	GEV
8	11	**2,24**	1,72	0,99	GLO/GEV	**GLO**	**-2,06**	GLO
9	19	-0,20	-1,14	-1,17	LN3	**GLO**	**-1,68**	LN3

10	16	0,46	1,00	1,17	LN3	GLO/GEV	0,14/-0,76	LN3
11	12	1,14	-0,20	0,38	LN3	GLO/GEV	0,00/-0,91	LN3
12	7	0,35	-1,05	-1,00	LN3	GEV/LN3	-0,06/-0,64	LN3
13	21	1,00	0,09	-0,17	GLO	**GLO**	**-1.86**	GLO
14	11	1,01	0,66	0,26	GEV	GLO/GEV	0,14/-1,23	GEV
15	17	0,85	2,21	2,63	LN3/PE3	LN3/GEV	0,02/0,54	GEV
16	12	-0,26	-0,24	0,16	PE3	PE3/LN3	-0,70/0,82	PE3
17	5	0,41	0,12	0,13	LN3/GEV	LN3/GEV	-0,27/0,59	LN3
18	13	-0,95	-1,23	-0,5	GEV	GLO/GEV	-0,45/-0,69	GEV
19	11	-1,90	0,81	0,66	PE3	PE3/LN3	-0,36/1,01	PE3
20		-0,50	-1,52	-1,80	GEV	GEV/GLO	-0,56/0,60	GEV

We see that except two regions all proved regional homogeneity and those two are not homogeneous only in terms of *L-Cv*. The L-moment ratio diagram for all regions is shown in figure 4.

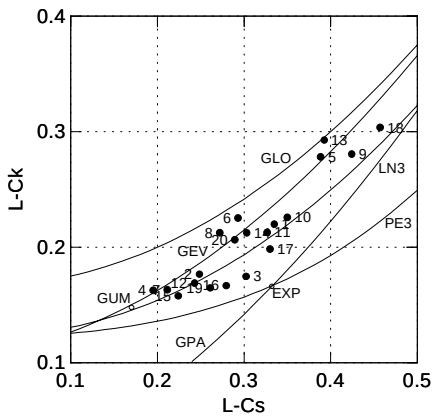

Fig. 4 L-moment ratio diagram for derived regions (EXP-exponential, GUM-Gumbel, LO-logistic, NRM-normal, UNI-uniform, GEV-generalized extreme value, GLO-generalized logistic, GPA-generalized Pareto, LN3-log-normal, PE3-Pearson III. R1-11 = regional average values of *L-Cs* and *L-Ck* weighted proportionally to the sites' record length).

Regional probability distributions chosen by this diagram together with the results of the Hosking's goodness of fit test are summarized in table 3. We see that both methods in most cases identified the same distributions. Spatial presentation of catchments attributed to identified regions is in figure 5. Regions are not geographically compact, however some indications of spatial relations depending on catchment characteristics are apparent. Regions can be easily interpreted, for instance region 4 is a region consisiting of small catchments with medium average slopes and high annnual precipitation. Another advantage of this method is that regions are distinct in the space of regional characteristics in contrast to multivariate methods (cluster analysis), so the regions do not overlap in parameters space.

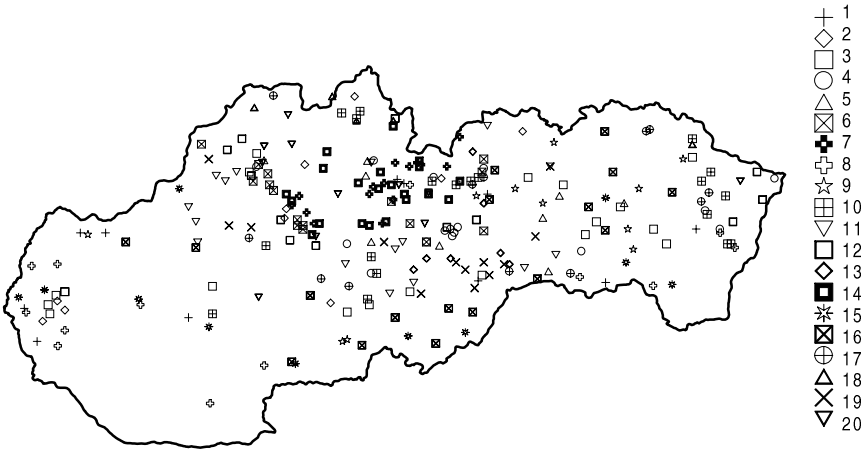

Fig 5 Spatial presentation of catchments attributed to identied regions.

Several regression models were defined for the estimation of $\overline{Q}_{\max}^{AN}$ comprising basic physiographic characteristics including catchment area, main river length, drainage density, average catchment slope and elevation, average annual rainfall and 24-hour extreme rainfall. The best result in terms of the correlation coefficient was achieved by the equation:

$$\overline{Q}_{\max}^{AN} = 0{,}393 * AREA^{\,0{,}791} * ECRANGE^{\,0{,}11} \qquad (8)$$

where *AREA* stands for catchment area and *ECRANGE* is the catchment elevation range. The coefficient of correlation *r* is 0,767. N-year floods (Q_N) were estimated by combination of the proposed regionalization with the RLS method. Figure 6 shows relative errors of Q_N derived from the comparison of the estimated quantiles and quantiles calculated from at site data. From the figure 10 we see, that the suggested approach gives relative errors of Q_{10} within ± 20%, Q_{50} less than 25% and Q_{100} not exceeding 35%.

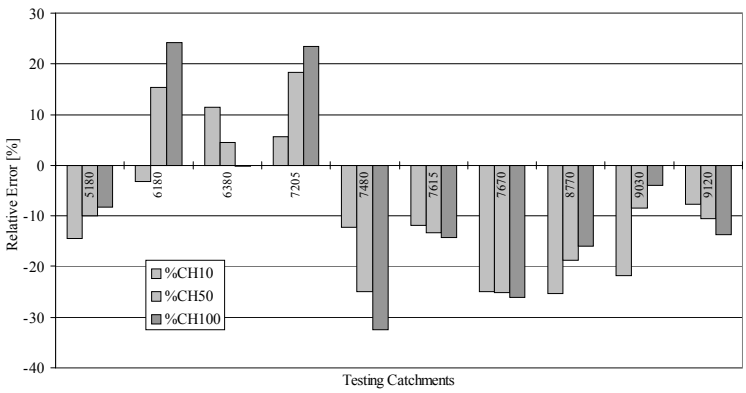

Fig 6 Relative errors of Q_N estimation for 10 testing catchments.

5 Conclusions and recommendations

The method introduced in this article is an alternative approach to iterative search regionalization. The technique pools river catchments into flood regions according to similarity in physiographic catchment descriptors, but the concrete division values are identified using hierarchical step by step iterative algorithm. The optimal division is defined as the one with minimum within and maximum between regional variance of certain probability distribution parameters of annual maximum discharges. Distribution parameters were expressed in terms of L-moments. Over 260 selected river catchments were used for analysis. Ten catchments were left for testing purposes. N-year quantiles were estimated by the modified RLS method. The

index flood parameter was estimated from catchment characteristics by means of a regression model and the *L-Cv* is inferred from contour map. The RLS method in combination with the proposed regionalization showed promising results with the average relative errors of Q_{10}, Q_{50} and Q_{100} not exceeding 15%. Future work will be directed towards the issue of improving the estimation of the index flood and the coefficient of linear variation, which can be either estimated from catchment characteristics. Regionalization can be improved by including the flood and rainfall seasonality measures.

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Occurrence of Floods in the Ipeľ River Basin

Viera Gápelová, Jana Podolinská, Helena Šipikalová

Abstract: Significant floods caused by local rain gushes and storm rainfalls were registered on many small rivers in Slovakia in last years. Many of the river Ipeľ right tributaries had been hit by these rainfalls. Floods occured in June and July 1999 had very destructive effect and stimulated us to reconsider occurence of floods.

Key words: surface water, floods

Vorkommen der Hochwasser in dem Flussgebiet von Ipeľ

Zusammenfassung: In letzten Jahren wurden auf vielen kleinen Wasserläufen in dem Gebiet der Slowakei bedeutungsvolle Hochwasser vorgemerkt, die von den örtlichen kräftigen Gussregen und Starkregen verursacht wurden. Gerade mit diesen Regen wurden viele rechtseitliche Nebenflüsse eingegriffen. Die Hochwasser, die in Juni und in Juli 1999 erschienen, hatten sehr vernichtende Wirkungen und regten uns an, das Vorkommen der Hochwasser zu überprüfen.

Schlüsselworte: Oberflächenwasser, Hochwasser

1 Short basin characteristics

The river Ipeľ basin is a boundary river between the Slovak Republic and Hungary. The basin area in the profile of its outlet to the Danube is 5 151 km^2, from which 3 649 km^2 is on the Slovakian part, it represents 71 %. Long-term average discharge in the profile of its outlet is 21,57 $m^3.s^{-1}$.

The source of the river is in the west part of Slovenské Rudohorie below the hill Čierťaž in 1030 m a. s. l. and flows into the Danube in 101,6 m a. s. l. The shape of basin is irregular quadrangle expanded in the east-west direction. Bigger tributary from the left side is Suchá on the Slovakian part, others are on the Hungarian part. The most important tributaries from the right side are: Krivánsky potok, Tisovník, Krtíš, Krupinica with tributary Litava and Štiavnica.

The river Ipeľ belongs to the rivers with the most extreme regime of outflow in Slovakia. Usually higher water bearing concentrates into three months (February - April), with almost half of long-term average volume of runoff. The most water bearing month is March. In spring discharge waves are mostly of jumbled type, created by snow melting and rain. They generally have bigger volume and duration than rain ones. Secondary increasing of water bearing is significant in November - January. Low flow begins in July and lasts till October, minimum reaches in September. Runoff during low flow months July - October is more than 10 % of long-term year volume.

2 Occurence of Floods

Data from hydrological stations of The Slovak Hydrometeorological Institute were used to study occurence of floods. We used stations with discharges series 1931 - 1999 which are minimally influenced by men activities. There are three of such stations in the basin. Characteristics of hydrological stations with three maximum peak discharges are given in the table 1.

Table 1 Characteristics of hydrological stations

Station	River	Basin area [km^2]	Long-term average discharge [m^3.s^{-1}]	Q_{30d} [m^3.s^{-1}]	Maximum peak discharge [m^3.s^{-1}], date of occurence		
Holiša	Ipeľ	685,67	3,490	8,795	129 2.3.1937	125 20.5.1939	117 22.10.1974
Plášťovce	Krupinica	302,79	2,060	5,933	140 14.7.1999	108 4.7.1936	94 26.7.1960
Plášťovce	Litava	214,27	1,290	3,689	125 22.6.1999	64,9 3.12.1976	58,1 22.10.1974

First of all for determination of floods occurence frequency we wanted to use data from mentioned stations stored in Hydrological information system (HIS) - mean daily discharges and maximum discharges (so, we have data sets of maximum peak discharges in the year).

Occurence of maximum discharges in the stations observed period is in the table 2.

Table 2 Time distribution of maximum discharges occurence

Station: Holiša **River: Ipeľ**

Month	**11.**	**12.**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**total**
number of occurence	5	1	6	13	16	11	6	1	3	2	0	5	69
%	7	1	9	19	24	16	9	1	4	3	0	7	100

Station: Plášťovce **River: Krupinica**

Month	**11.**	**12.**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**total**
number of occurence	4	1	6	10	23	7	7	2	3	1	2	3	69
%	6	1	9	15	34	10	10	3	4	1	3	4	100

Station: Plášťovce **River: Litava**

Month	**11.**	**12.**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**total**
number of occurence	3	3	7	9	19	12	5	4	2	1	1	3	69
%	4	4	10	13	28	18	8	6	3	1	1	4	100

From the previous tables we can see, that the most number of maximum discharges occurence were during spring season, but the highest were in the summer months (except station Holiša - Ipeľ). Even three of maximum discharges in the station Plášťovce - Krupinica during observed period were in July.

We have found out, if the frequency of floods is higher in last years. Because there are only one yearly maximum in the database, we proceeded as follows. We determined number of days in the year in which 30-day discharge Q_{30d} were reached and found out the number of occurence (according State Standard 75 1400 “Hydrological Data of Surface Water” M-day discharges are determined for reference period 1931-80). There is decreasing number of Q_{30d} occurence in all investigated stations. It was mainly caused with absence of spring ouflow in many years of the last twenty years. In the station Plášťovce-Krupinica it shows figure 1. (Mean yearly discharges are analogous, decreasing is also caused with absence of spring ouflow in many years of the last twenty years.)

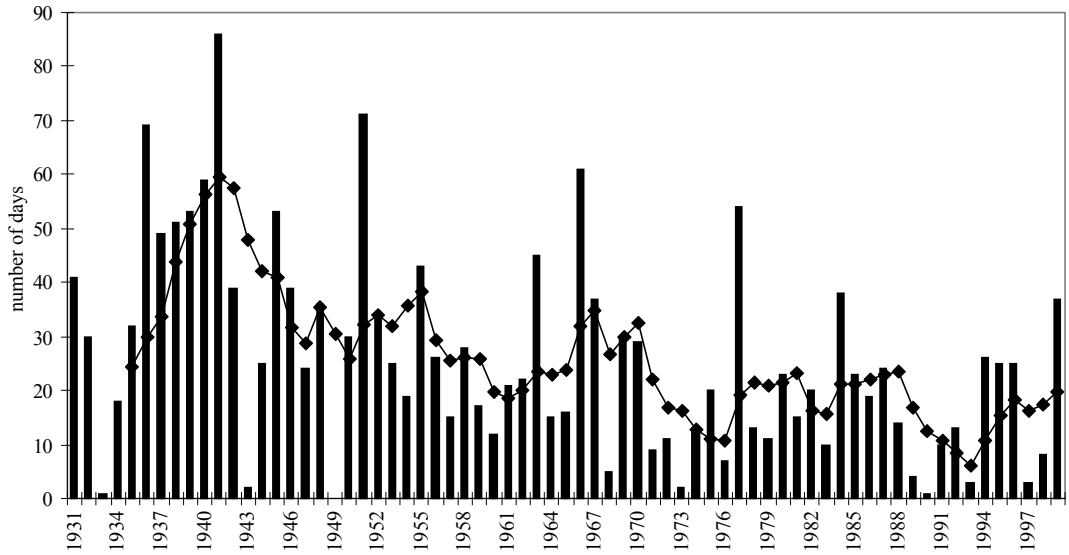
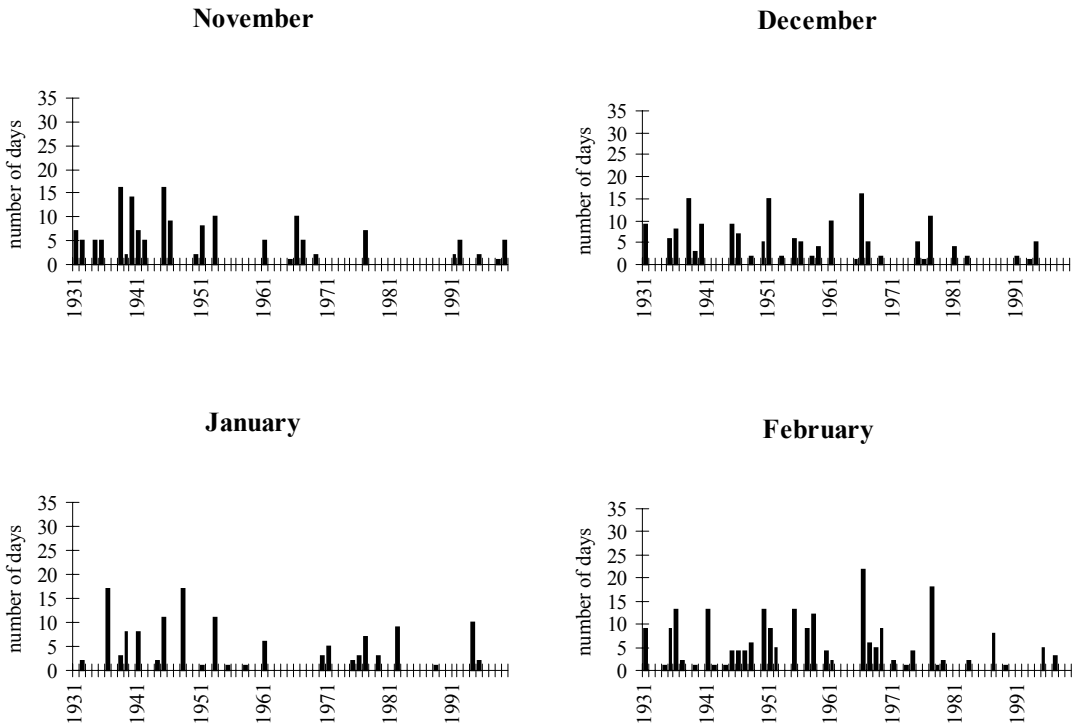


Fig. 1 Number of days during year with discharge above Q_{30d} and 5-years running means in the station Plášťovce - Krupinica in the period 1931-1999

Decreasing number of days above Q_{30d} (especially in March) was also confirmed in individual months. Unchanged number of days or slightly increasing is on Krupinica on July, August and October. In the station Plášťovce - Krupinica it shows figure 2.



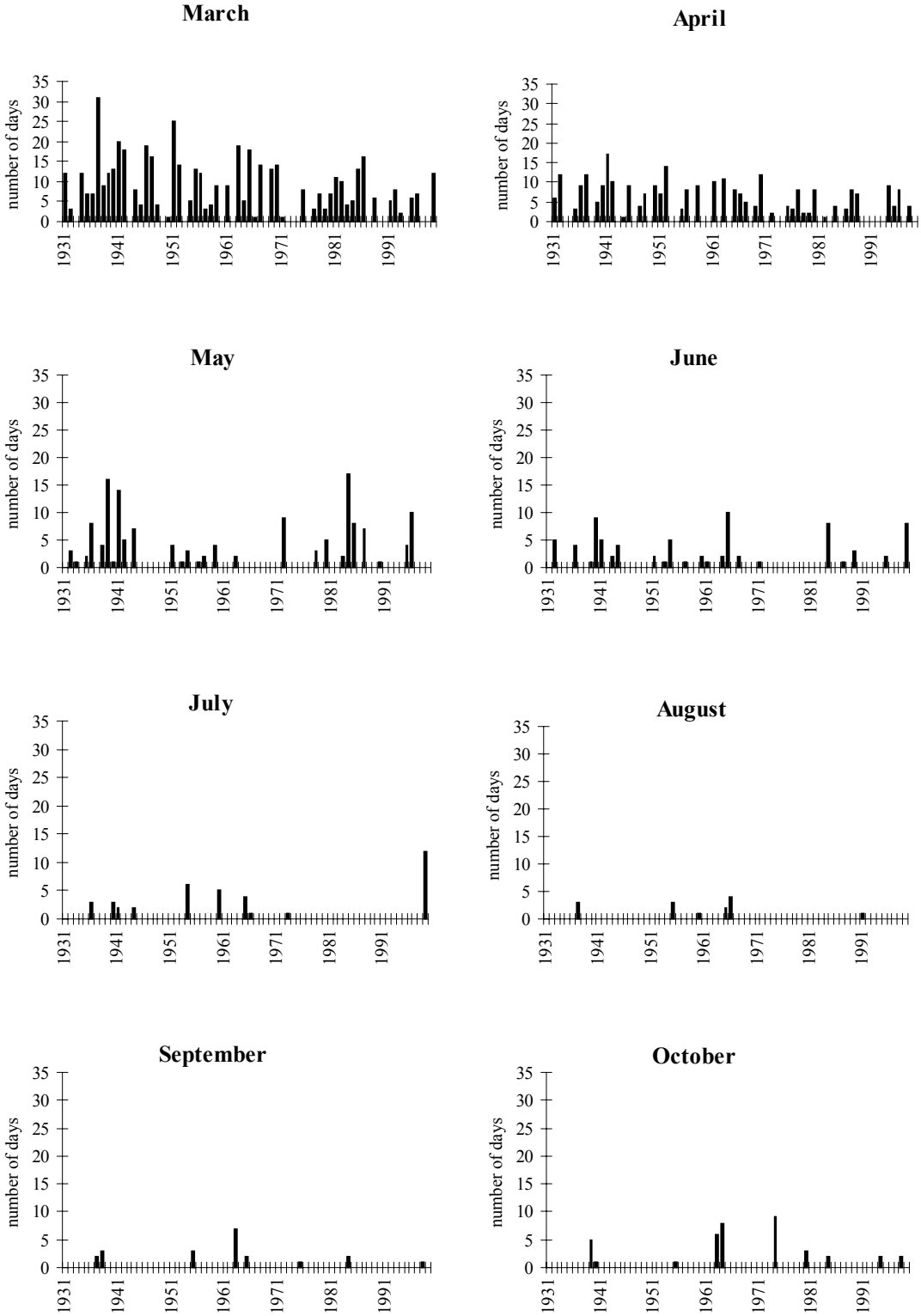


Fig. 2 Number of days during year with discharge above Q_{30d} in the station Plášťovce - Krupinica in the period 1931- 1999

From these results we can notify, the number of days during year with discharge above Q_{30d} is decreasing, so the number of episodes with higher discharges or floods is also decreasing.

Because this tendency is not clear in the months June, July and partly in August (months with the most probable ocurence of local rain gushes and storm rainfalls) we have focused on this months. We have choosen specific discharge waves with daily mean discharge Q_{10d}. It was very hard and required work with primary archive materials. We have found out the highest number of these events was registered in the last ten years, but only in the stations Plášťovce-Krupinica and Plášťovce-Litava (figure 3).

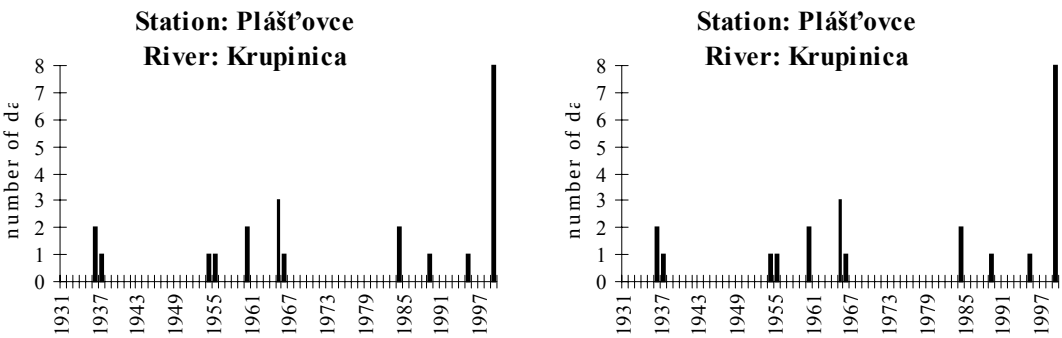


Fig. 3 Number of summer floods (June - August) in the year with discharge above Q_{10d} in the period 1931 - 1999

It means this region is more sensitive on flash floods, then upper part of basin, which is represented by station Holiša - Ipeľ.

We have also investigated, if the values of maximum peak discharges are increasing during summer rains (figure 4). Really, in last years occurennce was not only more frequent, but maximum peak discharges had the most significance.

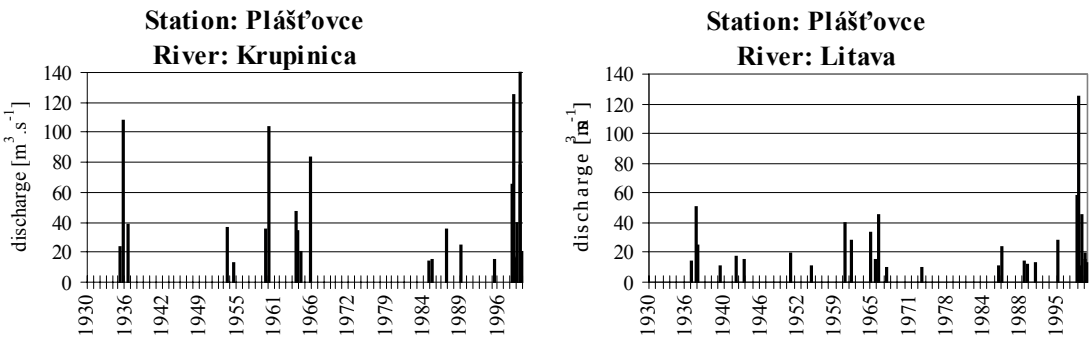


Fig. 4 Occurence of summer maximum peak discharges above Q_{10d} in the period 1931 - 1999

The highest maximum peak discharges during observed period were registered during floods on June and July 1999.

On June 1999 maximum peak discharge in Plášťovce - Krupinica reached Q_{100} and on Litava more than Q_{1000}. 22.6.1999 unfavourable entering of flood waves on Krupinica and Litava caused huge flood wave below their conclusion. Part of water also flowed in the embankment territory. Near villages and part of the town Šahy were flooded.

On July 1999 maximum peak discharge in Plášťovce - Krupinica reached Q_{100} but on Litava only Q_5. In the town Krupina in the upper part of the Krupinica basin was evaluated Q_{1000} and flood wave in the hydrological station was higher than 450 cm. Unfortunately, this flood required human casualty and caused material demages. The course of discharges is on figure 5.

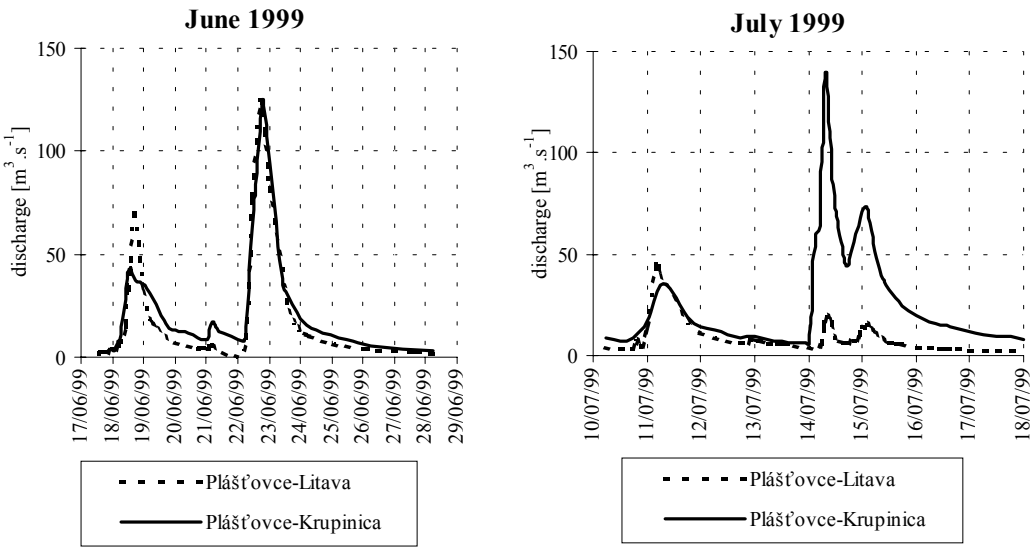


Fig. 5 Course of discharges during floods on June and July 1999

3 Conclusion

The problems of floods and especially flash floods are really topical in the last years. It is necessary consistently study this phenomenon to better knowledge of their origin and development. It required to know sensitive regions, rainfall intensities, possible changes of rain and runoff conditions, modelling of runoff from the rainfall. It would enable to reduce floods demages, which are considerable.

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Spatial Distribution of the Mean Annual Precipitation in the Jalovecky Creek Basin

Ladislav Holko, Juraj Parajka.

Abstract: Performance of eight precipitation interpolation methods was tested in the Jalovecky creek basin, Western Tatra Mountains, Slovakia. All existing precipitation stations (22-23) in and around the basin in hydrological years 1989-1998 were used in computations. The results shown that various interpolation methods provided similar estimates of basin precipitation. However, small differences in computed precipitation resulted in significant differences in evapotranspiration calculated from hydrological balance equation. Interpolation method based on data measured directly in the basin proved to provide reasonable results.

Keywords: mountain basins, hydrological balance, areal precipitation, interpolation methods

Räumliche Verteilung des mittleren jährlichen Niederschlages im Einzugsgebiet des Jalovecky Baches

Zusammenfassung: Acht Niederschlagsinterpolationsverfahren wurden im Einzugsgebiet des Jalovecky Baches, westliches Tatragebirge, Slowakei, getestet. Bei der Berechnung des Niederschlages für die Wasserhaushaltsjahre 1989-1998 wurden alle im Gebiet der westlichen Tatra existierenden Niederschlagsstationen benutzt. Verschiedene Interpolationsverfahren führten zu ähnlichen Ergebnissen. Aber kleine Unterschiede im Einzugsgebietsniederschlag führten zu beachtlichen Unterschieden in der von der Bilanzgleichung berechneten Verdunstung. Die Analyse zeigte, dass die im Einzugsgebiet standardmäßig angewandte Interpolationsmethode gute Ergebnisse liefert.

Schüsselworter: montane Einzugsgebiete, Wasserhaushaltsberechnung, Gebietsniederschlag, Interpolationsverfahren

Introduction

Hydrological balance as one of basic hydrological methods strongly depends on accuracy of the input data, i.e. in the simplest case on runoff and precipitation. While runoff measurement accuracy is generally rather high for hydrological balance computations, precipitation measurements and spatial interpretation can be subjected to substantial errors, especially in mountains. Because mountains give birth to majority of river systems, accurate hydrological balance of mountain basins is very important. Under the assumption of correct point precipitation measurement the problem of basin precipitation computation consists in choice of proper method used to interpolate point measurements. There were several excelent papers devoted to evaluation of performance of precipitation interpolation techniques (e.g., Tabios and Salas, 1985, Papamichail and Metaxa, 1996). However, they analyzed solely the differences between techniques themselves. We have analyzed the interpolation techniques in the light of their influence on hydrological balance as well.

There are so many interpolation methods available that it is not possible to test all of them. The choice of particular method usually depends on available data and know-how. Previous research conducted in the mountain basin of Jalovecky creek, Western Tatra, Slovakia (Kostka, 1998, Holko and Kostka, 1998) indicated that on the average, there were not big differences among simple interpolation methods like Thiessen polygons, gradients and elevation zones. Even the arithmetic mean provided the results which were, on the average only 9% lower

compared to elevation zones. Having more data from longer period available, we could test the performance of other, mostly more sophisticated methods and analyze the results against measured runoff.

Data and methods

We used annual precipitation data measured at 22-23 sites in the region of the Western Tatra Mountains in hydrological years 1989-1998. Hydrological balance with precipitation estimated by different interpolation techniques was calculated for the Jalovecky creek basin. Basin area is 22.2 km^2, mean elevation 1500 m. Computations were performed in GIS with maps grid resolution of 100 m. Five of the above mentioned precipitation stations are situated directly in the Jalovecky creek basin. Precipitation stations and basin boundary are shown in Fig. 1.

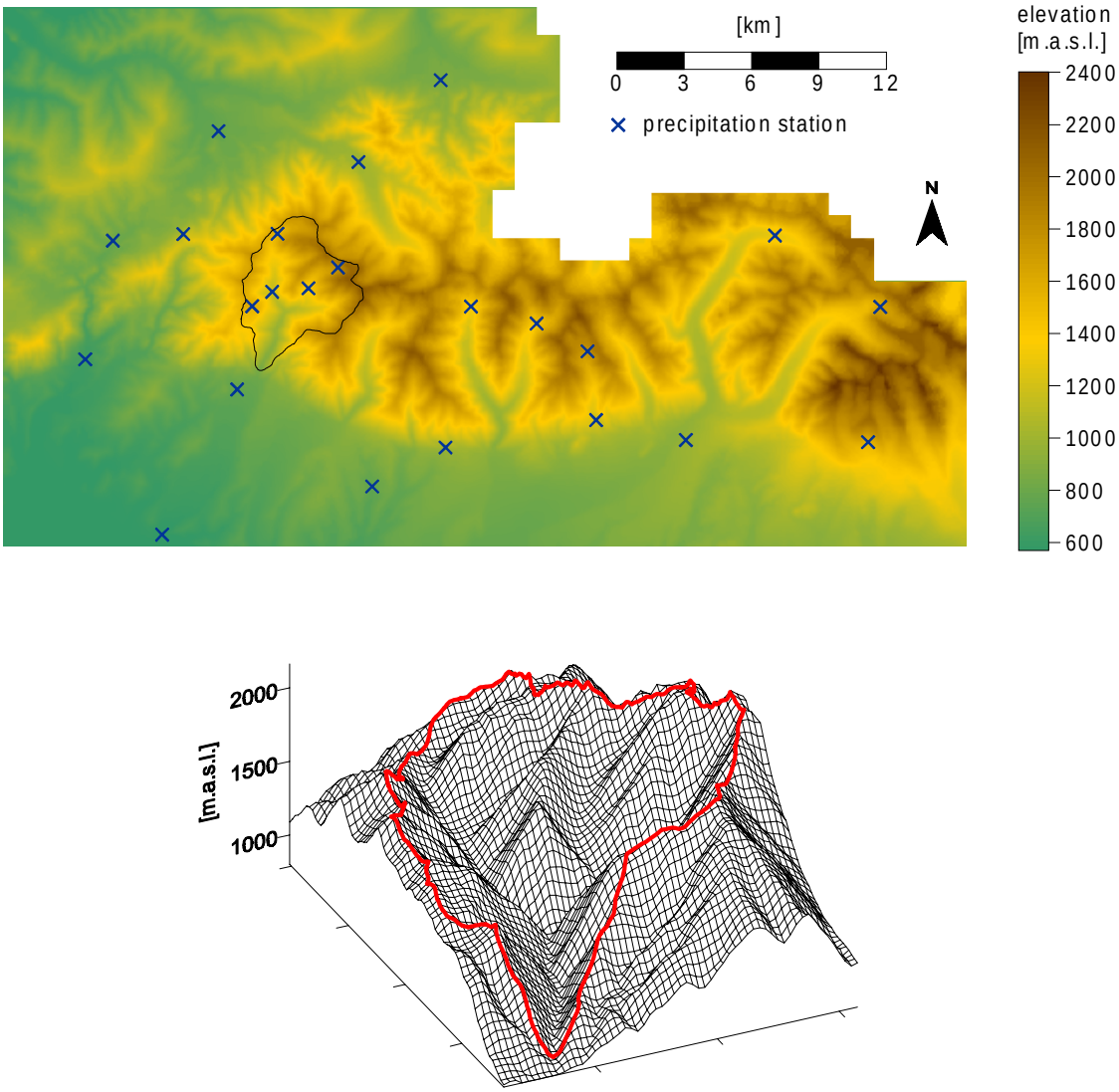

Fig. 1: The Jalovecky creek basin and location of precipitation stations

Eight interpolation methods were used to compute basin precipitation. Most of them use the weighted average approach. It means that the closer a data point is to a point for which precipitation height is interpolated, the more weight it carries in determining precipitation value.

Methods of this type differ in how the weighting factors are computed and applied to point data. Inverse distance, linear triangulation, nearest neighbor, radial basis functions (multiquadratic method and regularized spline with tension), and kriging are in this group of methods. Other methods like linear and quadratic regressions define large-scale trends in precipitation data.

We computed annual precipitation in every hydrological year 1989-1998 as well as the long-term mean annual precipitation 1989-1998. Performance of interpolation methods was tested with the so-called jack-knife method and with respect to hydrological balance. We also compared computed precipitation with precipitation estimate given by method of elevation zones, which has been using to compute basin precipitation routinely and, simple arithmetic mean (both based only on data from basin).

So called "jack-knife" analysis consists in setting aside a precipitation sample (precipitation station), using remaining samples to produce an interpolated surface, and then analyzing the difference between values interpolated from the surface and actual values at the withheld sample sites (Bishop and Church, 1992). The efficiency of selected interpolation methods was evaluated by statistical parameters of arithmetic mean and standard deviation.

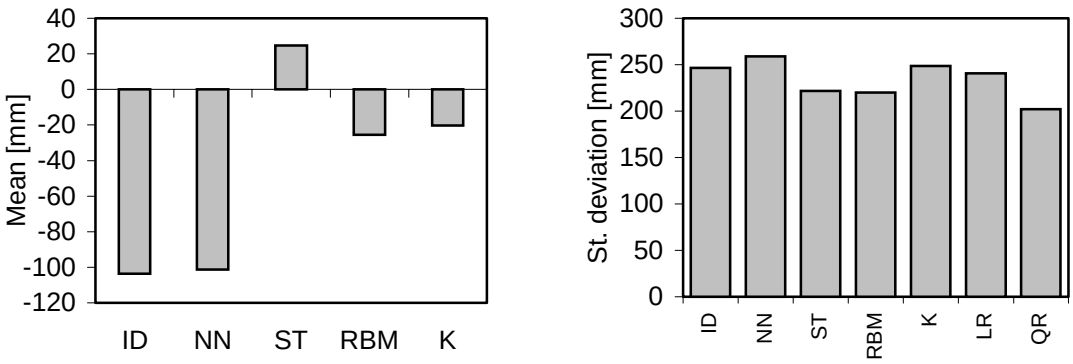

Fig. 2: Basic statistics of differences in jack-knife analysis for the long-term mean annual precipitation (1989-1998); ID–inverse distance, NN-nearest neighbour, ST-regularized spline with tension, RBM-multiquadratic radial basis, K-kriging, LR-linear regression, QR-quadratic regression

Results

Jack-knife analysis for the long-term data

This analysis provided the information on how sensitive particular interpolation method is with respect to missing data. Fig. 2 shows mean values and standard deviations of differences between measured and estimated precipitation. It can be concluded that most methods tend to provide lower estimates when measured precipitation is set aside (missing). Variation of differences measured by standard deviation indicates that sensitivity of all methods is similar. Quadratic regression followed by multiquadratic radial basis and regularized spline with tension had the smallest standard deviations of differences. Linear triangulation can not cope with problem of extrapolation when the boundary samples are set aside. Therefore, statistics of differences of linear triangulation would not be comparable with other methods and are not presented in Fig. 2. Regression methods are based on minimizing differences from the mean. Therefore, they are not included in Fig. 2 either.

Jack-knife analysis for single years

Performance of interpolation methods in single years 1989-1998 is shown in Fig. 3. Regularized spline with tension was the only interpolation method, which, on the average provided higher precipitation estimates. Results of multiquadratic radial basis and kriging were

relatively only slightly underestimated. However, these results should be seen in view of variance of differences around the mean value, which was rather high for all the methods.

Basin precipitation

Long-term mean annual precipitation in the Jalovecky creek basin (1989-1998) computed by the above-mentioned eight interpolation methods is shown in Fig. 4. It is evident that the differences among the methods are small – the difference between the minimum (linear triangulation) and maximum (inverse distance) estimate is only 3%.

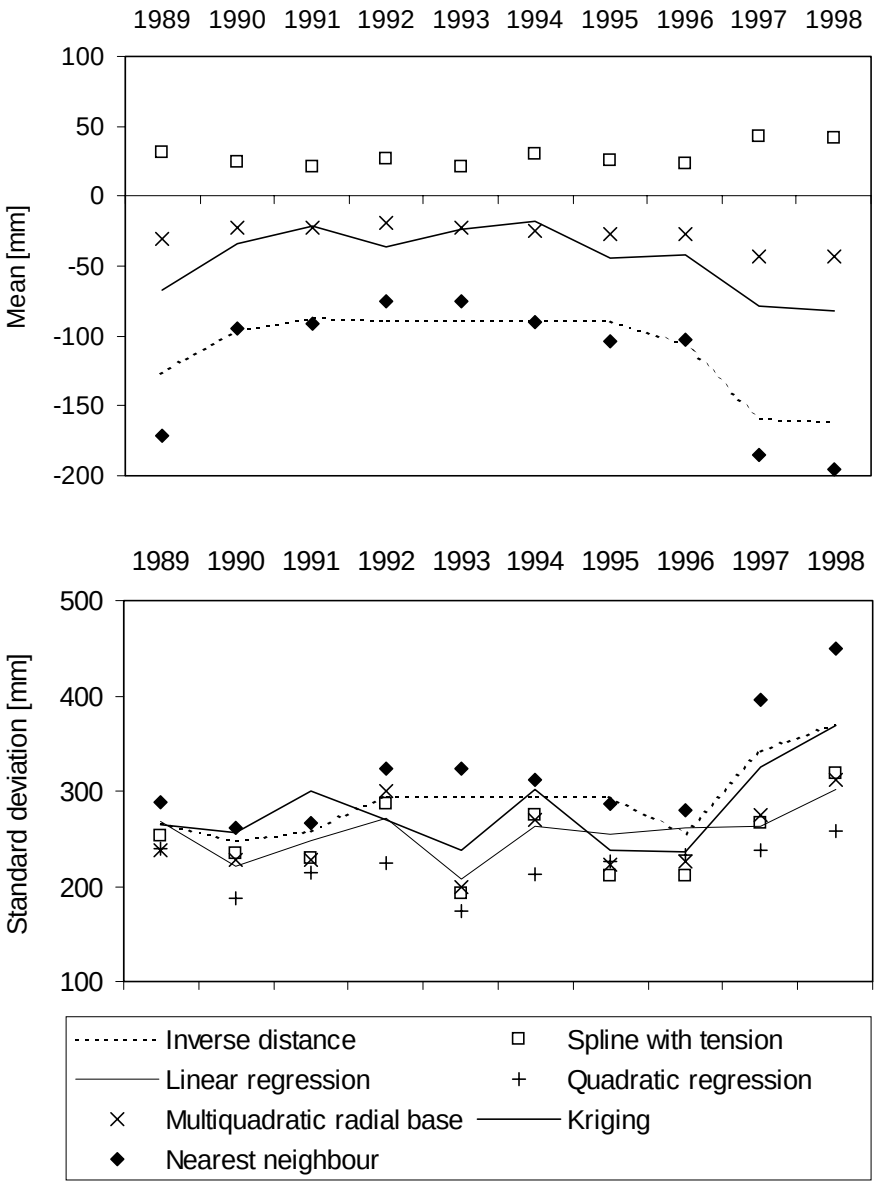

Fig. 3: Basic statistics of differences in jack-knife analysis for single years 1989-1998

While basin precipitation computed by various interpolation methods was similar, spatial interpretation within basin was different (Fig. 5). Although it is not possible to conclude which method provides the best spatial precipitation estimates, it is evident that nearest neighbour interpolation is not suitable for such a task. Also inverse distance and linear triangulation provided geometric spatial patterns (polygons and triangles). Only the regression methods considered basin topography – naturally, spatial pattern of precipitation estimated by regression

methods is the same as the pattern of elevation contour lines. Kriging and radial basis functions (regularized spline with tension, multiquadratic method) provided similar very smooth spatial patterns.

Analysis of differences in basin precipitation estimates for single years 1989-1998 showed that linear triangulation gave the lowest estimate in 5 of totally 10 hydrological years and quadratic regression in 4 years. Highest estimates were given by linear regression (5 years of 10), and inverse distance. Differences between minimum and maximum estimates in single years ranged from 3 to 9%, average difference was 6%. The ranges of precipitation estimates in single years 1989-1998 given by the above mentioned 8 interpolation methods are shown as lines in Fig. 6.

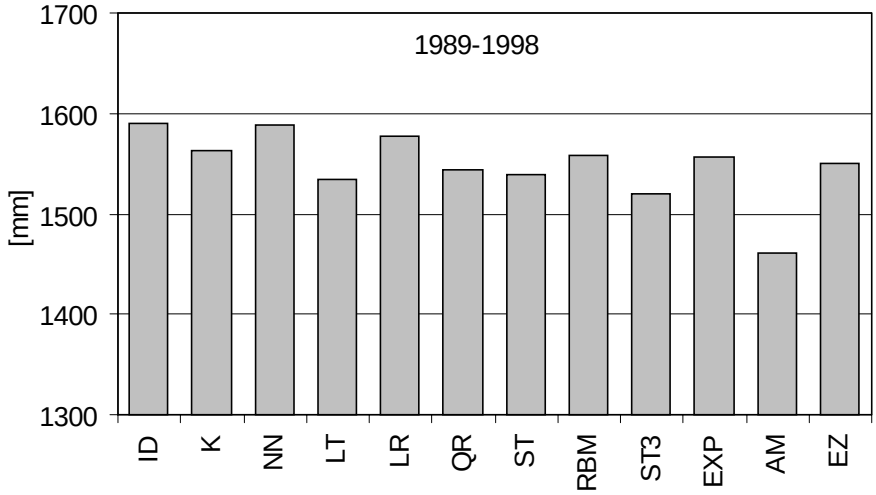

Fig. 4: Long-term mean annual precipitation (1989-1998) in the Jalovecky creek basin computed by various methods; ID-inverse distance, K-kriging, NN-nearest neighbour, LT-linear triangulation, LR-linear regression, QR-quadratic regression, ST-regularized spline with tension, RBM-multiquadratic radial basis; ST3- 3-D spline with tension (Mitasova et al.,1995), EXP-expert-drawn isohyetal map, AM-arithmetic mean, EZ-elevation zones

Discussion

Last four columns in Fig. 4 represent results of other interpolation methods like the above mentioned 8 methods. We used these “other” methods just for comparative purposes. Three-dimensional spline with tension, that considers basin topography, gave lower basin precipitation than linear triangulation. The long-term mean annual precipitation computed from isohyetal map drawn manually by an expert provided value, which was very close to the mean of all the 8 interpolation methods. Method of elevation zones based only on data from the basin, provided the result similar to other interpolation methods (also the expert-drawn map) based on all available (measured) data from the region. It means that the mean basin precipitation is mostly determined by the data measured directly in the basin. Consideration of outside data did not significantly influence computed mean annual precipitation.

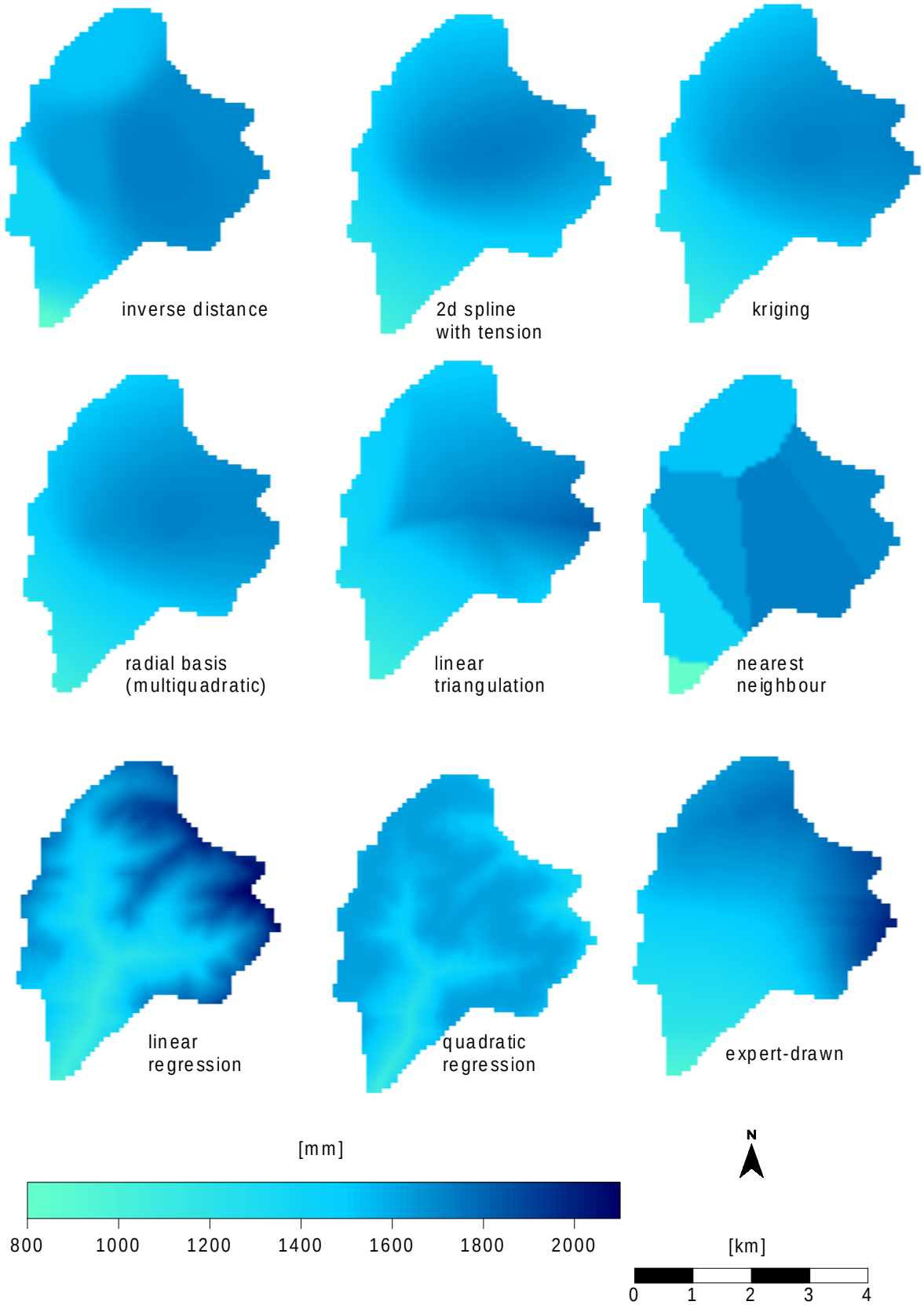

Fig. 5: Spatial interpretation of the long-term mean annual precipitation (1989-1998) in the Jalovecky basin provided by particular interpretation methods

As it was mentioned above the differences in basin precipitation computed by different interpolation methods were not very high. Even the arithmetic mean provided result that was for the long-term data only 6% lower than the estimate given by elevation zones. Considering possible measurement errors one would conclude that the differences among precipitation interpolation methods are not significant from the point of view of hydrological balance. However, the differences in basin long-term evapotranspiration computed from the hydrological balance equation with different precipitation inputs were as high as 11%. Though it is just a "game with numbers" - the difference of 100 mm in precipitation estimate that varies in the order of thousands in relatively lower than the same difference in evapotranspiration estimate which varies in the order of hundreds - these facts should be considered. The differences in single years 1989-1998 were even higher. Evapotranspiration calculated for the largest precipitation estimates was in single years 9-140% higher than evapotranspiration calculated for the lowest precipitation estimates in the same particular years. Thus, depending on the precipitation-runoff relationship (proportion) the small difference in basin precipitation may cause significant difference in calculated evapotranspiration.

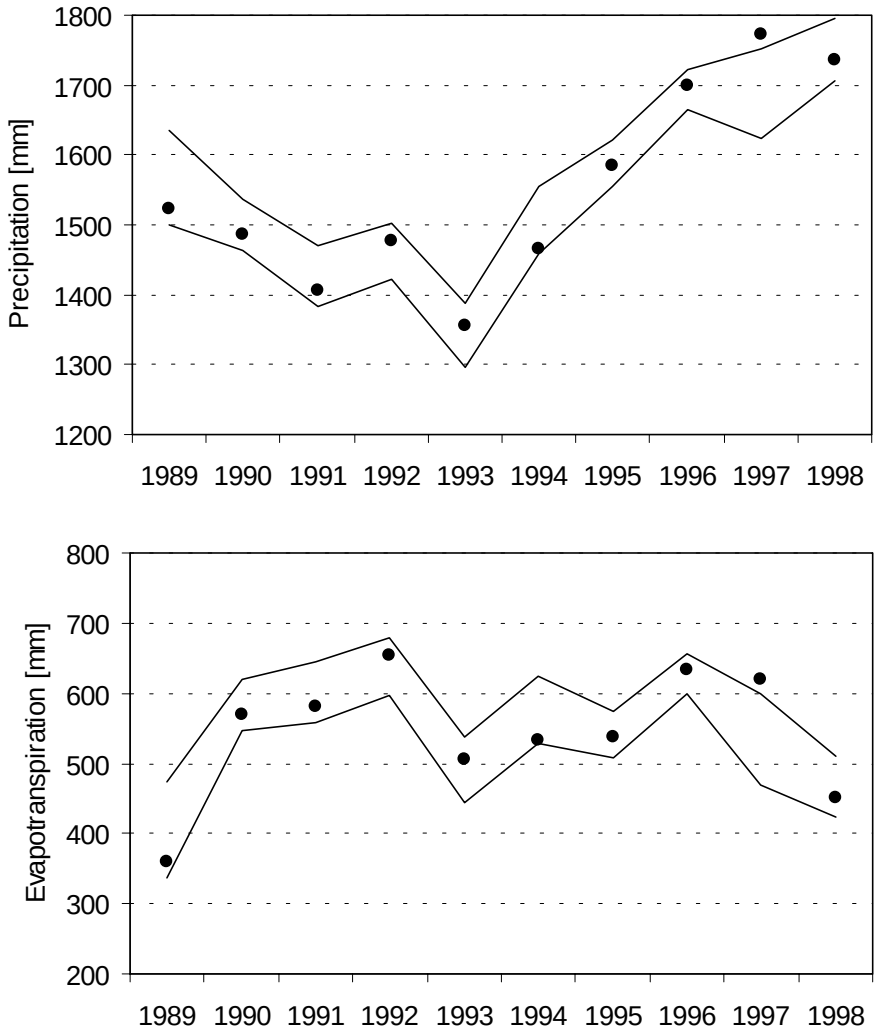

Fig. 6: Basin precipitation and evapotranspiration calculated by method of elevation zones (points) compared with results of the 8 interpolation methods (lines representing minimum and maximum estimates)

Comparison of results provided by method of elevation zones which is routinely used to compute basin precipitation and the resulting evapotranspiration is shown in Fig. 6. The method

solely based on data from the basin provides results, which mostly lie within the range of estimates provided by the above-mentioned 8 interpolation methods.

Conclusions

Interpolation methods tested in this study provided similar results in computing basin precipitation for the Jalovecky basin, Western Tatra Mountains, Slovakia. The differences between maximum and minimum estimates reached just 3% for the long-term (1989-1998) mean annual precipitation and 3-9% for single years 1989-1998. However, in hydrological balance such differences in precipitation resulted in significant differences in calculated basin evapotranspiration - 11% for the long-term data and 9-140% for single years. Though it is directly not possible to conclude which interpolation method gives the best result, the analysis gives idea on probable magnitude of errors in hydrological balance computations in small mountain basins caused solely by applied interpolation method. Justified computation of evapotranspiration in mountain catchment based on the model which takes basin topography into account (Meszaros, 1998) could provide additional information needed to identify the best precipitation interpolation method(s).

Comparison of different interpolation methods indicated that the method routinely used to compute basin precipitation (elevation zones method) provides reasonable results.

Acknowledgement

This study was supported by the research grant VEGA 2/7149/20. Isohyetal maps for the Western Tatra Mountains were prepared by P. Fasko. We also thank J. Hofierka and H. Mitasova for computation of the long term mean annual basin precipitation by three-dimensional spline with tension.

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Spatial and temporal variations of the Palmer drought severity index in the Hungarian catchment area of the Tisza River

Szilvia Horváth, László Makra, János Mika

Abstract: Spatial and temporal characteristics of monthly dry and wet anomalies are examined in the sub-catchment area of the Tisza River in the Great Hungarian Plain, which is characterised by high proportionality of managed vegetation. Assessment of humidity conditions is performed by employing the Palmer Drought Severity Index (PDSI). The Palmer's model is employed to monthly data (mostly in the vegetation period) for the period 1951-1992 by applying monthly meteorological data of 17 selected stations of the regions. This study is similar to the one, presented at the XVIII. Conference of the Danube Countries (Mika, 1996), but for a sub-catchment area with similar number of stations, hence, providing better spatial resolution for this time.

Besides that, computation of basic statistics, determination of the spatial and temporal correlation and factor analysis are also employed to define sub-areas in the region, inside of which PDSI covary in time. Long-term variations are analysed in the series of the PDSI for the period of 1881-1990, although they are not monotonous. Spatial differences of both the long-term behaviour and also the interannual variations point out the high importance of soil parameters in the synchronous occurrence of hydrological anomalies.

Key words: PDSI, Kolmogorov-Smirnov test, χ^2-test, factor analysis, trend significance, special application of the two-sample t-test

Die räumlichen und zeitlichen Änderungen des Palmerischen Trockenheits-Indexes auf dem Einzugsgebiet der Theiss in Ungarn

Zusammenfassung: In unserer Arbeit haben wir die räumlichen und zeitlichen Änderungen der monatlichen trockenen und feuchten Anomalien auf dem Einzugsgebiet der Theiss untersucht, das sich auf der grossen ungarischen Tiefebene befindet. Das Untersuchungsgebiet ist zu grossen Prozent angebaut. Die Feuchtigkeitswerhältnisse sind mit Hilfe von Palmerischen Index (PDSI) bewertet worden. Wir haben das Palmerische Modell auf die meteorologischen, monatlichen Aufgaben der 17 ausgewählten Stationen (meist aus der vegetations Periode) zwischen 1951-1992 angewendet. Diese Arbeit ist ähnlich der Darstellung, die wir an der XVIII-en Konferenz von Donauländer vorgestellt haben, aber diesmal stellen wir ein kleineres und wichtigeres Gebiet mit einer pünktlichen räumlichen Spaltung in dieser Arbeit der.

Ausserdem haben wir einige grundstatistische Rechnung, räumliche und zeitliche Korrelation verwendet. Weiterhin haben wir eine Faktoranalysis auf das ausgewählte Gebiet ausgewendet um einige Subregionen zu definieren, deren PDSI-Werte eine zeitliche Kovarianze haben. Am Ende haben wir die Änderungen des PDSI-Werten zwischen 1881-1990 analisiert, die nicht monoton sind.

Sowohl das Verhalten der 110 jährigen Änderungen des PDSI-Werten, als auch die räumlichen Unterschiede der Änderungen in jedem Jahr hinweisen auf die Bedeutung der Bodenparameter, die zu dem gleichzeitigen Eintritt der hidrologischen Anomalien in engen Beziehungen stehen.

Schlüsselworte: PDSI, Kolmogorov-Szmirnov Probe, χ^2-Probe, Faktor Analysis, Trend Analysis, spezielle Verwendung der t-Probe

1 Introduction

There is an increasing concern about the observed climate variations since the pre-industrial period. World agriculture shows adaptation to the present-day climate patterns, but this situation could change due to the likely global warming (IPCC, 1996).

2 The Hungarian catchment area of the Tisza River

The region, selected for the investigation is the Hungarian catchment area of the Tisza River. This large landscape has always been characterised by high proportionality of managed vegetation. Recently, 74 % of the total geographical area (35,700 km^2) is cultivated. Hence, the investigated region is highly vulnerable to climate variations and also to non-climatic conditions of plant management.

A more detailed analysis of frequent droughts in this area helps to elaborate potential answers to mitigate damages in agricultural production and in free nature. Besides droughts, the other extremity, inland water is also frequently experienced in some periods of the year.

3 The Palmer drought severity index (PDSI)

There is no universal quantitative definition of droughts. In the present study, drought is considered as a meteorological anomaly characterised by a prolonged and abnormal moisture deficiency (Palmer, 1965, Dalezios et al., 1991). To determine onset and severity of meteorological droughts, the Palmer's drought severity index (PDSI) is used in this paper. Drought indices, comprising difference or rate of precipitation and potential evapotranspiration for a given long period, usually characterise drought periods well.

The whole procedure and the basic concepts and steps for computing the PDSI are described elsewhere (Palmer, 1965, and Horváth, et al., 1999).

4 Spatial variations and short-term fluctuations

Short-term variability is analysed for three stations of the examined region (Sárospatak, Szeged and Berettyóújfalu) for the period of 1951-1992. (The selected stations correspond to the poles of the regions in autumn, obtained by factor analysis in Section 4.3, Fig. 1b). These calculations include some basic consist of the distributions including the tests for normality, as well. Spatial and temporal correlations aim to characterise how variations in this relatively small area are interrelated between each other and which part of the year is mostly responsible for the water availability anomalies of the vegetation period. Spatial relations are more thoroughly analysed by spatial factor analysis with the intention to determine objective subregions by applying the PDSI.

4.1 Basic statistics

In principle, PDSI is a non-seasonal characteristics of water availability, but it is worth checking if independence of a given season (represented by a given month) is really fulfilled for the basic statistical parameters (Table 1).

As the normality of the distributions is concerned, the z-values of the Kolmogorov-Smirnov (K-S) test are lower for each PDSI data set than the threshold number belonging to the 1 % probability level (1.63). Consequently, the normality is realised for the considered data sets. According to the χ^2-test, normality is also fulfilled for each PDSI data set. The k-values are far less for each data set than the threshold number belonging to the 1 % probability level and 5 degrees of freedom (13.28) (Table 1). Without monthly separation, the series exhibit definitely irregular, non-Gaussian distribution (Mika et al., 1994).

Table 1 Basic statistics of the PDSI and results of normality tests (probability in %)

PDSI	Sárospatak				Szeged				Berettyóújfalu			
	Apr	Jun	Aug	Oct	Apr	Jun	Aug	Oct	Apr	Jun	Aug	Oct
mean	0.06	0.11	0.13	0.07	-0.11	-0.21	-0.15	-0.02	0.16	0.03	0.10	-0.24
standard deviation	2.71	2.68	3.00	3.00	2.20	2.36	2.66	2.30	2.72	2.81	3.21	2.82
skewness	-0.36	-0.28	-0.23	-0.19	0.22	0.26	0.25	0.49	-0.42	-0.35	-0.16	-0.28
z-value (K-S test)	0.72	0.86	0.83	0.51	0.62	0.76	0.76	0.86	0.95	1.07	0.55	0.65
k-value (χ^2-test)	0.36	4.48	8.19	3.24	2.78	1.22	1.16	1.90	5.40	4.60	6.20	2.10

Since normality is realised for each examined data set, the two-sample t-test can be applied to them to decide whether or not there are significant differences between the means of the data sets of the neighbouring months. According to the results, there is no significant difference between the above-mentioned means for each case. By applying the F-test, no any significant differences can be detected between standard deviations of any pairs of PDSI data sets.

The Palmer model originally assumes independence of the neighbouring seasons, represented by the neighbouring months. At the same time, according to the two-sample t-test and F-test, independence is not realised. That is to say, the neighbouring months depend on each other, since PDSI accumulates changes of former months. Dependence of neighbouring months makes it meaningful to analyse only every second month of the vegetation period.

As for standard skewness, lower (relatively dry) values are more frequent, but high extremes are more severe. In those months with positive skewness (mostly at the rest of the stations), the situation is generally the opposite: high (wet) extreme values are more frequent, but strong droughts occurred in the investigated period between 1951 and 1992.

This cyclicity also supports that in the followings we analyse the PDSI statistics separately for the selected months (April, June, August and October).

4.2. Space and time correlations

Spatial correlations are computed for synchronous monthly PDSI data sets of the above characterised three stations (Sárospatak, Szeged and Berettyóújfalu) for the period of 1881-1990) situated more or less uniformly in the region. Analysing spatial correlations, corresponding to identical months of the year, it can be concluded that drought/wetness conditions may vary in this region, likely due to spatial irregularity of precipitation (Table 2).

Table 2 Spatial (synchronous) and temporal (retarded) correlations of the PDSI values in three selected stations of the examined region

PDSI		Sárospatak				Szeged				Berettyóújfalu			
		Apr	Jun	Aug	Oct	Apr	Jun	Aug	Oct	Apr	Jun	Aug	Oct
Sáros-patak	Apr					0,23				0,46			
	Jun	0,81					0,23				0,38		
	Aug	0,74						0,31				0,37	
	Oct	0,59							0,21				0,27
Szeged	Apr									0,65			
	Jun					0,74					0,69		
	Aug					0,61						0,69	
	Oct					0,17							0,50
Berety-tyó-újfalu	Apr												
	Jun									0,82			
	Aug									0,76			
	Oct									0,57			

According to Table 2, PDSI values of the late months of the vegetation period are basically determined by the disponible water capacity at the beginning of the vegetation period and not by the moisture balance of the vegetation period itself.

4.3. Regionalisation by factor analysis

One of the best methods to study time series data for a large number of stations or grid points, where strong spatial and temporal correlation prevails, is factor analysis (see e.g. Bartzokas and Metaxas, 1993).

Factor analysis defined different numbers of subareas in the different months of the year. The eigenvalues and the percentages, explained by the retained and rotated factors for PDSI for each month, are shown in Table 3. It is found that the retained factors explain 74.6 - 79.9 % of the total variance exhibited by all initial variables. The number of retained factors varies between 2 and 3. This means that the monthly PDSI-fields, coming from data series of the investigated 17 stations in the region, consist of three subareas in autumn (September, October and November) and two subareas in the rest of the months (Fig. 1a -1b). (Central parts of the subregions are indicated by the 0.8 factor loading isolines. Stations are indicated by points.)

Table 3 The significant eigenvalues and the total percentage of variances explained by the retained and rotated factors

factors	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.	11.6	11.4	11.4	11.3	10.6	10.5	10.5	10.6	9.7	10.3	10.4	11.2
2.	1.8	1.8	1.8	2.0	2.1	2.0	2.0	2.1	2.4	2.1	2.0	1.9
3.									1.1	1.2	1.0	
expl var, %	**78.9**	**78.1**	**78.0**	**78.3**	**74.5**	**74.0**	**75.3**	**74.6**	**77.9**	**79.9**	**78.9**	**77.1**

5 Analysis of long-term variations

Two questions are statistically analysed during the examined 110 years term in the four months-indicators of the vegetation period, i.e. April, June, August and October:

i.) When did significant linear trends occur during the investigated term?

ii.) When did time averages significantly differ from that in the whole period?

In both cases, two-sample t-test was applied in different design.

5.1 Local trend analyses

Significance of linear trends during any subperiods within the 110 years is checked by two-sample t-test (Horváth et al., 1999). According to this, linear trends of monthly PDSI series are usually significant only for relatively short sequences (Table 4).

Drying tendencies are more frequent and have longer periods, while more rainy tendencies are sporadic and include much shorter terms. Signs and extensions of significant periods are generally not much similar either in the four month or at the three sites. This means that mainly the short sequences are yielded rather by random interannual fluctuations, than by the long-term trends (Table 4).

5.2 A special application of the two-sample t-test: significant deviations of time-slices

The aim of this section is to identify averages of subperiods which are significantly different from the 110 years mean. This search was performed by a special case of Students t-test, applied to detect differences between averages of non-independent data sets (Makra et al, 2000). The significance tests were performed at 1 % significance level (Table 5).

It is remarkable, that number of significant periods is generally two at each station. The most characteristic result of this analysis is that, depending on stations and months, a wet period can be observed between 1881 and 1940-1945, which is followed by a significant dry one until 1990 (Table 5).

Table 4 Subperiods with significant PDSI linear trends in 1881-1990

	PDSI							
month	**April**		**June**		**August**		**October**	
settlement	**period**	**year***	**period**	**year***	**period**	**year***	**period**	**year***
Szeged	1908-1914	7 (-)	1885-1898	14 (+)	1881-1887	7 (-)	1896-1908	13 (-)
	1932-1936	5 (-)	1897-1899	3 (-)	1896-1905	10 (-)	1920-1941	22 (+)
	1934-1942	9 (+)	1937-1950	14 (-)	1937-1950	14 (-)	1976-1980	17 (-)
	1940-1950	11 (-)	1953-1962	10 (-)	1955-1960	6 (-)	1930-1963	34 (-)
	1960-1962	3 (+)	1962-1966	5 (+)	1946-1978	33 (+)	1946-1978	33 (+)
	1977-1980	4 (-)						
Debrecen	1909-1911	5 (+)	1881-1890	10 (-)	1885-1887	3 (-)	1881-1904	84 (-)
	1946-1987	42 (+)	1956-1962	7 (-)	1979-1983	5 (-)		
	1881-1974	94 (-)	1979-1990	12 (-)	1936-1964	29 (-)		
			1946-1985	40 (+)				
Nyíregyháza	1904-1916	13 (+)	1910-1915	6 (+)	1904-1915	12 (+)	1907-1905	9 (+)
	1973-1978	6 (+)	1934-1942	9 (+)	1931-1942	12 (+)	1946-1955	10 (+)
	1883-1990	108 (-)	1972-1980	9 (+)	1963-1965	3 (+)	1962-1966	5 (+)
			1881-1987	107 (-)	1972-1980	9 (+)	1972-1980	9 (+)
							1882-1990	109 (-)

*Legends: (-) significant tendency for drought; (+) significant tendency for higher amount of precipitation

The experienced similarity among the long-term anomalies of identical sign in the consecutive months and at the examined sites suggests that these long sequences be already yielded the long-term trends.

Table 5 Subperiods with significantly different averages of PDSI from that of the full data set in 1881-1990

	PDSI							
month	**April**		**June**		**August**		**October**	
settlement	**period**	**year***	**period**	**year***	**period**	**year***	**period**	**year***
Szeged	1946-1990	45 (-)	1946-1990	45 (-)	1945-1963	19 (-)	1942-1990	49 (-)
	1889-1945	57 (+)	1892-1944	53 +)	1895-1941	47 (+)	1895-1941	47 (+)
Debrecen	1881-1945	65 (+)	1945-1973	29 (-)	1946-1964	19 (-)	1934-1974	41 (-)
	1925-1965	41 (-)					1942-1990	49 (-)
							1881-1941	61 (+)
Nyíregyháza	1881-1967	87 (+)	1881-1955	75 (+)	1913-1915	3 (+)	1881-1967	87 (+)
	1934-1990	57 (-)			1968-1976	9 (-)	1916-1990	75 (-)
	1917-1987	71 (-)						

*Legends: (-) significant dry period; (+) significant wet period

These results are in harmony with those ones, according to which relative frequency of warm-dry years are increasing in the Great Hungarian Plain, in the period between 1901 and 1990 (Tar, 1993). Also, these results are in full coincidence with conclusions elaborated in a previous review paper (Mika, et al., 1995), declaring that climate of the Great Hungarian Plain becamedrier in the more recent decades, according to series of native references.

6 Conclusions

1. Independence for seasons (months) is not realised for PDSI values.

2. Distribution of each monthly PDSI data set is normal, according to both Kolmogorov-Smirnov test and χ^2-test.

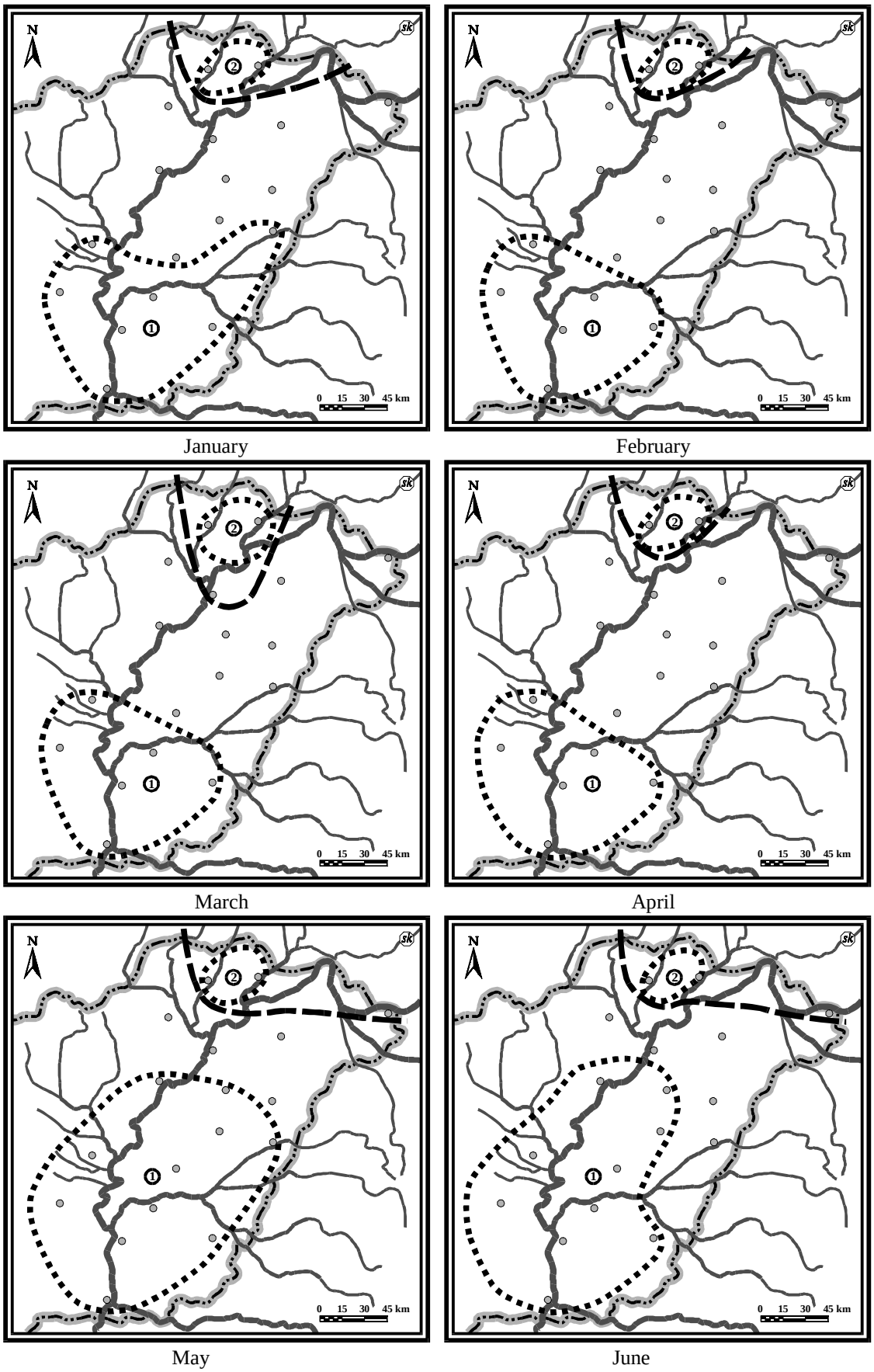

Fig. 1a Subareas formed according to rotated factor loadings for PDSI in the months, when the number of retained factors is >1. Isopleths for loadings 0.8 are indicated.

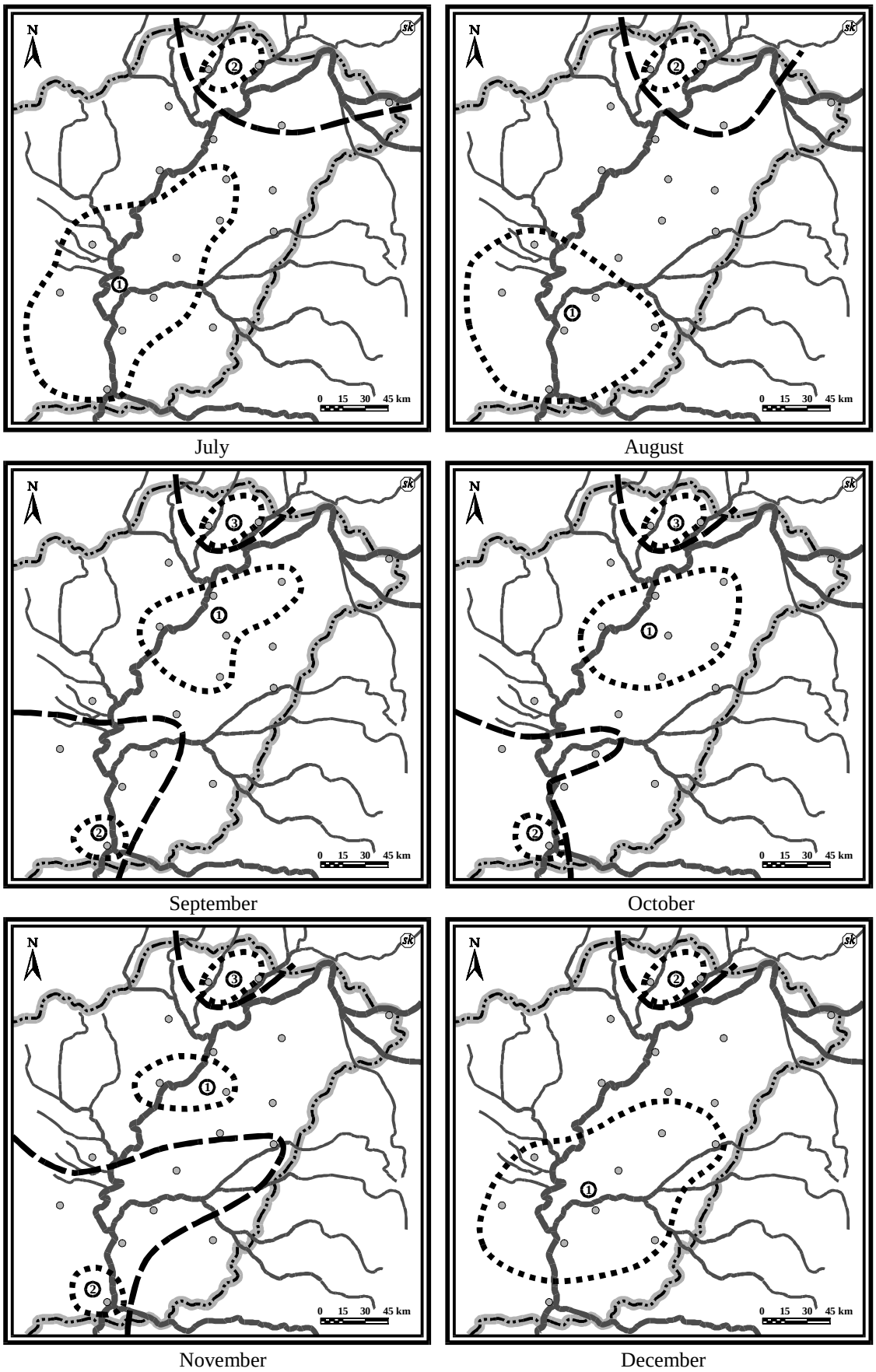

Fig. 1b Subareas formed according to rotated factor loadings for PDSI in the months, when the number of retained factors is >1. Isopleths for loadings 0.8 are indicated.

3. On the basis of variability of PDSI, the examined area generally consists of two subregions, except for autumn, when three subregions can be identified.

4. PDSI indices show medium correlations in the vegetation period. Inclination to drought and inland water has spatial variability of meteorological origin.

5. Saturation in the middle of spring influences soil moisture content significantly at some stations till the middle of autumn (October), while at other stations till the end of summer (August).

6. Significant periods between 3-15 years of linear trends in PDSI data sets amount 70 % of all those. According to the special application of the two-sample t-test, the most characteristic result is that, a wet period can be observed between 1881 and 1940-1945, which is followed by a significant dry one until 1990.

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Ecological Evaluation of Landscape of Araeas with Small Water Reservoirs

Eva Klementová, Jana Skalová

Abstract: This contribution presents the evaluation of landscape ecological stability of areas with small water reservoirs (SWR) by coefficients of ecological stability for Danube River Basin. For assignment of degree of ecological stability was been applied quantitative and qualitative method.

Keywords: Landscape, Ecological stability, Coefficients of ecological stability, Small water reservoirs

Landschaftsökologische Bewertung eines Gebietes mit kleinen Stauseen

Zusammenfassung: Dieser Beitrag behandelt die Bewertung der landschaftsökologischen Stabilität in Gebieten mit kleinen Stauseen durch den Koeffizient der ökologischen Stabilität. Für die Ermittlung des Grades der ökologischen Stabilität wurden quantitative und qualitative Methoden verwendet.

Schlüsselworte: Landschaft, ökologische Stabilität, Koeffizient der ökologischen Stabilität, kleine Stauseen

1 Introduction

The spatial classification of the ecological stability is part of the territorial systems methodics, in which the positive and negative factors and properties of the area are assessed. This classification results in the separation of areas with approximately the same stability degree, which enables to ascertain the protection needs and area utilization hierarchy. The generation of an optimum spatial structure, i.e. the appropriate relation between the ecologically stable and ecologically labile elements, constitutes an inevitable precondition for the healthy ecology of the landscape. The spatial stability characteristic is then based on the following thesis: the higher the area share of “more stable” ecosystems in the given area and the more heterogeneous the area, the more stable the area and the better preconditions for the elimination of eventual unfavorable effects.

2 Methods of the evaluation of ecological stability

Landscape ecological stability is determined by means of quantitative or qualitative characteristics of biotechnical elements. There are most commonly applied coefficients of ecological stability (KES). The calculation procedure has been worked out by several authors. Each of them created his own assessment criteria - concerning the quality of the individual landscape elements on the one hand, and the extent and range of the ecological stability assessment degree on the other hand.

2.1 Quantitative method

Coefficients of ecological stability KES1 is based on the assessment of the area share of the individual landscape elements and their effect, which is either positive (stabilizing) or negative (destabilizing) in the natural environment.

It can be calculated as follows:

$$KES1 = \sum_{i=1}^{i=n} PK_{st} \cdot \left(\sum_{i=1}^{i=m} PK_{nst} \right)^{-1} \quad (1)$$

$\sum_{i=1}^{i=n} PK_{st}$ - areas of landscape elements which have a stabilizing effect upon the surrounding landscape,

$\sum_{i=1}^{i=m} PK_{nst}$ - areas of unstable landscape elements in the area of interest.

Landscape elements having a stabilizing effect upon the surrounding landscape include forests, dispersed green growth, permanent grass stands, special cultures, unpolluted water reservoirs, protected areas, natural reserves and arable land on which the same crop has been grown for several years. Landscape elements with an unstable effect include arable land which is cultivated every year, untreated grass stands, built-up and traffic areas, polluted water reservoirs, mining and wood-cutting areas and other devastated areas.

2.2 Qualitative methods

In this contribution two qualitative methods are used which are marked as KES2 and KES3.

The first coefficients of ecological stability KES2 has regard for the significant fact that each biotechnical element affects the landscape stability not only by its area but also by its point stability, real state and impacts of human activity. It is also necessary to know their inner properties and qualitative aspects (biotope humidity, value of the genetic fund, biomass structure, regional scarcity, geological structure, land position and morphology, etc.). The coefficient of ecological stability can be calculated as follows:

$$KES2 = \frac{\sum_{i=1}^{i=n} P_{pn} \cdot k_{pn}}{P_{zu}} \cdot k_r \quad (2)$$

P_{pn} is area of the biotechnical element,
k_{pn} - coefficients of ecological significance of the individual biotechnical elements,
P_{zu} - area of the entire area of interest,
k_r - coefficient of geological-morphological stability of the relief of the concerned area.

The second method - assessment of ecological quality of the landscape spatial structure (methodic of Institute of Landscape Ecology of the Slovak Academy of Sciences, Bratislava 1991) it is based on the ecological quality of elements of the current landscape structure, their spatial arrangement and area. The cadastre area constitutes the basic unit of the assessment, as the smallest administrative unit of Slovakia. Each cadastre area is assessed on the basis of four basic indicators, which are: coefficient of the cadastre area structure, coefficient of arable land fragmentation, coefficient of need, coefficient of density of line anthropogenic elements.

The indicator of the cadastre area spatial structure is the basic information on the ecological state of the given cadastre. The assessment is based on two fundamental criteria.

Ecological quality of the assessed current landscape structure elements criterion - here we determine the so-called landscape-ecological significance of the individual elements. We consider the natural landscape elements (forests, meadows, pastures, water reservoirs) to be the most valuable ones from the ecological point of view and we gave them the highest value of the coefficient of ecological significance when calculating the coefficient of the structure. They

have many ecological functions - soil conservative, microclimatic, amelioration, biological-ecological and hygienic functions. Anthropogenic elements with a high economic effect but unfavourable impacts upon the landscape (waste dumps, industrial areas, highways, agricultural structures and many other built-up areas) are classified as least valuable elements of the landscape structure from the ecological point of view. The smallest values of the landscape-ecological significance were given to these elements. Several examples of the negative impact of these elements upon the landscape quality - areal elimination of forests, meadows and agricultural land, jeopardizing the quality of natural resources, jeopardizing the spatial stability of the landscape.

And area criterion - it takes the effect of the area of the given biotechnical element upon its significance within the landscape into consideration. The larger the area, the greater the favourable and unfavourable impacts of the element.

The following expression is applied to the calculation of the coefficient of cadastre area spatial structure, which was calculated as KES3 follows:

$$KES3 = \sum_{i=i}^{i=n} \frac{p_i \cdot k_{pi}}{p} \qquad (3)$$

p_i - areas of the individual elements,

k_{Pi} - coefficients of ecological significance of the elements, which have been worked out in detail for this method. This means that the method can respond very sensitively to changes in the landscape,

p - measurement of the cadastre area,

n - number of elements in the cadastre area.

The authors recommend to divide the cadastre area into the built-up area and open area when performing the assessment. The assessment given in the paper includes calculated results of the coefficient of cadastre area structure, which was designated as KES3.

3 Results of ecological stability evaluation of areas with small water reservoirs

The paper was targeted at ascertaining the degree of ecological stability in cadastre areas with small water reservoirs based on the calculation of coefficients of ecological stability. The ecological stability degree is determined on the basis of the calculated KES value by quantive and qualitative methods (table 1). Values calculated in compliance with the mentioned methods give basic information on the ecological stability degree of the monitored landscape and constitute the basis for a differentiated approach to the solution, evnt. for the choice of convenient restoration measures for landscape protection and landscaping.

Table 1 Degree of ecological stability of landscape by evaluated coefficients of ecological stability (KES)

Degree of Ecological Stability	Landscape	KES1	KES2	KES3
I.	Unstable	≤ 0,50	≤ 0,33	≤ 0,30
II.	Low stable	0,51-1,0	0,34-0,50	0,31 - 0,60
III.	Intermediate stable	1,01-3,0	0,51-0,66	0,61 - 0,80
IV.	Very stable	> 3,01	> 0,66	> 0,80

The Danube River Basin was the area of our interest, as there are 43 small water reservoirs in this area.. The results of KES calculations projected into the ecological stability degree are shown in figure 1 - frequency of SWR occurrence in the ecological stability classification degrees for the Danube River Basin (KES1, KES2 and KES3). Figure 2 gives the percentual shares.

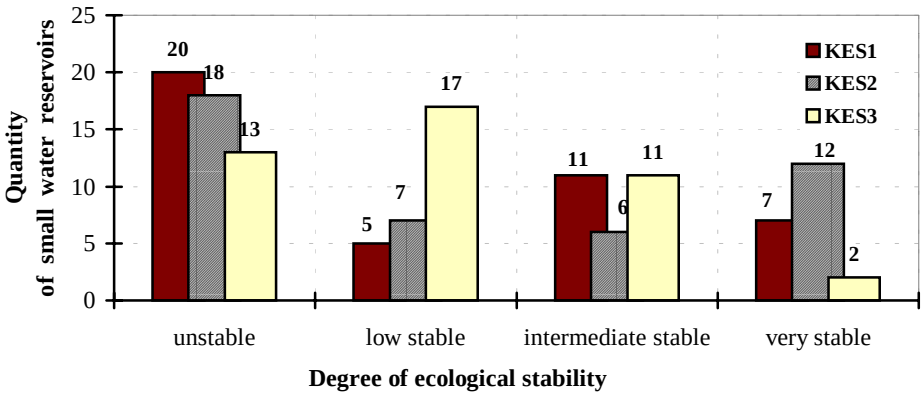

Fig. 1 Ecological stability degree of area with small water reservoirs – frequency of SWR occurrence – Danube River Basin

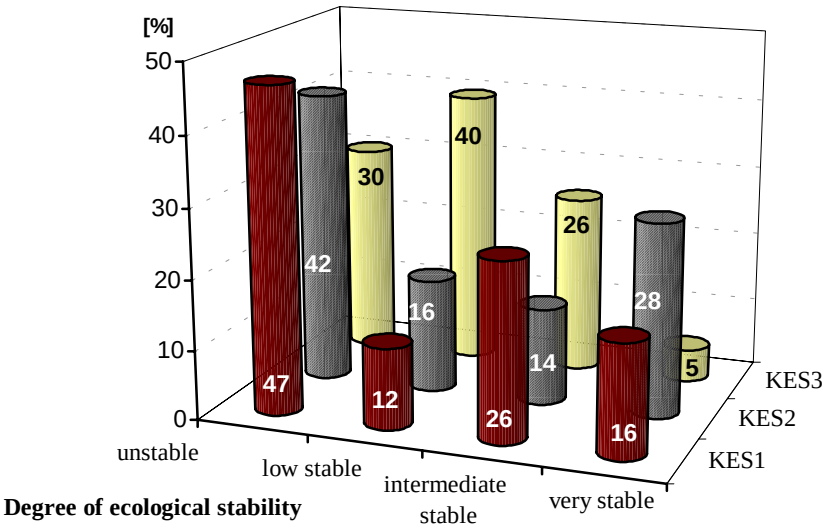

Fig. 2 Classification of areas with small water reservoirs – Danube River Basin

Further analyses enabled to separate the stable areas with SWR in the Danube River Basin from the unstable ones, which gives a quick overview of the landscape ecological stability degree. Areas of the first and second categories are considered to be unstable and areas of the third and fourth categories are considered to be stable (see table 1). The results are given in table 2.

Table 2 Ecological Stability of Areas of Small water reservoirs in Danube River Basin

KES	Ecological Stability Classification Degrees of Landscape			
	I. very stable	II. intermediate stable	III. low stable	IV. unstable
KES1	7	11	5	20
KES2	12	6	7	18
KES3	2	11	17	13

Table 2 results in the fact that most of the SWR are located in the unstable area (KES1 - 20, KES2 –18 and KES3 - 13). It means this small water reservoir need more care and we have to think of their correct exploitation. Mainly we have to try on right integrating of small water reservoirs into landscape during revitalization of landscape.

4. Conclusions

Landscape Ecological Stability was evaluated by three methods - the quantitative method (KES1) and two qualitative methods (KES2, KES3). The results of KES calculations projected into the locality of small water reservoirs and we were found out ecological stability degree of area with small water reservoirs.

Based on the assessment of the ecological stability we may in way of conclusion state that the most of small water reservoirs are located in the unstable area. The given assessment can be useful for the new considered designs of complex utilization of small water reservoirs and for landscape-ecological planning.

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Water Runoff Redistribution Between the Danube' Delta Branches

Michail Kornilov

Abstract: Water runoff redistribution within the delta net is the main feature mostly determining the processes of delta formation. Runoff redistribution is not constant. It changes in dependence from phase of water regime as well as during the multi-year period. The calculation and analysis of water runoff in the Danube delta had been done in this work.

Key words: delta, discharge, water runoff redistribution.

Durchflussverteilung zwischen den einzelnen Flussarmen des Donaudeltas

Zusammenfassung: Die Abflussverteilung ist eine Charakteristik der Deltabildungsprozesse. Sie ist nicht unveränderlich. Sie wechselt vielmehr in Abhängigkeit vom Abflussregime und innerhalb vieljähriger Perioden. Der Vortrag umfasst die Berechnung und Analyse der Durchflussverteilung in den Flussarmen des Donaudeltas.
Schlüsselwörter: Delta, Abfluß, Durchflussverteilung

1 Introduction

Water runoff redistribution within the delta net is the main feature mostly determining the processes of delta formation. The distribution of water runoff among the Danube delta branches is not constant. It changes in dependence from phase of water regime as well as during the multi-year period.

2 Long Term Water Runoff Redistribution Between the Danube Delta Branches

Long-term water runoff distribution and its alterations in the Danube Delta depend on morphometric parameters of the delta branches. Artificial or natural alterations of the same parameters of the delta branches (length, width, depth e.t.c.) always induce water runoff redistribution.

Current water runoff distribution between the Danube delta branches was calculated by hydrometric method. As a result of these calculations the relationship was obtained, as follows:

$Q_1=Q_1(H_r)$, $Q_i=Q_i(H_r)$,

where H_r is the water level at the head of the Danube delta (Reni station); Q_1 and Q_i are the river discharges at the head of the delta and in each of its branches, respectively.

At the end of the last century water runoff of the Chilia branch was about 70% of the total Danube one (Table 1.). It was distributed between Ochakovski and Starostambulski branches as 1/2 (24.5% and 45.% respectively). At that time the Tulcea branch had about 30% ratio in the total Danube water runoff (Sulina branch – 7%, Sf.George – 23%).

Table 1 Long-term water runoff redistribution between the main delta branches.

Years	Water runoff distribution between the branches, %					
	Chilia	Ochakovski	Starostambulski	Tulcea	Sulina	Sf.George
1872	63.0	21.0	42.0	37.0	8.0	29.0
1859	70.0	24.5	45.5	30.0	7.0	23.0
1928	66.0	28.8	37.2	34.0	14.0	20.0
1943	64.5	29.3	35.2	35.2	15.5	20.0
1960	62.5	25.1	37.4	37.5	17.0	20.5
1965	62.3	23.1	39.2	37.7	17.2	20.5
1970	61.2	21.5	39.7	38.8	18.3	20.5
1975	60.0	19.7	40.3	40.0	18.9	21.1
1980	58.8	18.2	40.6	41.2	19.5	21.7

1995	56.3	15.6	41.7	43.9	19.6	24.7
1998	53.9			46.1		

However, in 1902 the extensive river-dredging and bed straightening works in the Sulina branch were completed. Its depth was increased from 2.4 to 6.0 m, and length was decreased by 21.2 km (about 25% of it total length). The stone dike built at the Chilia branch head redistributed Danube water runoff between Chilia and Tulcea branches. These works induced the increase of Sulina branch water runoff. By 1920 the share of Sulina branch water runoff grown up to 12% of the total Danube one. At the same time the share of Sf.George branch water runoff decreased from 23% to 20%.

These and further hydrotechnical works in the Sulina branch (increase of the depth to 7.3 m in the 1930, building of the directive dikes in the estuary) induced water runoff redistribution between Chilia and Tulcea systems. The present water runoff distribution between these systems are as follows: Chilia branch – 53.9%, Tulcea branch – 46.1%.

During the period 1872 – 1943 delta subsystem of Ochakovski branch was the most active within the Chilia delta. During that time water runoff of Ochakovski branch increased from 21% up to 29.3%. At the same time water runoff of the Starostambulski branch decreased from 42% to 35% of total Danube runoff. However, since 1943 tendencies in development of the Ochakovski and Starostambulski branches changed and the Starostambulski branch became active.

Present water runoff distribution between these branches are as follows: the Starostambulski branch – 41.7% and the Ochakovski branch – 15.6%.

3 Seasonal Water Runoff Redistribution Between the Danube Delta Branches

Seasonal redistribution of the water runoff through the Danube delta branches is a sufficiently researched phenomenon. The general common features were discovered in this respect. With the water content increase the share of water runoff increases in those arms where the section area proceeds quicker(Fig. 1).

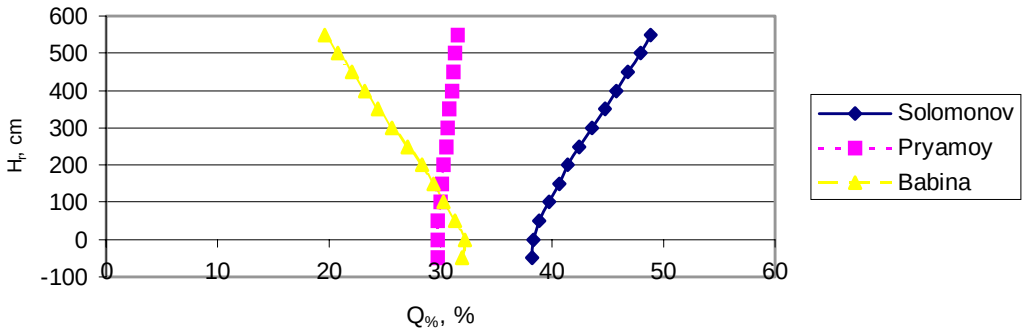

Fig. 1 Alterations of water runoff with the changing of water content in different branches of Chilia delta system.

This feature is usually observed with wider and shallow branches (i.e. fading) and decreases with those developing. Thus, the trend of alterations of water runoff share with the changing of water content may construe the character of the trend in development of the relevant arm.

During the analysis of seasonal water runoff redistribution within the branches of the Chilia delta system it was determined the following phenomenon. In some cases the increase of the water section area of the active branch with the water content increase, rise more intensively than in the fading one.

Therefore the more objective parameter characterizing the trends of the seasonal water runoff redistribution, and, consequently, the trends in the branch's development may be the intensity of the discharge increase.
This is to propose a Z-criteria as the water flow increase intensity factor:
$Z_i=dQ_i/Q_{i.av}$,
where $Q_{i.av}$ is the average discharge per the relevant branch, $dQ_i=Q_{i.max} - Q_{i.min}$ is the annual range of the branch's discharge alterations.
According the results of calculations of the Z-criteria and the seasonal alterations of the share of water runoff among the branches ($dQ_{\%.i}$,%) the Z=f($dQ_{\%.i.}$,%) graph had been construed for some branches of Chilia delta system (Fig. 2).

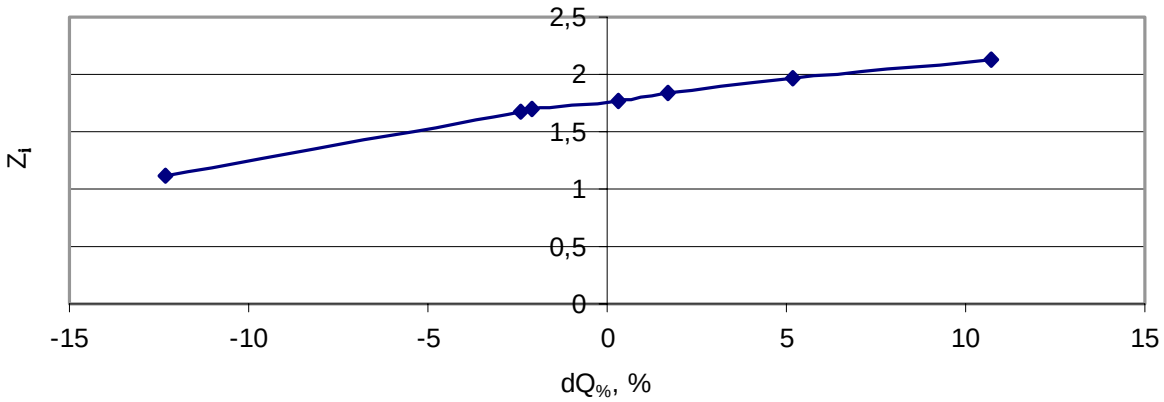

Fig. 2 Graph of dependence Z=f($dQ_{\%.i.}$,%).

This allowed to obtain an empiric factor Z_0 characterizing the trends in seasonal redistribution of water runoff. Comparing the criteria Zi and Z_0 a conclusion may be drawn about the manner in which the branch's runoff ratio alters with the water content increase.
$Z_i<Z_0$ – reduces;
$Z_i>Z_0$ – increases.
Finally, subject to the results of comparative analysis of the Zi and Z_0 criteria one may draw certain conclusions about the trends in the relevant branch's development.

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Modelling of Soil Moisture and Evapotranspiration Spatial Distribution in Mountain Catchment

Zdeno Kostka

Abstract: Mountain catchments represent the specific environment regarding the modelling of hydrological balance components and their distributed pattern. Relief of mountain regions with great amplitude, the spatial variability of meteorological inputs and vegetation and soil characteristics influence the water balance components spatial distribution. The topography based distributed hydrological model was chosen for modelling of soil moisture and evapotranspiration in the Jalovecký potok experimental basin in the Western Tatra mountains. Model calculations were calibrated against field measurements of total discharge at the catchment outlet, soil moisture measurements and snow water equivalent measurements at several sites in the experimental catchment.

The WaSiM-ETH model simulation analysis proved the suitability of topography analysis based semi-distributed model for modelling of spatially distributed pattern of soil moisture and evapotranspiration in mountain catchments with great height amplitudes provided the suitable sophisticated algorithms for simulation of processes above soil surface are used. Both hydrological model and field measurements confirmed the substantial influence of relief and vegetation cover on total evapotranspiration as well as on spatial distribution of soil moisture and snow cover.

Key words: evapotranspiration, soil moisture, mountain catchment, distributed model

Modellierung von der räumliche Verteilung von der Bodenfeuchte und Verdunstung in dem Gebirgsflussgebiet

Zusammenfassung: Das Gebirgflussgebiet repräsentiert spezifisch Umwelt soweit die Modellierung der hydrologische Bilanz Komponenten und seine räumliche Aufteilung betrifft. Relief der Gebirgregionen mit dem großen Höhenunterschied, räumliche Variabilität der meteorologischen Einzugsdaten, Landnutzungsdaten und Bodendaten beeinflussen die räumliche Aufteilung der hydrologische Bilanz Komponenten. Das deterministisches, flächendifferenziert arbeitendes hydrologisches Einzugsgebietsmodell war für Modellierung der Bodenfeuchte und Verdunstung in dem Jalovecky potok Forschungseinzugsgebiet in der West Tatra Gebirge gewählt. Die Modellberechnungen wäre nach der Feldmessung der Gesamtabflußtiefe in der Einzugsgebiet-mündung, der Bodenfeuchtemessung und der Schneewasseräquivalentmessung auf den mehreren Stellen in den Forschungsflußgebiet kalibriert.

Die Analyse der Simulation des WaSiM-ETH Modell hat die Zweckmäßigkeit der flächendifferenziert hydrologisches Modell mit der topographischen Analyse für modellierung der räumliche Verteilung der Bodenfeuchte und Verdunstung in der Gebirgseinzugsgebiet mit der grossen Höhendifferenzen bestätigt. Die unvermiedliche Bedingung ist die Anwendung der geeigneten Berechnungsmethode für die Simulation der Processes über der Bodenoberfläche. Das hydrologisches Modell und auch die Feldmessungen haben den wesentlichen Einfluß des Reliefs und Landnutzung auf die gesamt Verdunstung und auf die räumliche Aufteilung der Bodenfeuchte und Schneebedeckung bestätigt.

Schlüsselworte: Verdunstung, Bodenfeuchte, Gebirgflussgebiet, flächendifferenziert Modell

1 Introduction

Soil moisture dynamics is the key of water balance of a region. Climate plays the essential role at hydrological regime formation but any hydrological phenomenon cannot exist independently on soil and vegetation cover. Hydrological conditions of the unsaturated zone determine the groundwater recharge from the rain falling on soil surface and from the melting snow as well as the degree of satisfaction of evapotranspiration demands.

Mountain catchments represent the specific environment regarding the modelling of hydrological balance components and their distributed pattern. Flow and accumulation of surface water and

groundwater are primary influenced by the relief of mountain regions with great amplitude. Soil water content, as well as other hydrological components, are secondary influenced by the spatial variability of meteorological inputs and vegetation and soil characteristics that are also markedly influenced by complicated relief. These facts determine the choice, calibration and verification of hydrological models.

2 Terrain based hydrological modelling

Soil water regime evaluation needs the knowledge of sufficient number of annual courses of soil regime characteristics. One to three years long courses of soil moisture do not allow generalisation of soil water regime. Such courses can be instrumental to the calibration of hydrological mathematical model making the retrospective calculation of soil regime characteristics (soil moisture, soil water potential) possible.

One-dimensional models simulating the water movement processes and energy transformations within the soil-vegetation-atmosphere system differ each other by the applied analytical methods solving the water movement in soil environment but mainly by the subtlety of solving the processes in plant body and processes within the atmosphere above ground (applied methods of evapotranspiration calculation, snow accumulation and melting processes). Such models can simulate the hydrological processes at single site or at small homogenous area reliably but they are primarily not dedicated for spatial dynamics simulation. The dynamics of the spatial distribution of soil moisture and evapotranspiration can be satisfactory simulated only by distributed or semi-distributed models.

Starting from previous considerations the distributed hydrological modelling system WaSiM-ETH was chosen for modelling of soil moisture and evapotranspiration in the experimental catchment. The model is based on topographic analysis included in TOPMODEL principle and utilises the subroutines for meteorological inputs interpolation, evapotranspiration, interception, infiltration and discharge routing. Authentic modelling of time and space distribution of hydrological balance components requires inclusion both of snow accumulation and melting calculation and topography based radiation and temperature correction that are important phenomena in mountain regions. TOPMODEL principle is based on the variable source area theory and it is capable to predict the mosaics of soil moisture deficit and distribution of the saturated source areas using terrain characteristics and soil properties.

The basis of TOPMODEL is the topographic index, which is sometimes called the soil moisture index

$$\lambda_i = \ln\left(A_S / \tan\beta_i\right) \tag{1}$$

where A_S is the specific area of catchment and β_i is slope angle at specific point. Alternatively the soil-topographic index can be used

$$\chi_i = \ln\left(A_S / \tan\beta_i\right) + \left[\ln\left(T_e\right) - \ln\left(T_i\right)\right] \tag{2}$$

where T_i is transmisivity (hydraulic conductivity integrated over the whole depth of soil profile) at specific point and $\ln(T_e)$ is the average value of $\ln(T_i)$ over the whole area of catchment.

Velocity of subsurface flow through the contour line unit length at the specific point is approximately determined by the equation

$$q_i = T_i \tan\beta_i \exp\left(-\frac{S_i}{m}\right) \tag{4}$$

where T_i is the soil transmissivity coefficient, β_i is slope angle, S_i is local soil moisture deficit, and m describes the vertical change of soil transmissivity. Based on the exponential equation the local soil moisture deficit can be expressed as (Beven, 1986):

$$S_i = \overline{S} + m\gamma - m \cdot \ln\left(\frac{A}{\tan\beta}\right)_i + m \cdot \ln\left(T_i\right) , \tag{5}$$

where $\overline{S}$ is the catchment average soil moisture deficit and γ is the weighted average of soil-topographic index defined by the equation:

$$\gamma = \frac{1}{A}\int_A \ln \frac{A_i}{T \tan \beta_i}\, dA \ . \qquad (6)$$

Equation (5) is applied at simulation of the saturated source areas distribution and the value of average soil moisture deficit is recalculated at each time step.

$$SBAR_t = SBAR_{t-1} + Qb - Qv \, . \qquad (7)$$

where *Qb* is value of subsurface flow into the river network at *t - 1* time step and *Qv* is sum of inflow from upper soil layers to groundwater level at *t - 1* time step summed over the whole catchment area.

Simulations were performed with daily time step. The minimum input data required at individual flood event simulation are precipitation and air temperature as well as the appropriate grid maps - digital elevation model, map of subcatchments (if any), map of zones (necessary for statistical analysis of output data), landuse map, map of soil types and map of topographic index. Maps of slope angles and aspect can be generated during model run but they may be prepared as input maps in order to accelerate calculation.

Long term water balance simulation or continual simulation including floods requires additional necessary data - air humidity, global radiation and/or sunshine duration and wind speed - and the appropriate interpolation routines.

3 Study site

The experimental research coupled with model simulations was performed Jalovecky creek catchment located in the northern part of Slovak Republic in the Západné Tatry (Western Tatra) mountains (Fig. 1). The Institute of Hydrology of the Slovak Academy of Sciences performs the hydrological research within the catchment since the year 1986.

The catchment area is 22.2 km2 . The average altitude is 1500 m a.s.l. while the lowest point altitude is 816 m a.s.l. and the highest is 2178 m a.s.l.. The average slope angle is 30°. Nearly 20% of slopes are oriented to south-west and only 5% is north oriented. The climate in the study catchment is cool, temperature continental

The geology of the region consists mostly of metamorphic crystalline rocks (gneiss, migmatites) representing about 48% catchment area. Other components of the crystalline complex are granodiorites (21% of the area). Small part of the catchment (7%), representing the ridge line in the west, consists of Mesozoic rocks (predominantly dolomite and limestone). Relief was shaped mainly by the activity of Pleistocene glaciers resulting in formation of glaciofluvial sediments representing about 24% of catchment area together with alluvial sediments in bottom parts.

Soil cover is characteristic by vertical zonality similar to that of relief, climate and vegetation. Vertical zonalitycan be expressed by the regular series of cambisols, podzols, ranker and lithosol on silicate rocks. The rendzina soils occur in the areas on the Mesozoic carbonate rocks. All the soils are characteristic by the great content of skeleton (> 2 mm) often reaching 40 - 50% or more. Soil depth and layering in the experimental basin was surveyed by geoelectric vertical sounding compared to test pits. The thickness of the main series is about 80 - 125 cm in the middle altitude zone, 70 - 80 cm in lower altitudes and 55 - 65 cm in the upper parts. According to the hydropedological regime all the soils in Jalovecky creek basin belong to the seepage type with good permeability.

Vegetation cover is characterised by spruce dominated forests (44.1%), dwarf pine (31.3%) and alpine meadows (24.6%). Since 1978 the Western Tatra mountains are included into the Tatra National Park. Therefore nearly all the negative human activities were eliminated.

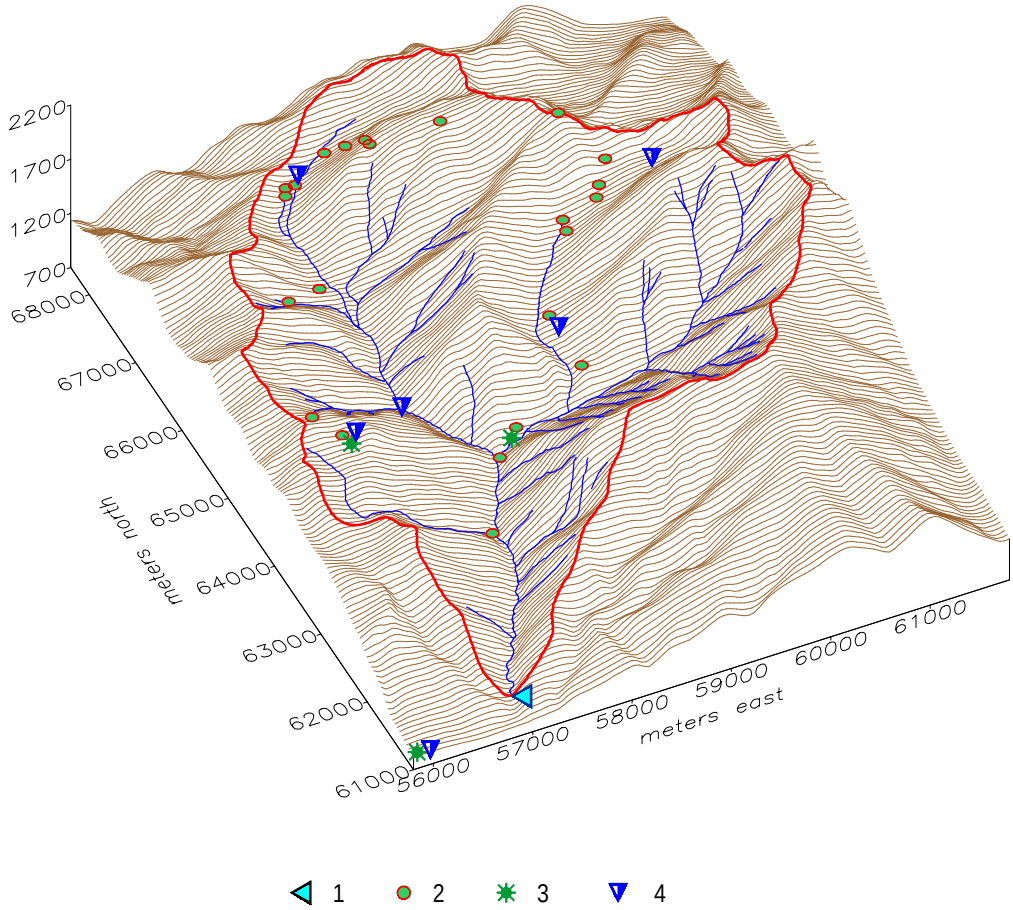


Fig. 1 Relief of the mountain part of Jalovecký potok creek catchment with location of measuring sites (1 - water level gauge, 2 - soil moisture measuring sites 3 - meteorological stations, 4 - storage rain gauges)

4 Calibration and validation results

Model simulations are based on the input air temperature data with daily time step from the stations Červenec (1500 m a.s.l.), Parichvost (1100 m a.s.l.), Priemstav (800 m a.sl.) and Ondrašová (570 m a.s.l.) (Fig. 1). The daily precipitation data were available from the stations Ondrašová and Červenec (only summer season) where also wind speed, air humidity and global radiation are measured.

During the model run the output files are created according to the specifications in the control file. Possible outputs are either grids describing the spatial distribution of fluxes or states accumulated or averaged over a given time period (e.g. snow storage in solid or liquid phase, intercepted water storage, water content within the root zone, water content within the unsaturated zone, soil moisture deficit, potential evapotranspiration, actual evapotranspiration) or statistical output files containing spatially averaged values of fluxes or storage contents as time series for the specified subbasins or zones.

The approach after Penman-Monteith was applied at potential evapotranspiration calculation. Snow accumulation and snowmelt were simulated with extended combination approach after Braun (1985) where melt is composed from radiation melt, melt by sensible heat, melt by latent heat and melt by import of energy by precipitation. The infiltration subroutine uses an approach after Green and Ampt

(1911). The modelling of the soil water balance and of runoff generation was done using a modified variable saturated area approach after Beven and Kirkby (1979) extended by capillary rise and interflow. The calculation was done separately for each of the grid cells opposed to the modelling of classes of topographic indices like in the original TOPMODEL. The base for the model is the spatial distribution of the topographic index. Using this index, the potential extent of saturation areas can be estimated depending on the mean saturation deficit within the basin.

Model calculations were calibrated against field measurements of total discharge at the catchment outlet (Fig. 2). In order to evaluate the performance of the model several of performance criteria were calculated. Another criterion used was the Nash-Sutcliffe criterion specially developed for evaluation of measured and modelled hydrological data time sets that is able to eliminate the impact of systematic shifts of the data along the *y*-axis. Soil moisture measurements and snow water equivalent measurements at several sites in the experimental catchment were compared to the corresponding simulated grids (Fig. 2, Fig. 3).

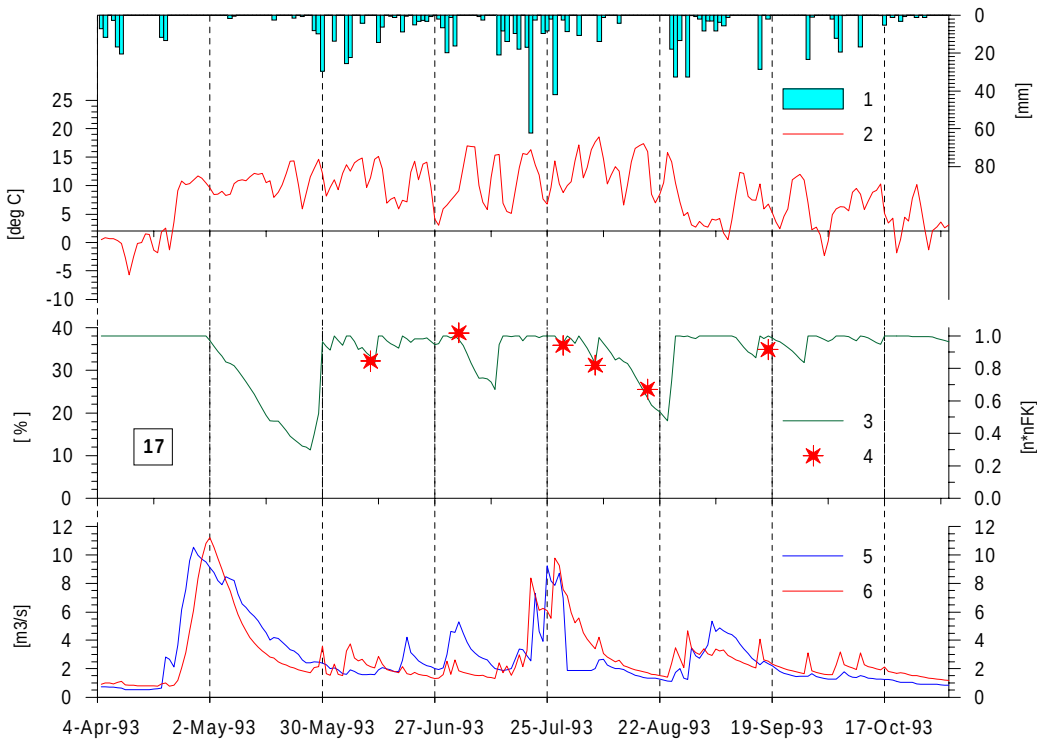


Fig. 2 Results of simulation of average daily values of soil moisture at study site number 17 at the altitude of 1500 m a.s.l. and simulations of total runoff from Jalovecký creek catchment for the hydrological year 1993 (1 - catchment daily totals of precipitation, 2 - average daily temperature, 3 - simulated soil moisture, 4 - measured soil moisture, 5 - measured daily runoff, 6 - simulated daily runoff)

Hydrological model uses several parameters and their number increases with the number of applied subroutines and subtlety of physical processes simulation. The importance of individual parameters at model simulations varies. The parameter sensitivity analysis was performed to find the most important parameters for the results of hydrological processes modelling.

Based on the analysis the following parameters seem to have the greatest influence on simulated hydrological components

- parameters of evapotranspiration calculation (surface resistance of vegetation cover r_s)

- parameters of the interception model (vegetation coverage degree, leaf area index, maximum interception capacity)
- parameters of TOPMODEL subroutine (recession parameter *m*, correction factor for the transmissivity of the soil T_{corr}, correction factor for vertical percolation K_{corr})
- parameters of snow accumulation and snowmelt (threshold temperature between snowfall and rain, temperature-transition range from snow to rain, temperature for beginning of snow melt and degree-day factor).

WaSiM-ETH model simulation using TOPMODEL principle needs preferred calibration of recession parameter *m*, correction factor for the transmissivity of the soil T_{corr} . The initial values of parameters may be estimated from hydrograph analysis or adapted from the simulations for similar catchment.

The simulations in this study consider also the interflow component. Therefore the number of runoff components was increased from two to three. At that case the recession parameter *m* affects only base flow that is much less dynamic than the compound base flow and interflow controlled jointly by this parameter before. The correct values of both the recession parameter and transmissivity correction factor need to be calibrated again after including interflow component because these parameters are interdependent.. The average value of *m* parameter was 0.72 for the year 1992 and 0.48 for the year 1993. The corresponding coefficient T_{corr} were 0.00045 and 0.00005.

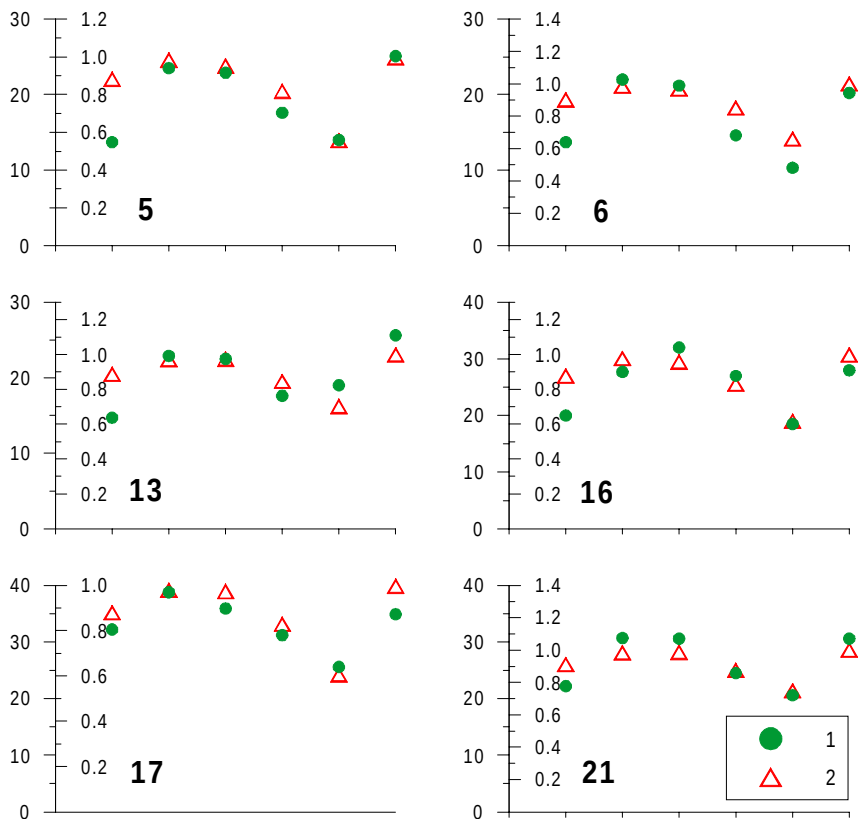
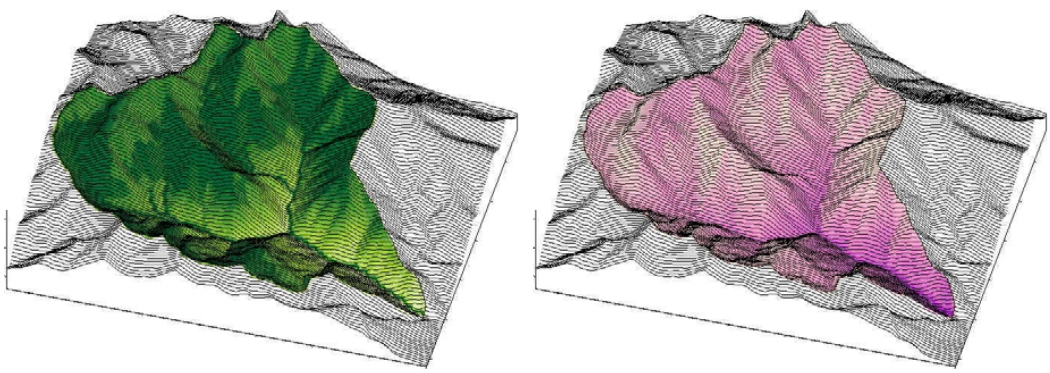


Fig. 3 Comparison of simulation results for the average daily values of soil moisture at the monitored sites No. 5, 6, 13, 16, 17 a 21 for hydrological year 1993 (1 - measured soil moisture, 2 - simulated soil moisture; horizontal axis - measurements in days 9.6., 1.7., 27.7., 4.8., 17.8., 16.9.1993; left vertical axis - values of measured soil moisture in percent; right vertical axis - simulated soil water content expressed as the relative value to the soil water content at field capacity)

5 Results

Dynamic simulations by means of distributed hydrological model provide realistic results. Besides the influence of environment characteristics the influence of spatial and altitudinal distribution of meteorological factors starts to demonstrate markedly in the mountain catchments. The spatial distribution pattern of soil water content is significantly influenced by the distribution of evapotranspiration and its components besides the decrease of soil water due to faster movement within the soil layers. Spatial distribution of actual evapotranspiration is displayed in Fig. 4 (part 2). The influence of vegetation cover is evident (higher evapotranspiration values within the forested parts of catchment) as well as influence of vertical gradient of air temperature (greater evapotranspiration at lover parts of catchments). Higher values of evapotranspiration from forest cover are caused mainly by higher transpiration of spruce forest compared to dwarf pine and even grassland. Moreover the influence of interception demonstrates in the forest both during summer and winter season.

The incorporation of terrain shadowing of individual elementary cells of catchment area grid into the distributed model calculations enabled even more realistic pattern of distribution due to the corrections of incoming solar energy and air temperature. The three-dimensional image (Fig. 4) represents also the evident differences between the actual evapotranspiration or soil moisture at north and south oriented slopes.



1 2

Fig. 4 Comparison of the spatial distribution of annual average soil moisture (1) and actual evapotranspiration (2) influenced by the relief of Jalovecky creek catchment (lighter colours - lower values).

6 Summary and conclusions

The WaSiM-ETH model simulation analysis proved the suitability of topography analysis based semi-distributed model for modelling of spatially distributed pattern of soil moisture and evapotranspiration in mountain catchments with great height amplitudes provided the use of suitable sophisticated algorithms for simulation of processes above soil surface. Both hydrological model and field measurements confirmed the substantial influence of relief and vegetation cover on total evapotranspiration as well as on spatial distribution of hydrological components (soil moisture, evapotranspiration components, snow cover). Vegetation cover, that could be subject of change due to global changes, can demonstrate to be the dominant agent affecting the hydrological response of mountain catchment.

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Variation in Daily Extreme Precipitation in the Lower Danube Basin

Loutchian Krastev, Ekaterina Koleva

Abstract: In this study an examination of number of days with precipitation above 20 mm is made. Database consists of the daily precipitation for the period 1931-1999 for five climatological stations. The number of days with precipitation above 20 mm, 30 mm and 50 mm are calculated. The distribution of annual and summer maximim daily precipitation is investigated. To analysed variations and tendency in extreme precipitation statistical methods are used.

Key words: day precipitation, extreme value analysis, mathematical statistic.

Schwankungen der täglichen Extremniederschläge im Bereich des unteren Donaubecken

Zusammenfassung: In der Studie werden die täglichen Niederschläge größer als 20 mm untersucht. Es wurden Daten der täglichen Niederschläge von fünf Klimastationen für den Zeitraum 1931 – 1999 ausgewertet. Die Anzahl der Tage mit Niederschlägen von über 20 mm, 30 mm und 50 mm wurden bestimmt. Die Verteilung der täglichen Extremniederschläge bezogen auf das Jahr als auch auf das Sommerhalbjahr wurden untersucht. Mit Hilfe von statistischen Methoden wurden die Schwankungen und Tendenzen in der Änderung der extremen Niederschläge analysiert.

Schlüsselworte: täglicher Niederschlag, Extremwertanalyse, mathematische Statistik.

Introduction

Recent climatological studies on the variability of various meteorological elements, particularly temperature and precipitation, have emphasized regional characteristics of their evolution, not always in good agreement with the global results on climate changes. In the last decades, the cumulative effects of the lack of precipitation and the increasing temperature have affected extended areas of the Danube Plain and caused considerable damages to the agriculture. This paper deals with the analysis of the extreme precipitation in the lower basin of Danube at representative Bulgarian stations.

There is much uncertainty about increase or decrease of extreme events due to an artificially enhanced greenhouse effect (Auer, 1995). In the case of precipitation one assumption is that a warmer atmosphere should contain more water and by that an increase of extreme precipitation should follow, sometimes including simultaneously the intensification of dry spells.

One of the main features of the climate in the Danube Plain is insufficient precipitation - a tendency toward dryness and frequent droughts. The annual amount of precipitation is 500-600 mm. The highest monthly values are measured in June (in some places in May), with 55-75mm. In recent years drier than normal conditions persisted throughout the entire region of the lower part of the Danube Basin.

Extreme precipitation can occur in any month, but the probability of this happening in the warm half year is higher. The term heavy precipitation is used when the daily rainfall is above 20 mm.

Besides the change of the average values very important is the change of frequencies of the heavy precipitation. Generally, the extreme meteorological events are risk factors, and the changes of their frequencies must be taken into account either during durable climate variability

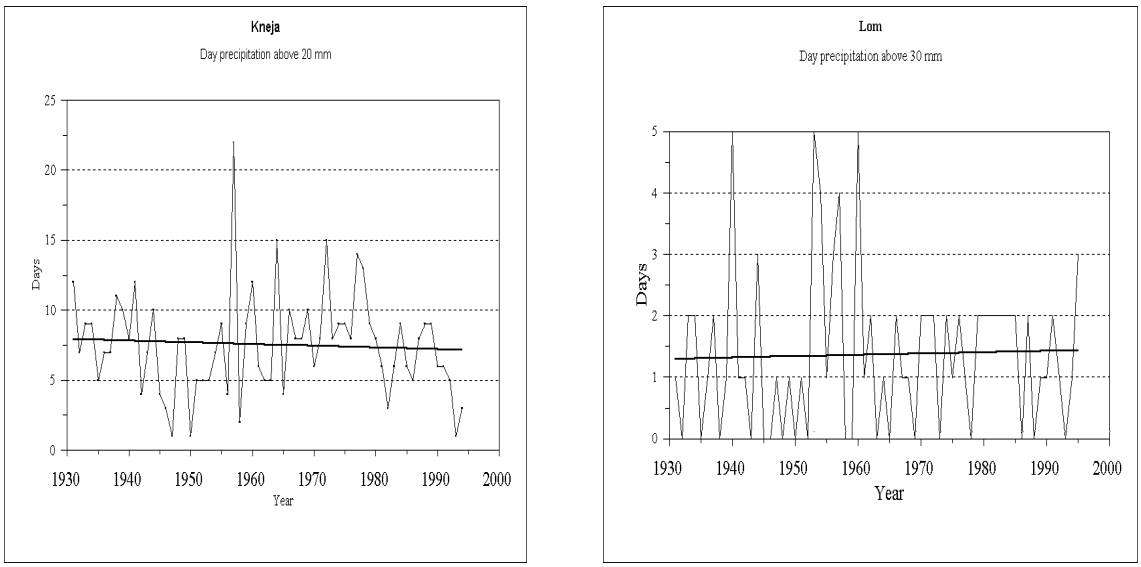
or during the climate change. These changes can be the consequences and the indicators of the global change.

This study presents an examination of the annual and summer maximim of the day precipitation and number of days with precipitation above 20 mm. Data base consists of the day precipitation for the period 1931-1999.

Principal results

It is worth noting that there is some difference in regional distribution of the heavy precipitation. In the western part of the region the annual number of days with heavy precipitation is smaller than in the eastern one. About 35 % of these cases occur in June-August, and 70-80 % in warmer half of the year. In winter the occurrences of days with precipitation above 20 mm are the smallest and are about 20 %. Most frequent is the occurrence of such precipitation in June. From a comparison of occurrence frequencies in other months it follow that the July occurrence is more frequent than the august one, and the October one is also more frequent than those in September.

The linear trend analyses for the annual number of days with precipitation bigger than 20 and 30 mm do not show statistically significant trends during the last decades (Fig. 1). The same



tendency exists in the summer season.

Fig. 1 Annual number of days with heavy precipitation

The comparison between the number of days with extreme precipitation in the last 30-year period (1961-1990) and the previous one (1931-1960) shows that annual distribution of occurrence of such precipitation are different (fig. 2).

The occurrences of days > 50 mm are very rarely. It happened mainly in summer. In recent years such cases are not observed. It can be said that the occurrence of days with high precipitation does not show a decrease, which would exceed the natural climate variability.

In order to characterise the time variation of maximum annual daily precipitation in the period 1931-1999, deviations from the mean value were calculated. These deviations were smoothed by 10-years moving average and represented graphically (Fig.3). A slight decreasing trend is present. It is interesting to note, that the positive deviations from the mean are greater then the negative ones (Fig. 3).

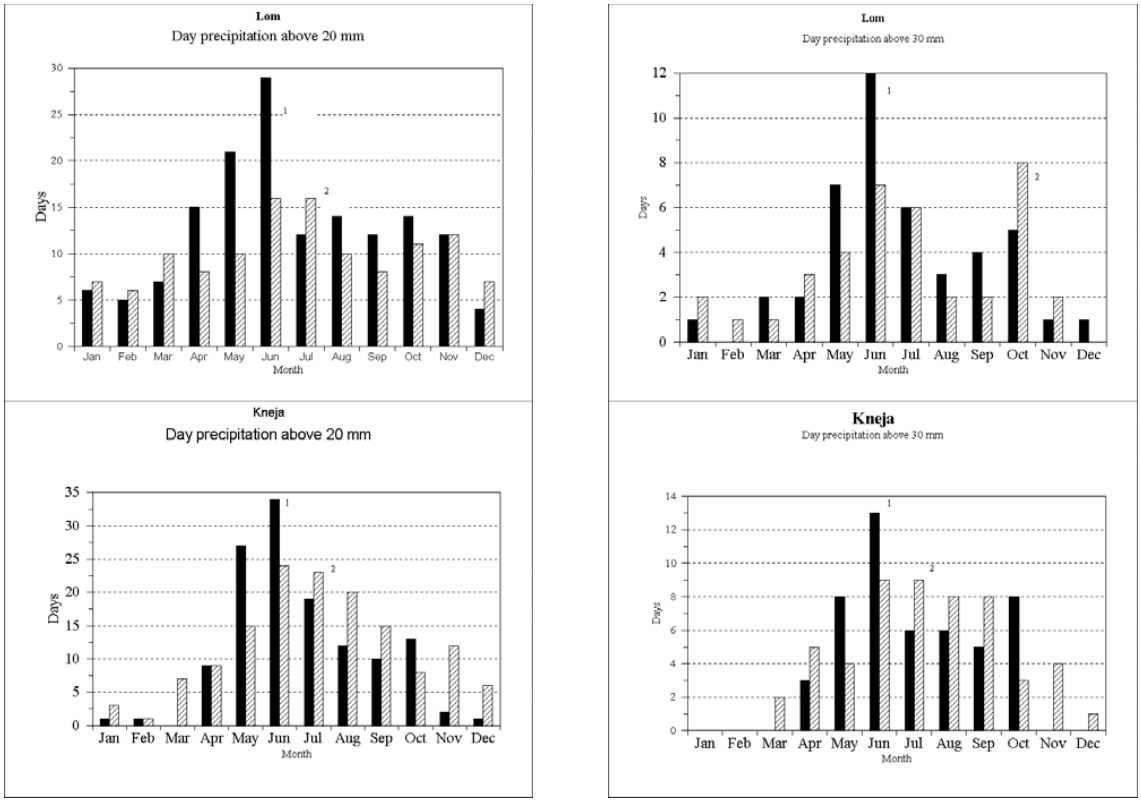


Fig. 2 Frequencies of monthly occurrence of days with precipitation above 20mm and 30 mm for the periods 1931 – 1960 (1) and 1961 – 1990 (2).

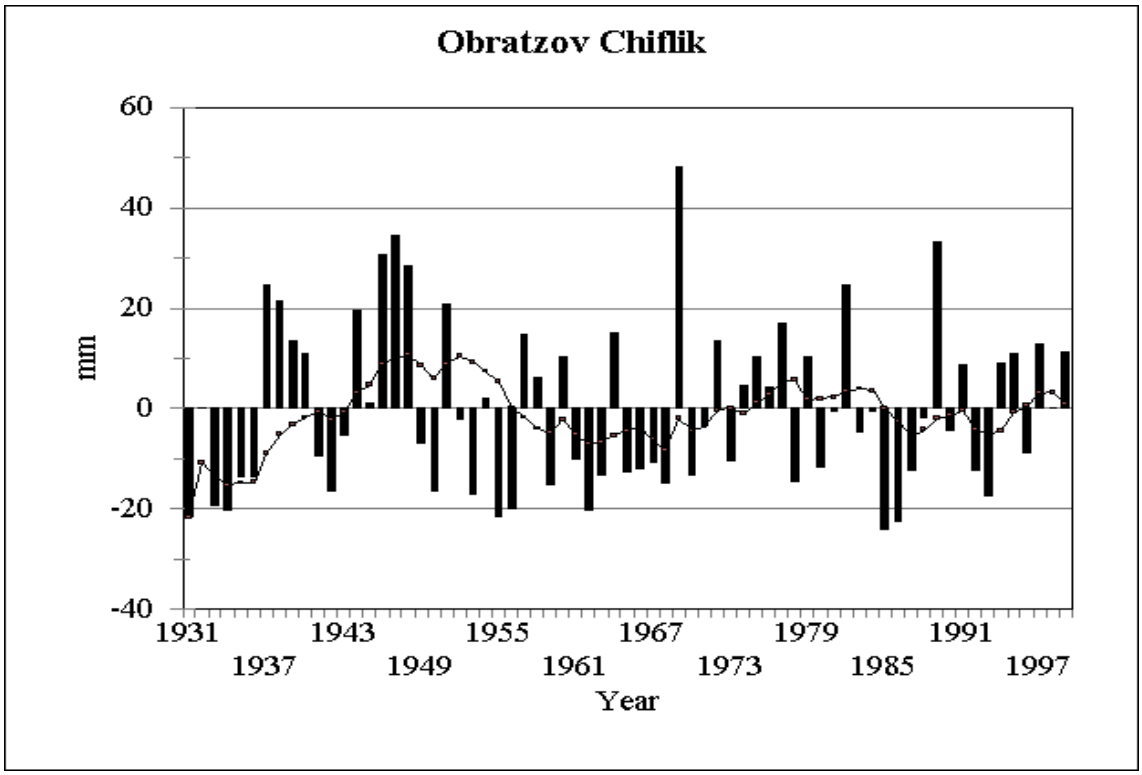


Fig. 3 Deviation of the maximum day precipitation from the 1931 – 1999 average and 10-year moving average.

Conclusion.

On the base of statistical methods of extreme values analysis the reduced values and empirical probabilities were computed (Fig. 4). Probability of maximum annual day precipitation under 32 mm is equal to zero and the probability of being below 90 is 1.

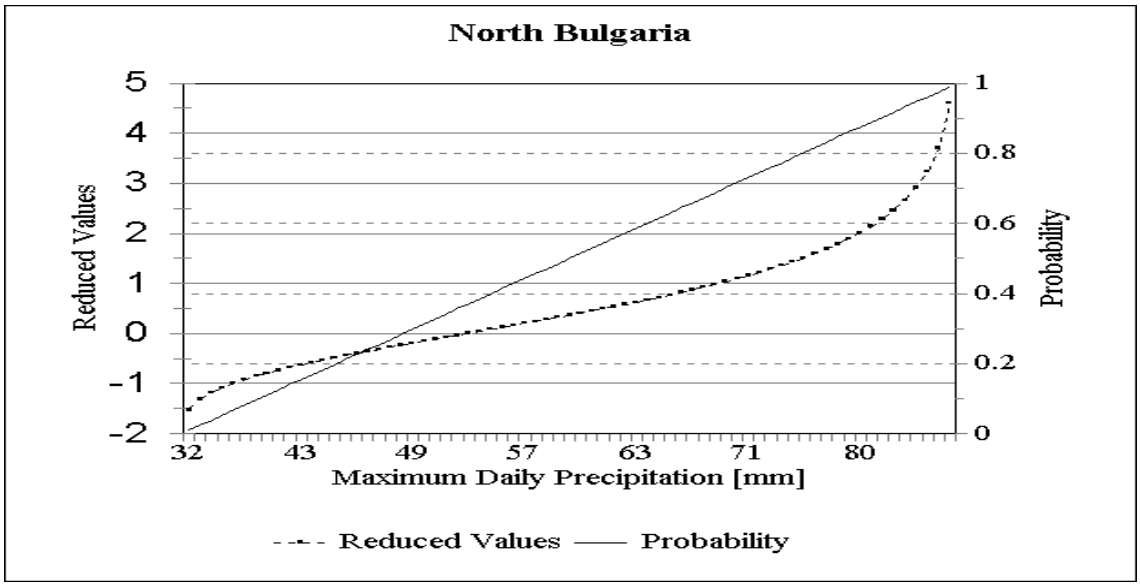


Fig. 4 Empirical probability and reduced values of the precipitation for the period 1931 – 1999.

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Snowmelt Runoff Simulation for the Upper Hron Basin

Daniela Kyselová, Kateřina Hrušková, Juraj Parajka

Abstract: This study was focused on performance of the degree-day SRM model for the snowmelt runoff simulation. The model was applied for the Upper Hron basin, middle Slovakia. Different snowmelt conditions were simulated, including normal, wet and relatively dry snowmelt seasons. Input data and parameters were selected and derived with GIS tools. The snow depletion curve, one of the most important input parameter, was constructed using data from regular snow observations at meteorological stations. The accuracy of simulations was verified by the Nash-Sutcliff coefficient and by the coefficient characterising proportion between the total measured and simulated runoff volumes. Results show that GIS methods could be very helpful for the determination of input data and model parameters. Modelling results indicate that SRM model can be successfully used for snowmelt runoff simulations in the Upper Hron basin.

Key words: Snowmelt runoff modeling, Upper Hron basin, SRM model.

Schneeschmelz-Abfluss-Modellierung im Einzugsgebiet des Hron

Zusammenfassung: Die Schneeschmelze ist ein wichtiger Bestandteil des Wasserkreislaufes in vielen Regionen der Welt. Es werden verschiedene Modelle benutzt, um die Schneeschmelze besser vorherzusagen oder zu simulieren.

In diesem Beitrag wird das Tagestemperaturen-SRM-Modell für die Schneeschmelz-Abfluss-Modellierung vorgestellt. Das Modell SRM wurde im Einzugsgebiet des Oberlaufes des Hron getestet. Verschiedene Bedingungen für die Schneeschmelze wurden untersucht, für eine normale, feuchte und relativ trockene Wintersaison. Eingabedaten und Parameter wurden mit Hilfe von GIS ausgewählt und abgeleitet. Die Konstruktion der Schneeschmelzkurve, des wichtigsten Modellparameters, wird diskutiert. Die Genauigkeit der Modellierung wurde mit Hilfe des Nash–Sutcliff-Koeffizienten und mit dem Koeffizienten der Volumendifferenz überprüft.

Schlüsselworte: Schneeschmelz-Abfluss-Modellierung, Parameterverifizierung, Einzugsgebiet des Oberlaufes des Hron, SRM-Modell.

Introduction

Snowmelt is a significant component of hydrological cycle in mountainous regions. In order to estimate this resource better, different types of models are applied for snowmelt runoff simulation and forecasting, ranging from relative simple degree-day to complex energy balance models. Operational hydrology prefers models, which are relatively simple, without high demand on input data, time-consuming calibration or simulation. Snowmelt Runoff Model (SRM, Martinec, et al., 1998) also falls into the category of models that fulfill these requirements.

This paper is focused on performance of the SRM model in the snowmelt runoff simulations in the upper Hron basin. The results from preliminary study (Parajka, 1999), which was directed to the determination and selection of appropriate input data and model parameters have shown that SRM could be successfully used for the snowmelt runoff simulations. The comparison of observed and computed runoff indicated that the best results were achieved for the upper Hron basin considered as 1 zone.

The main goal of this study is to simulate runoff in different snowmelt conditions (1993-97), including normal, wet and relatively dry snowmelt seasons. Model parameters were determined for hydrologic year 1995 (Parajka, 1999) and then applied for all snowmelt seasons.

SRM model structure

According to the classifications applied in the WMO report on hydrological models (Becker, Serban, 1990), SRM is categorized as deterministic, conceptual, distributed and physically based model. It can be transferred geographically and climatically, and the model parameters can be derived from assessable basin characteristics (Rango, 1992).

SRM is designed to simulate and forecast daily streamflow in mountain basins where snowmelt is a major runoff factor. Model uses a degree-day approach (Martinec et al., 1998):

$$Q_{n+1} = \left[c_{Sn} * a_n * (T_n + \Delta T_n) * S_n + c_{Rn} * P_n\right] * \frac{A * 10000}{86400} * (1 - k_{n+1}) + Q_n * k_{n+1}$$

where :

Q = average daily discharge [$m^3.s^{-1}$]; c = runoff coefficient expressing the losses as a ratio (runoff/precipitation), with c_S referring to snowmelt and c_R to rain; a = degree-day factor [$cm.°C^{-1}.day^{-1}$] indicating the snowmelt depth resulting from 1 degree-day; T = number of degree-days above the base of 0 °C [°C.day]; ΔT = the adjustment by temperature lapse rate when extrapolating the temperature from the station to the average hypsometric elevation of the basin or zone [°C.day]; S = ratio of the snow covered area to the total area of the basin; P = precipitation contributing to runoff [cm]. A preselected threshold temperature, T_{CRIT}, determines whether this contribution is rainfall and immediate. If precipitation is determined by T_{CRIT} to be new snow, it is kept on storage over hitherto snow free area until melting conditions occur; A =area of the basin [km^2]; 10000/86400 = conversion from $cm.km^2.d^{-1}$ to $m^3.s^{-1}$; k = recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall: $k=Q_{m+1}/Q_m$ (m, m+1 are sequence of days during a true recession flow period). Recession coefficient k is not a constant, but increases with the decreasing Q according to the equation $k_{n+1} = x * Q_n^{-y}$, where x and y must be determined for a given basin; n = sequence of days during the discharge computation period. Model equation is written for a time lag between the daily temperature cycle and the resulting discharge cycle of 18 hours. In this case, the number of degree-days measured on the nth day corresponds to the discharge on the n+1 day.

Precipitation P, temperature T and snow covered area S are variables to be measured or estimated each day. As with other models, SRM requires the measurement or estimate of certain parameters – k, c_R, c_S, lapse rate (γ) for the determination of ΔT and T_{CRIT} , mean hypsometric elevation of the basin and lag time (L). Runoff data are not required as input to SRM, but actual streamflow observations are used to compare the simulated hydrograph to the actual hydrograph (Rango, 1992). In the forecasting mode, updating by actual measured discharge could be used to improve the runoff simulation.

Assessment of the model accuracy

In the past, the SRM model was applied in basins representing a wide range of climatic and physiographic conditions. Because the model parameters are pre-selected on a physical basis depending on the specific time and place of application rather than determined by computer optimization techniques, an adequate simulation of runoff may be considered as a verification of pre-selected values (Martinec, Rango, 1986).

The accuracy of such simulation was characterized (Nash, Sutcliffe, 1970) by:

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (Q_i - Q_j)^2}{\sum_{i=1}^{n} (Q_i - Q_{avg})^2} \quad \text{and} \quad D_V = \frac{V_M - V_S}{V_M} * 100$$

where:

R^2 is a measure of model efficiency
Q_i is the measured daily discharge
Q_j is the computed daily discharge
Q_{avg} is the average measured discharge of the given year or snowmelt season
n is the number of daily discharge values
D_V is percentage difference between the total measured and simulated runoff [%]
V_M is measured runoff volume
V_S is simulated runoff volume

The R^2 value indicates the variations in daily flows, seasonal variation is expressed by the D_V coefficient.

Data

The upper Hron basin (490 – 1946 m. a. s. l., 582 km2) is situated in central mountainous part of Slovakia. Input precipitation and snow cover data were obtained from seven meteorological stations: Brezno, Benuš, Polomka, Pohronská Polhora, Pohorelá, Šumiac and Telgárt. Additional snow cover data from Chopok station were used for the construction of snow depletion curves. Chopok station is located outside the upper Hron basin, but at elevation of 2005 m.a.s.l., which could with some approximation represent snow coverage changes at maximum elevations of the basin. Temperature measurements were available at two meteorological stations: Brezno and Telgárt. Topography of the upper Hron basin has been represented by digital elevation model (DEM) with resolution 100x100 meters. DEM was used for the computations of mean hyspometric elevation of the basin, as well as a guide for the determination of seasonal snow cover curves. In order to compare the simulated hydrograph to actual hydrograph, runoff measurements from Brezno streamgauge were used. Locations of selected measurement stations and DEM are presented in Figure 1.

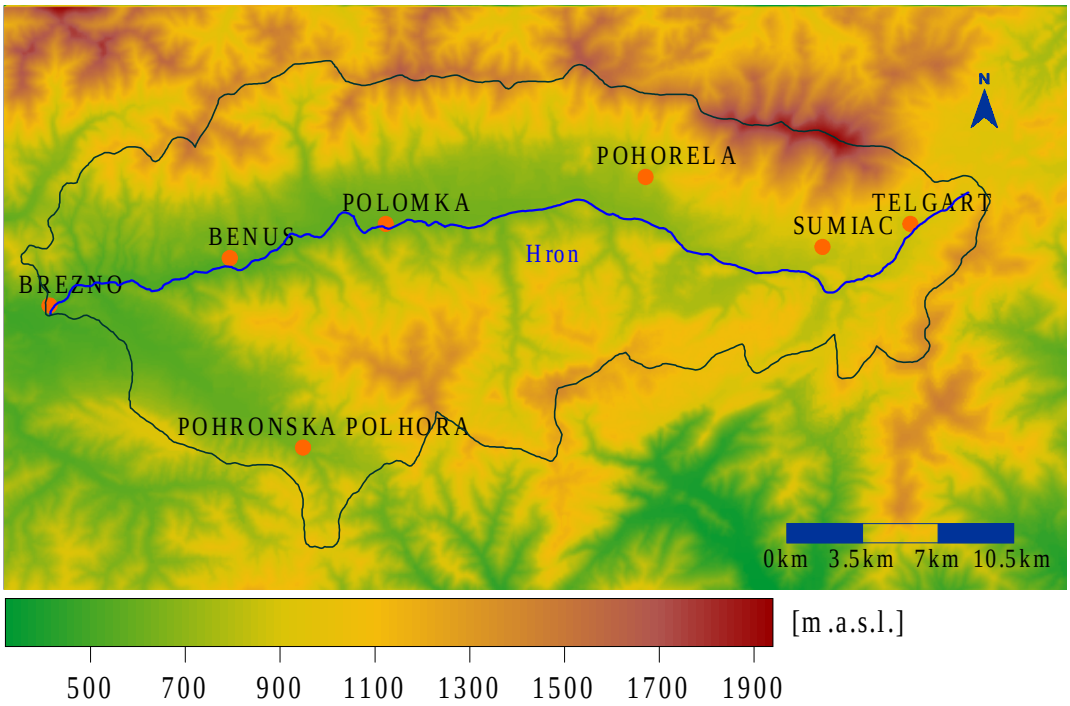

Fig. 1 Topography and location of measurement stations in the upper Hron basin

For the snowmelt runoff simulations in the upper Hron basin, data from snowmelt seasons 1993-97 were used. The years 1993-97 represent different snowmelt conditions, including normal, wet and relatively dry snowmelt periods. The monthly runoff volumes of particular snowmelt seasons and their percentage from the long-term mean monthly runoff volume are listed in Table 1.

Table 1 Comparison of monthly runoff volumes of selected snowmelt seasons and the long-term mean monthly runoff volumes from period 1931-80.

Runoff volumes [1000 000 m^3]	March	April	May	Σ
1931-80	28.5	41.9	32.9	103.3
1993	11.5	12.6	10.9	35.0
% of 1931-80	40.3	30.1	33.2	33.9
1994	36.5	85.6	31.1	153.2
% of 1931-80	128.2	204.1	94.7	148.3
1995	34.3	34.0	44.5	112.8
% of 1931-80	120.6	81.0	135.2	109.2
1996	10.3	41.8	60.1	112.2
% of 1931-80	36.1	99.7	182.8	108.6
1997	10.8	10.5	16.6	37.9
% of 1931-80	37.8	25.1	50.3	36.6

Sums of seasonal runoff volumes showed that snowmelt seasons 1995 and 1996 corresponded to normal snowmelt periods, seasons 1993 and 1997 represented dry and season 1994 wet snowmelt periods.

Results

Geographical analysis of the upper Hron basin has shown that meteorological station Telgart is situated nearby mean elevation of the basin. Precipitation and temperature data from this station were thus selected as inputs to the model. Snow depletion curves were evaluated by an approach presented in Parajka (1999). This approach uses daily observations of snow depth at eight meteorological stations and hypsometric curve of the basin. Changes in snow depth at meteorological station are considered as changes in snow depth at elevations represented by this meteorological station. Snow depletion curves constructed for snowmelt seasons 1993-97 are presented in Figure 2.

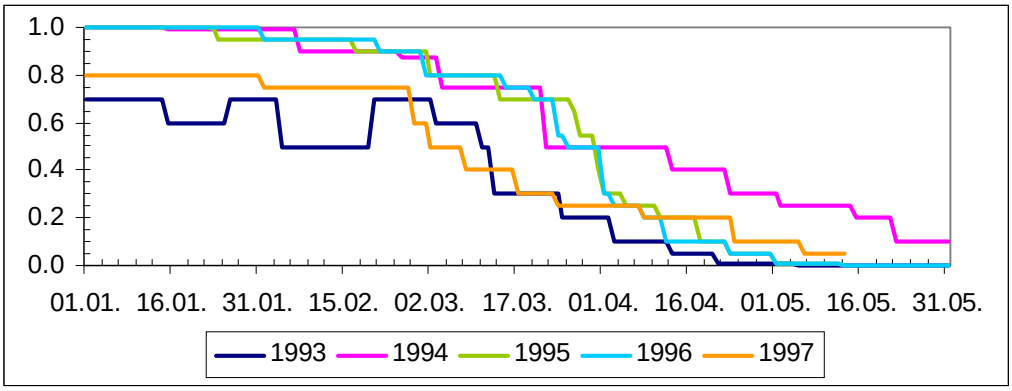

Fig. 2 Snow depletion curves for particular snowmelt seasons

The model parameters used in this study were determined for snowmelt season 1995. The same parameters (listed in Table 1) were then used for simulations in all snowmelt seasons.

Table 1 SRM model parameters used for simulation

	a	c_s	c_r	G	T_{CRIT}	L
January	0.3	0.95	0.95	0.67	2.0	10
February	0.3	0.95	0.95	0.67	2.0	10
March	0.3	0.85/0.7	0.85/0.7	0.67	2.0	10
April	0.3	0.6/0.55	0.6	0.67	2.0	10
May	0.35/0.4	0.7	0.5	0.67	1.0	10

Simulations of snowmelt runoff for snowmelt seasons 1993-97 in the upper Hron basin are presented in Figure 3. Accuracy of each simulation, characterized by R^2 and D_V coefficients, is documented in Table 2.

Table 2 Assessment of SRM model accuracy for different snowmelt seasons

	1993	1994	1995	1996	1997	1993-97
R^2	-0.6042	0.9375	0.9015	0.8775	0.5886	0.9170
D_v [%]	-2.032	-10.14	-0.255	-6.794	3.366	-4.614

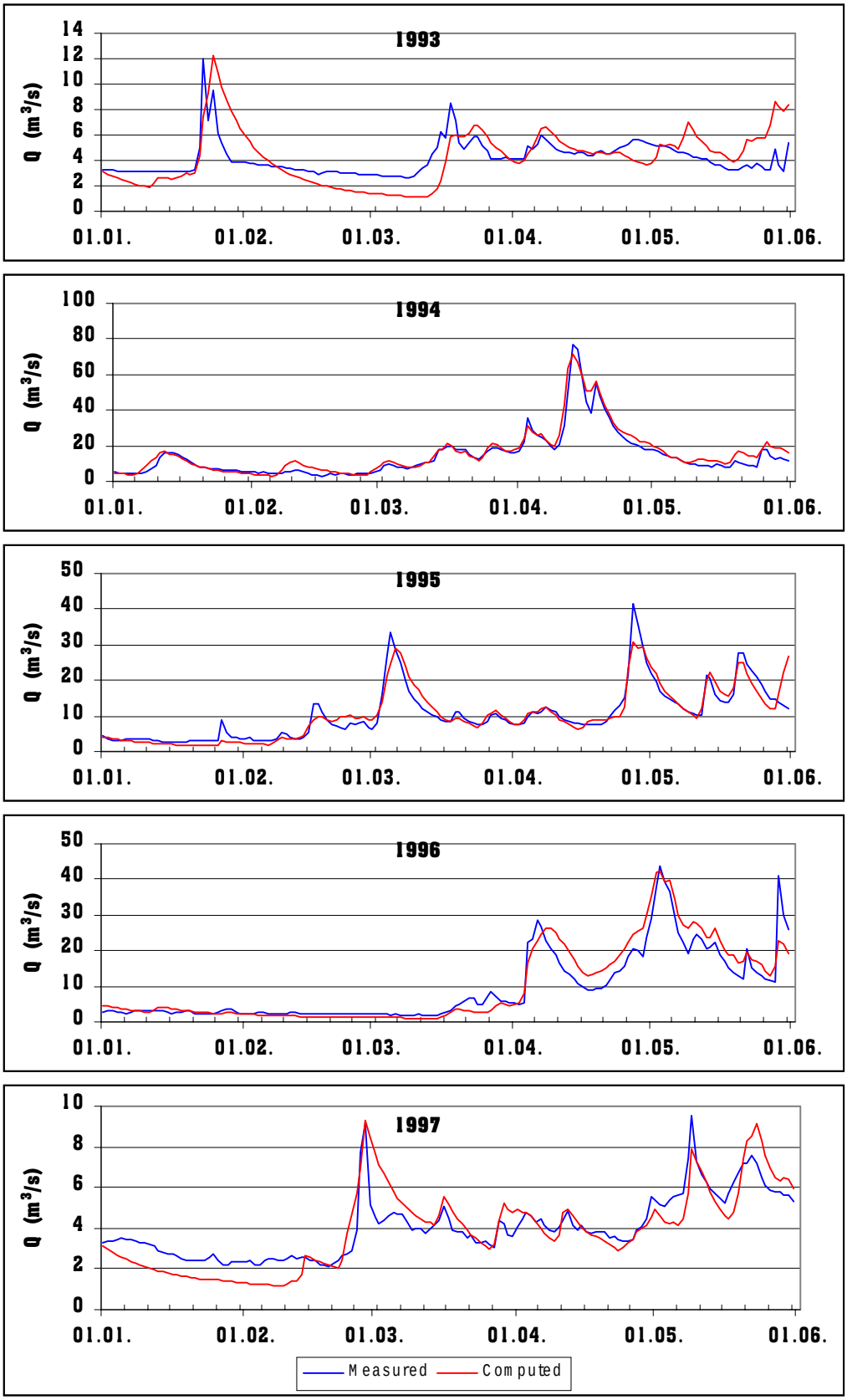

Fig. 3 Snowmelt runoff simulation for 1993 – 1997 snowmelt seasons in the upper Hron basin

Statistics (Table 2) computed for all snowmelt seasons (1993-1997) demonstrated that SRM simulations gave in general satisfactory results. Visual and statistical comparison between observed and computed runoff for particular snowmelt seasons has shown that the best simulation was achieved for wet snowmelt season 1994. Good results were also obtained for normal snowmelt seasons 1995 and 1996. The highest differences were observed for relatively dry snowmelt periods (years 1993 and 1997). Model parameters should be revised for these periods, especially the recession coefficients.

Conclusions

This paper reviews results of snowmelt runoff simulations in the upper Hron basin. More than 50% of annual peak discharges observed in this basin occurred during snowmelt periods. Snowmelt events have larger volumes, longer duration than rainfall events and are more difficult to simulate or forecast.

The effort of this study was directed to snowmelt simulations in the upper Hron basin for different snowmelt conditions, including normal, wet and relatively dry snowmelt seasons (1993-97). SRM input data and parameters were selected and derived using GIS tools. Model parameters were determined for hydrologic year 1995 and then applied for simulations for all snowmelt seasons. The snow depletion curves for particular snowmelt seasons were constructed using data from regular snow observations at meteorological stations. Comparison between observed and computed snowmelt runoff has shown that SRM could be used for snowmelt runoff simulation in the upper Hron basin. Plans to the future are directed to applying the SRM in operational hydrology for forecasting of snowmelt events in the upper Hron basin.

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Using Different Soft-Computing Techniques to Improve the Modelling of Extreme Rainfall-Runoff Events

Nils Thorsten Lange, Leonie Jaeschke

Abstract: Data from the Jalovecký Creek catchment situated in the northern part of Slovakia are used in this study of soft-computing techniques in hydrology. It is shown that a neural network can learn the rainfall-runoff response characteristics of the selected mountainous catchment. Additionally fuzzy logic concepts are integrated to support the advanced handling of model input parameters. This is another example of a fuzzy logic and neural networks combination which is proofing the capability of soft-computing in hydrology modelling.

Key words: rainfall-runoff modelling, neural network, fuzzy logic, soft-computing.

Anwendung verschiedener Methoden des Soft-Computings zur Verbesserung der Modellierung von extremen Niederschlag - Abfluss - Ereignissen

Zusammenfassung: Daten des Jalovecký Einzugsgebietes im Norden der Slowakei wurden in dieser Studie über Soft-Computing Methoden in der Hydrologie verwendet. Es wird gezeigt, dass ein neuronales Netz die Niederschlags-Abfluss Eigenschaften dieses gebirgigen Einzugsgebiets lernen kann. Zusätzlich werde Konzepte der Fuzzy Logik angewendet, um Eingangsparameters dieses Modellansatzes besser zu verarbeiten. Dies ist ein weiteres Beispiel einer Kombination von Fuzzy Logik und neuronaler Netze, welches die Eignung der Anwendung von Soft- Computing Methoden in der Hydrologie beweist.

Schlüsselworte: Niederschlag - Abfluss Modellierung, Neuronale Netze, Fuzzy Logik, Soft-Computing Methoden.

1 Introduction

Soft-computing techniques are describing methods like fuzzy logic, neural networks and genetic algorithms in various applications. This paper is concentrating on neural networks and fuzzy logic in the application of hydrological rainfall-runoff modelling. The capability of neural network learning of relations between input parameters and output parameters is used to set up a neural network as hydrological black box model learning the catchment response within the mountainous Jalovecký Creek catchment. The fuzzy logic is used in this study to estimate one input parameter which is not measured directly by a logical combination of two measured parameters. This study has two main objectives, first the application of soft-computing in hydrological modelling and second the determination of improvements by the combination of fuzzy logic and neural network techniques. Because the availability of data is always a topic of rainfall-runoff modelling this approach should lead to methods which are robust and able to deal with poor data situations.

2 Artificial Neural Networks

The artificial neural network is a very simplified mathematical method describing the learning process of human brains. In this study a neural network simulator named Neural Dragon is used (Lange, N. 2000). So in this section the mathematical basics of this simulator is described very shortly. The neural network is a black box model which is learning the relation from the input to the output by training of various input and output pattern. The knowledge of the neural network is stored by weights which are between the different layers. Each connection between a single neurone is represented by a weight.

In figure 1 the basic structure of a neural network is displayed. The neural network has always one input layer and one output layer. In each layer there a specific number of neurons. The number of hidden layers is not limited. In this study the neural network has one hidden layer.

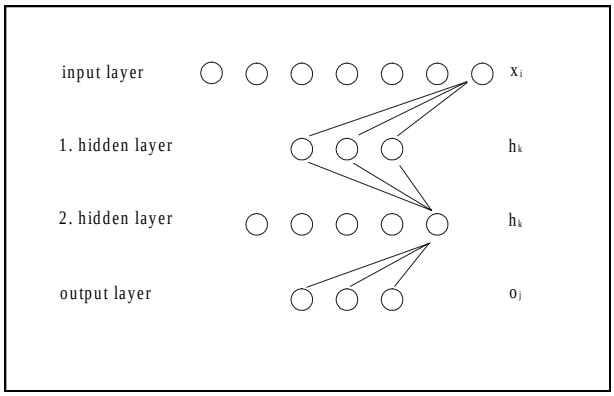

Fig. 1 The basic structure of a neural network

In Formula 1 the activation function is presented. The activation function is responsible for the transmitting of the "signal" from one weight of a neurone to the weight of a neurone in the next layer. In this case it is the logistic function. The results of this function is in a range between 0 and 1.

$$f_{\log}(x) = \frac{1}{1+e^{-g*x}} \qquad (1)$$

Because of the limitation of the range 0 and 1 of the activation function all input values has to be standardised. Formula 2 shows this standardisation.

$$f_{st}(x) = \frac{(x - Min\_x_i)}{(Max\_x_i - Min\_x_i)} * 0.985 + 0.005 \qquad (2)$$

where Min_x_i = minimum of all x values; Max_x_i = maximum of all x values.

$$f(x) = \frac{(x_{st} - 0.005)}{0.985} * (Max\_x_i - Min\_x_i) + Min\_x_i \qquad (3)$$

where x_{st} = value of standardised x in the interval of [0.005; 0.99].

After calculating the network output the results have to transfer backwards. In Equitation 3 this backward method of the standardisation is shown. In this way the network output is comparable with the measured values.

The Neural Dragon simulator use the backpropagation algorithm for the weight adjustment. The backpropagation learning algorithm is characterised by the adjusting the weights depending on the difference between measured and calculated output. In Equitation 4 this difference between the target and the calculated output is determined.

$$\delta_{pj} = t_{pj} - o_{pj} \qquad (4)$$

For hidden neurons this difference is calculated as shown in Equitation 5. It is the weighted sum of the difference values of the output or previous layer.

$$\delta_{pj} = \sum_k \delta_{pk} w_{jk} \qquad (5)$$

Optimising the network the weights have to be changed. In Equitation 6 it is displayed how the amount of the weight change is determined. The weight change is a sum of the product of the output neurone and the delta value.

$$\Delta_p w_{ij} = \sum_p o_{pi} \delta_{pj} \qquad (6)$$

A weight change is added to the existing value of the particular weight (Equitation 7).

$$w_{ij}(t+1) = w_{ij}(t) + \Delta_p w_{ij} \qquad (7)$$

The learning of a neural network is done by feeding the neural network with training patterns. A validation set of pattern is used to avoid a over-learning of the neural network. Finally the network is tested by a set of test patterns. A comprehensive description of the neural network techniques can be found in literature (e.g. Zell, A. 1997).

3 Fuzzy Logic

Fuzzy logic is supporting the human language in the field of computing. Description of conditions like "it is very hot today" are not very easy to handle by the traditional binary logic. So the fuzzy logic provides an alternative to deal with this kind of human descriptions (Zadeh, L. & Kacprzyk, J. 1999).

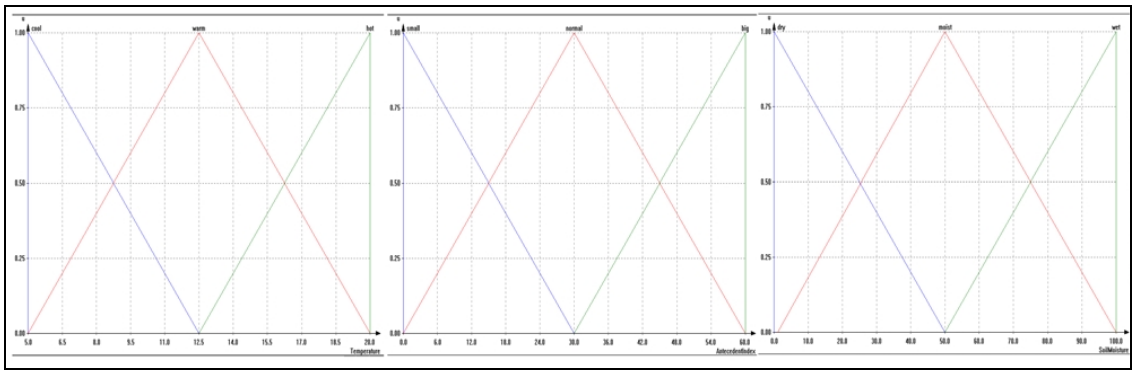

Fig. 2 The combination of two input fuzzy sets are leading one output fuzzy set

Fuzzy sets for different parameters are set up. The combination of this fuzzy sets are following a strict mathematical method. First the input values of the parameters have to be fuzzified. Second the inference of two different fuzzy sets is based upon a set of rules. These rules are responsible for a logical combination of two input fuzzy sets to a third fuzzy set the output fuzzy set. As displayed in Figure 2 two input fuzzy sets are leading to one output fuzzy set. Finally the value of the output fuzzy set has to be defuzzified getting an exact value for the output parameter. A detailed description of the background of fuzzy logic can be found in literature (e.g. Seraphin, M. 1994).

4 Jalovecký Creek Catchment

The Jalovecký Creek catchment is situated in the northern part of the Slovak Republic and it is a small basin within the big Danube river system. It is a mountainous catchment with an area size of 22.2 km². This area belongs to the western part of the Tatra Mountains. The highest point of the catchment is the Banìkov mountain with an altitude of 2178 m.a.s.l. The lowest point of this basin is at 800 m.a.s.l. at the gauge station. The mean slope gradient of the mountains is 30 degrees. The topographical situation of the catchment is shown in Figure 3. This catchment is a natural area with no land use by human population. 44.1 % of the area is forest (spruce) and 31.3 % is covered by pine trees. The rest of the area is Alpine grass land or stone fields without vegetation. This catchment is a research basin of the institute of hydrology of the Slovakian academy of science. This institute has provided a large amount of data and knowledge from this special catchment for this study (Kostka, Z. & Holko, L. 1997).

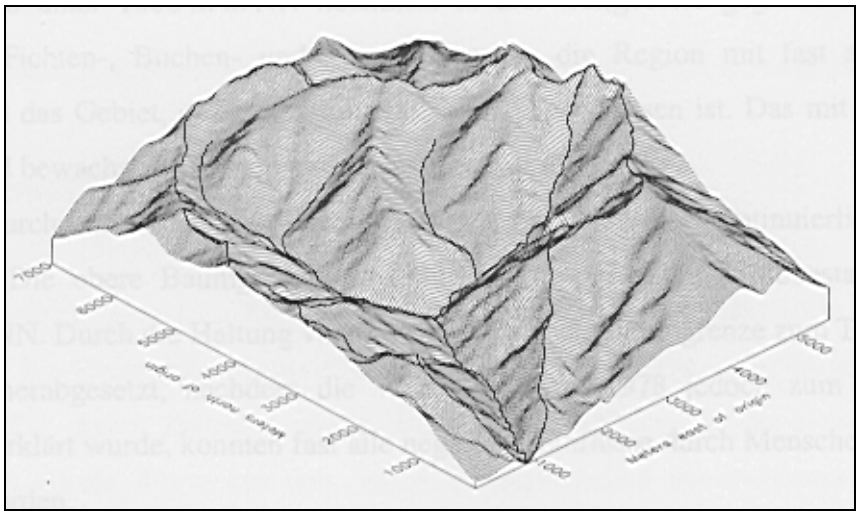

Fig. 3 A topographical view of the Jalovecký Creek catchment (Kostka, Z. & Holko, L. 1997).

In Table 1 the annual water balance of the years 1989 to 1994 is presented (Kostka, Z. and Holko, L. 1997). The average precipitation is 1435 mm per year. The average discharge from this basin is 858 mm/year. The average evapotranspiration is estimated to be 570 mm/year. This numbers are leading to an average runoff coefficient of 0.60 in this basin.

Table 1 Annual water balance of the Jalovecký Creek basin (Kostka, Z. & Holko, L. 1997).

year	1989	1990	1991	1992	1993	1994	1989-1994
	mm	mm	mm	mm	mm	mm	mm
precipitation	1487	1477	1386	1459	1342	1460	1435
discharge	1041	881	793	779	796	858	858
evapotranspiration	613	558	519	492	583	675	570
runoff coefficient	0.70	0.60	0.57	0.53	0.59	0.59	0.60

Although this catchment is observed by various measurements of different parameters during the last years the data situation to build up a rainfall-runoff model is not perfect.

5 Data Analysis

An intensive data analysis has been made to get useful events for a rainfall-runoff model.

Table 2 Overview of the selected rainfall-runoff events

event		N	Nmax	NI	VN	Qmax	QBasis	ψ
nr.	date	mm	mm/d	mm/d	-	m³/s	m³/s	-
01	09.07.1997	224.7	91.4	37.4	48.0	6.799	1.086	0.58
02	08.09.1996	178.8	136.2	44.7	28.7	6.354	1.491	0.45
03	04.08.1991	150.2	49.1	37.6	29.7	5.034	0.671	0.73
04	31.08.1997	88.1	50.3	44.0	2.3	3.828	0.451	1.11
05	24.09.1990	117.6	50.2	19.6	25.6	3.754	1.199	0.29
06	27.06.1995	40.5	34.4	13.5	18.3	3.379	0.633	0.98
07	25.05.1990	101.3	58.0	25.3	7.4	2.914	0.663	0.32
08	28.07.1991	59.6	34.4	14.9	23.4	2.788	0.552	0.55
09	31.08.1989	83.3	67.1	16.7	5.0	2.611	0.349	0.47
10	12.09.1990	143.0	45.3	14.3	15.2	2.492	0.316	0.54

In Table 2 an overview over the selected rainfall-runoff events is given. This ten events are based upon a data basis of daily records. During the up building of the rainfall-runoff model event 05 and 10 were not used any further. So only 8 events were used to validate the rainfall-runoff model of the Jalovecký Creek catchment.

6 Modelling concept

The modelling concept is twofold. First the fuzzy logic approach is used to integrate the an additional parameter into this model concept. The parameter soil moisture is determined by the combination of the fuzzy set temperature and an Antecedent Index describing the rainfall activity in the basin before the selected rainfall-runoff event. And second a neural network has to learn the catchment response by training with a series of rainfall-runoff events.

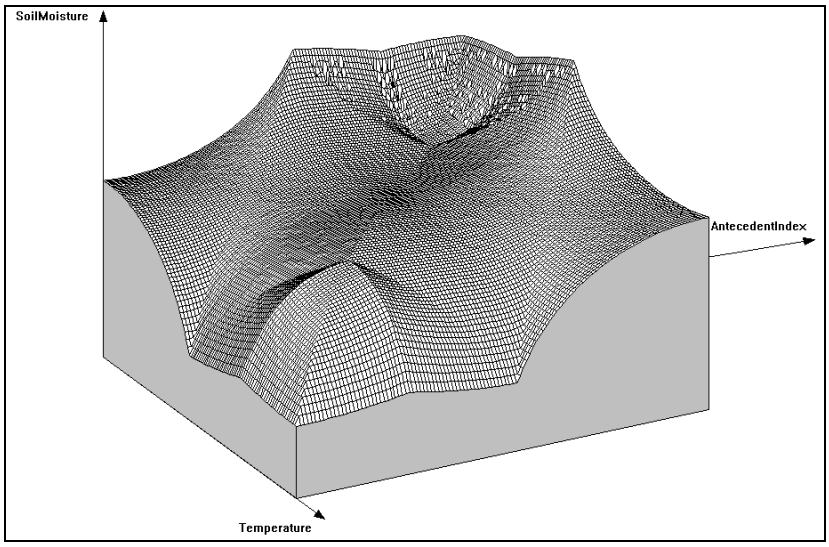

Fig. 4 The display of the resulting relations of the fuzzy sets temperature and antecedent index leading to the soil moisture parameter.

In Table 3 the rules for a logical combination of the fuzzy sets are listed. This matrix is the basis of the 3 dimensional visualisation given in Fig. 4. In 2 versions of the neural network this input parameter "soil moisture" has been used to show the capability to handle such "fuzzy" parameter.

Table 3 The rule matrix of the fuzzy sets

Rule	Input Temperature [5.0 ... 20.0]	Input Antecedent Index [0.0 ... 60.0]	Output Soil Moisture [0.0 ... 100.0]
1	hot	small	dry
2	warm	small	dry
3	cool	small	moist
4	hot	normal	moist
5	warm	normal	dry
6	cool	normal	wet
7	hot	big	moist
8	warm	big	wet
9	cool	big	wet

In Table 4 the different input neurons of the neural network simulation are presented. The number of input neurons is going from 4 to 6 neurons.

Table 4 Parameters representing the input neurons

Parameter	Version 2-1	Version 2-2	Version 4-1	Version 4-2
Runoff level at the start of the event	X	X	X	X
Sum of precipitation	X		X	
Sum of effective precipitation		X		X
Maximum intensity of precipitation	X		X	
Maximum intensity of effective precipitation		X		X
Time point of the precipitation maximum	X	X	X	X
Runoff coefficient	X		X	
Fuzzy parameter soil moisture			X	X
Sum of input neurons	5	4	6	5

Because the number of input neurons of a neural network cannot be changed within a neural network simulation, 4 different neural networks (version 2-1, 2-2, 4-1 and 4-2) have been set up and trained, validated and tested by the same data.

7 Modelling results

A main aspect of the neural network training is the need of enough rainfall-runoff events. In this case just 8 such events were available. So with an intensive study about the rainfall-runoff response of the catchment additional artificial rainfall-runoff events were created. This has been done by using an unit hydrograph approach. Finally there were 10 events for the training, 10 events for validation and the 8 measured events to test the neural network. All events are from the summer period and independent from each other.

Table 5 Parameters of the neural network training

Parameter	value
Learning rate	0.15
Momentum term	0.90
Flat spot elimination	0.10
Initialisation	1.00
Gain of logistic function	1.00
Range of initial value of hidden neurons	1.00
Number of training cycles	1000

All different neural networks have been trained with the same values of the technical parameter of the neural networks itself. These values are given in Table 5. After a successful training the test data set has been given to the neural network. The result of the 8 events are presented in Table 6. The numbers are indicating that the neural network has its problems to estimate the effective rainfall. So when the neural network is trained with the effective rainfall data it is able to estimated rather good the run and the peak of the discharge. The integration of the "fuzzy input parameter "soil moisture can been done without any problems. In this study it is just slightly improving the overall result but it is indicating a way to realise such approach.

Table 6 Comparison between calculated and measured runoff peak

	01 09.07. 1997 m³/s	02 08.09. 1996 m³/s	03 04.08. 1991 m³/s	04 31.08. 1997 m³/s	06 27.06 1995 m³/s	07 25.05 1990 m³/s	08 28.07. 1991 m³/s	09 31.08 1989 m³/s
Measured	6.799	6.354	5.034	3.828	3.379	2.914	2.788	2.611
2-1	5.509	4.387	4.971	1.691	2.995	1.162	1.979	3.164
diff. abs.	-1,290	-1,967	-0,063	-2,137	-0,384	-1,752	-0,809	0,553
diff. %	-19%	-31%	-1%	-56%	-11%	-60%	-29%	21%
4-1	5.901	4.630	5.309	1.616	3.625	1.164	2.589	3.107
diff. abs.	-0,898	-1,724	0,275	-2,212	0,246	-1,75	-0,199	0,496
diff. %	-13%	-27%	5%	-58%	7%	-60%	-7%	19%
2-2	6.378	6.498	5.107	3.182	2.185	2.493	1.808	2.481
diff. abs.	-0,421	0,144	0,073	-0,646	-1,194	-0,421	-0,98	-0,13
diff. %	-6%	2%	1%	-17%	-35%	-14%	-35%	-5%
4-2	6.041	5.386	5.273	3.365	2.407	2.758	2.112	2.687
diff. abs.	-0,758	-0,968	0,239	-0,463	-0,972	-0,156	-0,676	0,076
diff. %	-11%	-15%	5%	-12%	-29%	-5%	-24%	3%

As one example the rainfall-runoff event from the 25.05.1990 is displayed in Figure 5. This Figures elucidates that the neural network is weak in predicting the discharge from the rainfall information just with the information of the runoff coefficient (version 4-1). In contrast to this fact it is surprising that the neural network is able to present a fairly good discharge curve when it is trained with the effective rainfall information (version 4-2).

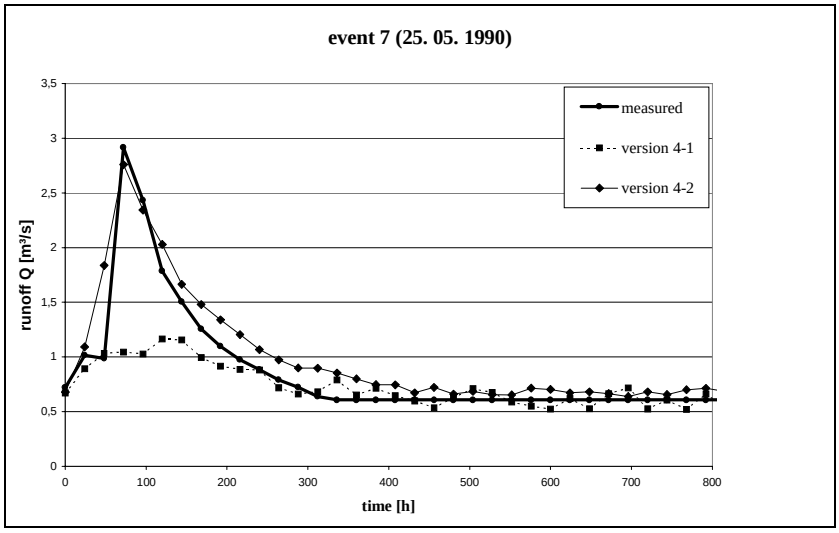

Fig. 5 Display of event 7: Comparison between measured and calculated runoff curve

In Figure 6 version 2-2 and 4-2 are compared to each other. Both are leading to very good results. The neural network 4-2 has as additional information the fuzzy parameter soil moisture. So this network has one more input neurone. This example proofs that there is no improvement but also no worsening of the result. This fact is indicating that it is possible to integrate this kind of parameters as input parameters of neural networks.

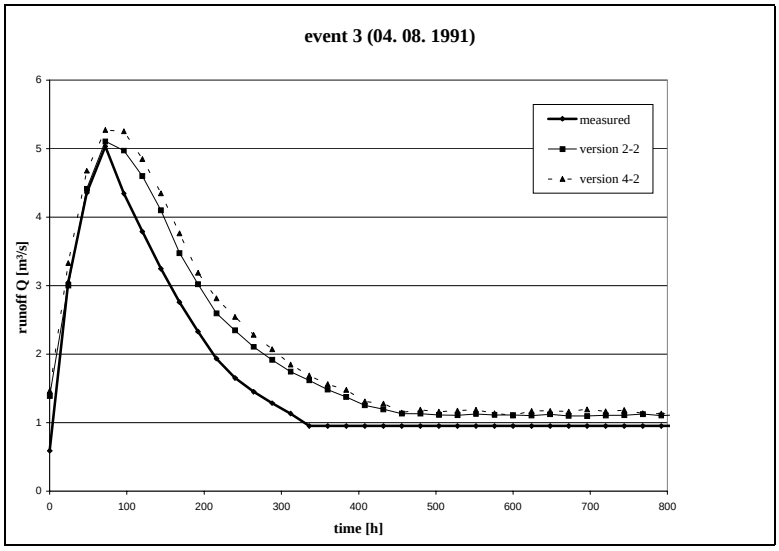

Fig. 6 Display of event 3: Comparison between measured and calculated runoff curve

8 Conclusion

Fuzzy logic methods has been used to create an new input parameter for the neural network. Information of the temperature and the antecedent index of rainfall activity are combined with the knowledge of the climatically situation within Jalovecký Creek catchment.

A deeper understanding of the rainfall-runoff response of the catchment has been used to create a series of artificial rainfall-runoff events. With this events it was possible to train a neural network. After a successful training the neural network was able to determine the run and the peak of the discharge curve using input information of real measured events. Taking into account that the data base of this catchment is not perfect the results are fairly good. The average estimation of the peak is ±13 % over all 8 test events.

Finally one can point out that combination of soft-computing techniques can be a promising approach in hydrological modelling.

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Effect of Land Use Changes Associated with Collectivization in a Rural Landscape on Hydrological and Geomorphic Processes: Case Study: the Jablonka Catchment, Slovakia

Milan Lehotský, Ľubomír Solín, Miloš Stankoviansky

Abstract: The aim of the contribution is to characterize the hydrological and geomorphic response of the Jablonka Catchment to large scale land use changes associated with the collectivization in agriculture conducted in stages in the period 1949-1975. The hydrological and geomorphic response to the above mentioned changes was evaluated in three levels: i) in the level of the changes in susceptibility of the catchment territory to soil erosion, ii) in the level of the changes in the character of operation of actual erosion processes and iii) in the level of the total geomorphic effect of the medium-term operation of these processes since the begening of the collectivization till present time.

Key words: hydrological and geomorphic processes, soil erosion, collectivization in agriculture.

Der Einfluss der Landnutzungsänderungen auf die hydrologischen und geomorphologischen Prozesse im Zusammenhang mit der Kollektivierung der Landwirtschaft dargestellt am Fallbeispiel des Einzugsgebietes der Jablonka, Slowakei

Zusammenfassung: Das Ziel dieses Beitrages ist die Charakterisierung der hydrologischen und geomorphologischen Reaktionen des Einzugsgebietes der Jablonka auf die Veränderungen der Landnutzung im Zusammenhang mit der Kollektivierung der Landwirtschaft in den Jahren 1949-1975. Die hydrologische und geomorphologische Reaktion des Einzugsgebietes auf die Veränderungen der Landnutzung wurde auf drei Gebieten abgeschätzt: i) Änderungen der Anfälligkeit des Einzugsgebietes gegenüber Bodenerosion, ii) Änderungen im Charakter des Verlauf der aktuellen Erosionsprozesse, iii) gesamter geomorphologischer Effekt des Prozessverlaufs vom Beginn der Kollektivierung bis zur heute.

Schlüsselworte: Hydrologische und geomorphologische Prozesse, Bodenerosion, Kollektivierung der Landwirtschaft.

1 Introduction

The collectivisation of agriculture in former Czechoslovakia after political changes in 1948 brought about transformation of spatial organisation of rural landscape. These land use changes have resulted in significant changes in the susceptibility of landscape to fluvial slope processes. So far no systemic attention was paid to the evaluation of changes of fluvial slope processes in Slovakia or the Czech Republic and their possible linkage to collectivisation. Only rough and considerably differing estimates have been published in works of Bulíček (1977), Stehlík (1981), Hraško et al. (1985), Juráň (1990), Mederly (1992), Lehotský, Stankoviansky (1992) ,Lehotský et al. (1993), Jambor and Zrubec (1994). The aim of the paper is to contribute to the discussion o f the fluvial system response to the above mentioned changes.

2 The study area

The Jablonka Catchment (163 km^2) is situated in the western Slovakia. Maximum altitude (950 m) is in the watershed of the White Carpathians , minimum one (180 m) is in the outlet of the Jablonka basin. The characteristic feature of the topography is the alternation of flat ridges and valleys, dendritic drainage pattern and the dissection of 40-300 m. It is built prevailingly of flysch-like rocks of medium to low resistance, resulting in a considerable thickness of a fine-textured regolith. Locally the presence of loess loams promote it. Cambisols and Luvisols are the most spread soil types on slopes, ridges and plateaus. Mean annual precipitation of the area under study is 650-800 mm. The catchment was almost completely forested still at the end of the 13th century (Stankoviansky 1996).

3 Approach and methods

The approach to the assessment of the response of the catchment to the large scale land use changes due to the collectivization was based on a comparison of the structural and dynamic aspects of the landscape in two temporal horizons, namely the one before collectivization (the beginning of the 1950s) and contemporary (the 1990s). Structural aspects concerns the land use pattern. The dynamic aspect concerns the changes of susceptibility of the area under study to soil erosion, changes in behaviour, effect of actual fluvial slope processes and these ones of material accumulation during the whole post-collectivisation period.

Table 1 Evaluation scheme of susceptibility of land use categories to soil erosion (Solín, Cebecauer 1998)

CATEGORIES	**year**	**1955**	**year**	**1990**
	susceptibility to soil erosion		susceptibility to soil erosion	
	degree	index	degree	Index
Urbanized areas	subjectless	- 2	subjectless	- 2
Agricultural land				
Arable land:				
-contour cultivated	moderate	3	high	4
- profile cultivated	high	4	very high	5
- terraced	low	2	low	2
Other land:				
- meadows on limestones and dolomites	low	2	low	2
- meadows on another rocks	very low	1	very low	1
- meadow-scrub on limestones and dolomites	low	2	low	2
- meadow-scrub on another rocks	very low	1	very low	1
-scrub-forest	insignificant	- 1	insignificant	- 1
-alluvial forest	insignificant	- 1	insignificant	- 1
- forest	insignificant	- 1	insignificant	- 1
- hop-gardens	-	-	moderate	3
-cottages	very low	1	very low	1
- railway dikes	subjectless	- 2	subjectless	- 2
- dams	subjectless	- 2	subjectless	- 2

Changes of land use pattern were identified by comparison of land use maps created by interpretation of aerial photographs from years 1955 and 1990. The interpretation of aerial photographs has been realised in GIS environment from the point of view of the basic categories of land use as well as of the size, spatial arrangement and way of cultivation of fields on arable land. Evaluation of susceptibility of landscape to soil erosion was based on investigation of i) susceptibility to the generation of overland flow, ii) protective function of vegetation against the erosion effect of rain drops and iii) protective function of the root system against transportation of soil particles. Susceptibility of land use categories to soil erosion is expressed by ordinal scale and by the susceptibility index (IN) in interval from -2 to 5. The positive values of susceptibility index are especially important (tab. 1). The areas with the negative index are considered insignificant from the viewpoint of susceptibility regardless positive index of values of other factors (relief and soil parameters). The actual fluvial slope processes were studied on the basis of the detailed terrain geomorphologic investigation of erosion-accumulation consequences of chosen meteorological-hydrological events related to extreme rainfalls or snowmelt. The obtained facts were compared to the experience of the local farmers concerning the course of processes before collectivisation. The effect of fluvial slope processes occurring in the framework of sequence of anonymous, consecutive events in course of the post collectivisation period was assessed especially in case of depressive land forms, filled by young sediments. Resulting geomorphic effect, expressed by rise of colluvial bodies at footslope position or in bottom of dells, dry valleys or cuts in them was measured using various buried objects, buried soils, ^{137}Cs and dendrogeomorphic methods.

4 Results

4.1 Land use evolution before collectivization and its influence on the operation of fluvial slope processes

The present-day cultural landscape of the catchment is the result of 7 centuries lasting anthropic transformation of an originally forested landscape. Major stages of anthropic intervention were in the 14th century and so called kopanitse colonization dating back to the 16th century and culminating by the end of the 18th and early 19th centuries (Stankoviansky 1997a).The end of the 19th century brought about the lessening of the fluvial slope processes. This situation lasted practically until the beginning of the 1950s. The kopanitse landscape then existing was typical by a dense network of small, narrow contour and/or gradient plots (while the contour ones prevailed), alternating with the islands of villages, hamlets, meadows, pastures and forests. By interpretation of aerial photographs from 1955 (Fig.1) land use of that time looked like this: forests 32.4% from the total area of the catchment, arable land 48.7% (out of it 36.5% contour cultivated, 12.2% profile cultivated), grass-shrubby stands 12.3%, settlements 5.5%, etc.(Solín, Cebecauer 1998).

4.2 Character of collectivization in the Jablonka Catchment and a change of the land use pattern.

The collectivization has been realised in some stages between 1949 and 1975. Its most inconvenient consequences were above all the merging the former small private plots in large cooperative fields and drastic terrain adjustments accompanied by destruction of network of artificial linear landscape features. Significant terrain adjustments were performed also in the framework of reclamations realised in the second half of the 1970s and even in the 1980s. Especially negative feature of collective farming was the introduction of unsuitable crop rotation, as well as the utilization of heavy machinery. Land use after collectivization in the year 1990 (Fig. 1) was following: forests 41.2% from the total area, arable land 42.8% (out of it 28.2% contour cultivated, 14.6% profile cultivated), grass-shrubby stands 5.2%, settlements 5.7%, etc. Comparison of land use pattern in years 1955 and 1990 shows that in the period between the quoted time horizons the area of forests increased by approx. 12 km^2 and the area of grassy communities diminished by approx. 12 km^2. From the point of view of spatial distribution of the fluvial slope processes, the changes concerning arable land are, of course, the most ones. The total area of arable land shrank by approx. 10 km^2 (964 ha). This shrinkage was

caused by transformation to forest communities (52%), orchards and fruit plantations (32%) and grassland (14%). In spite of the decrease of the area of arable land as a whole, the area of the arable land cultivated along the gradient increased by about 4 km^2. The largest share in increase of the area of gradient cultivated arable land was that of the category of contour tilled arable land. The difference between spatial units in both time horizons is above all in their number, size and inner structure. In older period these units represent blocks of narrow, small private is above all in their number, size and inner structure. In older period 2,898 units (mean size 2.7 ha), in recent period 977 spatial units (mean size) 7.1 ha were identified (Solín, Cebecauer 1998). Inner heterogeneity created by alternation of strips of different crops sawn on private fields is typical for the units before collectivisation. Inner structure of the units from the post-collectivisation period is homogeneous.

4.3 Changes of susceptibility of the Jablonka Catchment to soil erosion due to collectivization.

Susceptibility of Jablonka catchmnet to soil erosion is considered by two groups of parameters i. e. land use and topographic and soil ones (aspect, slope, profile and contour curvature, stability of soil aggregates, texture and moisture of soil). Topographic and soil as static parameters have been evaluated from this point of view by Solín, Lehotský (1996). Judging the effect of collectivization on changes of susceptibility of catchment to soil erosion, the assessment of arable land pattern in above mentioned two time horizons is decisive. Estimating the overall degree of susceptibility of single categories of arable land we have to take into account the different structure of spatial units of category "arable land" in time before and after collectivisation (Tab. 2).

Table 2 Susceptibility of Jablonka catchment to soil erosion

Degree of susceptibility (Year 1955)	area (ha)	% from catchment area	% from threatened area
1	9,88	0,1	0,1
2	1841,44	11,3	21,9
3	5167,56	31,8	61,3
4	1408,36	8,7	16,7
- 1	6881,88	42,3	-
- 2	964,24	5,9	-
catchment area	***16273,36***		
threatened area (1-4)	***8427,20***		

Degree of susceptibility (Year 1990)	area (ha)	% from catchment area	% from threatened area
1	11,92	0,1	0,2
2	1052,80	6,5	15,0
3	1861,68	11,4	26,6
4	3930,56	24,1	56,2
5	140,08	0,9	2,0
- 1	8186,32	50,3	-
- 2	1094,04	6,7	-
catchment area	***16277,40***		
threatened area (1-4)	***6997,00***		

Spatial units of categories of arable land tilled in direction of contour and arable land tilled in direction of gradient line before collectivisation are innerly heterogeneous in the consequence of

stripcropping. Spatial units of the same category in the period after collectivisation were monocultural i.e. homogeneous. Contour stripcropping on arable land is generally considered the system of management supporting antierosion effect of contour tillage. Assessment of the effect of number of gradient cultivation furrows which occur in stripcropping in the periods before and after collectivisation is considered decisive for the assessment of susceptibility to erosion of arable land cultivated by gradient line. In the period before collectivisation we detected major number of cultivation furrows that in the period after collectivisation. On the one side the cultivation furrows assist to concentration of surface runoff but as certain volume of runoff is dispersed into several lines and its erosion force is weakened. Moreover, it was the primary interest of private farmers to lower the effects of erosion by diging out more furrows intersecting the gradient cultivated fields in order to interrupt the forming concentration surface runoff, or to change the direction of its movement. Such active antierosion protection on the co-operative fields was rare, if it existed at all. Such reflection leads to the suggestion that susceptibility of gradient cultivate arable land was lower before collectivisation than after it. Departing from the cited logical consideration we aligned to the category of arable land tilled along contour line in the period before collectivisation moderate or high and to category of arable land cultivated along the gradient line very high degree of susceptibility to soil erosion. Category of terraces on arable land for both periods was aligned low degree of susceptibility to soil erosion. The area with high, or very high degree of susceptibility to soil erosion was increased by 40%after collectivisation (Solín, Cebecauer 1998).

4.4 Evaluation of the sedimentation rate during post-collectivisation period..

For the purpose of differing the thickness of the accumulation, caesium-137, dendrogeomorphic approach and so called “in situ” investigations have been appli ed. On the basis of interpretation of the activity of caesium-137 in soil of 10 localities along five catenas in the Kostolné subcatchment we stablished that the rate of soil accumulation in the outlet of subcatchment is approximately 0,8 cm/year (30-35 cm/35 years).

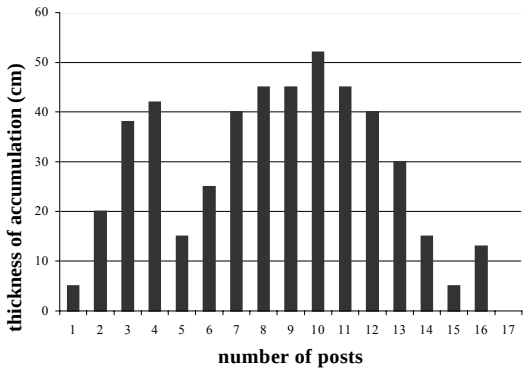

Fig. 1 Fan-like soil accumulation in the contact zone between large block of arable land and meadows affected by concentrated rill erosion and measured by means of buried fence posts.

By means of so called “in situ” investigations when we investigated the accumulated soil layer by knowing the age of fence posts (locality u Otiepkov-Fig.1) ,buried telephone pole (locality Luskovica), or by analysing of soil profile (localities Luskovica, Paprad, u Hučkov). On the basis of obtained results we approximately determined that the rate of soil accumulation is in this above mentioned type of landscape about 2-4 cm/year.Dendrogeomorphic investigation has been applied in 6 landscape types i. e. 3 locality in the flood plain of Rudník stream (upper, middle and lowest part), 1 in the bottom of dell and gully and 1 in colluvial fan. The average rates of sedimentation in upper part of stream is 1,3 mm/y, middle part 2,8 mm/y and the lowest one 0,5 mm/y. The bottom of dell is filling by velocity around 1,3 mm/y, the bottom of gully 4,4 mm/y and the rate of soil accumulation in the colluvial fan 2,9 mm/y.

5 Conclusions

In relation to the post-collectivisation large-scale changes of the use of original landscape a distinct acceleration of fluvial slope processes was observable. The result of this acceleration was the disturbed landscape quasi-equilibrium existing there at the end of the 19th century and the first half of the 20th century. The present post-collectivisation period can be interpreted as a strong, well-defined pulse of disequilibrium which disrupted the existing balance of catchment infiltration rates, runoff generation indices, sediment yields and delivery ratio and the resulting geomorphic characteristics of land form shaping. The characteristic features of the slope processes response of the quoted changes are as follows:

- the first change is connected with the basic feature of the operation of fluvial slope processes, namely with its temporal and spatial variability based on its selectiveness in relation to land use and type of cultivation (they occur almost exclusively on active fields). The above processes operate today also on the hillslope portions where they absented before (e.g. on previous meadows transformed to fields) and, on the contrary, they absent today there, where operated before (e.g. on previous fields transformed to meadows and forests). In the case of Jablonka catchment it is evident the increase of the areas with high, or very high degree of susceptibility to erosion processes by about 40 % (in spite of overall shrinkage of arable land),
- the enlargement of fields and the removal of artificial linear landscape features resulted in a marked increase of slope portions regularly affected by intense areal erosion. However, the intensification of processes was not a area-wide one and not of the same value on all affected places. It differed from site to site in relation to the previous type of cultivation. The extension of areas affected by areal erosion resulted in the change of the share of partial fluvial slope processes in the total balance of fluvial slope processes as a whole. While in the previous landscape the linear erosion was predominant, in the post-collectivization the areal erosion prevails. In relation to the land use changes, also the geomorphic effectiveness of the areal erosion was increased, both in case of rill/interrill erosion and of sheet wash (cf. Stankoviansky 1997b).
- the land use changes and utilisation of heavy machinery on co-operative fields resulted also in the change in acting of linear erosion. The formation of both permanent and ephemeral gullies in the past was changed to exclusive creation of ephemeral gullies in the present-day conditions. The current linear erosion is controlled almost exclusively by topography, on the contrary to the previous period, when it was controlled both by artificial and topographical linear landscape elements, while artificial ones highly predominated.
- the overwhelming part of the material washed down from straight hillslopes by areal erosion remains on footslopes and on flood plain margins. Material eroded by linear erosion and carried by concentrated flow along the thalwegs of different linear landscape depressions is partially sedimented in their bottoms (usually in case of presence of barriers or active buffer zones), but its predominant part is carried away to the valley of higher order. After reaching this valley, the carried material is partially deposited in the form of various colluvial bodies (with thickness of approximately 0,5 m) and partially carried away by local streams (Stankoviansky 1997a).

For the operation of fluvial slope processes in the investigation period it is possible to introduce the following statements:

- heavy spring rainfalls were the most harmful events in the course of the year,
- geomorphic effectiveness of heavy rainfalls was much higher than in case of snow melts,
- areal erosion predominated over linear one,
- the most damaging partial erosional phenomenon was represented by the concentration flow erosion ,
- the most affected landscape features during the events are the slope hollows, dells and dry valleys, where both areal and linear erosion occur, while topographically raised effect of fluvial slope processes can be further increased by introduction of an unsuitable crop,
- significant increase of slope portions regularly affected by intense areal erosion and generation of conditions favouring areal erosion on the territories affected also beforehand,
- intensification of geomorphic effect of linear slope processes (concentrated flow) and erosion by distinct lowering of the density of linear landscape elements,
- increase of geomorphic effectiveness of the processes expressed by much faster filling of terrain hollows compared to previous period. The quoted conclusions confirming a marked

intensification of the processes in post-collectivisation period obtained in the Jablonka Catchment are applicable also to other sub-mountainous agricultural landscape regions of Slovakia (cf. Stankoviansky et. Al. 1999).

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Veränderungen der Abflußverhältnisse und ihre Berücksichtigung in der Bewirtschaftung der Wasservorräte in Ungarn

Pál Liebe, György Varga

Zusammenfassung: Innerhalb des Donaueinzugsgebietes gehört das Landesgebiet Ungarns zu den trockensten Teilen. Kennzeichnend dafür sind: eine bedeutende räumliche und zeitliche Variabilität de Niederschlags, das Auftreten sowohl von äußerst niederschlagsarmen als auch von äußerst niederschlagsreichen Jahresfolgen. Die für den ober- und unterirdischen Abfluß zur Verfügung stehende Wassermenge – d.h. die Differenz zwischen Niederschlag und gebietlicher Verdustung – hat während des Jahrzehntes 1980-90, besonders in den niederschlagsarmen Gebieten des Flach- und Hügellandes, wesentlich abgenommen. In der Grundwasserbilanz wurde das während der Trockenjahre anfallende Defizit durch die Entleerung des im ungespannten, untiefen Behälter gespeicherten Wasservorrats ausgeglichen, was natürlich zu Senkungen des Grundwasserspiegels führte. Bei der Bewirtschaftung der Wasservorräte können diese natürlichen Speichervorgänge zwar berücksichtigt werden, doch muß dabei auch der Umweltbeschränkungen der damit einhergehenden Wasserspiegel-Veränderungen Rechnung getragen werden.

Schlüsselworte: Wasserbilanz, Trockenperiode, Senkung des Grundwasserspiegels

Changes in Runoff Conditions and Their Taking into Account in Water Resources Management of Hungary

Abstract: Within the Danube Catchment, the national area of Hungary is one of the driest regions, characterized by a considerable fluctuation of precipitation in space and time as well as by the occurrence of both extremely dry and extremely humid groups of years. The water amount available for surface and underground runoff – i.e., the difference between precipitation and areal evaporation – has rapidly decreased during the decade of 1980-90. In the groundwater balance, the deficit resulting from the dry period has been balanced by a depletion of the unconfined, shallow aquifer, causing of course droppings of the groundwater level. In the course of water resources management, these natural storage processes can be taken into account, while not forgetting the limitations in water level fluctuations as reqvired by environmental considerations.

Key words: water balance, dry period, dropping of groundwater level.

1 Veränderungen des Niederschlags und der gebietlichen Verdunstung

Aufgrund seines langjährigen (1961-1990) gebietlichen Niederschlags-Mittelwertes von 600 mm/Jahr gehört das Landesgebiet Ungarns zu den trockensten Teilen des Donaueinzugsgebietes. Kennzeichnend ist eine bedeutenede räumliche und zeitliche Variabilität der Niederschlagshöhe. Innerhalb des Landesbetietes varidert der langjährige mittlere Niederschlag zwischen verhältnismäßig weiten Grenzen (Bild 1). Auch der zeitliche Verlauf der jährlichen Niederschlagshöhen zeigt bedeutende Fluktuationen (Bild 2).

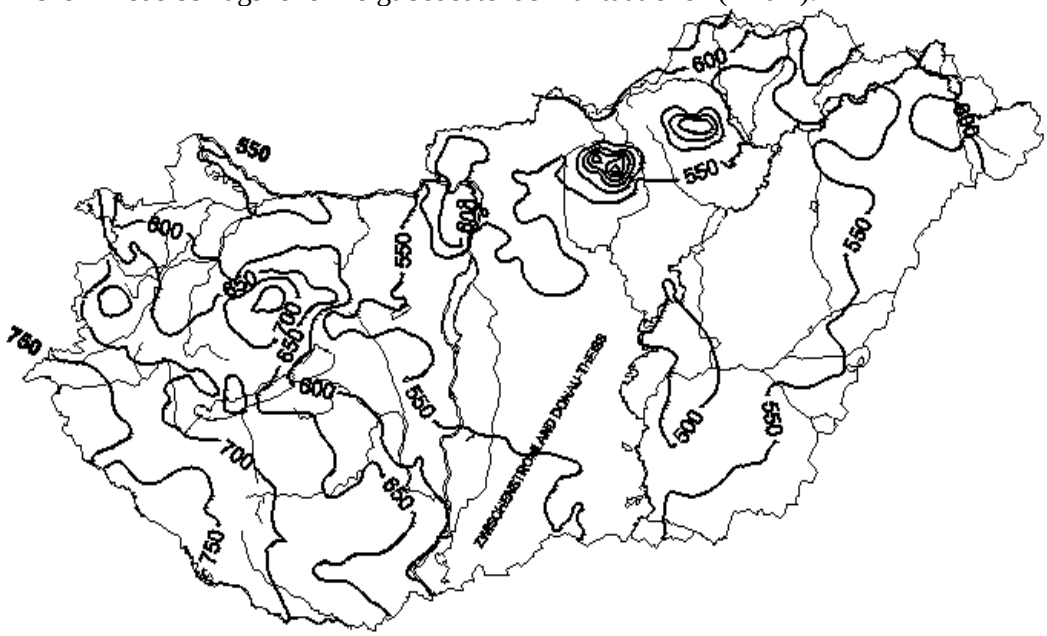

Bild 1 Gebietliche Verteilung der langjährigen (1961-1990) Mittelwerte des jährlichen Niederschlages in Ungarn [in mm]

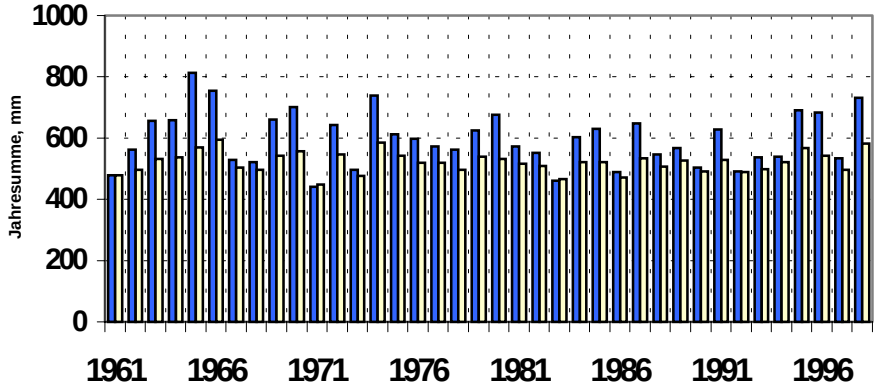

Bild 2 Jahressummen des Niederschlags (blau) und der Verdunstung (gelb) in Ungarn

Die Größe der gebietlichen Verdunstung (Evapotraspiration) wird grundlegend vor der Niederschlagshöhe, von der Lufttemperatur sowie von der Pflanzenbedeckung bestimmt. Der für die Periode 1961-1990 ermittelte langjährige Mittelwert der gebietlichen Verdunstung liegt bei 525 mm/Jahr. Vergleicht man diesen Wert mit der durchschnittlichen Niederschlagshöhe, so erhält man im Landesdurchschnitt eine Differenz von 75 mm/Jahr, deren gebietliche Verteilung

innerhalb des Landesgebietes jedoch bedeutende Unterschiede aufweist (Bild 3). Die Differenzen unter 50 mm/Jahr sind för die Flachlandregionen kennzeichnend, für welche auch ein Wasserdefizit typisch ist.

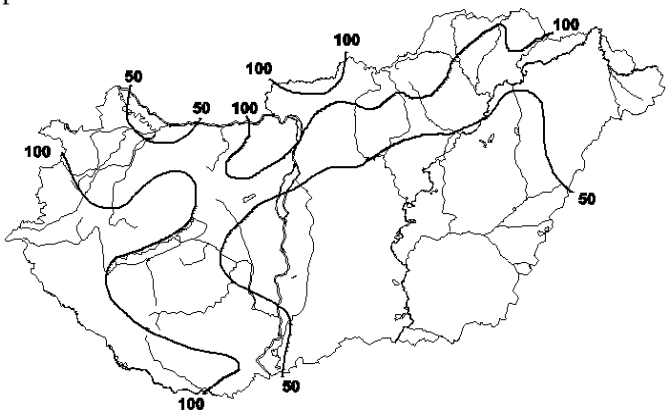

Bild 3 Geschätzte Differenz zwischen Niederschlag und gebietliche Verdunstung (aufgrund berechneter Werte der Periode 1961-90 und gemessener Abflußdaten)

2 Eigentümlichkeiten der Abflusses

Läßt man die Speicherung unberücksichtigt, so ergibt sich der Abluß einer längeren Periode als die Differenz zwischen Niederschlag und Verdunstung. Der für die Periode 1961-1990 ermittelte langjährige Mittelwert der aus den Ungarn zufließenden aund sein Landesgebiet verlassenden Abflüssen errechneten Wassersäule liegt bei 76 mm/Jahr (Bild 4),

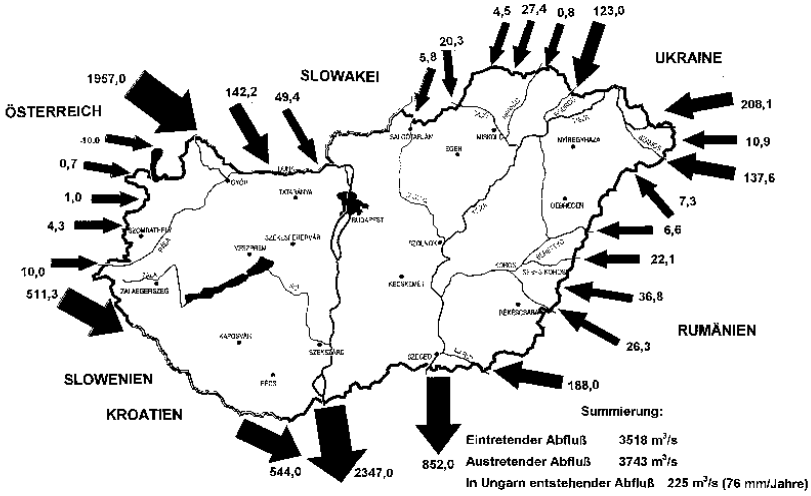

Bild 4 Langjährige (1961-1990) mittlere Abflüsse der größeren Flüsse Ungarns [in m^3/s] in fast genauer Übereinstimmung der früher errechneten Differenz von 75 mm/Jahr zwischen Niederschlag und Verdunstung. Untersucht man jedoch letzgenannte Differenz (den sog. berechneten Abfluß) sowie den gemessenen Abfluß in Abhängigkeit vom Niederschlag, findet man, daß die Veränderungen des Abflusses diejenigen des Niederschlages beträchtlich übertreffen. Z.B. gehört zu einer 10 %-ige Abnahme des Niederschlags im Landesdurchschnitt eine etwa 40 %-ige Abnahme des berechneten Abflusses (Bild 5).

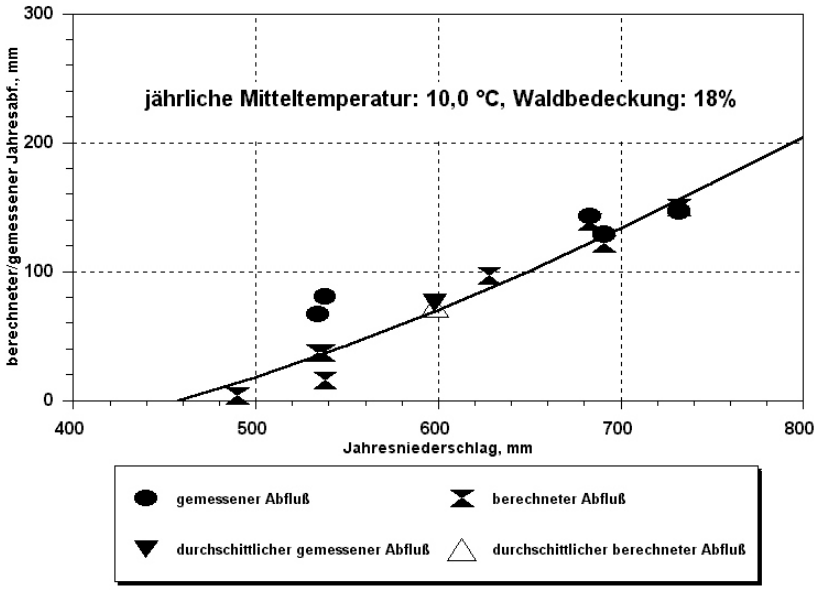

Bild 5 Beziehung zwischen dem berechneten und dem gemessenen Abfluß sowie dem Niederschlag in Ungarn

Die Daten des berechneten und des gemessenen Abflusses sind – inforge der Unsicherheiten bei der Ermittlung der gebietlichen Verdunstung sowie der Fehler der Abflußmessungen – oft selbst mit Fehlern behaftet. Laut unserer Analysen treten die größten Abflußschwankungen in den an Niederschlagarmsten Gebieten auf, so daß ein 15-20-iger Niederschlagsdefizit – besonders, wenn es gehäuft auftritt – zu einer fast größenordungsmäßigen Abnahme des Abflusses führen kann (Bild 6).

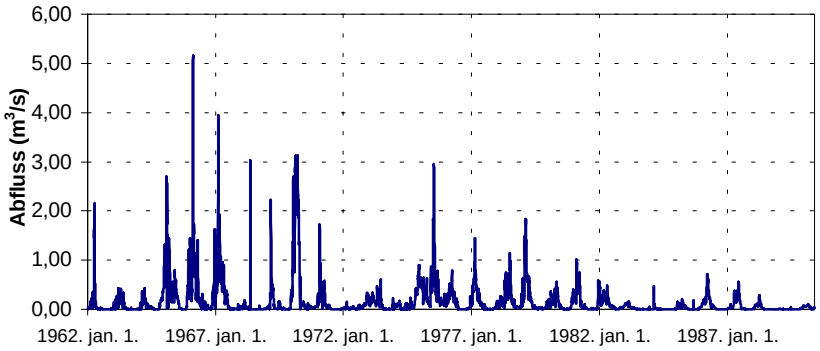

Bild 6 Ganglinie der Tagesabflüsse von einem Einzugsgebiet der Südlichen Tiefebene [A_E = 270 km^2]

3 Grundwasserneubildung

Im größten Teil des Landesgebietes erfolgt die Speisung der Grundwässer der tieferen Schichten durch die klastischen bodennahen wasserführenden Schichten, worin sich meistens ein freier Grundwasserspiegel bildet, für welchen sowohl eine typische jährliche periodische Schwankung als auch sich auf größere Regionen erstreckende langjährige Veränderungen kennzeichnend sind. Letztere sind grundlegend von den Niederschlagsverhältnissen abhängig. Da die Veränderungen der Evapotranspiration wesentlich geringer sind, als diejenigen des

Niederschlags, kommt es zur Akkumulation der – im Vergleich zum langjährigen Mittelwert definierten – Niederschlags-Defizite bzw. – Überschüsse. Die Vorratsänderungen des gespeicherten Grundwassers richten sich hauptsächlich nach dieser akkumulierten Menge. Dieses Phänomen wird in Bild 7 veranschaulicht.

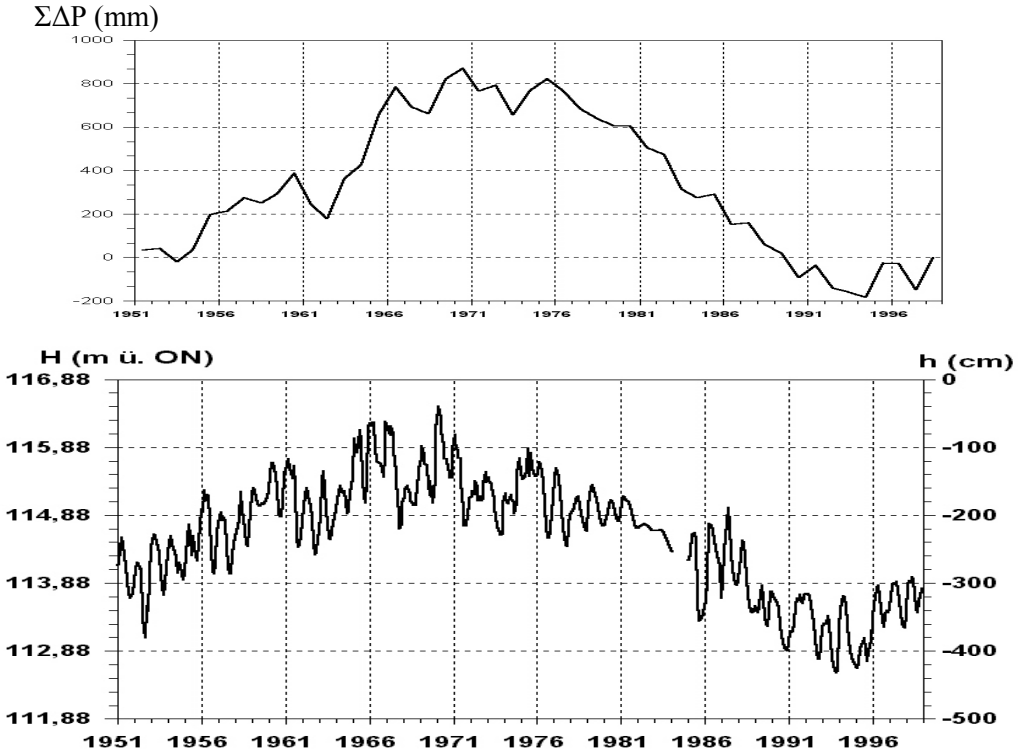

Bild 7 Summendifferenzenlinie des Niederschlags (∑ΔP) und langjährige Ganglinien des bodennahen Grundwasserstandes (H = über Ostsee, h = Flurabstand) in einem Beobachtungsbrunnen des Zwischenstromlands Donau-Theiß

Das Zwischenstromland Donau-Theiß fällt auch dadurch auf, daß hier – im Vergleich zum Zustand der 1950-er-1960-er Jahre – die bedeutendsten Senkungen des Grundwasserspiegels verzeichnet wurden (Bild 8).

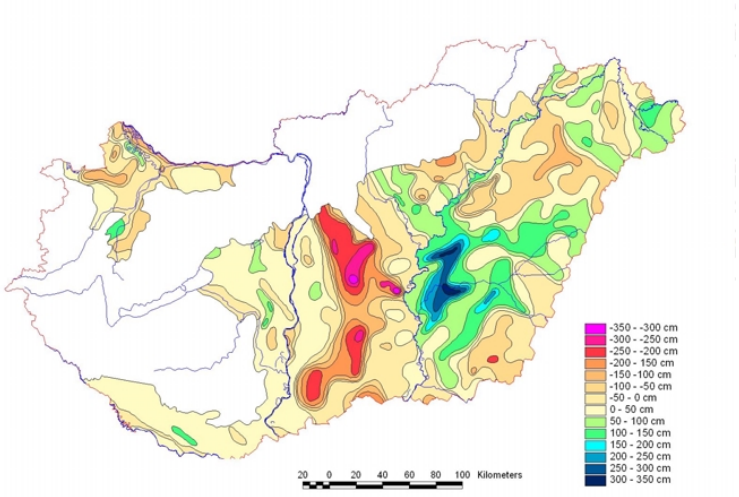

Bild 8 Veränderung des bodennahen Grundwasserstandes in Flachlandgebieten (Differenz der Durchschnittswerte der Basisperiode 1956-60 und Jahres 1998)

Unter allen Flachlandgebieten des Landes war es diese Region, die am schärfsten auf das während einer Folge von Trockenjahren akkumulierte Niederschlagsdefizit reagierte. Es handelt sich dabei um einen Sandrücken mit einer Fläche von 9000 km^2 (Bild 1), der sich höhenmäßig um etwa 30-60 m über die tieferen Teile der Großen Ungarischen Tiefebene erhebt. Der Großteil des Niederschlags verdunstet, an Ort und Stelle, während ein geringerer Teil ober- und unterirdisch abfließt. Ein Teil des unterirdischen Abflußes sickert durch die bodennahen Schichten des Grundwasserleiters den nächsten Vertiefungen zu, wo er ebenfalls verdunstet.An diese Stellen erschien das bodennahe Grundwasser auch an der Oberfläche, in der Form von Zickseen, welche allerdings während der Trockenperioden austrockneten. Ein anderer Teil des einsickernden Wassers sickerte auch im Originalzustand den tieferen Schichten zu und wurde sodann, nach einer Strömung regionalen Ausmaßes, größtenteils über Evapotranspiration, in den ferneren tiefer gelegenen Gebietsteilen angezapft. Infolge Wasserentnahmen hat die in die Tiefe sickernde Wassermenge, im Vergleich zum ursprünglichen Naturzustand, etwas angenommen, wobei die in den erwähnten ferneren Gebietsteilen stattgefundene aufsteigende Strömung durch die Wasserentnahmen unterbunden wurde. Die Veränderungen de Wasserhaushalts können heute schon, aufgrund der im Zwischenstromland Donau-Theiß durchgeführten weitläufigen Untersuchungen, verhältnismäß gut eingeschätzt werden.

Tabelle 1 Geschätzte Veränderungen der Elemente des Wasserhaushalts am Sandrücken zwischen Donau und Theiß (in mm/Jahr)

Wasserbilanz-Element	**Im ursprüng-lichen, durch-schnittlichen Zustand**	**Während der letzten Trockenperiode (-)**	**Während der erwarteten feuchten Periode**
Niederschlag	+ 530	+ 450	+ 600
Evapotranspiration	- 450	- 430	- 470
Oberflächenabfluß	- 30	- 5	- 60
Oberflächennaher Abfluß*	- 35	- 25	- 25**
Tiefenabfluß*	- 15	- 20***	- 20***
Speicherung (-)/Entleerung (+)	0	+ 30	- 25

* verdunstet größtenteils

** infolge des abgesunkenen Grundwasserspiegels geringer am Anfang der feuchten Periode, als im ursprünglichen Zustand

*** infolge Wasserentnahme aus den tieferen Schichten größer, als im ursprünglichen Zustand

Aus Tabelle I geht hervor, daß während der typischen Trockenperiode der 80-er Jahre das durchschnittliche Wasserbilanz Defizit von 30 mm/Jahr durch die Entleerung des ungespannten bodennahen Grudwasserleiters ausgeglichen wurde, was – unter Berücksichtigung der Gravitations—Porenvolumens – mit einer Grundwasserspiegel-Senkung von 15-20 cm/Jahr einherging. Infolge der seit Mitte der 90-er Jahre verzeichneten, an Niederschlag reicheren Witterung hat die Senkung des Grundwasserspiegels im größten Teil des Untersuchungsgebietes aufgehört, wobei auch die – aus ökonomischen Gründen erfolgte – Abnahme der aus den tieferen Schichten erfolgten Wasserentnahmen wohl eine Rolle spielen durfte. Kommt es wieder zu feuchteren Jahren, so ist ein Anstieg der Grundwasserstandes – etwa in der Größenordnung der früheren Senkung – insbesondere in den Gegenden zu erwarten, wo er tiefer als 1-2 m unter der Bodenoberfläche liegt.

In den 80-er Jahren kam es überall in den Flachlandgebieten des Landes zu Senkungen des Grundwasserstandes, doch erreichen sie anderswo, mit den Werten der 1950-60-er Jahre verglichen, nirgends das Ausmaß der Grundwasser-Senkung im Zwischenstromland Donau-

Theiß. Dies ist in den östlichen Teilen der Großen Ungarischen Tiefebene auch auf den Umstand zurückzuführen, daß dort am bis Anfang der 80-er Jahre ein Anstieg des Grundwasserspiegels typisch waer, der dann von einer Senkung gefolgt wurde. In den Gebietsteilen, wo der Grundwasserspiegel in Bodennähe (1 – 2 m Tiefe) befand, führte das Niederschlagsdefizit zu keiner bedeutenderen Senkung, da sie durch die zu einer verhältnismäßig geringen Senkung gehörige Abnahme der Evapotraspiration ausgeglichen werden konnte, so daß es früher zur Stabilisierung des jeweiligen neuen Gleichgewichtszustandes kam.

Bei der Ermittlung der nutzbaren unterirdischen Wasserdargebots muß man der während der maßgeblichen niederschlgasarmen Periode abgenommenen Neubildung Rechnung tragen, doch kann dabei der während der feuchten Jahre akkumulierte Vorrat ebenfalls berücksichtigt werden. Der mit der Vorratsänderung einhergehenden Veränderungen des Grundwasserspiegels werden jedoch durch die Umweltbewirtschaftung Grenzen gesetzt, die bei den wasservorratswirtschaftlichen Entscheidungen keineswegs vergessen werden dürfen.

Die für die niederschlagsarmen Jahre typische Abnahme der Grundwasserneubildung hat sich auch im Bergland, namentlich in den Karstgebieten bemerkbar gemacht, doch war hier die Abnahme der Einsickerung prozentmäßig geringer, als in den Flachlandgebieten. Bei durch Quellen angezapften unterirdischen Wasservorräten, deren Schüttung verhältnismäßig rasch auf jegliche Veränderung der Niederschlags reagiert, hat die Speicherung eine geringere Rolle als Flachlandgebieten.

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The Strong Vrancea Earthquakes and Geoenvironmental Problems on the Danube River Shoreline of Bulgaria

Margarita Matova

Abstract: The November 10, 1940 (M=7.2) and the March 4, 1977 (M=7.2) Vrancea, Roumania, earthquakes are only a part of the numerous middle-focus seismic events with considerable influence on the geological environment in Bulgaria, the southern neighbour of Roumania.

The Vrancea earthquake influence is very significant in the Northeastern Bulgaria or on entire territory of Northern Bulgaria. The seismic effects are most respectable along the Bulgarian sector of the Danube River coast. The Vrancea earthquakes were the cause for the significant deformation of the crust's surface: faults, land subsidence, landslides, sandy volcanoes, etc. The seismic deformations create problems in the geoenvironment of the coastal territory.

Die Starke Vrancea Erdbebens und die geologischen ökologischen Probleme am bulgarischen Ufer der Donau Fluss

Zusammenfassung: Der 10 November 1940 (M=7.2) und der 4 Marz 1977 (M=7.2) Vrancea, Rumanien, Erdbebens sind nur ein Teil der zahlreichen mittel-focus seismischen Effekten mit bedeutendem Einfluss uber die geologische Ökologie in Bulgarien, der Sudlichen Rumanische Nachbar.

Der Vrancea seismische Einfluss ist sehr stark in Nordost Bulgarien oder in das gesamten Territorium von Nord Bulgarien. Die seismische Effekten sind besser ausdrückt entlang der Donau Ufer. Die Vrancea Erdbebens sind die Ursache fur bedeutende Deformation der Krustische Oberflache: Storungstructuren, Sinken, Rutschen, sand Vulkane, etc. Die seismische Deformations schaffen Probleme in der Ökologie der Ufer Gebietes.

Introduction

The strong middle-focus Vrancea, Roumania, earthquakes are of regional importance for the geodynamics of the Balkan Peninsula. The Vrancea earthquake influence is very well marked along the Danube River coast of Bulgaria, where the social activity is with good traditions and the economic development is considerable. The seismic effects create considerable geoenvironmental problems in Bulgaria, the southern neighbour of Roumania.

Geological and tectonic notes for the Danube River coast

The most distributed on the surface Mesozoic and Neozoic rocks are of specific characteristics along the Danube River coast (Bonchev, 1960). The Mesozoic sediments (Hotrivian-Aptian limestone, Aptian sandstone) are presented mainly locally in the eastern part of the investigated territory, especially on the coast to the E of the town of Svishtov. There are certain limited manifestations of the karst in the Lower Cretaceous limestone in the vicinity of the town of Rousse. The Neozoic cover is with the largest distribution. The cited cover includes mainly the Pliocene clay and sands in localities of the coast to the E of the town of Nikopol, also the Quaternary loess, gravel and sands along a big part of the coast. The loess sediments are of different depth (10-100 m).

The above mentioned Pliocene and Quaternary deposits are young, a few deformed and without good cohesion. There are data for a considerable karst evolution in some localities. The tectonic and atectonic collapse structures, land subsidence, landslide and rockfall phenomena are realised generally in the Lower Cretaceous karst limestone and in the Quaternary loess.

The Moesian Platform is included in the plate's regional tectonic movements and in the considerable block fragmentation. Regional and local, horizontal and vertical block displacements are also established. The tectonic movements, including the formation of fractures, landslides, rockfalls, land subsidence, are manifested mainly along the block boundaries, also along the inner block zones of fractures and faults. The engineering geological and the hydrogeological characteristics of the rocks in the region permit to suppose the local increasing of the effects of the tectonic, including of the seismic, mobility.

Data for the influence of the strong Vrancea earthquakes to the geoenvironment of the coast

In Bulgaria the strong middle-focus Vrancea earthquakes deformations were and will be the best expressed in the territory of the Danube River coast. The seismic deformations are relatively well described only for the 20th century. There are special studies for the November 10, 1940 (Fig. 1) and the March 4, 1977 (Fig. 2), Vrancea, Roumania, earthquakes (Kirof, 1941, Brankov, 1983).

The influence of the previous centuries seismic effects on the crust surface could be taken also in attention. The periodical manifestations of strong Vrancea earthquakes provoke real and potential deformations of the earth's crust, also of the technogenic constructions on and in it. The deformations caused by the previous Vrancea earthquakes could be similar to the same provoked by the 1940 (Fig. 1) and the 1977 (Fig. 2) earthquakes.

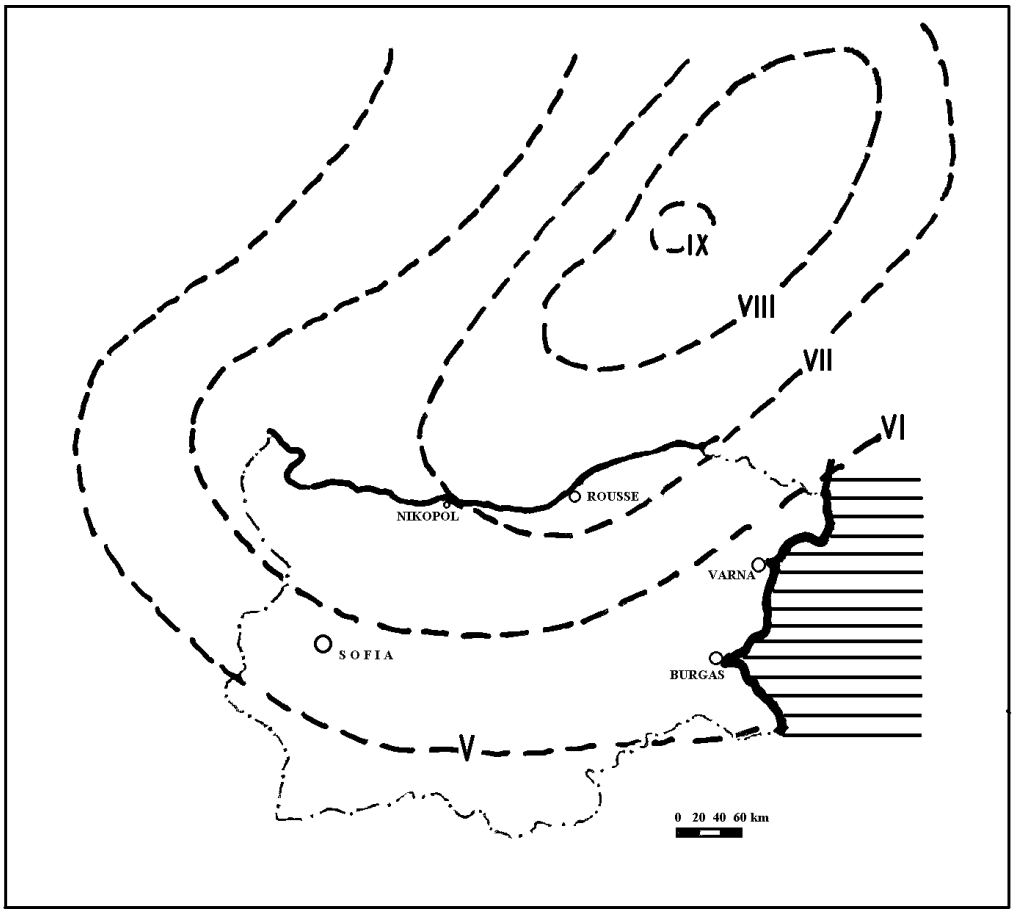

Fig. 1 Isoseist map of the November 10, 1940, Vrancea, Roumania, earthquake (after Brankov, 1983)

The strongest middle-focus Vrancea earthquakes are with M=7.0-7.5. It is remarkable that the recurrence period of the mentioned seismic events is generally of several tens years. The seismic foyers are situated in the upper mantle, in the depth of about 100-150 km. The influence of the above mentioned middle-focus earthquakes is considerable in the Balkan Peninsula. The cited influence reaches very often destructive effects in the Bulgarian sector of the Danube River coast and in a part of the country. The Vrancea earthquake's epicenters are placed 180-400 km to the N and the NE of the Bulgarian Danube River coast.

The subject of the study will be the seismic environmental problems related to the most representative Vrancea seismic events in the 20th century. They are the November 10, 1940 (M=7.2) and the March 4, 1977 (M=7.2) Vrancea, Roumania, earthquakes. The seismic effects in Bulgaria are considerable ones. The cited seismic events have provoked considerable damages along the Danube River coast of the country, also in the surrounding territories of the Northern and the Middle Bulgaria.

The November 10, 1940 Vrancea, Roumania, earthquake (M=7.2) had an epicenter 200-400 km to the N and NE of the Danube River coast. Its foyer was in the depth of 135 km. The main isoseist's axes were of NW-SE (43°) direction (Fig. 1).

The cited seismic event had provoked significant destructive damages along a very big part of the Danube River coast (Kirof, 1941, Brankov, 1983).

The isoseit of the VII degree's intensity, the isoseist of considerable destructive deformations, had included all Bulgarian Danube River coast to the E of the town of Nikopol (Fig. 1). The documentation of the seismic damages in Bulgaria was very limited for the cited earthquake.
The March 4, 1977, Vrancea, Roumania, earthquake (M=7.2) had an epicenter 180-380 km to the N and the NE of the investigated coast. The epicenter was relatively nearer to the Danube River coast than the same in 1940. The earthquake foyer was 110 km deep. The direction of the isoseist's axes was generally NW-SE (35°).
The isoseist of the VII degree's intensity included all Danube River coast between the towns of Vidin and Silistra (Fig. 2). The important seismic effects were marked in large surrounding territories.

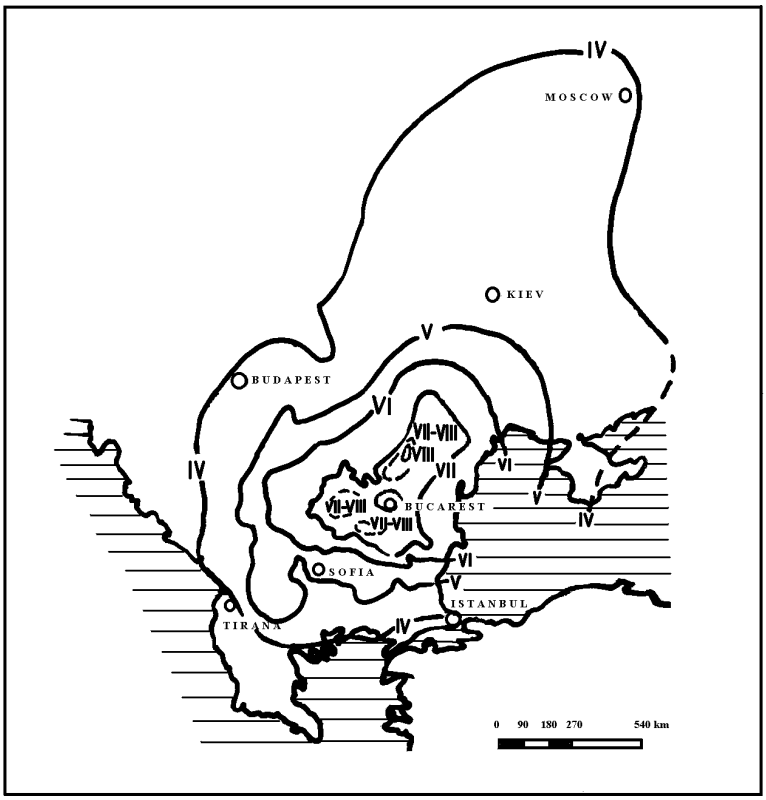

Fig. 2 Isoseist map of the March, 4, 1977, Vrancea, Roumania, earthquake (after Brankov, 1983)

The damages of the 1977 Vrancea earthquake were well analysed and synthesed in the Bulgarian monograph for the effects of the cited seismic event in the country (Brankov, 1983). Numerous institutes of the Bulgarian Academy of Sciences and some other state organisations had participate in the field observations and in the contacts with the peoples from the damaged regions. The obtained data were analyzed and synthesed in the monograph. The problems of the geological, the engineering geological and hydrogeological situation, of the seismological (Fig. 2) and the seismotectonic conditions, of the demolished and damaged residential buildings, industrial enterprises and various communications, of the social and the psychological effects on the society are discussed by experts (Brankov, 1983).

Analysis of the seismic effects on the coast

The 1940 and the 1977 Vrancea earthquakes had caused considerable deformations on the Danube River coast. The most distributed deformations were expressed by building's and

construction's destruction, by fracture's, landslide's, rockfall's activation, by liquefaction's manifestations etc.
The destruction of residential and public buildings, of various technogenic constructions were largely presented in the territory of the Danube River coast and related to the 1977 Vrancea earthquake. The mentioned seismic damages are developed in well populated territory with a big economic, scientific and cultural importance for the country.
The same earthquake had provoked also the formation and the activation of very impressive fractures, landslides, rockfalls between the towns of Vidin and Silistra along the investigated coast. The most significant ones were established in the rock basement of the towns of Nikopol, Svishtov and Rousse.
The presence of sandy and clay-sandy volcanoes in the Quaternary sediments were marked along the Danube River coast, the island Vardim and the Yantra River (the Danube River tributary). They were a subject of special research.
The earthquake had provoked also certain gravity phenomena. A lot of landslides and rockfalls were formed or activated along the investigated coast. The most representative of them were observed in of the towns of Nikopol and Svishtov.
Manifestations of local land subsidence were established mainly in the towns of Svishtov and Rousse. The land subsidence was of limited values of several cm or several tens cm. They were presented on mall spaces.
The changes in the ground water levels in the superficial part of the crust was established in certain towns and villages of the Danube River coast. The cited changes were provoked by the seismic movements.
The degree of the intensity and the spatial distribution of the seismic effects on the Danube River coast was analogous during the 1940 and the 1977 Vrancea earthquakes. The comparison could not to be doing in many details, because the information for the 1940 Vrancea earthquake's deformations in Bulgaria is very limited. We can only suppose the development of analogous deformation's processes in the both cases. The similar seismic effects could be caused by the numerous Vrancea earthquakes in the previous centuries. The documentation of the cited historic earthquakes is very limited. The small data are taken only on the basis of historical and archaeological documents and investigations.
The geoenvironmental conditions along the Danube River coast could be estimate like complicated. The complication is as a result of the very long-term seismic influence of the earthquake activity in the Vrancea region, the presence of active faults and the large distribution of young continental sediments with variable engineering geological and hydrogeological characteristics.

Conclusion

The forms and the intensity of the seismic effects are various along the Danube River coast. Their specificity is a subject of analysis and synthesis. The above mentioned specificity could be related to the main characteristics of the regional and local geoenvironment. The intensity and the forms of the seismic effects of the Vrancea earthquakes in Bulgaria depend generally from:

- the released seismic energy, defined by the magnitude M value of the Vrancea earthquake,
- the depth of the middle-focus seismic foyers, placed in the upper part of the upper mantle of the Vrancea region,
- the coordinates of the earthquake epicenters in the Vrancea region,
- the main direction of seismic energy's distribution, indicated generally by the orientation of the long axes in the isoseist's areas,
- the local lithological and engineering geological peculiarities of the Mesozoic-Neozoic sediments,

- the regional and local tectonic characteristics (recent block fragmentation and movements),
- the recent gravity processes,
- the changes in the ground water levels.

The intensity of the seismic influence of the Vrancea seismic events is closely related to two types of data. The data are for the main quality and quantity characteristics of the Vrancea earthquakes, from one side, and to the geological peculiarities of the investigated territory, from other one.

The long-term manifested and periodically repeated Vrancea earthquakes create considerable deformation of the crust and of the technogenic constructions on and in it. That is a real seismic effect. The earthquakes caused also the accumulation of potential possibilities for seismic deformations. That is a potential capacity for the crust deformation of the investigated coast.

The Danube River coast is well populated region of Bulgaria. It is of a big economical, political and cultural importance for the country. The Vrancea seismic danger causes some difficulties for the next development of the cited territory.

The complexity of the geoenvironment along the Danube River coast is the reason for the numerous specialised studies of the investigated region. Special methods are developed for the realisation of the technogenic constructions of high significance.

The scientific and economical needs of the country provoked the appearance of specialised institution for the Danube River coastal investigations. That is the Research Geotechnical Station in the town of Rousse. The Station is created by the Geological Institute of BAS in the second half of the 20th century. The Station is occupied generally by the Loess Engineering and the Engineering Geological Dynamics.

Acknowledgments

The study is doing on the basis of the published materials, also on the basis of author's field investigations along the Bulgarian Danube River coast in the spring of 1977. The research was realised in the frame of the Geological Institute's expedition. The expedition was organised for the documentation of the seismic effects in Northern Bulgaria in the first days after the 1977 Vrancea earthquake. The management of the expedition was realised personally by Acad. Prof. Dr. Ekim Bonchev, which interest for the seismotectonics was of a great importance for the Bulgarian science. Special thanks to the chiefs of the Geological Institute for the possibility to do field research.

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Variation of the Danube Floodplain Forest Transpiration during Vegetation Season

Ivan Mészároš

Abstract: There are a lot of very important parameters (hydrological, biological etc.) which could influence nature along the big man made water structures, like Gabcikovo water structure on the Danube river is. Measuring the transpiration by floodplain forest was done since 1991 on three monitoring plots covered by different tree species (oak-Quercus robur L., ash-Fraxinus excelsior L. and poplar-Populus). Results obtained since during several years show that the basic seasonal course of transpiration is determined by the vegetation cycle of deciduous forest, but substantially depends on the limiting soil water resources in one plot. On the other hand the results from the other two permanent plots show dominant influence of meteorological characteristics on transpiration instead of soil water resources which are not limiting factor, because the groundwater table is within the reach of root system of the trees.

Key words: transpiration, floodplain forest, hydrometeorological data, soil water content

Variabilität der Transpiration im Danauauenwald während der Vegetationsperiode

Zusammenfassungen: Es sind viele wichtige Parameter (hydrologischer, biologischer Natur etc.), die die Umwelt entlang von großen, von Mensch errichteten Wasserbauwerken wie z.B. Staudamm Gabcikovo am Donau, beeinflussen können. Seit 1991 wird hier die Transpiration in Wäldern im Überschwemmungsgebiet überwacht. Die drei Beobachtungsgebiete sind mit drei unterschiedlichen Baumarten (Eiche-Quercus robur L.; Esche -Fraxinus Excelsior L. und Pappel-Populus) bewachsen. Die Ergebnisse aus der mehrjährigen Beobachtungszeit zeigen, daß die zeitliche Entwicklung der Transpiration vom Vegetationszyklus der Laubwälder und vor allem von den begrenzten Bodenwasser Ressourcen im betreffendem Gebiet abhängig sind. Anderseits zeigen die Ergebnisse aus zwei anderen Überwachungsgebieten einen überwiegenden Einfluss von meteorologischen Gegebenheiten auf die Transpiration. Das Bodenwasser ist nicht mehr ein limitierender Faktor, da der Grundwasserpegel innerhalb der Reichweite des Wurzelsystems der Bäume liegt.

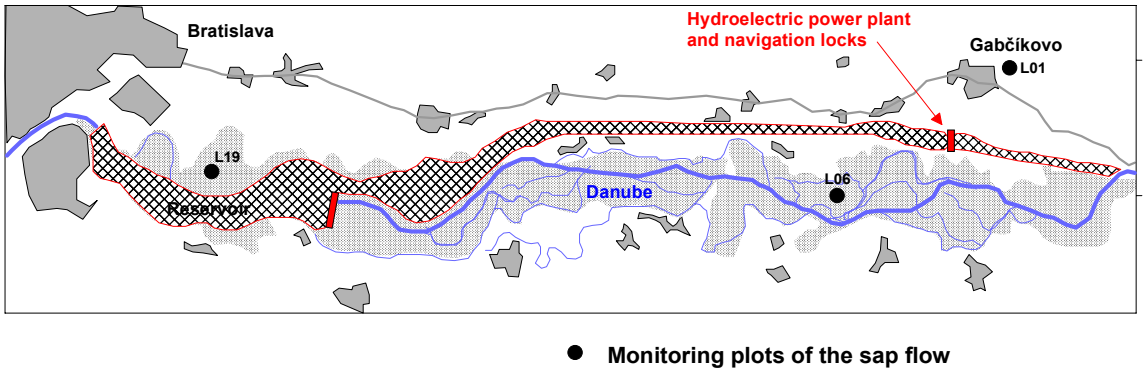
Schlüsselworte: Transpiration, Auenwälder, hydrometeorologische Daten, Bodenwassergehalt

1 Transpiration of water through the forest ecosystems

Direct measurements of transpiration by floodplain forest was needed for monitoring of the water requirements of vegetation cover under natural and later also man affected hydrological regimes within the inundation area of the Gabcikovo hydraulic structure on the Danube river. Three main transpiration monitoring plots (L01, L06, L19) are shown on the Fig. 1. They were selected with the aim to find different influence of the Gabcikovo hydraulic structure on the surrounding floodplain forest environment. Plot number L06 is in the area with the direct influence of water structure, where the ground water table is in the reach of the forest root. Plot number L19 is in the area where ground water table is very deep (till 6m). The importance of direct and continuous measurements of transpiration depends upon the immediate assessment of water consumption by vegetation, the evaluation of disposable soil water resources and vegetation conditions.

Testing the equipment started during the second half of the vegetation season in 1990 on two representative plots in Gabcikovo (L01) and Kralovska luka (L06). Measurements of the

selected trees (oak-Quercus robur L. in Gabcikovo and poplar-Populus in Kralovska luka) continued during 1991.



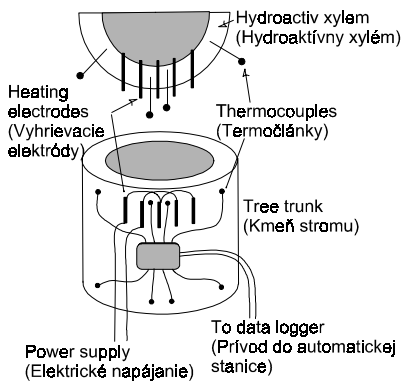
Monitoring of the transpiration continued during the vegetation season in 1992 on the same sites and selected trees. In 1993, after the reservoir was filled in, and the hydropower plant in Gabcíkovo put into operation, monitoring of the transpiration continued in Kralovska luka (L06) and was furthermore located next to the reservoir in Podunajske Biskupice (L19).

During the vegetation season in 1994, 1995 and 1996 monitoring of transpiration continued on the same sites. Results are published in the reports (Molnar, Meszaros, 1991, 1992, 1993, 1994, 1995, 1996).

Soil water content was observed close to the transpiration plots, as it is mentioned in other paper at this conference by Miklanek and Meszaros "Soil water storage in the Danube floodplain forest in Slovakia".

Sap flow was calculated from the data monitored in 20 minutes time step and related with the other hydrometeorological data measured next to the selected trees.

The below described method of sap flow measurement has been tested, calibrated and used on different tree species and under different hydrological and/or morphological conditions. The flatland features of the Danubian floodplain forest are favourable for the use of method. There is



no problem with slope orientation, altitude and shading effect of the relief as in mountainous areas. It is easier to find some relationships between measured sap flow and other

supplementary meteorological characteristics. Calculation of water balance always requires clear definition of the catchment area. In mountainous areas it is necessary to take in account both, horizontal and vertical parts of water fluxes, in comparison with floodplain areas where the horizontal part could be neglected as runoff occurs exceptionally.

2 Method of measurements and equipment

The continuous measurement of sap flow within the stem of selected tree is based on heat balance method by Cermak, Deml and Penka (1973). This non-destructive method depends on accurate measurements of the heat conductivity in the active xylem of a plant. For constant heating 5 electrodes are used. The electrodes are placed into the measured segment of a stem, so that the whole cambial profile is heated. Temperature of the hydroactive xylem is measured by 8 thermometers arranged in two levels just below and over the electrodes (Fig.2). Recorded difference of temperature (up to 3 degrees of Celsius) or so called cooling effect is related to the speed of sap flow in the hydroactive xylem, which allows to account the amount of water consumed for transpiration. Recorded differences of the sap flow temperatures together with the power input, distance and number of electrodes, and finally circumference of the tree, are input parameters for determination of the intensity of transpiration of the selected representative tree.

The actual sap flow Q_{wt} is result of separation according to the equation (1)

$$Q_{wt} = Q_{wt,rec} - Q_{wt,sep} \tag{1}$$

where : $Q_{wt,rec}$ - recorded sap flow [$l.hrs^{-1}$]

$Q_{wt,sep}$ - separated part of sap flow on the level of night values which represent heat losses [$l.hrs^{-1}$]

The recorded sap flow $Q_{wt,rec}$ is calculated according to the equation (2)

$$Q_{wt} = \frac{P \cdot \Delta t}{\Delta T \cdot c_w} \cdot \frac{O_{bk}}{d \cdot (n-1)} \tag{2}$$

where
- P - is wattage [W]
- Δt - time interval [s]
- ΔT - measured differences of sap temperature [^oC]
- c_w - specific heat of water 4 186.8 [$J.K^{-1}.kg^{-1}$]
- O_{bk} - tree circumference without bark [cm]
- d - distance of electrodes [cm]
- n - number of electrodes

3 Interpretation of monitored data

Transpiration through the forest is a final product of interrelation of different phenomena. The dominant diurnal course of transpiration with daily maxima between 12:00 and 15:00 hrs., is mainly determined by physiological processes of vegetation and considerably reduced by occasional rainfall. The transpiration intensity within a day also depends on solar radiation, air

temperature, humidity and wind speed. All these meteorological characteristics have not been measured on all the sites selected for monitoring of transpiration, and therefore, the most related and easy measurable, the air temperature and global radiation over the canopy, were chosen and recorded.

Changes of disposable soil water resources have the most significant influence on transpiration in the case of floodplain forest. Results obtained since 1991 show, that the basic seasonal course of transpiration is governed by the vegetation cycle of deciduous forest, but substantially depends on the limiting soil water resources in Podunajske Biskupice (L19). On the other hand the results from the two permanent plots in Kralovska luka (L06) and Gabcikovo (L01) show dominant influence of meteorological characteristics on transpiration instead of soil water resources which are not limiting factor. The groundwater table is within the reach of root system of the trees. The close relationship between the diurnal course of transpiration and global radiation is documented on Figures 3, 4, 5. The diurnal course of transpiration, naturally remained depending on the meteorological conditions and rainfall in every particular day of the season.

During the year 1995 and 1996 mean soil moisture on the *monitoring plot L01* was 30 – 40%, mainly influenced by underground water table, which was within the range 200 and 260 cm below the surface. The underground water table was mostly under the reach of root system of the trees. The close relationship of transpiration and measured global radiation is shown on the Figure 3. Dominant influence of global radiation is determined by regression coefficient r = 0.8 which was in the year 1996 and r = 0.95 in the year 1995.

Very similar results were obtained from the *monitoring plot L06.* Mean soil moisture was in the range 40 – 50 %. There was no soil moisture limitation for the floodplain forest. Therefore close relation ship between transpiration and global radiation r = 0.8 is shown on the Figure 4.

Soil moisture on the *monitoring plot L19* was during several years 5 – 28.6 %. The underground water table was within the range 320 – 350 cm and was not under the reach of root system of the trees. As it is shown on the Figure 5, transpiration is quite low, with rapid decrease at the beginning of August. It is due to low soil moisture and leaf fall of the trees.

Table 1 Basic characteristics of the monitored tree and their daily means of transpiration.

Station	**Species**	**Characteristics Girth(cm)/height(m)**	**Daily transpiration ($l.day^{-1}$)**			**Obs. Period**
			Min.	**Max.**	**Mean**	
L 01	Oak	77.5 / 10.5	2.3	34.4	13.8	V –IX 1992
L 01	Oak	77.5 / 10.5	0.3	84.8	32.1	VI – IX 1995
L 01	Oak	77.5 / 10.5	0.8	126.0	25.3	VI – XI 1996
L 06	Poplar	98.0 / 31.5	290.3	1 029.8	699.1	VII –VIII 1992
L 06	Poplar	98.0 / 31.5	95.1	417.0	232.3	VI – IX 1992
L 06	Ash – tree	128.0 / 35.0	72.3	736.6	318.2	VII – X 1993
L 06	Ash – tree	128.0 / 35.0	1.5	551.1	134.2	VI – IX 1994
L 06	Ash – tree	128.0 / 35.0	0.5	210.6	48.4	VI – IX 1995
L 06	Ash – tree	128.0 / 35.0	0.0	164.17	39.4	VI – XI 1996
L 19	Oak	70.0 / 9.0	0.9	21.6	7.5	VIII –X 1993
L 19	Oak	70.0 / 9.0	0.5	72.5	23.9	VI – X 1995

The significant ecological and also water resources management parameters are daily sums of transpiration of the selected tree species. As it has been stated, the daily sums of transpiration vary due to the characteristics of studied trees, as well as due to meteorological characteristics, rainfall and disposable soil water resources. The Table 1 shows the daily means of transpiration

of the selected trees, including the measured variability of daily transpiration for a given period of time.

The values presented in figures and/or table confirm rather stable moisture conditions on permanent monitoring plot in Gabčíkovo (L01) and improved conditions in the middle of inundation area in Kráľovská lúka (L06) due to the water supply into the Danube river branches system. The selected oak in Podunajské Biskupice (L19) which is close to the reservoir, despite of rising groundwater levels in 1993 (1.95 - 2.10 m from the ground surface), has not indicated a considerable improvement of its vitality so far. A further improvement of the situation in the area of Podunajské Biskupice is expected.

The water balance which included precipitation, runoff, soil water storage and evapotranspiration was calculated for Kralovska luka plot (L06) taking into account the infiltration into the groundwater. The mentioned area was analysed also by Sutor et al. (1997) and Novak et al. (1998). The surface runoff from the subject flat area was neglected. Then the cumulative actual evapotranspiration was calculated and compared with cumulative measured transpiration. Obtained results prove the dominant role of tree transpiration which is in the studied case 67 % of the actual evapotranspiration and allow to determine the actual water resources for studied forest ecosystem. The above mentioned results are published by Molnar, Meszaros (1995b).

Finally, the monitored data allow to conclude that the proper knowledge of the diurnal and seasonal courses of transpiration by selected representative trees gives us an unique opportunity to define the actual state of the studied forest ecosystem. Presented quantified information has the authentic value for optimalization of the Gabcikovo water distribution system in real time, and not after some damages on floodplain forests are visible.

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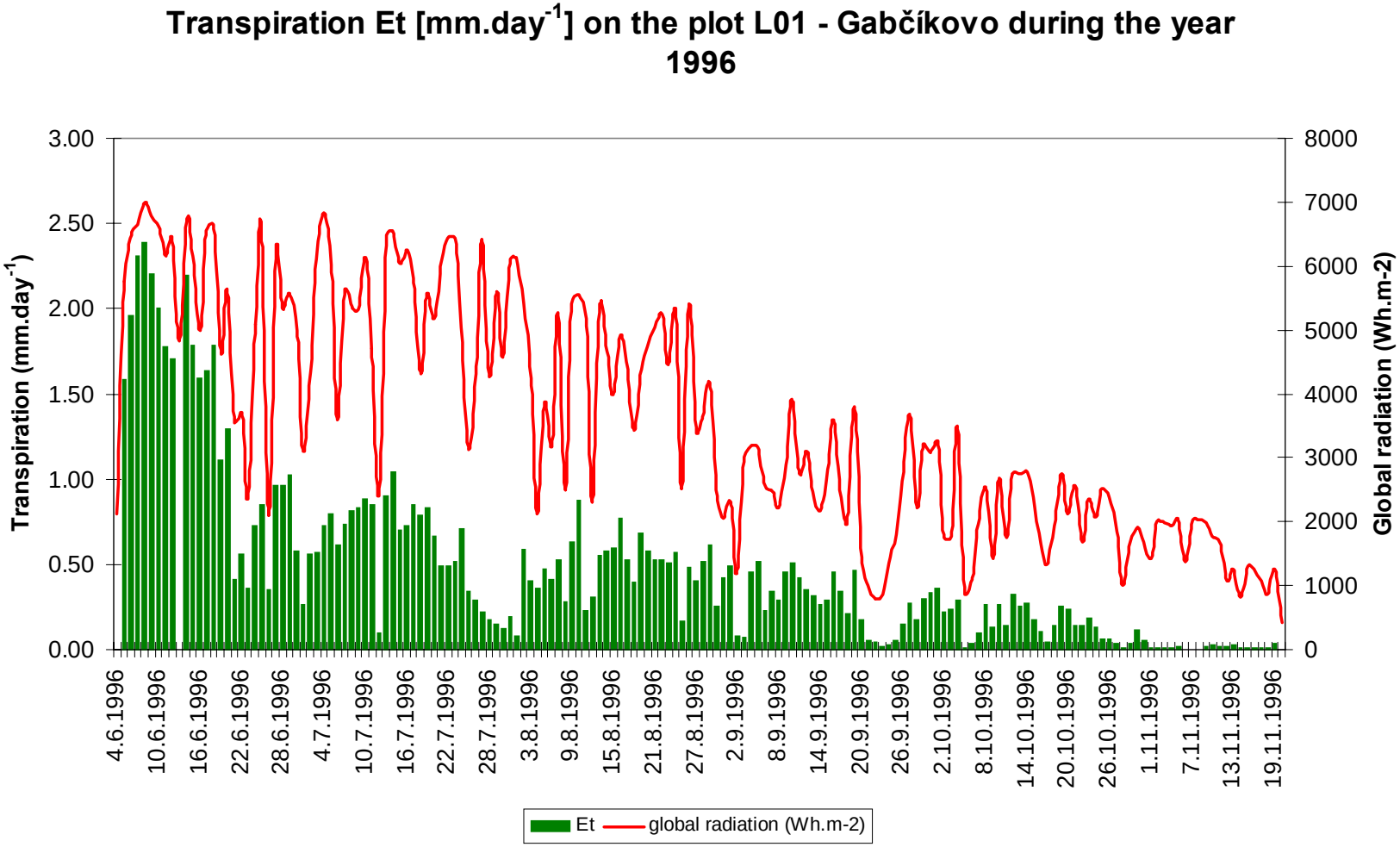

Fig. 3 Transpiration Et [mm.day^{-1}] on the plot L01 - Gabčíkovo during the year 1996

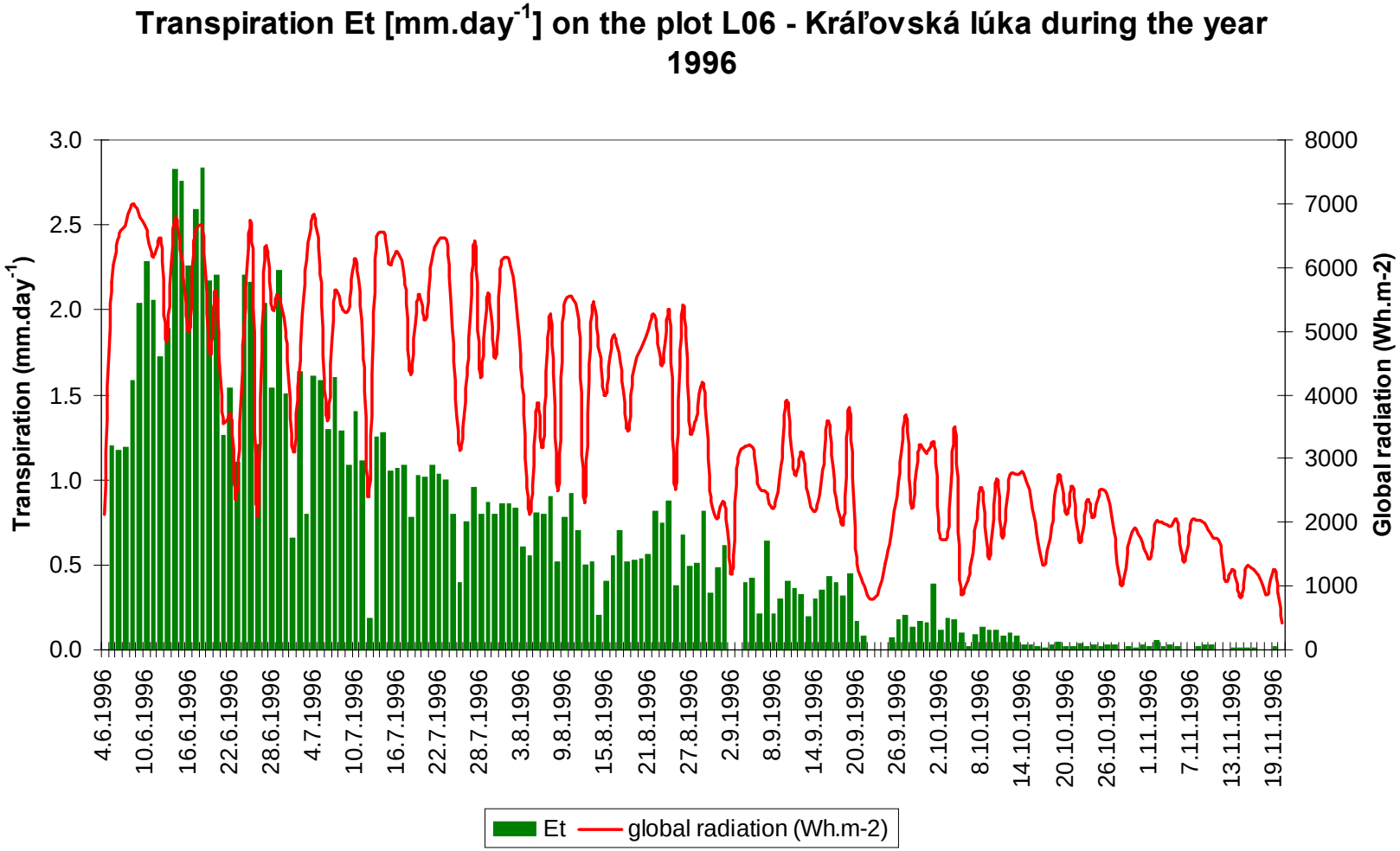

Fig. 4 Transpiration Et [mm.day-1] on the plot L06 - Kráľovská lúka during the year 1996

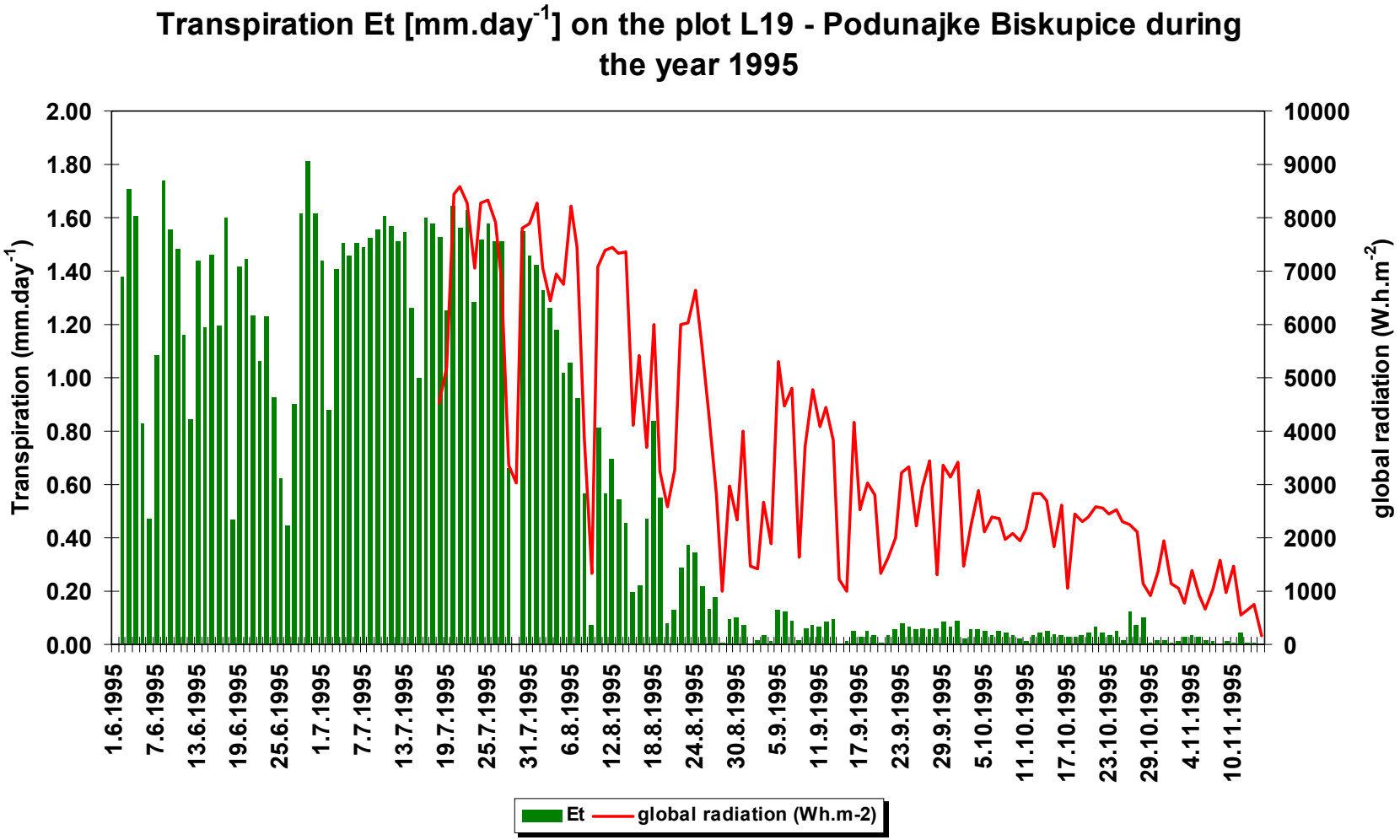

Fig. 5 Transpiration Et [mm.day-1] on the plot L19 – Podunajske Biskupice during the year 1995

Soil Water Storage in the Danube Floodplain Forest in Slovakia

Pavol Miklánek, Ivan Mészároš

Abstract. Totally 23 sites are monitored within the floodplain forests since 1996. Eleven of the sites are situated along Danube river between the old river and the new inlet channel for the water power plant. Other twelve sites are on the left bank of the Cunovo reservoir near to Bratislava. The soil water content is calculated from the soil moisture data by standard technique. The paper describes the temporal and spatial variability of the soil water content in layers with different depth. This data is important for evaluation of the disposable water for plants and their growing.

Key words: floodplain, Danube, soil, moisture, water storage

Bodenwassergehalt im Donauauenwald in der Slowakei

Zusammenfassung. Insgesamt 23 Stellen sind in dem Donauauenwald seit 1996 gemessen. Elf Stellen liegen entlang der Donau zwischen dem alten Fluss und dem neuen Wasserkraftwerkkanal. Andere zwölf Stellen liegen am linken Ufer des Wasserspeichers Cunovo in der Nähe von Bratislava. Der Bodenwassergehalt wurde aus der Bodenfeuchtigkeit standardweise berechnet. Die zeitliche und räumliche Veränderlichkeit des Bodenwassergehaltes ist für die unterschiedlichen Bodenschichten beschrieben. Diese Daten sind für die Einschätzung des verfügbaren Wassers für die Planzen und ihren Wuchs wichtig.

Schlüsselworte: Aue, Donau, Boden, Feuchtigkeit, Wassergehalt

1 Introduction

Soil moisture and groundwater table monitoring is one of the key parameters for detection of the Gabcikovo water structure impact on environment. The complex monitoring system is operated because of its potential environmental impacts. It includes all possible impacts - climate, water, forests, agriculture, health aspects, etc.

The soil moisture in floodplain forests along the Danube river is studied in this contribution. Soil moisture is the main water source for vegetation and its insufficiency or abundance may significantly influence the forest. The essential change in moisture conditions may force vegetation cover changes.

The Gabcikovo water structure is a huge hydroelectric system or barrage system on Danube river on Slovak-Hungarian borders. It is in operation since early 90'ties. The main idea behind the barrage system construction was the multipurpose complex solution of the watershed situation. The complexity is created by the following purposes of the system:

- a perfect protection against floods at Danube lowland,
- excluding the worst, from the navigability point of view, ford river section,
- exploitation of the river energy potential by the water power plants,
- creating new recreation and water sport conditions for the inhabitants of Bratislava.

Generally, near the water reservoir the groundwater levels rise, at the central part they are stable and at the lower part they decrease. The soil and ground water regimes are influenced, too. As this region is very rich in water used for water supply, the pollution concerns are important, too.

The impact of ground water level fluctuation on the moisture condition is evident. It is also evident that the soil moisture reflects the image of the geological profile, granulometric structure of the sediments and impact of the so called capillary barrier (Hlavaty et al., 1999).

2 Soil water content

The soil moisture is monitored at 23 sites within the floodplain forests since 1996. They are marked as L01 – L24. The monitoring site L02 was excluded from the monitoring after the optimisation of the networks (Molnar, 1995).

The localisation of the individual monitoring sites is in Fig. 1. One group of the sites is situated along Danube river between the old river channel and the new inlet channel for the water power plant, and the other one on the left bank of the Cunovo reservoir.

During the vegetation season selected sites are monitored weekly, other ones each two weeks or monthly. During winter all the sites are monitored monthly.

Similar program of soil moisture monitoring was also organised in agricultural areas around the area (Novak et al., 1998; Sutor et al., 1997).

The soil moisture is measured by the Neutron Probe System IH-II produced by Didcot Instruments (Bell, 1987). Error analysis in estimating soil water content from neutron probe measurements from both local and spatial standpoint was studied by Haverkamp et al. (1984) and Vauclin et al. (1984).

The volumetric soil moisture distribution in depth depends mainly on soil profile lithology (clay, peat, loam, sand, gravel layers). Its variation in individual layers is not so high, mostly. In some localities and depths (surface layers and groundwater contact) does atmospheric precipitation and groundwater table movement modify this situation more significantly.

The soil water content in this paper is calculated from the volumetric soil moisture data by standard technique in 10 cm layers and integrated for the upper 100 cm soil layer. This data is important for evaluation of the disposable water for plants and their growing.

The soil moisture monitoring sites are grouped in two regions (Fig. 1). The first 11 sites (L01-L12, except L02) are located in the floodplain forest between the old river channel and the new inlet channel for the water power plant, and the other one on the left bank of the Cunovo reservoir (L13-L24).

These two main groups of monitoring sites have a different hydrological behaviour. This fact is demonstrated by two typical examples of L05 (Fig. 2) and L19 (Fig. 3). In these figures, there is the instantaneous soil water storage in upper 100 cm soil layer in [mm] during the whole 4-years period of 1996-1999.

The first area is typical by higher soil water content and more smoothed regime. The annual regime is not very marked. The monitored sites in the second area have generally lower soil water content and a very marked annual regime. The highest values are in late spring (April-May) and the lowest values in autumn (October).

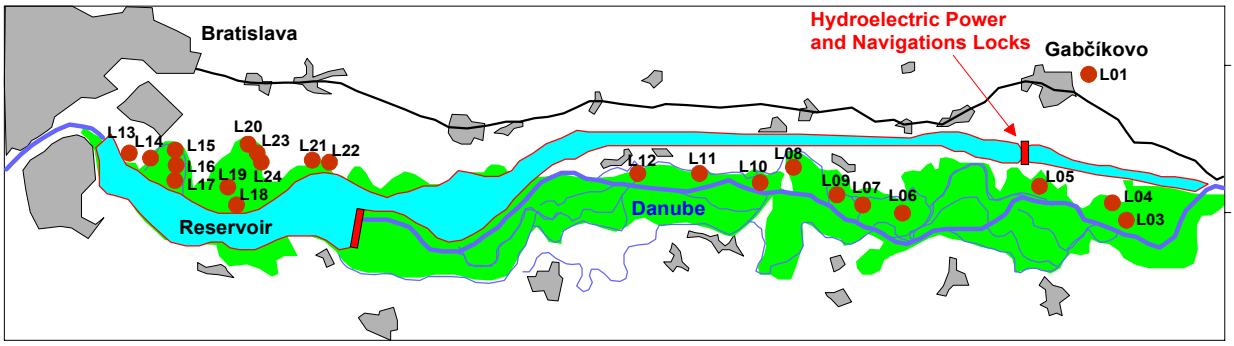

Fig. 1 Soil moisture monitoring sites in floodplain forest around Gabcikovo water structure.

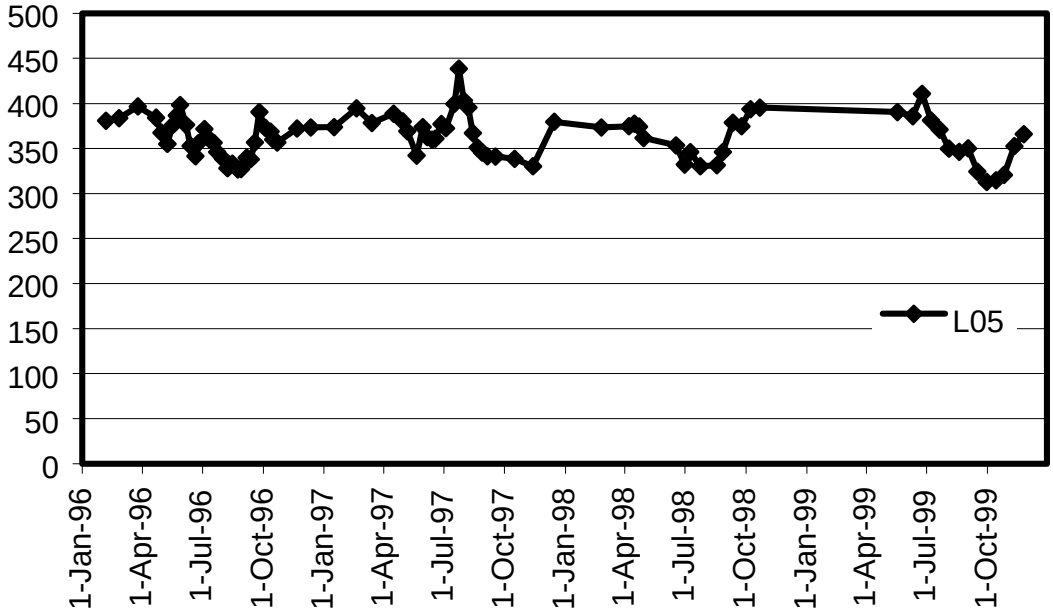

Fig. 2 Instantaneous soil water storage in upper 100 cm soil layer in [mm] at measuring site L05 in Danube floodplain forest.

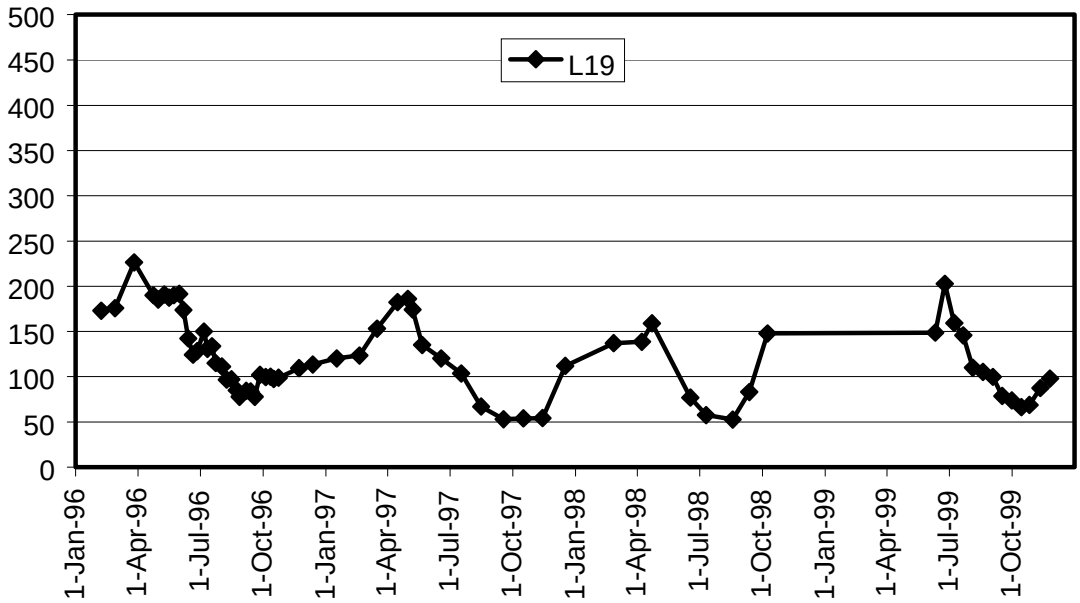

Fig. 3 Instantaneous soil water storage in upper 100 cm soil layer in [mm] at measuring site L19 in Danube floodplain forest.

The temporal variability of the soil moisture in different depths during the year is illustrated by the chronoizopletes (depth-time-soil moisture plot). An example of the monitoring site L05 in 1997 is in Fig. 4. The solid bold line also shows the ground water level.

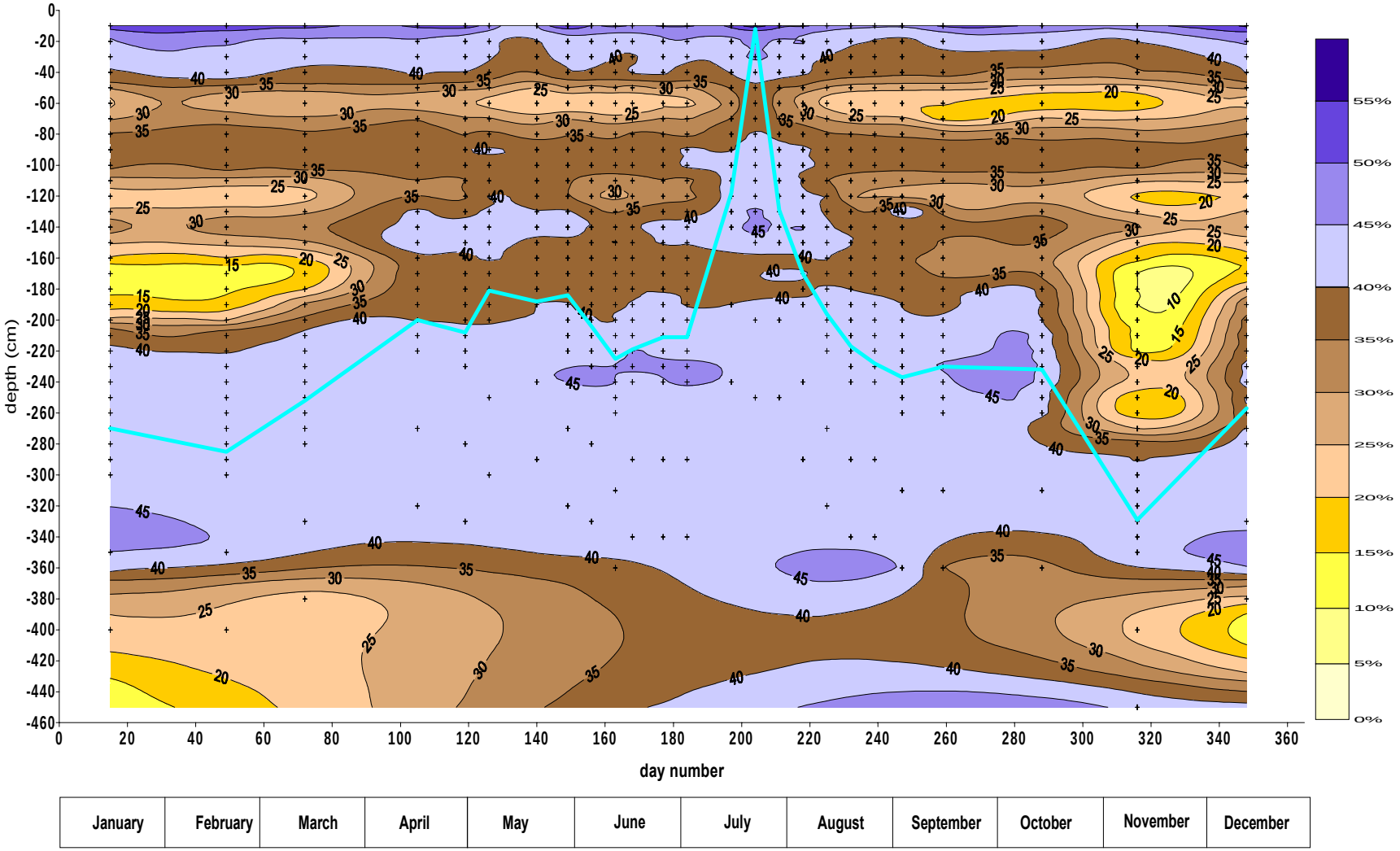

Fig. 4 Chronoizopletes (depth-time-soil moisture plot) at monitoring site L05 in 1997.

3 Mean annual regime of the soil moisture content

The mean annual regime of the soil moisture content is important parameter for the water availability for plants. This is particularly important in floodplain forest. The water stress in longer periods can damage the plants and ecosystems and influence the forest management.

Four years of data collection (1996-1999) allowed to derive the mean annual regime of the soil moisture content in studied area. The presented results should be considered as preliminary ones from two reasons.

Firstly, the 4-years data series are not long enough from the statistical point of view. Secondly, the temporal frequency of data collection is not equal in all stations and all years. Generally, the presented mean values represent 4-years, but they were obtained from different number of samples in individual months and years. In some sites some of the winter data are missing completely (L08, L14, and L16).

Mean monthly soil water storage in upper 100 cm soil layer at individual measuring sites in Danube floodplain forest is in Table 1. The data are better to be interpreted from Figs. 5 and 6. In Fig. 5 there are the measuring sites from the first area between the old river channel and the new inlet channel, while in Fig. 6 there are the sites near the Cunovo reservoir.

Table 1 Mean monthly soil water storage in upper 100 cm soil layer in [mm] at individual measuring sites in Danube floodplain forest

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
L01	281	320	354	355	333	280	256	218	223	228	230	259
L03	311	303	331	387	432	380	376	296	328	251	279	285
L04	332	311	337	303	364	315	326	292	245	214	265	271
L05	374	383	387	377	377	366	369	346	351	354	354	376
L06	430	415	424	426	431	421	430	414	419	421	421	425
L07	252	254	265	249	260	238	241	222	220	206	217	251
L08	387	364	399	381	380	345	339	338	336	322	304	
L09	200	241	279	272	298	241	209	169	158	152	164	200
L10	222	302	326	293	271	234	224	216	209	198	189	239
L11	136	186	216	205	195	155	143	144	142	121	136	134
L12	310	306	337	298	321	264	251	251	223	215	252	262
L13	203	241	280	291	258	209	193	156	156	148	156	188
L14		292	312	305	286	237	229	224	214	237	217	251
L15	328	342	347	350	341	314	300	311	353	327	339	335
L16		193	220	196	191	137	131	112	157	159		
L17	85	131	136	126	143	84	63	55	90	84	81	81
L18	193	217	220	213	228	210	197	194	209	183	196	194
L19	120	145	190	174	172	129	111	80	77	92	85	113
L20	199	233	270	268	237	198	167	129	129	134	153	186
L21	176	210	223	240	221	159	143	105	110	142	125	154
L22	325	327	319	319	337	288	285	282	330	317	322	323
L23	69	117	162	157	122	73	59	47	49	48	50	70
L24	131	180	246	251	235	167	133	90	93	88	94	124

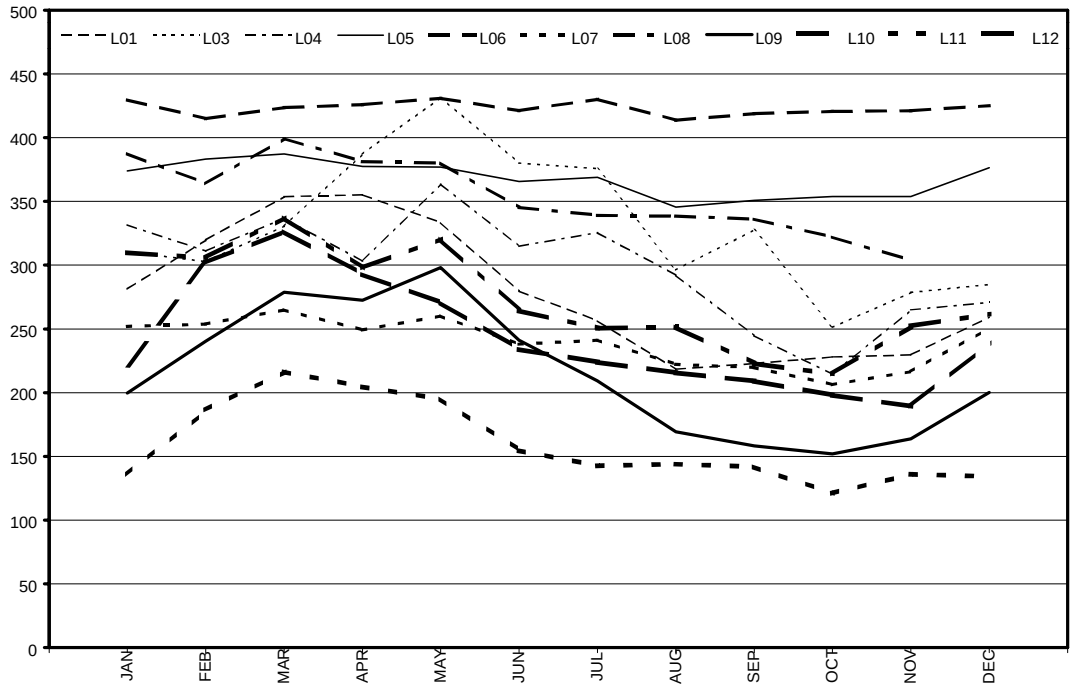

Fig. 5 Mean annual regime of the soil water storage in upper 100 cm soil layer in [mm] at individual measuring sites in Danube floodplain forest in surroundings of Gabcikovo.

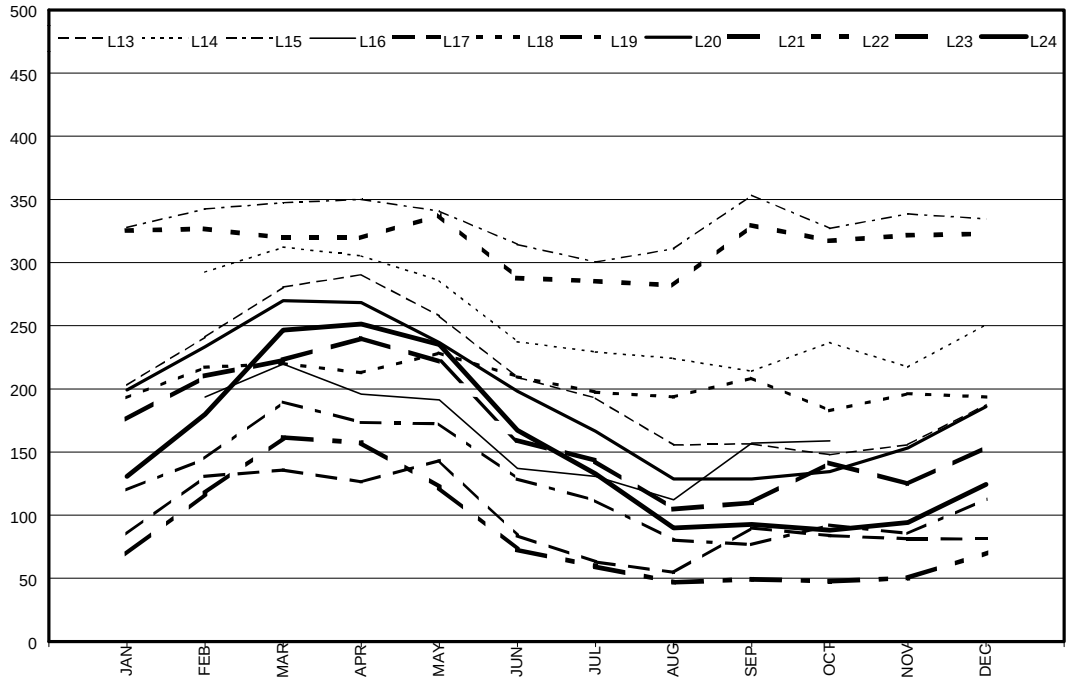

Fig. 6 Mean annual regime of the soil water storage in upper 100 cm soil layer in [mm] at individual measuring sites in Danube floodplain forest near Cunovo reservoir.

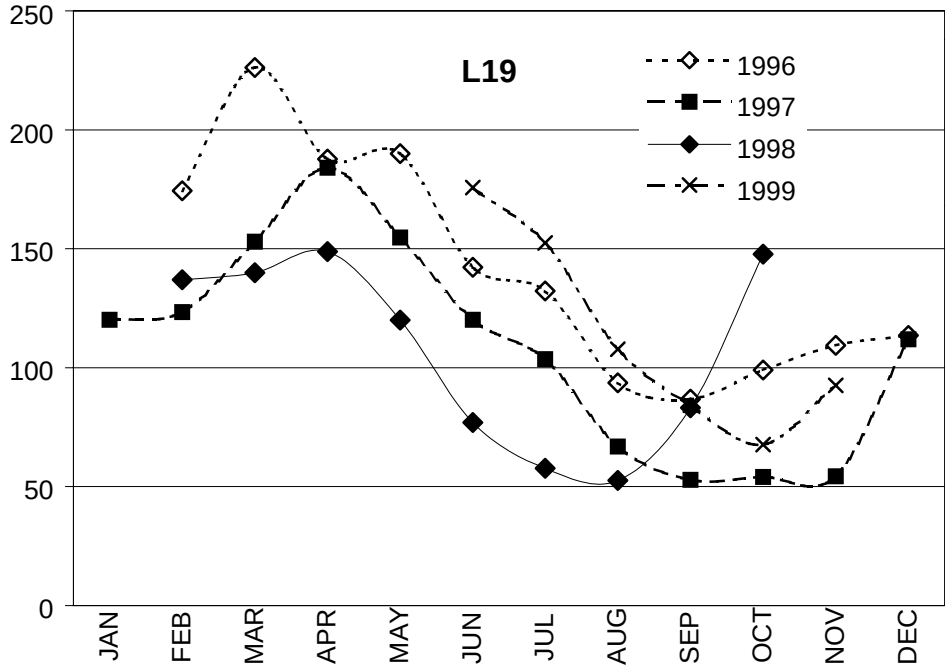

Fig. 7 Monthly soil water storage in upper 100 cm soil layer in [mm] at L19 site in Danube floodplain forest near Cunovo reservoir in individual years.

The variability of the monthly soil water storage in upper 100 cm soil layer in individual years is demonstrated in Fig. 7 showing the values for L19 site in Danube floodplain forest near Cunovo reservoir.

4 Conclusions

The soil water content was estimated in 23 sites in the floodplain forest in surroundings of the Gabcikovo water project on Danube river. There are two major forested floodplain areas.

One area is situated between the old river channel and the new artificial intake channel of the power plant, and the second area is on the left bank of the Cunovo reservoir near to Bratislava. The areas differ in the hydrological behaviour due to different ground water conditions. The difference is also obvious in the soil water content regime.

The first group of the localities is typical by higher soil water content and the annual regime is not very marked. It is related to the ground water levels, which are also relatively high. The area is in good hydraulic connection with the water levels in the old river channel and also in the inundation area side arms, which are supplied by surface water from the water power plant intake channel.

The second group of the localities is typical by lower soil water content and the annual regime is in most of the sites very marked with maximum values in March-May and minimum values in September-November. It is also related with the ground water levels, which are relatively deep under the soil surface. The relatively stable water level in the neighbouring water reservoir increased also the ground water levels in the area by up to 2 m after construction of the dam.

The high spatial and temporal variability of soil moisture and relatively short time series of monitored data do not allow to make definite conclusions on the water structure impacts. On the other hand, the soil moisture monitoring during the few years after operation of the structure did not show significant permanent changes.

Considerable decrease of ground water level, which occurred in the last 30 years before putting the project into operation, is evident mainly in the upper part of the area. The changes in the ground water levels in the flood-plain area, and generally in the whole region, confirm the positive impact of the project, in particular on the upper part of Zitny ostrov, and an important positive role of the water supply system for the left side Slovak flood-plain area since 1993. The measurements of the ground water levels confirm that there is a general trend towards the re-establishment of the situation known some 30 years ago on the greater part of the territory. After the putting of the project into operation, there is an improvement of the water supply to soils via capillary transport in the upper part of the area in comparison with the pre-dam conditions (Hlavaty et al., 1999).

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Palaeogeography of the Danube and Its Catchments

Ferenc Neppel, Miklós Domokos, Sándor Somogyi

Abstract: The hydrological cooperation of the Danube Countries, commenced in 1972, resulted in 1986 in publishing the Danube Monograph. It created also the framework for the compilation of further follow-up volumes, including that about the palaeogeography of the Danube. – The "backbone" of this work are nine synoptic palaeogeographic maps, each of which displaying the general hydrographic situation of the Danube Catchment during a selected geological age. – The work outlines first the present situation in the Danube Catchment in physico-geographic, hydrographic, hydrographic and political terms. This gives, on the one hand, a useful orientation in the study of the palaeogeographic development in Chapter 4, where regular reference to today's conditions is made, and on the other hand, it defines and characterizes the three main regions (Upper, Central, and Lower Danube Region). – A historical overview follows about the palaeogeographical research in the Danube Catchment. This was considered necessary to pay due tribute to the scientists who had created the basis for the present up-to-date compilation. – Chapter 4 of the work, finally, is devoted to the very actual topic itself, presenting an in-depth treatment of the palaeogeographic development of the Danube Catchment, commenting the synoptic maps designed by F. NEPPEL and referring occasionally to explanatory illustrations.

Key words: palaeogeography, hydrography, orography

Paläogeographie der Donau und ihres Einzugsgebietes

Zusammenfassung: Die 1972 begonnene hydrologische Zusammenarbeit der Donauländer führte 1986 zur Herausgabe der Donaumonographie und schuf auch den Rahmen für die Erstellung weiterer Folgebände, darunter auch des Werkes über die Paläogeographie der Donau. Das "Rückgrat" des Werkes bilden neun synoptische paläogeographische Karten, die jeweils die allgemeine hydrographische Situation für einen bestimmten geologischen Zeitabschnitt veranschaulichen. – Im Band werden zunächst die gegenwärtigen physisch-geographischen, hydrographischen, gewässerkundlichen und politischen Verhältnisse des Donaueinzugsgebietes skizziert. Dies dient einmal der Orientierung beim Studium der paläogeographischen Entwicklung in Kap. 4, wo laufend auf die gegenwärtige Situation Bezug genommen wird, zum anderen werden auch die drei Hauptregionen (Oberes, Mittleres und Unteres Donaugebiet) definiert und charakterisiert. – Es wird dann ein geschichtlicher Überblick über die Forschungen zur Paläogeographie des Donaueinzugsgebietes gewährt. Dieser Überblick schien notwendig, um die Bemühungen der Wissenschaftler zu würdigen, welchen die Grundlagen dieser zeitgemäßen paläogeographischen Zusammenfassung zu verdanken sind. – Kapitel 4 des Werkes befaßt sich mit dem schwerpunktmäßigen Thema, indem es in chronologischer Reihenfolge die paläogeographische Entwicklung des Donaueinzugsgebietes ausführlich behandelt, bzw. die durch F. NEPPEL entworfenen paläogeographischen Karten kommentiert und gelegentlich auf erklärende Abbildungen verweist.

Schlüsselworte: Paläogeographie, Hydrographie, Orographie

Introduction

The folow-up volume No. V/2 of the Danube Monograph (1986), "Palaeogeography of the Danube and its catchment", compiled by the competent experts of the cooperating Danube Countries under Hungarian coordination, has been published, with a substantial support of the UNESCO ROSTE Office, Venice, in December 1999 in Budapest.

The volume intends, in the first line, to present a comprehensive description of the palaeogeographic development of the River Danube. With a catchment of 817,000 km² it is the second largest river in Europe. To give a well-balanced, up-to-date overview, all relevant

information on this topic – from scientifically substantiated facts to theories and hypotheses – had to be collected, selected, and arranged for presentation. The review given is based on material supplied by experts in the cooperating Danube countries and is – of course – only one of several possible concepts. Before going to press, the manuscript was reviewed by these experts, so that the whole volume can be considered as a kind of collective opinion of all those who contributed.

Background

Chapter 1 describes the hydrological cooperation between the Danube countries that had begun as early as in 1972. In 1986, the Danube Monograph was published, and it set the frame for follow-up volumes, including the one at hand. It is confined in its scope in so far as some topics, which are treated in other volumes, like questions of solids transport or impacts of anthropogenic activities, are omitted here. The "backbone" of the volume consists of nine synoptic palaeogeographic maps.

Chapter 2 outlines the present situation in the Danube basin in physico-geographic, hydrographic, hydrologic, and political terms. This gives, on the one hand, a useful orientation in the study of the palaeogeographic development in Chapter 4, where regular reference to today's conditions is made, and on the other hand, it defines and characterizes the three main regions (Upper, Central, and Lower Danube Region) and the two outer boundary areas (Uppermost Danube Region and Danube Delta).

Chapter 3 gives a historical overview on research in the palaeogeography of the Danube basin. This was found necessary to pay due tribute to the scientists to whom we owe this modern palaeogeographic compilation. A number of selected works are cited, from MARSIGLI (1726), CVIJIČ (1908), FINK (1966), NICULESCU (1977) to MIKE (1991) and other contemporary authors. A first series of paleogeographic maps comprising three sheets had been designed already by FINK (1966) and gave the inspiration for the development of nine similar maps in the present volume.

Chapter 4 is devoted to the actual topic itself and presents an in-depth treatment of the palaeogeographic development of the Danube catchment basin, commenting the palaeogeographic maps designed by F. NEPPEL, and referring occasionally to explanatory illustrations.

Description of palaeogeographic evolution

Tertiary

The Danube Catchment belongs to the zone called "Neo-Europe", which joined the continent only through the Tertiary orogenesis. In the Tertiary, the Danube Catchment was a part of the so-called Paratethys, a branch of the Tethys, the proto Mediterranean Sea. Young mountain chains developed from the Tethys through plate tectonic processes: the Alps, the Carpathian Mountains, the Dinarides, and the Balkan Mountains. These elements of the so-called alpidic system were separated from each other by depressions, which acted as sinks for the debris delivered from the rising mountains.

Miocene

In the Miocene and Pliocene, the sea was still prevailing, but it gained increasingly the character of an archipelago. The nuclei of the later mountain chains emerged as islands from the relatively shallow sea. Intensive erosion – conditioned by the sub-tropical climate in the late Miocene – compensated their rise mostly; a process which furnished also the material for the onsetting silting-up of the sea basin. From this time, no rivers are known which can be assigned to the Danube system.

The rivers that exist nowadays appeared for the first time in the Middle Miocene. They emerged as small river systems, partly on the islands in Paratethys Sea, but preferentially in the coastal zones of the surrounding mainland. Independently from each other they flowed into the separate arms and bays of the Parathetys. It is striking that the water divide of the former Parathetys is – except in

some single stretches – identical with that of the Danube Catchment today. Only at some locations did an exchange of areas occur to a limited extent between neighbouring basins.

Pliocene

During the Pliocene, the erosion process intensified further due to the stronger uplift of the mountains. The masses of debris gradually filled up the arms of the sea. Progressing subsidence of single blocks created a system of sub-basins, a process that was typical particularly for the Pannonian Basin, i.e. the Middle Danube Region. In the second half of the Pleistocene, the water depth in the sea further decreased; first it became brackish, and then it freshened completely. What was once the Paratethys, turned into a network of lakes, swamps, and watercourses. This fluviolacustrine system disappeared only when the residual lake Geta silted up completely in the first half of the Pleistocene.

Pleistocene

Periodic cooling of the climate during the Pleistocene led to partial or – as in the Alps – to complete glaciation of the still rising mountains. Physical weathering, that prevailed in the Pleistocene cold periods, generated vast volumes of solid material, which could then fill the basin of the Danube up to today's level. Where the watercourses coming from the mountains entered the lowlands, they built up large alluvial fans and bedload ramps, while shifting their courses permanently. Conversely, in glaciation-free mountains, the river courses were fixed by continuous incision. In ice-covered areas, the valleys were strongly re-shaped by glacial erosion, while in ice-free mountain regions and uplands, terraces could develop as a consequence of climate variations.

The Upper Danube Region suffered massive areal losses in the Pleistocene, *inter alia* through the connection of today's Alpine Rhine and the River Reuss to the Rhine river basin. The Danube was pushed towards the northern margin of the Swabian-Bavarian Basin, while the tributaries coming from the Alps permanently changed their courses, with a prevailing tendency of shifting their mouths towards the east.

The Central Danube Region has been characterized since the end of the Pliocene by distinct variations of the river's course. Following the aggradation of the Vienna Basin, the Danube first flowed along the eastern margin of the Alps southwards, to turn then at the southern border of the Pannonian Basin towards the east, thus reaching the Iron Gate. Tectonic processes during the Middle Pleistocene made the Danube flow downstream of the Vienna Basin directly eastwards to the Visegrád Pass, where it accumulated one of its largest alluvial fans, called Ostrov and Szigetköz. Downstream of the Visegrád Gate, it was gradually filling up the depression of the Great Hungarian Plain, while its flow direction slowly turned towards south.

Shifting of the main river and ongoing tectonic processes (lifting and subsidence) had strong influence on the development of the courses of the tributaries entering the lowland plain from the uplands. Towards the end of the Pleistocene, swamps and some larger lakes emerged (Neusiedlersee/Fertő and Lake Balaton).

In the Lower Danube basin, the variations of the river courses were less significant. Due to climate-induced low flow, the tributaries coming from the mountains soon deposited their coarse bedload material, so that only smaller volumes of solid material (mainly suspended matter) reached the Danube. Its river valley, structured by several terraces, stretched along the southern margin of the Romanian Lowland.

In the early Pleistocene, it met here a swampy flat which it filled up gradually. When Geta, the last residual lake, was silted up, the river finally found its way to the Black Sea. Its first mouth was south of the Dobrogea region, but due to the tectonic uplift of this area in the second half of the Pleistocene, it was forced to take a roundabout way along the northern margin of the Dobrogea. Because of climate-induced variations of the water level of the Black Sea in the order of 70 to 80 m, a rather far east-west shift of the debouchure took place. Even today, one finds traces of ancient

beds of the Danube on the seafloor. One of the most significant changes in flow direction was experienced by the River Olt, which originally had been a tributary to the River Mureş/Maros, but was then captured by a smaller, yet direct Danube tributary that had cut deeply into the Southern Carpathian Mountains, so that it was diverted towards the Danube. In this way, the Transylvanian Basin, that was originally uniform in hydrographic terms, became divided between the catchments of the River Tisza/Tisa and the Danube.

Holocene

At the beginning of the Holocene, the development of the present-day river system was nearly completed. Only three changes are worth mentioning. First, karstification of the Swabian Alb continued, with the consequence that a considerable portion of Danube's discharge has been reaching the Rhine basin underground via sinks. This process will lead after some time to the loss of the Danube headwater area.

Secondly, there was a tectonic uplift of the region Nyírség in the north-eastern part of the Great Hungarian Plain. This forced the River Tisza/Tisa to leave its original southward course towards the Criş/Körös Depression, to turn northwards, and to flow round the block of Nyírség. The Tisza/Tisa then followed the depressions along the northern margin of the lowland plain, so that its whole system of tributaries was re-structured.

Finally, in the early Holocene, the Black Sea transgressed into the debouchure area of the Danube up to the foreland of the Carpathian Mountains. This transgression, however, was limited in time, so that the Danube was then able to fill up the embayment and to develop over the past 2000 years its present Delta.

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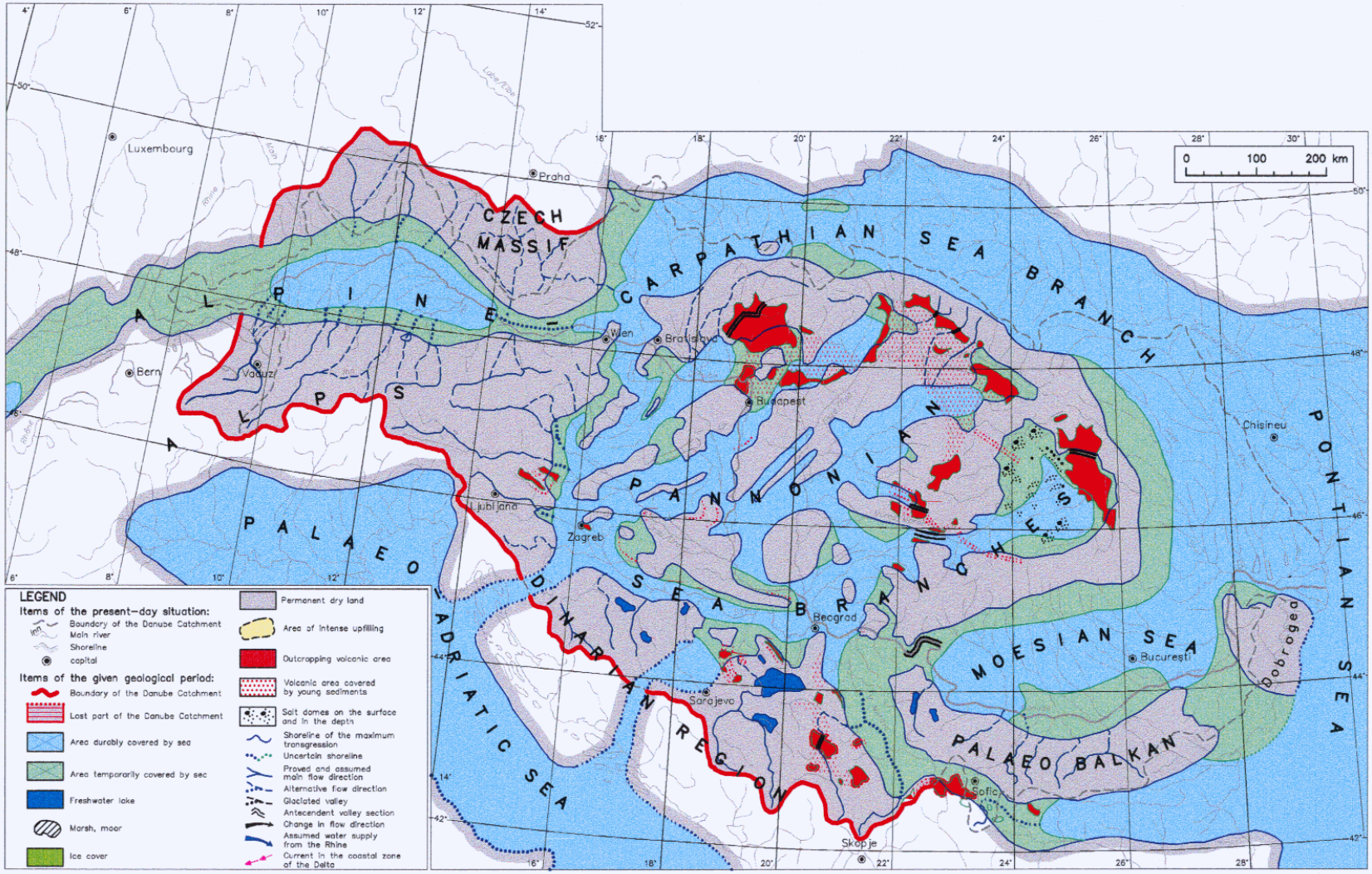

LEGEND
Items of the present-day situation:
Boundary of the Danube Catchment
Main river
Shoreline
capital
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Boundary of the Danube Catchment
Lost part of the Danube Catchment
Area durably covered by sea
Area temporarily covered by sea
Freshwater lake
Marsh, moor
Ice cover
Permanent dry land
Area of intense upfilling
Outcropping volcanic area
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Salt domes on the surface and in the depth
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Current in the coastal zone of the Delta
0 100 200 km
CZECH MASSIF
ALPINE – ALPS
CARPATHIAN SEA BRANCH
PANNONIAN SEA BRANCHES
PALAEO – ADRIATIC SEA
DINARIAN REGION
MOESIAN SEA
PALAEO BALKAN
PONTIAN SEA
Dobrogea
Luxembourg
Praha
Wien
Bratislava
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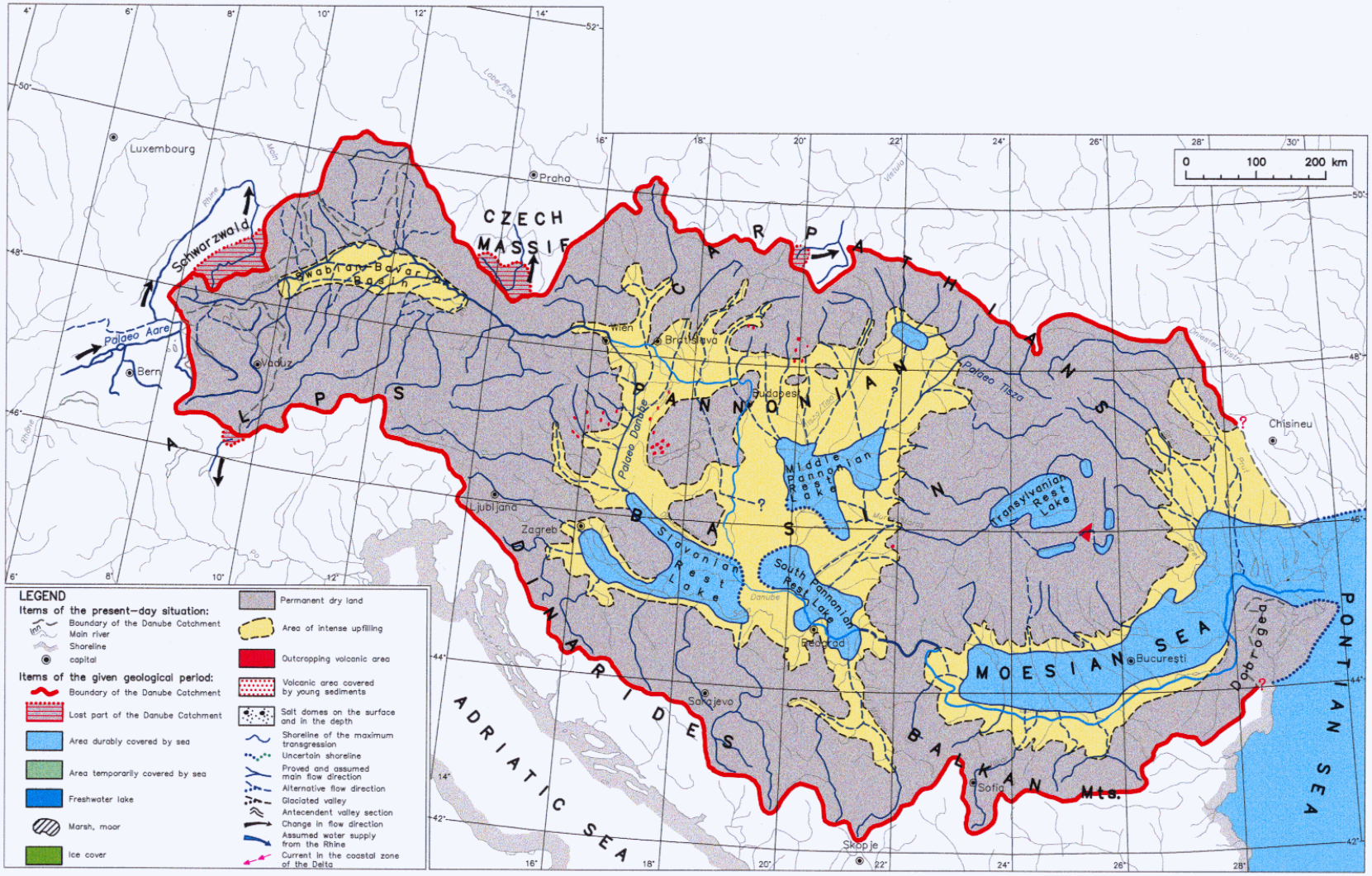

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Palaeo Danube
Palaeo Tisza
Middle Pannonian Rest Lake
Slavonian Rest Lake
South Pannonian Rest Lake
Transylvanian Rest Lake
Dobrogea
Luxembourg
Praha
Wien
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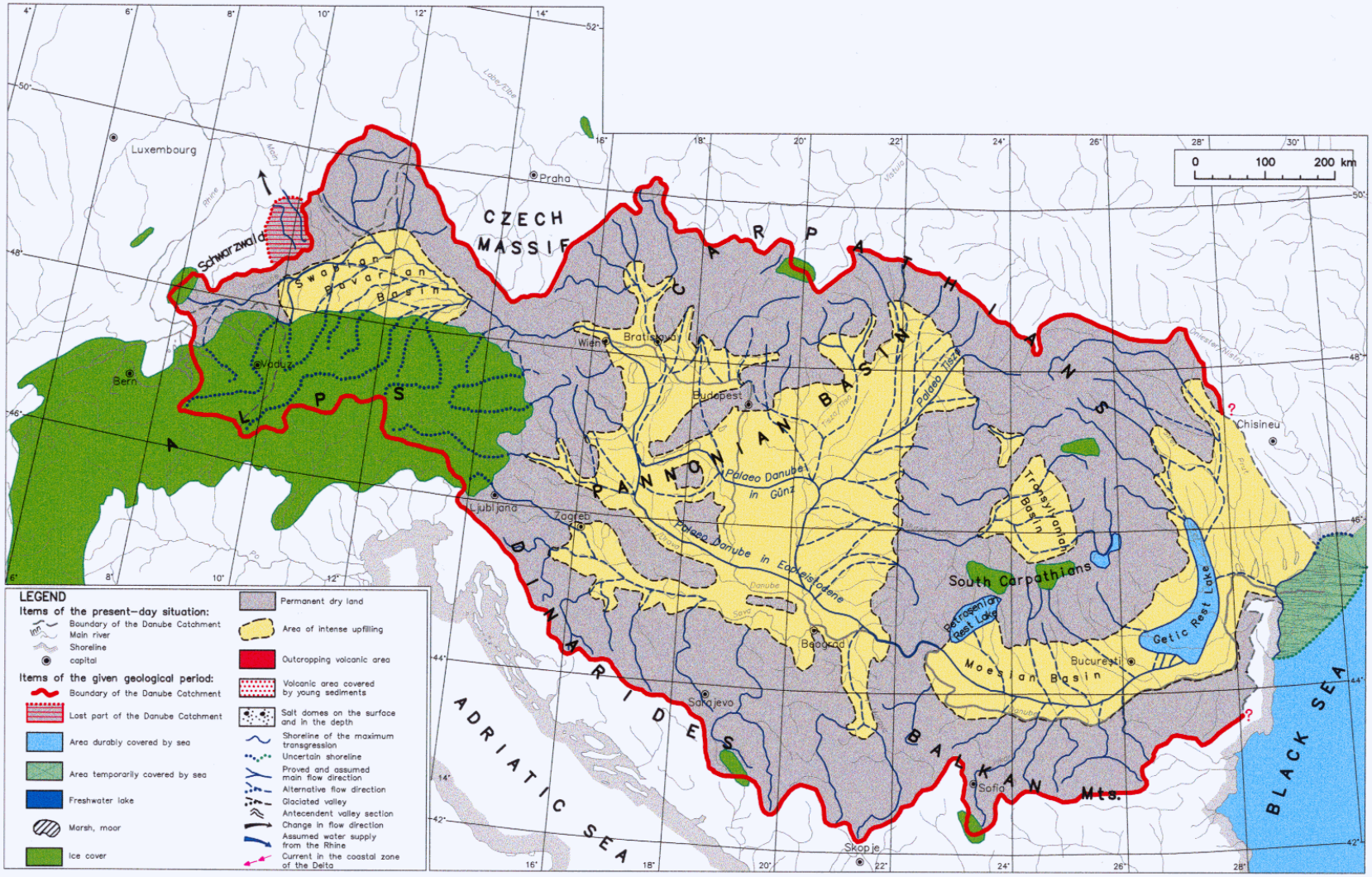
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BALKAN Mts.
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BLACK SEA
Schwarzwald
Swabian Bavarian Basin
Palaeo Tisza
Palaeo Danube in Günz
Palaeo Danube in Eocene/Oligocene
Transylvanian Basin
South Carpathians
Petroseni Rest Lake
Getic Rest Lake
Moesian Basin
Luxembourg
Praha
Wien
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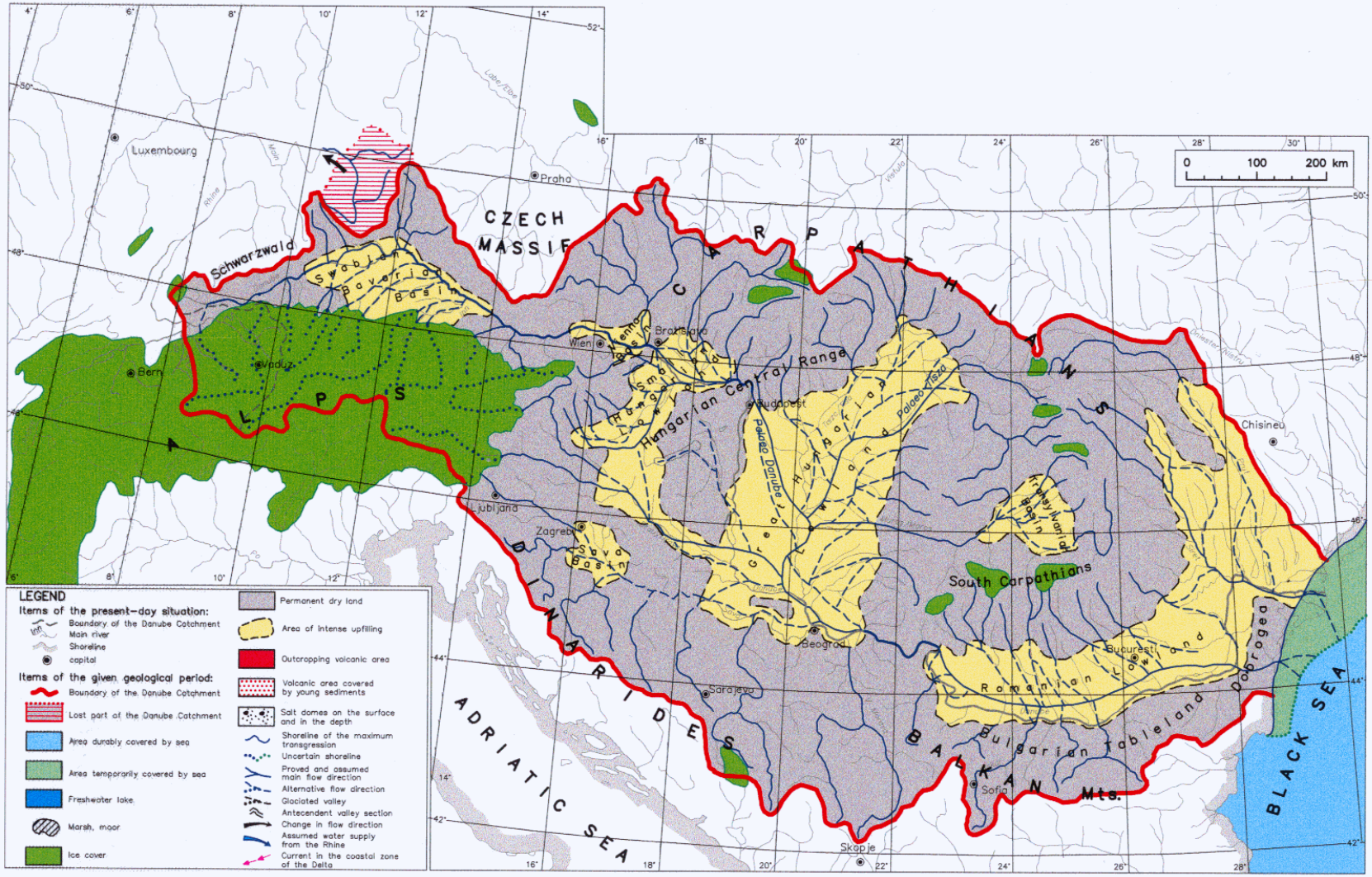

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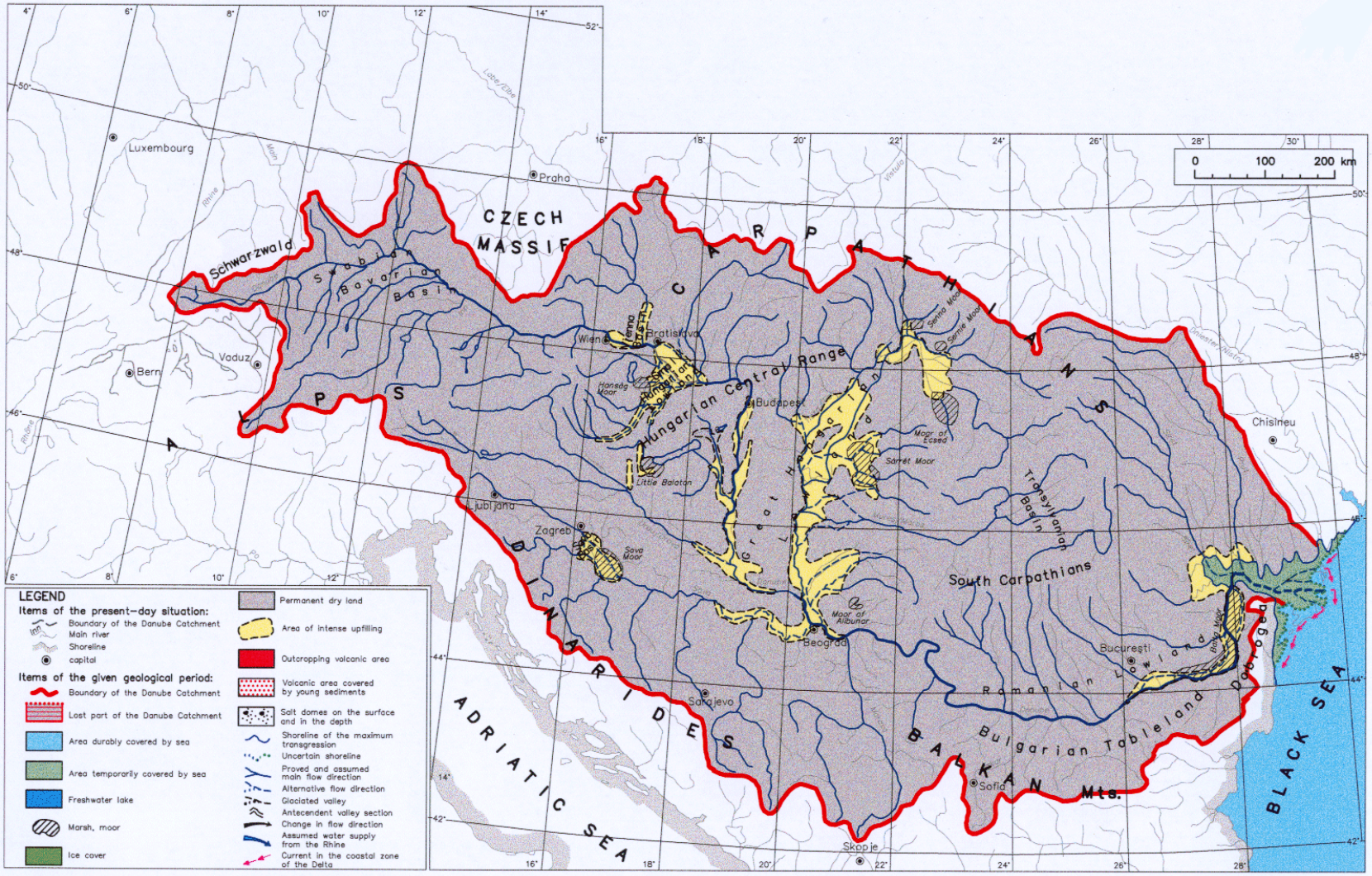

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Boundary of the Danube Catchment
Main river
Shoreline
capital
Items of the given geological period:
Boundary of the Danube Catchment
Lost part of the Danube Catchment
Area durably covered by sea
Area temporarily covered by sea
Freshwater lake
Marsh, moor
Ice cover
Permanent dry land
Area of intense upfilling
Outcropping volcanic area
Volcanic area covered by young sediments
Salt domes on the surface and in the depth
Shoreline of the maximum transgression
Uncertain shoreline
Proved and assumed main flow direction
Alternative flow direction
Glaciated valley
Antecendent valley section
Change in flow direction
Assumed water supply from the Rhine
Current in the coastal zone of the Delta
0 100 200 km
CZECH MASSIF
CARPATHIANS
ALPS
DINARIDES
BALKAN Mts.
ADRIATIC SEA
BLACK SEA
Schwarzwald
Swabian Bavarian Basin
Hungarian Central Range
Great Hungarian Lowland
Transylvanian Basin
South Carpathians
Romanian Lowland
Bulgarian Tableland
Dobrogea
Luxembourg
Praha
Bern
Vaduz
Wien
Bratislava
Budapest
Ljubljana
Zagreb
Sarajevo
Beograd
Sofia
Skopje
Bucureşti
Chisineu
Hansag Moor
Little Balaton
Sava Moor
Moor of Ecsed
Sarrét Moor
Moor of Alibunar
Senna Moor
Semie Moor
Rhine
Main
Lobe/Elbe
Vistula
Dniester/Nistru

Seasonal course of agricultural canopies evapotranspiration and its components over Slovakia

Viliam Novák

Abstract: Seasonal courses of agricultural canopies monthly evapotranspiration totals and structural components (transpiration and evaporation) are presented. Three agricultural canopies at the Trnava site (typical of the south - western lowland region of Slovakia) are evaluated: winter wheat, spring barley and maize. A modified Penman - Monteith type of equation was used for evapotranspiration daily totals and its components calculation, during the 1981 season. It is shown that seasonal totals of evapotranspiration of three canopies are close, but components of its structure are different in time. A map of long - time relative evapotranspiration (the ratio of evapotranspiration and potential evapotranspiration) is also given to characterize differences of soil water resources for plants over Slovakia.

Key words: Transpiration, Evaporation, Regional distribution of evapotranspiration, Evapotranspiration - Slovakia

Saisonalverläuf der Evapotranspiration und ihrer Komponenten von landwirtschaftlicher Vegetation in der Slowakei

Zusammenfassung: Im Beitrag sind die Jahresverläufe der täglichen Summenwerte der Evapotranspiration und ihrer Komponenten (Transpiration, Evaporation) dargestellt. Drei Vegetationsarten wurden im Raum Trnava, typisch für die südwestlichen Flachlandregionen der Slowakei, ausgewertet: Winterweizen, Frűhjahrsgerste und Mais,. Zur Berechnung wurde die modifizierte Penman - Monteith Gleichung verwendet. Es zeigt sich, dass die jährlichen Evapotranspirationssummen fűr alle drei landwirtschaftlichen Produkte im Jahre 1981 sehr nahe beieinander liegen, ihre Komponenten aber deutlich verschiedene Jahresverläufe aufweisen. Eine Karte der relativen Evapotranspiration (Verhältnis der Jahressummen der Evapotranspiration zur potentiellen Evapotranspiration) der Slowakei ist ebenfalls beigefügt, um die Unterschiede der für die Pflanzen verfügbaren Bodenwasserressourcen zu charakterisieren.
Schlűsselworte: Transpiration, Evaporation, Regionale Verteilung der Evapotranspiration, Evapotranspiration - Slowakei

1 Introduction

Vegetation plays a crucial role in energy and mass exchange in the soil - plant - atmosphere system (SPAS) especially in Europe, where majority of evaporating surfaces are represented by canopies of different kinds. Approximately 42 % of Slovak Republic area is covered by forests and nearly one third of republic territory is covered by agricultural canopies. Typical for agricultural canopies is, that spatial and time variability of their properties is significantly changing during the season because of relatively short vegetation period, which is starting and finishing with bare soil surface. Study of the impact of spatial variability of canopies distribution over the soil surface on transport processes in SPAS is of special importance. Very important is partitioning of evapotanspiration between its components - transpiration and evaporation, called evapotranspiration structure (Budagovskij, 1964). Because only transpiration is related to crop yields, its estimation is of special importance. In case of scarce

water resources, the schedulling of irrigation is usually based on evapotranspiration estimates. Large scale canopy structure changes can modify water balance of the region, therefore it is important problems to be solved.

This paper presents seasonal courses of the actual evapotranspiration and its components of agricultural canopies, represented by winter wheat, spring barley and maize at Trnava site (South Slovakia) as a results of mathematical modeling, of daily evapotranspiartion totals using the model HYDRUS -ET (Šimunek, et al., 1997). It makes possible to characterize different canopies by their albedo, roughness, leaf area index and soil water content. On the differences between canopies is focused our attention.

2 Estimation of evapotranspiration

Potential evaporation can be defined as an intensity of water evaporated from unit surface area under non-limiting water content of evaporating surface. Consequently, potential evapotranspiration E_0 can be referred to surfaces covered by vegetation adequately supplied with water. Quantitative definition of potential evapotranspiration is based on different formulas and resulting values can be different. The wide -spread quantitative definition of E_0 is given by the Penman (1948) formula.

Different methods are used for calculation of evapotranspiration, but many of them are based on Penman and Penman - Monteith approach (Monteith, 1965). It is supposed that HYDRUS - ET model used here can describe evapotranspiration from soil, covered by relatively dense and wet canopy. Nevertheless, model can be used with success even for sparse canopies. Sparse canopies differ from dense ones (in this model) by the roughness length, albedo, and leaf area index. The model reflects the above mentioned differences in different potential evapotranspiration, followed by different actual evapotranspiration and its structure.

Typical features of presented model are the following:

- potential transpiration of wet "big leaf" is calculated

-" big leaf" canopy is supposed with roughness length of a real canopy

Daily totals of evapotranspiration and elements of its structure, i.e. evaporation and transpiration were calculated using modified Penman method (Budagovskij 1981, Novák 1989, 1995, Novák, Hurtalová, 1987).

Presented method of calculation of evapotranspiration can be applied for a wide variety of evaporating surfaces. However, it is important, that the meteorological characteristics taken into account must be measured above the zero displacement level of canopies. It means that the standard meteorological characteristics cannot be used for calculation of the evapotranspiration rates from the high canopies (forest) because "standard" characteristics are usually measured above the low "grass" canopies. Therefore, to calculate forest evapotranspiration, the special measurements performed above the forest canopies are needed. The standard meteorological data employed for the calculation of evapotranspiration of the forest may lead to serious errors.

Daily totals of evapotranspiration and its structure can be calculated using standard meteorological data, soil and canopy properties were measured in the field. Net radiation was calculated and soil heat flux was neglected, because its average daily value is close to zero.

Soil water content profiles of the soil root zone were estimated simultaneously with evapotranspiration calculation using simulation model HYDRUS - ET (Šimunek, at al., 1997), to calculate necessary soil water content profiles. A series of another soil characteristics necessary for mathematical modelling were simultaneously measured according to standard methods : soil water retention curves, soil hydraulic conductivities, soil bulk densities, etc.,

(Kutilek, Nielsen,1995). Points of measurements and sampling were located at the middle of particular field.

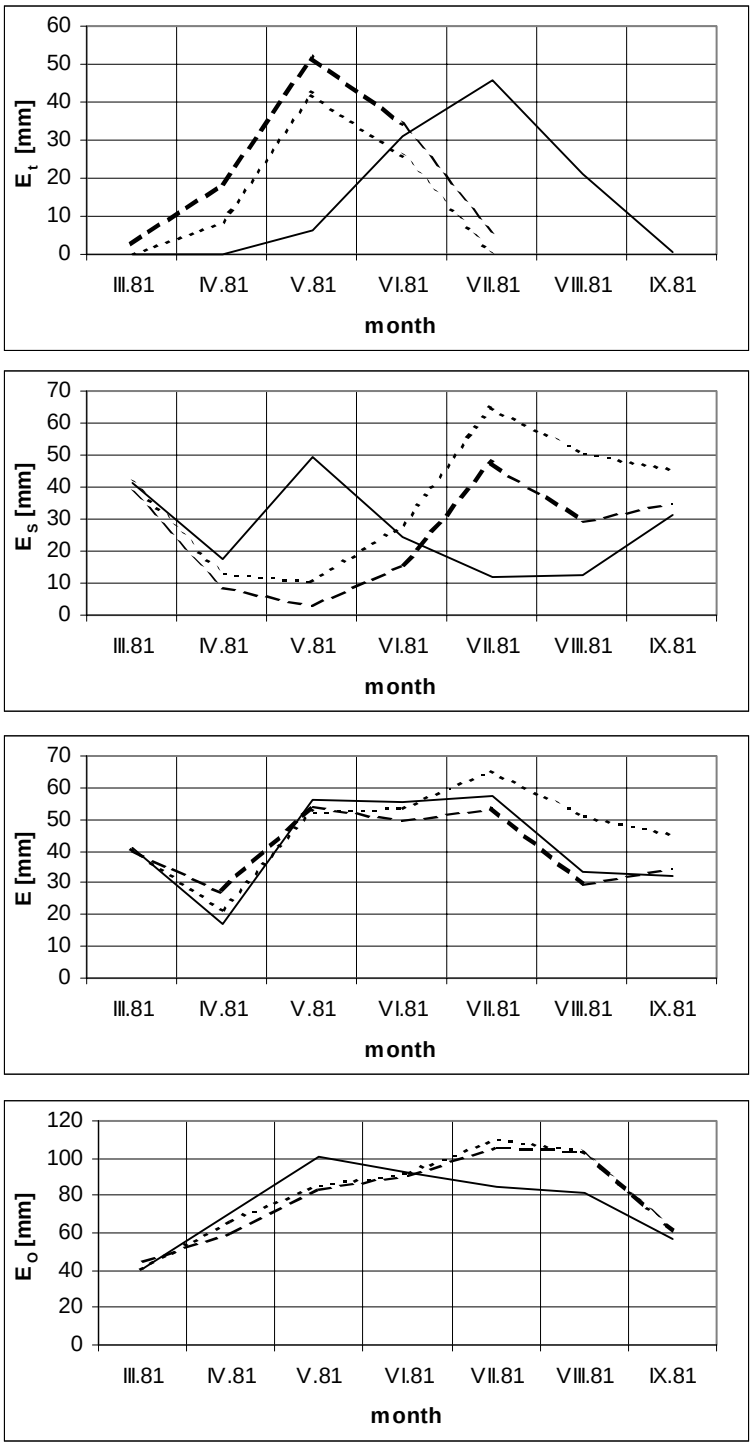

Fig. 1 Seasonal courses of monthly evapotranspiration totals and its components for three agricultural canopies - maize (-----), winter wheat (- - -) and spring barley (…..). E_t - transpiration, E_s- evaporation, E - evapotranspiration and E_o - potential evapotranspiration. Evapotranspiration and its components were estimated for Trnava locality conditions, (South Slovakia) during the year 1981.

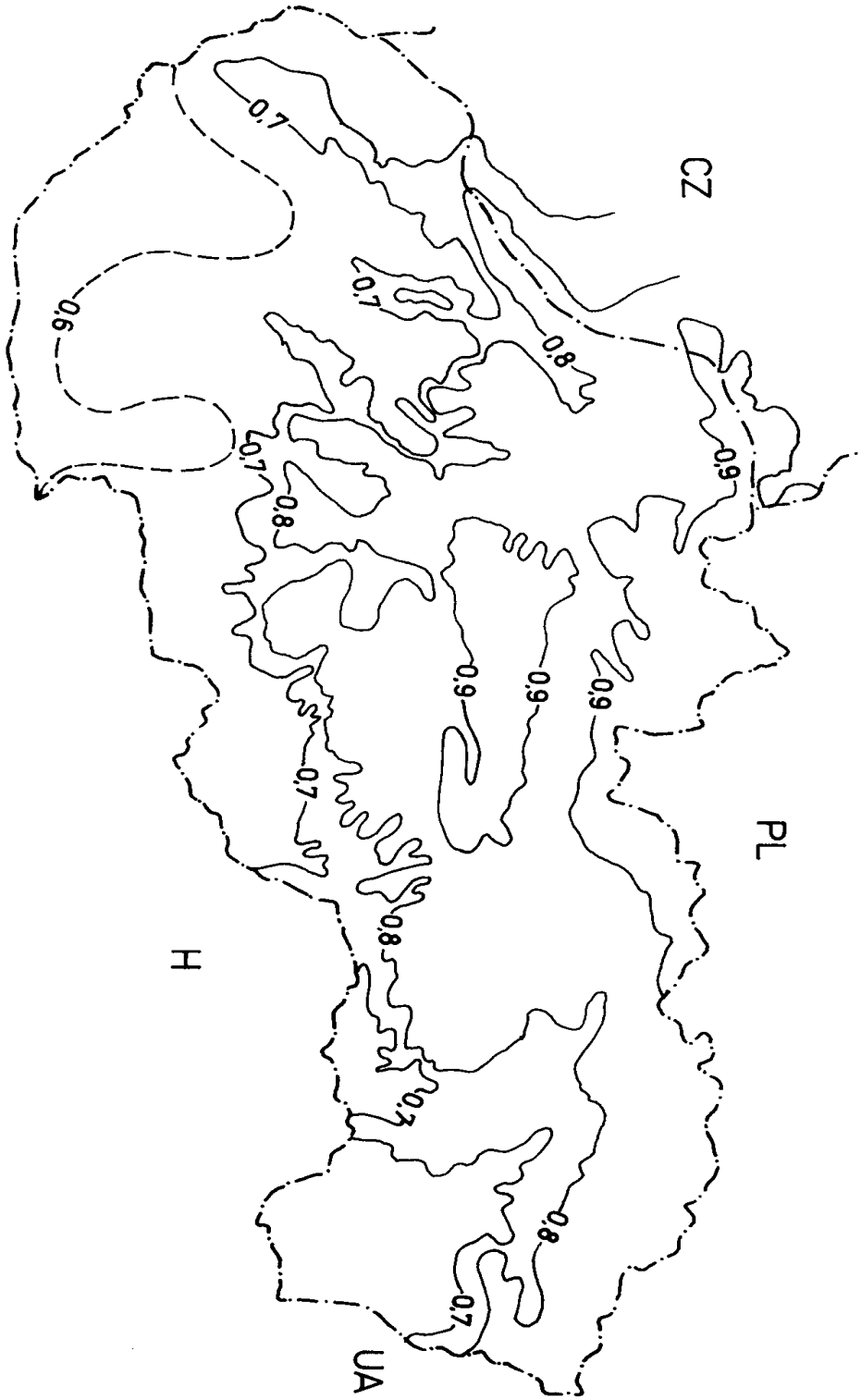

Fig. 3 Distribution of long time ratio of seasonal evapotranspiration to potential evapotranspiration of grass (E / E_o) over Slovakia for years 1951 - 1981. This distribution was designed using some data of Tomlain (1991).

3 Results and discussion

Figure 1 presents seasonal courses of evapotranspiration (E) daily totals, and components of its structure, transpiration (E_t), evaporation from the soil surface (E_s), as well as potential evapotranspiration (E_0) for three agricultural canopies maize, winter wheat and spring barley during the vegetation period (March – September, 1981) at Trnava agricultural site, estimated according to presented method.

What can be seen on this Figure ? At first, transpiration courses of particular plant are regular and they exactly characterize length of their vegetation period. Their shape is typical, triangular. Absolute values of those courses are given by meteorological conditions, but they can be taken as typical. Soil evaporation minimum usually takes place during the period of maximum transpiration intensity. During the majority of the vegetation period evapotranspiration totals of different green canopies are close, because evaporation from soil usually replaces transpiration decrease during early and late stages of vegetation period. Approximately the same can be stated for potential evapotranspiration.

Integral values of evapotranspiration and its structure as well as relative values of evapotranspiration components are in Table 1.Transpiration totals differ according to canopy type and transpiration maximum are shifted to different time intervals. Evapotranspiration totals of all the three canopies types studied are surprisingly close during the vegetation period as well as during the period March – September. The differences (Tab. 1) are not remarkable. The same can be told about potential evapotranspiration totals of canopies studied.

Presented courses of evapotranspiration were estimated for year 1981 and Trnava site (Southern Slovakia). Courses can be different for different sites (soil properties) and meteorological conditions. In Fig. 2, there are presented isolines of relative evapotranspiration (ratio of annual evapotranspiration and annual potential evapotranspiration) over Slovakia. Data published by Tomlain (1991) were used for its design and they are representing period (1951 – 1981), and grass canopy. Areas below ratio $E / E_0 = 0.7$ are supposed to be short of soil water resources and irrigation is needed, e.i., during the vegetation period occasional draughts are observed.

Table 1 Transpiration E_t evaporation E_S, evapotranspiration E and potential evapotranspiration E_o (in milimeters) for three different canopies at Trnava experimental site during the 1981 season.

Canopy	Vegetation period					March – September				
	E_t	E_s	E	E_0	E/E_0	E_t	E_s	E	E_0	E/E_0
Maize	105	187	292	526	0,55	105	187	292	526	0,55
Winter wheat	113	113	255	385	0,66	113	177	290	551	0,52
Spring barley	76	51	127	244	0,52	76	213	289	521	0,55

4 Conclusions

Time courses of evapotranspiration and of their structure are presented for three canopies as calculated by the HYDRUS – ET model for Trnava agricultural site, (Southern Slovakia).
The differences between canopy properties - as they are characterized in the above mentioned model HYDRUS – ET - are reflected mainly in different time courses of evaporation and transpiration. Surprisingly, seasonal courses of monthly evapotranspiration totals of all the three green canopies are close, in accordance with the old hypotheses of Penman (1948) stating, that all green dense canopies appropriately supplied with water can transpirate at approximately the same rates.
Transpiration totals during the vegetation period of particular plants are different. Especially, spring barley transpiration, evaporation and evapotranspiration totals differ significantly. Interesting is, that the ratio of evapotranspiration and potential evapotranspiration of all the three canopies studied are close during both vegetation period and all the season (March - September) with values between 0.52 - 0.55, with the only value 0.66 for winter wheat vegetation period. Probably due to vegetation period located in winter - spring time interval.

Courses of transpiration daily totals are of triangular shape, with distinct peak shifted to different time according to canopy type. Minimum evaporation daily totals correspond to maximum transpiration and on the contrary: maximum evaporation daily totals can be observed at time of minimum transpiration.
A map of long - time relative evapotranspiration (the ratio of evapotranspiration and potential evapotranspiration) is also given to characterize differences of soil water resources for plants over Slovakia. It can be noted, that $E / E_o < 0.7$ is supposed to be area in which irrigation is needed. Continuous clima changes during the last years can shift the ratios E / E_o to less favourable, i.e. lower values.

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Mapping Long-Term Regional Runoff/Precipitation Ratios in Slovakia

Juraj Parajka

Abstract: Knowledge of spatial distribution and variation of runoff can be useful for many water resources tasks. We conducted research to develop and test some spatially and statistically correct ways to create a mapping method, which would produce repeatable rational concept for the construction of long-term runoff map of Slovakia. In this study methods for the generation of the runoff-to-precipitation ratio (R/P) maps are tested as an approach for regional mapping of runoff. We have mapped the R/P ratios in two different ways. First method uses regression between measured values of runoff, elevation computed from digital elevation model and precipitation values. Second method computes the R/P ratio maps using different interpolation techniques and measured runoff and precipitation values.

The quality and cross-consistency of the resulting grid R/P maps has been tested against measured station data, as well as within the framework of the hydrological balance. The acceptable results of the verification procedures demonstrated that R/P maps could be helpful for preparation of long-term runoff maps for the territory of Slovakia.

Key words: Long-term mean annual runoff**,** runoff-to-precipitation ratio, grid maps, interpolation, GIS

Hydrologische Kartierung der vieljährigen regionalen Mittelwerte des Abfluss-Niederschlag-Verhältnisses in der Slowakei

Zusammenfassung: Für die verschiedensten Anwendungsbereiche der Wasserwirtschaft werden die räumliche Verteilung und Variation des Abflusses benötigt. Die vorliegende Untersuchung leistet einen Beitrag zum Problem der hydrologischen Kartierung der vieljährigen Mittelwerte des Abflusses in der Slowakei. In dieser Arbeit wurden zwei Methoden für die räumliche Interpolation der vieljährigen regionalen Mittelwerte des Abfluss-Niederschlag (R/P) -Verhältnisses geprüft. In der ersten Methode wurde eine Regressionsbeziehung zwischen den mittleren Gebietshöhen und des R/P-Verhältnisses hergeleitet. Das zweite Verfahren verwendet mehrere Interpolationsalgorithmen für die räumliche Interpretation der R/P-Werte.

Die Qualität und Konsistenz der resultierenden Karten der vieljährigen Mittelwerte des Abfluss-Niederschlag-Verhältnisses wurden gegen die Abflusswerte geprüft und im Rahmen der Wasserbilanz untersucht. Die brauchbaren Resultate aufgrund der Prüfungsverfahren lassen die Nutzungsmöglichkeiten der räumlichen Interpretation des R/P-Verhältnisses bei der hydrologischen Kartierung erkennen.

Schlüsselwörter: Vieljährige Mittelwerte des Abflusses, Abfluss-Niederschlag-Verhältnis, digitale Karten, Interpolation, GIS.

Introduction

The knowledge of spatial distribution of runoff has numerous applications in water resource planning, climate change impact studies and hydrological modelling. There exist a variety of methods for the construction of runoff maps, ranging from manual contouring method (e.g. Domokos, Sass, 1990; Krug et al., 1990), grid maps constructed by automated procedures (e.g. Solomon et al., 1968; Foyster, 1975; Bishop, Church, 1992; Church et al., 1995; Bishop et al., 1998), to the output of complex models (e.g. Neilson, 1995). Manual mapping allows the exercise of potentially more accurate expert local knowledge, but requires considerable time, effort and expertise (Bishop, Church, 1995) and there is only limited possibility to verify its cross-consistency with respect to balancing constraints (Szolgay, Parajka, 1998a, 1998b). The development of new techniques in geoscience and demand for repeatable and rational mapping concepts produced a new type of map representation, based on a regular grid network

(Gottschalk, Krasovskaia, 1997). Arnell & Gottschalk (1993) and Hladny (1994) discuss in detail methods for the construction of runoff grid maps, such as the spatial averaging of the mapped values within a grid, deterministic and stochastic interpolation methods for interpolation of observations from an irregular network to a regular grid net, the overlay of a grid mesh over an isopleth map, the use of empirical regression relationships for the runoff computation from grid maps of physiographic data.

In the present paper, another method of runoff grid map construction has been employed. We tested various interpolation methods for the constructions of the runoff-to-precipitation ratio (R/P) maps as a way for automate regional mapping of runoff. The mapping of R/P ratios is rare in the literature. The examples we could find were from Bishop and Church (1992 and 1995). Results of their work indicate that simple automated R/P mapping procedures can produce long-term runoff maps with regional accuracy equivalent or superior to those produced by manual methods.

This study focuses on the estimation and spatial interpretation of the long-term mean annual R/P ratio as an approach for the construction of grid-based long-term mean annual runoff map of Slovakia. Its main goals are:

- to test the performance of interpolation methods (inverse distance weighting, kriging, nearest neighbourhood, linear triangulation, 2-dimensional spline with tension) for spatial interpretation of R/P ratio estimates on a regular grid for the whole territory of Slovakia,
- to construct grid maps of R/P ratio using regression relationship between R/P ratio and mean basin elevation,
- to calculate grid maps of long-term mean annual runoff using computed R/P ratio grid maps and grid map of long-term mean annual precipitation,
- to investigate with the methods of map algebra the accuracy and cross-consistency of automated methods in comparison with gaged runoff data as well as with manually produced isoline map of evapotranspiration.

Data and mapping approaches

Data

We used long-term mean annual runoff data from the period 1951-80 from 57 gaged sites for calculating R/P ratio of the basins. The sites represent basins ranging in size from 40 to 3800 km^2. For the determination of regression relationship between R/P ratio and mean basin elevation we used only data from 49 basins with areas less than 400 km^2. Spatial arrangement of basins with runoff measurements is presented in Fig. 1. Basin averages of precipitation values were obtained from the digital interpretation of expert-drawn isoline precipitation map of the same long-term period using GIS map algebra operations. The elevation values for regression model were derived from digital elevation model (DEM) of Slovakia with spatial resolution of 1x1 km (Fig. 1).

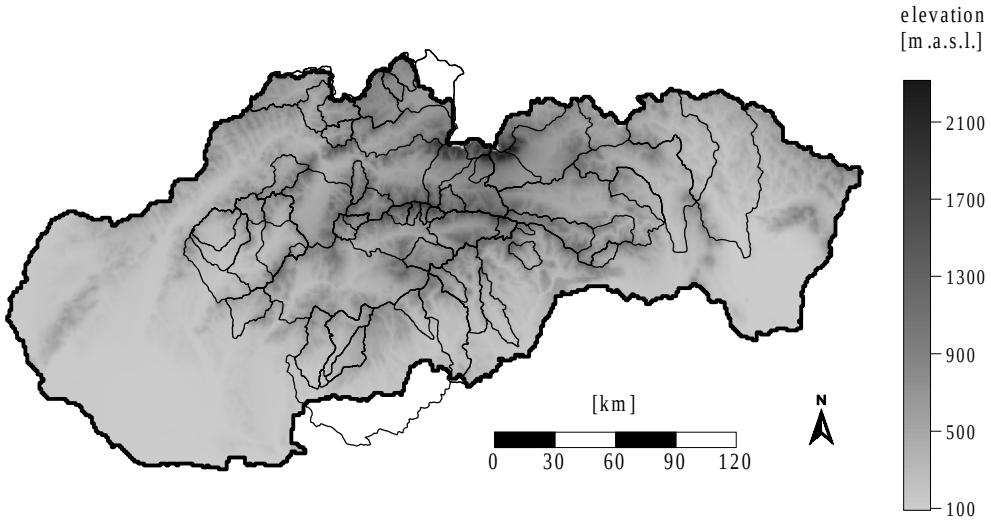

Fig. 1 Digital elevation model of Slovakia and spatial arrangement of basins with runoff measurements.

Mapping approaches

We considered two methods for spatial interpretation of R/P ratio in this study. First approach computes R/P ratios at the basin centroids using basin averages of long-term mean annual precipitation (P) and gaged long-term mean annual runoff (R). These values were then used to create surfaces of R/P using different interpolation algorithms - inverse distance weighting, kriging, nearest neighbourhood, linear triangulation and 2-dimensional spline with tension method.

Second mapping approach uses simple linear regression model developed using mean basin elevation as independent variable and dependent gaged runoff data. DEM, with the help of map algebra operations, were then applied to transform regression relationship to the R/P grid.

These R/P surfaces created by both approaches were then for cross-validation purposes applied to the precipitation surface to generate the long-term mean annual runoff grids – R=P*R/P.

Cross-validation

To test the accuracy of interpolating procedures, so called “jack-knife” analysis was conducted. The analysis consists of setting aside a R/P sample, using remaining samples to produce an interpolated surface, and then analysing the difference between values interpolated from the surface and actual values at the withheld sample sites (Bishop and Church, 1992). The efficiency of selected interpolation schemes was evaluated by statistical parameters of standard error and sample variance. The suitability of gridded runoff maps has been assessed by statistical analysis of the differences between computed and gaged runoff in 57 selected basins.

The spatial quality and cross-consistency of resulted runoff maps have been investigated with respect to digital interpretation of the isoline map (DIIM) of evapotranspiration (Tomlain, 1985). Methods used for the construction of DIIM are in detail discussed in Parajka and Szolgay (1998a, 1998b). Gridded map of evapotranspiration (ETMAP) has been constructed from each runoff map using water balance equation. Each ETMAP has been compared to the DIIM. Their difference has been expressed as a gridded map of the absolute percentual difference (MAPD). MAPD maps have been reclassed to the four categories (0% – 10%; 10% –20%; 20% –30%; 30% and more) and frequencies of these categories have been tabulated.

Results

In comparing the accuracy of automated methods used for R/P grid construction, we first statistically compared the interpolation methods using "jack-knife technique". Results of this quantitative uncertainty analysis are shown in Table 1.

Table 1 Statistical summary of interpolation errors (interpolated R/P value minus withheld R/P sample) using "jack-knife" procedure.

	inverse distance	nearest neighborhood	linear triangulation	2-d spline with tension	kriging
count	57	57	45	57	57
range	0.54	0.69	0.52	0.47	0.57
mean	-0.014	-0.028	-0.007	0.003	0.000
std. deviation	0.087	0.107	0.090	0.066	0.063
standard error	0.012	0.014	0.013	0.009	0.012
variance	0.008	0.012	0.008	0.004	0.008

The most noticeable differences among the methods are statistical parameters of sample variance and standard error. The smallest sample variance is produced by 2-dimensional spline with tension interpolation method, the highest is observed for nearest neighbourhood method. Statistical summary for linear triangulation method is not comparable to the other methods, because this method does not allow interpolating R/P values for all withheld R/P sites.

For the second mapping approach, we developed simple linear regression relationship between mean basin elevation and R/P values. Regression model, presented in Fig. 2, shows good correlation relationship between selected variables.

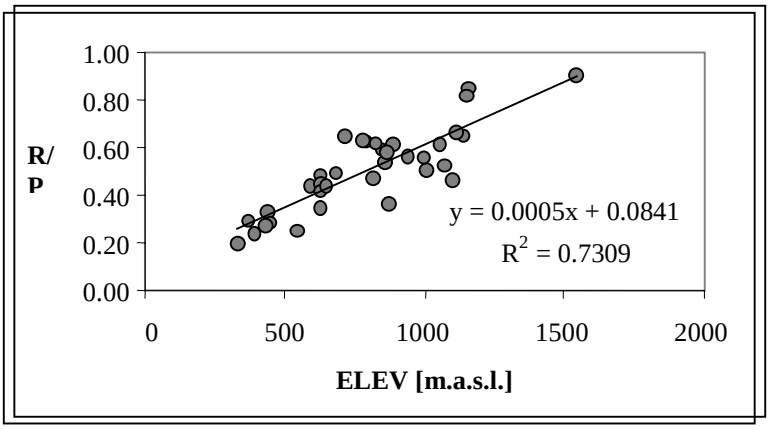

Fig. 2 Simple linear regression model developed between mean basin elevation and R/P values using data from 49 basins with area less than 400 km^2.

As a result of both mapping approaches, surfaces of R/P values were generated for the territory of Slovakia. Examples of two R/P grid maps that were estimated by linear regression model and 2-dimensional spline with tension interpolation method are presented in Figure 3 and Figure 4.

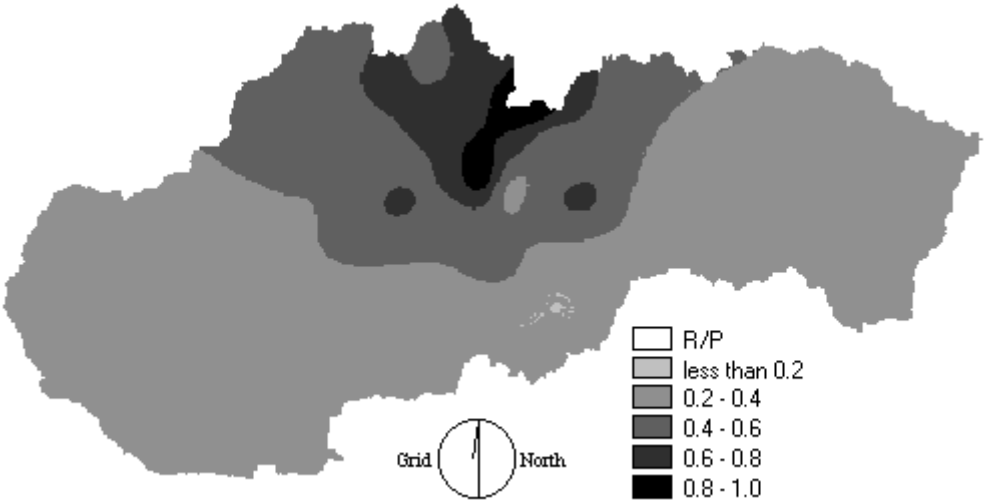

Fig. 3 Grid maps of long-term mean annual runoff produced by 2-dimensional spline with tension interpolation method.

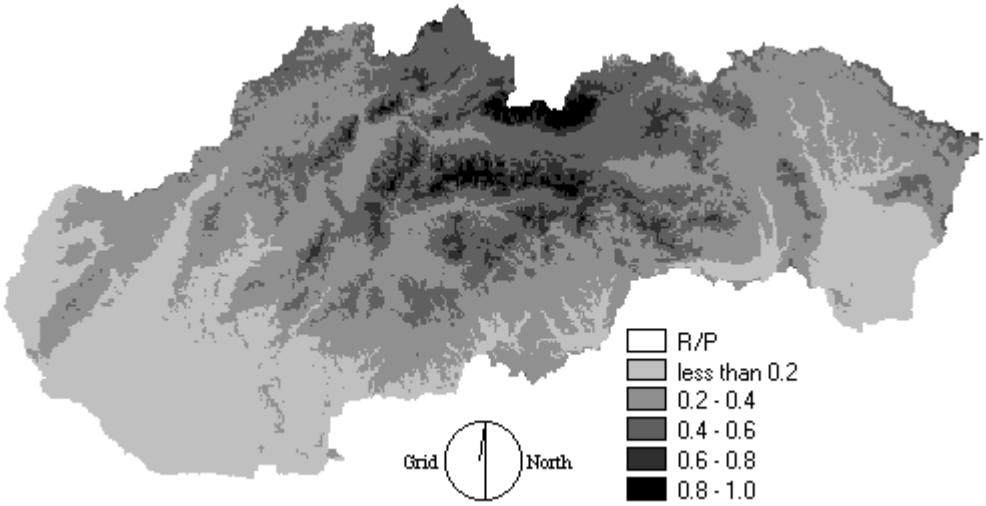

Fig. 4 Grid maps of long-term mean annual runoff produced by simple linear regression model.

The R/P estimates computed by regression model are closely related to the topography. On the other hand, spline with tension method does not take topography into account and thus R/P estimates show only general smooth patterns. These R/P grid maps were then, for cross-validation purposes, subsequently transformed into grid maps of long-term mean annual runoff, using digital interpretation of expert-drawn precipitation (DIPM) map – R=DIPM*R/P.

The evaluation of the accuracy of resulted grid runoff maps was based upon measured runoff data. Statistical summary of the differences between computed and gaged runoff values is listed in Table 2.

Results we obtained (Table 2) show that the smallest range, standard error and sample variance is calculated by the nearest neighbourhood, followed by the 2-dimensional spline with tension interpolation methods. The highest difference between calculated and observed runoff was reported by linear regression model. Runoff estimates computed by triangulation method were again not fully comparable to the other methods, because triangulation could calculate runoff basin averages for only 31 basins. Although nearest neighbourhood method yielded the best statistical summary, spatial interpretation of R/P produced by this method shows artificial “block” patterns. Thus 2-dimensional spline with tension method was considered as the most satisfactory mapping method.

Table 2 Statistical summary of differences between observed runoff and runoff estimated by different methods.

[mm]	inverse distance	nearest neighborhood	linear triangulation	2-d spline with tension	kriging	linear regression
Mean	13	13	5	10	32	17
Standard Error	5.10	2.61	8.53	2.99	6.24	11.50
Standard Deviation	38.52	19.74	47.50	22.56	47.12	86.84
Sample Variance	1483.67	389.67	2256.26	508.89	2220.59	7540.94
Range	210	83	185	101	305	447
Minimum	-127	-20	-87	-39	-178	-187
Maximum	83	63	98	63	127	259
Count	57	57	31	57	57	57

The cross-consistency of resulted grid runoff maps has been investigating within the framework of hydrological balance. We have compared grid maps of evapotranspiration (ETMAPs) calculated for each grid runoff map using water balance equation with digital interpretation of evapotranspiration map (DIIM). Such cross-consistency check is not only important for testing the validity of grid runoff maps for regions with runoff measurements, but for the whole territory of Slovakia as well.

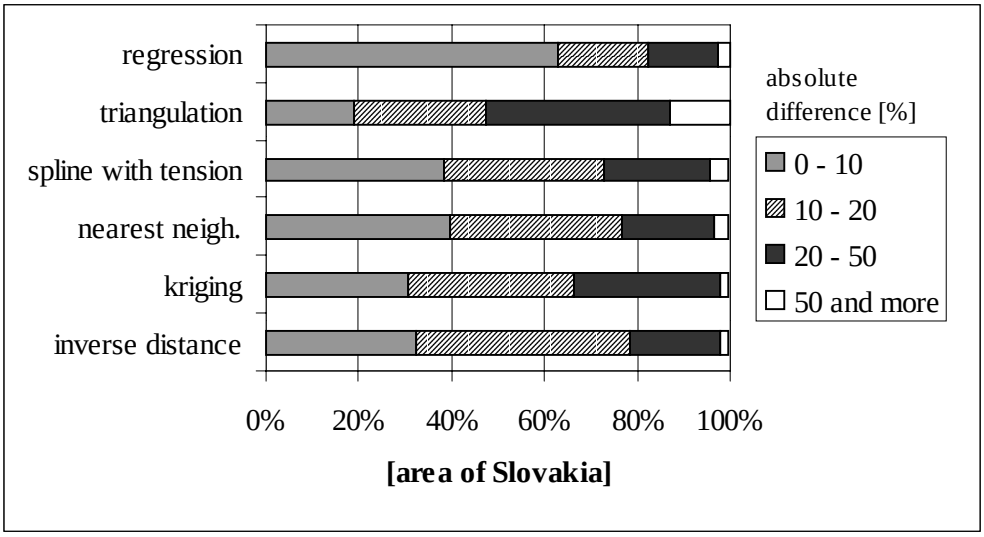

Fig. 4 Frequencies of absolute percentual differences between grid evapotranspiration (ETMAPs) maps (computed from water balance equation, where runoff grids were computed by different automated approaches) and DIIM (((ETMAP-DIIM)/DIIM)*100).

Results of this cross-validation (presented in Fig. 4) indicate that linear regression was spatially representing evapotranspiration, which is on 63% of the territory of Slovakia within 10% range and on 83% of territory of Slovakia within the range 20% with DIIM. Grid evapotranspiration map based upon inverse distance and spline with tension interpolation methods are approximately on 75% area of Slovakia within the range of 20% difference with DIIM. Cross-validation results obtained for regression method – the highest difference between

computed and measured runoff, but the best cross-consistency with evapotranspiration DIIM map – indicate that direct R/P interpolation is more acceptable in regions with runoff observations. On the other hand, R/P estimates computed by simple linear regression model are more accurate and consistent for the whole territory of Slovakia, or in regions, where data availability is low.

Conclusions

This paper is explores and tests the accuracy of two mapping approaches for the spatial interpretation of long-term mean annual R/P ratio over the territory of Slovakia. Each of the approaches, illustrated and discussed here, has relative strengths and weaknesses. Selection of particular regional mapping approach depends on the data availability and specific user needs.

Results presented here indicate that direct interpolation of R/P ratio is preferable only in regions with sufficient runoff and precipitation data. Cross-consistency check with evapotranspiration has shown that this mapping approach applied in regions with low data availability could lead to unacceptable results. Regression relationship between R/P values and mean basin elevation offers a mapping method, which is not so accurate for particular small basins, but is more consistent for large regions or regions with low data availability. The advantage of both mapping approaches is that they offer a rational and repeatable mapping concept.

The approaches used in this paper are not intended to be final solution to the problem of runoff mapping. They are considered as only one approach for repeatable and rational grid runoff map production.

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Modelling the Dynamics of the Snow Cover in Accumulation and Melting Periods for the Forecasting of the Snow-Melt Runoff

Marinela Simota

Abstract: The dynamics of the snow cover area and its water equivalent depends on precipitation type – rain or snow – and on snowmelt process. In the snowmelt runoff forecasting models the decision to evaluate the precipitation type and the part of catchment area where the snowfall contributes to the increase of the snow pack or the part area where rain contributes to snowmelt and runoff, is conditioned by altitude air temperature distribution. In the same time the catchment area where snowmelt process occurs depends on the air temperature variation in altitude, snow cover area and its water equivalent. It is proposed a dynamic procedure estimating for each time step the snow cover area, its water equivalent and snowmelt water. The basin average precipitation and the air temperature at a single meteorological station, as input data, were used in this algorithm. The procedure has two temperature threshold parameters *Tpz* (corresponding to isotherm delimiting liquid and solid precipitation areas) and *Tit* (corresponding to isotherm delimiting freezing and snowmelt areas). The algorithm was coded in a VisualBasic macro included in an EXCEL workbook and was tested for a river basin in Romania.

Key words: snow cover dynamics modelling, snowmelt runoff forecasting

Modellierung der Dynamik der Schneedecke für die Zeiten ihres Auf- und Abbaues zum Zwecke der Vorhersage des Abflusses hervorgerufen durch die Schneeschmelze

Zusammenfassung: Die Dynamik des schneebedeckten Bereiches und dessen Wasseräquivalent hängt von der Niederschlagsart – Regen oder Schnee – so wie vom Schmelzprozess der Schneeschicht ab. In den Modellen zur Vorhersage der Abflüsse hervorgerufen durch die Schneeschmelze wird die Entscheidung in Bezug auf die Niederschlagsart und den Anteil des Einzugsgebietes, in dem der Schneefall zur Erhöhung der Schneedecke beiträgt oder der Gebietsanteil, in dem Regen zur Schneeschmelze und Abfluss beisteuert, durch die Lufttemperaturverteilung mit der Höhe bedingt. Gleichzeitig, ist der Anteil des Einzugsgebiets, in dem Schneeschmelze auftritt, von der Änderung der Lufttemperaturverteilung mit der Höhe, so wie dem schneebedecktem Gebietsanteil und dessen Wasseräquivalent abhängig. Es wird ein dynamisches Verfahren vorgeschlagen, das für jeden Zeitschritt den schneebedeckten Gebietsanteil, das Wasseräquivalent der Schneedecke und das Schmelzwasser abschätzt. In diesem Algorithmus werden der mittlere Gebietsniederschlag und die Lufttemperatur an einer einzelnen meteorologischen Station als Eingangsdaten verwendet. Das Verfahren besitzt zwei begrenzende Temperaturparameter: T_{pz} (entspricht der Isotherme, die die Gebiete von flüssigen und festen Niederschlag begrenzt) und T_{it} (entspricht der Isotherme, die die Gebiete von Frost und Schneeschmelze begrenzt). Der Algorithmus wurde als Makrofunktion in der Programmiersprache Visual Basic in Excel codiert, und wurde an einem Flusseinzugsgebiet in Rumänien getestet.

Schlüsselwörter: Modellierung der Dynamik der Schneedecke, Vorhersage des Abflusses hervorgerufen durch die Schneeschmelze.

1 Background

The snowmelt is a main part (40-50%) of the annual runoff, mainly in the mountain and hill regions in the spring time. More, in the last years, the frequency of floods from the combined snowmelt-rain events in the winter time increased. These particularities of the runoff are the

reason to study in depth the inflow of water in a catchment from the snowmelt processes. The quantity of the inflow from the snowmelt depends on the spatial distribution of the snow cover, on the water equivalent of the snow cover, on the thermal-physical proprieties of the snow and on the meteorological parameters, which determine the area and depth snow cover variation due to the melt processes and snowfall. The complexity of the snowmelt processes and the scarcity of snow characteristics and the meteorological parameters in real time data, make the advantage of using the simple models to simulate the snowmelt, especially for the operational forecasting purposes.

The paper shows a procedure to easy determine the snow cover dynamics on the catchment depending on the precipitation type (rain or snow) and of the melt process occurrence. For the snowmelt process the temperature index model was adopted.

2 Method

The main meteorological parameters used in snowmelt process modelling and available in operational hydrological forecasting are the precipitation and air temperature.

In the models forecasting the snow-melt runoff the decision for the selection on the basin area of the precipitation type: rainfall or snow, is depending on the air temperature (Ta) and a threshold temperature value (Tpz) which is selecting the precipitation as rainfall (Ta≥Tpz) from that as snowfall (Ta<Tpz). Using the hypsometric curve of the basin and the relationship of temperature with altitude, the elevation, Hpz, corresponding to the isotherm of Tpz is estimated. For elevations higher than Hpz the precipitation is as snowfall contributing to the accumulation of the existing snow cover. For elevations smaller than Hpz the precipitation is as rainfall contributing to the melting process.

The dynamics of the snow cover is related to the delimitation of the area with melting process, too. This area is estimated considering the threshold temperature, Tit, separating melting (Ta≥Tit) and freezing (Ta<Tit) processes, and the corresponding elevation (Hit) of Tit. Using the hypsometric curve the areas for melting and freezing processes were estimated.

The area for melting is depending on the area covered with snow (Fzap) and the snow water equivalent of the area (hz), too. In the literature (Anderson, 1973, Serban and Simota, 1976) for each basin is a well defined depletion curve expressed as the relationship between the ratio of the snow covered area at a given time to the catchment area, and the ratio between snow-water equivalent at the same time and a characteristic parameter of the catchment, hz max. This parameter (hz max) is the snow water equivalent for all the catchment in the just time moment corresponding to passing away of the snow at the point with the lowest elevation of the basin.

Due to the fact that it is not possible to determine a single defined value for hz max it is proposed a dynamic procedure estimating for each time step the area Fzap and hz from the two threshold temperature parameters Tpz and Tit and the air temperature which determines the snow accumulation and melting process and the areas where these phenomena occur.

The main meteorological parameters available in snowmelt process forecasting are precipitation and air temperature.

The average catchment precipitation is calculated based on the precipitation data registered at rain gauging and meteorological stations located into catchment or nearby areas.

The air temperature at the basin level is often obtained from one meteorological station as reference station, because this parameter varies linear with altitude. The available temperature data analysis shown a average vertical temperature gradient of 0.6-0.- 7°C/100m.

Following is a brief description of the algorithm used for computing the dynamics of snow cover in accumulation and ablation periods:

- the algorithm parameters are: **HSM** – reference meteorological station altitude (m), **Tit** – temperature threshold corresponding to isotherm delimiting freezing and snowmelt areas

(^oC), **Tpz** - temperature threshold corresponding to isotherm delimiting the area where the precipitation is considered as snow by this considered as rain (^oC) **(Tit≤Tpz)**, **mf** – melt factor (mm/^oC*day), and hypsometric curve, **FT** – catchment area (km^2);

- calculation of **Hmed** – catchment mean altitude (m);
- for each time step (1 day) :
  - using the input data: **P** – catchment average precipitation (mm), **TSM** – reference meteorological station temperature (^oC), **Fzap** – snow cover catchment area (km^2), **hz** – water equivalent corresponding to the snow covered catchment area, Fzap (mm);
  - are computed: **Tmed** – catchment average temperature corresponding to Hmed (^oC), **Hzap**- minimum altitude of the snow cover catchment area (m), **HMzap**- mean altitude of the snow cover catchment area (m), **Hit** – altitude corresponding to Tit parameter (m), **FTing** – freezing catchment area (km^2), **FTtop** – snowmelt catchment area (km^2).

    FTtop calculation is depending on Fzap:

    FTtop = FT – FTing for Fzap = FT

    FTtop = Fzap – FTing for 0 < Fzap < FT
  - for time steps with precipitation are computed additionally: **Hpz** - altitude corresponding to Tpz parameter (m), **FTz**- catchment area where the precipitation is considered as snow (km^2), and **FTpl**- catchment area where the precipitation is considered as rain (km^2);
  - are computed: **htc** – melt water quantity (carried out from the melt process modelling) (mm); **ht** – area weighted average of the snowmelt water quantity (mm), **hp** - total water quantity (snowmelt and rain) as input data in runoff modelling (mm), Fzap and hz to be used in the next time step. Different algorithms computing these parameters where developed for the following cases:
    - all catchment is covered with snow (Fzap = FT), all catchment has not snow cover (Fzap=0), the catchment is partially covered with snow (0<Fzap<FT);
    - freezing on the all catchment area (FTing = FT), melting on the all catchment (FTtop = FT), melting only a part of the catchment area covered with snow (0 < FTing < Fzap);
    - solid precipitation (snow) on all catchment area (FTz = FT); liquid precipitation (rain) on all the catchment area (FTpl = FT); solid precipitation on the upper part of the catchment and rain on the rest of the catchment (0 < FTz < FT)
  - the output data for each time step are: hp (used for runoff calculation), Fzap and hz

The snow melt process was simulated using the index temperature method:

htc = mf * (Ttop – Tit)

The algorithm was coded in a VisualBasic macro included in an EXCEL workbook.

3 Case study

The testing of the programme was made initially for an arbitrary basin with a surface (FT) of 1000 km^2, a maximum altitude (Hmax) of 700m, a minimum altitude (Hmin) of 55 m and an mean altitude (Hmed) of 211 m resulted from hypsometric curve. The altitude for representative meteorological station (HSM) is considered at 270m. Different input data (average precipitation, air temperature, snow cover aria and its water equivalent) were considered. Also, the values adopted for the parameters were been 2 mm/^oC *day for the melt factor, 2^oC for Tpz and 0 ^oC for Tit. In the table 1 is shown an example of the case study considering for initial moment Fzap = 600 m and hz =10 mm.

Table 1 The dynamic of the variables implied in accumulation and ablation of the snow cover for an arbitrary cathment

t (day)	0	1	2	3	4	5	6	7	8
P (mm)		10	8	5	0	0	12	10	10
TSM (^oC)		-3	-1	0	2	3	6	3	-4
Tmed (^oC)		-2.6	-0.6	0.4	2.4	3.4	6.4	3.4	-3.6
Tmax (^oC)		-6.0	-4.0	-3.0	-1.0	0.01	3.0	0.01	-7.0
Fzap (km^2)	600	1000	1000	1000	1000	1000	1000	140.8	1000
Hzap (m)	110	55	55	55	55	55	55	412.6	55
HMzap (m)	299	210.8	210.8	210.8	210.8	210.8	210.8	543.4	210.8
Hit (m)		0	127.1	270	555.7	698.6	112.7	698.6	0
FTing (km^2)		1000	557.1	274.0	62.7	0.6	0	0.6	1000
HMing (m)		210.8	312.9	440.5	627.9	699.3	-	699.3	210.8
Ting (^oC)		-2.6	-1.3	-1.2	-0.5	0	-	0	-3.6
FTtop (km^2)		0	442.9	726	937.3	999.38	1000	999.38	0
HMtop (m)		-	82.5	124.2	182.9	210.5	210.8	134.4	-
Hpz (m)		0	0	0	-	-	841.4	412.9	0
FTz (km^2)		1000	1000	1000	-	-	0	140.8	1000
HMz (m)		210.8	210.8	210.8	-	-	-	337.0	210.8
FTpl (km^2)		0	0	0	-	-	1000	859.2	0
hz (mm)	10	16	23.9	28.6	27.3	25.6	15.0	24.5	13.4
htc (mm)			0.16	0.51	1.3	1.7	10.6	0.5 6.08	-
Ttop (^oC)			0.3	1.02	2.6	3.4	6.41	1.0 3.94	-
ht (mm)		-	0.07	0.37	1.22	1.7	10.6	6.58	-
hp (mm)		-	0.07	0.37	1.22	1.7	22.6	12.9	-

The result of the testing shows that the algorithm produces output in agreement with the expert knowledge for the dynamic of the snow covered area and is useful for runoff simulations.

The algorithm was applied for Prahova river basin at the hydrometric station Cimpina with the area FT = 476 km^2, maximum altitude Hmax = 2504 m, minimum altitude Hmin = 372 m. Hmed resulted from hypsometric curve (fig. 1) is 1158 m. The reference meteorological station for the air temperature records is SM Sinaia with HSM 1510 m located in the catchment. Three more meteorological stations are located inside the catchment: SM Cimpina (H = 461 m), SM Predeal (H = 1090 m) and SM Vf. Omul (H = 2504 m). Figure 2 confirms the value of the gradient of temperature with altitude resulted from a general analysis of data over the country.

The average daily catchment precipitation was derived using instrumental values from the same meteorological stations and additionally, the values from six rain gauging stations uniformly distributed over the catchment and in altitude. Figure 3 shows the dynamics of average daily catchment temperature and precipitation.

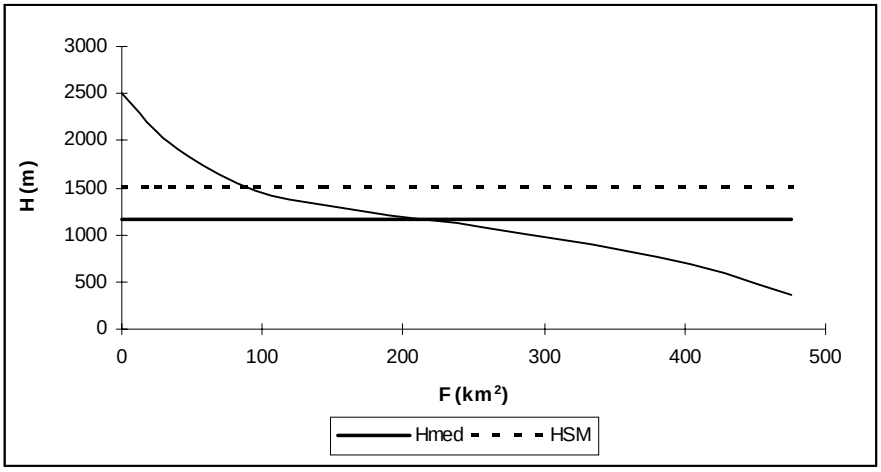

Fig. 1 Hypsometric curve for the Prahova river basin at the Cimpina gauging station

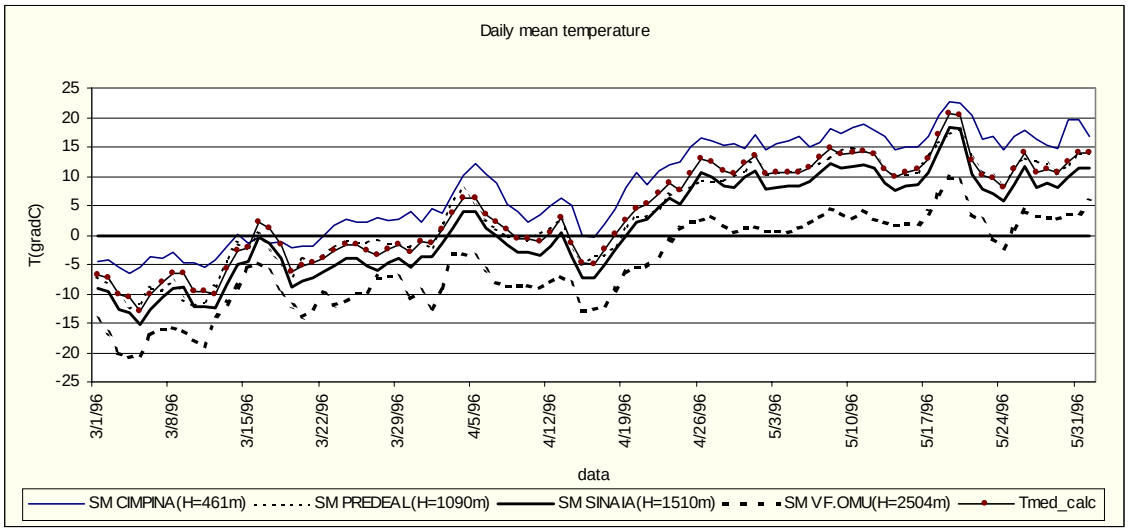

Fig. 2 Daily mean temperature recorded at the four meteorological station in the case study area, and the calculated mean temperature on the catchment (Tmed)

Some accumulation and ablation periods were selected from the recorded daily discharge series at Cimpina gauging station considering the availability in the same period of snow water equivalent measured data series at the four meteorological stations in the catchment.

The proposed algorithm was used for modelling the snow cover dynamics for obtaining the snow water equivalent corresponding to the snow covered catchment area. Figure 4 shows the simulated average snow water equivalent (hz) compared with the snow water equivalent recorded at the four meteorological stations during the 1996 year spring time. The melt factor used was 1 mm $^{o}C^{-1}$ day^{-1} (Serban, 1984).

The algorithm simulates the snowmelt water (ht), too. The snowmelt water added to the rain on the catchment gives the total water quantity (hp) available for the runoff (figure 5).

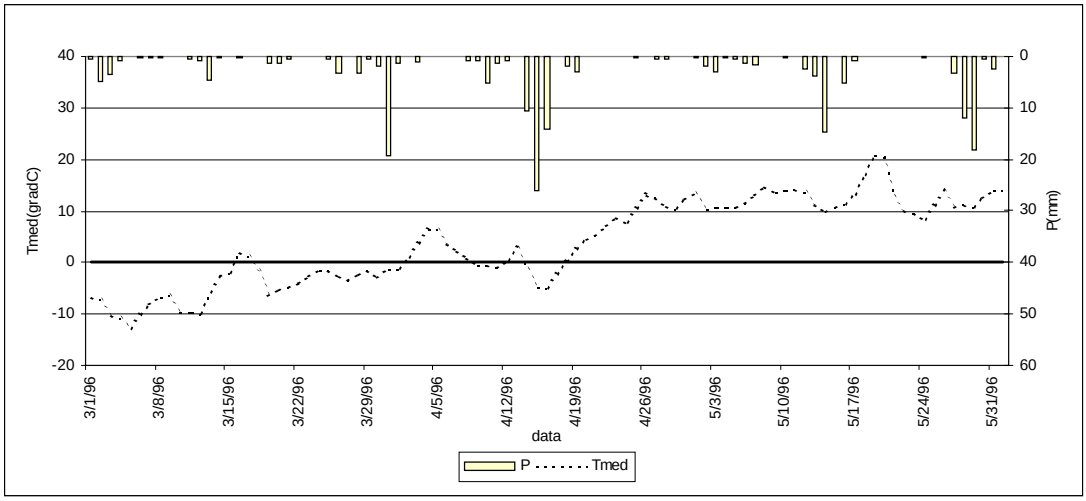

Fig. 3 Catchment average temperature (Tmed) and precipitation (P). Hydrometric station Cimpina (river Prahova)

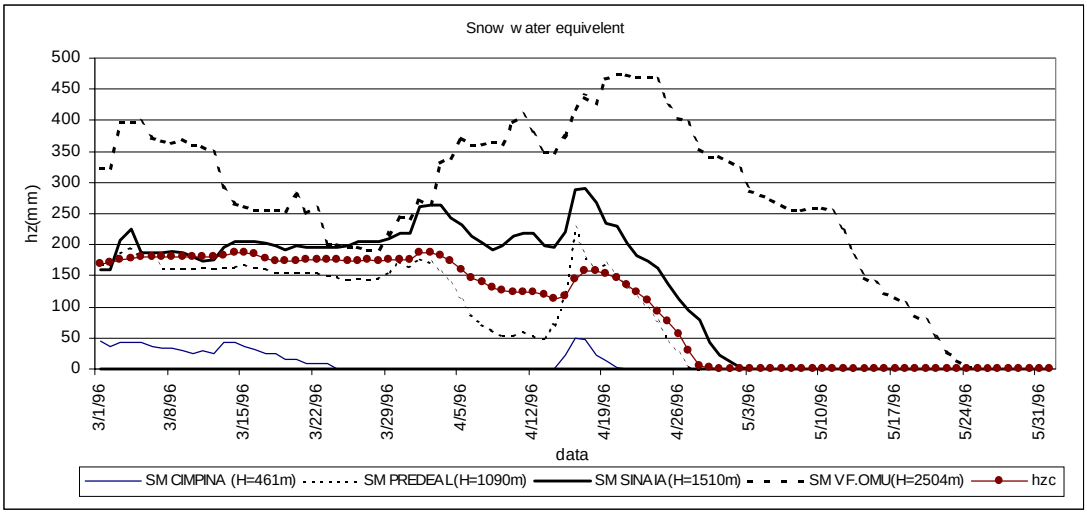

Fig. 4 Snow water equivalent recorded at the four meteorological stations in the case study area, and the calculated water equivalent corresponding to the snow covered catchment area (hz)

The runoff (daily discharges) was simulated using the relationship (Matinec and all, 1994):

$$Q_{i+1} = a_i \, hp_i \frac{FT*1000}{86400}(1-K_r) + Q_i \, K_r$$

where:

Q_{I+1} is forecasted discharge for (I+1) day;

Q_I is the simulated discharge in the I day;

a_I is the runoff coefficient for the I day;

hp_I is the total quantity of water resulted from the snowmelt and rain;

K_r is the recession coefficient.

K_r was calculated from discharge hydrograph data for the recession periods having the value about 0.9. For the runoff coefficient a value in the range 0.1 – 0.6 was used depending on the type of precipitation (rain, snow, mixt).

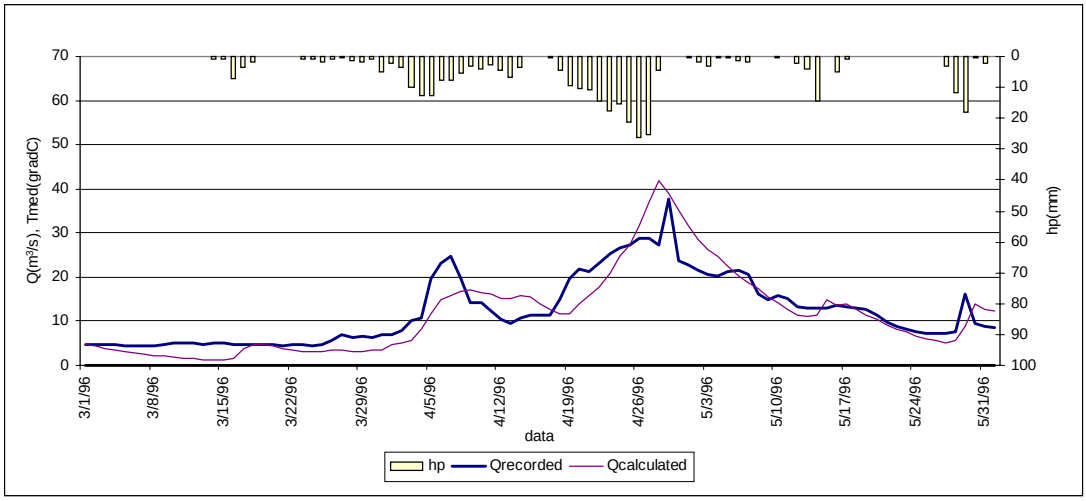

Fig. 5 Simulated and recorded daily discharges (Q) at the hydrometric station Cimpina, and the simulated total quantity of water resulted from the snowmelt and rain (hp)

3 Conclusions

The proposed dynamic procedure estimating for each time step the snow cover area, its water equivalent and snowmelt water proved to be accurate enough for forecasting objectives. The advantage of the algorithm is using for snowmelt process modelling only the parameters available in operational hydrological forecasting: the precipitation and air temperature.

An improvement of simulation could be obtained using a rainfall-runoff model (like VIDRA, Serban, 1984)

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Effect of Groundwater Table on Evapotranspiration: The Role of Soil and Meteorological Properties as Estimated by Mathematical Modeling

Jana Skalová, Viliam Novák

Abstract: Results of numerical simulation of the transport of water from groundwater to the soil, plant and atmosphere are presented as depending on soil and atmosphere properties as well as on groundwater table depth below the soil surface. Daily velocities of water flow from groundwater were calculated for five positions of groundwater table below soil surface (25, 50, 75, 100, 150 cm), three types of soils and one type of canopy - maize. Maize is characterised by constant value parameters. Results enabled to evaluate the influence of soil and atmosphere properties on ratio of groundwater inflow to soil and evapotranspiration during steady state flow. It was shown, that soil hydraulic conductivity is a basic factor in this process, the ratio of groundwater contribution to evapotranspiration is decreasing dramatically with its depth and for soils with high content of clay particles.

Key words: soil - plant - atmosphere continuum, unsaturated flow, groundwater, mathematical modeling

Der Einfluss des Grundwassers auf die Evapotranspiration : Die Aufgabe der Böden und meteorologischer Eigenschaften als ein Ergebnis mathematischer Modellierung

Zusammenfassung: Die Ergebnisse der Simulation des Wassertransportes aus dem Grundwasser in die ungesättigte Bodenzone, zu den Pflanzen und die Atmosphäre werden in Abhängigkeit von den Böden, meteorologischen Gegebenheiten, und dem Flurabstand präsentiert. Die tägliche Intensität des Wasserzuflusses aus dem Grundwasser hat man für fünf Werte des Grundwasserflurabstandes (25, 50, 75, 100, 150 cm), drei verschiedenen Böden und für eine ausgewählte Pflanzenart - den Mais - berechnet. Der Mais ist durch einen konstanten Parameter charakterisiert. Die Ergebnisse ermöglichen es den Einfluss der Böden und der meteorologischen Eigenschaften auf die Größe des Wasserzuflusses aus dem Grundwasser sowie auf die Evapotranspiration im stationären Zustand zu bestimmen. Es wurde gezeigt, dass die hydraulische Durchlässigkeit der bestimmende Faktor in diesem Prozess ist. Der Einfluss des Grundwassers auf die Evapotranspiration sinkt dramatisch mit einer Grundwasserspiegelabsenkung, vor allem in Böden mit hohem Tonanteil.

Schlüsselworte: Boden, Pflanze, Atmosphäre, Wasserzufluss, Grundwasser, mathematische Modellierung

1 Introduction

Feeding of agricultural canopies by water rising from groundwater table is one of the most frequently used method of irrigation. Millennia passed without possibility of evaluating quantitatively intensities of groundwater contribution to evapotranspiration. Empirically was estimated simple rule: groundwater table depth below soil surface must be held at position suitable for plants: it was estimated visually. The first quantitative approach to estimate intensity of water flow from groundwater table held at stable position to soil at given depth characterised by soil water potential was presented by Gardner (1958). Delay between first

using of subsurface irrigation and ability to quantify it was due to lack of method of unsaturated flow quantification. Richards (1931) was first who published glorious Richards equation, which is until now the basic governing equation used in mathematical models. It should be said, that Gardner's approach was based on steady state flow conditions and this case is occurred only exceptionally as particular case and intensity such a flow case is maximum (Šutor, Krasňanská, 1975). Currently, transport of water from groundwater through plant and soil to atmosphere is usually calculated as an internal part of some mathematical models used: HYDRUS-ET (Šimůnek et al., 1997), GLOBAL, (Majerčák, Novák, 1992), SWATRE (Feddes et al., 1978) and numerous other models. The above mentioned models are simulating transport of water through soil - plant - atmosphere system (SPAC) as unsteady process taking into account changing plant properties, so results should be close to reality in the field. But for sake of quick and simple orientation it is useful to know some basic relationships between SPAC characteristics and this part of evapotranspiration which is supplied by upward flow from positioned groundwater table.

This contribution presents results of numerical simulation of the transport of water from groundwater to the soil, plant and atmosphere as depending on soil and meteorological properties as well as on groundwater table depth below soil surface.

2 Mathematical model

Mathematical simulation of soil water flow was performed by model GLOBAL (Majerčák, Novák, 1992). Governing equation of this model is Richards equation. Evapotranspiration and its components are calculated as a part of the model using modified Penman - Monteith method (Novák, 1995), root extraction pattern in the model was estimated using basic approach of Feddes, which was designed by Novák (1987). Initial conditions were used here as an equilibrium soil water potential distribution. Hydrophysical characteristics of soil used are standard ones (soil-water retention curves, saturated and unsaturated hydraulic conductivity). Soil profile was considered as homogeneous, according to Table 1.

3 Sites description

Aim of this contribution is to characterize the influence of soil properties on groundwater contribution to evapotranspiration, so three different sites with different soil characteristics were chosen. All the three sites are located at Záhorská nížina, west of Male Karpaty Mountains. This area is characterized with relatively dry climate and mostly sandy soils. Groundwater table depth oscillated between 0,5-3,0 m below soil surface. One soil chosen was sandy soil from Kostolište site, other soil was sandy - loam from locality Male Leváre. Relatively heavy, clayey soil from Šaštín locality was also used. Some basic soil characteristics used as model inputs are in Table 1.

Table 1 Hydrophysical characteristics of soil profiles used (θ_s - saturated soil water content, θ_r - residual soil water content, K - saturated hydraulic conductivity of soil [m.d^{-1}], α, n - van Genuchten's coefficient for retention curves approximation)

Site	Soil Type	Θ_s	Θ_r	K	α	n
Kostolište	sandy soil	0,300	0,03	2,26	0,0188	1,8635
Malé Leváre	sandy loam	0,354	0,09	0,59	0,0098	1,1179
Šaštín	clay soil	0,257	0,02	0,02	0,0136	1,3521

As an illustration, meteorological characteristics of the three different summer days were used to calculate typical evapotranspiration intensities, ranging from resulting daily potential evapotranspiration E_{01}= 5,76 mm.day^{-1} , E_{02}=3,78 mm.day^{-1} to E_{03}=1,49 mm.day^{-1}. Necessary meteorological characteristics were measured at meteorological station Malacky, during summer 1987.

As a model plant was used maize. Plant characteristics needed as input data were leaf area index (LAI=2,0), roughness coefficient (r_0=0,02 cm), height of the canopy z_r=50 cm, and albedo a=0,20. Depth of roots (50cm below soil surface) as well as root mass distribution below soil surface was also involved in the calculation. Constant values of plant parameters were used.

4 Results and discussion

Results of mathematical modeling are daily totals of upward water flow from groundwater table, depending on groundwater table position below soil surface and on meteorological characteristics resulting to three different potential evapotranspiration intensities. Such results were calculated for three different soil types: sandy soil, sandy - loam, and clayey soil. Figures 1, 2. and 3 are illustrating some basic features of results obtained.

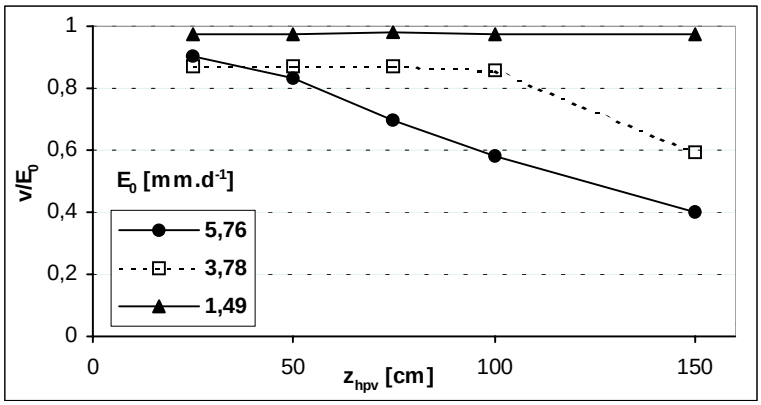

Fig.1 Relative contribution of daily total upward flow from groundwater to potential evapotranspiration daily totals (v/E_0) as depending on groundwater table depth below soil surface (z_{hpv}) and different potential evapotranspiration daily totals (E_0). Sandy soil, Kostolište site.

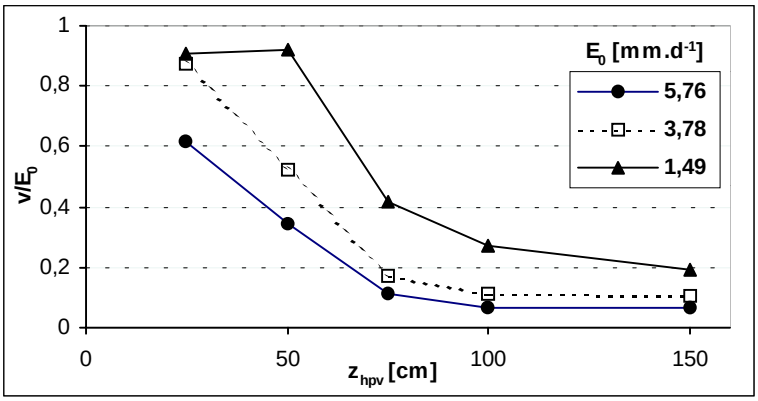

Fig.2 Relative contribution of daily total upward flow from groundwater to potential evapotranspiration daily totals (v/E_0) as depending on groundwater table depth below soil

surface (z_{hpv}) and different potential evapotranspiration daily totals (E_0). Loamy soil, Malé Leváre site.

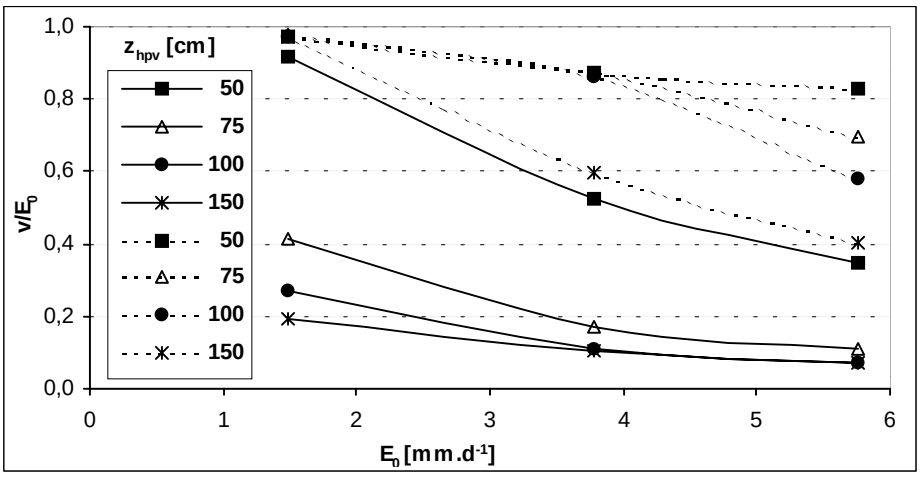

Fig.3 Relative contribution of daily total upward flow from groundwater to potential evapotranspiration daily totals (v/E_0) as depending on different groundwater table depth below soil surface (z_{hpv} = 50, 75, 100 and 150 cm) and different potential transpiration daily totals (E_0). Results of two sites are shown- Kostolište (sandy soil ———), and Malé Leváre (loam ————).

From results of calculation it follows, that groundwater contribution to evapotranspiration was found as significant for light, sandy soil with saturated hydraulic conductivity K=2,26 m.d^{-1}. In this case with groundwater table at the depth 1,0 m below soil surface more then half of daily evapotranspiration total is covered by groundwater contribution (GC) for our highest potential evapotranspiration total. For lower daily potential evapotranspiration totals even higher ratio of GC was estimated. Looking for clay soil (Male Leváre), for groundwater depth 100 cm and our highest daily potential evapotranspiration total (5,76 mm) less then 10% of it can be covered by GC. For our daily lowest evapotranspiration total approx. 24 % of GC can be expected. For heavy soil (Šaštín site) and groundwater table depth below soil surface 100 cm, only 5% of daily potential evapotranspiration total (E_0=5,76 mm) can be supplied by groundwater, which is practically negligible.

From the above mentioned analysis it follows:

- Flow of water from groundwater to unsaturated zone of soil and contribution of this groundwater inflow to evapotranspiration strongly depends on soil properties, mainly on hydraulic conductivity of soil.
- It was shown, that at “standard” 100 cm groundwater table depth below soil surface significant contribution of groundwater inflow to soil root zone was calculated for sandy soil (saturated hydraulic conductivity K=2,26 m.d^{-1}), for loamy soil (K=0,59 m.d^{-1}) groundwater flow contribution to evapotranspiration was rather small, and in heavy soil groundwater flow contribution was negligible. From it follows, that subsurface irrigation can be effective for relatively highly conductive soil. Saturated hydraulic conductivity K=1,0 m.d^{-1} can be supposed as a breakthrough value for effectiveness of such technical solution.
- Important is, that groundwater supply of soil root zone is more effective for relatively low daily evapotranspiration totals. Daily evapotranspiration totals below 2,0 mm can be covered by groundwater contribution in medium textured soil effectively.
- Results of modelling, presented here are taking into account root system and its soil solute extraction function. It means, that groundwater table contribution to evaporation - i.e. soil is

without canopy- will be much smaller in comparison to values given here for canopy covered field.

– Another note may be useful: comparison of data presented here with those estimated using known Gardner's approach (Gardner, 1958) is not possible. Gardner's approach is an approximation for bare soil and steady state flow. Presented data should reflect reality: soil covered by maize canopy. Especially canopy with its root system is important in strengthening of groundwater table contribution to evapotranspiration. Roots are extracting water along whole depth of root system thus intensifying groundwater contribution to evapotranspiration.

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New Incentives for the Identification of the Regional Hydrogeographical Types of Long-Term Mean Annual Runoff in Slovakia.

Ľubomír Solín, Tomáš Cebecauer

Abstract: Changes of hydrological network, development of database of basin characteristics and processing and visualisation of spatial data by GIS in the 90` represent a new impulse in hydrogeographic regional typification of territory of Slovakia. The aim of the paper is to contribute to more accurate identification of hydrogeographic regional types of the mean annual runoff leaning on use of hydrological data of small basins and a newly created extensive database of physical-geographical characteristics of small basins.

Key words: mean annual runoff, physical-geographical regional type, testing of hydrological heterogeneity and homogeneity, hydrogeographic regional type.

Neue Ansätze zur Bestimmung von hydrogeographischen regionalen Typen des vieljährigen mittleren Abflusses in der Slowakei

Zusammenfassung: Die Veränderungen im hydrologischen Beobachtungsnetz, die Entwicklung von Datenbanken mit geographischen Charakteristiken der Einzugsgebiete und die Bearbeitung und Darstellung von räumlichen Daten durch GIS in den 90er Jahren, waren starke neue Anreize zur Identifizierung von hydrogeographischen regionalen Typen in der Slowakei. Das Ziel dieses Artikels ist zu einer genaueren Identifizierung von hydrogeographischen regionalen Typen des vieljährigen mittleren Abflusses beizutragen aufbauend auf hydrologischen Daten aus kleinen Einzugsgebieten und neugeschaffenen umfassenden Datenbanken mit geographischen Charakteristiken aus kleinen Einzugsgebiete.

Schlüsselworte: vieljähriger mittlerer Abfluss, hydrogeographische regionale Typen, Test der hydrologischen Heterogenität und Homogenität.

Introduction

The process of identification of hydrogeographic regional types can be divided into the following stages:

a) creation of database of hydrologic and basin characteristics of small basins

b) analysis of the relation between spatial variability of hydrologic characteristics and basin characteristics

c) establishment of the hydrogeographic regional types.

Identification of hydrogeographic regional types is the more accurate the more hydrological empirical data, especially from small basins, and the more precise are the data on basin characteristics available. In this sense the 90’ are a kind of milestone as far as the hydrologic data of small basins and creation of database of the basin characteristics from the point of view of the data extent and accuracy, are concerned. The new data are also a challenge for new research in relation between spatial variability of hydrological characteristics on the one side and basin characteristics on the other side and for more precise identification of hydrogeographic regional types.

The contribution deals with identification of hydrogeographic regional types of the mean annual runoff in the territory of the SR, which is based on application of hydrological data of small basins and an extensive database of their basin characteristics created by application of GIS techniques.

Hydrological data, analytical thematic digital layers, network of small basins and database of basin characteristics.

In the years 1931-1999 the discharge in territory of Slovakia was gauged in 108 stations. The area of 33 of them was smaller than 150 km^2. By the end of the 60's and the beginning of the 70's the network of gauging stations was expanded in order to improve the anti-flood alarm service. Today we have more than 20 years of hydrological observation above all of the small streams. In the years 1961-1995 the discharge was recorded in 440 stations and the basin area of 302 of them was smaller than 150 km^2.

As far as the basin characteristics concern, at the beginning they were assessed from the basic topographic maps. Only characteristics easily readable from the maps such as the basin area, length of valley, shape of basins, inclination of the main basin valley, afforestation was taken into account (Hydrologické pomery ČSSR, díl I, 1970). Important sources of the basin characteristics were also thematic maps in Atlas of the SR (1980). But many thematic maps became obsolete before they could be used for the typification of hydrogeographic regionalisation. In the 90's the development of mathematical models of relief, method of interpretation of satellite images and GIS technologies created new possibilities for a much more precise, detailed and efficient determination of basin characteristics. Using digital model of relief (DMR) morphometric characteristics for whole Slovakia were calculated with pixel resolution 50x50m (Šúri et al. 1997). Interpretation of satellite images resulted in a new land cover map of the SR (Feranec et al. 1996). By vectorisation of some thematic maps, for instance, hydrogeological map and maps of isohyets, digital thematic layers of transmissivity (Grešková 1997), rock permeability, soil-weathering mantle permeability and the mean annual precipitation were created in GIS environment.

The present procedures of hydrogeographic regional typification are based on philosophy of clustering of spatial units - basins - into regional types. Network of basins, into which the territory of Slovakia should be divided, is requested to fulfil a few conditions. Some of them are general, for instance any spatial unit should be spatially continuous, none of the units should overlap another and all together should cover the territory of interest. But there is also specific condition that the hydrological response of spatial units in final profile must by the product of their basin characteristics. Spatial units (cca 4,380 units) which were delineated at the third hierarchic level on hydrological maps in scale 1:50 000 are not altogether suitable for the purposes of hydrogeographic regional typification. This network contains a large amount of inter-basins, hydrological response of that in final profile is not a only product of basin characteristics but also reflects the contribution of the tributes from the contiguous basins. Solín (1993), Solín, Faško (1999) created another set of basins with an area smaller than 150 km^2 in connection with hydrogeographic regional typification of mountainous part of Slovakia from the mean annual runoff point of view. Water dividing lines of the basins were drawn in basic maps in scale 1:200 000. However, many basins in the mountainous part of the Slovak territory in the quoted scale were not drawn in the consequence of cartographic generalisation of the river network. During the years 1996 -1997 the digital form of network of the mentioned detailed basins was created by SAŽP. This made possible to adjust in GIS environment the original network of detailed basins and create a new network of small basins of Slovakia (cf. Solín, Grešková 1999) suitable for the purposes of the hydrogeographic regional typification.

Overlapping of digital analytical thematic maps of physical components of the SR with the newly created network of small basins led to creation of an extensive database containing more than 30 physical characteristics of small basins of Slovakia (Solín, Šúri, Cebecauer, Grešková 1999).

For the purpose of our study 155 small basins (area smaller than 300 km^2) was selected (fig. 1). They sufficiently represent physical diversity of the Slovakia's territory. The value of the mean

annual minimum runoff was assessed on the basis of 20 years of hydrological observation (1976-1995).

As far as the basin characteristics are concerned, the long-term mean annual precipitation of basins for the period 1976-1995 was determined by application of method of the regularised spline with tension resulting in raster with pixel resolution 100x100 m. As input data the vectorised map of isohyets in scale 1:750 000 (Faško 1999) were used. Out of the pixel set of the basins the value of long term mean annual precipitation in basin was assessed by arithmetical mean.

The relief characteristics such as: the mean slope inclination, mean, maximum, minimum altitude and relative high of basins, the share of slope in basins with north-east and south-west aspect were calculated on the basis DMR with pixel resolution 50x50 m. The mean values of characteristics were determined from the pixel set of basin.

Categories of land cover identified by the PHARE Corine Land Cover programme by visual interpretation of the satellite image maps created from the Landsat TM data by Feranec et al. (1996) were the basis for the expression of land cover character of basins. In connection with the analysis of relation between the long term mean annual runoff and land cover, a class with similar character of the effect on runoff were clustered into categories of higher hierarchic level. The share of the following land cover categories in each basin was determined: 1. urbanised and technicised areas, 2. areas of arable land, 3. forest areas, 4. areas of meadows and pastures, 5. areas of alpine meadows and rocky relief, were expressed in each small basins. Thematic map of transmissivity rock environment contains four classes of after Melioris et al. (1986). The value of transmisivity for individual basins was calculated as the weighed mean taking into consideration the areal representation of all degrees contained in basins. This rounded-off value represents the degree of transmisivity of the rock environment for the whole basin.

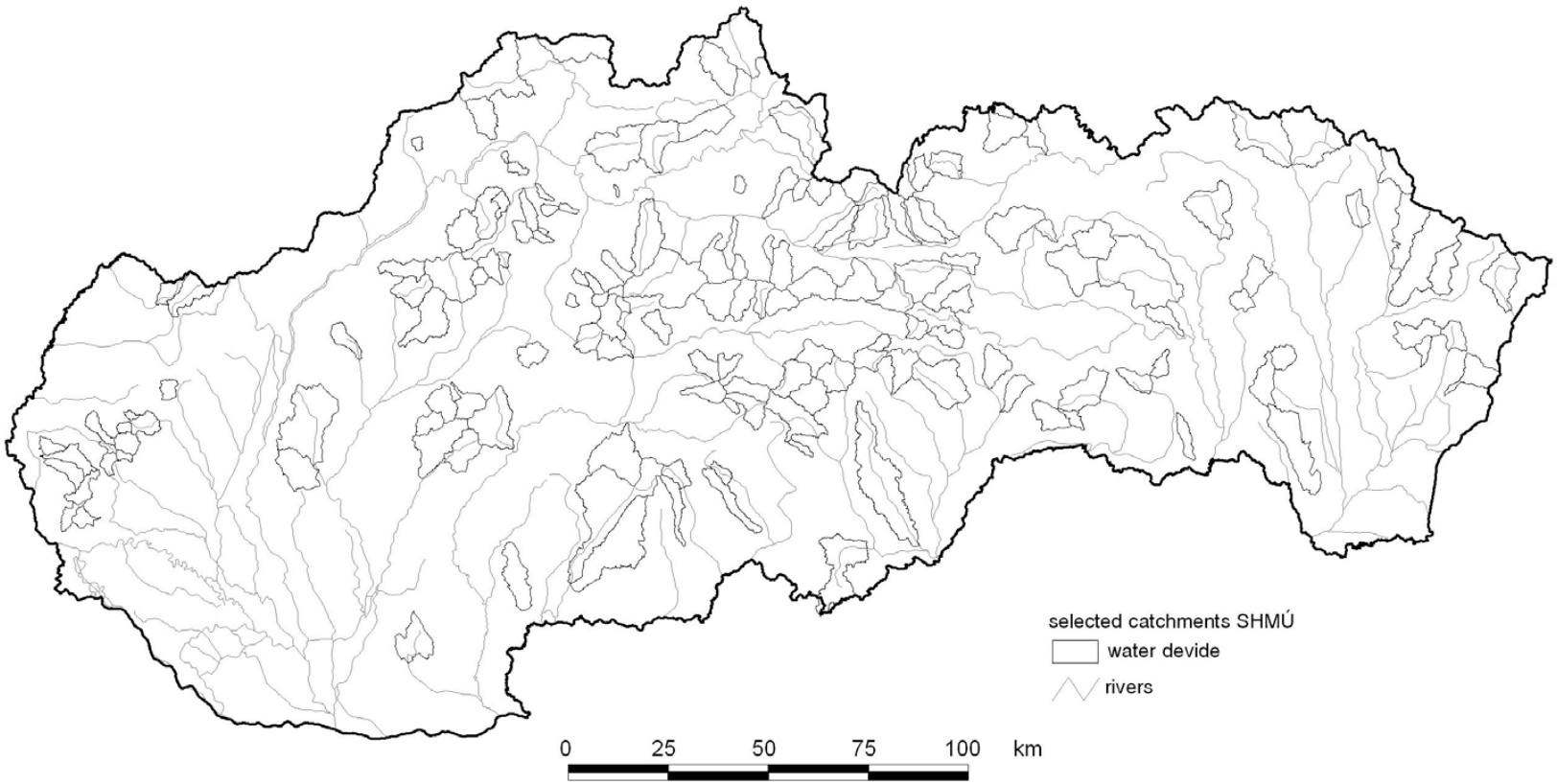

Fig. 1 selected basins with hydrological data

Identification of hydrogeographic regional types of the mean annual runoff

Hydrogeographic regional types were identified in the framework of a selected set of the mentioned 155 small basins. Hydrogeographic regional type is defined as a set of spatial units - small basins - not contiguous in geographic space, which was delimited on the basis of similarity of basin characteristics relevant from the point of view of spatial variability of the mean annual runoff. It complies with the condition of inner hydrologic homogeneity and hydrological heterogeneity in mutual comparison with other hydrogeographic regional types. So, in the process of hydrogeographic regional typification, first physical regional types of basins are delimited and then their mutual hydrological heterogeneity and inner homogeneity are tested.

The graphic analysis of dependence between spatial variability of mean annual runoff and basin characteristics showed that out of selected basin characteristics the decisive influence upon spatial variability of the mean annual runoff within the territory of Slovakia is that of the mean annual precipitation total. An important characteristic is also the mean basin altitude regarding the existence of causal dependence between this characteristic and the mean annual precipitation. Mutual combination of their differentiating values characterising the different groups of basins from the viewpoint of the mean annual runoff values was used for creation of the following classification scheme for delineation of physical regional types of basins:

1 PRT : P < 950 mm, MBA < 350 m n.m.

2 PRT : P < 950 mm, MBA 350-700 m n.m.

3 PRT : P < 950 mm, MBA > 701 m n.m.

4 PRT: P 951-1500 mm, MBA < 950 m n.m.

5 PRT: P 951-1500 mm, MBA > 951 m n.m.

6 PRT: P > 1500 mm, MBA > 951 m n.m.

PRT = physical regional type, P = mean annual precipitation, MBA = mean basin altitude

The sample mean annual runoff representing physical regional types of basins along with other statistical indices is quoted in table 1.

Table 1 The values of sample arithmetic mean of mean annual runoff in physical regional types

PRT	number of basins	arithmetic mean of mean annual runoff (mm)	standard deviation
PRT 1	12	99	65.95
PRT 2	60	273	108.29
PRT 3	33	356	89.59
PRT 4	24	540	116.90
PRT 5	20	686	146.16
PRT 6	6	1364	161.37

Gauged basins classified into physical regional types are samples of the small basins from basin populations of physical regional types. Let μ_i are expected mean values of mean annual runoff of physical regional types. Sample arithmetic means of mean annual runoff x_i are estimations of μ_i. Then our task is to estimate, whether the differences between sample arithmetic means of the mean annual runoff of physical regional types are big enough to justify assertion that the physical regional types of basins are different populations with different expected mean of mean annual runoff. If they do represent such populations, then the identified physical regional types of basins are also hydrogeographic regional types.

Evaluation of the differences among arithmetic mean values of mean annual runoff of the identified physical regional types was carried out by the method of variance analysis (cf. Neter et al. 1985). However, hydrological consequence of classification scheme as a whole was tested first by testing the zero hypothesis: H_0: $u_1 = u_2 = u_3 = u_4 = u_5 = u_6$. The testing criterion was F statistics form of which is

$$F = \frac{\sum n_i (Y_{i.} - Y_{..})^2 / r - 1}{\sum\sum (Y_{ij} - Y_{i.})^2 / n_{T-r}}$$

where

Y_{ij} = j-value of the mean annual runoff in i-PRT, Y... = the total mean of the mean annual runoff of the selected basin set, Y_i = arithmetical mean of the mean annual runoff in i-PRT, n_i = number of values in i-PRT, r = total number of PRT, n_T = total number of basins.

A zero hypothesis is rejected with probability of p if the value of the calculated F statistics is bigger than the value of F distribution with n_T -r, r-1 degrees of freedom. Results of F test are quoted in table 2.

Table 2 Anova table

source of variance	degree of freedom	sum of square	mean sum of square	F value	F probability
between FRTs	5	9762009	1952402	156.73	0.001
within FRTs	149	1856090	12457		
total	154	11618099			

Size of the calculated F value = 156.3 rejects zero hypothesis on equality of the mean expected values of the mean annual runoff of the physical regional types. After rejecting zero hypothesis we logically passed to the second step of variance analysis to pair comparison.

The comparison of differences between pair of arithmetic means of the mean annual runoff of physical regional types was carried out by testing zero hypotheses: $H_0 : u_1 - u_2 = 0$, $H_0 : u_1 - u_3 = 0$, $H_0 : u_1 - u_4 = 0$,..., $H_0 : u_6 - u_5 = 0$ ...

Confidential intervals delimiting with probability of p the intervals of the expected difference value between the mean values of the mean annual runoff of physical regional types were used as testing criterion. Confidential intervals were established by

$$R' + t(1 - a/2; n_T - r)s(R'),$$

where

$$R' = Y_i - Y_j$$

and

$$s^2(R') = \frac{\sum\sum (Y_{ij} - \bar{Y}_{i.})^2}{n_T - r}\left(\frac{1}{n_i} + \frac{1}{n_j}\right)$$

Y_i Y_j are the values of arithmetical means of the mean annual runoff of the different PRT.

If zero is not part of confidential interval, the difference between physical regional types is statistically significant and the zero hypothesis on equality of differences of expected mean values of mean annual runoff is rejected. Results of pair comparison are quoted in table 3.

Table 3 Pair comparison of differences of arithmetic mean values of the mean runoff between PRTs

PRT	difference between arithmetic means	confidental +/- interval
1 - 2	-174.54	69.76 *
1 - 3	-256.70	74.36 *
1 - 4	-441.32	77.99 *
1 - 5	-586.79	80.55 *
1 - 6	-1265.00	110.30 *
2 - 3	-82.17	47.81 *
2 - 4	-266.79	53.28 *
2 - 5	-412.25	56.96 *
2 - 6	-1090.46	94.45 *
3 - 4	-184.62	59.18 *
3 - 5	-330.08	62.51 *
3 - 6	1008.30	97.90 *
4 - 5	-145.46	66.79 *
4 - 6	-823.67	100.69 *
5 - 6	-678.21	102.68 *

** statistically significant differences*

Calculated confidential intervals do not contain zero hence the differences between arithmetical means of mean annual runoff of physical regional types are statistically significant.

However, the model of variance analysis assumes that the values of the mean annual runoff within the physical regional types have normal distribution of probabilities, a constant variance and are independent on each other. Goodness of fit of mean annual runoff value with normal distribution was tested graphically by means of the normal probability plot. The values of the mean annual runoff in the framework of regional types did not show distinct errors of normal division. Regional types are then homogeneous. Bartlet's test was applied for test of variance constancy. Test value $B = 1.08$ does not suggest any expressive deviation from the request on variance constancy. Independence of hydrological values is eliminated to a considerable rate by identification of physic-geographical regional types (cf. Solín, 1995).

Regarding satisfaction of the mutual heterogeneity and inner homogeneity request from the viewpoint of the values of the mean annual runoff, the character of the identified physical regional types is that of hydrogeographic regional types.

Cartographic representation of hydrogeographic regional types of the mean annual runoff in territory of Slovakia though, require ranking of the remaining about 4,400 ungauged small basins regional types into the identified hydrogeographic regional types. These basins were ranked into the individual hydrogeographic regional types by the mean annual precipitation value and the value of mean basin altitude (fig. 2).

Acknowledgement

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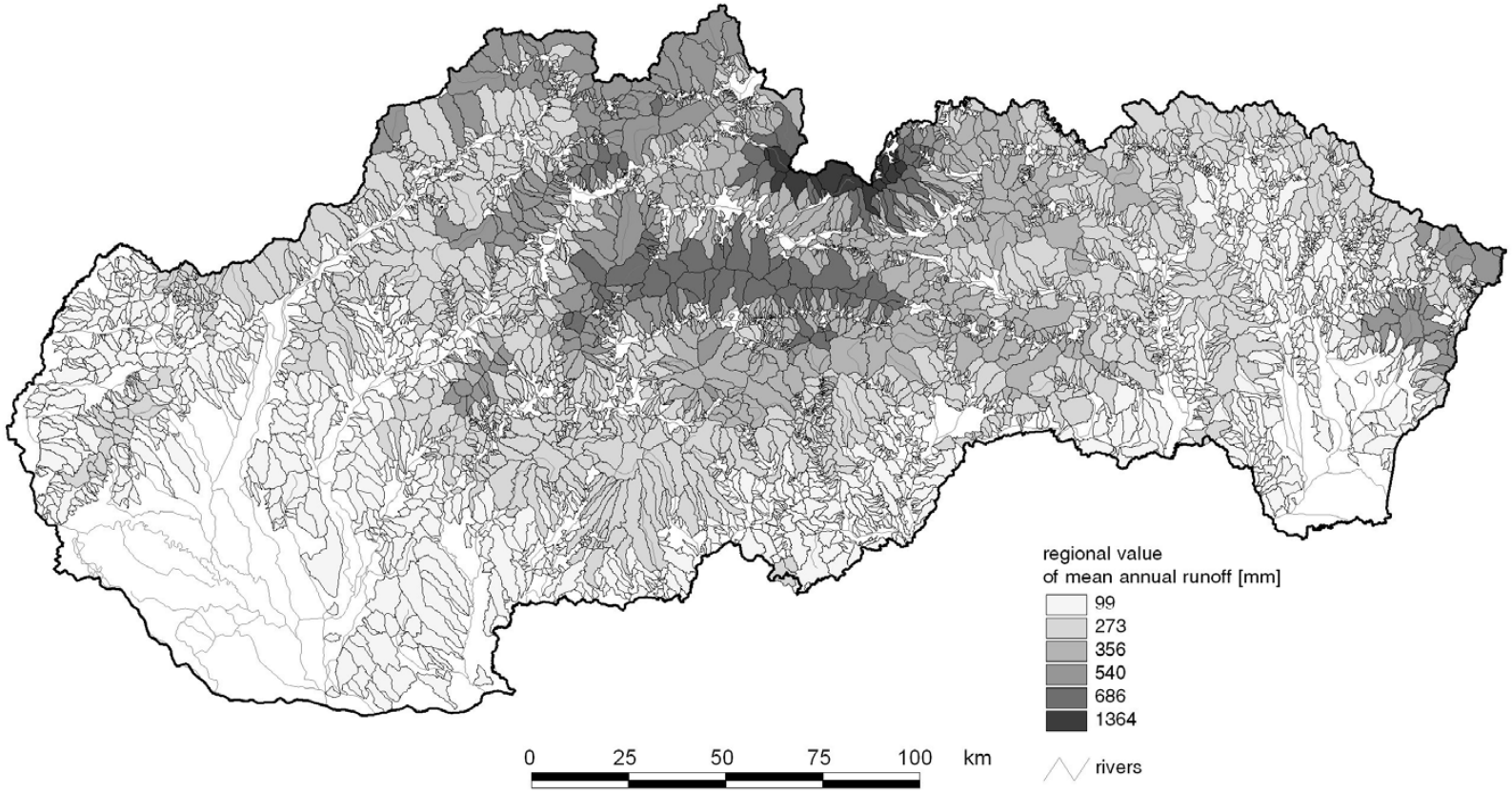

Fig. 2 hydrogeographic regional types of the mean annual runoff

Monitoring the Groundwater Level in the Hydropedological Profiles in the Valleys of the Morava and Dyje Rivers

Eva Soukalová

Abstract: Observation of groundwater in the boreholes of the hydropedological profiles begun in 1933 and today serves the purpose of providing general knowledge of the groundwater regime alongside the flow of the Morava and Dyje rivers.
Key words: groundwater level, borehole, groundwater regime, periods

Die Beobachtung des Grundwasserspiegels in den hydropedologischen Profilen in den Tälern von den Flüssen March und Thaya

Zusammenfassung: Die Beobachtung der Wasserspiegel in den hydropedologischen Profilen begann im Jahre 1933. Heute liefern diese Zeitreihen von Grundwasserständen allgemeine Kenntnisse über das Grundwasserregime entlang der Flüsse March und Thaya.
Schlüsselwörter: Grundwasserspiegel, Beobachtungsrohre, Grundwasserregime, Perioden

1 Introduction

One of the largest projects that necessitated the use of recognaissance work, which included also the drilling of boreholes for the water level observation of groundwater, was the planning of the construction of the Odra-Danube shipping canal. The boreholes make up the so-called hydropedological profiles (HP profiles), placed mostly across the long section of the canal, and at the same time across the longitudinal axes of the river valleys or the flat Moravian floodplains. They have been placed in the basins of the Odra, the Bečva, the Dyje and the Morava rivers.

2 Monitoring of groundwater levels

The first observations begun in 1933 and 1934, and others were added gradually from 1940 onwards. Today these boreholes serve the purpose of providing general knowledge of the groundwater regime alongside the flow of the abovementioned rivers. In geological terms, the HP profiles are in the region of Quarternary sediments, and largely consist of lighter clays, sandy loams, and slightly clayey and non-cohesive sands.

The observation is made with the help of a whistle or a measuring tape, from the top edge of the casing pipe. The measurement was, and still is, always made on Wednesdays, and the overall time of measurement in the individual hydropedological profiles is 2.5 to 3.0 hours. The bores are propped with seamless steel casing pipes with internal diameter of 5.5 cm, which , in their lower part, are perforated, up to a 1.0 m height above their bottoms. In the Morava and Dyje river valleys, the Brno Regional Office of the Czech Hydrometeorological Institute currently monitores 21 hydropedological profiles (14 in the Morava river catchment and 7 in the Dyje river catchment), which together have 332 boreholes. The location of the hydropedological profiles is on the Figure 1.

Among the longest hydropedological profiles is the HP 214 Kostelany, which is in the floodplain of the Morava river. Its predominant part lies in a forest on the left bank of the Morava river, while its shorter part is in the fields on the right bank of the Morava. Altogether, 33 bore logs have been drilled along the profile's 5.015 km length. It is being monitored since 1940.

The second longest profile is the HP 216 Veselí-Zarazice-Bzenec. It is located along the body of the Veselí upon Morava - Bzenec railway line. Originaly, 54 bore logs have been drilled here, along the length of 4.848 km. The bore logs are more frequent in the vicinities of the Morava river, the Bata's Canal, the diversion arm of the Morava river, the Syrovinka brook, and to some extent the proposed shipping canal. It has been monitored since 1933.

At the present time, the useful life of many of the bore logs is comming to an end. For this reason, selected bore logs in 14 hydropedological profiles were re-drilled in recent years, so as to prevent any discontinuity of these long-term series of groundwater level monitoring. In 1991, the reconstruction of 6 bore logs in the HP 223 Strážnice was made. This profile is 2.58 km long and lies between the Velička and Morava rivers, in the Lower Moravian Valley, whose depression is filled with Neogene sediments and its uppermost parts with Quarternary sediments. These 6 bores have been equipped with automatic recording of the groundwater level movement. Records from this equipment were utilised to determine the hydraulic inter-dependence of surface water and groundwater. It has been found that the delay of the rise of groundwater level caused by the rise of the free water surface in the Morava river, at a distance of about 80 m from the Morava, is two days, at a distance of 200 metres it is 7 days, and at 800 to 1400 metres it is 25 to 30 days. These data are important especially for the determination of potential pollution of groundwater by river water.

2.1 Statistical Analysis of Groundwater Level Time Series

Most of the time series of groundwater levels appear to be non-homogeneous, or are homogeneous only within a certain time period. A break in homogeneity of groundwater behaviour often occurs after 1986, when many bore logs registered a significant lowering of groundwater levels. For example, the lowering of groundwater level in the HP 207 Hulín-Bílany, near the city of Kroměříž, behaves in this way. The average levels during the period of 1971 - 1997 are 1 to 2 m lower than those during 1941 - 1970. In some boreholes, the average yearly lowering since 1940 has been up to 0.05 m. A rise in groundwater levels has been occurring in the HP 209 and 210, which are located near the city of Otrokovice. The rise in the levels is 0.01 to 0.025 m annually since 1970, when observations started, and it has probably been caused by the narrowing of the Morava river valley near the town of Napajedla, as well as by an impermeable „sill“ in the underlying geological strata.

Figures 2 and 3 show the average yearly groundwater levels in a bore log of the HP 222 Lanžhot profile, and in a bore log of the HP 216 Veselí profile (catchment of the Morava), which have both been monitered since 1934. Figure 2 depicts a long, statistically significant 30-year period, together with a long-term lowering trend (0.008 m per annum since 1934), which significantly influences the sequence of the groundwater levels. The dashed line in turn shows modelled groundwater levels for 5 most significant periods, as well as the forecast of levels till the year 2002. Figure 3 shows a statistically significant 10-year period, together with a linear lowering trend (0.007 m since 1934), and a forecast of average yearly levels till 2002.

2.3 The Groundwater Regime

The monitoring of groundwater level in hydropedological profiles has importance mainly because of the tying of the profile with the stream on which a stage-measuring staff has always been fixed, and also with respect to the need to keep the long monitoring record continuous. The length of the time series of observation till the present day is up to 67 years. From the knowledge of the groundwater regime in these profiles one can generally deduce:

- The groundwater level, in the long term, for all boreholes follows virtually identical fluctuation, being a minimum in October and a maximum in April, with gradual movement of groundwater levels in between.

- The groundwater levels in the boreholes are mainly dependent on the discharge in the stream,and not on direct contribution from precipitation.

- The groundwater surface level does not lie deep below the terrain. Its depth below ground surface is up to 8 m at the most, and the highest groundwater levels, in the vicinity of streams, rise above the terrain.

- The fluctuation of the groundwater levels is large, due to the overall extent and magnitude of flooding. The difference between the maximum and minimum levels is, on average, about 3 m. Its greatest values are found in bores near the river, where it may reach up to 5 m. The standard deviation has an average value of 0,5 m.

- With respect to the long time-sequences, periods of interest may also be evaluated. For the majority of the boreholes, the most significant period appears to be a twelve-monthly one, corresponding with the seasonal recharging of groundwater. The second most significant period, of those that were reliably found and proven, is a period of approximately five years. A two-yearly period is the third most significant one. Where there is a sixty-year sequence of observations, the thirty-year period is, for some profiles, also statistically significant.

- Besides the significant periods, of importance is also the incidence of minimum groundwater levels. These occur approximatelly every ten years. From the groundwater point of view, the following years were extraordinarily water-depleted: 1934, 1944, 1954, 1964, 1974, 1984 and 1993. The very lowest levels for most bores occurred in 1983-84, and the second most frequent lowest minimum was recorded in 1993.

- In the Dyje river catchment after 1972, the groundwater level was lowered by about 0.5 m,and the fluctuation of the groundwater levels was diminished, as a result of the regulation of the Dyje river. The construction of the Nové Mlýny dams influenced particularly the groundwater regime within bore logs in the immediate vicinity of the dams. In these bores, the fluctuation of the groundwater levels has been diminished, while the standard deviation has been halved.
- The July 1997 flood influenced the groundwater levels in the proximity of the Morava river. In the region around the city of Kroměříž, as late as October 1997, the groundwater levels were, on average, 0.74 m above the long term October average, and further downstream, in the region of the city of Uherské Hradiště, 0.46 m above. In the spring of 1999 the groundwater levels in the Morava river catchment were in general 0.30 m above the long-term average, but on the other hand in the Dyje catchment, which was not affected by the flood, the groundwater levels were around 0.15 m below the long-term average.

3 Conclusion

In a resolution of the Government of the Czech Republic dated 11.12.1996, the Minister for Local Development, in co-operation with the Minister for Transport and Communication, is given the task of carrying out all necessary steps to protect the land for the future alterations to the Odra and Morava rivers which would make them suitable for shipping, and to protect the land within the proposed location of the considered Danube-Odra-Labe shipping canal connection, within the bounds of the directives for land plans of large area units. In carrying out the above, the original intention for the long-term groundwater level observation sequences would be fulfilled.

4 References

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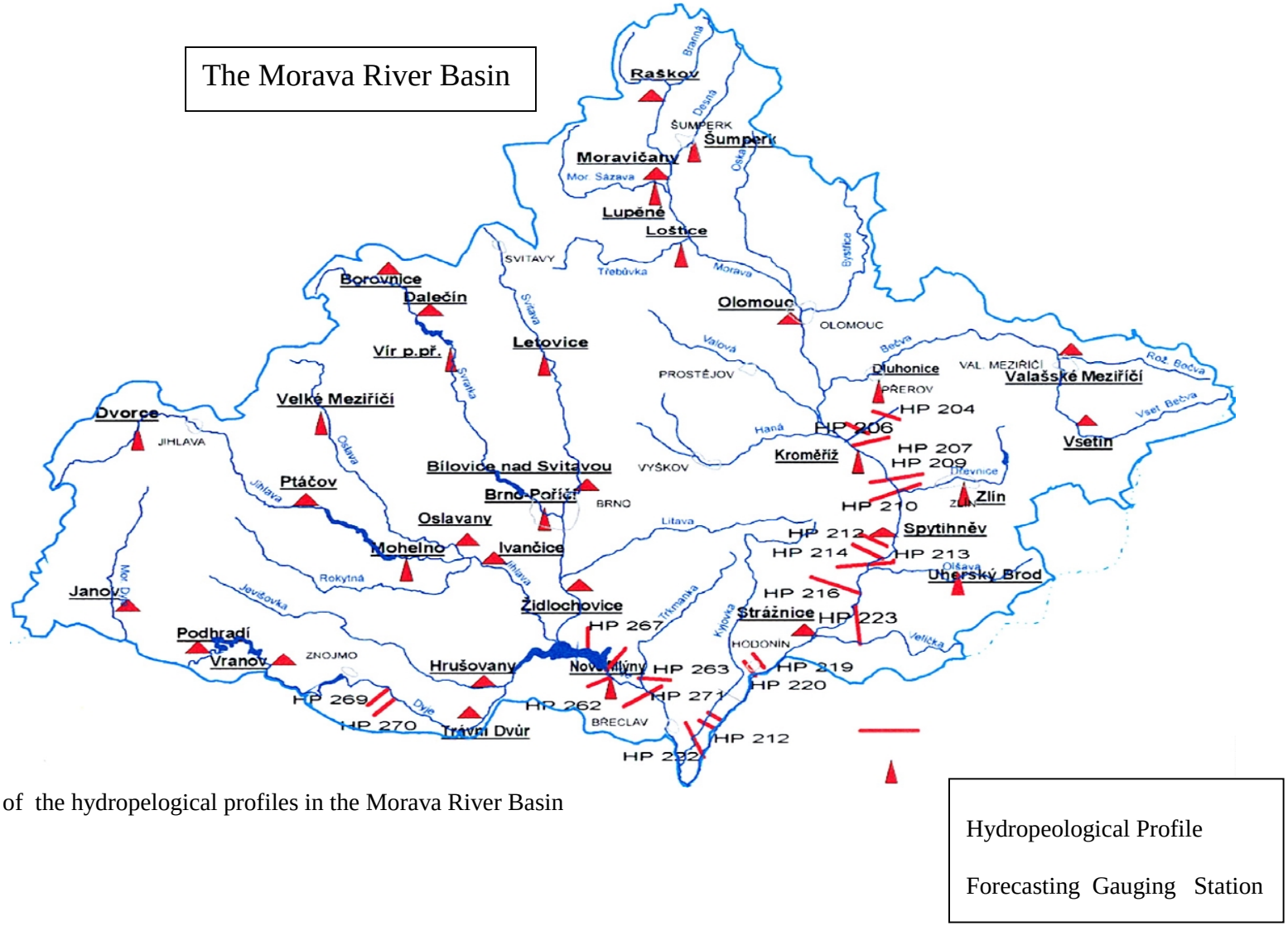


Fig. 1 Location of the hydropelogical profiles in the Morava River Basin

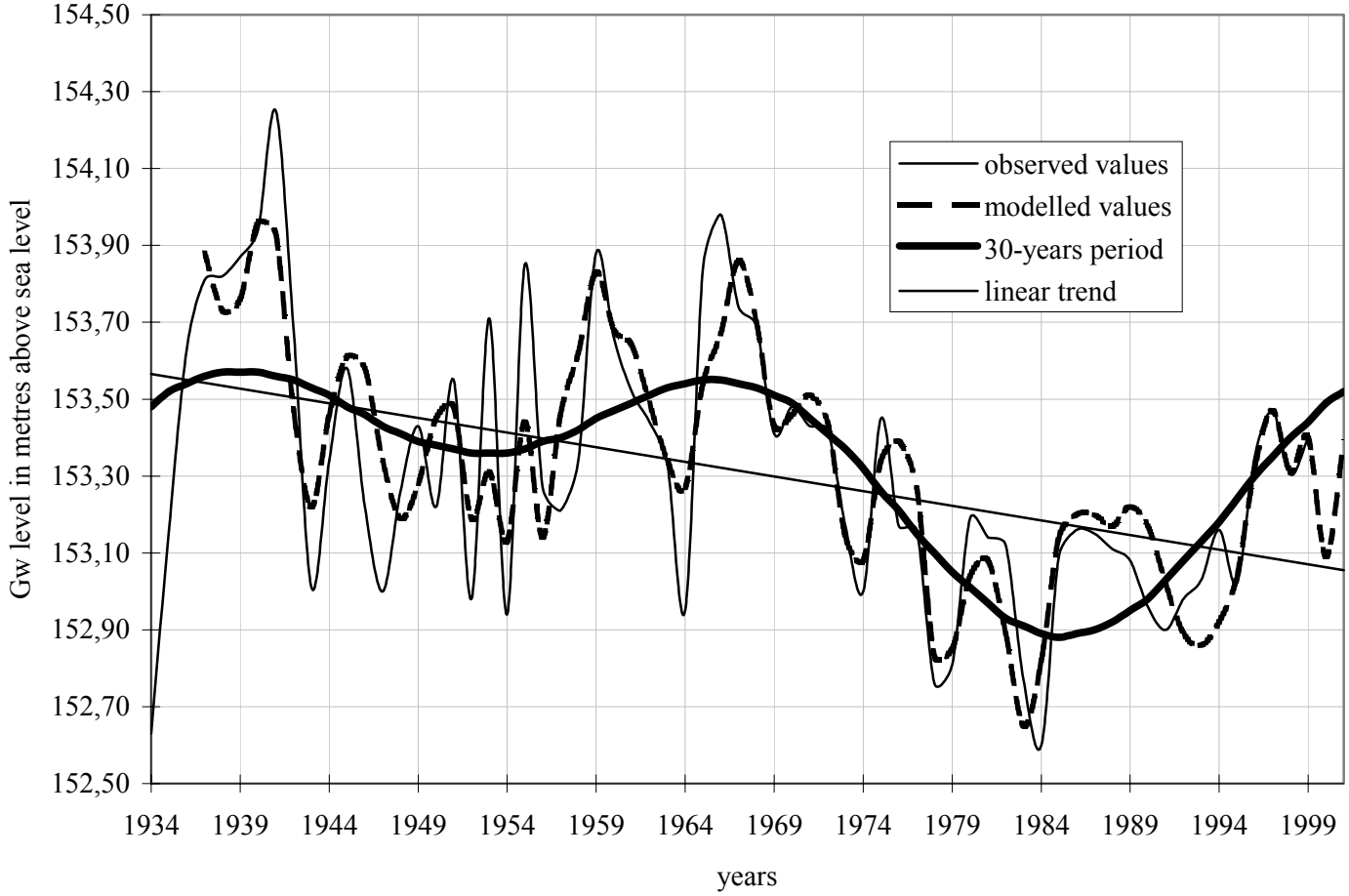


Fig. 2 Observed and modelled values of groundwater levels in the borehole of the Hydropedological Profile 222 Lanžhot

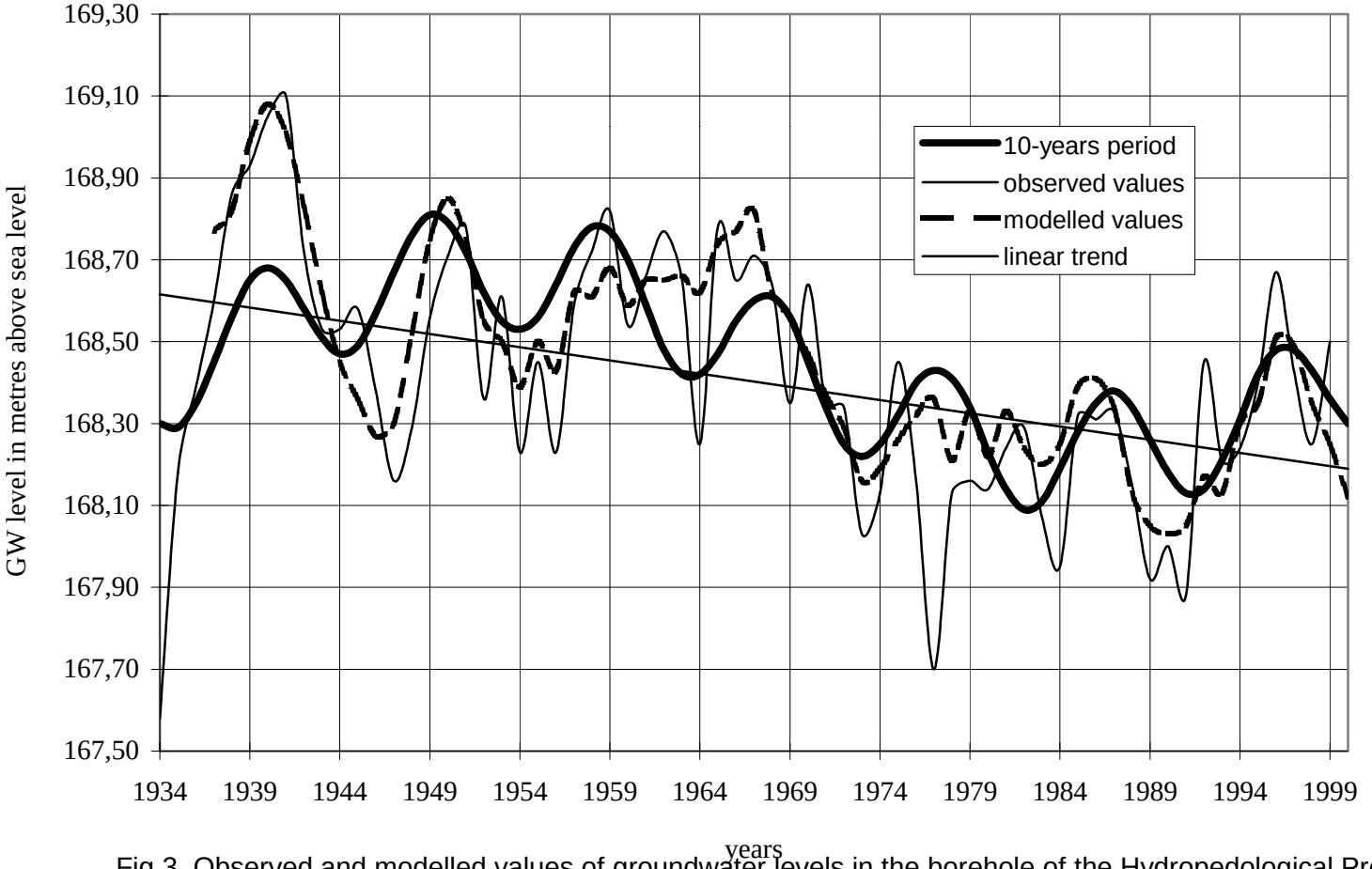


Fig.3 Observed and modelled values of groundwater levels in the borehole of the Hydropedological Profile 216

Veselí

Regional Analysis of Annual Flood Discharges in the Danube Basin

Viorel Stanescu, Valentina Ungureanu, Miklós Domokos

Abstract: In 1986 the Hydrological Monograph of Danube and its catchment was published in Munich, as a result of the 15 years long cooperation of the Danube Countries. Since that time, the Danube Countries (whose number increased to 13) have continued the cooperation in the frame of IHP/UNESCO. Its main purpose is to compile follow-up volumes to the Danube Monograph on selected topics of common interest. One of these projects has dealt with the analysis of annual maximum discharges observed in the Danube Catchment. The present paper offers a survey of the results of the project, obtained by common efforts under Romanian coordination. A more detailled, full report will soon be published in one of the next follow-up volumes to the Danube Monograph.

Key words: probability distribution function, annual maximum discharges, regionalization

Analyse der jährlichen Hochwasser im Donauraum als Beitrag zum Hochwasserschutz und der Regionalisierung hydrologischer Daten

Zusammenfassung: 1986 wurde in München, als ein Ergebnis der 15-jährigen Zusammenarbeit der Donauländer, die "Hydrologische Monographie der Donau und ihres Einzugsgebietes" herausgegeben. Hauptzweck der seitdem im Rahmen des IHP der UNESCO laufenden Zusammenarbeit der nun 13 Donauländer ist es, Folgebände zur Donaumonographie über ausgewählte Themen zu erstellen. Eines dieser Projekte befasste sich mit der Analyse der jährlichen Hochwasserabflüsse. Der folgende Beitrag gewährt einen Überblick über die unter rumänischer Koordination, in gemeinsamer Arbeit erzielten Ergebnisse, über welche bald in einem der nächsten Folgebände zur Donaumonographie ausführlich berichtet wird.

Schlüsselworte: Verteilungsfunktionen, jährliche Hochwasser, Regionalisierung

1 Aim and rationale

The master plans for an integrated and complex water management implies good knowledge of the hydrological parameters in the basins lying above more points than those where the data are recorded. An approach towards the knowledge of the laws that govern the manner of existence of the hydrological parameters over a territory is the regional analysis. This analysis results in a regionalization that may be defined as interpolation of location-specific data across a spatially contiguous area.

The main problems of the hydrological regionalization refer to the manner in which the transfer of data to the ungauged basins or to deficient data sites is carried out. There are two main procedures to perform this transfer (*Stanescu, 1992)*.

The first one consists in finding out some relationships aiming to the spatial interpolation of the principal statistics of the probability curves, namely the mean and the variation. The mean may be correlated with the basin characteristics with acceptable results at a significance level of 95% (*Roald, 1989*), (*Acreman, 1989*).

The second procedure consists in finding out several statistical distribution curves of standardised annual maximum discharge. Standardisation is achieved by dividing the maximum discharges quantiles by their average magnitude $\overline{Q}$. The mean value $\overline{Q}$ may be regionalised through correlating it with the physiographic characteristics of the basin (*NERC, 1975*), (*Acreman, 1989*), (*Roald, 1989*). To apply the second procedure it is necessary to establish, both the regions to which several growth curves are assigned and correlation between $\overline{Q}$ and

basin characteristics.

Coming back to the problem of the assessment of the regions, it is well known that in order to decide whether a group of catchments may form a region, their hydrological similarity should be analysed. One of the procedures which can be used to assess the regions is the split-sample method (*Acreman, 1989*). Another method of grouping consists in producing groups of basins where their physiographic characteristics present maximum similarity. One considers a multivariate normal distribution to which the set of characteristics of each group considered "a priori" is fitted. A last procedure consists in allocating to an ungauged basin of weights of membership to a set of zones in order to take into account the discontinuities at the their borders (*Accreman and Wiltshire, 1987*).

Unfortunately, the restrictions concerning the availability of a great and complete data for the Danube Basin do not allow applying these more or less objective methods of grouping the basins within regions. That is why, a regionalization of the annual maximum discharge based upon the relationships with the physiographic factors across the whole basin of Danube has been performed only on a limited area where sufficient data are available.

Taking into account all the above mentioned considerations on the theoretical and informational bases of the hydrological regionalization, the aims of this report are:

- Regionalization of the probability curves across Danube Basin (macro regionalization);
- Regionalization procedure to assess the maximum discharge quantiles for a partial area of Danube Basin (micro regionalization).

2 Data collection and data base

The present work has been carried out as a result of the regional co-operation of the Danubian countries in the framework of IHP program. The following countries provided data on which this study is based: Germany, Austria, the Czech Republic, Slovakia, Hungary, Ukraine, Slovenia, Croatia, Yugoslavia, Romania, Bulgaria and the Republic of Moldavia.

The database concerning information on the annual maximum discharges comprises:

- Location and recording periods of the selected hydrological stations.
- Some physiographic characteristics of the catchments.
- The series of the annual maximum discharges recorded at the selected stations.
- Some countries have supplied information on the estimates of the annual maximum discharges of certain probability of exceedance.

Table 1 Length of the series of the recorded data (years)

Country	**Ranges**							
	30÷40	**40÷50**	**50÷60**	**60÷80**	**80÷100**	**100÷120**	**>120**	**Total**
Germany	1	5	9	23	7	1	-	**46**
Austria	-	15	-	-	-	1	-	**16**
Czech R.	-	-	-	4	-	-	-	**4**
Slovakia	4	3	3	8	-	-	-	**18**
Hungary	31	-	-	-	-	-	-	**31**
Ukraine	-	4	1	-	-	-	-	**5**
Slovenia	6	-	-	-	-	-	1	**7**
Croatia	3	-	-	2	-	-	-	**5**
Yugoslavia	-	13	-	-	-	-	-	**13**
Romania	1	11	3	3	3	4	1	**28**
Bulgaria	-	-	3	-	-	-	-	**3**

Moldavia	-	2	-	-	-	-	-	**2**
Total	**48**	**60**	**28**	**41**	**10**	**5**	**3**	**176**

The number of the gauging stations on the ranges of areas is relatively uniform, although there are only 13 stations in the range of 50÷200 km^2 and 49 in the range of 1000÷3000 km^2. As far as the lengths of the data series are concerned in Table 1 one can see that out of 176 stations there are long enough rows ranging between 40-80 years.

3 Methodology of regionalization used in the study

3.1. Method of regionalization of the probability distribution curves

For each point observation the series Q_i of the maximum discharges is considered.

The values of the empirical probability (expressed as percents) are obtained by the formula:

$$p = \frac{m}{n+1} \tag{1}$$

where p is the probability of exceedance of a sample occupying in decreasing order the mth place in a series of n members.

For each series, the variable K_i (modulus coefficient) has been computed as follows:

$$K_i = \frac{\frac{Q_i}{\overline{Q}} - 1}{C_v} \tag{2}$$

where: $\overline{Q}$ is the mean values of the series and C_v is the coefficient of variation:

Then, the empirical distribution curves of the probability of exceedance of K_i were plotted on probability graphs. From (2) there results the value of the maximum discharge of a given probability of exceedance Q_p as follows:

$$Q_p = \overline{Q} \cdot \left(C_v \cdot K_p + 1\right) \tag{3}$$

The next step is to draw the correlation between the variable K_p on the one hand and the coefficient of variation C_v and the probability of exceedance p on the other.

Thus the relationships $K_i=f(C_v,p)$ and then the regional probability curve belonging to a specific zone were determined. Relied on this curve, for a certain established zone, the maximum discharge of a certain probability of exceedance may be estimated according to the relation (6) provided that the parameters C_v and $\overline{Q}$ are known.

The skewness C_s of the distribution curves are implicitly considered in the relationship $K_i=f(C_v,p)$ as a linear function of C_v. One considers that the ratio C_s/C_v is constant across a certain region and this fact is reflected in the differentiation of the relationships $K_i=f(C_v,p)$ from a zone to the other one. Anyhow, this procedure of "averaging" the K_p over a relative homogeneous zone is more correct than that which deems the on-site computed estimate of the skewness coefficient C_s. The punctual computation of C_s is subject to important errors of it unlike the number of terms of a series is great (100÷150 years).

3.2. Procedure for regionalization of the annual maximum discharge quantiles

This procedure consists in the determination of the relationships between each standard quantile of the maximum specific discharge ($q_p=Q_p/AREA$) and a set of basin physiograpfic characteristics. This approach leads to an analytical model, which reveals the manner in which each set of characteristics has a different influence on each quantile.

Denote y=log q_p and x_i = log X_i, X_i being the value of a basin characteristic. Than, the linear regression relation is assumed:

$$y = \log a_0 + \sum_{i=1}^{n} a_i x_i \tag{4}$$

where: n is the number of the characteristics considered in the set, a_i are the corresponding coefficients and a_0 is a constant.

From (4) one can write the equation:

$$q_p = a_0 X_1^{a_1} X_2^{a_2} \ldots X_n^{a_n} \tag{5}$$

Each relationship of type (5) is then assigned to a region across which there is a cvasi-homogeneity of the physiographic and climatic characteristics.

4 Description of the work and results

4.1. Regionalization of the probability distribution curves

Relied on the theory and the methodology described before, taking into account some considerations concerning the philosophy of the regionalization procedures and the availability of data, the following works were carried out:

- For each series of annual maximum discharge the statistical parameters $\overline{Q}$ and C_v have been derived.
- Then, each series of annual maximum discharge has been transformed in a series of modulus coefficients according to the relation (2).
- The empirical curves of the probability of exceedance of K_i were drawn on Gauss paper, after putting in a decreasing order the terms of the series K_i to which the probability p computed by relation (1) has been assigned.
- The next step was to make a visual "on-trend" extrapolation on the empirical probability curves up to 1%.
- From the extrapolated empirical curves the estimates of the modulus coefficient K_p for all standard probability values p (1%; 5%; 10%; 20%; 50%; 80%; 90% and 95%) have been derived.
- Afterwards, the relationships between the coefficients K_p and the coefficient of variation C_v (for each of the standard value of p) have been derived. While drawing up the correlation K_p - C_v the points were grouped so that on the one hand, their deviations from a regression curve should be minimised and simultaneously, they should be gathered as representing contiguous basins in an "a priori" selected zone, on the other hand. The membership of the points to a specific zone has been justified by the cvasi-homogeneous characteristics of the topography and the climate (****, *1986*), (*Stancik A. et. all, 1988*), (*Stanescu, 1967*). After some iterations a final gathering of points K_p - C_v and therefore a zonation of the Danube Basin (Figure 1) has been carried out.

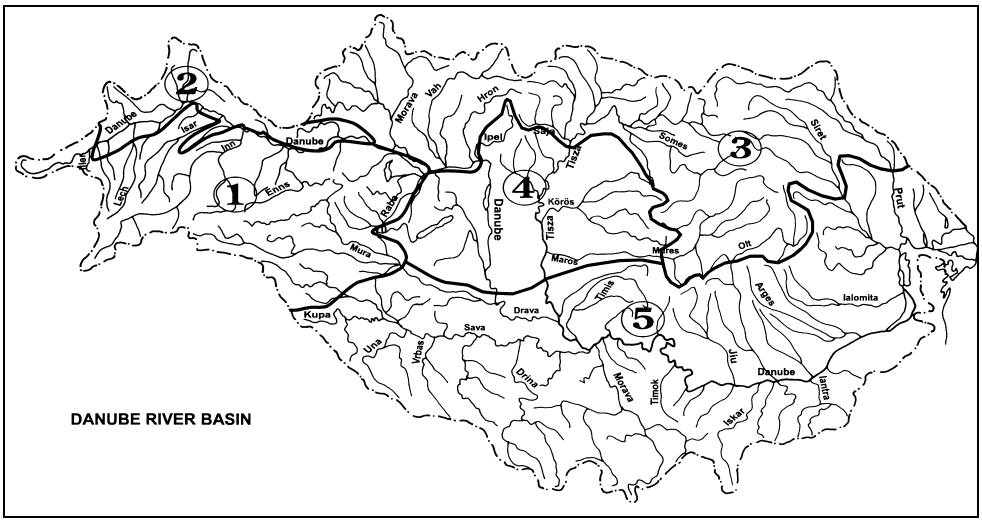
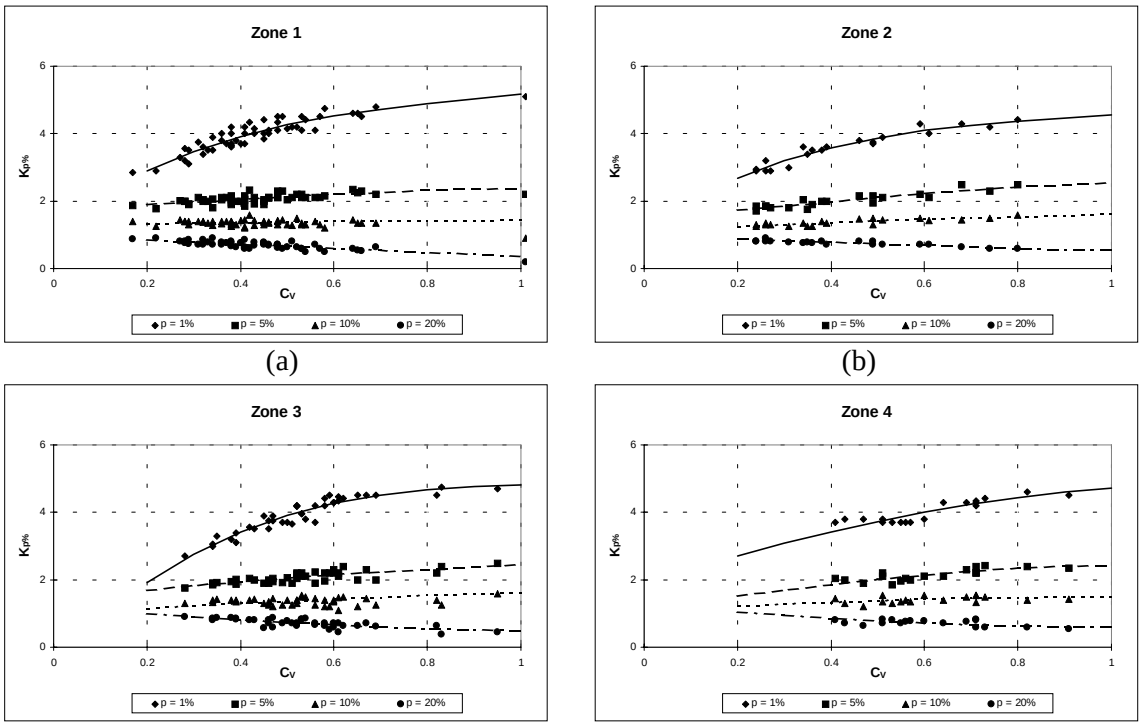
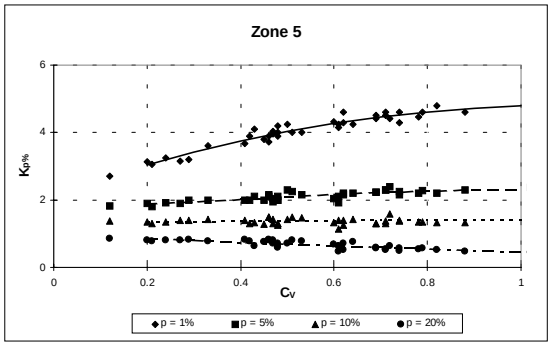


Fig. 1 Zonation of the regional probability curves

It is noteworthy to point out the facts, that the zonation has a "macro character" having in view the number of series used in the study, especially for the areas where the density of the stations is somehow limited. For example, a better and hence more detailed zonation was possible for the stations from Germany, which has a good density over the upstream area of the Danube Basin. The same is the case of the stations from Slovakia, Ukraine, Hungary and Romania which allowed to better share the area from the middle part of the Danube Basin into specific zones. The correlation K_p-C_V grouped on the five specific zones is presented in Figure 2 and the analytical equations of their regression curves have been derived.





(e)

Fig. 2 Relationships $K_{p\%}$ function of C_v and the probability of exceedance of 1%, 5%, 10%, 20% corresponding to the zone 1 (a), zone 2 (b), zone 3 (c), zone 4 (d) and zone 5 (e)

Besides their similar characteristics of the climate and the relief, the regions have been chosen so that there were a differentiation between the curves K_p-C_V . For 1% probability the relationships K_p-C_V valid for all five regions are superimposed plotted in Figure 3.

Further on, an analysis of the deviations of the regional probability curves from the probability distributions functions (**pdf**), the most commonly used in hydrology was carried out.

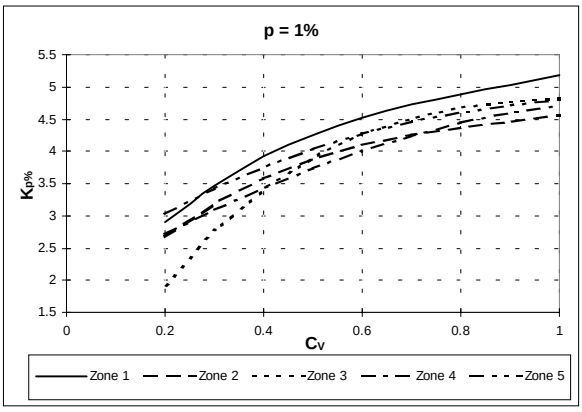


Fig. 3 Relationships $K_{p\%}$ - C_v and the probability of exceedance of 1% for all five zones

The relative deviation of the maximum discharge of a certain probability of exceedance p determined on the basis of the regional curves and of the **pdf** ones is:

$$\varepsilon_{Q_{pT}} = \frac{\Phi_T - \Phi_R}{\Phi_R} = \frac{C_v \cdot \left(K_T^{\{p\}} - K_R^{\{p\}}\right)}{C_v \cdot K_R^{(p)} + 1} \tag{7}$$

In Table 2 the deviations between the maximum discharges computed on the basis of a regional curve and a certain **pdf** one, function of the probability and C_v are presented.

Table 2 Relative deviations $\varepsilon_{Q_{pT}}$ of the regional probability curves from the **pdf** ones

Zone	**p**	**C_v = 0.4**			**C_v = 0.6**			**C_v = 0.8**		
	(%)	**PS**	**KM**	**LN**	**PS**	**KM**	**LN**	**PS**	**KM**	**LN**
1	1	0.097	0.113	0.127	0.114	0.140	0.156	0.107	0.162	0.165
	5	0.018	0.037	0.040	0.044	0.078	0.073	0.121	0.156	0.148
2	1	0.030	0.048	0.063	0.067	0.094	0.111	0.068	0.125	0.129
	5	-0.023	-0.002	0.000	0.044	0.078	0.073	0.108	0.144	0.136
3	1	0.018	0.037	0.052	0.095	0.121	0.138	0.099	0.155	0.158
	5	0.013	0.033	0.035	0.047	0.081	0.075	0.101	0.137	0.129

4	1	-0.003	0.015	0.031	0.035	0.064	0.081	0.055	0.113	0.116
	5	0.002	0.022	0.025	0.021	0.056	0.051	0.113	0.149	0.141
5	1	0.065	0.083	0.097	0.087	0.114	0.131	0.092	0.147	0.151
	5	0.000	0.020	0.022	0.044	0.078	0.073	0.083	0.120	0.111

From Table 2 one can observe that the Pearson III distribution curve shows the smallest deviations from the regional curves for any zone and any given probability.

Taking into account that for the coefficients of variation which do not exceed 0.5 the deviations are below 5%, one admits that under these circumstances the Pearson III distribution curve is the closest one to the regionalization curves.

The extrapolation from the 1% quantile $Q_R^{1\%}$ is made according to Pearson III distribution curve which has shown the smallest deviation from the regional curve.

The regional probability curve extrapolation starts from the estimate of $K_R^{1\%}$ and the Pearson III frequency factor $K_P^{(p)}$ as follows:

$$Q_R^{(p)} = Q_R^{1\%} \frac{C_V \times K_P^{(p)} + 1}{C_V \times K_P^{1\%} + 1} \tag{8}$$

Then any quantile of maximum discharge of certain probability p (p<1%) is computed making use of relation (8) and the modulus coefficient $K_R^{(p)}$ is derived as:

$$K_R^{(p)} = \frac{K_R^{1\%}\left(C_V \times K_P^{(p)} + 1\right) + K_P^{p\%} - K_P^{1\%}}{C_V \times K_P^{1\%} + 1} \tag{9}$$

The regional probability curve specific to a certain zone of the Danube river basin may be used in two ways:

- Either in the considered point there are observations on the maximum annual discharges over a relative short period (20-25 years) which nevertheless allows to have good enough estimates of C_v and $\overline{Q}$. Then, one adopts the regional probability curve belonging to the zone where the basin is located;
- Or, in the considered area a relationship between the statistical parameters $\overline{Q}$ and C_v or the maximum discharge quantiles on the one hand and some characteristic feature of the basin, on the other, might be found.

4.2. Regionalization of the maximum annual quantiles in a limited area

Relied on a great number of hydrological stations from Romania where reliable estimates of maximum discharge quantiles are assessed, the procedure described before was applied.

The following set of physiograpfic parameters were considered: (H, F); (H/$\sqrt{F}$); (F, H, I_b); (F, H, B/L) where H, F, I_b, and B stands for the mean altitude, area, mean slope and width of the basin, respectively and L is the length of the main course of the catchment.

The quantiles of the specific maximum discharge were correlated with each set of the above mentioned variables. By means of the analysis of the deviations of the quantiles as resulted from the regression (denoted q'_p) and those which were directly assessed at stations (q_p), five zones were established (Figure 4).

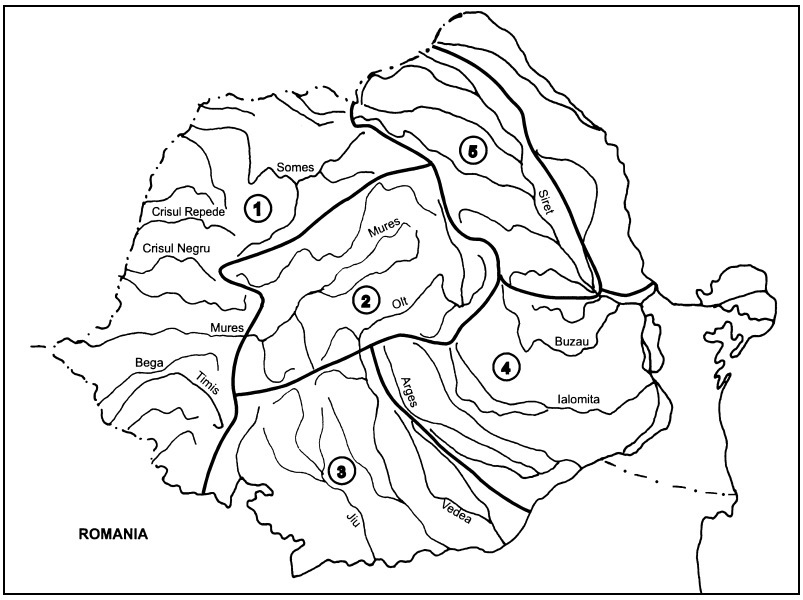


Fig. 4 Zonation of the regression coefficients

For each region, the combination of basin characteristics which resulted in the best estimation of 1% quantile has been chosen. The best result is given by the correlation of the 1% quantile with the set (F, H, B/L).

Further on, considering the set (F, H, B/L) the regression coefficients of all standard quantiles (0.1%, 0.5%, 1%, 2%, 5%, 10%) have been determined. The distribution of errors ($E_r=(q'_p-q_p)/q_p$)) by ranges is presented in Table 3.

Table 3 Errors - variables: F, H, B/L

Zone	p (%)	Errors				
		$E_r>25$	$20<E_r<25$	$10<E_r<20$	$5<E_r<10$	$E_r<5$
Zone 1	0.1	0	3	18	10	17
	1.0	0	4	14	11	19
	10.0	2	7	18	13	8
Zone 2	0.1	1	2	11	6	14
	1.0	1	0	13	9	11
	10.0	2	4	8	10	10
Zone 3	0.1	0	5	13	3	6
	1.0	1	2	12	6	6
	10.0	5	1	10	3	8
Zone 4	0.1	0	1	9	3	7
	1.0	0	1	9	3	7
	10.0	0	2	4	5	9
Zone 5	0.1	0	4	2	2	9
	1.0	0	4	2	4	7
	10.0	1	1	4	4	7

5 Conclusions

- This study is based on an important volume of data concerning the annual maximum discharges recorded at 176 stations located within the Danube basin.
- The length of the records is considered sufficient to accurately estimate the statistical

parameters of the series. An important number of series provided by the Danube countries show records, which exceed 80 years.

- The spatial distribution analysis of the reduced variable K_i shows a regional grouping of it. Five specific zones valid for several relationships $K_p = f(C_V, p)$ were established.
- The limited number of series does not allow performing a regionalization of the distribution curve parameters. This can be achieved for limited, areas by the use of much greater number of hydrological rows of annual discharges.
- A comparative analysis of the deviations of the regional curves from some usual theoretical distribution ones (Pearson III, Lognormal, Kritzky-Menkel) reveals that the Pearson III distribution curve shows the smallest deviations against the regional curves. Therefore, for the extrapolation of the regional curves in the domain of rare frequencies (0.01% and 0.1%) the use of Pearson III curve is recommended.

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The Correction Factor of the Aerodynamic Method

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Abstract: The necessity of getting physical meaning for watershed model's parameters is discussed. Presently, lumped conceptual and empirical watershed models are the only truly tools for river forecasting. To get reliable results, their parameters are tuned with local data by an optimisation method. The consequences of non-conformity of data used for model operation and calibration are discussed and demonstrated by the linear regression model.
The operational use of the aerodynamic method has been chosen to illustrate the case of non-conformity of a model and data. The recommended use of the mean daily temperature underestimates the evaporation rate. The values of the derived correction factor (*CF*) can be quite significant both for arid and humid tropic zones. Taking into account that wind speed and air temperature shows usually positive correlation in a daily run, the bias will exceed the *CF* value.

Key words: Aerodynamic method, Evaporation, Vapour pressure, Bias, Taylor expansion, Regression, Variance, Mean Square Error.

Der Korrekturfaktor in der aerodynamischen Methode

Zusammenfassung: Es wird die Notwendigkeit diskutiert, Parametern in Einzugsgebietsmodellen eine physikalische Bedeutung zu geben. Zum jetzigen Zeitpunkt sind konzeptionelle und empirische Einzugsgebietsmodelle die einzigen genauen Werkzeuge für Vorhersagezwecke. Um zuverlässige Ergebnisse zu erhalten, werden ihre Parameter mit Hilfe von lokalen Messwerten durch eine Optimierungsmethode abgestimmt. Die Auswirkungen von nicht konformen Daten, die für den Betrieb und die Kalibrierung des Modell verwandt werden, werden diskutiert und durch ein lineares Regressionsmodell aufgezeigt.
Es wurde die operationelle Anwendung der aerodynamischer Methode gewählt, um den Fall der Nichtkonformität des Modells und der Daten aufzuzeigen. Die vorgeschlagene Empfehlung, die tägliche Mitteltemperatur zu verwenden unterschätzt die Verdunstungsrate. Die Werte des abgeleiteten Korrekturfaktors (CF) können sowohl für aride als auch für humide tropische Zonen sehr bedeutend sein. In Anbetracht der Tatsache, dass Windgeschwindigkeit und Lufttemperatur im Tagesverlauf in der Regel positiv korreliert sind, übertrifft der systematische Fehler den CF Wert.

Schlüsselworte: Aerodynamische Methode, Verdunstung, Dampfdruck, systematischer Fehler, Taylor-Entwicklung, Regression, Varianz, mittlerer quadratischer Fehler

1 Introduction

The idea challenging physical hydrology is to introduce explicitly the catchment descriptions into distributed physically based models through parameters, which could be directly assessed from field measurements. The parameters may also vary seasonally and spatially. With model's parameters having the physical meaning, one can assess effects of land cover changes or of expected climate change, included feedback relations, on water storage in basin and runoff process.
It is the soil, which controls the amount of water available for evapotranspiraton and the downward movement of water in the subsurface. Therefore, knowledge of soil physical and hydraulic properties is a key element in modelling moisture transfer in the soil-vegetation-atmosphere system. However, data on soil hydraulic properties are sparse and often unreliable as they base on small samples from highly heterogeneous medium. The assessment of potential evapotranspiration of a crop is also highly uncertain. Philip (1975) points out that synthesis of small-scale local processes to model large and spatially heterogeneous basins presents formidable tasks of integration, system characterisation, and data collection. The GIS interface

enables to delineate, characterise, and parameterise topographical, hydrological and biological basin features for use in distributed-parameter modelling approach. Fundamental question is, whether the concept of the new generation models is realistic even in respect to a selected basin, and if so what would be benefit of this for other not adequately monitored basins.

It is well known that hydrological models used in river forecasting must be tuned with local data to get reliable results. Then the calibrated values of parameters take into account of simplifications in the model and errors in input data. Therefore, they do not have a purely physical interpretation and they may be out of acceptable physical range. In distributed runoff models, the calibration becomes unreliable by the over-parameterisation of these models (e.g. Grayson et al., 1992a,b). Therefore, lumped conceptual or empirical watershed models seem to be today the only truly operational rainfall-runoff tools for practical hydrological issues. One of the goals of Model Parameter Estimation Experiment (MOPEX) (Hall and Shaake, 1996) is to relate empirically the parameters of calibrated models to physical characteristics. However, measurement and lumping errors would affect the calibrated values of parameters.

The paper deals with the data requirements of models. The problem of conformity of model and data is discussed taking as examples the linear regression model and the aerodynamic method of calculation the evaporation rate from an open surface.

2 Data requirements

The problem of conformity of data used for model operation and calibration is presented here. Obviously, an application of a calibrated model is constrained to the same kind of data, which were used for its calibration. However, it often happens that the some input data available for model operation differ from those used for model calibration. There may be several reasons for this as a change in measurement techniques, in number and location of observation and measurement sites, in lumping technique or some missing data. For flood forecasting, the space-time prediction of precipitation and other climatological factors is required and then the predicted rainfall is used as input to the model instead of the observed one.

The case when the model is operated with a higher accuracy of input data then that, which was used for its calibration is examined in Appendix A. Consequences of feeding a model by data statistically differing from those used for its calibration were analysed by Strupczewski (1999). In general, the permanent change in quality of input data calls for re-calibration of a model. Commercialisation of hydrologic research, the advance in computerised data processing and software development have made that more attention is paid to easy access both to the data and software then to their relevance for the particular problem investigation. The question arises, how far one shall go in making a model applicable for data scarcity or in producing and supplying regional values, presumable of low accuracy, for use in the case of lack of observations in developing countries.

3 Aerodynamic Method

The vapour transport equation of the aerodynamic method developed by Thornwaite and Holzman (1939) is the common basis for many evaporation equations, with various forms of the vapour transfer coefficient. It is based on no-memory system, as unlimited supply of water and no storage capacity in the boundary layer above the evaporation surface are assumed. For operational application, the aerodynamic equation is reduced to the form:

$$E_a = \frac{C}{(273+T)}(e_{as} - e_a) \qquad (1)$$

where E_a [m/s] is the evaporation rate from an open water surface, T [^{o}C] is the air temperature, $(e_{as} - e_a)$ [Pa] - the vapour-pressure deficit equal to the difference between the saturated vapour pressure (e_{as}) and the ambient vapour pressure (e_a), which are the non-linear functions of the air temperature and wet bulb temperature, respectively while

$$C = u_2 \cdot A$$

where u_2 [m·s^{-1}] wind speed at 2m and A the coefficient which can be considered as constant:

$$A = \frac{0.622 \cdot k^2}{R_a \cdot \rho_w \cdot [\ln(z_2/z_0)]^2} \tag{2}$$

$k \approx 0.4$ is von Karman constant, $\rho_w \approx 998 [kg \cdot m^{-3}]$ - density of water, $R_a \approx 289 [J \cdot kg^{-1} \cdot K^{-1}]$ - the gas constant of the moist air, z_0 $[m]$ - the roughness height and $z_2 = 2\,m$.

Obviously, daily evaporation rate should be computed as the total of evaporation rate of short time intervals. However, if the wind speed is not correlated with the vapour pressure deficit in a daily run, i.e. if

$$\underset{t}{E}(u_2) \cdot \underset{t}{E}(e_{as} - e_a) \approx \underset{t}{E}[u_2 \cdot (e_{as} - e_a)], \tag{3}$$

then the daily evaporation rate can be estimated from the average daily values of the wind speed, the vapour pressure deficit and the air temperature.

4 Daily temperature averaging

The saturated vapour pressure (e_{as}) and the ambient vapour pressure (e_a) are the function of the air and wet bulb temperature, respectively: $e_{as} = f(T)$ and $e_a = f(T_d)$, where

$$f(\tau) = 611 \cdot \exp\left(\frac{17.27 \cdot \tau}{237.3 + \tau}\right) \tag{4}$$

Because Eq.(4) is non-linear, the procedure of averaging daily temperature for evaporation estimation will produce a bias. Fortunately, as the ambient vapour pressure is fairly constant in daily interval, its averaging is admissible. Therefore the bias mainly depends on the daily run of air temperature. Despite of this, Doorenbos and Pruitt (1977) recommend the use of mean daily air temperature motivating it from the way in which the wind function used by them was derived. It is not convincing argument, as the wind speed does not show high correlation with the daily magnitude of the air temperature fluctuation and because of that the wind function can not reduced the bias caused by non-linearity of Eq.(4). In fact, they leave the part of physical background of Eq.(1) for an empirical relationship recommending the form

$$E_a = f(u)(e_{as} - e_a) \tag{5}$$

where

$$f(u) = 0.0027\left(1 + \frac{u}{100}\right) \tag{6}$$

in which $f(u)$ is in mm/day·Pa and u is the 24-hour wind run in km/day measured at height 2 m. Chow et al. (1988) demonstrating application of the aerodynamic method use the mean daily air temperature as well.

It is well known that the aerodynamic method is usually combined with the energy balance method in the form of Penman equation (Penman, 1948). The chief assumptions of the energy balance are that steady state energy flow prevails and that changes in heat storage over time in the water body are not significant. These assumptions limit the application of the method to daily time intervals or longer and to shallow waters. Therefore, the reason of using mean daily temperature in Eq.(4) may be found in an attempt both to make the aerodynamic method applicable in case of scarcity of climatological data and to make uniform the both terms of Penman equation in respect to a length of computational time interval. However, if the Penman open water evaporation serves for estimation of potential evapotranspiration, storage of heat in the water body and therefore the water depth should be insignificant. Shuttleworth (1993) notices that the use of daily mean temperature can affect the estimated value as much as 30

percent particularly in arid environments where the daily temperature cycle is often large. He recommends computing vapour pressure deficit at the measured maximum and minimum air temperature and then taking the average of these deficit values.

5 Correction factor

In order to asses the bias caused by averaging daily temperature, it is assumed here that

- the air temperature does not fall below the wet bulb temperature in a daily run;
- the wind speed is no-correlated with the air temperature in the daily cycle.

Then the bias can be derived by a first order Taylor expansion of Eq.(1):

$$CF = \frac{1}{2}\frac{d^2 E_a}{dT^2}\Big|_T \cdot \sigma^2(T) \tag{7}$$

which equals

$$CF = \left[\frac{\varphi(T)}{(1-RH)} + \psi(T)\right] \cdot E_a \cdot \sigma^2(T) \tag{8}$$

where $\sigma^2(T)$ and RH are the variance of air temperature in daily interval and the relative humidity corresponding to the mean air temperature (T), respectively, while

$$\varphi(T) = \frac{8{,}192.32\left(219{,}153.07 + 532.09 \cdot T - 4 \cdot T^2\right)}{(237.3+T)^4 \cdot (273+T)} \tag{9}$$

and

$$\psi(T) = \frac{1}{(273+T)^2} \tag{10}$$

or approximately

$$CF \approx \frac{\varphi(T)}{(1-RH)} \cdot E_a \cdot \sigma^2(T) \tag{11}$$

The magnitude of daily temperature fluctuations can be assessed for every month and every region. Therefore, knowing a pattern of daily temperature run, one can estimate the variance of air-temperature in a daily run. For example, sinusoidal cycle gives:

$$\sigma^2(T) = \frac{(T_{\max} - T_{\min})^2}{8}. \tag{12}$$

It is clearly seen from Eq.(11) and the function $\varphi(T)$ that the evaporation will be under-estimated if the mean daily temperature is in use and then the correction factor (CF) shall be applied to reduce the bias. Note that for a humid tropic zone both $(1-RH)$ and $\sigma(T)$ are small values, while they are great for an arid zone. Therefore the correction is needed for both zones. Taking into account that day/night wind ratios are usually greater than one, the bias will exceeds the CF - value.

Examples:

- If mean daily values of the air temperature (T), the relative humidity (RH) and the standard deviation $(\sigma(T))$ are 30^0C, 0.5 and 15^0C, respectively, then the correction factor (CF) equals 18% of the estimated evaporation value (E_a).
- If mean daily values of the air temperature (T), the relative humidity (RH) and the standard deviation $(\sigma(T))$ are 30^0C, 0.95 and 2^0C, respectively, then the correction factor (CF) equals 10% of the estimated evaporation value (E_a).

6 Conclusions

Investigation of the impact of change in both land cover and climate on runoff process requires the use of distributed physical models with physically assessed parameters. In order to improve GCMs' performance, both more sophisticated physical models of watershed and more detailed physical information are required. The fundamental question is whether the concept the distributed model is realistic.

Presently, lumped conceptual and empirical watershed models are the only truly operational rainfall-runoff tools for practical hydrological issues. The application of these models is constrained to the same kind of data as used for their calibration. Therefore, in case of substantial change in observation network or measurement techniques of input variables, the model should be re-calibrated.

The operational use of the aerodynamic method illustrates the case of non-conformity of a model and data. The use of the mean daily air temperature in the model underestimates the evaporation rate from an open water surface. The respective correction factor has been derived. Its magnitude depends on daily temperature fluctuation and the relative humidity corresponding to the mean air temperature, being within a range of dozen or so percentages. The correction is needed both for arid and humid tropic zones. Taking into account that day/night wind ratio usually exceeds one, the underestimation caused by the use of the mean daily air temperature will be even greater then the value of correction factor. The question is how far we should go in model's simplifications and attempts to assess regional values of some parameters for every place of the Globe to meet the demands of practising hydrologists.

Appendix A.

The data of different quality for a model calibration and its application.

Statistical unhomogeneity of hydrological time series is the problem frequently met by mathematical modellers of hydrological systems. It may be caused by a lot of reasons as the change in measuring technique, change in measurement points or time of observations and change in the method of assessment of lumped variables describing spatial fields of hydro-meteorological quantities. Here the case is taken for consideration when the change took place while the model is being operated. Then the available input data differ in origin from those used for the model calibration. The purpose of this Appendix is to investigate consequences of feeding a model by data statistically differing from those used for its calibration. In this respect, two cases can be distinguished:

- the change in systematic error (bias) of measurement of the independent variable, which includes lumping of spatial variable;
- the change in accuracy of measurement of the independent variable.

The first case leads to the prediction bias of the constant value. It is the second case, which is more interesting; if the model is operated with a higher accuracy of input data then that, which was used for its calibration. For the sake of brevity and clarity, the linear regression model is

chosen as exemplification. It might seem that an increase in accuracy of input data should improve an accuracy of prediction.

Notation:

y - dependent variable;

x - exact value of the independent physical variable;

$x^{(\alpha)}$ - measured value of x got by the α-technique

$$x^{(\alpha)} = x + \varepsilon^{(\alpha)} \quad \text{where } \varepsilon^{(\alpha)} \in N\left(0, \operatorname{var}\left(\varepsilon^{(\alpha)}\right)\right);$$

x^{β} - measured value of x got by the β-technique

$$x^{(\beta)} = x + \varepsilon^{(\beta)} \quad \text{where } \varepsilon^{(\beta)} \in N\left(0, \operatorname{var}\left(\varepsilon^{(\beta)}\right)\right);$$

$m(\cdot)$ - mean value.

Note that measurement errors do not affect the value of covariance if they are not correlated either with x and y or mutually, i.e. $\operatorname{cov}\left(y, x^{(\alpha)}\right) = \operatorname{cov}\left(y, x^{(\beta)}\right) = \operatorname{cov}(y, x)$.

The assumption: $\operatorname{var}\left(\varepsilon^{(\alpha)}\right) > \operatorname{var}\left(\varepsilon^{(\beta)}\right) \geq 0$.

While the α-model is being in operation the change of the measuring technique from the α-technique to the β-technique takes place and because of lack of sufficient information to derive the β-model

$$\hat{y} = \beta\left(x^{(\beta)}; a^{\beta}, b^{(\beta)}\right) = a^{(\beta)} + b^{(\beta)} \cdot x^{(\beta)} \tag{A.1}$$

where $a^{(\beta)} = m(y) - b^{(\beta)} \cdot m(x)$ and $b^{(\beta)} = \dfrac{\operatorname{cov}(y, x)}{\operatorname{var}\left(x^{(\beta)}\right)}$, (A.2)

the α-model is still used for the β-technique input values:

$$\hat{y} = \alpha\left(x^{(\beta)}; a^{(\alpha)}, b^{(\alpha)}\right) = a^{(\alpha)} + b^{(\alpha)} \cdot x^{(\beta)} \tag{A.3}$$

where $a^{(\alpha)} = m(y) - b^{(\alpha)} \cdot m(x)$ and $b^{(\alpha)} = \dfrac{\operatorname{cov}(y, x)}{\operatorname{var}\left(x^{(\alpha)}\right)}$. (A.4)

Therefore the bias resulting from the use of the α-model for the input of β-technique equals:

$$\begin{aligned} Bias(\hat{y}) &= \alpha\left(x^{(\beta)}; a^{(\alpha)}, b^{(\alpha)}\right) - \beta\left(x^{(\beta)}; a^{(\beta)}, b^{(\beta)}\right) = \\ &= \left(b^{(\alpha)} - b^{(\beta)}\right)\left(x^{(\beta)} - m(x)\right) = \\ &= \left[\frac{1}{\operatorname{var}\left(x^{(\alpha)}\right)} - \frac{1}{\operatorname{var}\left(x^{(\beta)}\right)}\right] \operatorname{cov}(y, x)\left(x^{(\beta)} - m(x)\right) \end{aligned} \tag{A.5}$$

Corollary: Use of the β-technique data to the model calibrated by the α-technique data produces the prediction bias, which is growing linearly with the deviation of x from its mean value.

Comparison of accuracy of prediction:

(1) $x^{(\beta)}$ used as an input to the α-model. Then the mean square error equals

$$MSE(y; \beta) = [Bias(\hat{y})]^2 + \operatorname{var}\left(\hat{y} \middle| x^{(\beta)}\right) \tag{A.6}$$

where

$$\operatorname{var}\left(\hat{y} \middle| x^{(\beta)}\right) = \operatorname{var}(y)\left(1 - \frac{\operatorname{cov}^2(y, x)}{\operatorname{var}(y)\operatorname{var}\left(x^{(\beta)}\right)}\right); \tag{A.7}$$

(2) $x^{(\alpha)}$ used as an input to the α-model

$$MSE(y; \alpha) = \operatorname{var}\left(\hat{y} \middle| x^{(\alpha)}\right) =$$

$$= \mathrm{var}(y)\left(1 - \frac{\mathrm{cov}^2(y,x)}{\mathrm{var}(y)\mathrm{var}(x^{(\alpha)})}\right) \tag{A.8}$$

Hence

$$MSE(y;\beta) - MSE(y;\alpha) < 0 \quad \text{if} \quad \frac{\left[x^{(\beta)} - m(x)\right]^2}{\mathrm{var}(x^{(\beta)})} < \frac{\mathrm{var}(x^{(\alpha)})}{\mathrm{var}(x^{(\alpha)}) - \mathrm{var}(x^{(\beta)})} \tag{A.9}$$

or denoting $\mathrm{var}(x^{(\beta)}) = \gamma\,\mathrm{var}(x^{(\alpha)})$ where $\gamma < 1$

$$MSE(y;\beta) - MSE(y;\alpha) < 0 \quad \text{if} \quad \frac{\left[x^{(\beta)} - m(x)\right]^2}{\mathrm{var}(x^{(\beta)})} < \frac{1}{1`-\gamma} \tag{A.10}$$

Obviously, the above condition is fulfilled by the integrated mean square error as $\frac{\gamma}{1-\gamma} > 0$ for $0 < \gamma < 1$.

Corollary: For extreme values of x, which might be of our interest, the use of the β-technique data to the model calibrated by the α-technique data causes the decrease in accuracy of prediction. However, higher accuracy of input, i.e. $\gamma < 1$, results on the average in an increase of accuracy of prediction even without the α-model re-calibration.

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Impact of the Gabčíkovo Hydropower Plant upon Subsurface Water Retention in Rye Island (Žitný Ostrov)

Július Šútor

Abstract : In this contribution is quantified the relative the relative change of subsurface water retention in natural environment of the Rye Island (Žitný Ostrov, southern Slovakia), as a consequence of completion of the hydro power plant Gabčíkovo and its setting up into operation. The method of calculation is based upon :

- depth of the boundary upper soil layer – gravel horizon,
- groundwater depth below the surface in 1989 and 1996,
- hydrophysical parameters of the both layers mentioned above.

Changes in water retention in the upper soil layer are presented, determined from the soil moisture retention curves and from change of the groundwater level as a reference surface. In the gravel layer, relative change of the water storage was determined from its porosity and from changes of the groundwater level location.

Key words : Regional underground water storage (Rye Island, southern Slovakia), Impacts of water structures, Moisture regime in the unsaturated zone of soils, Retention capacity of soils

Einfluss des Wasserkraftwerkes Gabčíkovo auf die Retentionseigenschaften des Untergrundes im Bereich der Korninsel (Žitný Ostrov)

Zusammenfassung : In diesem Beitrag ist die relative Änderung der Retention von Porenwasser im Bereich der Korninsel (Žitný Ostrov, Südslowakei) beschrieben, die durch die Inbetriebnahme des Donaukraftwerkes Gabčíkovo hervorgerufen wurde. Die verwendete Berechnungsmethode stützt sich auf Informationen über :

- der Tiefe der Schichtgrenze zwischen oberer Bodenschicht und unterer Kiesschicht,
- des Grundwasserflurabstandes in den Jahren 1989 und 1996,
- den hydrophysikalischen Charakteristiken der beiden obengenannten Schichten.

Es werden die Änderungen der Retentionseigenschaften der oberen Bodenschicht beschrieben, die aus den Retentionskurven und den Veränderungen des Grundwasserspiegels ermittelt wurden. In der Kiesschicht wurde die relative Änderung der Speicherkapazität aus ihrer Porosität und der Änderungen des Grundwasserspiegels bestimmt.

Schlüsselworte: Regionale Untergrundretention (Südslowakei), Einfluss von Wasserbauwerken, Feuchtigkeitsregime der ungesättigten Bodenschicht, Retentionskapazität von Böden.

1 Introduction

Setting up of the hydropower scheme Gabčíkovo into operation caused a significant change of the groundwater level regime, i.e. of the change of its location and variability, as compared with the state which would endure without the external structure impact. In locations where the groundwater level sank, underground water storage was decreased, and vice versa. In relation to this change, also the conditions were changed for formation of the water regime in the soil aeration zone, or all water storage in soil has changed. This change of storage of soil water and groundwater (subsurface water retention) is difficult to quantify in an absolute expression. Quantification of a relative change appears easier. Under the relative change of retention of the subsurface waters it is understood its determination with respect to the selected reference

groundwater level elevation, in a selected year prior to setting up of the hydropower structure Gabčíkovo into operation, and after it.

Under the groundwater level are pores of the porous media completely filled up with water. Change of the groundwater storage is determined through the change of the groundwater level location and of a given porosity of the water bearing layer. Above the groundwater level surface in soil pores occurs also a gaseous phase, therefore this part of soil is called the zone of aeration. Water retention in this zone of soil is determined by the moisture retention curve, and in its particular horizons it depends upon location of the groundwater surface as its reference level.

The relative retention change of the subsurface waters can be fairly exactly quantified through a direct monitoring. To determine it indirectly (i.e. by calculation) it is necessary to know :

- ✓ the areal variability of the porous media,
- ✓ the retention properties of the aeration zone of the soil,
- ✓ course of the groundwater level in a regional manifestation, which can be acquired e.g. by mathematical modeling for a reference time horizon.

All the above stated pertains to a quasi homogeneous porous media, both, under the groundwater level surface, and above it.

Under conditions of the Rye Island region, monitoring of the groundwater level has a required professional standard. Mathematical models for determination of the course of groundwater levels in the whole Rye Island region also exist. Therefore, there should be no problem to determine the relative change of the groundwater storage, assuming the knowledge of characteristics of the water bearing porous media. Another situation exists in monitoring of the water stored in the zone of aeration (Šútor,J. 1997; Petrovič,P. and Džupová,D. 1995 **).** Organized monitoring prior and after completion of the Gabčíkovo structure does not cover the whole Rye Island area. In addition to this fact, on a selected monitoring sites, moisture is not monitored along the whole depth of the soil aeration zone. Course of the aeration zone water storage dynamics determined by use of mathematical modeling, has been performed just for few selected monitoring sites (Novák et al., 1998). There is another complicating factor present in determination of the subsurface water storage dynamics in the Rye Island natural environment. Depth of the topsoil layer, as well as of the underlying gravel deposits in this region, show considerably high areal variability. Similarly also the boundary depth of these both layers. Under such conditions, the groundwater level in the course of the year can be found across the area of the region either in the topsoil layer or in the underlying gravel horizon, or in a single point, it can vary throughout the year several times across this boundary surface. These conditions complicate significantly quantification of the underground water changes.

2 Methodology of quantification of the subsurface waters retention

Quatification of the relative retention change of the subsurface waters starts from the digitized map of the Rye Island region in scale 1 : 50000, namely according to :

1. depth of the boundary upper (topsoil) layer – groundwater bearing horizon,
2. mean annual depth of the groundwater level below the soil surface, but above the before mentioned boundary in the years 1989 and 1996,
3. mean annual depth of the groundwater level below the mentioned boundary (point 1.) in the years 1989 and 1996.

Digital map form enables to determine the areal extent of the above characteristics 1. to 3.in km^2 Data acquired by this procedure as to the characteristic 1. are presented in fig.1. Data for characteristics per 2. and 3. are in tab.1 and tab.2.

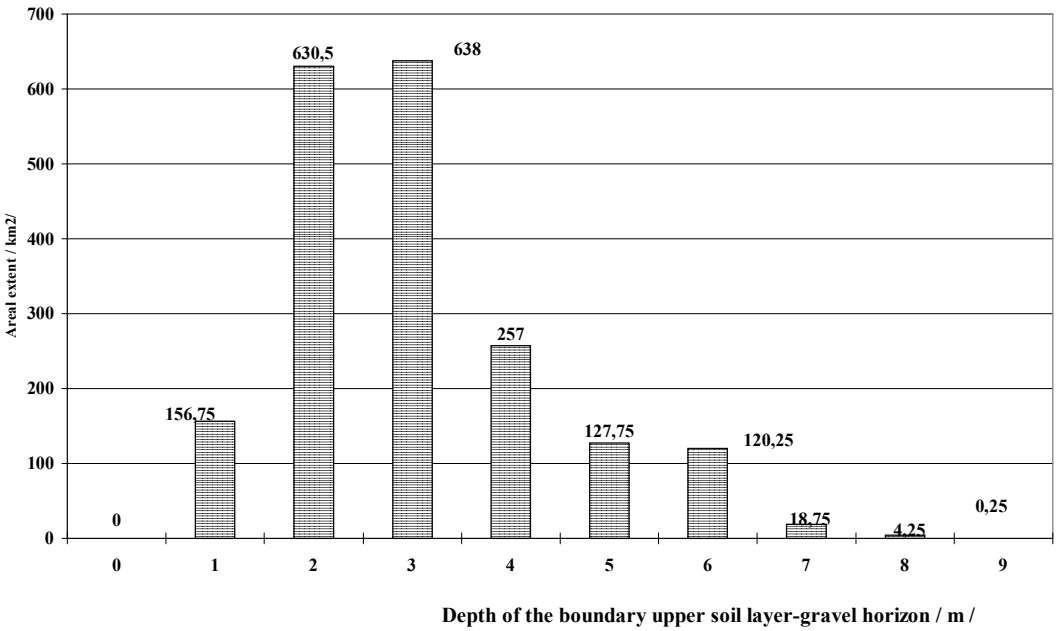

Fig.1 Depth of the boundary upper soil layer-gravel horizon below the soil surface (areal extent in km ^{2})

It can be seen from tab.1 that depth of the groundwater table within the range from 0,0 to 2,0 m increased its areal extent by 239 km^2 after Gabčíkovo plant completion. This change is compensated by decrease of 183 km^2 of the areal extent of the groundwater level located below the boundary, which indicates that in this extent the originally unsaturated zone changed into saturated. In the rest of 55,73 km^2 takes part the groundwater level change in the lower horizons of the zone of aeration.

Tab.1 Groundwater depth (GWD) below the soil surface and simultaneously above the boundary topsoil-gravel horizon.

Depth	GWD areal extent	
range	year 89	year 96
/m/	/ km^2 /	/ km^2 /
0,0-1,0	8,75	61,75
1,00-2,00	315	501
2,0-3,0	341,75	303,75
3,0-4,0	62	46,75
4,0-5,0	3,75	1,25
5,0-5,26	0	0,25
Total	731,25	914,75

A separate approach is necessary for determination of the water storage change in the upper soil layer and in the gravel horizon, i.e. above and below of their boundary, for the years 1989 and 1996.

The upper soil layer is formed by soils of several types, with different retention properties. Changes of the water storage, in this case, need to be related to changes of the integral water content in the zone of aeration in the years 1989 and 1996. Determination of the integral water content in the soil aeration zone is possible using the information on the areal extent of the mean depth of the groundwater level as in tab.1. Another characteristic needed for this determination is the information on the retention properties of the Rye Island soils. For sake of the calculations simplification, it is assumed that the areal extent of soils (239,25 km^2) with a changed groundwater level in the upper soil layer pertains to medium heavy soils. On the Rye Island, 66% of its area are formed by medium heavy soils, 23% by heavy soils, 6% by very heavy soils, and 5% by light soils.

Fig.2 Groundwater depth (GWD) below the boundary topsoil-gravel horizon.

Depth	GWD areal extent	
range	year 89	year 96
/m/	/ km^2 /	/ km^2 /
0,0-1,0	496,5	510
1,0-2,0	263	250,75
2,0-3,0	118,25	116,5
3,0-4,0	103,75	75,25
4,0-5,0	99,5	51,5
5,0-6,0	68,5	34,25
6,0-7,0	39,25	0,5
7,0-7,94	33,5	0
Total	1222,25	1038,75

Then using the moisture retention curves for the Rye Island medium heavy soils, particulary of their characteristic points (point of saturation - FS, field capacity - FC, point of the decreased availability - PDA), and computational procedures used by Šútor and Rehák (1999), the change of water content in the upper soil layer has been determined.

For the deeper gravel layer below the mentioned boundary, following procedure was used. When the groundwater level sinks, the pores above it are being emptied leaving there only the residual water retention. Water content corresponding to the sinking water level was determined from the horizon porosity and from drop of the water level. Similarly, for the groundwater level rise, the water volume needed for filling up the pores was determined from the layer porosity and from the level rise. Areal extent of the mean annual groundwater levels was used which is indicated in tab.2.

3 Results

Results of determination of the water volume changes in the aeration zone for the year 1996 as compared with the state in 1989 were achieved using the above described methodology.

Assuming the water volume change of the area of 239,25 km^2 within the range of depth 100 to 200 cm (see tab.2), from the point FC to point FS, the total volume of water rose by 2 528 872,5 m^3. Within the range of depth 0 to 100 cm, the increase of water volume from PDA to FC was 7155727,5 m^3 . In horizon 200 to 300 cm, the increase of water volume from FC to FS

corresponds to 401 652 m^3. Water volume changes in the rest of the covering layers were not significant.

The total increase of water volume in the covering layer before setting up of the hydro power structure Gabčíkovo into operation (1989) and after it (1996) amounts to 10 086 252 m^3.

Results for the layer below the boundary upper soil – gravel were achieved using the above described procedures. Calculations were performed for a maximum drop of the mean groundwater level 8 m below the boundary, separately for 1989 and 1996 with use of data from tab.3. Difference of the areal extent in both years is attributed to crossing of the groundwater level through the boundary up to the covering topsoil layer. Results achieved by this approach are contained in tab.3. Increase of the water volume below the boundary in 1996 with respect to 1989 is 1 835 000 m^3.

Tab.3 Determination of the water volume change below the boundary topsoil-gravel horizon.

Depth	Integral water volume	
range	year 89	year 96
/m/	/ m^3 /	/ m^3 /
0,0-1,0	4 965 000	5 100 000
1,0-2,0	2 630 000	2 507 500
2,0-3,0	1 182 500	1 165 000
3,0-4,0	1 037 500	752 500
4,0-5,0	995 000	515 000
5,0-6,0	685 000	342 500
6,0-7,0	392 500	5 000
7,0-7,94	335	0
celkom	12 222 500	10 387 500

In all calculations of the water volume changes below the boundary, the storage capacity P = 20 volumetric % used, according to Mucha et al. (1993), Šoltész (1991), Šoltész et al. (1993), Kosorin (1997) and Burger (2000).

Based on the achieved results, it can be concluded eventually, that the all over change of retention of subsurface waters before the setting up into operation of the water structure Gabčíkovo (1989), and after it (1996), equals to the increase of volume of 10 086 252 m^3 in the aeration zone, and to increase of 1 835 000 m^3 below the boundary topsoil – gravel horizon. Thus the total retention increase of the subsurface waters amounts to 11 918 252 m^3.

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A Hyrological Analysis of GAT Diversion in Croatia

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Jozo Korov, Ivo Crnčan, Željko Turkalj

Abstract: Gat diversion is point where water of Karašica river flows to Drava river and to Vučica river, which is also Drava river tributary. Due to different hydrological situations where water stage magnitude of Drava river is app. 7 m and Vučica app. 3 m there are different flow directions depending on water stages in Drava and Karašica. Rivers Drava, Vučica and Karašica makes triangles where Karašica has connection to Drava river at Gat diversion but flows to Drava with Vučica river downstream 13 km. Direction of flow depends on present water stage of Drava river. Gat diversion is situated near Osijek and Valpovo municipalities at river Drava 62 km upstream from Drava river confluence to river Danube.

Paper presents analysis of different water regime at that point together with upstream and downstream influence. Analysis also covers erosion process of lower Vučica river where water with human influence made shortcut to Drava river. Hydrologic and hydraulic mathematical models were applied to recognise different situations depending on water stages. River Drava has the greatest influence. Probability of event that maximum water in Drava correspond to maximum water to Karašica is very small due to different regime of Drava and Karašica. Main flooding of the area comes from long high Drava river stages followed by rainstorm on Karašica river basin.

Basic flood protection project at Gat diversion was given in 1930. by Stefan Bella, later establisher and professor at Bratislava University. The realisation of that project ensures release of water excess to river Drava at three points at Karašica river to ensure flood protection of lower terrain around Karašica river. Karašica river basin has 2347 km2 mainly arable land. Around 70 % of that area are lowland area from 100 above sea level to 92 m above sea level. Terrain is protected from floods by dikes and water management through objects at mentioned release points.

Key words: diversion point, Floodprotection, mathematical modeling

Hydrologische analyse des Umkehrpunkts „GAT“ in Kroatien

Zusammenfassung: Der Umkehrpunkt „Gat“ ist die Stelle, an der der Fluss Karašica in die Drau mündet, aber auch in den Fluss Vučica, der ebenfalls ein Nebenfluss der Drau ist. Die unterschiedlichen hydrologischen Regime der Flüsse Drau und Vučica verursachen unterschiedliche Fließ-Richtungen in den genannten Gewässern. Die Wasserstandsschwankungen der Drau liegen innerhalb von 7 m, die des Flusses Vučica innerhalb von 3 m.

Die genannten drei Flüsse bilden ein interessantes hydrologisches Dreieck, das sehr wichtig für den Hochwasserschutz ist. Diese Arbeit präsentiert eine Analyse der unterschiedlichen Flussregimes in dem betrachtenden Punkt, einschließlich der Auswirkungen flussauf und flußab. Die Analyse umfasst den Erosionsprozess, der als Wirkungsfolge des Menschen entstanden ist. Um die zusammengesetzten hydrologischen und hydraulischen Prozesse erkennen zu können, wurde ein mathematisches Modell eingesetzt, das die unterschiedlichen wasserstandabhängigen Situationen simuliert.

Schlüsselwörter: Umkehrpunkt, Hochwasserschutz, mathematische Modelle

1 Introduction

In order to protect city of Belišće and Valpovo form the high water floods through Karašica river in 1887. was constructed GAT diversion point. Area around GAT was meandered flat region close to Drava river in Slavonian part of Croatia. At the Gat point river Drava is very close to Karašica river and this diversion is predominantly constructed to released high water to Drava river and to

preserve low water flow further to cities Belišće and Valpovo. Present situation shows good results during high water regime and not satisfactory results during low flows.
Karašica river basin has 684,2 km^2 of mainly arable and flat land with dominant agricultural production. Karašica river collect some tributaries form hilly region (Vojlovica, Voćinska, Branjinska) but predominant part of the river flows through flat region altitude 105 – 95 m above sea level. This river drained area with numerous of canals. While upper part of Karašica is protected by dikes from floods, lower part from Klokocevac is eroded to terrain with maximum depth at Gat point of approximately 6 m. Length of river Karašica is 78 km and Gat diversion is 20 km upstream from Karašica confluence to Vučica river, tributary of Drava river. Length of Vučica from Karašica mouth to river Drava is 13 km. So, Gat diversion reduce flow length for approximately 33 km and ensure height difference in Drava river of approximately 0,5 m (medium flows).
Prof. Stjepan Bella developed basic concept of river Karašica flood protection program in 1930. with Project for flood protection of Karašica – Vučica area by retention. In this project Prof. Bella suggested use of three shortcuts from river Vučica to Drava (VVD, Miholjac and Gat) to release at least 50 % of flood water from the area. Gat diversion has the greatest protection influence to the most developed and populated area. Prof. Stjepan Bella is well known as a publisher of the book: Land Melioration which he published personally in 1935. Same book were translated and published in Praha when he was professor at the University of Praha. He was also one of the establishers and first professors of water management at the University of Bratislava later. It is very interesting that concept of not only flood protection but also water management of Karašica – Vučica region which Prof. Bella had been proposed is in use even at present time.

2 Problem Definition

Main task of the analysis is define optimum water regime at Gat canal – Gat diversion to ensure low flow during medium and low flows and to define water management elements at Gat diversion during high flows and floods.
Basic concept of Gat diversion functioning was given by schematic presentation as follows:

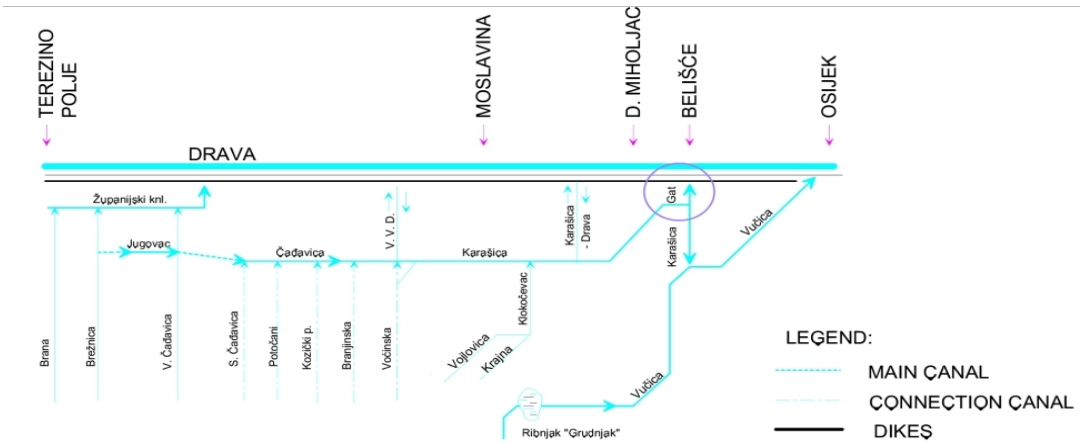


Table 1 : Schematic presentation of Karašica flow situation

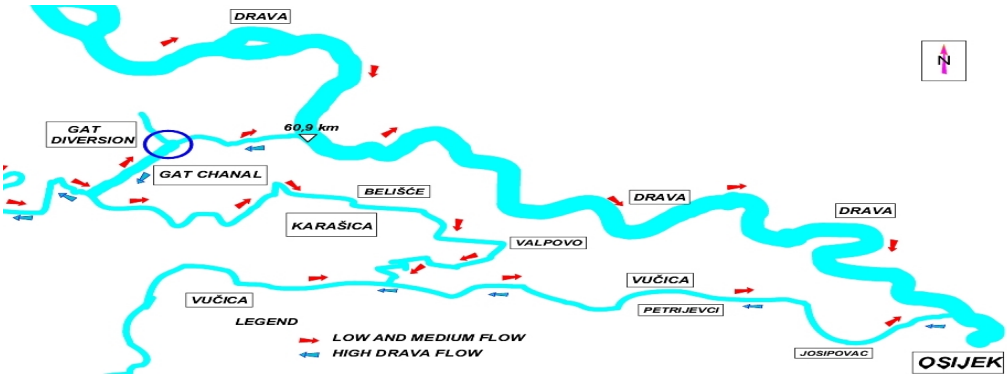


Fig. 2 Schematic presentation of Gat diversion functioning

Basic element which ensure water regime is present spillway which is necessary to be increased on such way to increase low flows to lower Karašica but also to preserve upper Karašica part from floods.

3 Hydrological and Hydraulic Elements

Main hydrological elements were analysed at Kapelna location situated upstream from Gat point. According to measurements from 1980 to 1993. (With partly breaks in 1991. and 1992.) basic characteristics of Karašica rivers are:

Table 1 Monthly discharge elements of Karašica at Kaplena location – (in m^3/s)

	1	2	3	4	5	6	7	8	9	10	11	12	Y
Qmax	**3.5**	**11.6**	**17.5**	**18.7**	**23.2**	**4.3**	**2.1**	**2.3**	**0.7**	**11.3**	**2.2**	**21.2**	**23.2**
Qavgmax	**1.7**	**4.1**	**7.8**	**8.1**	**8.8**	**2.3**	**1.1**	**1.0**	**0.4**	**2.6**	**1.1**	**5.2**	**3,7**
Qavg	**0.8**	**1.6**	**2.2**	**3.2**	**2.7**	**0.9**	**0.4**	**0.2**	**0.2**	**0.3**	**0.4**	**2.6**	**1.3**
Qavgmin	**0.5**	**0.4**	**0.7**	**1.3**	**0.4**	**0.3**	**0.2**	**0.1**	**0.1**	**0.1**	**0.2**	**0.3**	**0.6**
Qmin	**0.07**	**0.05**	**0.07**	**0.09**	**0.10**	**0.06**	**0.06**	**0.03**	**0.03**	**0.04**	**0.05**	**0.09**	**0.03**

As it was mentioned before, Karašica reach Vučica 20 km from Gat diversion point and following Vučica flows 13 km to river Drava. When Gat culvert is closed flow through Karašica is totally blocked and water stages in lower Karašica through Belišće and Valpovo fully depends on Vučica water regime. As Vučica is under Drava river influence at that location, Drava river defines water regime during high flows.

So, main characteristics of Karašica can be shown by next elements according to (3) : Complex melioration study of territory of west Osijek combinats at the area of Karašica - Vučica water enterprise" (1979.) :

- Vučica - 100 g. return period - Drava 100 g. return period Z = 88.70 m a s l
- Vučica - 100 g. return period - Drava average flow Z = 88.10 m a s l
- Vučica - 25 g. return period - Drava average flow Z = 87.40 m a s l

Table 2 Hydrological characteristics of river Drava at Gat canal location

	1	2	3	4	5	6	7	8	9	10	11	12	Y
H_{apsmax}	**88.6**	**88.8**	**90.1**	**90.2**	**90.3**	**90.6**	**91.3**	**91.1**	**90.1**	**90.3**	**90.3**	**89.8**	**91.3**
H_{srvv}	**87.4**	**87.5**	**87.9**	**88.4**	**88.9**	**89.0**	**88.9**	**88.3**	**88.3**	**88.0**	**87.9**	**87.5**	**89.7**
H_{sr}	**86.6**	**86.7**	**86.9**	**87.4**	**88.0**	**88.2**	**87.9**	**87.4**	**87.1**	**86.9**	**86.9**	**86.8**	**87.2**
H_{srmv}	**86.1**	**86.2**	**86.3**	**86.7**	**87.2**	**87.6**	**87.2**	**86.7**	**86.5**	**86.2**	**86.2**	**86.2**	**86.6**
H_{apsmin}	**85.5**	**85.5**	**85.6**	**85.9**	**85.0**	**85.4**	**85.8**	**85.7**	**85.7**	**85.5**	**85.5**	**85.5**	**85.5**

Comparing Drava river stages to Gat spillway crest at altitude 87,65 m a s l it is obvious that this spillway has bi-directional flow depending on river Drava water regime.

4 Result Analysis and Conclusions

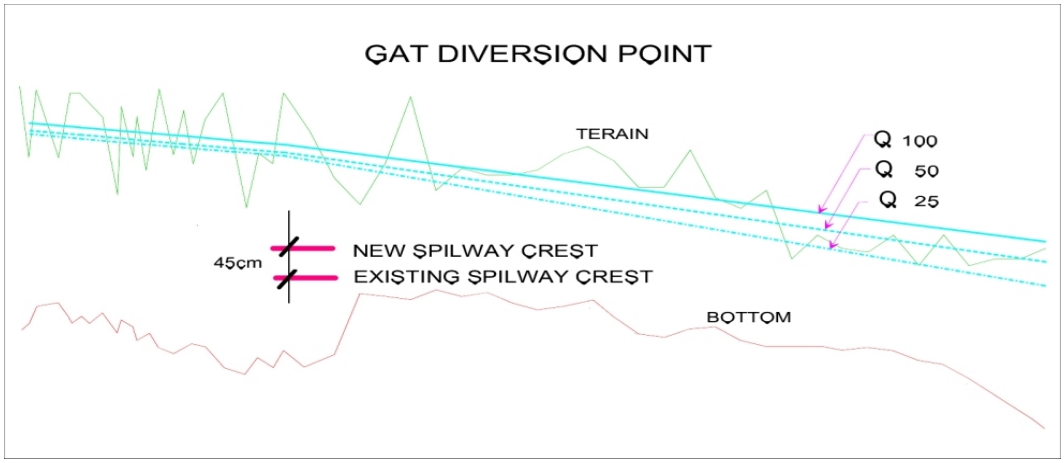
Main analysis has been done to analyse possibility of existing culvert at lower Karašica and define regime at inflow side to ensure flow regime at lower Karašica. Calculations were done for 15, 30, 45 and 60 cm of increase water stage comparing to present situation. For these four regimes it was defined that only 30, 45 and 60 cm has significant influence to lower Karašica flow regime. Of course, these calculations were done for low flow and low characteristics of Karašica, Vučica and Drava rivers. Culvert calculations were done by CULVERTMASTER mathematical model and flow characteristics by mathematical model HEC- RAS. With increase of more than 30 cm culvert inflow is submerged or inflow water is higher than culvert profile.

With this spillway increase it was necessary to analyse influence to upper Karašica part during high water regimes. At that period spillway at Gat point is under the Drava river regime, in other words it is submerged. For purpose of flood protecting lower cities it is necessary to close Gat culvert. That means that only influence comes to upper part of Karašica river. With this division of two regimes it is possible to organise water management process which is in practice last few years.

Upper Karašica has very narrow slope of 0,3 ‰. With Drava river water height at Gat point of 90 m a s l upper Karašica is almost overflowed. As it is mentioned before this flat region is very sensitive to increase of water level due to shallow water table at the agricultural fields. According to discharge analysis of different return periods for upper Karašica there are possibility to increase this spillway. But, comparing to hydrologic and hydraulic analysis or comparing different crest height and necessity for building of new dikes to economic evaluation of different proposed solutions it was concluded that maximum crest increase is 45 cm.

This can be presented on longitudinal cross section:

Fig. 2 Longitudinal cross section of Karašica river



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The Characteristics of a Capacitive Humidity Sensor Based on Polyimide Film

Gabriela Telipan

Abstract: The paper presents a capacitive humidity sensor made by thin film technology. On the thin film of polyimide was deposited chromium by vacuum e-beam evaporation in a state of tensile stress. As connection materials were deposited copper and silver. The capacitance of sensor linear increase with relative humidity in the 0-100% RH range, the sensitivity was 0,2 pF/%RH, hysteresis was 2% at 56% RH and temperature coefficients of capacitance at 33,43, and 75,5%RH in 10-50°C range of temperature were 0,07, 0,06, 0,2 %RH/°C respectively and presents ±3%RH drift after 1000 hours exposure to 80°C and 96% RH conditions.

Key words: Humidity sensor, capacitive –type sensor, dielectric. hydrophobic polymers, thin film technology.

Die Charakteristiken eines kapazitiven Luftfeuchtesensors basierend auf einer Polyamid-Beschichtung

Zusammenfassung: Der Beitrag stellt einen kapazitiven Luftfeuchtesensor vor, der in Dünnschichttechnologie hergestellt wurde. Eine dünne, straff gespannte Polyamid-Membran wurde mit Chrom beschichtet. Als Kontaktwerkstoffe wurden Kupfer und Silber aufgebracht. Die Kapazität des Sensors nimmt im Bereich 0 - 100 % relat. Feuchte linear zu, die Empfindlichkeit beträgt 0.2 pF pro Prozent relat. Feuchte, die Hysterese beträgt 2 % bei 56 Prozent relat. Feuchte, die Temperaturkoeffizienten bei 33, 43 und 75.5 Prozent relat. Feuchte liegen im Temperaturbereich zwischen 10 °C und 50 °C bei 0.07, 0.06 bzw. 0.2 Prozent relat. Feuchte pro °C, was einer Drift von +/- 3 Prozent relat. Feuchte nach 1000 Stunden bei 80 °C und 96 Prozent relat. Feuchte entspricht.

Schlüsselwörter: Luftfeuchtesensor, kapazitiver Sensor, dielektrische hydrophobe Polymere, Dünnschichttechnologie

Introduction

The humidity is a very common component in our environment, measurements and/or control of humidity are important not only for human comfort but also for broad spectrum of meteorological and hydrological building automation, industries and technologies. So, recent developments in automated systems have made ever-increasing demands for various kinds of physical and chemical sensors. A humidity sensor has to fulfill the following requirements to satisfy the widest range of applications: 1. good sensitivity in a wide humidity range; 2. quick response; 3. good reproducibility and small hysteresis; 4. fitness to circuitry; 5. tough durability and long life; 6. resistant to contaminants; 7. small dependence on temperature; 8. simple structure and low cost./1/. Among the different types of humidity sensors, those based on electrical properties such as impedance or resistance and capacitance. Recently, capacitive type humidity sensors have been widely used because of their wide range, high accuracy and long term stability./2/. The technology used is that of thin film capacitors./3/. The stages of the process consist first in the choice of a hygroscopic dielectric (a polymer) and secondly in the elaboration of a porous electrode. A variety

of sensing polymer hydrophobic materials has been reported, including cellulose acetate butyrate, crosslinked polymethyl methacrylate and polyimide thin films. Polyimide has advantages over the other engineered polymers due to its stability against solvents and other volatile chemicals, high resistance mechanic and of temperature about 400°C. The dielectric constants of these hydrophobic polymers are usually very low (c.3) when compared to that of water (c.80). When a small amount of water is sorbed by these polymers, the apparent dielectric constants increase, resulting in a linear increase in capacitance with relative humidity. The porous electrode is obtained by chromium evaporation under conditions such that the thin film is tensile stressed. These some cracks 500-2000 Å wide and spaced a few microns from each other, transform the polymer into a lot of small islets, protected by a thin layer of chromium. Thanks to this technology, permeability is achieved without impairing conductivity rate of moisture is increased by several orders of magnitude, whatever the thickness of chromium (200Å to 1 μm). /3/. In this study, we present a new structure and characteristics of a capacitive humidity sensors utilizing polyimide as a sensing material, the fabrication process and sensing characteristics are presented.

2 Experimental

A variety of polyimide film by 30μm thickness was metallised using vacuum e-beam evaporation, by selective deposition of three metals coats: the first coat is a chromium for generating of cracks in the polymer in a tensile stress, copper and silver as connection materials.The coats were done through tree metal masks in a vacuum e-beam evaporation plant at the follow parameters: pressure $2x10^{-5}$ torr and deposition rate of 10 Å/s. The thickness chromium deposition was 1000 Å. For connection materials was coated: copper 500 Å thickness and silver 1500 Å thickness, to assure a proper soldering on IC circuit. The sensor was mounted in a plastic capsule. Fig. 1 shows the structure of the sensor.

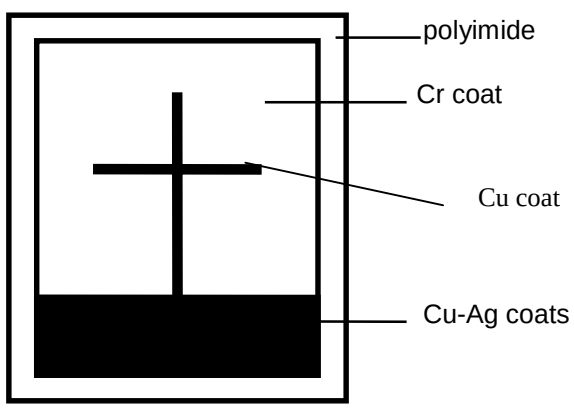

Fig.1 The structure of the capacitive humidity sensor

3 Results and Discutions

The sensor was tested in a apparatus which consists: thermostat test chamber, selector, recipients of saturated salts who generates humidity controlled atmosphere, a Hewlett Packard type LCZ bridge analyzer. Fig. 2 shows the characteristic capacitance-relative humidity of the sensor

which was measured in the range 0-100 % RH at 20 KHz and 25°C. The stabilizing time between each measurement was about one hour. Calibration of the sensor was accomplished in the saturated salt solutions: LiCl for 12 % RH, $MgCl_2$ for 33 % RH, K_2CO_3 for 43 % RH, NaBr for 56 % RH, NaCl for 75,5 % RH, KCl for 85% RH, K_2SO_4 for 96 % RH and for 100 % RH was utilized water vapour. According to this characteristic, the capacitance of the sensor increase linear with relative humidity in the range studied. For the whole range, the average sensitivity was 0,2 pF/ % RH. The hysteresis in the humidity range was 2% at 56% RH. The temperature dependence of the sensor capacitance was effectuated at 33, 43, and 75,5 % RH in 10-50 °C range of temperature In table 1 are presented the values for temperature dependence and fig, 3,4,5 shows temperature dependence of the sensor capacitance with temperature.

Table 1 Temperature coefficient of capacitance

Relative humidity (%)	Range temperature (°C)	Temperature coefficient of capacitance (% RH/°C)
33	10-50	0,07
43	10-50	0,06
75,5	10-50	0,2.

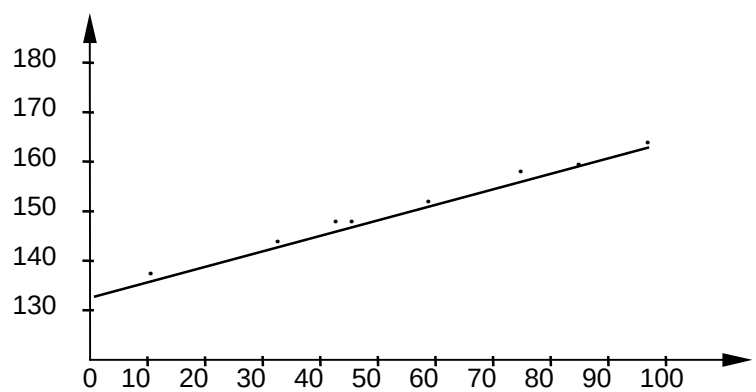

Fig.2 The characteristic capacitance- relative humidity

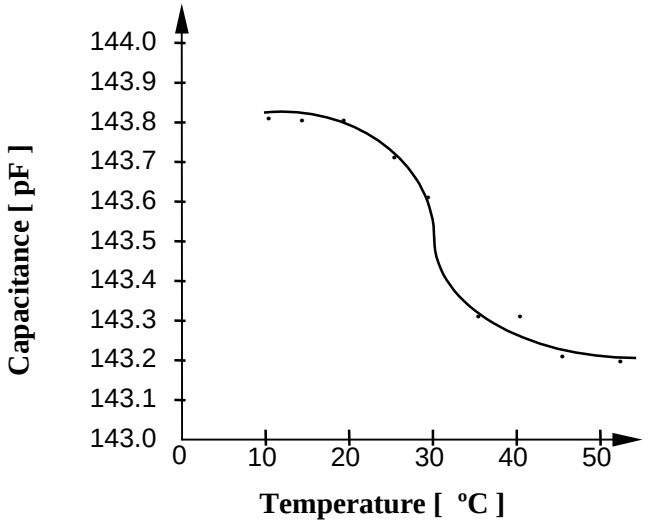

Fig.3 Temperature dependence of the sensor capacitance for 33 %RH; F=20 KHz

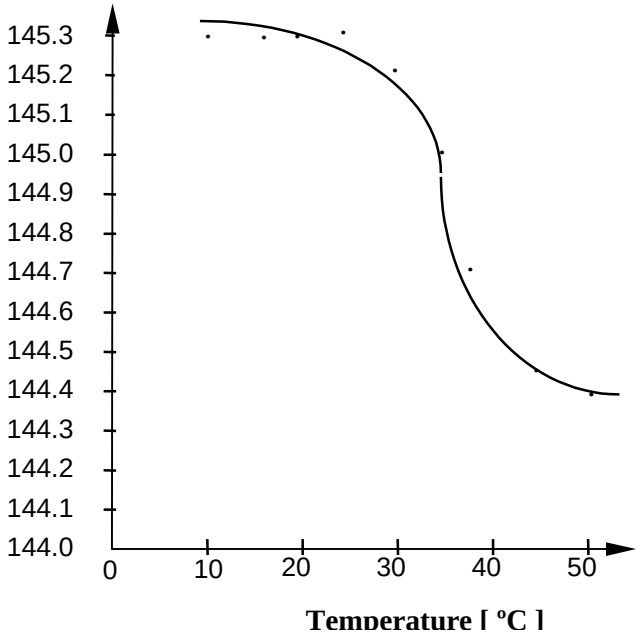

Fig.4 Temperature dependence of the sensor capacitance for 43 %RH; F=20KHz

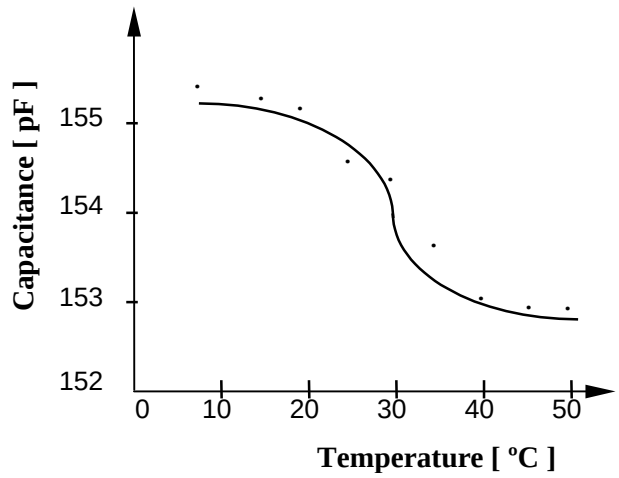

Fig.5 Temperature dependence of the sensor capacitance for 75,5 %RH; F=20KHz

Long term stability of the sensor was evaluated under various hostile environments: -20°C +80°C, volatile solvents (alcohol, acetone, oil). The sensor showed as small as +3% RH drift after 1000 hours exposure to 80°C, 96% RH conditions. This stability some of the test results are summarized in table 2.

Table 2 Long term stability of the polyimide sensor

Test condition	Sensor output shift (% RH)
Low temperature, -20°C, 1000 h	±2,5
High temperature, +80°C, 1000h	±3
Temperature cycle –20°C, +80°C, 100 cycles	±3
Volatile solvents	±2
5 cycle 50°C, 96% RH, 1000 h	±3

Other characteristics of performance, that terminal linearity, response time, dissipation factor and base error are presented in table3.

Table 3 Characteristics of performance

Terminal linearity at 25°C, 0-100 % RH, (%RH)	0,5
90 % Response time 0-100 % RH, at 25°C (min)	5
90 % Response time 100-0 % RH, at 25°C, (min)	7
Dissipation factor at 56% RH, 25°C at 20 KHz	0,01
Base error at 25°C, 20 KHz (%)	2

4 Conclusions

We have fabricated a humidity sensor by generating cracks by depositing of chromium 1000 Å thickness using vacuum e-beam evaporation at a pressure $2x10^{-5}$ torr and deposition rate of 10 Å/s. As connection materials were coated copper 500 Å and silver 1500 Å thickness respectively. Sensor shows a linear response of a capacitance with relative humidity in range 0-100 %RH, a sensitivity of 0,2 pF/%RH and 2% hysteresis at 56 % RH. A temperature coefficients of capacitance for 33, 43, 75,5 %RH in 10-50°C were 0,07, 0,06, 0,2 %RH/°C respectively. These results demonstrate an overall superior performance of the sensor for opening up a wide variety of applications.

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Modelling the Monthly Increments of the Palmer Drought Index (PDSI) for Southeast Hungary

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Abstract: The monthly increment of the Palmer Drought Severity Index, the so called Z-index (moisture anomaly index), calculated for 17 stations in South-East Hungary is investigated. The dependence structure among the sites was estimated using the empirical semi-variogram and a standard kriging procedure was used for predicting the Z-values of the region for every month in 34 years. This stochastic process was modelled by a transformed Gaussian random field (where the critical point is to capture behaviour of the univariate distributions at the sites as well as the correlation structure between the sites) in order to easily simulate the process. The simulations enabled us to estimate the return periods for extreme agrometeorological situations affecting a subregion of at least a given size.

Key words: Z-index, variogram, kriging, Gaussian random field, extremes, return period

Modellierung der Monatsschritte des Trockenindex nach Palmer (PDSI) für Südost-Ungarn

Zusammenfassung: Die Monatsschritte des Trockenindex nach Palmer, der sogenannte Z-Index (Feuchteanomalieindex) wurden für 17 Wetterstationen in Südost-Ungarn untersucht. Die Abhängigkeitsstruktur zwischen den Stationen wurde durch eine Variogrammschätzung nachgeprüft. So es wurde möglich, ein Standard-Kriging-Verfahren zu benutzen, und die Z-Werte für die ganze Region für jeden Monat in den 34 Jahren zu schätzen. Diesen stochastischen Prozess haben wir durch eine Mischung von transformierten Gausschen Zufallsfeldern modelliert (wobei der kritische Punkt darin liegt, nicht nur die eindimensionalen Verteilungen, sondern auch die Korrelationstrukturen abzubilden), um auch Simulationsergebnisse zu erhalten. Diese haben es ermöglicht, die Wiederkehrperioden für extreme agrometeorologische Situationen zu schätzen, die eine Subregion von einer gewissen Größe betreffen.

Schlüsselworte: Z-Index, Variogramm, Krigen, Gaussche Zufallsfelder, Extreme, Wiederkehrperiode

1 Introduction

The monthly increment of the Palmer Drought Severity Index, the so called Z-index (moisture anomaly index) is a proper characteristic to indicate the persistence of extreme soil moisture conditions (Alley, 1984). Although, PDSI is referred to as an index of meteorological drought, the procedure considers precipitation, evapotranspiration, and soil moisture conditions, which are determinants of hydrological drought and of agricultural drought. In addition, the PDSI and, hence, the Z-index is standardised for different regions and time periods, a necessary requirement for the aerial assessment of moisture conditions. (More precisely, the relation between PDSI and Z-index of a given *i*-th month is: $PDSI_i = 0.897PDSI_{i-1} + Z_i$.) Negative values of the Z-index refer to dry conditions, while positive ones represent wet periods. In principle, values of the Z-index are standardized relative to obvious climatographical differences caused by the annual cycle and the geographical situations.

In this paper we continue some earlier work, where the Z-index (calculated for 16 sites, scattered in Hungary), was investigated as univariate time series (Mika et al, 1994, Mika, 1998 and Zempléni et al, 2000). We decided to use the Z-index in the current modelling procedure too, as this allowed us to make comparisons for the marginal (univariate) return periods, estimated now by simulation and previously by classical methods in the abovementioned papers. This time we had the values for 17 sites, concentrated in a relatively small part (approx. 100 km x 100 km) of a homogenous, flat part of south-east Hungary (see Fig. 1 for the locations of the observation sites together with the squared region, for which we carried out the estimation). We had a complete data set for all the sites from January, 1952 to December, 1985. The early termination of the series can be explained by subsequent changes of the data post-processing and the reduction of the stations in the recent decade. Some further computations related to the remainder of the period are being performed for independent comparison.

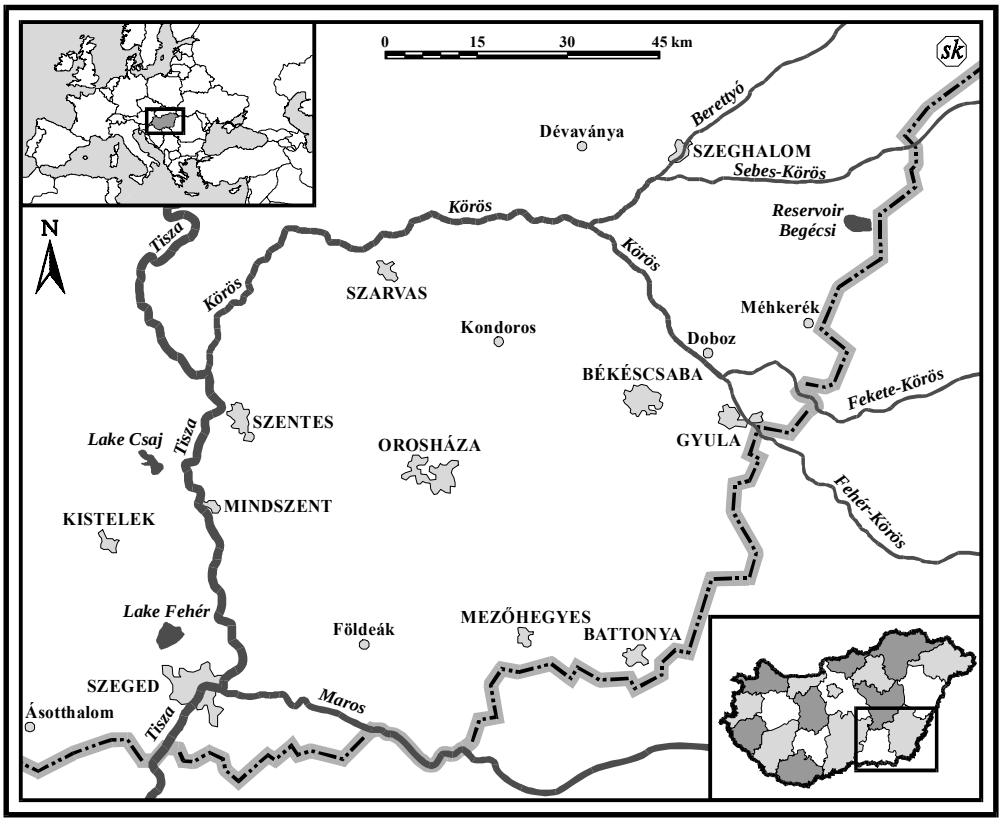

Fig. 1 The area under investigation, with its location in Europe as well as in Hungary

The study of the dependence structure between sites is essential when the spatial behaviour of the process is investigated, as in the current paper. In Section 2 we give the estimated (semi)variograms and present the results of the standard kriging procedure, which gave a predicted surface for the Z-values of the region, based on the data of 17 stations for every month in the 34 years under investigation. The homogeneity of the geography of the region made our assumption of a homogenous spatial correlation structure physically plausible. The tail behaviour of the Z-index is rather different for negative (dry) and positive (wet) months and because we have more reasonable simulation results for the dry months in this paper we concentrate primarily on the extreme negative values of the Z-index. We show the predicted surfaces for the month with the most extreme relative dry conditions, as well as the effect of the kriging prediction for a month with an unusual observation.

In Section 3, this stochastic process is modelled by a transformed Gaussian random field (where the critical point is to capture the univariate distributional behaviour as well as the correlation structure). We present here some simulation results, including an example for the predicted surface in an extreme case, as well as the observed probabilities for extreme agrometeorological situations affecting a subregion of at least a given portion of the region.

The results of the simulation are compared to the estimators obtained by classical methods for a station (Szeged), for which also a much longer (110 years) sequence of observations was available.

2 Modelling the temporal and spatial structure

Initially sample autocorrelation and sample partial autocorrelation functions were investigated for the Z-index data separately at each site. It did not appear too unreasonable to take the Z-index values as being uncorrelated over time (as it was observed for the Z-index of other sites by Mika et al., 1994).

With respect the more important spatial correlation, its modelling is essential when predicting Z-values at unobserved sites. The empirical semivariogram is a widely used measure of spatial autocorrelation (Cressie, 1993, p70), defined as

$$\gamma(C_l) = \frac{1}{2N_l} \sum_{d(i,j)\in C_l} (z(i) - z(j))^2$$

where the pairs of observation sites are classified into K classes, based on the distances between the elements of the pair, C_l is the lth distance class, and the summation is extended to all pairs, belonging to the given class (N_l is the nunber of pairs in the given class). Note that $z(i)$ and $z(j)$ are the observations at sites i and j, and $d(i,j)$ is the distance between the sites. The semi-variogram was calculated for each month and then an average of the semi-variograms was taken over all the months. One expects the semi-variogram to increase with the distances (lags) at least for moderate ones, and it was indeed the case (Fig. 2).

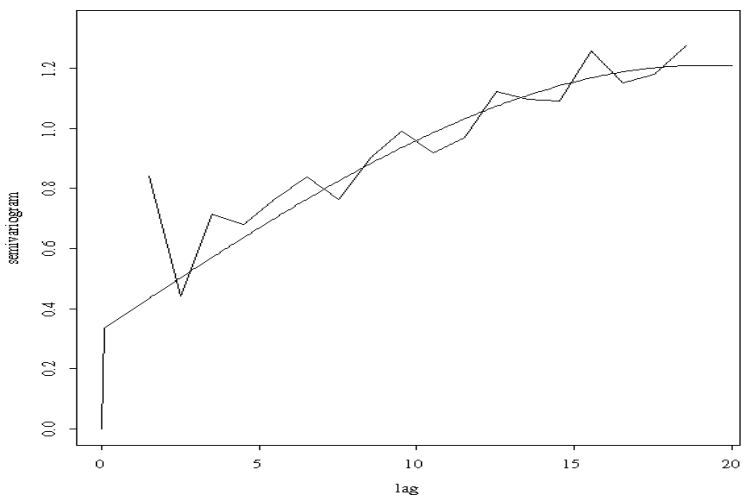

Fig. 2 Empirical semi-variogram of the observed data, with the fitted isotropic spherical semivariogram. (It must be noted that we used an isotropic scaling and translation of the geographical locations, so the lags represent relative distances only. We actually investigated the area shown in Fig. 1, which was considered as a square with "size" 20x20.)

Figure 2 also shows the fitted isotropic spherical semivariogram model (using the Cressie and Hawkins (1980) robust estmator), as follows:

$$\gamma(x) = c + d(1.5x/R - 0.5(x/R)^3)$$

(if $x<R$) and $c+d$ otherwise, where c is the so-called nugget-effect (c=0.33 in our fitted model), representing variance present for nearby locations. The range R is the distance, beyond which the semivariance is constant, and $c+d$ (the so-called sill) is the value of this constant. In our case $c+d$=1.21, and R=19.

Based on the above fit, the predicted Z-index surface was estimated by the geostatistical method called kriging, which provides least squares prediction for the unknown quantity. We used a grid of 201x201 points, and the contours of equal Z-index values were drawn, where different shades (colours) were used for different levels.

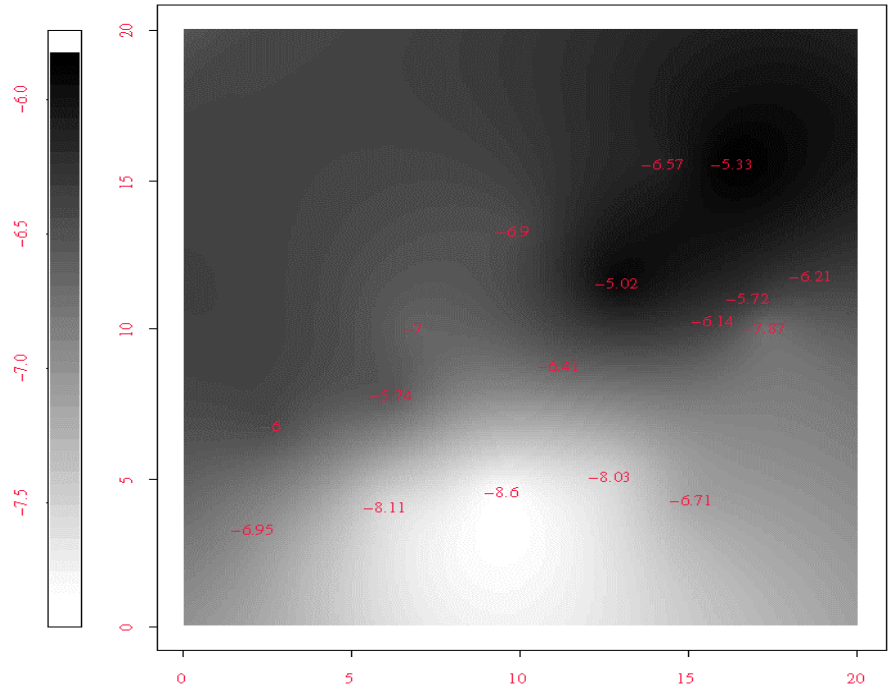

Fig. 3 The estimated Z-value surface for the most extreme negative month (November, 1974). The actual observations are indicated.

We give two contour maps: Fig. 3 is the driest month and Fig. 4. is a month with an unusual observation: among the generally rather wet observations there is a dry one. These figures give an idea of the actual Z-index values, but it must be noted that the standard error of the estimates is is quite large: they vary between 0.5 and 0.8, which is unavoidable due to the scarcity of the actual observation sites.

Figure 4 shows the effect of the kriging. Due to the nugget effect, the values are smoothed (not interpolated): the actual outlier of -4.62 is in a region of values near 0, It would require a special investigation to establish if this single low Z-index is realistic in the given month, or just a consequence of an erroneous precipitation or temperature data in the series.

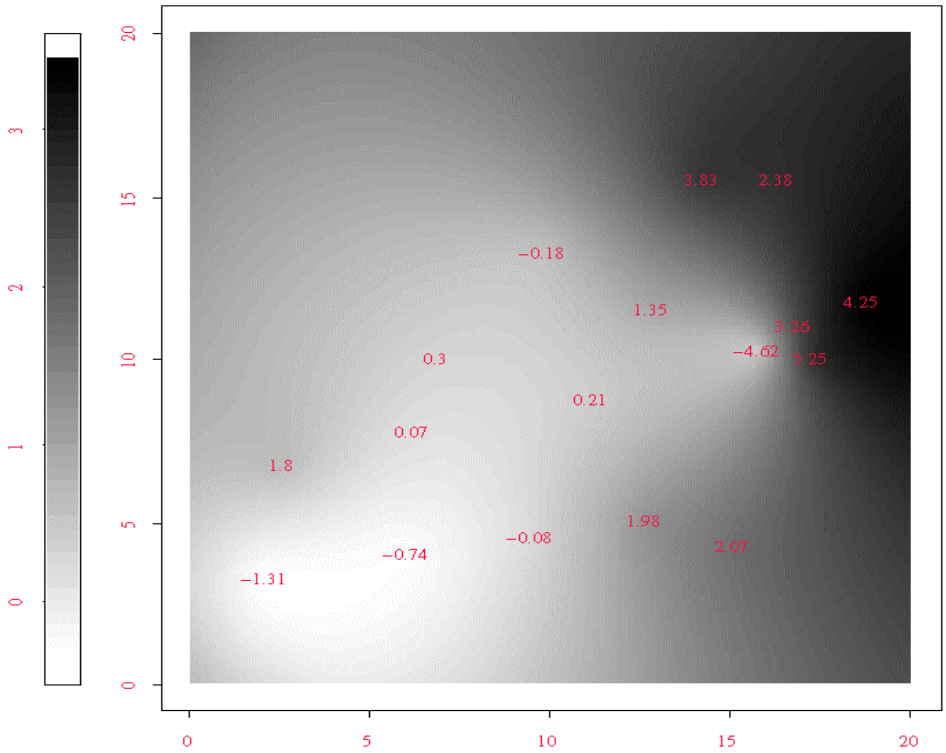

Fig. 4 The estimated Z-value surface for a month with a dry observation among normal and wet ones (June, 1953). The actual observations are indicated.

3 Simulation studies

In this section we present the initial results of a simulation study, which is one possible approach to the analysis. We plan to present further results on alternative methods at the conference.

The first obvious step was the investigation of the univariate distribution of the observed Z-values. As the normal Q-Q plot shows (first part of Fig. 5), the normality was far from being acceptable. There are definitely too many extreme observations both in the positive and in the negative direction and there is a break near the values of -4. So we decided to transform the values in order to achieve a better fit to a normal distribution, and using the following transformation, we were able to create values much nearer to the desired normal distribution:

$$y = \begin{cases} -(-x-2{,}2)^{5/9} - 2.2, & \text{if } x < -3.2 \\ x, & \text{if } -3.2 \le x \le -0.5 \\ (x+1.5)^{10/13} - 1.5, & \text{if } x > -0.5 \end{cases}$$

This transformation was chosen, since these powers provide the highest correlations in the Q-Q plot among a range of alternatives.

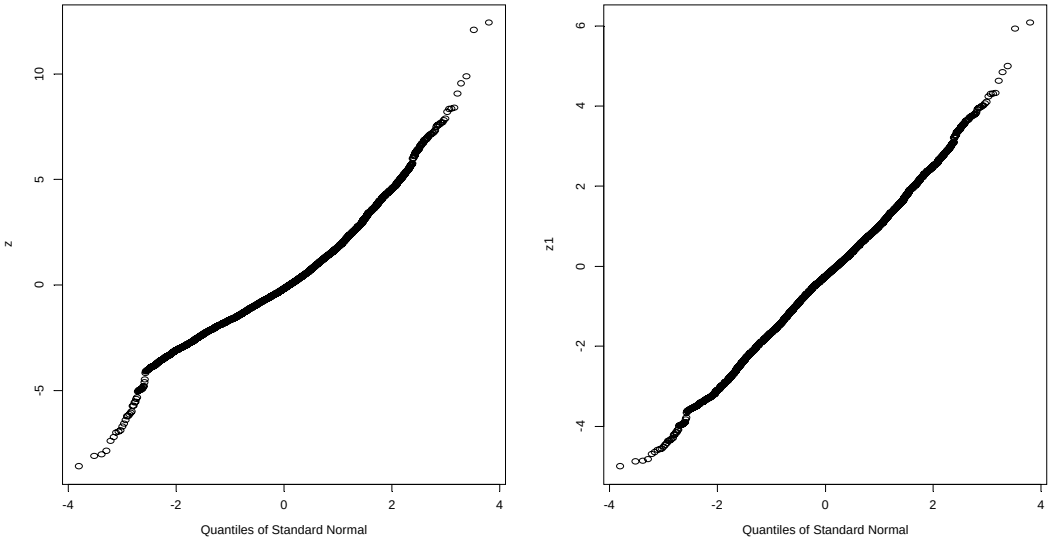

Fig. 5 Normal probability plots (Q-Q plots) of the observed data (z; first figure) and the transformed data (z1; second figure).

The second plot of Figure 5 shows the Q-Q plot of these transformed values. It is quite good (apart of the few outliers near the upper end of the distribution, which turned out to be an important point, as we shall see it later).

From this point the simulation was very straightforward: we calculated the sample mean and the between sites sample variance-covariance matrix of the observations, and generated normal vectors with these parameters. Finally, the inverse transformation of the above was used, in order to obtain values with approximately the same distribution as the original observations.

These results were the starting point of the same kriging procedure as was described in Section 2 (the same variogram model was used here). The kriging surface of the most extreme month for a simulated 1000 months' period is shown in Fig. 6.

We also estimated the probabilites for given extreme conditions to affect large parts of the investigated area (Fig. 7.) We note that the simulated distribution functions are not too far from the observed distribution function for the negative extremes, but the fit is quite poor for the positive extremes.

Finally we present a comparison of the univariate values we got by the simulation procedure described above, to the actual observations of a longer period (1881-1990). It turns out that the only major difference is at the upper extremes (in accordance with the results shown in Fig. 7).

Table 1 Estimated return periods for one of the observation sites. The first row is based on the classical extreme-value method of annual maxima/minima, while the second row is the empirical estimator of our simulation.

	10 y. min	10 y. max	100 y. min	100 y. max
Szeged (110 years of observed data)	-3.46	5.36	-4.32	7.12
Szeged (simulated data)	-3.67	5.34	-4.98	11.42

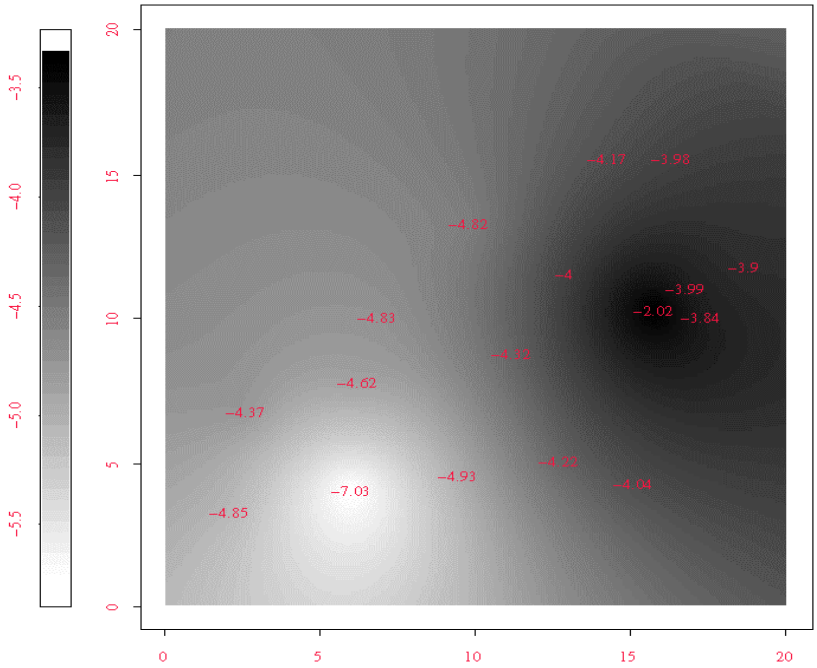

Fig. 6 The estimated Z-value surface for a month, based on simulated data. The simulated values for the observation sites are indicated.

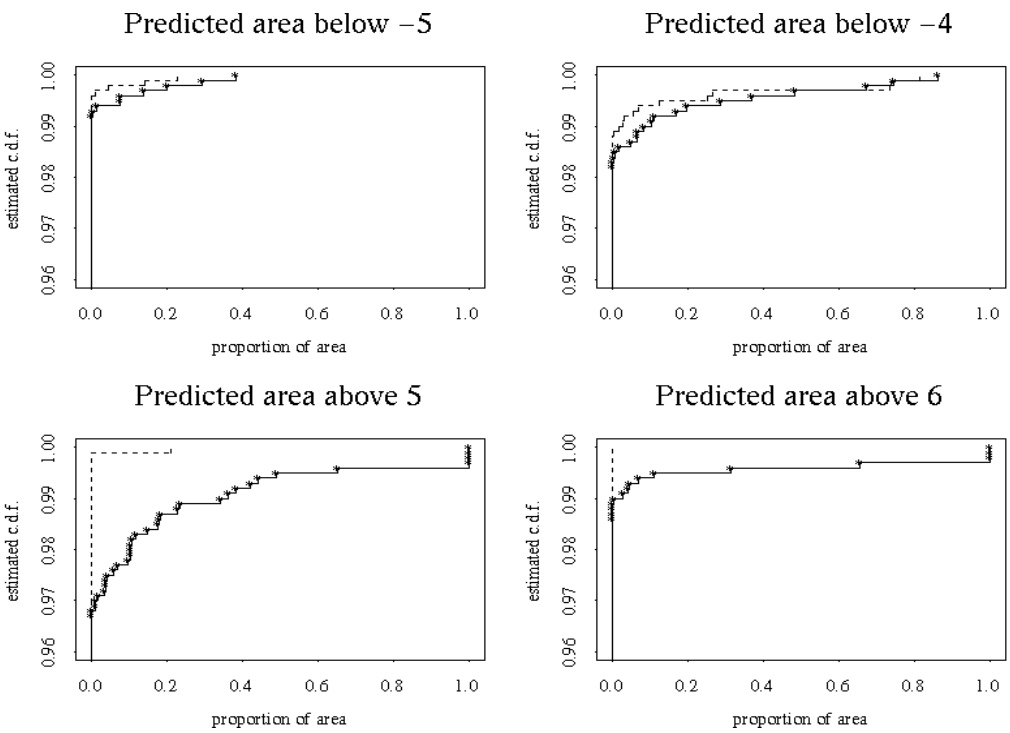

Fig. 7 The empirical probabilities of extreme conditions affecting regions with different proportions. The solid lines are based on 1000 simulated months (showing the relative frequency of months, where there was an extreme prediction affecting at least the given proportion). The dashed lines are the same relative frequencies, based on the observed data).

Conclusions

The kriging method that we used for estimating the Z-values for the area is standard geostatistical methodology, which seems to be readily applicable to the meteorological data investigated. The simulation method can be improved (especially for the wet periods). Note that there is no theoretical basis for our transformation - its only aim being to obtain a Gaussian variable which is easy to simulate. Although the exponents were adjusted (and this can be done for other data sets, too), we believe that other methods (hidden Markov models, for example) should be investigated as well. We hope to be able to present improved simulation results during the conference.

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Regionalization of the Slope Surfaces in the Archar-Orsoja Lowland (Bulgaria) according to Their Degree of Stability

Dora Angelova

Abstract: The Archar-Orsoja lowland is situated in the western part of the Danubian plain at an area of 35 km^2. Its origin is connected with formation of the Lom depression. The present work considers the complicated slope surface complex formed as a result of the action of different factors - tectonic, erosion, erosion-accumulative, anthropogenic, gravitation or karst ones, developed under the action of different geological-geomorphological processes (endogenic, exogenic, anthropogenic). An attempt is made on the basis of the analysis to evaluate the stability of the whole ecosystem in a region with very complicated engineering geological conditions and catastrophic geodynamic processes. A regioning map of the slope surfaces according to their degree of stability against complex geodynamic impact has been worked out on the basis of expert assessments of the different factors and summation of the obtained ranks.

Kartierung der Hangstabilität in der Artschar-Orsoja Niederung (Nordwest-Bulgarien)

Zusammenfasung: Die Artschar-Orsoja Niederung (Gesamtfläche 35 km^2) liegt im nordwestlichen Teil der Donau-Ebene. Ihre Entstehung ist mit der Entwicklung der Lom-Depression verknüpft. Die dort zu beobachteten komplexen Hangbildungen sind das Resultat verschiedener Faktoren. Dazu gehören tektonische, erosive, erosiv-akkumulative, gravitative und anthropogene Einflüsse sowie Verkarstungsprozesse. Somit sind endogene, exogene wie auch anthropogene Einwirkungen vorhanden. Auf analytischer Basis wird versucht, die Stabilität des ganzen Ökosystems in einem Bereich abzuschätzen, der durch komplizierte bodenmechanische Verhältnisse und katastrophale geodynamische Prozesse gekennzeichnet ist. Die beigelegte Karte teilt die Hangoberflächen in unterschiedliche Grade der Stabilität bezüglich der komplexen geodynamischen Einwirkungen auf. Grundlage dafür war die Abschätzung der Wirksamkeit der einzelnen Faktoren und die anschließende Summierung der so erhaltenen Grade.

Introduction

In a morphographic aspect the Archar-Orsoja lowland falls within the western part of the Danubian plain. It consists of two parts – the Archar and the Orsoja ones. The first one occupies an area of 4 km^2 with an altitude of 30-32 m, and the second one - an area of 31 km^2 with an altitude of 27-30 m. The relief of the Orsoja lowland is hilly and is full of sand deflation heights, the height difference not exceeding 10-11 m. Shallow boggy lowerings are formed between the deflation heights. The northern board of the lowlands is formed by the high Danubian bank, representing in the investigated section a continuous landslide strip, situated at a distance of 100-130 m above the present level of the Danube river. The landslide phenomenon has been studied by many authors (Minkov, 1959, Mishev, 1959, Angelov et al., 1983, Georgiev et al., 1985, Kenderova, Mladenova, 1992, Frangov, Angelova, 1999). The regional geological-tectonic and geomorphological situation is evaluated in a number of works (Popov, 1964, Popov, Kojumdgieva, 1966, Velev et al., 1988, Frangov, Angelova, 1999).

Geological-tectonic conditions

Quaternary deposits (Minkov, 1959, Mishev, 1959, Popov, 1964) and the Neogene sediments of the Smirnen, Archar And Brusar Formations (Popov, Kojumdgieva, 1966, Kojumdgieva et al., 1983) are observed in the southern periphery of the Archar-Orsoja lowland. The Smirnen Formation is represented by grey-bluish to grey-greenish dense stratified clays, building the interior zone of the Lom basin. Its thickness varies between 20 and 60 m in the region of the Archar village, reaching 550 m in the region of the town of Lom. The chronostratigraphic range is from the Lower Meotian to the Upper Pontain, including. The Archar Formation is situated with a gradual transition above the Smirnen one. Its lithological composition includes whitish and yellowish sands with a thickness from 20-30 m to 50-60 m near the Archar village. The lower part is laterally transferred into the clays of the Smirnen Formation in the vicinity of the Lom town, its thickness being 45-60 m. The age ranges from the Upper Pontain to the Lower Dacian. The sediments of the Brusar Formation are situated also with a normal transition on top of the Archar Formation. It is represented by grey-greenish sandy and aleurite clays with sand and lignite coal intercalations. The thickness does not exceed 40-50 m. The age is Dacian-Roman. Natural discovering of the Smirna Formation is not found in the investigated region. The Archar Formation is observed in the vicinity of the Archar village, where it has been subjected to the contemporary erosion process. The Brusar Formation is obviously most strongly affected by contemporary landslide processes in the section between the town of Lom and the Dobri Dol village. The Neogene complex is separated from the Quaternary one by an erosion washout.

The Quaternary is represented by gravel-clayey deposits covered by a loess complex. The gravel materials are deposited on the top parts of the plateaux and are presented by semi-rounded pieces of different size and shape and different mineral and lithological composition – limestone, sandstone, quartz, and not so often magmatic and metamorphic rocks. They are mixed with medium- to coarse-grained sands of yellowish to rusty colour (between the Skomlya and Lom rivers), the clayey component being the predominating one (to the west of the Skomlya river). The thickness varies from 0.5 to 3-4 m. The genesis is alluvial-proluvial one. The sands are situated on an erosion surface with strong denudation (to the south of the Archar lowland on the sediments of the Archar Formation, and to the east of the Skomlya river – on the sediments of the Brusar Formation). Natural discovering of the “covering gravel” (Popov, 1964) is observed between the Slivata, Dobri Dol and Orsoja villages and in the proximity of the town of Lom. The reddish limy-sandy clays of mixed eolian-alluvial origin (Minkov, 1959, Popov, 1964) lie on the gravel-clayey complex either with an abrupt lithological transition or directly on the diverse Neogene base. Their thickness is different but it does not exceed 5-17 m. The clays are observed at the surface as single strips or spots between the Orsoja village and the town of Lom. The loess complex is represented by loess-like clays and clayey loess of eolian-alluvial-deluvial genesis and by typical and sandy loess of eolian genesis (Popov, 1964). One to three buried soils are observed in the loess complex. The total thickness of the loess formation does not exceed 40-50 m. The Pleistocene alluvial materials building the accumulative structure of the river terraces are represented by bed facies and lie with an erosion washout on different Neogene sediments. They are connected with the overflood terraces (from the first to the fifth one) (Minkov, 1959, Mishev, 1959, Frangov, Angelova, 1999). Their heights above the contemporary river level are respectively: T_5 – 72 m, T_4 – 45-50 m, T_3 – 35-40 m, T_2 – 20-25 m, T_1 – 10-15 m. The thickness of the alluvial materials changes within the range from 1-2 m to 17 m. The Holocene sediments are alluvial, deluvial, proluvial and coluvial. The alluvial ones build the lowest and the highest flood river terraces and the riparian Archar and Orsoja lowlands. The thickness in the mouth sections of the effluent Archar, Skomlya and Lom rivers reaches 8 m, and in the lowlands – 12 to 18 m. The coluvial formations are the result of the gravitation processes along the high Danubian bank and along the steep right banks of the tributaries. Most

of them were formed during the Pleistocene and were activated during the Holocene and the contemporary stage.

From a tectonic point of view, the investigated region falls within the range of the Lom depression (Velev et al., 1998, Frangov, Angelova, 1999) as a part of the Moezian microplate with craton structure from the Paleozoic till now. Its paleogeodynamic development is related with the opening and closing of the ocean basins Paleotethys and Neotethys, the subsequent collision and post-collision graben formation. The behaviour of the Lom depression during the Neogene was that of a passive continental periphery, its development being divided in 4 stages. A vast alluvial plain inclined to the north-northeast existed during the Early Miocene. The concentric disintegration of the Carpathian-Balkan orogenic arch started during the Middle Miocene as a result of an extension. The origin of the Lom depression is connected with the extension during the Middle Miocene – early Sarmatian stage. The whole investigated region was subjected to total block sinking and loading with Neogene sediments. The filling of the Lom basin with sediments continued during the Meotian-Pliocene. Then denudation took place and the entire basin disappeared. The two foothill structural steps with considerable accumulative super-structure on top of them were formed during the Plio-Pleistocene as a result of an extension. The last one is situated on a contemporary benchmark of 130-150 m and is the initial one for the modelling of the contemporary relief.

Types of slopes surfaces

A complex of slope surfaces of different genesis and in different dynamic phase is observed in the Archar-Orsoja lowland. The determination of their type depends on the dominating geological-geomorphological process and it reflects their contemporary geodynamic behaviour (Fig. 1).

As already mentioned the formation of the Archar-Orsoja lowland is closely connected with the development of the Lom depression. It was formed on tectonically predetermined blocks: with tectonic lines that had not been active for a long period of time, with tectonic lines that had been reactivated during different periods and with tectonic lines that are active in contemporary plan (Fig. 2).

The erosion and erosion-accumulative slope surfaces were formed after the changes in the erosion bases and the subsequent processes.

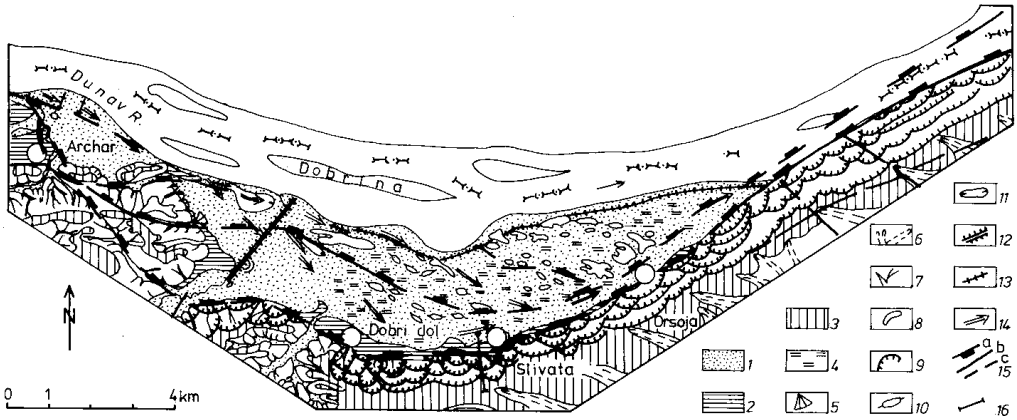

Fig. 1 Geomorphological map of the Archar-Orsoja lowland: 1 – river flood terraces (Holocene); river overflood terraces (Pleistocene); 3 – Plio-Pleistocene levels and terraces covered by loess (loess plateaux); 4 – boggy places; 5 – deposited cones (Holocene); 6 – gullies and dry gullies; 7 – ravines and glens; 8 – abandoned river beds; 9 – landslides; 10 – deflation heights; 11 – lowerings between deflation heights; 12 – canalised river bed sections; 13 – dikes and embankments;14 – old beds of the Danube river; 15 – faults: a) listric, b) established; c) supposed ones.

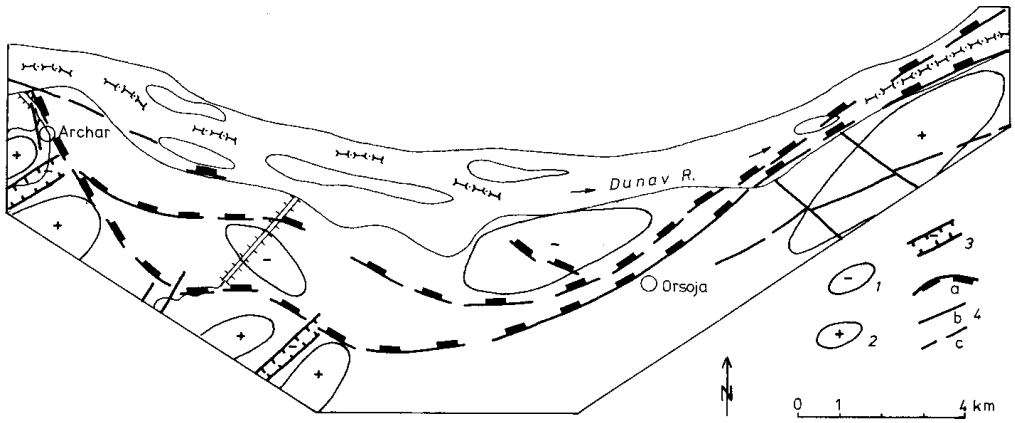

Fig. 2 Map of the Holocene and contemporary tectonic structures: 1 – negative; 2 – positive; 3 – Holocene and contemporary grabens; 4 – faults: a) listric, b) established, c) supposed ones.

The accumulative (alluvial and deflation) sediments build the Archar-Orsoja lowland, the foothills of the loess plateaux, the loess plateaux themselves and the deflation heights in the lowland.

The gravitation slopes build the whole zone between the destructive part of the plain and the lowland. They have a considerable territorial range and dynamics.

Stages in the development of slope surfaces and processes

The beginning was marked by the paleomagnetic boundary 680 thousand years and the entering of the Danube river in the Lower Danubian Plain (Frangov, Angelova, 1999). The process of tectonic rising of the whole Lom depression started. The Quaternary geodynamics was controlled by the rhythmic global changes that affected Europe. The borders of the main structural units were delineated by the main fault structures. Faults of lower rank were formed too with amplitudes from several metres to 20-30 m (Figs. 1 and 3). No seismic events have been established along them till now. Similar structures are the faults in the section between the town of Lom and the Orsoja village, along the downstream of the right tributary valleys, as well as the fault structure on Rumanian territory, marking the deepest part of the Lower Danubian Plain. The structures that were activated in the beginning of the Holocene exerted a considerable effect on landslide activity. The direction of the river valleys was predetermined by the activation of the fault structures with northeast direction. The river-terrace complex, its formation and deformations, illustrate the Quaternary geodynamics (Fig. 1). The river terraces were formed during the pluvial phases of the glacial and stadial epochs when the erosion burst took place. The socle of the terraces was formed during the maximum of these phases. The alluvial sedimentation is connected with the processes of deglaciation. The loess accumulation was realised during the dry and cold stages of the glacial and stadial epochs under conditions of higher carbon dioxide content in the atmosphere. Two genetic types of loess are observed in the loess complex – an old one with alluvial genesis, and young eolian loess (Minkov, 1959, Mishev, 1959). The formation of the buried soil horizons took place during the warm phases of the interstadials. The loess complex formed a common accumulative surface covered by loess plateaux. It built further on the differently eroded surface of the young Plio-Pleistocene step. It is at the same time strongly dismembered by the contemporary river-ravine network and by the landslide processes. Typical relief forms have been developed at its surface as a result of complex reasons.

The beginning of the landslide processes was marked by the first tectonic impulse with a positive sign after the formation of the youngest Plio-Pleistocene erosion-accumulative step. Block type landslides with amplitude of sinking 30-40 m were formed then along a listric fault with northern direction. The structural strip dividing the Archar lowland from the Orsoja one was formed in this way (Fig. 1). It was subjected to new tectonic destruction and the landslide processes were reactivated during the formation of the fifth overflood terrace. Landslide steps were formed in the “Skeleto” locality, situated at a lower level (50 m) than the older landslide terrace and at a 50 m higher level than the contemporary level of the Danube river. The origin of the landslides along the southern board of the Orsoja lowland is connected with this cycle. The landslide steps are at a distance of 50-55 m above the level of the Danube river. Two-three cycles are observed in the development of the landslide process. They are related with the pluvial phases and the shifting of the Danube river-bed to the south.

The Middle Pleistocene was a period of vigorous tectonic activity in the whole of Europe and this had predetermined to a considerable degree the display of landslides in the investigated region. They built the base of the deflation heights in the Archar-Orsoja lowland (Frangov, Angelova, 1999). The sediments of the bed facies of the Danube river were deposited on the deflation heights during the formation of the second overflood terrace, the flood facies of the first overflood terrace being deposited on the top. These terrace sediments were then covered by loess forming the deflation heights situated at a distance of 10-12 m above the alluvial accumulative surface of the lowland.

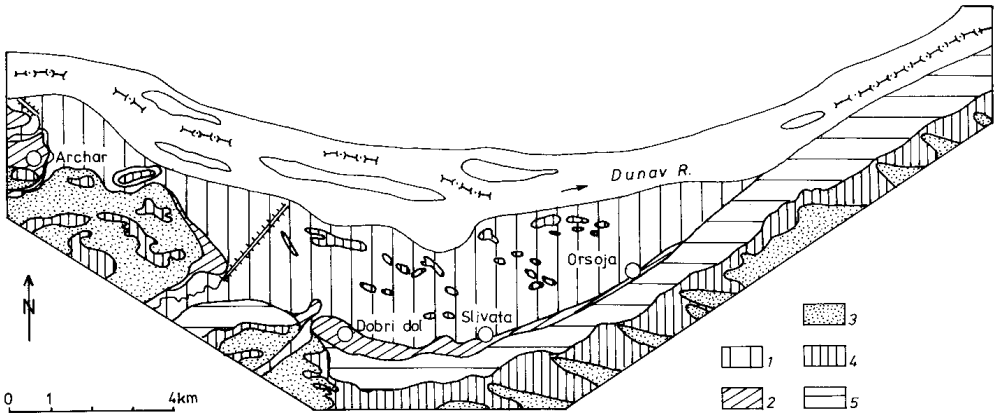

Fig. 3 Map of the regioning of slope surfaces according to their degree of stability: 1 – accumulative – stable; 2 erosion-accumulative – stable on limestone and stable under definite conditions on the other terrain; 3 – erosion – with low stability; 4 – deflation-accumulative – with good stability; 5 – gravitation – unstable.

The Holocene stage in the development of the landslide process represents a phenomenon – a deep erosion incision reaching up to 18-28 m under the contemporary level of the Danube river and a thick accumulation of river bed and flood facies. As a result of the final thawing of the glaciers in Europe and of the eustatic changes in the level of the Black Sea, as well as of the shifting of the Danube river bed to the south in the alluvial plain, one river branch was formed in the Archar lowland and two branches – in the Orsoja one (Fig. 1). The block differentiation of the considered region continued as a result of the subsequent differential tectonic movements, followed by a new change in the beds of the Danube river and some of its tributaries (the Archar river). The old river beds were finally abandoned and new abandoned river beds were formed in the spaces between the deflation heights (Fig. 2). The erosion socle of the tributary valleys (the Archar, Skomlya and Lom rivers) is situated at about 12 m above the erosion socle of the Danube river as a result of the Holocene tectonic movements. This predetermined their deepening and the subsequent activation of the landslide processes.

The contemporary activity of the slope surfaces has inherited the established trend during the Holocene. The contemporary vertical movements are very differentiated (Fig. 2). They determine the formation of contemporary positive structures with intensity of 2 mm/a. Single areas are observed that sink with an intensity of 1 mm/a in the regions along the valleys of the rivers Archar, Skomlya, Manastirski Dol, and in the Archar-Orsoja lowland itself. The seismicity according to the MSK scale is 6th degree.

The zoning of the slope surfaces according to their degree of stability (Fig. 3) has been performed on the basis of complex data including: data about the lithological composition and its physicomechanical parameters, the real slope inclinations, the erosion effect of the Danube river and its tributaries (depth of_erosion incision) the fluctuations in the level of surface and ground water, the tectonic processes and the time of their manifestation, the technogenic activity.

Conclusions

The slope processes in the investigated region are connected with its geodynamic development. Their origin and repeated activation is due to the complexly arranged and functioning natural-anthropogenic system. The disturbance of the natural equilibrium under the influence of the tectonic and anthropogenic factors leads to significant disasters with catastrophic consequences. The landslide/rock-fall processes that caused the moving of the inhabitants of the Orsoja and Slivata villages were one especially serious disaster.

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Kolmationsprozesse in Stauräumen von Flußkraftwerken

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Zusammenfassung: Die Austauschrate zwischen Oberflächengewässern und Grundwasser wird wesentlich durch die Kolmation (Selbstdichtung) der Gewässersohle bestimmt. Auf diesen Vorgang wirkt eine große Zahl von Einflußfaktoren ein, die in der vorliegenden Arbeit nach ihrer Wirkungsebene in „innere“, die Funktion und Wirkungsweise des Gewässerbettes und der Filterschicht beeinflussende, und in „äußere“, mit den hydraulischen und geohydraulischen Prozeßgrößen und der Materialzufuhr durch Schwebstofftransport in Zusammenhang stehende Faktoren unterschieden werden. Im Rahmen der Untersuchungen zum Kolmationsvorgang im Stauraum Freudenau wurden Messungen zur Definition der Systemkonfiguration und Sohlenbeobachtungen zum Auftreten der verschiedenen Kolmationstypen gemacht. Den bisherigen Ergebnissen zufolge zeigt sich die Sohlenkolmation als ein aus einer Abfolge von „Kolmationszyklen“ zusammengesetzter Vorgang, dessen einzelne Phasen durch Hochwässer und die dabei verstärkt auftretenden Erosions- und Sedimentationsprozesse bestimmt werden. Die Dauer bis zum Erreichen eines quasi-stabilen Zustandes beträgt wenige Wochen bis einige Monate. Videoaufnahmen der Flußsohle geben Aufschluß über die unterschiedliche Beschaffenheit des Gewässerbettes je nach Lage im Quer- beziehungsweise Längsprofil. Dabei deuten die Aufnahmen auf verschiedene Kolmationstypen mit jeweils eigenen dominierenden Mechanismen hin.

Aufgrund der im Stauraum Wien-Freudenau durchgeführten Messungen kann der zeitliche Verlauf des Selbstdichtungsvorganges ermittelt und daraus die Veränderung der Infiltrationsrate in das Grundwasser abgeleitet werden. Dabei zeigte sich der erwartete Rückgang der Infiltrationsrate (innerhalb eines Jahres um –20%), aber auch der große Einfluß der Temperatur auf die Austauschrate.

Schlüsselworte: Kolmation, Selbstdichtungsprozesse, Uferfiltrat, Interaktion Oberflächengewässer-Grundwasser

Riverbed clogging processes in dammend rivers

Abstract: The stream-aquifer interaction are important influenced from the riverbed clogging process. The parameters that affect hydraulic exchange include aquifer geometry, water-groundwater pressure difference and hydraulic properties like the hydraulic conductivity of the riverbed itself. Settling and straining of suspended and bed load sediment at the riverbed may cause a substantial reduction of the conductivity of the outermost layer of the riverbed material. The studie area in the reservoir „Freudenau“ shows the existence of different types of clogged layers. The effect of flood events in the whole clogging process are shown. Smaller flood events cause an increase in the leakage coefficient but only for a short time and bigger flood events cause a new clogging process due to sedimentation. Therefore the whole clogging process so far consists of several individual clogging processes and each takes a few weeks until reaching a quasi-stable state. Videos shows the different characteristic of the riverbed in the studie area.

From the pressure measurements under the riverbed with multi-level-piezometers the time series of the seepage rate at a given point are calculated. This computation shows that the seepage rate was reduced about –20%. We could also show that the change in the groundwater temperature from 2°C during winter to 20°C during summer caused a periodic change in the seepage rates of 50%.

Keywords: stream-aquifer interactions; seepage rate; clogging processes

1 Einleitung

Die für einen ufernahen Grundwasserleiter wichtige Interaktion mit dem Oberflächengewässer ist wesentlich durch die Beschaffenheit der Flußsohle beeinflußt. Speziell in großen Flüssen mit den meist vorhandenen Staustufen wird dies von der Kolmation (Selbstdichtung) der Gewässersohle wesentlich beeinflußt.

Unter dem Begriff „Kolmation“ einer Gewässersohle werden alle Vorgänge verstanden, die über eine Reduktion des Porenvolumens und eine Verfestigung des Gewässerbettes und der Filterschicht zu einer Abnahme der Durchlässigkeit der Sohle führen. Der Vorgang hängt eng mit dem Transport und der Ablagerung von Feinpartikeln zusammen und stellt damit einen natürlichen Prozeß dar, der grundsätzlich bei allen Gewässern anzutreffen ist, deren Sohle durchlässig ist. Das Ausmaß des Selbstdichtung kann am besten durch den „Kolmationsgrad“ beschrieben werden. Dieser setzt sich zusammen aus der Dicke der von der Feinteileinlagerung betroffenen Filterschicht und der resultierenden Durchlässigkeit nach einer bestimmten Zeit. Der zeitliche Verlauf der Kolmation strebt bei stabiler Sohle einem Grenzwert zu, wenn sich aufgrund des vollständigen Verstopfens der Poren der Filterschicht keine weiteren Feinpartikel mehr einlagern können und daher als Geschiebe weitertransportiert werden (BANSCHER (1975), CUNNINGHAM et al. (1987), SCHÄLCHLI (1993)). BANSCHER (1975) bezeichnete diesen Grenzwert als „quasi-stabilen Endzustand“ der Kolmationsentwicklung und impliziert damit eine gewisse Prozeßdynamik. So kann beispielsweise im Gefolge von Hochwässern die Sohle aufgerissen, die Deckschicht gelöst oder abtransportiert werden und in der Folge davon die Durchlässigkeit wieder ansteigen (Dekolmation). Nach SCHÄLCHLI (1993) kann in Angleichung an diesen zeitlich variablen Verlauf bei Fließgewässern von einer „Kolmations-Ganglinie“ gesprochen werden, in deren Auf und Ab sich das Auftreten von Phasen der Ablagerung und Einlagerung von Feinteilen bzw. von Phasen des Abtrags und des Aufreißens der Sohle widerspiegelt. Der vorliegende Beitrag befaßt sich mit den Einflußfaktoren auf die Kolmation, der Darstellung des prinzipiellen Kolmationsvorganges und der beobachteten Kolmationstypen in einer Flußstauhaltung. Aufbauend auf die zeitliche Kolmationsentwicklung werden die damit verbundenen Auswirkungen auf den Wasserhaushalt im lokalen und regionalen Maßstab dargestellt.

2 Einflußfaktoren auf die Kolmation

Im folgenden wird in einer prozeßnahen Betrachtungsweise auf die in einem bestimmten Gewässerabschnitt auftretenden Kolmationsstadien, -mechanismen und -phänomene eingegangen. Diese kommen durch das Zusammenwirken von in der Natur auf unterschiedlichen Maßstabsebenen parallel ablaufenden, zeitlich variablen „inneren“ und „äußeren“ Kolmationsfaktoren zustande. Dabei zählen zu den „inneren“ Kolmationsfaktoren alle jene Parameter, die die Funktion und Wirkungsweise des Gewässerbettes (der Filterschicht) beeinflussen. Auf diese wirken als „äußere“ Kolmationsfaktoren die hydraulischen, geohydraulischen und biologischen Prozeßgrößen, sowie die Materialzufuhr (siehe Abb. 1).

2.1 Äußere Einflußfaktoren

Als dominierende **hydraulische Einflußgröße** ist die Fließgeschwindigkeit als Parameter der durch Turbulenz gekennzeichneten Strömung anzusehen. Viele Autoren messen dieser Kenngröße auch eine wesentliche Bedeutung bei. Beispielsweise läßt sich die durch reine Beobachtung leicht nachvollziehbare Differenzierung in Bereiche mit unterschiedlichen Kolmationsformen direkt auf die Verringerung der Fließgeschwindigkeit zurückführen: Von „innerer Kolmation“ wird gesprochen, wenn Feinpartikel in das Korngerüst des Gewässerbettes eingelagert werden, während unter „äußerer Kolmation“ die Ablagerung auf der Oberfläche des Gewässerbettes verstanden wird.

Die wesentlichen **geohydraulischen Einflußgrößen** sind der hydraulische Gradient bzw. die Potentialdifferenz zwischen Oberflächengewässer und Grundwasser, die die Richtung der

Strömung im Sohlenmaterial und damit die Infiltration bzw. Exfiltration beeinflussen. Die Konzeptionen zur Berechnung dieser Einflußgrößen sind bei den einzelnen Autoren jedoch unterschiedlich, weshalb ein Vergleich der einzelnen Ergebnisse schwierig, und bestenfalls über die Potentialdifferenz möglich ist.

Die dritte wesentliche Einflußgröße ist die **Materialzufuhr** zum Gewässerbett, die von zwei Transportmechanismen bestimmen wird. Die Partikel gelangen entweder durch Sedimentation der Schwebstoffe („suspended load material“) oder durch Liegenbleiben des bewegten Sohlenmaterials („bed load material“) zu ihrem Ablagerungsort, wo sie die Kolmation bewirken. Die Rolle der Schwebstoffe für den Kolmationsprozeß wurde in den Laboruntersuchungen zum Teil sehr ausführlich untersucht, wobei ein eindeutiger Zusammenhang zwischen der Kornverteilung der Schwebstoffe und der Durchlässigkeitsreduktion nachgewiesen wurde. Laut BANSCHER (1975) und SCHÄLCHLI (1993) sind hauptsächlich mineralische und organische Teilchen mit einem Durchmesser < 0,06 mm für die starke Durchlässigkeitsabnahme verantwortlich.

Die Einflüsse der **Biologie** wurden in bisherigen Untersuchungen selten berücksichtigt. Der hohe organische Anteil der in Flußstauhaltungen anzutreffenden Sedimente läßt allerdings einen wesentlichen Einfluß erwarten. Biologische Faktoren wie die Biofilmbildung und die Besiedelung der Partikel durch Bakterien und das Auftreten von Algen haben Auswirkungen auf die Ablagerung, die Verfestigung, die Stabilisierung und die Durchlässigkeit von Sedimenten. Nicht zuletzt wird auch der qualitative Aspekt, der beispielsweise bei der Gewinnung von Trinkwasser aus Uferfiltrat von Bedeutung ist, stark von biologischen Vorgängen mitbestimmt.

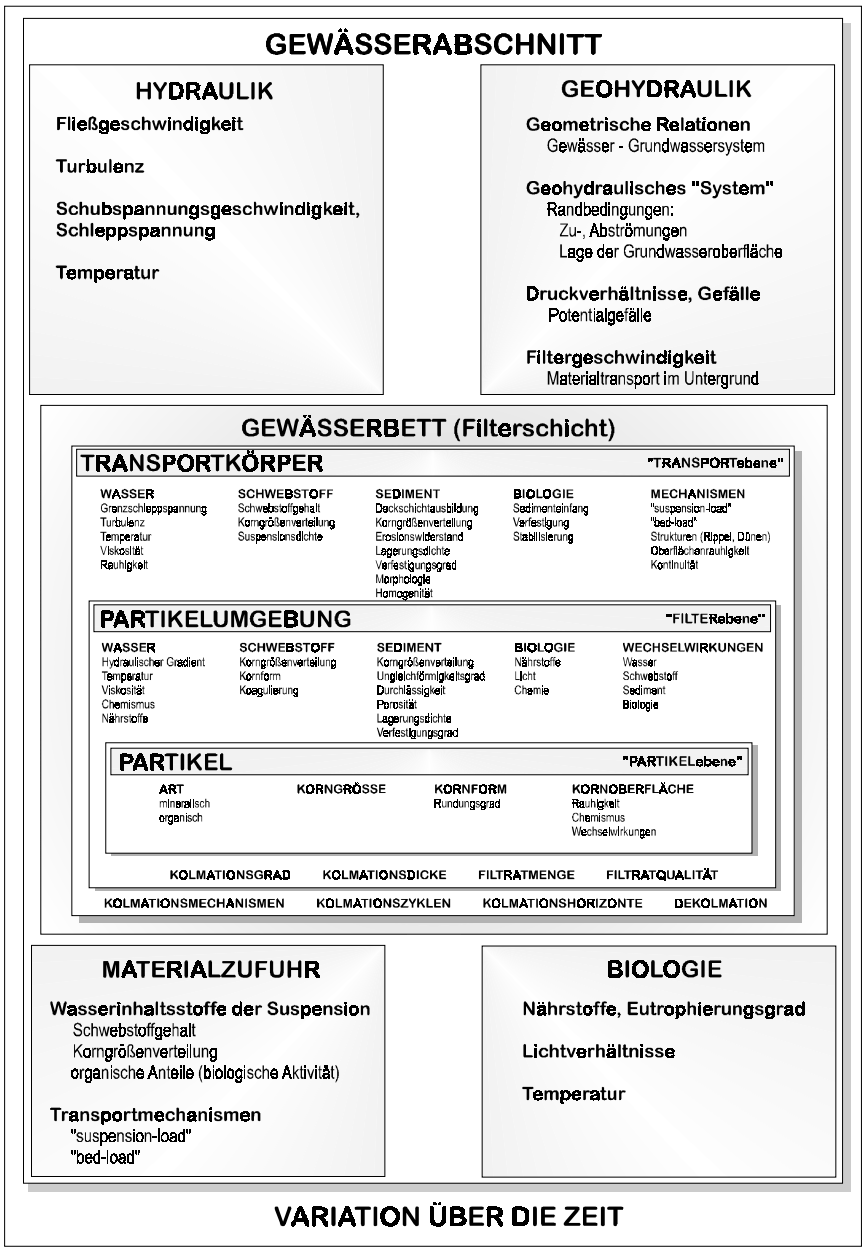


Abb. 1: Einflußfaktoren auf den Kolmationsvorgang

2.2 Innere Einflußfaktoren

Als innere Einflußfaktoren werden alle jene Größen betrachtet, die den eigentlichen Ablagerungs- und Filtervorgang beschreiben. Die während dieses Prozesses im Gewässerbett auftretenden Kräfte und Einfangmechanismen sind aufgrund der mikroskopischen Struktur der Filterschicht auf unterschiedlichen Maßstabsebenen wirksam, weshalb sich eine nähere Untergliederung in weitere „Interaktionsebenen“ (Transportebene, Filterebene, Partikelebene; siehe Abb. 1) empfiehlt. Auf der **Transportebene** haben all jene Parameter Einfluß, die die Bewegung der Partikel an der Oberfläche des Gewässerbettes steuern. Dazu zählen vor allem die oberflächennahe Sohlenschubspannung und die Korngrößenverteilung der Deckschicht. Bei der Betrachtung der Filter- und Partikelebene bilden sowohl die unterschiedlichen Kraftwirkungen als auch die verschiedenen Einfangmechanismen ein klares Unterscheidungsmerkmal. Auf der **Filterebene** wirken Gravitations-, Trägheits- und hydrodynamische Kräfte und Sedimentation, Siebung, Einkeilung bzw. Interzeption als

Einfangmechanismen. Auf der **Partikelebene** wirken die Brown'sche Diffusion, van der Waal'sche- und, elektrochemische Kräfte sowie chemische Bindung und Brown'sche Diffusion.

Die Vielzahl von Einflußfaktoren auf den Ablagerungs- und Filtrationsvorgang führte zu einer Beschreibung des Gewässerbettes über Ersatzgrößen bzw. Summenparameter, wobei einzelne Autoren unterschiedlichen Kenngrößenverknüpfungen den Vorzug gaben.

3 Kolmationsvorgang und Kolmationstypen in einer Flußstauhaltung

3.1 Kolmationsvorgang

Die bisherigen Beobachtungen im Stauraum Wien-Freudenau führten zu einem Bild vom Ablauf der Kolmation in diesem Flußstauraum, das durch Abbildung 2 wiedergegeben wird. Der Verlauf der Kolmation wird darin anhand des sogenannten Leakage-Faktors beschrieben, der eine Kenngröße für die Austauschrate zwischen Gewässerbett und Grundwasserkörper darstellt. Je kleiner er ist, desto geringer ist die Sickermenge.

Mit Stauerrichtung kommt es zu einer Reduktion der mittleren Fließgeschwindigkeit im Stauraum und zu einem vermehrten Absetzen von Schwebstoffen im Stauraum sowie andererseits – zumindest in der ersten Zeit nach Stauerrichtung – zu einer Erhöhung der Infiltration ins Gewässerbett. Beide Einflußfaktoren begünstigen die Kolmationsprozesse und führen daher in der Regel zu einer deutlichen Abnahme des Leakage-Faktors des Gewässerbettes (erster Kolmationszyklus, ① in Abb. 2). Dieser erreicht nach zirka zwei bis drei Monaten einen quasi-stabilen Zustand. Die Dauer eines quasi-stabilen Zustandes hängt davon ab, in welchem Zeitabstand Hochwässer auftreten, die zu einer Dekolmation, einem Aufreißen der Gewässersohle und einem damit verbundenen Wiederansteigen der Durchlässigkeit führen. Die bisherigen Beobachtungen ließen erkennen, das es im Gefolge kleinerer Hochwässer bei Fließgeschwindigkeiten v kleiner als 2 m/s mehrmals zur teilweisen Dekolmation kam (Situation ② in Abb. 2). Sie ging jedoch jeweils relativ rasch wieder zurück.

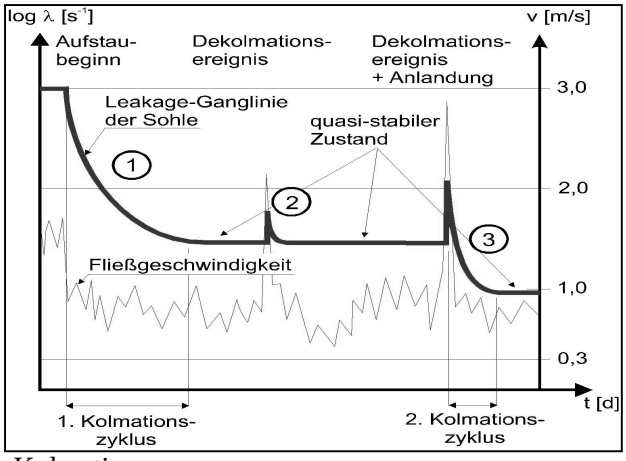


Abb. 2: idealisierter Kolmationsvorgang

Die Auswertungen der Messungen können dahingehend interpretiert werden, daß der Kolmationsvorgang aus einer Abfolge von „Kolmationszyklen" (③ in Abb. 2) besteht. Die beobachtete Dauer eines Zyklus beträgt dabei nur wenige Wochen bis einige Monate, was mit den aus der Literatur bekannten Ergebnissen von Laboruntersuchungen übereinstimmt (BANSCHER, 1975; van RIESEN, 1975; CUNNINGHAM et al., 1987; SCHÄLCHLI, 1993).

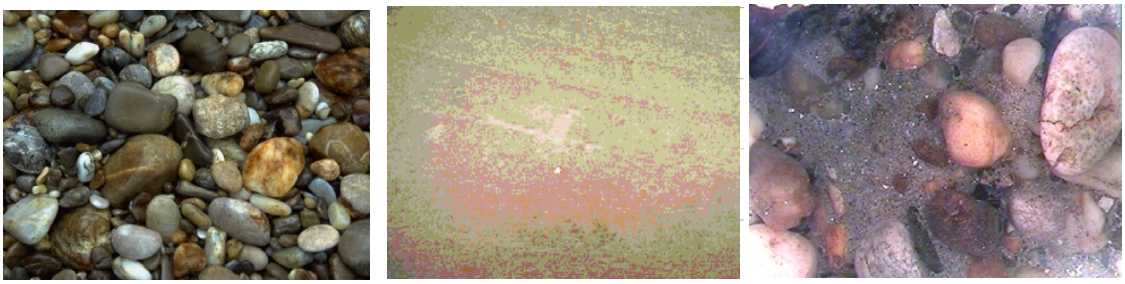
3.2 Beobachtete Typen der Selbstdichtung im Stauraum Wien Freudenau

Die unterschiedlichen Wassertiefen und Fließgeschwindigkeiten in einem Flußstauraum lassen erwarten, daß sich der Kolmationsprozeß nicht überall im Stauraum in gleicher Weise ausbildet. Da Messungen, wie sie für die Erfassung des Leakage-Faktors notwendig sind, nur mit speziellen Einrichtungen zur Druckhöhenmessung unter der Gewässersohle und daher nur in

Untersuchungen zur Erfassung der Vorgänge im gesamten Stauraum auf andere Formen der Beobachtung abgestellt werden. Im vorliegenden Fall geschah dies durch Einsatz einer eigens entwickelten Spezialunterwasserkamera („Videonaut“) und durch Einsatz von Tauchern. Die Aufnahmen ließen Typen von Selbstdichtungszuständen erkennen.

In jenen Bereichen, wo die Fließgeschwindigkeit nie unter 0,7 – 1,0 m/s tritt als vorherrschender Kolmationstypus die sogenannte „innere Kolmation“ auf (siehe Abb. 3/a). Darunter versteht man die Einlagerung abfiltrierter Partikel in das Korngerüst der Sohle. Die Feinstoffeinlagerungen sind damit an der Sedimentoberfläche nicht sichtbar und unterscheiden sich dadurch von der „äußeren Kolmation“, bei der es zu einer vollständigen Bedeckung der ursprünglichen Gewässerbettoberfläche mit sandigen und feinkörnigeren Sedimenten kommt. Dieser Typus tritt nur bei mittleren Fließgeschwindigkeiten unter 0,3 m/s auf (BANSCHER, 1975; INGERLE, 1991) und konnte daher im Stauraum Freudenau während der Teilstauphase nur kleinräumig festgestellt werden (siehe Abb. 3/b).

Bislang wurden in den früheren Untersuchungen zur Kolmation lediglich diese beiden morphologisch eindeutig zu unterscheidenden Kolmationstypen beschrieben. Im Übergangsbereich zwischen innerer und äußerer Kolmation kommt es aber zu einem weiteren Kolmationstypus, bei dem die Zwischenräume der Deckschichtkörner teilweise bzw. vollständig mit Feinsediment verfüllt sind („Deckschichtkolmation“, siehe Abb. 3/c). Die Ursache dafür liegt in der zeitweisen Unterschreitung der Grenzschleppspannung im Strömungsschatten der Deckschichtgerölle, wodurch feinkörnige Partikel und Schwebstoffe bei vorhandenem Infiltrationsdruck in deren Zwischenräume eingelagert werden und es zu einer weiteren über das Ausmaß der innerer Kolmation hinausgehenden Abdichtung sowie zu einer Verfestigung der Sohle und damit zu einer Erhöhung des Erosionswiderstandes kommt.



a b c

Abb. 3: Kolmationstypen: a) innere-, b) äußere-, c) Deckschicht-kolmation

4 Zeitliche Kolmationsentwicklung – „Kolmationszyklen“

4.1 Meßstelleneinrichtung

Die Abbildung 4 zeigt die installierten Meßeinrichtungen beim Meßprofil „Schulschiff“. Mit den beiden Multi-level-Sonden SS1 und SS2, die sich unterhalb des Schulschiffes in einem Abstand von 18,6 m voneinander befinden, können die Druckhöhen in den Tiefen 0.5, 1.0 und 1.5 m unterhalb der Donausohle gemessen werden. Zusätzlich sind am linken Donauufer sechs Peilrohrsonden eingebaut worden, um etwaige Unterschiede in den Kolmationsentwicklungen in Böschung und Sohle feststellen zu können.

4.2 Zeitliche Entwicklung der Kolmation

Die drei unbekannten Parameter C_1, C_2 und λ können im Falle des Profiles „Schulschiff“ aus den gemessenen Druckdifferenzen (s[x=220m]=SS2 sowie s[x=238.6m]=SS1) und der Randbedingung, daß am rechten Donauufer die Durchflußmenge im Aquifer unterhalb der Donausohle gleich Null ist (Dichtwandkastensystem)

$$Q(x=0) = h_{GW}.k_f.\frac{ds(x=0)}{dx} = 0,$$

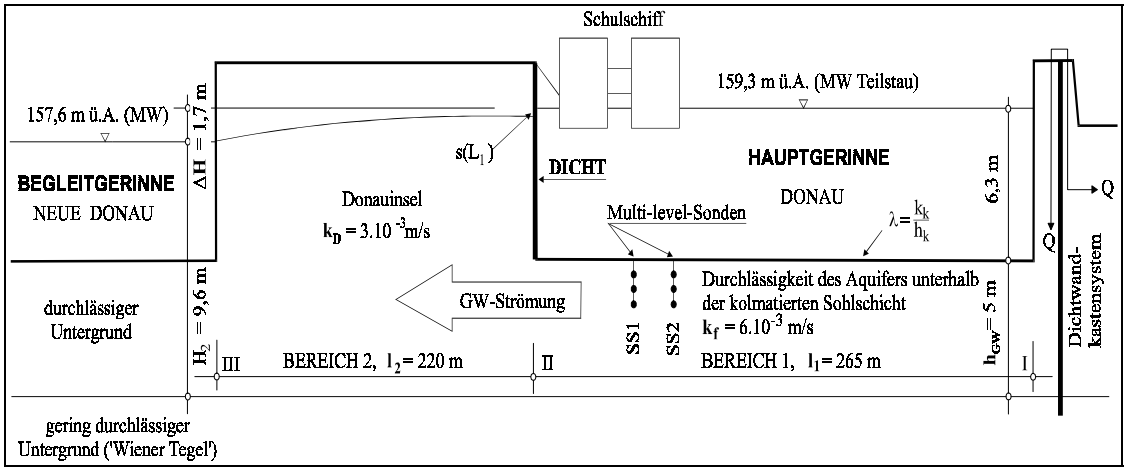


Abb. 4: Meßeinrichtungen beim Meßprofil „Schulschiff“ (Strom-km 1931.4)

$$Q(x=0) = h_{GW}.k_f.\frac{ds(x=0)}{dx} = 0,$$

bestimmt werden. Die Gleichung für den Leakage-Faktor λ ergibt sich damit unter Verwendung von (2) zu:

$$\frac{s(SS2)}{s(SS1)} = \frac{\cosh(238{,}6.\sqrt{1/(h_{GW}.k_f)})}{\cosh(220.\sqrt{1/(h_{GW}.k_f)})}$$

Auf Basis dieser Gleichung läßt sich λ bei Kenntnis der Aquifermächtigkeit h_{GW} und der Durchlässigkeit k_f unterhalb der Donausohle berechnen. Die Aquifermächtigkeit wurde anhand von Bohrergebnissen mit h_{GW} = 5 m abgeschätzt. Für die Durchlässigkeit wurde ein Kennwert von $k_f = 6.10^{-3}$ m/s mit Hilfe einer Wasserbilanz für den Donauinselbereich ermittelt. Die Abbildung 5 zeigt den Verlauf der Sohlenkolmation beim Meßprofil „Schulschiff“ anhand der Ganglinie des Leakage-Faktors der Sohle im Zeitraum März 1996 (Teilstaubeginn) bis Ende September 1999. Zum Vergleich dazu ist die Ganglinie der mittleren Fließgeschwindigkeit der Donau im betrachteten Profil angeführt.

Der steile Abfall des Leakage-Faktors zu Beginn läßt erkennen, daß der Kolmationsprozeß sofort nach Teilstauerrichtung beginnt. Er erreicht nach zirka zwei bis drei Monaten einen quasi - stabilen Zustand, der bis in den Herbst hin bestehen bleibt. Im Gefolge kleinerer Hochwässer (Fließgeschwindigkeiten > 2 m/s) während dieser Zeitspanne kann mehrmals eine teilweise Dekolmation beobachtet werden (Ende Mai, Mitte Juli und Mitte September), die jedoch immer wieder innerhalb weniger Wochen zurückging, wie sich am Erreichen der Ausgangs-Leakage-Faktoren feststellen läßt.

In weitere Folge nahm der Leakage-Faktor über mehrere Kolmationszyklen ständig ab und erreichte Ende 1998 einen bislang andauernden quasi stabilen Tiefwert.

5 Auswirkungen der Kolmation auf den lokalen und regionalen Wasserhaushalt

Häufig werden Interaktionen zwischen Oberflächengewässer und Grundwasser auf regionalem Maßstab betrachtet. Im Hinblick auf die zunehmende Bedeutung von Uferfiltrat für Trinkwasserzwecke bekommt aber auch eine lokale Betrachtung zunehmende Bedeutung.

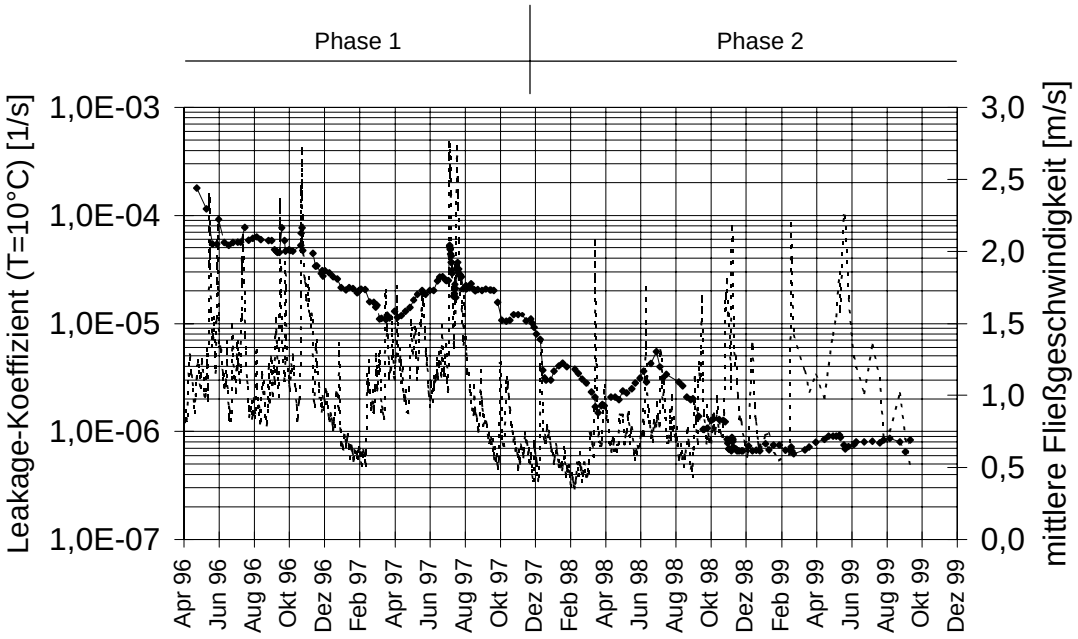


Abb. 5: Ganglinie des Leakage-Faktors der kolmatierten Sohlschicht beim Meßprofil „Schulschiff“

Um auch die im Labormaßstab vorgenommenen Untersuchungen integrieren zu können ist die Übertragung von Erkenntnissen zwischen Maßstabsebenen von interesse. So kann ein Vergleich zwischen Maßstaben mehrer Größenordnungen darüber Aufschluß geben, ob eine Übertragung von Egebnissen zwischen diesen Maßstabsebenen (z.B. lokale-regionale Betrachtung) zulässig ist. Zu diesem Zweck wurden die errechneten Sickermengen in einem Meßprofil (lokaler Maßstab) mit den Sickermengen aus einer regionalen Wasserbilanz für einen 11,93 km langer Stauraumbereich im Jahresabstand Juni 1996 bzw. 1997 (regionaler Maßstab) verglichen.

5.1 Grundwasserhaushalt im lokalen Maßstab - Meßprofil „Schulschiff“ (Strom-km 1931.4)

Die Grundwasserströmung beim Meßprofil „Schulschiff“ wird im wesentlichen von folgenden geohydraulischen Rahmenbedingungen bestimmt (siehe Abb. 4):

- Nach Teilstauerrichtung (Anfang März 1996) liegt der Wasserspiegel im Stauraum außer während der Hochwässer bei etwa 159.3 m ü.A..
- Die Mächtigkeit des Aquifers unterhalb der Donausohle h_{GW} ist im Vergleich zu seiner Längsausdehnung l_1 = 265 m gering und beträgt ca. 5 m (aus Probebohrungen abgeschätzt). Die Durchlässigkeit des Aquifers wurde aus der Wasserbilanz der Neuen Donau mit $k_f = 6.10^{-3}$ m/s (T=10° C) ermittelt.
- Am linken Donauufer werden die hydraulischen Rahmenbedingungen durch die Neue Donau wesentlich beeinflußt. Sie wirkt aus hydraulischer Sicht wie ein Begleitgerinne. Dabei erzeugt die vorhandene Wasserspiegeldifferenz ΔH während der Teilstauphase von etwa 1.7 m zwischen Donau und Neuer Donau eine Sickerströmung durch die Donauinsel in Richtung Neuer Donau.

- Die Donauinsel besitzt im Bereich des Profiles „Schulschiff“ eine Breite l_2 von 220 m und besteht aus geschütteten sandigen Kiesen mit einer mittleren Durchlässigkeit von rund $k_D = 3.10^{-3}$ m/s (aus der Wasserbilanz der Neuen Donau für T=10° C abgeschätzt).
- Am rechten Donauufer wurde ein Dichtwandkastensystem errichtet, mit dessen Hilfe eine direkte Kommunikation des Grundwasserkörpers im 2. und 20. Bezirk mit dem Stauraum unterbunden wird. Um trotzdem einen weitgehend den Verhältnissen vor Stauerrichtung entsprechenden Grundwasserhaushalt aufrechtzuerhalten, erfolgt eine Grundwasserbewirtschaftung mittels eines aus 21 Brunnenpaaren bestehenden Bewirtschaftungssystems. Ein merkbarer Einfluß der Förderbrunnen auf die Grundwasserströmung beim Meßprofil „Schulschiff“ kann ausgeschlossen werden, da sowohl flußauf als auch flußab die Brunnen mehr als 300 m entfernt liegen. So kann das rechte Ufer vor allem während pumpfreier Phasen aus hydraulischer Sicht als dichter Rand betrachtet werden.

Aus Abbildung 4 sind auch die installierten Meßeinrichtungen unterhalb der Donausohle beim Meßprofil „Schulschiff“ zu entnehmen.

Mit Hilfe dieser Daten kann nun auch eine Abschätzung über die Größe des Uferfiltratrückganges beim Meßprofil „Schulschiff“ erfolgen. Da die Zwischenräume der grobblockigen Ufersicherungen bereits nach dem Hochwasser Ende Mai 1996 mit mindestens 5 cm mächtigen sandig-schluffigen Sedimenten verfüllt waren, läßt sich bei einer mittleren Durchlässigkeit dieser Sedimente von 1.10^{-7} m/s (aus Labor- und in-situ-Untersuchungen von feinkörnigen Blockwurfverfüllungen ermittelt; IHGW, 1996) der Leakage-Faktor des sandig-schluffigen Materials mit 2.10^{-6} s^{-1} und daher der Leakage-Faktor der Böschung mit 1.10^{-6} s^{-1} abschätzen (etwa 50% der Böschung besteht aus dem undurchlässigen Blockwerk). Dies bedeutet, daß die Sohle Anfang Juni 1996 ($\lambda = 5{,}6.10^{-5}$ s^{-1}) um etwa das 60-fache durchlässiger war als die Böschung und daher nahezu der gesamte unterirdische Durchfluß durch die Donauinsel vom böschungsnahen Sohlbereich gespeist wird. So kann aufgrund dieser Überlegung eine Reduktion des unterirdischen Durchflusses praktisch allein auf die Verringerung der Durchlässigkeit der Sohle zurückgeführt werden. Bei einer Aquiferdurchlässigkeit unterhalb der Donausohle von $k_f = 6{,}9.10^{-3}$ m/s (T = 15 °C) und einer Mächtigkeit von $h_{GW} = 5$ m lassen sich diese Sickermengen für die beiden Zeitpunkte aus den Gradienten der Druckdifferenzen bei x = 265 m berechnen

$$Q = k_f . h_{GW} . \frac{ds_{(x=265m)}}{dx} . 1$$

Sie betragen am 10. Juni 1996 $\underline{2{,}62.10^{-4}\ m^3/(s.m)}$ und am 9. Juni 1997 $\underline{2{,}14.10^{-4}\ m^3/(s.m)}$. Diese **Durchflußreduktion um 18 %** zeigt sehr deutlich, daß aufgrund der Vergleichmäßigung der Infiltrationsraten bei einer um den Faktor 2,8 verringerten Sohldurchlässigkeit (Unterschied in den Leakage-Faktoren vom 10. Juni 1996 und dem 9. Juni 1997) nur eine verhältnismäßig geringe Reduktion in der entlang der Sohle anwachsenden Sickermenge entsteht.

5.2 Grundwasserhaushalt im regionalen Maßstab - Wasserhaushalt der Neuen Donau

Grundlage für die Erstellung von detaillierten Wasserbilanzen für die beiden Stauhaltungen der Neuen Donau bilden die kontinuierlich erfaßten Wasserstände an den Wehranlagen. Die Ableitung der Überschußwassermengen erfolgt nämlich ausschließlich während der täglichen Betriebszeit zwischen 7^{00} und 17^{00}, sodaß während der Nachtstunden die ungestörte Anhebung des Wasserspiegels beobachtet werden kann, welche durch die Zuströmung von Uferfiltrat aus dem Stauraum bewirkt wird.

Bei der Ermittlung des Grundwasserzuflusses durch die Donauinsel wurde dabei folgende Vorgangsweise gewählt:

Der Bilanzüberschuß (ohne Ableitung aus der betrachteten Stauhaltung) wurde anhand des Wasserspiegelanstieges während der Schließzeit der Wehre abgeschätzt. Die dafür erforderlichen Daten wurden den Wehrbetriebsprotokollen entnommen. Die Ermittlung erfolgte nach der Beziehung

$$\Delta V_S = \left(W_{BA,n} - W_{BE,n-1}\right) \cdot A_{SH}$$

mit

ΔV_S Volumsänderung der betrachteten Stauhaltung

$W_{BE,n-1}$ Wasserstand beim Schließen des Wehres am Vortag

$W_{BA,n}$ Wasserstand zu Betriebsbeginn (Öffnen des Wehres)

A_{SH} Fläche der jeweiligen Stauhaltung

In Abbildung 9 sind die Wasserhaushaltskomponenten für die beiden Zeiträume 3. - 9. Juni 1996 beziehungsweise 2. - 8. Juni 1997 gegenübergestellt.

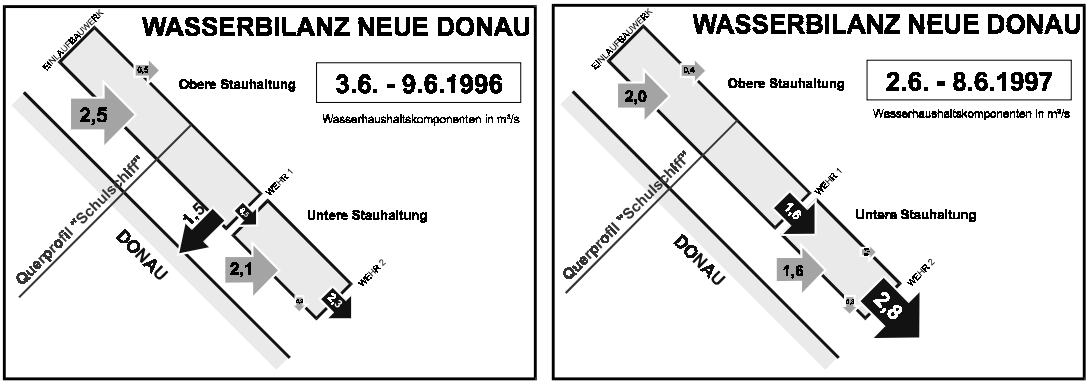


Abb. 9: Wasserhaushalt der Neuen Donau von Anfang Juni 1996 beziehungsweise von Anfang Juni 1997 (Wasserhaushaltskomponenten im m^3/s)

Die Zeiträume wurden so gewählt, daß bei einem Vergleich der Wasserhaushaltskomponenten temperaturbedingte Viskositätsunterschiede in der Aquiferdurchlässigkeit vernachlässigt werden können (die Temperatur des Grundwassers beträgt bei beiden Zeiträumen etwa 15 °C) und zusätzlich ein Vergleich mit dem Meßprofil „Schulschiff“ (lokale Maßstabsebene) möglich ist. So lag der Grundwasserzufluß zur oberen Stauhaltung Anfang Juni 1996 bei 2,5 m^3/s und zur unteren Stauhaltung bei 2,1 m^3/s. Ein Jahr später verringerte sich dieser Zufluß aufgrund der Kolmationsentwicklung an den Böschungs- und Sohlbereichen auf 2,0 m^3/s (-20 % für die obere Stauhaltung) und 1,6 m^3/s (-24 % für die untere Stauhaltung). Vergleicht man den **Uferfiltratrückgang für die obere Stauhaltung mit -20 %** mit den beim Meßprofil „Schulschiff“ lokal ermittelten -18 % (siehe Kapitel 5.1), so zeigt die gute Übereinstimmung, daß die beim Meßprofil beobachteten Phänomene

- Verfüllung der Zwischenräume der grobblockigen Ufersicherungen mit sandig-schluffigen Sedimenten, und daraus resultierend einer um 1 bis 2 Größenordnungen geringeren Durchlässigkeit zwischen kolmatierter Sohle und Böschung
- Verringerung der Sohldurchlässigkeit im betrachteten Zeitraum etwa um den Faktor 3
- Vergleichmäßigung der Infiltrationsraten über die gesamte Flußbreite bei zunehmender Selbstdichtung

nicht nur lokalen Charakter besitzen, sondern über weite Bereiche des Stauraumes Gültigkeit haben dürften.

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Effect of Human Activity on River Bed Deformations – A Mathematical Model

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Abstract: With a purpose to investigate development of the river bed deformations, one dimensional model and program are created, that make possible the prediction of the human activities impact. For the model testing the field data of Struma river experimental reach are used. The model is applied for investigation of river bed depth deformations in case of building of longitudinal and transverse stabilization dikes, as well as gravel pit for inert material. The model enables the prediction of the deformation processes depending on the size and the situation of the structures.

Key words: rivers, river bed deformations, sediment transport, river hydraulics

Anthropogener Einfluss auf die Flussbettdeformation - ein mathematisches Model

Zusammenfassung: Es ist geschaffen ein eindimensionales Modell und Programm für Untersuchung der Deformationsvorgänge in einem Fluβbettes. Das Modell und das Programm geben die Möglichkeit für eine Prognosierung des Enflusses der mennschlichen Tätigkeit. Für das Modelltesten sind Angaben von einer Versuchsstrecke an dem Fluβ Struma genutzt.Das Modell ist für eine Untersuchung der Tiefedenderungen der Fluβbetten infolge bestimmter antidefotmationsmaβnahmen und auch für Einschätzung des Kiesgrubeeinfluβes im Fluβbett angewandt.Das Modell gibt die Möglichkeit für eine Prognosierung der Deformationsvorgänge in Abhängigkeit von der Lage und Dimensionen der verschiedenen Korrektionsbauwerke im Fluβ.

Schlüsselworte: Fluβe, Fluβbettdeformationen, Geschiebetrieb, Fluβhydraulik

1 Introduction

The rivers have been , are and will be a permanent object of human activities for example: using of water for drinking , irrigation , draining and building of hydroelectric power systems. The construction of different hydrotechnical structures influences not only the river regime but also the whole hydraulic and morphological conditions. It is impossible reservoirs, river corrections, bridges and other structures to be designed without an assessment of their influence on the future state and the development of the whole river system. In Republic of Bulgaria the major part of the river are trained and built-up but a small part of them are non-deformable. Activation of depth deformations and banks erosion is observed resulting not only from river bed trainings, but also from formation of gravel pits and other structures in the river bed. The aim of the present investigation is to be established and predicted by means of a mathematical model the influence of the river bed bank stabilization structures and gravel pit on the river bed depth deformation processes.

2 Description of the Mathematical Model

The application of numerical models for investigating and prediction of river bed deformations is already a convention in the fields of river hydraulics. These models include a system of flow equations and sediment continuity equation. The model, we have created , solves one-dimensional quazy-steady non-uniform flow. The basic set of equations are: energy equation; flow and sediment continuity equations and additional formulas for friction losses and

sediment transport. For an estimation of the friction losses the Manning equation is used. The roughness coefficient in this formulae is determined by preliminary established empirical relations valid for different mesoforms - pools, rifles and straight reaches. The sediment transport is calculated by Engelund-Hansen formulae [1]. The composed mathematical model enables the investigation of river bed depth deformations during high flood passing in case of construction of bank stabilization structures and gravel pits.

3 Application of the Mathematical Model

3.1 General conditions

The created mathematical model is tested for prediction of Struma river bed deformations. A big part of Struma river has been trained before 1976. Active deformations of the bed including erosion of the banks and destruction of the river dikes have occured as a result of rectification of the river bed and seizure of bed load sediments for inert material. This is the reason why in 1989 a scientific team from the Institute of Water Problems started regular field investigations of the river bed deformation processes on an experimental reach with full lenght 3600 m, situated in the middle part of the river. The movement of the bed mesoforms has been observed for 6 years in 18 fixed basic and some additional cross-sections. Struma river correction in the experimental reach is designed with compound cross-section for the river bed-formed discharge Q_r=350 m^3/s and maximum discharge Q_{max}=800 m^3/s. The test of the model is carried out with data from hydrometric measurements in 1990, when a tacheometrical survey is also made. The computation reach was chosen between cross-sections 12-29 and 18-35 with full lenght 1006 m. They are shown on Fig. 1. The bed deformations are calculated using a flood hydrograph with a duration of 8 days and a flood peak of Q=234 m^3/s. The description of the flood hydrograph is made in 24 steps (j=24) with different time duration. The bed-formed sediments, which enter the reach are assumed to be 5% from the measured suspended sediments. The calculation of the bed deformations is for discharges bigger than 20 m^3/s for which during field surveys is established that the movement of bed-formed sediments begins. As a result of granulometric study of bed-load material a mean diameter of the bed-load sediments of d_m=0.022 m for the experimental reach was measured. The initial longitudinal profile of the studied reach, obtained from the lowest bed levels for every cross-sections is shown on Fig. 2. The computed longitudinal profile after the passing of the high flood without bank stabilization structures and gravel pits is shown on the same figure. The analysis of the results shows that the erosion of the river bed in the upstream part of the reach between cross-sections 13-30 and 18-35 can reach to 0.33 m. In the downstream reach below cross-section 13-30 some depositions are observed and in cross-section 12-29 they reach to 0.05 m.

3.2 Investigation of River Bed Deformations after Building Transverse Dikes

Two cases are simulated to study the impact of the construction of transverse dikes. In the first case it is assumed that a transverse dike is designed on right bank of cross-section 15-32 which is strongly eroded and creates a risk for river dike break. The level of the dike is equal to the terrace level and the transverse dike decreases the cross-section area with 18 m^2. The computing results for the river deformations along the experimental reach resulting from a transverse dike construction after a high flood passing are shown on Table 1. It is obvious , that the biggest depth deformations are in the same cross-sections in which the structure is situated. The results show that the depth deformation in cross-section 15-32 reaches to 0.10 m, in comparison with the deformations without transverse dike, which reach to 0.08 m. The designed transverse dike doesn’t affect the deformations in the other cross-sections.

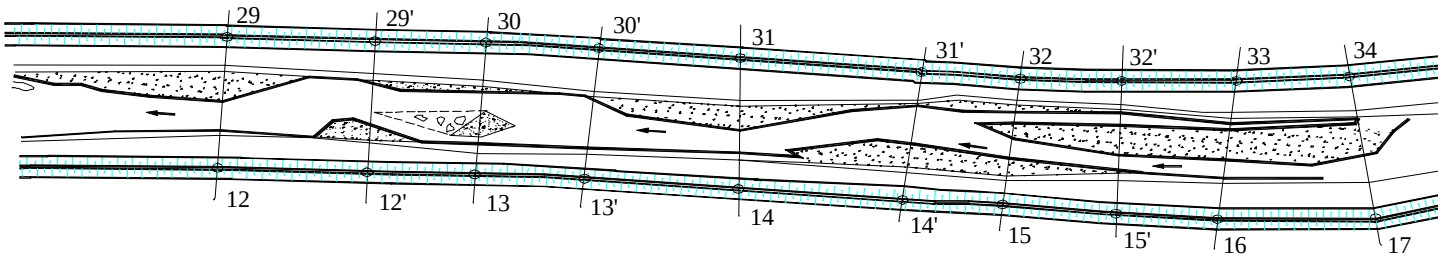

Fig. 1 Scheme of experimental reach of Struma river

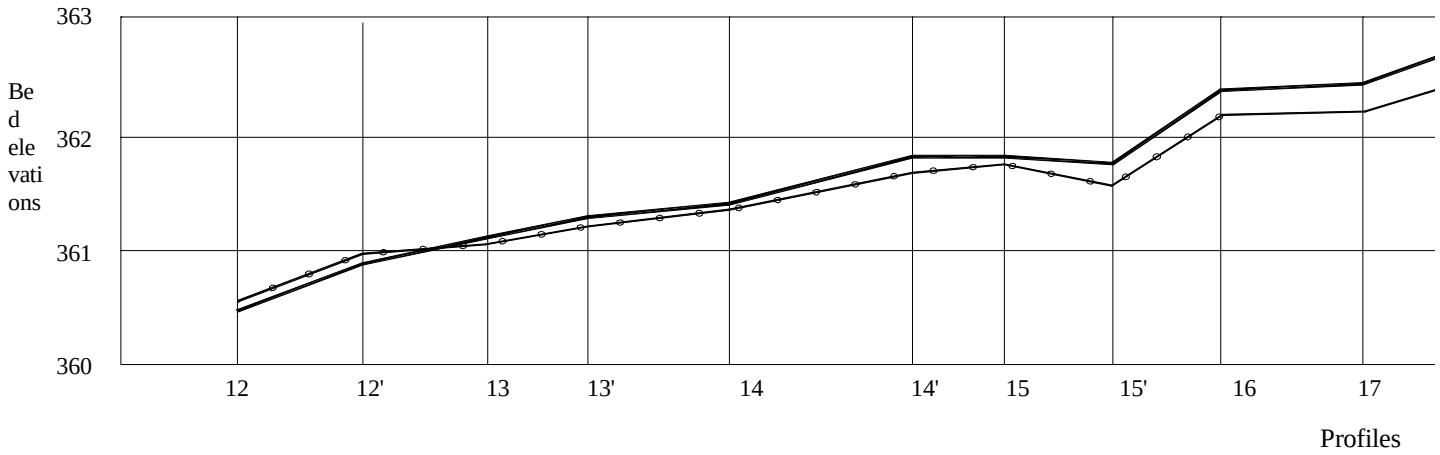

Fig. 2 Longitudinal profiles of experimental reach of Struma river before and after flood passing (—— before; ~~○ after~~)

The river bed deformation results, obtained from the transverse dike simulation in cross-section 15'-32', are shown in the same table. This structure decreases the cross-section area with 24 m^2. As a result the erosion of the cross-section 15'-32' is with 0.07 m bigger than the bed depth deformation before the simulation of the structure. It is peculiar in this case, that the deformations are spread out upstream and downstream from this cross-section. In the cross-sections 13-30 and 17-34 some sediment depositions are observed and they reach to 0.05 m. The computed values of the river bed deformations before and after the simulation of transverse dikes are not significant because the decrease of the cross-section area as a result of construction of bank stabilization structures reaches only to 13%.

Table 1 Bed elevations of experimental reach of Struma river before and after building of transverse dikes

Number of profiles	Distances from 12-29 m	Initial bed elevations	Bed elevations after flood passing		
			Without structures	With transferse dike	
				at 15-32 profile	at 15'-32'profile
12-29	0	360.48	360.531	360.511	360.537
12'-29'	120	360.89	360.966	360.965	360.974
13-30	199.73	361.08	361.062	361.055	361.076
13'-30'	294.73	361.30	361.198	361.198	361.223
14-31	396.76	361.40	361.358	361.348	361.363
14'-31'	498.26	361.82	361.735	361.731	361.730
15-32	604.63	361.83	361.757	361.734	361.782
15'-32'	685.63	361.75	361.626	361.622	361.551
16-33	772.13	362.43	362.219	362.23	362.165
17-34	894.60	362.50	362.244	362.231	362.293
18-35	1006.60	362.97	362.642	362.649	362.576

3.3 Study of the River Bed Depth Deformations in a Presence of Longitudinal Stabilization Structure

Simulation of the longitudinal stabilization dike influence on the processes of river bed deformations is carried out with situation of the structure along the bank between cross-sections 15-32 and 15'-32'. The initial conditions for the calculation are the same as in previous case of bank stabilization with transverse dikes. The results are presented graphically on Fig. 3. The river bed deformations in the downstream reach below cross-section 15-32 are not affected by the stabilization of the river reach. Insignificant differences in the bed levels are observed upstream of cross-section 15-32 . An increase of the scour between cross-sections 15-32 and 16-33 with 0.06 m is calculated. In this case of simulation the reach upstream of cross-section 13-30 is eroded and the reach downstream of cross-section 13-30 profile is accumulated. The performed study shows, that the river bank fortifications along given reach don't significantly influence on the size of the river bed depth deformations.

3.4 Modeling of the River Bed Depth Deformations in the Presence of a Gravel Pit

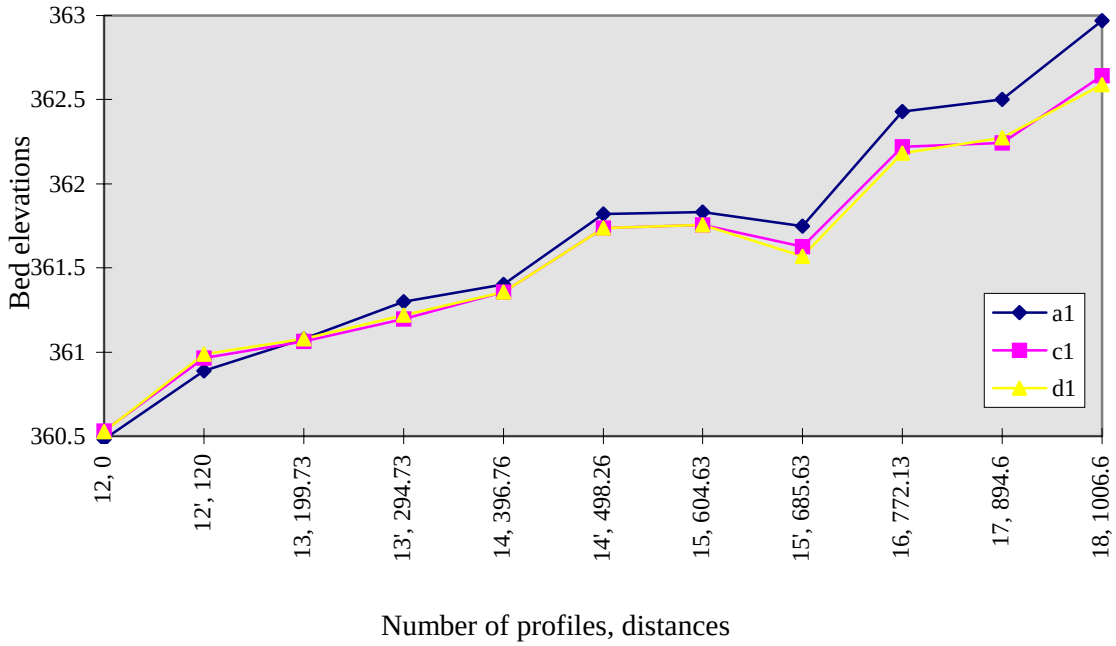

Fig. 3 Longitudinal profile of experimental reach of Struma river before and after building of longitudinal bank structure between 15-32 and 15'-32' profiles
(a1 - initial; c1, d1 - after flood passing without respectively with longitudinal dikes)

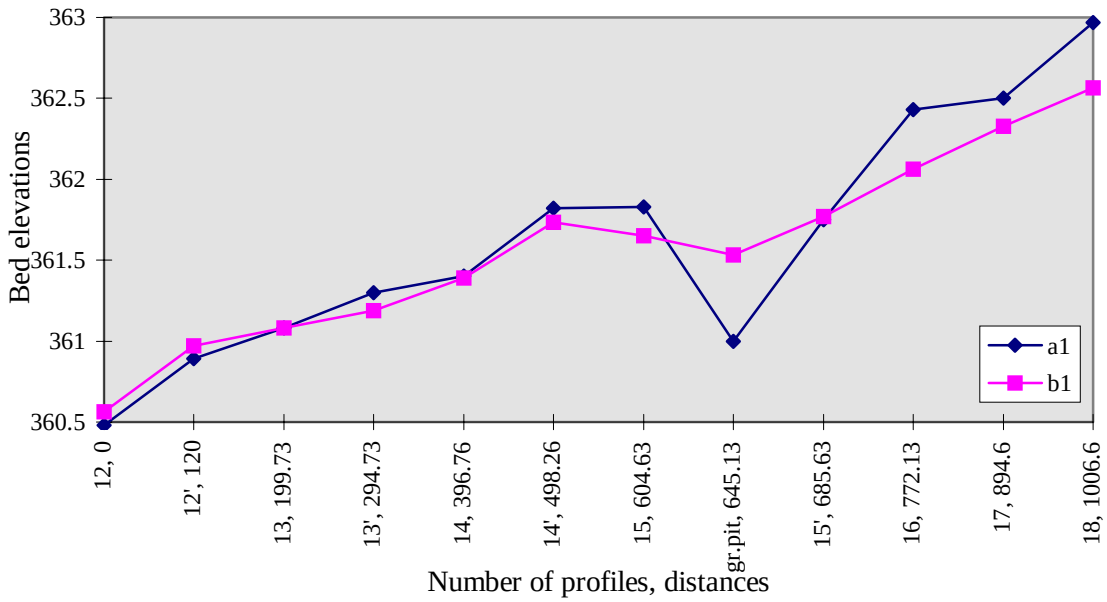

Fig. 4 Longitudinal profile of experimental reach of Struma river before and after building of gravel pit between 15-32 and 15'-32' profiles (a1 - before; b1 - after)

Numerical modeling of the bed deformations in the experimental reach of Struma river after excavation of sediments for inert material is carried out for simplified form of a gravel pit. It is assumed, that the excavation of the sediments has taken place between cross-sections 15-32 and 15'-32' and in the middle of the sub-reach with maximum depth at level 361.00. The longitudinal profile of the reach with the situation of the gravel pit is shown on Fig. 4. It is assumed that the volume of excavation is about 2000 m^3 when the low water period is and the field surveys are made. The local hydraulic resistance is taken into account in the flow equation. The bed deformations and the sediment depositions in the gravel pit are studied in the case of a high flood . The new formed profile is shown also on Fig. 4. The comparison of the initial and final longitudinal profiles shows, that a significant depth erosions occur in all cross-sections upstream of the pit. They reach up to 0.37 m in cross-section 16-33 and to 0.41 m in the cross-section 18-35. The reach downstream of the pit is also of interest as there a process of scour is observed too, which in the cross-section 15-32 reaches 0.18 m. Snishchenko and Meserlians (1988) have established a similar type of deformations in their laboratory experimental study of pit filling . It can be considered that the model adequately represents the river bed deformations processes in a presence of pits. The river bed levels of the experimental reach in different time steps are given in Table 2, where the development of the sediment accumulation process during a high flood can be seen. During the time of the rising limb of the flood (j=14) the maximum accumulated sediment quantity reaches a peak of level 361.80. A part of the accumulated sediments are washed away during the time of the falling limb of the flood (from j=14 to j=24) and bed level becomes 361.53. For the reach upstream of the pit the maximum bed depth deformations are observed during the time of the falling limb of the flood (j=24) while for the reach downstream of the pit they occur at the peak of the flood (j=14).

Table 2 Variations of the bed elevations during the flood passing in case of gravel pit between 15-32 and 15'-32' profiles

Number of profiles	Distance from 12-29 m	Initial bed elevations	Bed elevations in dependence of discharges Q, m3/s					
			j = 5 Q=20	j = 10 Q=130	j = 14 Q=195	j = 15 Q=190	j = 20 Q=100	j = 24 Q= 20
12-29	0	360.48	360.49	360.51	360.55	360.55	360.57	360.56
12'-29'	120	360.89	360.89	360.94	361.01	361.02	361.00	360.97
13-30	199.73	361.08	361.07	361.10	361.14	361.15	361.12	361.08
13'-30'	294.73	361.30	361.30	361.26	361.20	361.19	361.19	361.19
14-31	396.76	361.40	361.40	361.36	361.32	361.32	361.37	361.39
14'-31'	498.26	361.82	361.82	361.75	361.74	361.75	361.73	361.74
15-32	604.63	361.83	361.82	361.83	362.04	362.03	361.91	361.65
gravel pit	645.13	361.00	361.02	361.49	361.80	361.75	361.62	361.53
15'-32'	685.63	361.75	361.82	362.03	361.86	361.82	361.76	361.77
16-33	772.13	362.43	362.40	362.25	362.11	362.10	362.09	362.06
17-34	894.60	362.50	362.49	362.45	362.41	362.40	362.37	362.33
18-35	1006.60	362.97	363.00	362.91	362.75	362.72	362.62	362.56

4 Conclusion

Compound mathematical model and program for detailed study of the river bed depth deformations can be applied successfully for prediction of river bed changes in cases of construction of cross- and longitudinal stabilization dikes and excavation of the inert material from gravel pits.

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Aspects of Colmatage of a Storage Lake Located in a Hilly Zone of the Somes-Tisa Hydrographical Basin

Radu Farcas, Pavel Fetea, Mihai Cocut, Melinda Barna

Abstract: The paper presents the evolution of the colmatage of a storage lake the catchment basin of which is mostly occupied by hills and small depressions that belong to the area with the highest erosion index in the north-west of Romania. Beginning with the physical-geographical description of the catchment basin of the Varsolt storage lake (situated in the Somes-Tisa hydrographical basin), as well as with the presentation of the morphometrical elements and the characteristic values of the lake, the paper analyses in detail, the evolution of the colmatage of the lake for an operation period of 18 years (1979-1997), this process being pursued by successive topographic-bathymetrical surveys. The consequences of the colmatage are shown and it is estimated the tendency of the evolution of the phenomenon, recommending some measures to be taken for attenuating the phenomenon, with a view of extending the operation period of the storage.

Key words: colmatage, storage lake, catchment basin, characteristic levels of storage, capacity curve, surface curve, alluvia, colmatage rhythm, coefficient of accumulation of solid stock, colmatage rate, dead volume, useful volume, flood water storage volume, total volume, erosion indices.

Überlick über die Ablagerungen in einem Stausee welcher sich in einem Hügelgebiet des Somes-Tisa hydrographischen Beckens befindet

Zusammenfassung: In der vorliegenden Arbeit wird die Enwicklung der Ablagerung eines Stausees dargestellt, dessen Empfangsbecken größten Teils von Hügeln und Senkungen besety ist, welche sich auf der Oberflache mit dem hochsten Erosionszeiger sich befinden. Anhan der physisch-geographischen Beschreibung des Empfangbeckens des Varsolt Stausees (der im hydrographichen Becken Somes-Tisa sich befindet) sowohl als aus der Darstellung der morphometrichen Elemente und der charakteristischen Werte, analysiert man ausführlich die Entwicklung der Ablagerungen auf einer Yeitspanne von 18 Jahren (1979-1997) infolge der Verfolgung dieses Vorgänges, durch nacheinanderfolgende topometriche Anhöhungen. Die Konsequenzen der Ablagerungen werden gezeigt und es eird die Entwicklungstendez des Vorganges geschatzt sowohl als auch einige Empfehlungen betreffend den nötigen Maßnahmen die genommen werden mussen, anbetracht der Milderung des Ablagerungsvorganges, mit dem Zweck, die Lebensdauer des Stausees verlangern.

Schlüsselwörter: Ablagerung, Stausse, Empfangsbecken, charakteristiche Größen der Ablagerung, Kapazitätskurve, Oberflachenkurve, Alluvion, Ablagerungsrzthmus, Anhaufungskoeffizient der festen Schicht, Ablagerungsrate, totes Volumen, nutyliches Volumen, Milderungsvolumen der Anschwemmungen, totales Volumen, Erosionszeiger.

1 Colmatage of Varsolt storage lake

The colmatage of storage lakes, by its negative consequences regarding the operation period of these lakes constitutes a basic criterion in the location, the design, and the execution of storages, as well as in the elaboration of a hydrographical basin scheme.

This paper presents the results of the study of the colmatage phenomenon by topobathymetrical surveys of the Varsolt storage lake situated in the Somes-Tisa hydrographical basin, a basin covering a surface of 22500 km^2 in the northern-western part of Romania. (Fig.1)

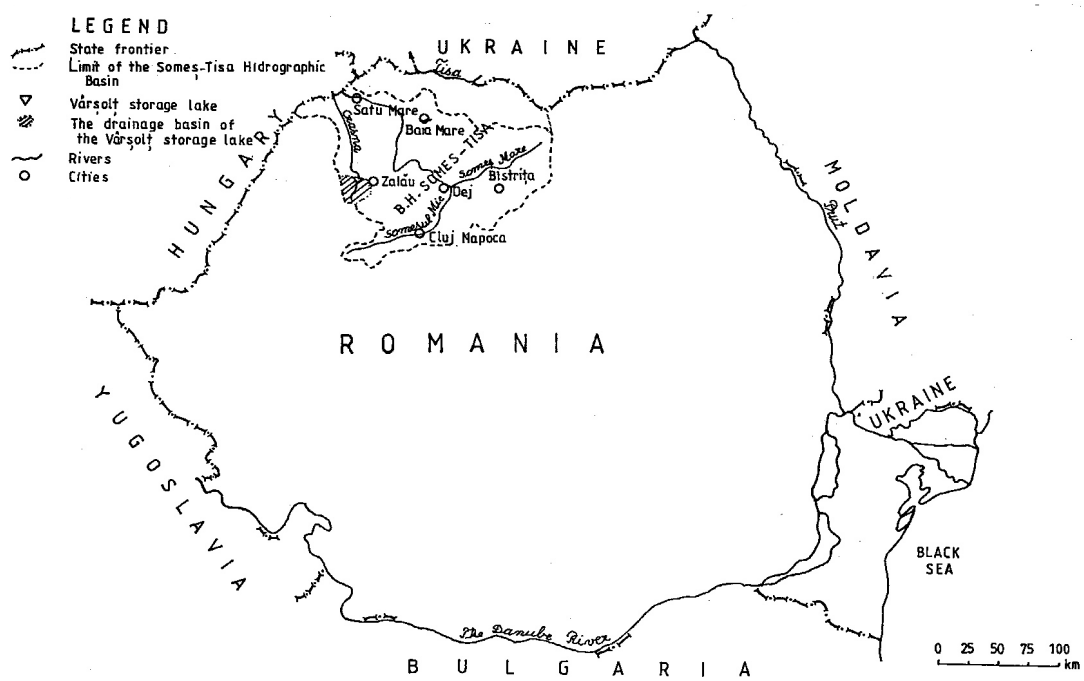

Fig.1 Location of Varsolt storage lake

The Varsolt storage lake was put into operation in 1979 and it is located in a hilly zone, on the river Crasna, being a permanent storage with complex functions among which the following play a prominent part:

-Drinking water supply for the towns of Zalau and Simleu Silvaniei (86000 inhabitants)
-Attenuation of floods occurred on the river Crasna
-Utilization of the piscicultural potential.

1.1 Characterization of hydrographical basin of storage

The hydrographical basin pertinent to the Varsolt storage lake totalises a surface of 327 km2 in the dammed section and it is drained by a stream system represented by the main rivers Crasna, Mortauta and Colitca. In the section of the dam, the hydrographical basin is approximately symmetrical as against the course of the river Crasna and it has an approx. circular form.

Table 1 shows some morphometrical and hydrological characteristics of the affluent water courses and of the catchment basin, as well.

Table 1 Affluent water courses in lake. Morphometrical and hydrological elements.

Crt no.	Affluent water courses	F (km^2)	H (m)	L (km)	I ($^o/_{oo}$)	Qma (m3/s)	Rma (kg/s)	Sw (ha)	AR (%)
1	CRASNA	214	422	23.5	14.5	1.15	4.18	2932	13.7
2	MORTAUTA	49	321	12	5	0.164	-	865	17.6
3	CATRICI	13	299	6	13	0.039	-	279	21.4
4	COLITCA	43	350	11	18	0.163	-	844	19.6
5	dammed section	327	382	-	-	1.52	-	4920	15

F - surface of basin
H - mean altitude
L-length of river
I-slope of river

Qma-mean multi-annual discharge
Rma-mean multi-annual discharge of suspended alluvia
Sw-surface of stock of wood
AR-afforestation rate

The climate of the region comprising this storage is of continental type having moderate touch with mean annual temperatures of 9.3^{o}C-9.6^{o}C and mean monthly temperature between –3.5^{o}C to 1.1^{o}C (in January) and 19.6^{o}C to 21.1^{o}C(in July).

The mean annual precipitations have values in the range of 500 to 600 mm/year for low depressions, between 600 and 800 mm/year for hilly zones getting to 800-900 mm/year for higher altitudes of the Meses Mountains.

The relief pertinent to the storage is characterised by the presence, to a large extent of the hills and the small depressions belonging to the morphological unit of the Simleu Depression, mountains zones belonging to the Meses Mountains and to a less extent, of the flood plains and the terraces of the rivers draining the basin.

The existent vegetation is represented by forests (15%), agricultural crops (49%) and secondary steppe – like meadows (36%).

The existent soils belong to the types of acid brown soils (high zone), forest brown soils in the zone of hills, and alluvial and hydromorphic soils in the zone of flood plains and depressions.

Geologically, the basin presents metamorphic rocks represented by micaschists and paragneisses in the mountainous zone, sedimentary rocks formed of conglomerates, sandstones, marls, sands and loams in the hilly zones and alluvial rocks represented by sands, red clays, powdery clays in the zone of flood plains and terraces. The existing sedimentary rocks favour the marked modelation of the hilly relief, the intense processes of surface and torrential erosion contributing to the transport of the alluvia and their depositing in the storage lake.

1.2 Morphometrical elements and characteristic values of lake

The Varsolt storage lake was formed by damming the main river Crasna by a dam of local heterogeneous materials having a length of 2160 m. The cuvette of the lake presents two distinct compartments corresponding to the rivers Crasna, Mortauta (compartment I) and the brooks Colitca and Catrici (compartment II). Some of the morphometrical elements are shown in Fig.2.

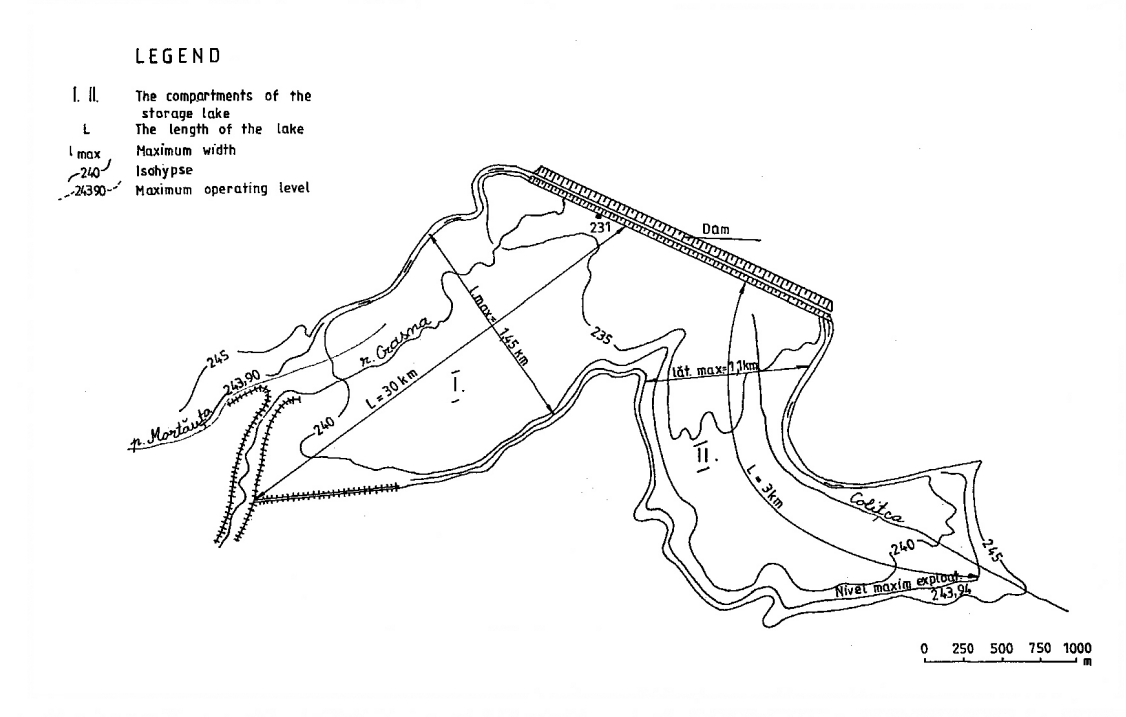

Fig. 2 Varsolt lake – morphometrical elements

The data of the Varsolt storage lake that define the latter's potential for fulfilling its functions, represented by the characteristic values and the corresponding volumes (capacity curves) and the surfaces (surface variation curves), determined for the initial stage (on projecting the work) and those resulted from the last topobathymetrical survey (1997) are graphically shown in Fig.3.

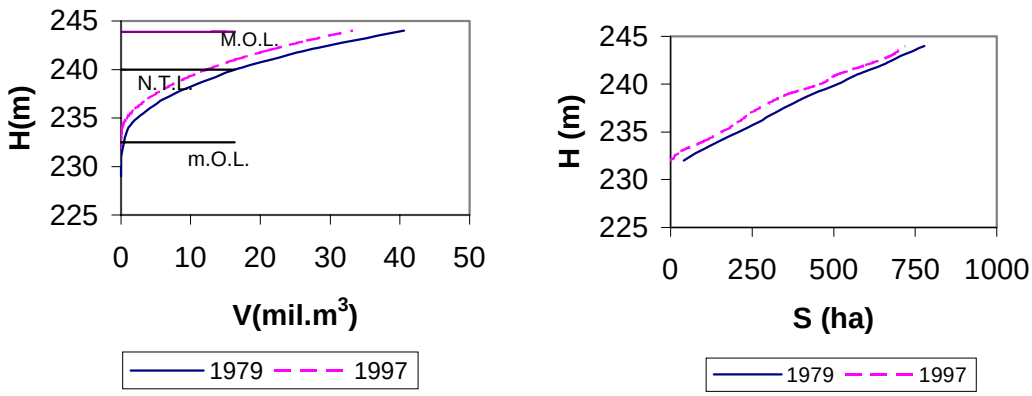

Fig. 3 Characteristic curves of lake: capacity curve V=f(H), surface curve S=f(H).
m.O.L. – minimum operation level 232.50 m
N.T.L. – normal top water level 240.00 m
M.O.L. – maximum operation level 243.94 m

1.3 Description and analysis of colmatage process of Varsolt storage lake between 1979 and 1997

The transport and deposition of the alluvia in the storage lake during the analysed period result from the interaction of more factors such as: relief, lithological constitution, river system, afforestation rate, precipitation regime, etc. briefly shown under sub-chapter 1.1. The conditions existing in the catchment basin of the storage were estimated by the designer and the user of the work as being particularly favourable for carrying out an intense colmatage, as it appears, so that this process has been carefully watched immediately after putting into operation by a series of successive hydrotopobathimetrical measurements performed in 1983, 1985, 1989, 1991, 1995 and 1997.

The colmatage of the lake for the analysed period is shown in the isohypses map of the cuvette of the lake when the storage was put into operation (1979) and after the last topobathimetrical survey made in 1997 (Fig.4).

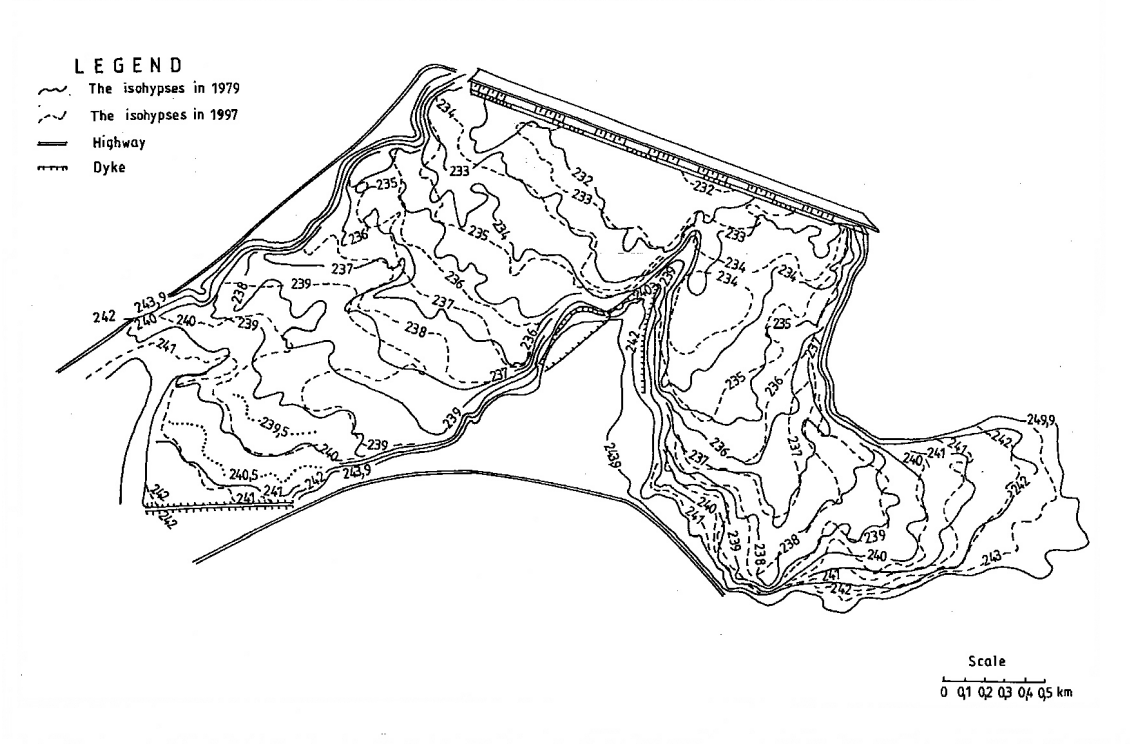

Fig. 4 Map of evolution of isohypses for the cuvette of Varsolt lake

The modification of the aspect of the initial isohypses is evident and it indicates:

-The marked colmatage of the lake with alluvial deposits of heavy thicknesses in the zone where the Crasna and Mortauta water courses get into the lake, within the area between the initial isohypses of 237.00 and 241.50 m.d.M.(the tail of the lake) where a bank of coarse alluvia built up.

-At the same time, the existence of a zone with heavy thicknesses of the deposits situated in the vicinity of the left shore of the lake nearly the dam within the space delimited by the isohypses of 232.00-236.00 m.d.M.

The thicknesses of the alluvia deposited in the Varsolt lake for the analysed period are given in Fig.5.

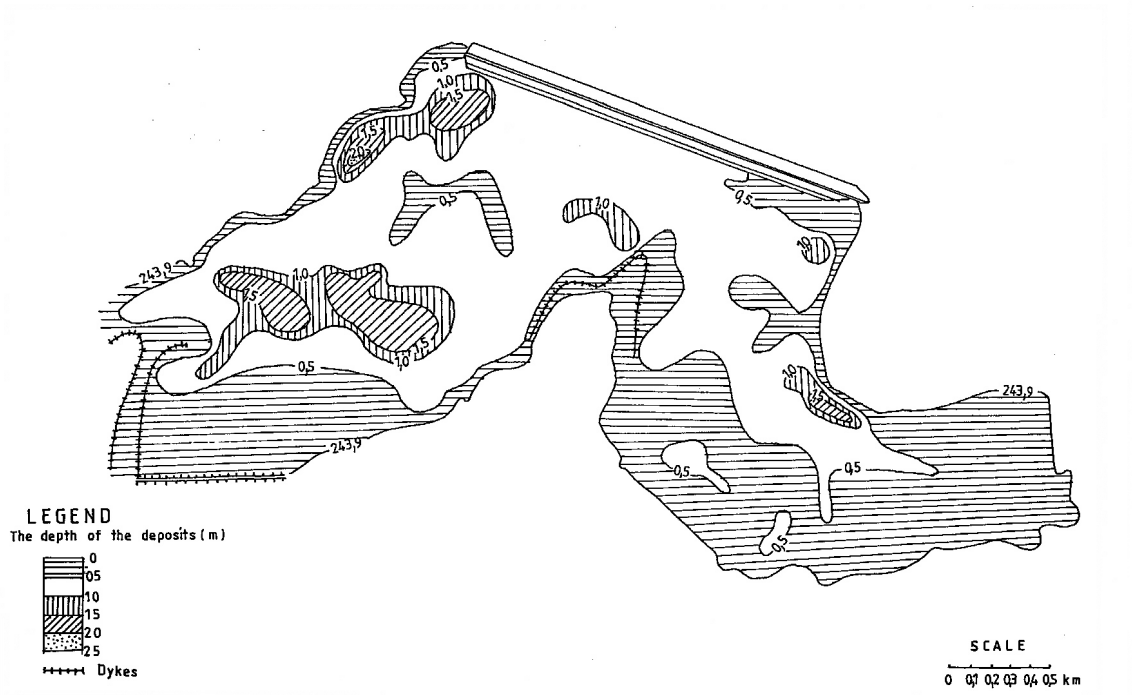

Fig. 5 Map showing the thickness of the alluvia deposited in the Varsolt lake

The thickness of the alluvial deposits is minimum with the space confined by the isohypses higher than 241.00-242.00 and it takes a large stretch from the corresponding surface of the lake at the maximum level of operation (level of 243.90 m).

Isolatedly, and over reduced spaces, the thickness of the alluvial deposits may exceed 2 m, while the deposits with thickness between 0.5 and 1 m occupy the largest part of the lake.

Quantitatively, the colmatage of the lake for the characteristic volumes and within the intervals among the topobathimetrical surveys is shown in Table 2.

The evolution of the colmated volumes within the interval analysed according to the successive bathymerical surveys, value represented in Table 2, shows a variable colmatage in time, a heavy colmatage during the first years of operation (1976-1989) when the dead volume, the useful volume and the flood water storage volume (timigation volume) colmated by percentages of 89.8,19.7 and 9.8 respectively.

After 1989 the colmatage rhythm considerably decreased as a result of dropped mean annual solid volume/discharge brought about by some hydrotechnical works (bank consolidation, bottom sills) made on water courses in the cathment basin of the storage and put into operation in 1987, as well as by the existence of a poorer hydrological regime (droughty years) during the period after 1980.

The utilisation of the values obtained from the surveying activity by systematic measurements of the suspended solid discharge R(t/year) on the river Crasna, within a section representing 47% from the total surface of the catchment basin of the lake lead to a mean multi-annual discharge of suspended alluvia of Rma=179.4 t/year for the period from 1979 to1997 which means a volume W=0.224 millions cu. m/year.

Table 2. Evolution of colmatage of the Varsolt lake (1979-1997 period)

Volumes($10^6 m^3$)	1979	1983	1985	1989	1991	1995	1997	Total 1979-1997
Period (years)	4	2	4	2	4	2		18
Dead volume 228.00-232.50	0.592	0.279	0.183	0.117	0.084	0.081	0.048	0.592
Colmated volume	0.313	0.096	0.066	0.033	0.003	0.033		
		0.313	0.409	0.475	0.508	0.511	0.544	0.544
% colmatage	0	52.9	77.3	89.8	85.8	86.3	91.9	91.9
Annual colmatage	0.078	0.048	0.0165	0.0165	0.008	0.165		0.030
Useful volume 232.50-240.00	20.9	18.38	17.88	16.78	16.69	16.45	16.36	20.9
Colmated volume	2.52	0.5	1.1	0.09	0.24	0.09		
		2.52	3.02	4.12	4.21	4.45	4.54	4.54
% colmatage	0	12.0	14.4	19.7	20.1	21.3	21.7	21.7
Annual colmatage	0.630	0.250	0.275	0.045	0.060	0.045		0.252
Timigation volume 240.00-243.91	26.3	25.85	25.62	23.79	23.88	23.33	23.24	26.3
Colmated volume	0.45	0.23	1.83	0.09	0.55	0.06		
		0.45	0.69	2.51	2.42	2.97	3.03	3.03
% colmatage	0	1.7	2.6	9.5	9.2	11.3	11.5	11.5
Annual colmatage	0.113	0.113	0.458	0.045	0.138	0.03		0.168
Total volume 228.00-243.94	47.8	44.58	43.68	40.69	40.65	39.86	39.65	47.8
Colmated volume	3.3	0.82	2.99	0.04	0.79	0.21		
		3.3	4.12	7.11	7.15	7.94	8.15	8.15
% colmatage	0	6.9	8.6	14.9	15	16.6	17.1	17.1
Annual colmatage	0.825	0.41	0.748	0.02	0.198	0.105		0.453

The lack of the data regarding the flow of suspended alluvia for the whole surface of the basin, controlled by the storage, as well as of the data regarding the bed-load discharge "G" does not make possible the determination of the colmated volumes using the method of the balance of the alluvia and therefore, the comparison of the resulted values with the data get by successive topobathymetrical measurements.

The values of the colmatage shown in their evolution, in Table 2 permit the calculation of the following synthetic indices which characterise the colmatage rhythm of this lake for a period of 18 years of operation (1979-1997).

-Coefficient of accumulation of solid stock

$\alpha = Vt/Wr = 47.8*10^6/0.453*10^6 = 105$

corresponding to the total volume,

$\alpha = Vu/Wr = 21.5*10^6/0.282*10^6 = 85$

corresponding to the useful volume.

Vt,Vu – (initial) total and useful volumes of the lake(millions m^3)

Wr – mean multi-annual volume of colmated alluvia (millions m^3).

-Colmatage rate r(%) representing the share from the initial volume of the lake which gets colmated during one year.

r = Wr/Vt = 0.9 % for the total volume,

r = Wr/Vu = 1.31 % for the useful volume.

The consequences of the colmatage of the storage lake for the analysed period are the following:

-Gradual decrease of the storage capacity with negative effect especially manifested by the losses of useful volume which affect the function of water supplying of storage by diminishing the role of flow regulation.

-Influence on the intake for water supplying (level 231.50 mdM) and on the bottom outlet served by the old operating tower.

-Depreciation of the quality of the water supplied as a result of turbidity and deterioration of other quality parameters.

To remedy the above-mentioned negative aspects and to increase the degree of operating safety, there were taken some technical measures consisting of putting the feed pipe from the river Barcau into operation and building of a new operating tower with higher levels of water intake of the new bottom gallery.

As a "positive" consequence of the colmatage of the Varsolt storage lake we may mention the progressive loss of the discharges ex-filtered through the permeable foundation of the dam with an effect on increasing the stability in the zone of downstream talus.

After an exploitation of 18 years the Varsolt storage lake presents an advanced stage of colmatage especially in the field of the useful volume so that in the case of keeping the existent colmatage rate at the level of the year 1997 we estimate that until 2020 the function of water supplying of the storage will be severely affected.

For attenuating the colmatage process the following measures are necessary:

-Restoring and maintenance of the hydrotechnical works existing in the catchment basin.

-Promotion of new specific works for the removal of the surface and torrential erosion within the basin belonging to the storage.

2 Conclusions

With a reduced vegetal protection and geological structure with predominant soft sedimentary rocks to which it is added the presence, on a large scale, of the surface and torrential erosion processes, the hydrographical basin of the Varsolt storage lake shows a reduced resistance to erosion a fact that places this basin within the areal with the highest erosion indices from the north-west of Romania.

The advanced stage of colmatage of the storage lake requires the adoption of measures for attenuating the colmatage process, by promoting specific works within the catchment basin of the lake, as well as by monitoring the colmatage process with a view of knowing permanently the evolution and the attained colmatage stage.

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The Mud Flow Phenomena in the Carpathian Territory

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Abstract: The peculiarities of a spatial distribution of mud flow phenomena in the Carpatians are presented. The regions of mud flow danger, the data of mud flow intensity and their frequency in the dangerous regions are discussed. Hydrometeorological conditions of mud flow formation are considerated as well.

Key words: mud flow, flood, mud flow intensity, hydrometeorological condition

Das Phänomen von Murenabgängen im Gebiet der Karpaten

Zusammenfassung: In diesem Beitrag werden Besonderheiten in der räumlichen Verteilung von Murenabgängen in den Karpaten vorgestellt. Murengefährdete Gebiete und Angaben über Murenabgangsintensität und Häufigkeit der Murenhochwasser werden behandelt. Die Aufmerksamkeit wird auch auf die hydrometeorologischen Bedingungen der Murenbildung gerichtet.

Schlüsselworte: Murenabgänge, murengefährdete Gebiete, Murenabgangsintensität, hydrometeorologische Vorgänge.

Introduction

The long terminate experience has demonstrated that the mud flow phenomena are systematically observed in the Ukrainian Carpathians. They bring a huge damage to the economy.

The complication of their formation and proceeding have stipulated the appearance of the numerous interpretations of the concept of a”mud flow”. Nowadays the following interpretation has been adopted: ” a mud flow is a temporary mountain stream of a mixture of water and big quantity of rock fragments which have a size from clayey particles to big boulders and stones that is the cause of the big changes of the river’s bed structure during a short period of time and formation of the specific sediments as a result of disintegration of the mud flow mixture or stooping its movement.

The mud stream differ from the water stream because of the big saturation of the hard material, that is about 15-60% and more of the mud flow volume; it accumulates in the form of mud flow mounds terraces or fields at the place of mud flow stop. The mud flows are characteristic of small permanent and temporary streams.

The systematic studding of the mud flow phenomena in the Carpathian territory and causes of their beginning, conditions and processes of their formations began in 1954.

The specialists of the Ukrainian hydrometeorological service, in particular Ukrainian research hydrometeorological institute, brought the big contribution in this direction of the research.

The specialise mud flow station of the Ukrainian Hydrometeorological service is functioning in the Carpathians.

The large volume of information about mud flow phenomena, their spatial distribution and intensity is accumulated now. The differentiation of the Carpathion territory according to the level of danger from mud flows was done , the catalogues of the mud flows basins and plots and the

detail maps of the spatial distribution of the mud flows were created, their frequency and destructive capability were determinated./1-6,9/.

The warning system about the possibility of the formation mud flow phenomena in mountain regions has been created in the establishments of the Ukrainian hydrolmeteorological service. The method of the probable fore casting of mud flows phenomena for the Carpathian territory was created in the research institute of this service. This method will be included as a component of the information forecasting system for the Tisa basin / 7,11 /.

Conditions of the mud flow formation, conformity of their spatial distribution and their intensity

The principal conditions of the mud flow formation in the Carpathions are:

1. The possibility of the formation of the intensive surface and channel flow due to the large rainfalls or intensive snow melting.

2. The presence of the sufficient quantity of the friable rock.

3. The presence of inclinations of slopes and mud flow channels which give possibility to displace and the farther transportation of the mud flow mass.

There are all these conditions of the mud flow formations in the Carpathians.

The mud flow formation, the volume of the transferring material, their destructive possibility and their frequency depend of the quality and an intensively of rainfalls regime and the preliminary moistening.

The daily maximums and maximal intensity of rainfalls, which form mud flows fluctuate in wide range from 50 mm and more with the intensity from 0.3-0.5 to 5 mm/minute. This wide range of parameters demonstrates variety of unification of the natural factors of mud flow formation.

The peculiarity of the Carpathian geological conditions determines the character of the rock destruction products and their litological composition.

The potential mud flow massifs (PMFM) of mud flow plots are formed with the sediments of the landslide-gravitation processes. These sediments characterise the friability and moving ability of the composition. which is determined by their permanent moisturening.

The formation of the PMFM and following mud flow phenomena is also stimulated by the alluvial-delluvial sediments. Their capacity fluctuate from ten centimetres to a few metres.

The water - stone mud flows prevail in the Carpathians, the dirt-stone and dirt mud flows occur rarely.

The rainstorms which is a cause of floods on the mountain Carpathian's rivers stipulate by the influence oragrafic obstacles on the air masses. These rainfalls spread to the areas more 15-30 km^2 and have an exceptional intensity. They are observed as a rule 12-36 hours with the intensity 1.5-2.0 mm/h and more. For instance, during the rainfalls on 8-10th of June 1969 in the Striy basin (the catchment area is 2400 km^2) fell down from 65 to 240 mm and the Bistritsa basin (2450 km^2) - 75-240 mm during 24 hours. The snow- melting and big rainfalls in winter is cause of winters' floods in the Tisa basin. / 8-10 /.

There are three regions of mud flow danger in the Carpathian territory: The Northwest, the Southeast and the Southwest.

1. The Northwest mud flow region consist of the Dniester basin and includes 3 small regions (according to the names of the rivers- the Svicha, the Striy, the Lomnitsa which are tributaries of

the Dniester) . There are 71 mud flow catchment with the area 0.06-130 km^2. The average inclinations of mud flows' basins are 200-250 m/km and the areas of mud flows source are 0.06-1.3 km^2. The mud flows usually form in summer (July-August) during the rainstorm period.

2. The Southeast mud flow region consist of the Prut and the Siret basins. It consists from four small ones. There are 88 mud flow basins with mud flow catchment areas from 0.2 to 106 km^2 here. The average inclinations of mud flows' basins are 170-150 m/km and the areas of mud flows source are 0.04-1.0 km^2.

3. The Southwest mud flow region consists of the Tisa basin and divided in to four small ones. There are more than 100 mud flow basins with mud flow catchment areas from 0.24 to 63 km^2 there. The average inclinations of mud flows' basins are 250-600 m/km .

The mud flow activity is the highest in the river's basins of the Chornaya Tisa, the Belaya Tisa, the Shopurka and the Teresva. The areas mud flow sources are about 0.1-2 km^2 there.

The great influence on the mud streams forming have such factors as: the structure of the rivers' bed, the arrangement of mud flow sources in the grounds which eroding easy, the presence of different channel construction with wide and narrow parts and others morphometrical forms of building rivers' bed and valleys' slops.

The addition factors of the mud flow formation is antropogenic one . The total cutting down forest massifs in highlands, imperfect technology of the transportation of wood and the pasture of cattle on the slopes in the highland influence on the mud stream activity.

The annual distribution of mud flow phenomena is stipulated by the periods of the greatest humidication of the catchment areas. For the Dniester and the Prut basin it is mainly summers' heavy rains and for the Tisa basin the activation of the mud flow is also observed as a result of intensive snow melt (table 1).

Frequency of the mud flow phenomena

The activity of the mud flow phenomena is closely connected with water-flow regime. Therefore the floods as the result of rains and snow melt always bring a threat of mud flow formation.

The long-termin dates demonstrate that mud flows come into existence after rain falls with precipitation about 50-100 mm and more for 24 hours. They were observed during rains with precipitation about 20-40 mm but they were isolated instances in the areas with steep slopes and with presents loose, dry substances material in the streams and on the slopes.

Table 1 The annual distribution of mud flow phenomena in 1947-1998

Basin	Period	according to month					
		Y	YI	YII	YIII	IX	other
The Dniester	16	2	5	8	1	-	-
The Tisa	39	3	11	8	6	3	9
The Prut, the Siret	17	1	5	7	2	-	-

The mud flow phenomena are especially often observed on the catchment areas of the Chornaya and Belaya Tisa, the Shopurka and the Teresva rivers. They take place almost every year and sometimes several time a year, but in different rivers' basin with the different degree of the widespread. The average mud flow manifestation is about once for 3-6 year in the others regions.

In some definite groups of years the mud flows are the most dangerous and destructive; these periods were called periods with a high level of water (abounding in water) by authors. In XX century these periods were obsereved in 1912-1927, 1940-1955, 1965-1984 on the Carpatian territory. These periods coincide with the periods of the most dangerous mud flow phenomena in the Carpations. In particular these are the floods in 1927, 1941, 1947-1948, 1955, 1966 and 1969, when mud flows were registered all over the Carpathian.

Since 1992-1993, when the next period with abounding in water had come, the activity of mud flow phenomena grew and have been growing till 1998. As the result in November 1998 intensive mud flow activity was observed on the majority the Tisa basins and especially in the Teresva basin which is the most dangerous as for these phenomena.

Conclusion

The mud flows is ordinary phenomenon in the Carpathians. Besides natural facts in some regions a human activity is cause of the mud flows. According to the observed data the most dangerous regions are determined. It is the headwaters of the Tisa, the Lomnitsa, the Bystritsa . These regions demand the greatest attention in the realisation mud flow protective .mesuarment.

The majority of the mud flows appears due to precipitation over 50 mm for 24 hours and presents loose, dry-substances material and friable-fragments of rock material in channels and valleys' slope. It is very important, that the preliminary long-term(10-20 days) moister and following rains have the great influence on the mud flow formation.

The activity of mud flow connected with stream-flow regime and increasing precipitation in winter with presence snow cover on the hills.. Their activity and frequency increase in the periods abounding in water, when great floods take place. This period began

in 1992-1993 and probably will be till 2005-2008. Therefore the activity of mud flow phenomena will not be expelled the following 7-10 years.

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Some Aspects of the Bedload Transport Regime in the Slovak Section of the Danube River

Katarína Holubová

Abstract : During the last 50 years the construction of run-of river hydroelectric power schemes, dredging, commercial gravel mining and navigation improvement measures significantly influenced sediment transport in the Danube river. Modified flow dynamics, which dominantly affected the natural character of the river regime, induced significant morphological changes in the river bed and thus influenced surface and groundwater levels. The research results focused at the identification of bedload changes on the basis of field measurements, which were re-established after more than 40 years in the Slovak section of the Danube river, are presented in the paper. Besides the actual bedload discharge conditions in Danube also relation of the river data to the theoretical and experimental sediment transport formulae was analysed (Meyer-Peter and Müller, Ackers and White, Schoklitsch, Jaeggi and Smart). The research results have a great importance particularly with regard to real prediction of the morphological development of the Danube river bed (calibration and verification of the numerical morphology models) further to evaluation of flood control and navigation route parameters.

Key words: sediment transport, bedload measurements, morphology development, bed material characteristics, bedload equations

Einige Aspekte des Geschieberegimes im slowakischen Donaubschnitt

Zusammenfassung: Der Geschiebetransport der Donau wurde im Verlauf der letzten 50 Jahre von vielen Ingenieureingriffen beeinflusst - insbesondere vom Aufbau und Betrieb der Wasserkraftwerkkaskade, der Flussbettregulierung für die Schifffahrt und durch übermäßige Schotterförderung für kommerzielle Zwecke. Die geänderte Strömungs-dynamik, die das Naturregime des Geschiebetransportes beeinflusst, hat bedeutsame morphologische Flussbettänderungen mit den Folgeänderungen Änderungen des Wasserspiegelregimes des Grund - und Oberflächenwassers bedingt. In diesem Beitrag sind die Ergebnisse der auf die Identifizierung der Geschiebedurchfussänderungen in dem slowakischen Donauabschnitt auf Grund der direkten Messungen orientierten Forschung präsentiert. Diese Messungen wurden nach mehr als 40 Jahren erneuert. Neben der Quantifizierung der Transportkapazität des Donauflussbettes sind die Messergebnisse auch im Bezug zu den theoretisch-experimentellen Abhängigkeiten für die Geschiebedurchflussberechnung (Meyer-Peter und Müller, Ackers und White, Schoklitsch, Jaeggi und Smart) analysiert. Die Forschungsresultate sind von außerordentlicher Bedeutung besonders in Beziehung zu den realen Vorhersagen der morphologischen Donaubettentwicklung (Kalibrierung und Verifikation der nummerischen Modelle) und zu der angeknüpften Beurteilung des Hochwaasserschutzes und der Schifffahrtsrinneparameter.

Schlüsselworte: Sedimenttransport, Geschiebedurchflussmessungen, morphologische Entwicklung, Bodenmaterial, Formulen des Gechiebedurchflusses

1 Introduction

During the last 50 years the construction of run of river hydro electric power schemes, dredging, gravel mining and navigation improvement measures in the adjacent reaches of the Danube river were realised. Such measures adversely affect the natural character of the river and are often only temporary palliatives since they were designed to transmit clear water and no consideration was

given to problems of sediment transport (Holubová, Kľúčovská & Szolgay, 1996). Many problems of river management arise from the inadequate prediction of bedload transport rate. A number of bedload transport equations are available for generating estimate transport rates. However, although they appear to arise from several different deterministic approaches, the fact that the problem they purport to solve is reasonably well defined inevitably means that there is considerable genetic similarity. This often means that personal preferences or input data availability may influence the equation choice. Some of equations are not calibrated or are calibrated only by flume data. As a consequence, they may by dangerous in applying them in field situation (Reid et al. 1997).

Bedload discharge conditions in the Slovak section of the Danube river (km 1870) were defined on the field bedload measurements during the years 1952 – 1960. Since the 1960s no further bedload measurements have been realised even if engineering works and increased influence of human impacts considerably effected the river processes. At present bedload transport capacity of the river is reduced by backwater effect of Čunovo reservoir. Thus actual aggradation of the river bed could result in the decrease of flood protection of the Slovak capital. On the other hand bedload transport capacity of the Danube has been increased by operation of Austrian hydropower scheme – Freudenau. Artificial releases of a large amount of coarse selected gravel that should stabilise the river bed could consequently contribute to the intensity of bed aggradation upstream of Čunovo reservoir. Correct prediction of sediment transport rate under significant changes in flow dynamics upstream and downstream of Gabčíkovo hydropower scheme is rather difficult. In order to dispel some of the resulting uncertainty in the bedload discharge estimation at the entrance part of Slovak section of the Danube river (upstream of Čunovo) this paper presents the essential results of the bedload transport regime research (Holubová, 1998, Holubová and Szolgay,1998).

2 River channel morphology

Sediment transport in the Danube has been strongly influenced by the construction and operation of Gabčíkovo hydropower scheme. In generally the river damming causes degradation of the river bed downstream and aggradation upstream of the weir or dam. This effect was expected and predicted by application of numerical models in the touched Danube river reaches. Due to lack of actual sediment transport data, morphology models were calibrated only on the basis of flow conditions and bed material analyses thus the results could not match with the present situation. Bedload transport rate upstream of Gabčíkovo is affected not only by reservoir backwater effect but also by artificial releases of a large amount of coarse selected gravel downstream of Freudenau. Situation downstream of Gabčíkovo is dominantly influenced by unsteady flow conditions, that induced rather high variability of the river bed changes downstream of the tailrace canal confluence. Morphology development in both markedly touched river sections of the Danube river bed for the short period 1992-1994 as well as for longer period 1993 - 1998 is shown in Fig.1 and Fig. 2. Rather regular alternation of the sections with intensive bed erosion and sedimentation (Fig. 1) was typical for the river bed development in the section downstream of tailrace canal confluence during the short period just after Gabčíkovo was put into operation (1992-1994). Trend of long-term morphology development of the river bed shown in Fig. 1 indicates significant changes. While the sections with bedload deposition almost disappeared the river bed degradation propagates downstream and intensive erosion prevails along the rather long river section (km 1811 – 1801).

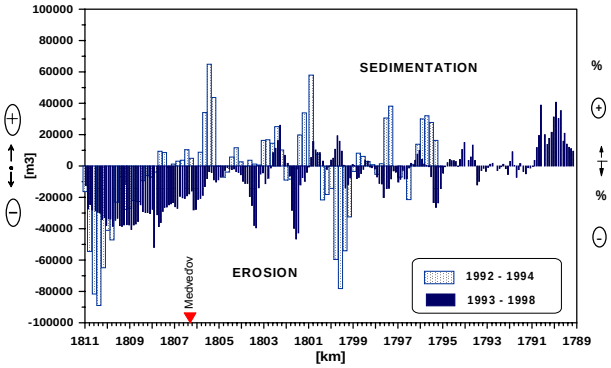

Fig. 1 Morphological changes of the Danube river bed between Sap and Kližská Nemá

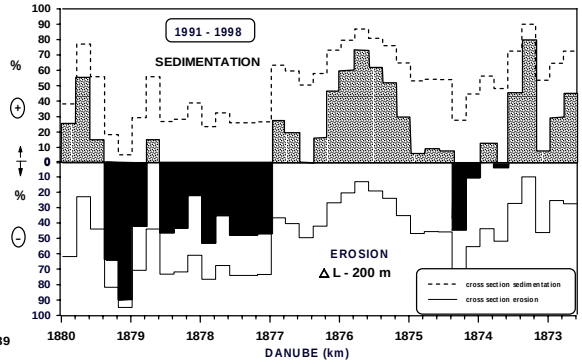

Fig. 2 Trend of morphological changes of the Danube river bed upstream of Čunovo reservoir

A high amount of gravel material dredged from the river near Bratislava in the past influenced strongly the dynamic equilibrium between sediment supply to a reach and transport capacity along the reach. This artificial interference into the sediment transport regime caused upstream and downstream degradation of the river bed. Intensive erosion processes resulted in significant drop of water levels during the period 1957 - 1992. At Bratislava water levels have decreased by 2 meters in the last 30 years. Since hydropower scheme Gabčíkovo was put into the operation (1992), the river processes throughout investigated length of the river have became opposite. The results of morphology analyses of the Danube river bed upstream of Čunovo reservoir confirmed previous assumption of rather intensive sedimentation has occurred downstream of km 1877 (see Fig. 2). Upstream of km 1877 erosion localities alternate sedimentation ones with slightly prevailing trend of the river bed degradation.

Changes of the physical characteristics of the bed material were determined on the basis of 115 samples analyses. The bed material consists mainly of the fine and coarse gravel that varies in wide range of particle size. The comparison of the Danube bed material composition obtained in the years 1957 and 1997 indicates changes resulted in larger percentage value of coarser fractions (D_{65}, D_{90}) in the majority of samples, while smaller fractions (D_{15}, D_{35}) do not exhibit any considerable differences. Figure 3 shows comparison of the size distribution of D_{90} and D_{65} along investigated river reach. Increase values of D_{90} is marked in locality between km 1880- 1871. In the same reach also slight increase of D_{65} is evident. Observations made with basket sampler in the past (Ehrenberger, 1931), document the variations of the particle size in the Danube river at Vienna, where the median size of the bed material is about 20 mm and maximum size is 70 mm. Actual value of median size, that reaches 28 mm and maximum size 90 mm also indicate coarsening of the particles size in the Danube. Higher volumes of coarser fractions in the samples could be cause by morphological development of the channel in this locality (intensive erosion in the past) and also by large amounts of coarsely sorted sediments (300 000-tones/ year) that are permanently released into the Danube river downstream of Freudenau in order to decrease bedload transport capacity and stabilise the riverbed (Zottl, 1998).

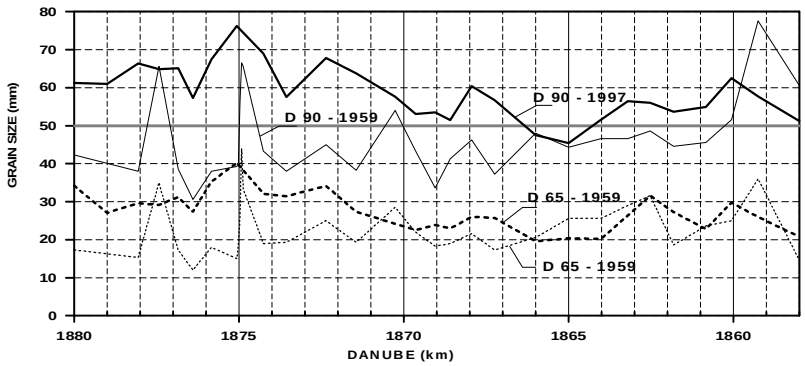

Fig. 3 Comparison of the grain size distribution of the Danube bed material for years 1957 and 1997

Downstream of km 1871 no significant changes have been observed but in the future we suppose that the content of finer grains in the bed material composition will predominate in this river part due to backwater effect. Values of D_{50} for bedload catches vary markedly from 11 mm to 40 mm throughout the gauging profile. Bedload samples that were taken in the area near the streamline showed larger content of the finer particles. On the other hand close to the left riverside (behind the system of groins) bedload particles have showed a coarsening trend. Non-uniform size distribution of the bedload particles in the gauging profile could be caused by bedload transported into the reach from the Morava river (D_{50} = 6 mm). The occurrence of armour layer on the riverbed was assessed using armouring criteria presented by Raudkivi A. (1981):

$$\left(\frac{d_{84,1}}{d_{15,9}}\right)^{0,5} \phi\ 2,5, \qquad \text{or} \qquad \frac{d_{90}}{d_{10}}\ \phi\ 5 \qquad (1)$$

Only a few grain size distribution curves indicate conditions for armour layer occurrence. Continual armour layer has not been formed along the investigated reach of the Danube due to integrated effect of the bed material composition and unsteady flow conditions (regulated discharges through Freudenau weir).

3 Bedload measurements, analyses and results

Bedload measurements carried out at the Danube river, downstream of the Morava river confluence in km 1878.15, covered the discharge range from 1 050 $m^3.s^{-1}$ to 4 348 $m^3.s^{-1}$. The choice of appropriate locality for the bedload measurements was limited by effect of impounded water level (influence of Čunovo reservoir), by existence of the system of groyons situated on both river sides and finally by the Morava river confluence. During two years (1997/1998) - 23 measurements were collected using basket sampler (Swiss type - modified) with a mesh size of 3 mm. Due to the coarse mesh, finer gravel and sand has not been retained in the sampler. The measurements were collected at three or five verticals from a boat fixed by anchor in the gauging profile. Typically nine or ten samples were collected at each vertical, making total of 27 to 50 samples in each measurement. The sampling times for basket sampler was two or three minutes and sample catches usually ranged from a few hundred grams up to a few tens of kilograms (max. 140 kg / 3 min.). The results of these measurements have been used for evaluation of the bedload transport rating curve. In order to evaluate temporal fluctuation in bedload movement

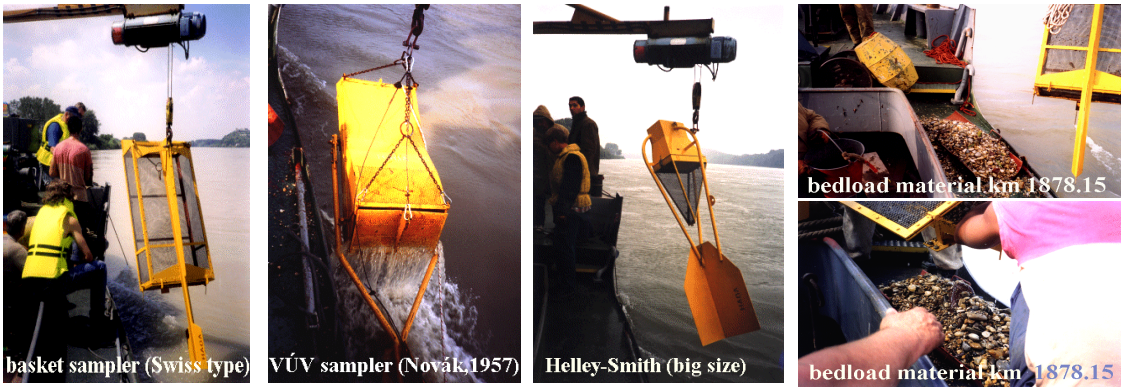

Fig. 4 Three types of bedload samplers tested in the Slovak section of the Danube river during bedload transport measurements 1997-1998

and compare efficiency of three different samplers' types, the permanent bedload measurement in one vertical has been done. Bedload samplers Helley-Smith (big size-modified), basket sampler (Swiss type) and VUV sampler (Novák, 1957) were used (see Fig.4). This type of measurements was done in constant interval of two minutes and its duration was about 4 - 6 hours. Hydrology conditions were permanently recorded at the hydrology gauging station – Devin placed upstream of the measurement locality. Flow velocities distributions were continually measured in each vertical by current meter during all sediment transport measurements. Statistical methods have been used to assess the precision of the measurements and determination of bedload transport rating curve. Derived regression relationship for the bedload transport rate is as follows:

$$G_s = 5.72154.10^{-6}.Q^{1,90295} \qquad (2)$$

Quite small scatter around the curve is indicated by rather high value of the correlation coefficient (r = 0.908). Figure 3 shows measured values of the bedload discharge and bedload curves for the periods of 1997/1998 and 1952/1960. Comparison of bedload discharge curves for two periods indicates present changes in the bed load regime

consisted in the occurrence of lower bedload amounts during low water discharge and in turn higher bedload amounts during higher water discharge at present. The beginning of bedload movement under the present conditions is connected with lower discharges (1 050 $m^3.s^{-1}$) than it was in the past (2 000 $m^3.s^{-1}$).

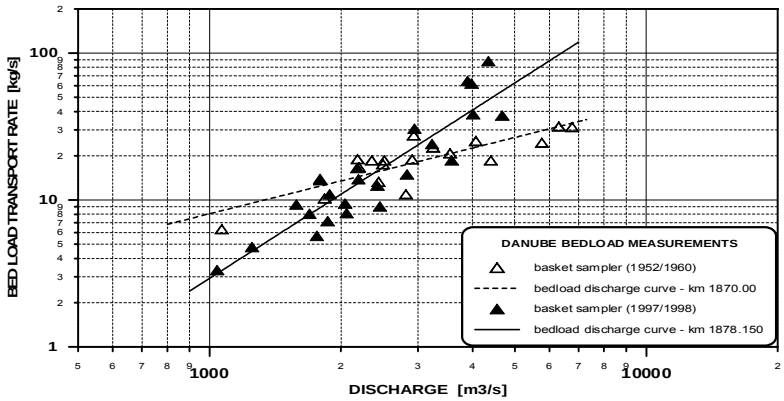

Fig. 5 Bedload sediment transport rating curves for the Danube river based on river data obtained from 1952-1960 and 1997-1998

4 The results of bedload measurements versus bedload equations

Sediment discharge equations of Meyer-Peter and Müller, Ackers and White, , Jaeggi and Smart, Schoklitsch were tested using the field data obtained at the Danube river (1997/1998). For each equation the mean normalised errors *(MNE)* and the mean prediction factor *(MPF)* were calculated. The mean normalised error is defined as normalised absolute deviation between predicted and measured values, expressed in percent. Another measure of prediction accuracy is given by the mean prediction factor, which is defined as the ratio of the predicted-to-measured value or ratio of measured-to-predicted value, whichever is greater (Karim, 1998). The mean predicted factor and mean normalised accuracy are defined as follows:

$$MNE = \frac{100}{n}\sum_{1}^{n}\frac{\left|X_m - X_{cal}\right|}{X_m} \tag{3}$$

$$MPF = \frac{1}{n}\sum_{1}^{n} \quad \text{larger of}\left(\frac{X_m}{X_{cal}}, \frac{X_{cal}}{X_m}\right) \tag{4}$$

where X_m, X_{cl}, = measured and calculated value, n = total number of measures. The results of tests are summarised in Table 1. Considering of equations in their original form and also versions modified by utilisation of individual fractions of grain size distribution curve and different values of τ_{cr} (non-dimensional shear stress). The most superior performance in terms of both means normalised error and mean prediction factor is provided by Schoklitsch equation (using fractions). At the next level both Jaeggi and Smart equations and Schoklitsch original form of equation (all overestimate values) have comparable errors. However, Meyer-Peter and Müller (using fractions) and Ackers and White (using fraction), show a much wider scatter. These equations significantly overpredict calculated values of bedload discharge. Meyer-Peter and Müller equation based on the Danube field data from 1952 – 1960 also does not provide satisfactory results due to markedly changed hydrological and morphological conditions at the Danube river. Bedload discharge curve (1) was based on field data that covered limited discharge range (from 1 050 $m^3.s^{-1}$ to 4 348 $m^3.s^{-1}$), thus application of this equation for

Table 1 The results of tests of the bedload equations using field data obtained in the Danube

Tested equation	MNE %	MPF
Meyer Peter and Müller, (constants for the Danube 1960)	209,2	3,09
Meyer Peter and Müller, (with fractions)	670,4	7,70
Ackers and White	202,2	2,91
Ackers and White (with fractions)	377,3	4,72
Schoklitsch	73,12	7,29
Schoklitsch (with fractions)	52,52	2,22
Smart-Jaeggi (τ_{cr} = 0.047)	60,35	3,11
Smart-Jaeggi (τ_{cr} = MPM)	60,34	3,12

higher discharge conditions would not be correct. In order to obtain a considerable improvement in the bedload prediction using Meyer-Peter and Müller equation, field data has been used for evaluation of the values of constants A´, B´, that reflect changed conditions at the Danube river.

5 Test of Meyer-Peter and Müller equation with field data

Bedload equation of Meyer-Peter and Müller was used for extrapolation of the bedload transport rating curve (regression relationship) in order to spread the range of its applicability. Using the Danube river field data the original values of the constants A´ and B´ in Meyer-Peter and Müller equation were modified as follows: A´ = 0.039, B´ = 0. 39. Figure 4 shows the comparison of the curves of Meyer-Peter and Müller equations with different values of constants A´, B´ for curves evaluated on the basis of river data obtained in the European rivers. Course of the curve based on the actual Danube river data is closer to the curves obtained from the rivers Rhine and Aare while the course of the equation based on the older Danube river data (1952/1960) markedly decline. Different course of the curves of Meyer-Peter and Müller equations obtained for the Danube river during different periods also indicate the changes in the bedload regime.

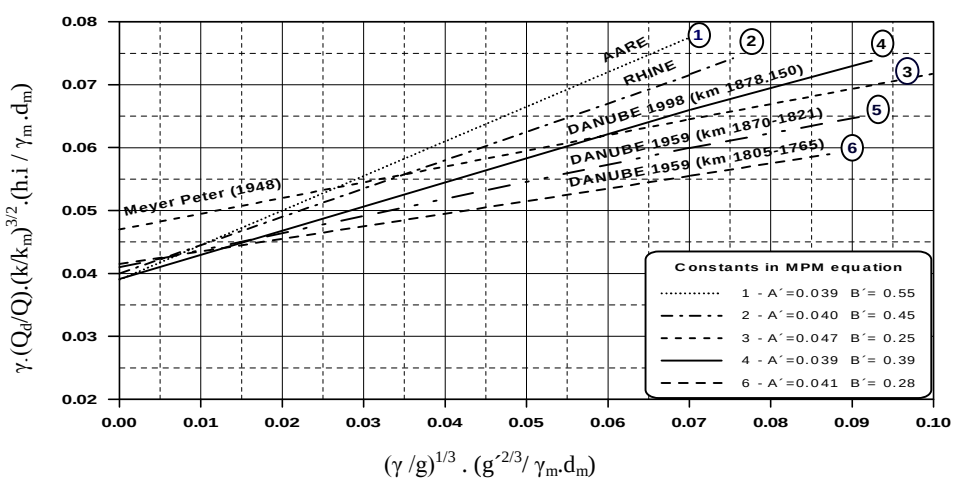

Fig. 6 Constants A´ and B´ of MPM equation obtained on bedload transport investigations on the Danube, Aare and Rhine rivers

A considerable improvement in the predictions of Meyer Peter and Müller equation is evident with modified values of constants A´ and B´ (see Fig. 6). Comparisons of measured bedload discharges with bed load discharges calculated by the different bedload equations (shown in figure 5) and by the MPM equation with modified constsnts based on the Danube field data

(shown in figure 6) comfired the best prediction of the MPM equation for the Danube river in km 1878.150 that reflects changed hydrological and morphological conditions.

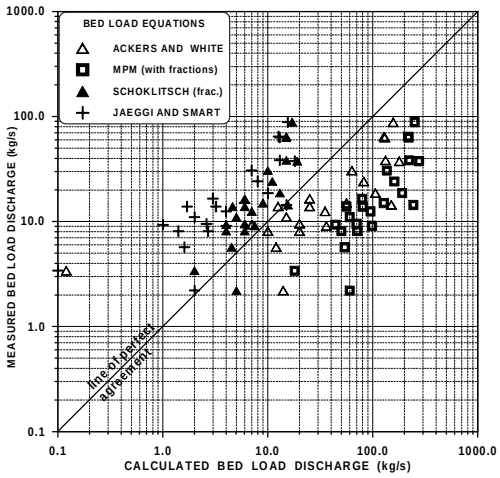

Fig. 7 Comparison of measured and calculated bedload discharge using modified MPM equation

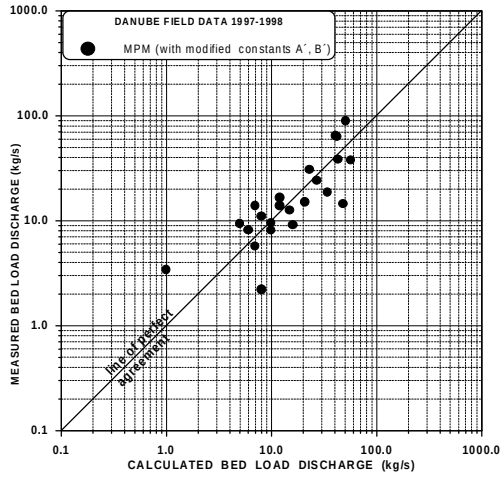

Fig. 8 Comparison of measured and calculated bedload discharge using different equations

6 Conclusions

Morphological analyses indicate more intensive aggradation in the Danube river reach up to km 1873. Coarsening of the bed material upstream of km 1870 is probably caused by the morphological development of the channel in this locality (intensive erosion in the past) and also by large amounts of coarsely sorted sediments (300 000 tones/ year) that are permanently released into the Danube downstream of Vienna. The field measurements in the Danube river have confirmed changes in the bedload regime under the changing conditions. Higher value of bedload rate influenced by human interventions will accelerate the process of the Danube river bed aggradation. As a result the flood protection of Bratislava could decrease in short future. Considering the bedload equations presented in literature, the best results in defined Danube section are provided by Schoklitsch equation (using fractions). Tested against river data Schoklitsch equation still underestimate sediment discharge. Using the Danube river data regression type of relationship was derived for the bedload discharge calculation. Applicability of this relationship is limited by the discharge range that covered field measurements (1 050 $m^3.s^{-1}$ to 4 348 $m^3.s^{-1}$) thus Meyer-Peter and Müller equation with constants A' = 0.039 and B' = 0.39 (using field data) provides prediction that can reflect changed conditions at the Slovak section of the Danube river. Intensive degradation of the Danube river bed downstream of tailrace canal (see Fig.1) induced urgent need of similar bedload research that should be focused at rather complicated conditions for bedload transport in this locality. As a response to this need the Ministry of Agriculture of the Slovak Republic accepted the new project proposal of Water Research Institute, which has been started (2000 - 2002) in the beginning of this year. Similarly as the previous one also this project is fully financially covered by Ministry of Agriculture of the Slovak Republic.

The results of the bedload research widen the knowledge concerned to the structure of bedload regime changes at the Danube river. They also have a great importance for practice of the river engineering and management (numerical modelling of channel morphology, flood protection, navigation, restoration measures, etc.). A new project finalising will provide complex information of the Danube sediment transport regime markedly changed by various types of human interventions.

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Donauausbau Straubing – Vilshofen, vertiefte Untersuchungen
1D-Modellverfahren, Modelltechnik, flußmorphologische Änderungen

Jürgen Kellermann, Bernhard Söhngen

Zusammenfassung: Im vorliegenden Beitrag soll die *Methodik* der in den vertieften Untersuchungen zum Donauausbau Straubing-Vilshofen verwendeten eindimensionalen Modelluntersuchungen erläutert werden. Dabei wird ein besonderer Schwerpunkt auf die eingesetzte Modellierungstechnik sowie die Berücksichtigung flußmorphologischer Änderungen gelegt. Eine Ergebnisdarstellung kann zu dieser Zeit nur bezüglich der Modellkalibrierung erfolgen. Die Variantenanalyse ist derzeit noch nicht abgeschlossen.

Development of the Danube River between Straubing and Vilshofen (Germany), 1D-Modeling, Model Technique, Morphological Changes

Abstract: In the present paper the applied methods for the used one-dimensional numerical investigations of the Danube river project between Straubing and Vilshofen will be explained. Especially the modelling techniques and the aspect of morphological changings will be in the center of concentration. The presentation of results is possible for the calibration stage. The analysis of the variants is still not finished.

Einführung

Im Rahmen der Planungen zum Donauausbau Straubing – Vilshofen wurden 1996, zur stärkeren Berücksichtigung ökologischer Belange, flußregelnde Maßnahmen in der Teilstrecke Straubing – Isarmündung unter der Randbedingung einer Staustufe im Bereich unterstrom der Isarmündung untersucht (Witte et al. 1997, Kellermann et al. 1998). Nach Abschluß dieser Untersuchungen beschlossen Bund und Bayern für eine politische Richtungsentscheidung im Jahr 2000, die Untersuchungen auf die gesamte Strecke zwischen Straubing und Vilshofen auszuweiten, mit dem Ziel, für das ganze Spektrum möglicher Varianten eine gleichwertige, vergleichbare Untersuchungstiefe zu erhalten. Die Spannweite der Varianten umfaßt dabei den IST-Zustand mit einer Tiefe von mindestens 2 m auf der gesamten Fahrrinnenbreite und ausgebautem Bürgerfeld, wie er etwa im Jahr 2000 hergestellt sein wird (IST-Zustand 2000), eine flußbauliche Lösung ohne Staustufen auf der Basis der bestehenden Fahrrinne (Variante A), eine verschärfte Flußregelung bei einer größeren Fahrrinnenbreite (Variante B), eine Variante mit einer Staustufe (Variante C) sowie mehreren Staustufen (Variante D). Im Rahmen dieses Beitrags wird auf die Methodik der hydrodynamisch-numerischen Modellierung (HN-Modellierung) der in der BAW erstellten Modelle eingegangen.

Ergebnissse der Modellierung sind u.a. Fließtiefen und -geschwindigkeiten. Sie dienen als

- hydraulische Eingangsgrößen in fahrdynamische Modellrechnungen zur Ermittlung von Schiffsgeschwindigkeiten und Absunkverhalten (Söhngen, 1999),
- abiotische Parameter für ökologische Untersuchungen, aus denen sich zusätzliche Aussagen z.B. Überflutungsdauern ableiten lassen,
- Instrument zum Aufzeigen heutiger Problemstellen der Schifffahrt,
- Randbedingungen zur physikalischen Modellierung des Isarmündungsbereichs (Roßbach et al., 1999) und
- Grundlage zum Aufzeigen des weiteren Optimierungspotentials.

Vor dem Hintergrund der für die Vergleichbarkeit der unterschiedlichen Varianten in einer politischen Einscheidung erforderlichen Untersuchungstiefe, wurde ein eindimensionales Modellverfahren zur hydraulischen Berechnung der *Gesamt*strecke gewählt. Diese Verfahren

gehen von flächengemittelten Kenngrößen aus, wie z.B. der Fließgeschwindigkeit und im Querprofil konstantem Wasserstand und Reibungsgefälle in charakteristischen Berechnungsquerschnitten. Darüber hinaus muss die Annahme einer langsam veränderlichen Strömung zwischen zwei Querprofilen erfüllt werden. Mehrdimensionale Effekte wie Strömungen in Buhnenfeldern oder die in Krümmungen auftretende Sekundärströmung können nur über parametrisierte Ansätze erfasst bzw. müssen ganz vernachlässigt werden. Somit sind Ergebnisse eindimensionaler Berechnungen im Wesentlichen für Großraumverhalten geeignet. Die Modellierung von komplexen Strömungsphänomenen, z.B. Ablösezonen oder Querströmungen sind nicht möglich. Detaillierte Ergebnisdarstellung wie z.B. Fließgeschwindigkeitsverteilungen im Querschnitt, die aus Reibungsgefälle und örlicher Fließtiefe abgeleitet werden kann, sind nur eingeschränkt möglich. Um detailliertere Aussagen zu erhalten, sind weitergehende Modellierungstechniken erforderlich.

Modellerstellung und Kalibrierung

Bild 1 gibt eine schematische Übersicht des Modellgebietes mit den wesentlichen hydraulischen Randbedingungen wieder, die im Folgenden kurz beschrieben werden:

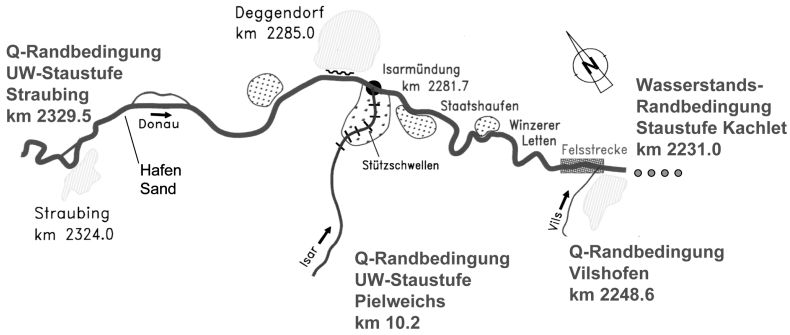

Bild 1: Übersicht des Modellgebietes mit Randbedingungen

- Der Bereich des von der Schifffahrt genutzten Untersuchungsgebiets der Donau beginnt an der Einmündung des Schleusenkanals der Staustufe Straubing in die Donau bei km 2319. Der oberstromige Rand des HN-Modells mußte davon abweichend in das Unterwasser der Staustufe Straubing gelegt werden, da der Abfluß des rechten Vorlandes am unteren Ende des Wehrarms durch die Strömungsverhältnisse in Wehrarm und Schleusenkanal – ein Teil des Hochwasserabflusses erfolgt durch den Schleusenkanal und wird vom Wasserstand bei km 2319 kontrolliert - beeinflußt wird.
- Im Bereich der Unteren Isar wird im Hochwasserfall der Vorlandabfluß zum Teil durch Bedingungen mehrere Kilometer oberstrom der Mündung geprägt. Um diesen Effekt zu berücksichtigen, wurde der oberstromige Rand der Isar in das Unterwasser der Staustufe Pielweichs bei km 10,2 gelegt.
- Durch das bayerische Landesamt für Wasserwirtschaft wurden Abflüße für das Bemessungshochwasser (100-jährliche Hochwasser, HQ_{100}) vorgegebenen. Um diese zu berücksichtigen ist der Zufluß der Vils bei km 2248,6 erfaßt worden.
- Da bei HQ_{100} keine Aussagen über Wasserstände, die am unteren Rand des Untersuchungsgebietes auftreten, vorlagen, wurde das Modell über den unteren Rand des Untersuchungsgebietes bei Vilshofen hinaus bis zur Staustufe Kachlet verlängert.

Zur Kalibrierung wurden drei Modelle mit Querprofilpeilungen des WSA Regensburg von 1990, 1995 und 1998 mit einem mittleren Querprofilabstand von ca. 300 m erstellt. Weiterhin wurden u.a. Daten aus Altwasserpeilungen, Buhnen- und Parallelwerksvermessungen, mehrere Befliegungen, terrestrische Aufmessungen und Sohlbeprobungen zur Modellerstellung verwendet. Zur Kalibrierung wurden aus der Fülle der Wasserspiegelfixierungen der letzten Jahrzehnte nur diejenigen verwendet, die etwa zur gleichen Zeit erhoben wurden, wie die entsprechende Querprofilpeilung. Trotzdem konnte ein möglichst weites Abflußspektrum (190 m^3/s bis 2570 m^3/s im Bereich oberstrom und 294 m^3/s bis 3020 m^3/s im Bereich unterstrom der Isarmündung) berücksichtigt werden.

Da 1995 mit der Vertiefung der Donau im Bereich Deggendorf - Straubing von 1,7 m auf 2,0 m begonnen wurde, ist es nicht sicher gewährleistet, dass die gemessenen Wasserspiegelfixierungen und die gepeilten Sohlprofile des gleichen Jahres zusammenpassen. Somit ist der Modellzustand 1995 zur Kalibrierung nur bedingt geeignet. Da für den Peilzustand 1990, der seit den siebziger Jahren im Wesentlichen nach gleichen Kriterien unterhalten wurde und somit morphologisch relativ geringen Änderungen unterliegt, umfangreiche für nahezu das ganze Abflußspektrum zwischen extremen Niedrigwasser und Hochwasser vom März 1988 Wasserspiegelfixierungen vorlagen, wurde dieser Zustand zur Kalibrierung der Rauheitsbeiwerte verwendet.

Darüber hinaus ist noch mit der 1998 durchgeführten Querprofilpeilung ein weiteres Modell erstellt worden. Dieses Modell, in das die kalibrierten Rauheitsbeiwerte des Modells von 1990 übernommen wurde, konnte mittels Wasserspiegelfixierungen von 1997 und 1998 und Geschwindigkeitsmessungen von 1998 verifiziert werden.

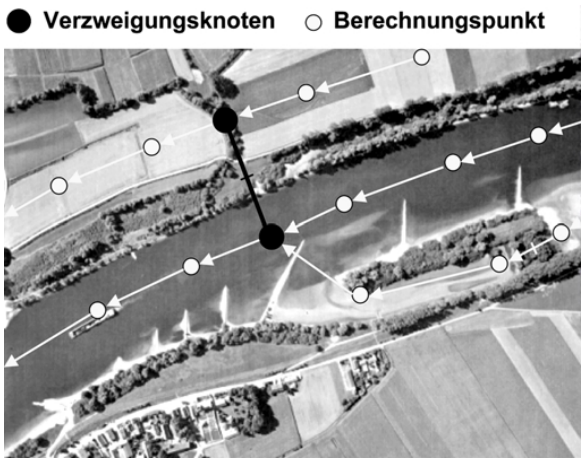

Bild 2: Auszug der Netztopologie bei Mariaposching

Zur Erhöhung der Aussagegenauigkeit wurden verzweigte und vermaschte Modelle eingesetzt. Einen Auszug der Netztopologie zeigt Bild 2. Im rechten Vorland wurde ein eigenständiger Strang angelegt. Um Austauschvorgänge zu simulieren, sind in regelmäßigen Abständen Querverbindungen vorgesehen. Auch am linken Ufer wird der Bereich hinter der Insel durch einen Strang modelliert. Da die Insel im Oberwasser einen Landanschluß besitzt, wurde an dieser Stelle ein Wehrelement vorgesehen, so dass die Simulation von Ansprungbedingungen gewährleistet ist.

Die Kalibrierung der fließtiefenabhängigen Rauheitsbeiwerte erfolgte in drei Stufen (Bild 3). Bei Niedrigwasserabflüssen wird die Systemrauheit im Wesentlichen durch die Kornrauheit des morphologisch aktiven Bereichs bestimmt. Da bei diesen Abflüssen in der Regel kein Sedimenttransport stattfindet, ist eine Formrauheit im Sinne einer „worst case“-Betrachtung für Ökologie und Schifffahrt nicht zu berücksichtigen. Diese Rauheitsbeiwerte wurden zwischen den Regelungselementen anhand der Kornverteilungen gemessener Sohlproben geschätzt (Söhngen, 1995) und mit gemesenen Niedrigwasserfixierungen überprüft. Bei höheren, bis etwa bordvollem Wasserständen ist die Rauheitswirkung von Buhnen und Parallelwerken mit parameterbehafteten Ansätzen (Ritzert et al., 1998) zusätzlich zu berücksichtigen. Zur Verbesserung der zu wählenden Parameter wurden in einem Forschungs- und Entwicklungsvorhaben dreidimensionale Berechnungen an einem schematisierten Recheckgerinne durchgeführt. Die Dimensionen orientierten sich dabei an typischen Maßen der Donau. Dabei wurden verschiedene Parameter wie z.B. Fließtiefe, Buhnen- bzw. Parallelwerkshöhen und –abstände variiert und die Teilabflüsse im Hauptquerschnitt und Buhnen- bzw. Parallelwerksbereich bestimmt. Vergleichsrechnungen mit dazu erstellten eindimensionalen Modellen lieferten

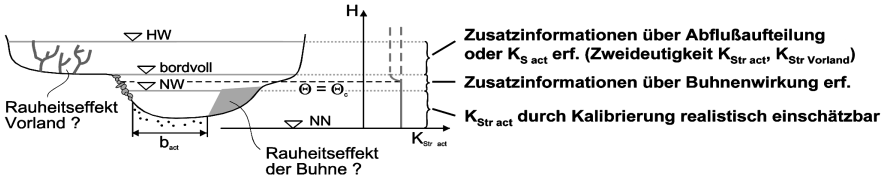

Bild 3: schematische Darstellung fließtiefenabhängiger Rauheitsbeiwerte

verbesserte Schätzungen der verwendeten parametrisierten Ansätze.

Bei Hochwasserereignissen ist die Systemrauheit um das Vorland zu erweitern. Um die Prognosefähigkeit der Modelle zu gewährleisten, sind die oben genannten Einflüsse getrennt und gemäß ihrer physikalischen Ursachen möglichst genau zu erfassen. Da mit steigenden Wasserständen der Sedimenttransport in der Regel zunimmt, ist auch zunehmend ein Rauheitseinfluß durch Transportkörper zu erwarten. Da das System nun zwei Freiheitsgrade (Form- und Vorlandrauheit) besitzt, sind weitere Annahmen erforderlich. Zur Schätzung der Vorlandrauheiten dienten Luftbilder mit abgebildetem Bewuchs. Mit Hilfe von Rauheitstabellen wurde die Vorlandrauheit ermittelt. Die Formrauheit wurde mit empirischen Ansätzen berechnet (Söhngen et al. 1996). Die sich daraus ergebenden rechnerischen Wasserspiegellagen wurden mit gemessenen Hochwasserereignissen überprüft.

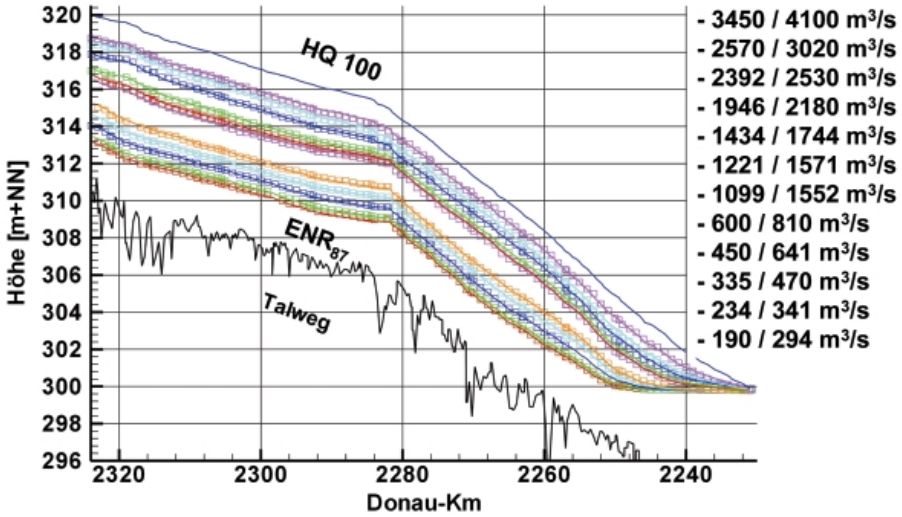

Bild 4: Ergebnisse der Kalibrierung: Wasserspiegellagen, Modell 1990

Der Bereich des Isarschüttkegels ist morphologisch die Kontrollstelle des Untersuchungsgebiets und unterliegt in Folge unterschiedlicher hydrologischer Verhältnisse der Einzugsgebiete von Donau und Isar starken Veränderungen in Größe und Gestalt. Im Frühjahr bei den Donauhochwasserereignissen wird ein Teil des Schüttkegels abgetragen, im Frühsommer bei den Hochwasserereignissen der Isar wird er durch Geschiebeeinträge wieder aufgebaut. Um Abweichungen in den Berechnungen der Wasserspiegellagen zu minimieren, wurden aus den zu Verfügung stehenden Querprofilpeilungen des Isarschüttkegels (Söhngen et al., 1992) ein gemittelter Zustand hergestellt, mit dem die Kalibrierung durchgeführt wurde.

Die Ergebnisse der Kalibrierung sind in Bild 4 dargestellt. Es zeigt die berechneten und gemessenen Wasserspiegel auf der Basis des Modells mit Peilzustand 1990. Zum Vergleich wurde zusätzlich noch der berechnete Wasserspiegel des HQ_{100} eingetragen. Abweichungen der berechneten von gemessenen Werten lassen sich im Wesentlichen durch morphologische Veränderungen insbesondere im Bereich der Isarmündung erklären. Dies hat eine direkte Auswirkung auf die Wasserspiegellagen des Bereichs der Donau oberstrom der Isarmündung. Durch die Verwendung gemittelter Querprofile im Bereichs des Schüttkegels liegen einige der berechneten Wasserspiegel zu hoch, während andere zu niedrig sind. Durch die kleinen Gefälle bleiben Abweichungen relativ weit nach oberstrom erhalten. Bei gesonderten Berechnungen der Teilstrecke oberstrom der Isarmündung zeigen sich nur geringe Abweichungen, da an dieser Stelle der gemessene Wert als Randbedingung vorgegeben wird.

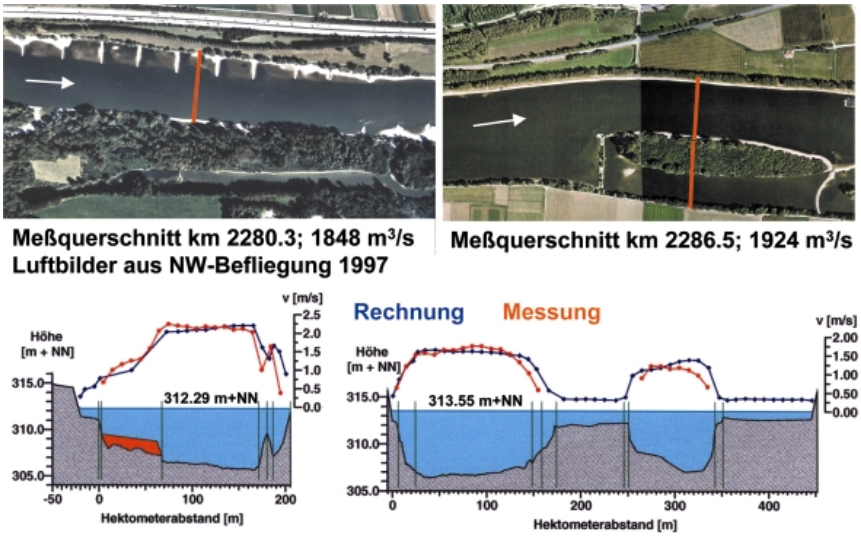

Bild 5: Auswertung der Geschwindigkeitsmessung vom 3.11.1998 im Vergleich mit dem 1D-HN.Modell der Peilung 1998

Der direkte Vergleich der mit dem Modell der Peilung 1998 prognostisch, also ohne weitere Anpassung der Reibungsbeiwerte, gerechneten Wasserspiegellagen zeigt eine vergleichbare Genauigkeit wie die Kalibrierungsergebnisse mit Modellzustand 1990. Durch die gute Übereinstimmung wird die Prognosefähigkeit des Modells bestätigt. Weiterhin wurden vorliegende Geschwindigkeitsmessungen, die bei dem Hochwasser im November 1998 ermittelt wurden, bezüglich des Abflusses im Hauptquerschnitt ausgewertet und mit berechneten Abflüssen verglichen. Dabei ergab sich eine mittlere Abweichung Abflüsse im Hauptquerschnitt von ca. 1% bei einer Standardabweichung von ca. 6%. Darüber hinaus sind auch direkt die Geschwindigkeits*verteilungen* verglichen wurden. In Bild 5 sind beispielhaft die berechneten und am 3.11.1998 gemessenen Geschwindigkeitsprofile dargestellt. Hierzu wurde mit dem berechneten Reibungsgefälle die Fließgeschwindigkeiten in den gleichen Streifen des Hauptgerinnes ermittelt, in denen auch die Messungen ausgewertet wurden. Dieser direkte Vergleich der Geschwindigkeits*verteilungen* kann nur dann zu guten Übereinstimmungen führen, wenn die Abflußverteilung über dem Querschnitt im Wesentlichen von der Fließtiefe gesteuert wird. In Bereichen mit Querimpulseinträgen bzw. Sekundärströmungen z.B. aus Krümmungen können nur grob angenäherte Aussagen über die Fließgeschwindigkeits*verteilung* gemacht werden. Da die beiden Beispiele diesem Kriterium genügen, zeigen sie eine gute Approximation der Geschwindigkeits- und somit auch der Abflußaufteilung. Auch die bei Donau-km 2280,3 durchgeführten Messungen im Buhnenfeld und im Vorland bei km 2286,5 zeigen gute Übereinstimmungen mit der Berechnung, die die Modellannahmen bestätigen.

Modellerstellung der Planungsvarianten

In den bereits vorgestellten Planungsvarianten soll für schifffahrtsrelevante Wasserstände zur Erreichung gleichmäßiger, größerer Fließtiefen im Bereich der Fahrrinne u.a. das Regelungskonzept angepaßt bzw. erweitert werden. Daher folgte die BAW für die Planungsvariante A und in den freifließenden Abschnitten der Variante C den von Kuhn formulierten Grundsätzen: „Die Niedrigwasserregelung strebt eine Linienführung und eine Querschnittsgeometrie der Art an, dass der Fluß mit Hilfe des strömenden Wassers sich sein Bett selbst umbildet und das benötigte Fahrwasser schafft. Damit wird das Flußbett als natürlich gewachsenes Gebilder stabiler als eine künstlich aufgezwängte Form“ (in Bretschneider et al. (Hrg.), 1993). Somit sind, im Sinne eines morphologisch stabilen Regelungskonzeptes, Sohlhöhenänderungen auf Grund von Baumaßnahmen zu berücksichtigen. Da die morphologischen Änderungen mit den eingesetzten Untersuchungsmethoden nur grob ermittelt werden können, sind die Ergebnisse im Sinne des erreichbaren Fahrrinnentiefe, nicht aber im Sinne einer abgeschlossenen Planung zu interpretieren.

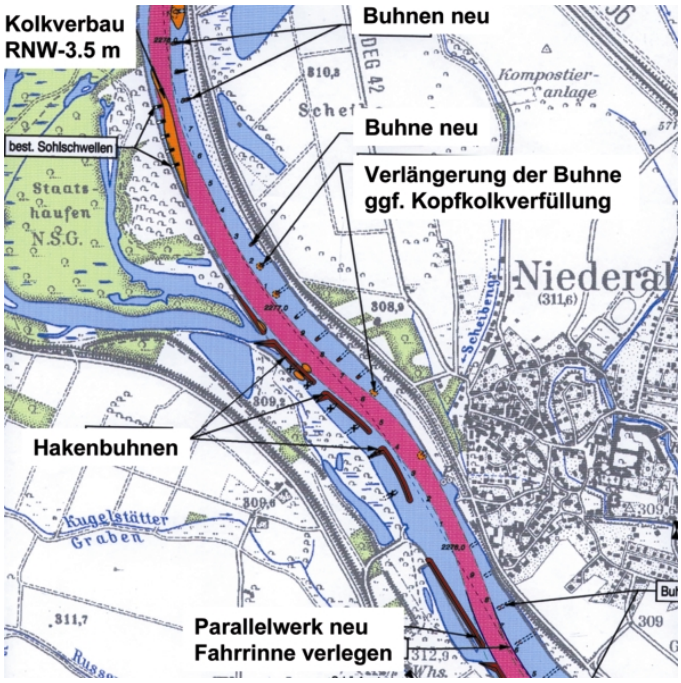

Bild 6: Lageplan eines Ausschnitts möglicher Regelungsmaßnahmen, Variante A

Daraus ergibt sich, dass, wie Kuhn weiter schreibt, „die Niedrigwasserregulierung nicht eine einmalige, kurze Baumaßnahme ist, sondern sich über einen längeren Zeitraum erstreckt“. In Bild 6 ist ein Ausschnitt am Beispiel eines möglichen erweiterten Regelungskonzeptes zur Variante A dargestellt. Die zu ergreifenden Maßnahmen zur Änderung des Regelungskonzeptes umfassen die Anpassung bestehender Buhnen und Parallelwerke, den Neubau von Buhnen und Parallelwerken, Ufervorschüttungen bzw. Kiesbankaufhöhungen, Kolkverbau und Fahrrinnenverlegungen zur besseren schifffahrtlichen Ausnutzung der Querschnitte nach Einbau von Regelungsmaßnahmen.

Mit Ausnahme der Fahrrinnenverlegungen haben alle anderen Methoden durch Änderung der hydraulischen Kenngrößen der Fließtiefe und Reibungsgefälle einen Einfluß auf die Flußmorphologie. Die Ermittlung morphologischer Änderungen in den Modelluntersuchungen werden unter Verwendung der folgenden Annahmen durchgeführt:

- Die Korngrößen werden durch die Veränderungen nicht wesentlich beeinflußt, da durch die Schifffahrt bei Niedrigwasserverhältnissen eine mögliche natürliche Abpflasterung der Sohle wieder aufreißen kann,
- die Wasserspiegel bleiben nahezu unverändert,
- die Gefälleverhältnisse ändern sich nicht signifikant,
- die örtliche, rechnerische Jahresgeschiebefrachtkapazität basiert auf der langjährigen Dauerlinie und muß auch für den künftigen Zustand erhalten bleiben,
- die rechnerische Jahresgeschiebefracht basiert auf dem Zustand der Peilung 1998 und ist durch heutige Baggerungen beeinflußt,

- morphologische Sohlhöhenänderungen können durch Parallelverschiebung der Sohle im transportwirksamen Bereich approximiert werden (eindimensionale Betrachtung).
- Sohlsicherungsmaßnahmen erfolgen, mit Ausnahme von Kolkabdeckungen, durch Geschiebemanagement

Daraus ergeben sich folgende Schlußfolgerungen:

- Die Rauheitsbeiwerte bleiben unverändert,
- die für die morphologischen Verhältnisse des IST-Zustandes angepasste Transportgleichung bleibt erhalten,
- die durch die Modifikation an den Regelungselementen hervorgerufene Veränderung der Jahresgeschiebefracht wird nur durch Sohlhöhenänderung auf das Maß des Ausgangszustands 1998 gebracht,
- die Anpassung der Sohlhöhenänderung erfolgt lokal, es wird angenommen, dass benachbarte Querprofile nicht beeinflußt werden,
- bisherige Unterhaltungsmaßnahmen des Modellzustandes 1998 sind auch in Ausbauvarianten zur Erhaltung der Querprofil*form* erforderlich.

Die Ermittlung der resultierenden Sohleintiefung ist durch die vergleichende Betrachtung vor dem Hintergrund der erforderlichen Untersuchungstiefe einer politischen Richtungsentscheidung ausreichend genau.

Die eingesetzten Modellverfahren erlauben keine „morphodynamische“, also instationäre Beschreibung der morphologischen Veränderungen, sondern nur „morphostatische“, die den Endzustand der Veränderungen bei gegebener Jahresgeschiebefracht und Wasserstände beschreibt. Analog zu morphodynamischen Modellen werden in morphostatischen Modellen die Sohlveränderungen in einer parallelen Sohlabsenkung im Bereich des morphologisch aktiven Betts berücksichtigt. Wesentliche Annahme ist, dass sich die Donau des Ausgangszustandes sich im morphologischen Gleichgewicht befand und für einen stabilen Zustand in Zukunft sich im langjährigen Mittel wieder die gleiche rechnerische, auf der Basis des Modells mit dem Peilzustand 1998 ermittelte Jahresgeschiebefracht einstellen wird. Eine Beispielrechnung dieser Vorgehensweise anhand realer Verhältnisse zeigt Bild 7. Durch einen Neubau einer Buhne am linken Ufer ergeben sich höhere Fließgeschwindigkeiten. Daraus resultieren größere Sohlschubspannungen die durch eine Sohleintiefung von rd. 4 dm kompensiert wird. Diese Sohleintiefung (gelbe Fläche) wirkt auf die gesamte Breite des morphologisch aktiven Bereichs.

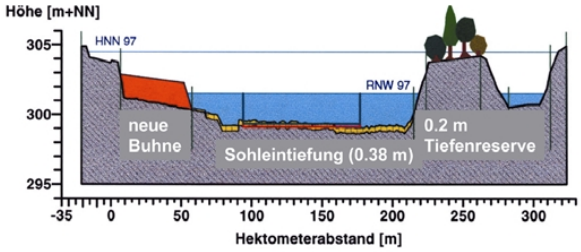

Bild 7: Morphologische Wirkung durch Regelungsmaßnahmen am Beispiel einer

Eine allgemeine morphologische Zustandsbeschreibung der Donau wurde bereits im Rahmen des Raumordnungsverfahrens erarbeitet. Umfangreiche Sohlerhebungen lieferten Datenmaterial für Kornverteilungen und Geschiebetransport (Söhngen et al., 1992), die durch fortlaufende Datenerhebungen ergänzt wurden. Diese Informationen wurden für die morphologische Kalibrierung verwendet. Die Berechnung des Geschiebetransportes wurde auf der Basis der in der BAW für die Donau ermittelte Transportgleichung ermittelt (Söhngen et al., 1996). Die auf dieser Basis mit dem Ausgangszustand 1998 berechnete mittlere Jahresgeschiebefracht werden durch Massenbilanzen bestätigt.

Die Erstellung der Planungsvarianten erfolgt in zwei (IST-Zustand 2000) bzw. drei Schritten (Variante A und C). In einem ersten Schritt werden die geplanten Regelungselemente in den Modellen verändert bzw. neu eingebaut und deren morphologische Wirkung ermittelt. Da durch die Staustufe der Variante C ein mit flußregulierenden Maßnahmen gestützter Wasserspiegel für schifffahrtliche Belange im Bereich Isarmündung – Staustufe voraussichtlich nicht erforderlich sein wird, kann durch Reduktion der Zugabemengen eine kontrollierte Sohleintiefung und damit verbunden, größere Fließtiefen erreicht werden. Diese Maßnahme wirkt auf alle Querschnitte des Hauptquerschnitts. In einem letzten Schritt werden dann für alle Varianten die mögliche Fließtiefe im Bereich der Fahrrinne durch zusätzliche Unterhaltungsmaßnahmen hergestellt. Die Herstellung der Planungsvarianten erfolgt unter der Randbedingung begrenzter Wasserspiegeländerungen. Diese Randbedingung soll die ökologischen Folgen begrenzen und die Hochwasserneutralität gewährleisten.

Prinzipiell können durch geeignete Dimensionierung von Regelungsbauwerken die Unterhaltungsmaßnahmen reduziert werden. Eine solche Dimensionierung ist jedoch mit eindimensionaler Modelltechnik nicht genau genug möglich, da hier u.a. der morphologische Einfluß der Strömung auf die Querprofilform nicht berücksichtigt werden kann. Die gewählte Vorgehensweise ist hinsichtlich der späteren Ermittlung der Kosten für Unterhaltungsmaßnahmen auf der sicheren Seite.

Bild 8 beschreibt die Ermittlung der Sohlhöhenänderungen im Falle von Kolkverbaumaßnahmen. Bei einer Erosion in den anstehenden Tertiär wird durch einen Kolkverbau der Kolk abgedeckt und mit einem Deckwerk gesichert. In Folge der verbauten Fläche und der erhöhten Rauheit im Bereich des Kolkverbaus ist eine Erosion der Kiesbank zu erwarten. Um das Maß dieser Veränderung abzuschätzen, wurde in einer Parameterstudie mit eindimensionalen Modellansätzen das Reibungsgefälle, die transportwirksame Sohlschubspannung und die Erosionstiefe mit mehreren unterschiedlichen Ansätzen berechnet und die Ergebnisse miteinander verglichen. Daraus wurde für jede einzelne Kolkverbaumaßnahme die Sohleintiefung abgeschätzt.

Die in dem letzten Schritt durchgeführten zusätzlichen Unterhaltungsmaßnahmen werden modellseitig durch Baggerungen berücksichtigt. Nach üblicher Unterhaltungspraxis wird die Sohle bei erforderlichen Baggermaßnahmen zur Berücksichtigung von Ungenauigkeiten der Baggerung sowie einer Gewährleistung des Sollmaßes der Fahrrinnentiefe lokal ca. 2 dm tiefer hergestellt. Unter der Annahme, dass erst wieder im Rahmen der Unterhaltungsbaggerung die Fahrrinne erneut gebaggert wird, wenn die Anlandungen das Fahrrinnenniveau erreicht haben, wird zur Herstellung der Modellquerschnitte von einem zeitlichen Mittelwert von 1 dm ausgegangen.

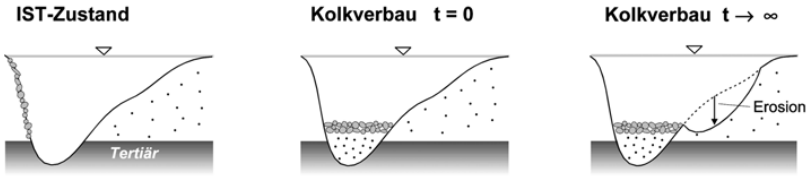

Bild 8: Morphologische Wirkung durch Regelungsmaßnahmen am Beispiel eines Kolkverbaus

Schlußfolgerungen

Das Untersuchungsgebiet weist komplexe Zusammenhänge der Strömungsverhältnisse und Morphologie auf. Um zu fundierten Aussagen künftig erreichbarer Schifffahrtsverhältnisse sowie ökologischen Randbedingungen zu gelangen, ist es erforderlich, diese Phänomene möglichst sorgfältig zu erfassen. In der Kalibrierungsphase zeigte sich, dass mehre Modelle und die Berücksichtigung möglichst vieler Naturdaten erforderlich waren, eine tragfähige Basis zur Erstellung der Planungsvarianten zu erhalten.

Zur Berechnung künftiger Wasserspiegellagen wird häufig die Wasserspiegel stützende Wirkung von Regelungsmaßnahmen überschätzt, da keine Sohlveränderungen berücksichtigt werden. Das dennoch solche Maßnahmen in Sinne der Verbesserung der Schifffahrtsverhältnisse dienlich sind, liegt an der sich vergrößernden Fließtiefe auf Grund von Erosionserscheinungen. Die Ermittlung der künftigen Zustände ist mit den für diese Untersuchung eingesetzten Instrumentarien nur grob zu erfassen. Durch eine vergleichende Betrachtung kann für eine politische Richtungsentscheidung eine ausreichende Aussageschärfe erzielt werden. Im Falle einer Umsetzung von Regelungsmaßnahmen ist immer eine erhöhte Aufmerksamkeit durch den Betreiber der Wasserstraße erforderlich.

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Soil Erosion and Sediment Transport in the Torrents Of Serbia

Stanimir Kostadinov

Abstract: Based on field research, in the paper the results of investigation of sediment transport in some torrential streams of Serbia (the Danube watershed) are presented and possibility of calculation of annual sediment transport, when the measurements are not at disposal.
For the forecast of average annual sediment transport (suspended and bedload) in hydrological not sufficiently investigated watersheds (without measurement data) in the watershed management practice of Serbia the methods by Gavrilovic and Polyakov was used. In the latest years is used the method: Modified method of Polyakov (Polyakov-Kostadinov). The modification of Polyakov method consist of the calculation of average annual turbidity of water based on the newly introduced parameter "pluvial-erosion index".
The research in the experimental watersheds in Serbia has shown that above mentioned methods, particularly that by Polyakov, deviate significantly from the results of field measurement. On the other hand, the results of the Modified Polyakov-Kostadinov method are quite close to measured data.
Key words: soil erosion, sediment transport, torrents calculation, pluival-erosion index.

Bodenerosion und Geschiebetransport in serbischen Wildbächen

Zusammenfassung: Geründet auf Feldforschung im Beitrag werden die Resultate der Untersuchung des Geschiebetransportes in einigen Wildbächen von Serbien (das Donaueinzugsgebiet) und Möglichkeit der Berechnung des jährichen Geschiebetransportes dargestellt, wenn die Messen nicht zur Verfügung stehen.

Für die Prognose des mittleren jährlichen Geschiebetransportes (Schwebstoff- und Feststofftransport) in hydrologisch nicht genügend nachforschen Einzugsgebieten (ohne gemessene Daten) werden im bisherigen Praxis der Wildbachverbauung in Serbien die Methode von Gavrilovi} und Polyakov verwendet. In letzten Jahren wird neue Methode - Geänderte Methode von Polyakov (Polyakov-Kostadinov) verwendet. Die Änderung der Methode von Polyakov besteht aus der Berechnung der mittleren jährlichen Trübung des Wassers, die auf dem eben eingeführten Parameter "Pluvioerosionsindex" basiert.

Die Forschung in den experimentallen Wildbacheinzugsgebieten in Serbien hat gezeigt, daß obenwähnte Methoden, besonders die Methode von Polyakov, erheblich von den Resultaten der Feldvermessung abweichen. Anderseits sind die Resultate der Geänderten Methode von Plyakov-Kostadinov durchaus nehestehend an gemessenen Daten.

Schlüsselwörter: Bodenerosion, Geschiebetransport, Berechnungen, Pluvioerosionsindex

Introduction

Erosion and sedimentation are part of the natural evolution of the landscape, but they constitute some of the most fundamental problems for the development of agriculture ,forestry and for utilization of natural resources.

In spite of the importance of this problem, it is a fact that sufficiently exact and cheap methods of sediment transport measurement in the open streams, and especially in the torrents, have not yet been worked out. The phenomenon of sediment transport is a very complex, but not enough researched problem in the fields of torrent hydrology and hydraulics. Due to a high concentration of sediment, with a wide range of sizes (from the finest particles to the large pieces more than 2 *m* in diameter), as well as due to great speeds of torrential flows, classical hydrometric methods cannot be applied for the measurement of water discharge and sediment transport, and the measurements are very difficult and very expensive.

This is the reason that for the forecast of average annual sediment transport (suspended and bedload) in hydrologically not sufficiently investigated watersheds (without measured data of sediment transport), in the watershed management practice of Serbia, the methods by Gavrilović (Gavrilović, 1972) and by Polyakov (Polyakov, 1948) were used. The new method used in the latest years is the Modified Polyakov's Method (Method by Polyakov-Kostadinov) (Kostadinov, , 1993).

This paper presents the results of research of sediment transport in some torrents of West and Southeast Serbia and the possibility of calculation of average annual sediment transport when field measurements are not at disposal.

Soil Erosion And Sediment Transport In Serbia

Serbia is in the central part of the Balkan Peninsula and extend 88,361 km^2 (Fig.1) This territory consists of two different regions: the large Vojvodina plain to the north and the hilly and mountainous area to the south, with the Danube and Sava rivers representing the border between them. Geomorphological features of the Serbian territory are strongly related to the soil erosion problems: wind erosion predominating in the northern plain, and water erosion in the southern region. The further review of erosion problems relates to the soil erosion by water.

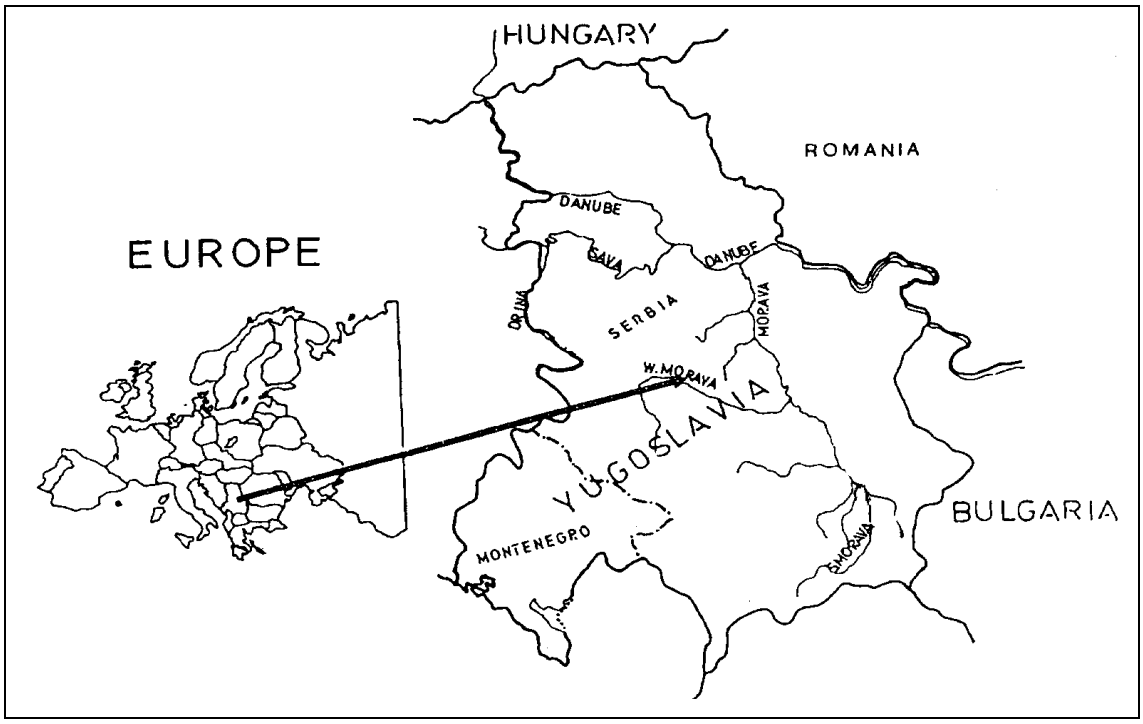

Fig. 1 Study area

Water erosion depends on a number of physical-geographical and antropogeneaus factors, consequently in order to define the state of water erosion in Serbia have been analyzed: parent rock, composition relief, climate, vegetal cover (land use). All the analyzed factors of presents the favorable conditions for water erosion processes. As the consequence of such natural conditions 86.41% of teritory of Serbia is under erosion processes of different intensities (from the low to the excessive erosion).

The share of certain categories of erosion intensity, i.e. erosion intensity in stream channel and in watershed, according to S. Gavrilović's classification, has been analyzed based on erosion map prepared by S. Gavrilović's method (Gavrilovic, S., 1972)(Table 1).

According to Gavrilović, the watersheds have been classified into five categories with the following coefficients of erosion (Gavrilović, 1972) :

I cat. - Excessive erosion, $1.01 < Z < 1.5$, average 1.25;

II cat. - Intensive erosion, $0.71 < Z < 1.0$, average 0.85;

III cat - Medium erosion, $0.41 < Z < 0.70$, average 0.55;

IV cat.- Weak (low) erosion, $0.20 < Z < 0.40$, average 0.30;

V cat. - Very weak (low) erosion, $0.01 < Z < 0.19$, average 0.10.

The coefficient of erosion Z is a numerical expression of the intensity of soil erosion in the watershed.Coefficient of erosion is calculated based on erosion map of the watershed and the formula given by the author (Gavrilović, 1972).

Water erosion causes great damages, such as: soil loss, water loss, loss of nutrients, dusturbance of runoff regime in the watersheds, catastrophic floods, reservoirs siltation etc.. Damages initially caused by erosion is the loss of the upper fertile soil horizon, coupled with loss of organic and mineral nutrients from steep and ploughed land, leading to inadequate air and water relations in the soil. The damage caused by water erosion results from detaching and transporting the fertile soil horizon from the slopes, as well as from torrential flows. Erosion removes organic and mineral nutrients from the top soil, the soil structure is destroyed leading to the disturbance of soil characteristics of air and water relationship.

Sediment transport related to gross erosion (total erosion production), is also considerable. Total average annual gross erosion in Serbia amounts 37,249,975.0 m^3, i.e. specific annual gross erosion amounts to 421.57 $m^3 \cdot km^{-2}$ while annual sediment transport is 9,350,765.0 m^3 and specific annual sediment transport is 105.80 $m^3 \cdot km^{-2}$. If annual gross erosion is turned into equivalent hectares of soil 20 cm thick, it can be concluded that every year 20,525 ha is endangered.(Đorđević, M., et al.1987).

Table 1 Distribution of Water Erosion Processes in Serbia

Category	**Erosion Processes Intensity**	**Area**	
		km^2	**%**
I	Excessive Erosion	2,888.0	3.27
II	Intensive Erosion	9,138.0	10.34
III	Medium Erosion	19,386.0	21.94
IV	Weak Erosion	43,914.0	49.78
V	Very weak Erosion	13,035.0	14.75
Total		88,361.0	100

Source:Water Resources Management Basic Plan of Serbia, 1996

In Serbia, erosion regions with the most disastrous torrents are in the gorges Grdelička Klisura and Ibarska Klisura, Vranjska Kotlina valley as well as the watershed of the river Timok.

One of the main characteristics of the torrential hydrological regime is a clearly expressed unsteadiness of hydrological phenomena. High waters (flood waves) occur occasionally after showers or sudden snow melting, with sudden inflow and relatively short duration. On the other hand, in a warm season, torrents are dry (without water). Consequently, water and sediment discharges during a year vary considerably. That is why in the torrents more than 80% of total annual discharge and 90% of total annual sediment transport are in the form of flood waves.

Subject And Method of Research

Study Area

The research was carried out in three small experimental watersheds in West Serbia: Dubošnički Potok, Lonjinski Potok and Djurinovac Potok and in the watershed Lještarska Dolina in Southeast Serbia (Fig. 1).The watersheds belongs to the group of hilly-mountainous watersheds. The main prameters of the watersheds are given in Table 1.

Table 2 Parameters of the Watershed Areas

Parameters	**Symbol**	**Dubošnički potok**	**Lonjinski potok**	**Djurinovac potok**	**Lještarska dolina**
Watershed area	F - km^2	1.25	0.76	0.54	2.64
Watershed perimetre	O - *km*	5.25	3.60	3.55	9.70
Watershed length	L_{gl} - *km*	2.48	1.40	1.40	4.10
Drainage density	G- $km \cdot km^{-2}$	3.26	2.38	4.04	3.34
Local erosion basis	B_e - *m*	490.50	295.20	246.80	551.50
Mean elevation of the watershed area	N_{sr} - m	487.90	363.90	299.70	722.70
Mean altitudinal difference of the watershed area	D - *m*	243.40	159.10	106.50	324.20
Mean slope of the watershed area	I_{sr} - %	47.24	38.87	43.59	32.07
Stream-bed slope	I_t - %	18.37	18.94	12.63	13.45
Erosion coefficient (Gavrilović)	Z	0.56	0.34	0.49	0.52
Erosion coefficient (Polyakov)	α	3.11	1.93	2.66	2.88
Coefficient of erosion risk	Ke	0.2534	0.0559	0.1324	0.3025

Method

According to the aims of the research, in the selected experimental watersheds, discharge measurements as well as suspended sediment and bedload transports, were recorded by means of regulated hydrometric profiles. Precipitation data were also recorded.Water discharge was measured by a measuring rod and by a limnigraph. Suspended sediment transport was measured by taking samples of water and by determining the concentration of solids. The concentration was determined by filtration method. Water sampling was carried out every day, and during the periods of flood wave, it was repeated several times during the wave. Bedload transport was easured by volume method. The sediment was retained in an accumulation space of check dams. Bedload transport was measured after every flood wave by means of the precise level method.Based on the measurements at the cross sections, the balance was made of water disharge and suspended sediment, bedload and total sediment load for individual flood waves, for days, months and for the whole year.

Annual sediment transport was calculated for the period of sediment transport measurement, using Gavrilović's (Gavrilović, 1972) and Polyakov's (Polyakov, 1948) methods. As the above calculations showed significant deviations from field measurements, some of these methods had to be adapted to get the results nearer to the measured values. In this sense, Polyakov's formula could be more easily modified due to its structure. Polyakov's method gives too high results because in the calculation of average annual turbidity based on the coefficient of erosion after

Polyakov - α, too high values are obtained for the conditions in Serbia. For this reason, Polyakov's method was modified (Kostadinov, 1993). The modification of Polyakov's method consists of the calculation of average annual turbidity of water based on the newly introduced parameter "pluvial-erosion index"- Pez (Kostadinov, 1985). Analytical dependence for the calculation of average annual turbidity is:

$$\rho_z = 0.2982 \cdot P_{ez} + 0.0049 \qquad \text{(Kostadinov, 1985)},$$

ρ_z – average annual turbidity in $kg \cdot m^{-3}$; Pez- pluvial-erosion index

$$P_{ez} = 100 \cdot \eta \cdot K_e \qquad \text{(Kostadinov, 1985)}$$

η - relation between maximum daily and annual precipitation,

$$\eta = \frac{h_{\max}}{H_{year}},$$

$h_{\max}$ - average value of maximal daily precipitation in a year, in *mm*,
H_{year} - average value oa annual precipitation, in *mm*.

$$K_e = \frac{F_u}{F},$$

F_u - part of watershed area affected by soil erosion (plowland, bare land, unproductive land and other land affected by soil erosion), in km^2;
F- watershed area, in km^2.

The main idea in the above expression is the attempt to link the main agents of sediment yield and transport, i.e. water (precipitation) and soil erosion processes in the watershed. It is known that total annual precipitation, H year, is not the decisive factor of soil erosion and sediment transport, a more significant influence is that of precipitation intensity. In the situation when there are no pluviographs in the watershed, but only simple rain gages (which is mainly the case in Serbia), this is the way (maximal daily rainfall in a year) to express the effect of precipitation intensity. As sediment in torrents is transported only in flood waves occurring after intensive showers, this is a potential method of solving the problem.

After calculation of average annual turbidity, calculation of average annual sediment transport (total sediment) is possible according in the Polyakov's method (Polyakov,B.V.,1948).

Results of Research And Discussion

Table 3 shows the precipitation and sediment transport (suspended and bedload) measurements per years, in four experimental watersheds. The symbols in the Table 3 denote:

$h_{\max}$ - average value of maximal daily precipitation in a year, in *mm*,
H_{year} - average value oa annual precipitation, in *mm*,
M_R - annual specific transport of suspended sediment, in $m^3 \cdot km^{-2} \cdot year^{-1}$
M_V - annual speific transport of bedload, in $m^3 \cdot km^{-2} \cdot year^{-1}$;
M_G - annual specific transport of total sediment in $m^3 \cdot km^{-2} \cdot year^{-1}$.

Table 4 presents the results of the calculation of mean annual sediment transport (total and specific) in the experimental watersheds according to empirical methods, as well as average measured values. The calculations were done by the following methods: Gavrilović's, Polyakov's, and modified Polyakov-Kostadinov's method. Input data were the watershed parameters (Table 1), the state of erosion in the watershed (field investigations) and average measured values of annual and maximal daily precipitation for each watershed in the study period (Table 3). In this way, we calculated the average values of total annual (m^3 $year^{-1}$) and specific annual transport of total sediment (m^3 $year^{-1}$ km^{-2}). Table 4 also shows the average measured values of these parameters of sediment transport regime in the watersheds.

Table 3 Annual Characteristics of Precipitation and Sediment Transport

NAME OF WATERSHED	YEAR	PRECIPITATION		SEDIMENT TRANSPORT		
		H_{year}	h_{max}	M_R	M_V	M_G
		mm		$m^3 \cdot km^{-2}$		
DUBOŠNIČKI POTOK	1980	1020.3	47.5	57.91	225.10	283.01
	1981	984.5	42.3	81.55	30.91	112.46
	1982	794.8	31.5	76.46	34.86	111.32
	1983	687.3	28.2	28.26	14.69	42.95
	1984	705.5	45.0	254.22	52.45	306.67
	1985	509.5	42.2	44.33	256.65	300.98
	1986	722.6	32.0	32.67	33.76	66.43
	1987	873.0	47.0	316.01	464.55	780.56
	1988	602.1	36.0	3.31	0.00	3.31
	1989	747.1	28.0	106.98	57.99	164.97
average value		764.67	38.0	100.17	117.10	217.27
LONJINSKI POTOK	1980	1054.7	41.5	16.03	0.00	16.03
	1981	1011.2	45.2	38.01	0.00	38.01
	1982	779.6	41.5	48.16	0.00	48.16
	1983	768.0	49.4	40.26	0.00	40.26
	1984	906.1	46.2	64.31	0.00	64.31
	1985	591.3	26.0	13.46	0.00	13.46
	1986	612.2	27.1	3.01	0.00	3.01
	1987	995.5	76.9	119.84	0.00	119.84
	1988	737.1	54.1	90.98	0.00	90.98
	1989	875.2	38.0	32.63	0.00	32.63
	1990	700.0	35.5	12.97	0.00	12.974
	1991	1159.0	64.1	101.49	0.00	101.49
average value		849.16	45.5	48.43	0.00	48.43
DJURINOVAC POTOK	1981	1011.2	45.2	44.27	110.98	155.25
	1982	779.6	41.5	101.47	76.82	178.29
	1983	734.1	48.3	10.78	0.00	10.78
	1984	906.1	46.8	24.64	18.83	43.47
	1985	591.3	26.0	11.87	22.31	34.18
	1986	703.0	31.6	30.85	63.53	94.38
	1987	674.6	52.7	129.44	263.26	392.70
	1988	889.1	60.4	152.38	295.46	447.84
	1989	916.6	40.8	72.75	123.34	196.09
average value		800.62	43.7	64.27	108.28	172.55
LJEŠTARSKA DOLINA	1980	579.8	32.1	41.73	43.22	54.95
	1981	544.4	45.1	76.07	27.38	103.45
	1982	681.4	105.0	545.6	333.91	879.51
	1983	559.4	49.5	75.65	22.18	97.83
	1984	576.0	36.5	55.00	8.08	63.06
	1985	598.0	32.0	87.34	16.07	103.41
	1986	600.7	40.5	28.58	14.33	42.91
	1987	667.7	85.5	590.24	133.36	723.60
	1988	713.2	45.5	6.35	5.40	11.75
average value		613.4	52.4	167.39	63.77	231.16

The calculations show that the Polyakov-Kostadinov's method gives the results nearest to the measured values. Somewhat higher (1.5 to 3 times higher) results are obtained by Gavrilović's method of calculation, whereas the classical Polyakov's method produces significantly higher results (3.5 to 10 times higher) than measured data.

Table 4 Calculated and Measured Values of Average Annual Sediment Transport

Method		**Torrent**			
		Dubošnički Potok	**Lonjinski Potok**	**Djurinovac Potok**	**Lještarska Dolina**
Gavrilović	Total [m^3]	480.33	113.90	107.20	1,036.65
	Specific [$m^3 \cdot km^{-2}$]	385.40	148.77	197.06	393.07
Polyakov	Total [m^3]	2,855.40	763.72	892.93	2,108.20
	Specific [$m^3 \cdot km^{-2}$]	2,290.90	997.55	1,641.42	799.38
Modified Polyakov-Kostadinov	Total [m^3]	256.25	45.44	68.21	602.23
	Specific [$m^3 \cdot km^{-2}$]	205.60	59.35	125.39	228.35
Measured values	Total [m^3]	270.80	37.08	93.87	609.64
	Specific [$m^3 \cdot km^{-2}$]	217.27	48.43	172.55	231.16

Based on the comparative analysis of sediment transport measurements and calculations on the example of four experimental watersheds, it can be concluded that Polyakov-Kostadinov's and Gavrilović's formulae give the similar values of annual sediment transport as the measurement values, whereas the original Polyakov's formula gives different results (i.e. approximately 10 times higher than the measured data). This means that the former two formulae are more acceptable for the natural conditions in Serbia (which is understandable, because they were derived based on the measurements in Serbia). Still, it does not mean that Polyakov's formula is not good and physically correct. However, it was derived based on the conditions significantly different form those in Serbia. As empirical formulae can never be universal, their application in different natural conditions (than those for which they were derived and tested) requires verification and modification of individual parameters. It should also be noted that these two methods give good results of the average (mean) annual transport of total sediment, but if applied to a concrete year with given measured precipitation, there can be some deviations. For this reason, mean values of precipitation for a longer period should be given.

Conclusion

The study period with the results presented in this paper, is not long enough.Still, the following conclusions can be made:

1. Soil erosion by water is the most serious problem for the development and sustainaible utilization of natural resources in Serbia. More than 86% of total area of the country is attacked by water erosion. As the consequence of intensive processes of erosion in the watershed occur the torrents which are two-phase watercourses and causes catastrophic floods.
2. The study of sediment transport in torrents is a very difficult problem. In the torrent control practice in Serbia, suspended sediment is determined by the method of filtration of water samples. Bedload transport is determined by volume method. Volume method does not give the sediment transport in the second (time unit), but it is the best method for balancing the sediment in a time period (usually a year), which is important for the design of all types of work in watercourses, and especially storage reservoirs;

3. Because of the complexity of annual sediment transport calculation in hydrologically unresearched watersheds, those methods should be used that are tested in local natural conditions by direct field measurements, even in a shorter time period;
4. The results of the research in the experimental watersheds of West and Southeast Serbia show that Polyakov-Kostadinov's method (Modified Polyakov's Method) can be successfully applied in the calculation of mean annual sediment transport in torrential watersheds in Serbia. The modification of Polyakov's method consists of the calculation of average annual turbidity of water based on the pluvial-erosion index. As sediment transport is a very variable magnitude, and as the study period was not long, this method of calculation should be tested by further research in other regions and outside Serbia.
5. In the calculation of mean annual sediment transport in Serbia, in hydrologically unresearched watersheds, in addition to the proposed Modified Polyakov-Kostadinov's method, the Gavrilović's method should also be used.

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Quantification of Suspended Load Transport at the Slovak Section of the Danube River

Miroslav Lukáč

Abstract: The paper presented summarises the main results of the suspended load regime investigations, which have been carried out in the frame of the extensive research project, focused at the sediment transport in the Slovak section of the Danube river, upstream from the Čunovo reservoir. The reliable estimate of the amount of suspended load, transported by the river, is of big importance for the prognosis of reservoir sedimentation. Field „in situ“ measurements can provide the most reliable information about this phenomenon. The major goals of the analysis of suspended load transport were as follows: to determine regression relations between the suspended load discharge and water discharge, to analyze relation between the distribution of suspended load concentration and flow velocity pattern in the river cross-section and to determine grain size curves of transported suspended load. The results of project are of big importance for the water management practice in the Slovak section of the Danube river in the fields of sediment transport, morphological development of river channel, river training, flood control and navigation

Key words: sediment transport, suspended load, regression analysis, grain size curves

Quantitätsbestimmung der Schwebstofffűhrung im slowakischen Donauabschnitt

Zusammenfassung: Der Beitrag fasst die Hauptergebnisse der Schwebstoffregimeforschung, der im Rahmen eines umfangreichen auf den Sedimenttransport im slowakischen Donauabschnitt oberhalb des Beckens Čunovo orientierten Projektes zusammen. Eine verlässliche Abschätzung der im Fluss transportierten Schwebstoffmenge ist fűr die Vorhersage der Stauraumverlandung von groβer Bedeutung. In situ Messungen kőnnen die verlässlichsten Informationen űber diese Erscheinung gewähren. Folgende Hauptziele bei der Schwebstoff-transportanalyse wurden in Betracht genommen: Ableitung der Regressionsbeziehungen zwischen dem Schwebstoff- und Wasserdurchfluss, Analyse der Beziehung zwischen der Schwebstoffkonzentrationsverteilung und der Strőmungsgeschwindigkeit im Flussprofil und die Bestimmung der Kornzusammensetzung der transportierten Schwebstoffe. Die Projektresultate sind von groβer Bedeutung fűr die wasserwirtschaftliche Praxis im slowakischen Donauabschnitt auf dem Gebiet des Sedimenttransportes, der morphologischen Fluβbett-entwicklung, der Fluβregulierung, des Hochwasserschutzes und der Schifffahrt.

Schlűsselworte: Sedimenttransport, Schwebstoffe, Regressionsanalyse, Korngrőßeverteilung

1 Introduction

The research project “Investigation of the Danube river suspended load and bed load regime in the region of Slovak capital at the changed conditions” has been solved at the Water Research Institute in Bratislava in the period 1996-1998. The most complex field measurements of suspended load and bed load at the Slovak section of the Danube river have been carried out in the 50´s (Szolgay, 1960). The conditions of erosion-sedimentation processes and sediment transport substantially changed, comparing with that period. Construction of weirs at the Austrian section of the Danube river and the river training influence flow conditions, morphological development of the Danube river channel, navigation and flood control. Sediment transport conditions changed at the Slovak territory, too. Bed load and part of suspended load settle in the Čunovo reservoir, which results in the decrease of its utilisable volume.

The setup of a new quantitative balance of the sediment transport in the changed conditions, upstream from Bratislava, has been the main goal of the research project. It consisted from several parts. Two of them focused at the suspended load:

- "Balance of suspended load transport at the Danube river, depending on the hydrological conditions" (Lukáč, 1998a) and
- " Distribution of suspended load in the river cross-section influenced by the flow velocity pattern" (Lukáč, 1998b).

The paper summarises main results of project in the field of suspended load regime.

2 Methods of sampling

The samples of water were collected in two different ways. The method of depth integration was applied in the cross-section of the Lafranconi bridge in Bratislava, situated in the river km 1871,35, upstream from the Čunovo reservoir. The samples were collected in three verticals, by means of the sampler, which was developed in the Water Research Institute. The sampler of this type was also used for the collection of point-integrated samples in the measuring cross-section, situated in the river km 1878,15, downstream from the Danube and Morava rivers confluence. In this cross-section, the samples have been collected in at least 4 verticals from the ship. Simultaneously, the water velocity has been measured in the same verticals, in order to analyse relation between the flow velocity pattern and the distribution of suspended load in the cross-section. The samples were analysed in the Hydroanalytical Laboratories of the Water Research Institute, using the method prescribed by the standard.

In the period 1996-1998, almost 300 samples have been collected in the bridge cross-section. Discharge ranged between 850 and 7300 $m^3.s^{-1}$, in this period. Average annual discharges for this three years are of values close to the long-term average. During the period of higher discharges, the samples were collected several times a day. The maximum measured concentration of suspended load was 786 $mg.l^{-1}$. The point-integrated samples have been collected in the measuring cross-section totally 19 times, in 5 levels of each vertical. These measurements covered the period from August 1997 to November 1998 and the range of discharge 1050 – 4300 $m^3.s^{-1}$. The analysis of suspended load grain size distribution was one of the project goals, therefore it was necessary to collect also the samples of higher volume (approx. 40 l) by means of pump. Grain size distribution was determined in the Research Institute of Chemical Technology, using the laser equipment Analysette.

3 Suspended load grain size distribution

The samples for the analysis of suspended load grain size distribution have been collected 4-times – in July 1997, October 1997, May 1998 and September 1998, under the discharges from 1200 – 3500 $m^3.s^{-1}$. The resulting grain size curves are plotted in the figure 1. For the comparison, we have also included here the results of analysis from 1991. It can be stated, that the curves are very similar. The major part of particles – around 80 % can be classified as a silt (d = 0,004-0,062 mm). The share of both very fine sand (d = 0,062-0,125 mm) and clayey particles is approximately 10 %.

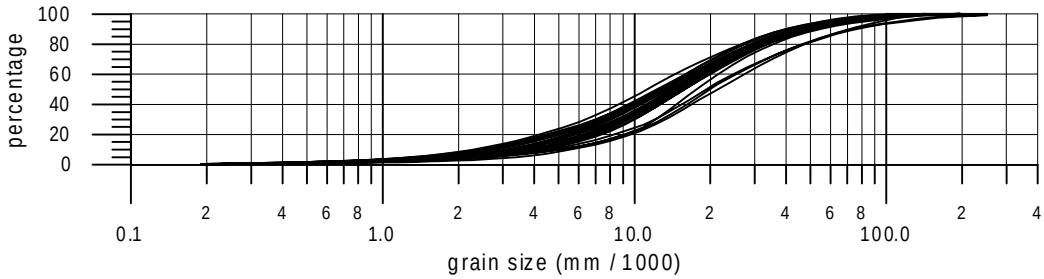

Fig. 1 Grain size curves of the Danube river suspended load

4 Results of the suspended load regime investigation

The depth-integrated samples of suspended load were analysed by means of regression analysis. The main goal of this analysis was to derive relation between the suspended load discharge and water discharge. The relations of this type are widely used mainly in the cases of large river basins, where it is difficult to identify influence of factors, affecting suspended load regime. The method of least squares was used for the analysis. At the beginning, samples from three measuring verticals have been analysed separately. Regression relations for the three measuring verticals were almost identical, so it was decided to analyse all samples as one data set. The resulting regression relations for the calculation of suspended load concentration c and discharge Q_S are as follows (Lukáč, 1998a):

$c = 1{,}118855.10^{-4} \cdot Q^{1{,}66497}$ $(mg.l^{-1})$

$Q_S = 1{,}118855.10^{-7} \cdot Q^{2{,}66497}$ $(kg.s^{-1})$

where: Q – Danube river discharge $(m^3.s^{-1})$.

The correlation coefficients of this relations are of rather high values, 0,829 and 0,936 respectively. Measured values of suspended load discharge and resulting regression relation for the calculation of suspended load discharge are given in the figure 2. The validity of these relations is limited by the range of discharges, which occurred during the measurements. Extrapolation should be performed with care.

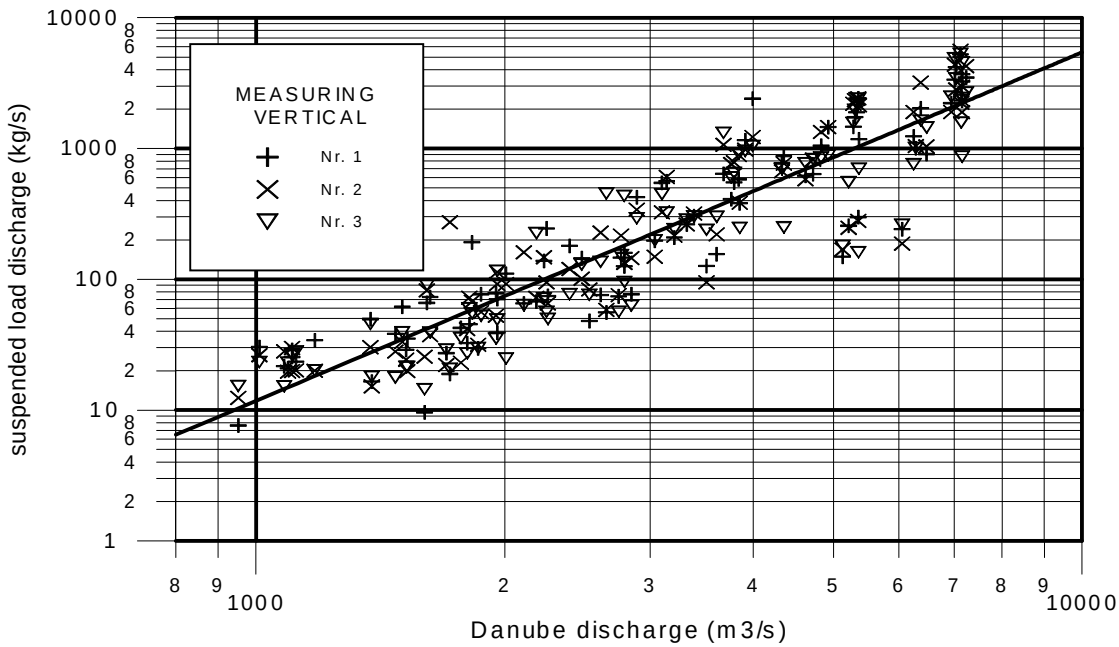

Fig. 2: Regression relation between the suspended load discharge and water discharge at the Danube river

Derived regression relation was also compared with the similar ones, which resulted from the analyses of suspended load regime at the Slovak section of Danube in the region of Bratislava from the past. Extensive field measurements were performed in the 50´s (Szolgay, 1960) by the WRI staff. Another regression relation was derived from the data, measured in the Austrian section of Danube – in Bad Deutsch Altenburg (Kališ et al., 1991). Suspended load regime in the Lafranconi bridge profile was also investigated by the WRI staff in 1993. Graphical comparison of these relations is given in the figure 3.

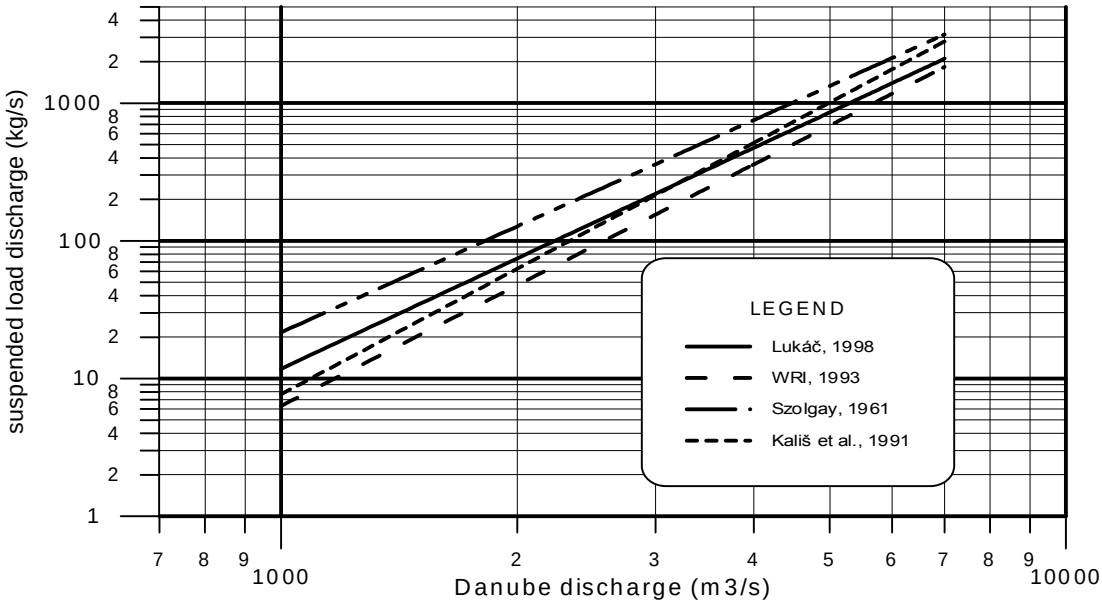

Fig. 3 Comparison of different regression relations

It can be seen from the figure 3, that the discharge of suspended load was substantially higher in the 50´s, comparing with later period. The construction of the cascade of new weirs at the Austrian section of the Danube river can be the decissive reason of this fact. The part of suspended load settles in the Austrian reservoirs. The construction of a new sewage treatment plants and application of modern technologies in the sewage water purification can be important, too. Based on the derived relation and discharge hydrographs, it was possible to determine annual amounts of transported suspended load. We had also data from the past – periods 1933-1936, 1952-1960, 1970-1987 and 1993 (Kališ et al., 1991), (Szolgay, 1960). The values of annual suspended load amount are plotted against the average annual water discharge in the figure 4.

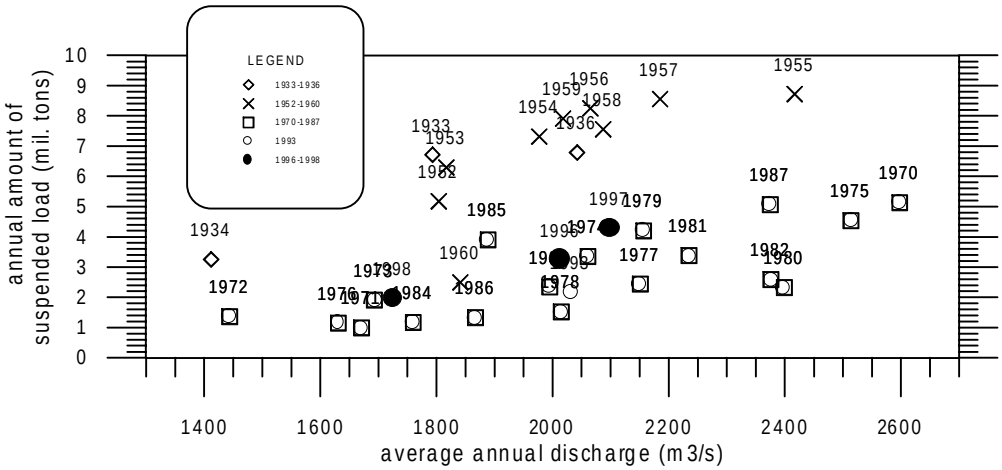

Fig. 4 Annual amounts of transported suspended load in the different periods

Substantial decrease of transported suspended load amount from 70´s is evident from this figure. When evaluating the period 1970-1998, it can be stated that the amount of transported suspended load slightly increased in the period 1996-1998. Let´s take the years 1978 and 1996 as an example. Average annual discharge was almost identical, but the amount of suspended load was around two-times higher in 1996. There are more possible causes:

- construction works (mainly dredging) in the Freudenau weir site, in the region of Vienna,
- stabilization of the Danube river bed downstream from Freudenau (filling of gravel and also finer particles into the river),
- occurrence of extreme floods in the Morava river basin (July 1997), connected with intensive sediment transport.

The point-integrated samples provided information about the suspended load distribution in the cross-section under a different discharge conditions. Comparing with theoretical distribution, the measured one was usually untypical (Lukáč, 1998b). The maximum concentration in the vertical frequently did not occur near the river bottom. These discrepancies could have been caused because of several reasons – local morphological and hydraulic conditions. The measured flow velocity was rather high (up to 3 $m.s^{-1}$) here, as well as turbulence of flow. The Morava river mouth is situated only around 2 kilometers upstream from the measuring cross-section, which is not long enough distance for good mixing of suspended load of two rivers. The similar untypical distribution of suspended load in the vertical was observed during the previous measurements at the Danube (Szolgay, 1960) and also at the Missouri river (USICWR, 1963) in the case of fine silty particles. Calculated cross-sectional concentration of suspended load was in a good agreement with the results of depth-integrated sampling in the Lafranconi bridge profile.

5 Conclusions

The results of project in the field of suspended load regime provided valuable information about this phenomenon at the Slovak section of the Danube river under the changed conditions. They can be utilised in the fields of sediment transport, morphological development of river channel, navigation, flood control, etc. not only in Slovakia, but also in the frame of the international cooperation of Danube countries. The similar research project started in 2000. The field measurements of both suspended load and bed load are carried out close to Medveďov, downstream from the Gabčíkovo power plant. The project will be completed in 2002 and its results will contribute to the balance of suspended load transport at the Slovak section of the Danube river.

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New Data on the Sediment Balance at the Mouth of the Danube River

Maria Mikhailova, Evgenia Levashova

Abstract: The sediment balance was analysed for the Chilia Delta at the Danube River mouth. The river sediment yield is the most important in the sediment balance of the protruding Chilia Delta. The comparison of variations in the fan volume and sediment yield reveals some underestimation of measured sediment discharges because of the neglect of bed load.

Key words: river mouth, delta, fan, water runoff, suspended sediments, bed load, sediment balance

Neue Angaben über die Geschiebebilanz an der Flussmündung der Donau

Zusammenfassung: Es wurde die Geschiebebilanz des Kilijer Deltas in der Donau Flussmündung analysiert. In der Geschiebebilanz des Kilijer Deltas spielt der Abfluss der Flussgeschibe die entscheidende Rolle. Der Vergleich der Volumenveränderung des Austragskegels und des Geschibeabflusses zeugt von einiger Herabsenkung der gemessenen Grösse des Geschibeabflusses infolge der Unerfassung der Geschiberführung.

Schlüsselworte: Flussmündung, Delta, Austragskegel, Abfluss, Schwebestoffracht, Geschiberführung, Geschiebebilanz

1 Introduction

The delta of the Chilia branch at the Danube River mouth (the Chilia Delta) provides an example of an active protruding delta that is being formed in the open nearshore zone of the tideless sea with a relatively stable level and moderate wind wave. The delta formation process began in the middle of the XVIII century (approximately in 1740). The peculiarities of the Chilia Delta formation were studied on a base of sediment balance at the mouth. The river sediment yield is the most important in the sediment balance of the protruding Chilia Delta. The comparison of variations in the fan volume and sediment yield revealed some inconsistency between them. New assessment of the sediment yield opens up possibility to correct the sediment balance items.

2 Formation Conditions of the Chilia Delta of the Danube River

According to data of Moscow State University and Danube Hydrometeorological Observatory, the mean annual water runoff of the Danube River at the delta head for the period 1921-1998 was estimated at 203 km^3/year. The Danube River runoff at the delta head is distributed between the Chilia and the Tulcea branches. During the XIX century, the share of the Chilia branch water runoff steadily increased from 53 to 70%.

In the XIX century, great changes occurred in the flow distribution between branches. Evidently, the division of branches in the Chilia Delta, particularly active in the first half of the XX century, caused the increase in hydraulic resistance of this branch and contributed to the flow redistribution in the adjoining system of the Tulcea branch. In addition to this, at the end of the XIX century, large-scale construction aimed at improving the navigation conditions was carried out in the Sulina branch. The works involved branch length reduction (by 21 km), dredging, and the construction of training dikes. These measures also considerably contributed to the fact that, from the beginning of the XX century, the share of the Chilia branch water runoff gradually decreased and reached 58% by 1998.

The Chilia branch water runoff remains virtually constant from its head to mouth.

After 1960, the suspended sediment yield of the Danube River at the Danube Delta head sharply decreased. Over the period 1921-1960, it amounted to 67.5 mln. t/year (2140 kg/s), and starting from 1961, it dropped to 39.4 mln. t/year (1250 kg/s). The reduction of the suspended sediment yield was noted by a number of researchers and resulted from the construction of a chain of reservoirs in the Danube River basin (Schwebstoff…, 1993). The Djerdap Reservoir, which was filled in 1971, had the greatest impact on suspended sediment yield.

A significant decrease in the suspended sediment yield of the Danube River at the delta head is reflected in the difference-cumulative curve of sediment discharges (Figure 1). Since 1960, this curve demonstrates a distinct drop. On the contrary, the difference-cumulative curve of water discharges does not show similar changes. Since 1961, a notable decrease in the suspended sediment yield can be also revealed using the correlation graph of suspended sediment and water discharges (Figure 2).

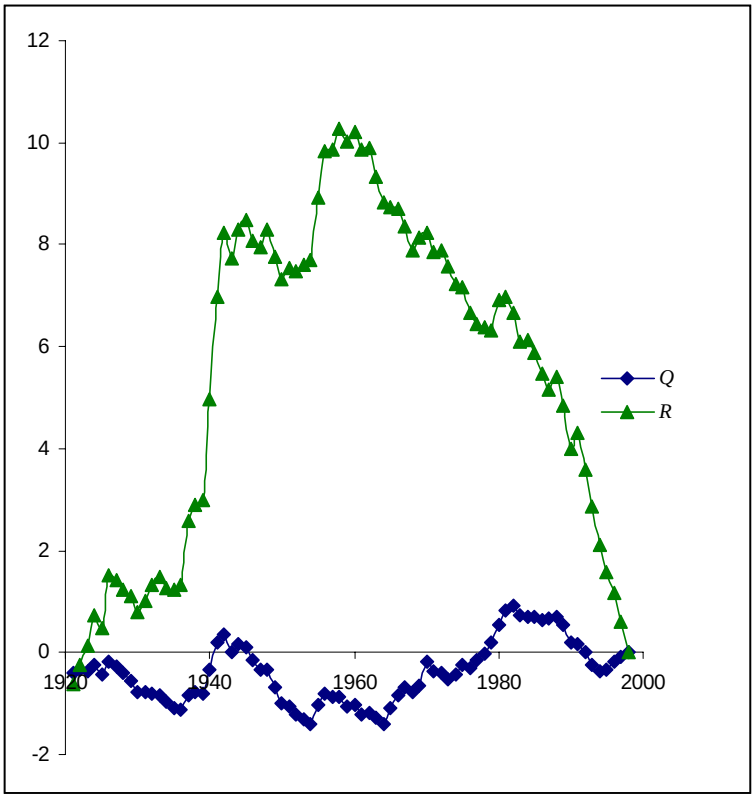

Fig. 1 Normalised difference-cumulative curves of water (*Q*) and suspended sediment (*R*) discharges at the Danube Delta head

The suspended sediment yield has been distributed among the branches of the Danube River Delta proportionally to the river water runoff. The suspended sediment yield along the Chilia branch, as well as the river water runoff, was practically constant. This is revealed by the comparison of suspended sediment discharges at the head and near the mouth of the Chilia branch.

During the lifetime of the Chilia Delta (260 years), the Black Sea level has insignificantly changed. If we assume the average rate of eustatic rise of the Black Sea level to be approximately 2 mm/year, then for 260 years, the sea level rise could make up only 52 cm. The sea wave in the nearshore zone is moderate. In the nearshore zone of the Chilia branch, the height of waves of 50% probability ranges from 0.2 to 0.4 m.

3 Sediment Balance at the Mouth of the Chilia Branch

The equation of sediment balance at the mouth of the Chilia branch has the form

$$\Delta W_f = W_r + W_{s.n} - W_{s.s} - W_d ,$$

where ΔW_f is the change in the fan volume for the period Δt; W_r is the total river sediment supply for the same period; $W_{s.n}$ is the volume of sea sediments coming with the longshore drift from the north; $W_{s.s}$ is the volume of products of delta abrasion going along the delta coastline to the south; and W_d is the volume of sediments (mainly, fine suspended particles) gone to the sea deep beyond the limits of the delta fan.

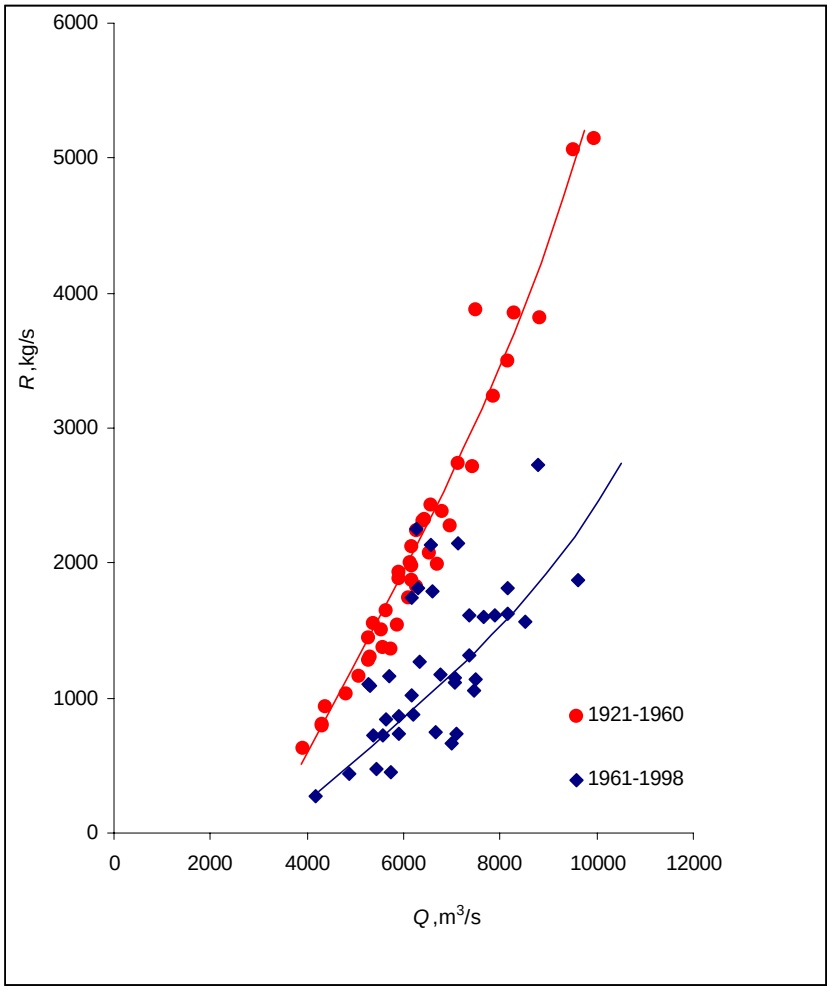

Fig. 2 Correlation graphs of water (*Q*) and suspended sediment (*R*) discharges at the Danube Delta head

The fan volumes W_f were defined from 11 charts of the Chilia Delta and its nearshore zone from 1830 to 1980 (Table 1), and the values ΔW_f were determined as the difference between these volumes (Mikhailova, 1995).

The inverse extrapolation of the curves showing the changes of the delta area and length, and the fan volumes made it possible to find out that the formation of the present protruding Chilia Delta began in 1740 (Mikhailova, 1995).

The sediment yield of the Danube River was calculated using a new method. The sediment yield calculation runs into many problems. Data of the suspended sediment discharges of the Danube River are available only since 1921. The suspended sediment discharges of the Chilia branch at its head and mouth are at hand since 1960 and 1963, respectively. In order to calculate the suspended sediment yield of the Danube River we used the method of analogue. As an analogue we used data of observations at Orşova (955 km from the sea) (Dunareă…, 1967).

For 1921-1959, the correlation graph of observed sediment discharges (kg/s) at Orşova (R_O) and the Danube Delta head (R_{DH}) was constructed (Figure 3). The R_{DH} dependence of R_O has the form of

$R_{DH} = 1.9365 R_O - 34$.

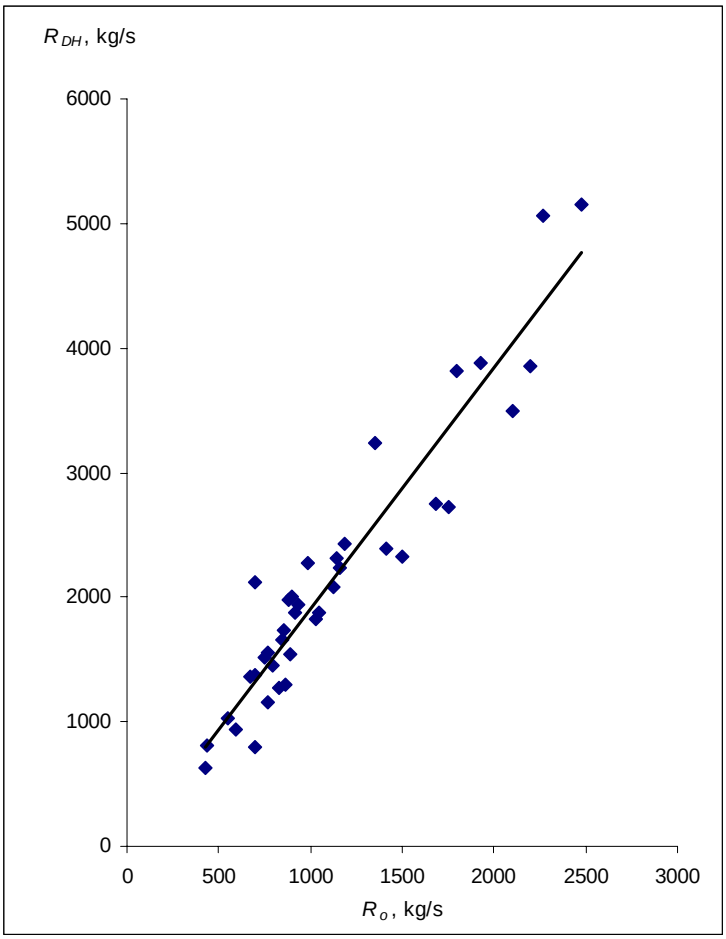

Fig. 3 Correlation graph of suspended sediment discharges at Orşova (R_O) and the Danube Delta head (R_{DH}) for 1921-1959

In 1831-1920, the suspended sediment yield at the delta head was calculated from the data of observations at Orşova (Dunareă…, 1967), using the above-mentioned correlation graph.

Before 1830, the suspended sediment yield was estimated, using the inverse extrapolation of the graph of the sediment yield variability after Bondar et al. (1994) and the above-mentioned correlation graph.

For the period 1740-1962, the suspended sediment yield of the Chilia Branch was determined from the data on the Danube River sediment yield with regard to varying share of the river

runoff in this branch. Since 1963, it was defined from data of the Danube Hydrometeorological Observatory observations at the branch mouth.

The values of suspended sediment yield were converted from units of mass (million tons) to units of volume of deposits (km^3) with regard to the prevailing grain-size distribution of the Chilia branch fan; such distribution corresponds to the density of deposits equalling 1100 kg/m^3.

Integrated suspended sediment yield of the Danube River at the delta head beginning 1740 is shown in Table 1.

Table 1 Sediment yield at the mouth of the Chilia branch and the fan volume

Year	Integrated W_r (km^3)		W_f (km^3)	W_f / W_r (%)	
	Without correction	With the 30% correction		W_r without correction	W_r with the 30% correction
1830	3.772	4.904	2.26	59.9	46.1
1856	4.857	6.314	2.89	59.5	45.8
1871	5.502	7.153	3.45	62.7	48.2
1883	6.017	7.822	4.05	67.3	51.8
1894	6.483	8.428	4.64	71.6	55.1
1922	7.559	9.827	5.66	74.9	57.6
1930	7.857	10.214	6.02	76.6	58.9
1943	8.501	11.051	6.55	77.0	59.3
1948	8.677	11.280	7.01	80.8	62.1
1957	9.005	11.706	7.54	83.7	64.4
1980	9.577	12.450	8.26	86.2	66.3

The amount of sediment input from the north along the coastline ($W_{s.n}$) was assumed to be $0.121 \cdot 10^{-3}$ km^3/year (Shuiskiy, 1984) and constant throughout the 240-year period. Sediment removal with the longshore sediment drift to the south ($W_{s.s}$) is now equal to $0.850 \cdot 10^{-3}$ km^3/year (Shuiskiy, 1984). For the period 1740-1980, it has been arbitrary assumed to be equal to half of this value, because in the past, the delta protruded less into the sea, and its contribution to the southward sediment drift was insignificant.

The sediment flux to the sea deep area W_d was defined as a remainder of the balance equation.

The items of the sediment balance are presented in Table 2.

Table 2 Averaged sediment balance at the mouth of the Chilia branch (1740-1980)

Item	Over the period, km^3	10^{-3}, km^3/year	% of W_r
ΔW_f	8.26	34.42	86.25 66.34
W_r	9.577 12.450	39.90 51.88	100 100
$W_{s.n}$	0.029	0.121	0.30 0.23
$W_{s.s}$	-0.102	-0.425	-1.06 -0.82
W_d	-1.244 -4.117	-5.183 -17.15	-12.99 -33.07

Note: sediment yield without (numerator) and with the 30% (denominator) correction

4 Results and Conclusions

The sediment balance analysis for the whole period of the Chilia Delta existence reveals that:

1) if the equation of sediment balance is set up for periods between the topographic surveys of the delta, it will turn out that, in some cases, increase of the fan volume exceeds the river sediment supply for the respective time interval. This indicates that the sediment yield data do not take into account the great amount of the bed load in the form of sand waves, as well as the fine sediments moving in near-bottom flow layer. The value of the bed load of the Danube River, which according to (Dunareă…, 1967; Schwebstoff…, 1993), makes up from 1 to 12% of the suspended sediment, is obviously underestimated. Actually, the amount of the bed load and suspended sediments moving near the bottom is considerably greater. Unfortunately, these values can not be measured by a bathometer. A discrepancy between the river sediment yield and changes in the fan volumes can be eliminated using the 30% correction of measured suspended sediment discharges (Table 1 and 2);
2) after applying the 30% correction, the total value of the suspended sediment yield and bed load of the Danube River at the delta head could be accepted as 87.8 mln. t/yr (1921-1960) and 51.2 mln. t/yr (1961-1998). In this case, the share of river sediments remaining in the delta fan during the period of its formation is 60% that is typical for large river deltas;
3) a large share of river sediments is deposited in the fan; the role of marine deposits in the delta formation is insignificant; and the amount of sediments gone beyond the limits of the fan is also small;
4) during the Chilia Delta evolution, the share of river sediments remaining in the delta fan grew steadily with the delta increase that is also typical for large river deltas.

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Analysis of River Sediments of the Slovenian-Austrian Border Reach of the Mura River

Gregor Petkovšek, Matjaž Mikoš

Abstract: The paper presents the results of a combined field and laboratory analysis of river sediments of the Mura River in the Slovenian-Austrian border reach. The analysis was done as a part of a Slovenian-Austrian co-operative work, started in 1998, on a Conceptual Water Management Action Plan for the Border Reach of the Mura River. In the reach under investigation, erosion problems, especially bed degradation, have been observed during the last 30 years. In the period from 1971 to 1995, the river bed has been degraded for 0.5 m on average and over 4 m locally, and 0.84 million m^3 of bed material (37.000 m^3/year) has been eroded from the reach in this period. Extensive morphologic and hydraulic analyses are being carried out within the first phase of the project. Among them, an analysis of river sediments was carried out. Sediment samples (volumetric and Wolman counts) were taken in 11 cross sections. The granulometric analysis showed that the arithmetic mean grain diameter in the reach is between 17.5 mm and 49.5 mm (coarse gravel). The main cause of such coarse river sediments may be the fact, that the inflow of bed load has been interrupted and the following degradation below the last HPP in Austria has caused a fairly coarse armour layer. Furthermore, critical shear stresses were evaluated using two methods: they are between 15 N/m^2 and 32 N/m^2 after Zanke, and between 22 N/m^2 and 42 N/m^2 after Günter, respectively. The preliminary sediment budget analysis was performed, using the Meyer-Peter and Müller equation for bed load transport capacity. Local widening will be investigated in the future as a possible measure to stop degradational trends in the border reach.

Key words: Mura River, river sediments, bed load, gravel bed, granulometric analysis, bulk samples, river hydraulics, river engineering

Analyse der Flußsedimente an der Grenzmur

Zusammenfassung: Dieses Paper stellt die Resultate einer kombinierten Feld- und Laboruntersuchung der Flußsedimente in der Grenzstrecke der Mur zwischen Slowenien und Österreich. Die Analyse wurde als ein Teil der slowenisch-österreichischen Kooperation gemacht, die im Jahre 1998 an einem wasserwirtschaftlichen Grundsatzkonzept für die Grenzmur beginnt. In der betrachteten Strecke wurden die Erosionsprobleme in den letzten 30 Jahren beobachtet, insbesondere die Eintiefung des Flußbettes für etwa 0.5 m im Mittel und lokal über 4 Meter in der Periode zwischen 1971 und 1995. In dieser Periode wurde über 0.8 Millionen m^3 (37.000 m^3/Jahr) Geschiebe aus der Strecke erodiert. Die umfangreichen morphologischen und hydraulischen Analysen sind in dieser erster Phase des Projektes unterwegs. Zwischen anderen Analysen wurde auch eine Analyse der Flußsedimente durchgeführt. Die Sedimentproben (volumetrische Proben und Linien-proben) wurden in 11 Querprofile entnommen. Die granulometrische Analyse hat gezeigt, daß der mittlere Korndurchmesser in dieser Strecke zwischen 17.5 mm und 49.5 mm liegt (grobes Kies). Die Hauptursache für ein so grobes Flußsediment kann die Tatsache sein, daß der Geschiebezufluß unterbinden worden war, und die damit verbundene Eintiefung flußabwärts der letzten WKK in Österreich diese grobe Deckschicht verursacht hat. Weiter wurden die kritischen Sohlenschubspannungen nach zwei Methoden gerechnet: die liegen zwischen 15 N/m^2 und 32 N/m^2 nach Zanke, und 22 N/m^2 und 42 N/m^2 nach Günter. Die erste Geschiebehaushaltstudie wurde gemacht, und die Meyer-Peter-Müller Transportformula gebraucht. Die lokale Aufweitungen werden in der Zukunft als eine mögliche Maßnahme gegen Erosionstrende in der Grenzstrecke untersucht.

Schlüsselworte: die Mur, Flußsedimente, Geschiebe, Kiessohle, granulometrische Analyse, volumetrische Proben, Flußhydraulik, Flussbau

1 The Mura River

The Mura River (*Mur* in German) is a Central European river, which originates in Austrian Alps and discharges into the Drava River (*Drau* in German). It crosses four countries (Austria, Slovenia, Croatia, and Hungary) and forms a part of the border between Slovenia and Austria. This reach has been taken into consideration for the analyses of river sediments discussed in this paper. In Figure 1, the geographical position of the Mura River and the border reach is shown.

Fig. 1 Geographical position of the Mura River (coloured white) and the border reach under investigation (inside the white circle) (after WWF, 2000).

The reach is 34.5 km long (between the river stations km 95.0 and km 129.5). In the past, it has been trained in two shorter reaches of the total length of 3.9 km. The width of the main channel is around 80 m, while the width of the flood plains in the untrained reaches is over 2 km. Average longitudinal river bottom slope is between 0.001 and 0.002, and it is one of a few typical lowland rivers in Slovenia, especially the part of the Mura River within the Slovenian territory, where meandering pattern still can be seen. Typical for the area along the border reach are extensive riparian forests and wetlands, among largest in the Central Europe.

Two surface water-gauging stations operate in the border reach, one in Gornja Radgona (catchment area of 10.197 km^2) (*Radkesburg* in German) and one in Petanjci (catchment area of 10.391 km^2). The mean annual discharge is 157 m^3/s (Gornja Radgona, period 1961-1990), flood with 30-year return period is 1490 m^3/s and flood with the return period of 100 years is 1800 m^3/s (HMZ, 1998). Bankfull discharge varies significantly from one cross section to the other, and was determined by the hydraulic analysis to be between 400 m^3/s and 1400 m^3/s, respectively (Četina et al., 2000).

Upstream from the considered border reach of the Mura River, a chain of HPP dams in Austria, causing impoundment of the river, has been constructed, disturbing water flow and sediment transport in this reach. The problems arising from this fact are discussed in the next section.

2 Current problems

A joint Slovenian-Austrian project named "Conceptual Water Management Action Plan for the Border Reach of the Mura River Between River Stations km 95.0 and km 129.5" started in 1998. The project is still under way, financed by the Permanent Slovenian-Austrian Mura Commission. Its main goal is to prepare a fundamental base or principles for a long-term Water Management Action Plan for this border reach of the Mura River as a result of a common project between two neighbouring countries.

In the past 30 years, a considerable bed degradation took place in the reach (Plattner, 1999). The volume of eroded sediments was calculated from measured changes in cross sections. Measurements of cross sections were taken in intervals of three years. The cumulative volume of eroded material is shown in Table 1. The total amount of eroded sediments in the past 30 years is estimated to 0.84 million m^3. Thus, the average degradation of the Mura River bed is 0.5 m. In addition, the thalweg (the deepest portion of the main channel) changed its position several times.

Table 1 The volume of river sediments, eroded from the border reach of the Mura River for each three years' period (after Plattner, 1999).

Year	Sediment balance [in 1000 m^3]	Year	Sediment balance [in 1000 m^3]
1971	0	1986	- 35
1974	- 297	1989	- 125
1977	- 180	1992	- 54
1980	24	1995	- 144
1983	- 26	Sum 1971 - 1995	- 837

Main aims of the common Slovenian-Austrian project are to prepare such an action plan to take into account possible eco-morphological improvements of the river channel and flood plains, and to plan measures to bring the river into stable morphological conditions again. Important reasons for these tasks are among others also human needs, such as recharging of ground water as the most important source of drinking water, and the improvement of the flooding situation.

The project was structured to encompass two approaches, one being the water management part, and the other being the ecological part. An important outcome of this first phase of the project (1998-2000) is a so-called model example (*Leitbild* in German), based on common discussions between hydraulic engineers, biologists and landscape engineers.

As an important part of the water management tasks within the project was to gather the relevant database for a sediment budget study, based on a sediment transport model of the river. A preliminary sediment budget study has been completed (Mikoš and Petkovšek, 2000), and the final one is still under way.

3 Analysis of river sediments

River sediment samples were taken in 11 cross sections along the border reach. For subsurface sampling of river sediments, volumetric samples of approximately 0.5 m^3 were collected under water by a machine excavator (see Figure 2).

Fig. 2 Subsurface sampling of river sediments under water using a mechanical excavator (photo authors, March 1998).

For surface sampling, Wolman samples were taken on exposed gravel bars. The subsurface volumetric samples were air dried and then sieved out using a mechanical screening machine (Gilson Test-Master®), and their grain-size sieve curves were determined using analysis-by-weight technique. The surface Wolman samples were analysed using analysis-by-number technique. The final granulometric analysis of the sampled river sediments was performed using the approach of Anastasi (1984) and Fehr (1987). They have defined how to convert and then rigidly or flexibly combine different grain-size curves as a result of different evaluation (analysis-by-number, analysis-by-weight) and sampling techniques (volumetric sample, grid sample, Wolman sample, etc.). Finally, the granulometric parameters of combined grain-size curves of sampled river sediments were calculated (d_{16}, d_{50}, d_{84}, d_{90}, d_m, sorting coefficient).
The granulometric analysis showed, that the arithmetic mean grain diameter d_m in the reach is between 17.5 mm and 49.5 mm (coarse gravel), and d_{90} is between 54 mm and 98 mm (Figure 3). To the contrary of what it could be expected, and as a field evidence of disturbed sediment transport in the reach, a coarsening trend downstream instead of fining of river sediments could be observed. The corresponding coarsening coefficient in a linear model was found to be 0.26 mm/km, with a high degree of scatter (R = - 0.37, 11 points). Sorting of river sediments was decreasing downstream with a decreasing coefficient value of 0.11/km, but the correlation was poor (R = 0.59, 11 points). There was no obvious trend in d_{90} along the river reach (Figure 3).
These field data show that riverbed sediments are coarser and better sorted in the downstream direction of the border reach of the Mura River.
We used measured d_{90} to calculate Manning's roughness coefficient ($n = d_{90}^{1/6}/21$) and computed coefficients n were comparable to those obtained from the calibration of the one-dimensional hydraulic model (Četina et al., 2000), only somewhat lower.

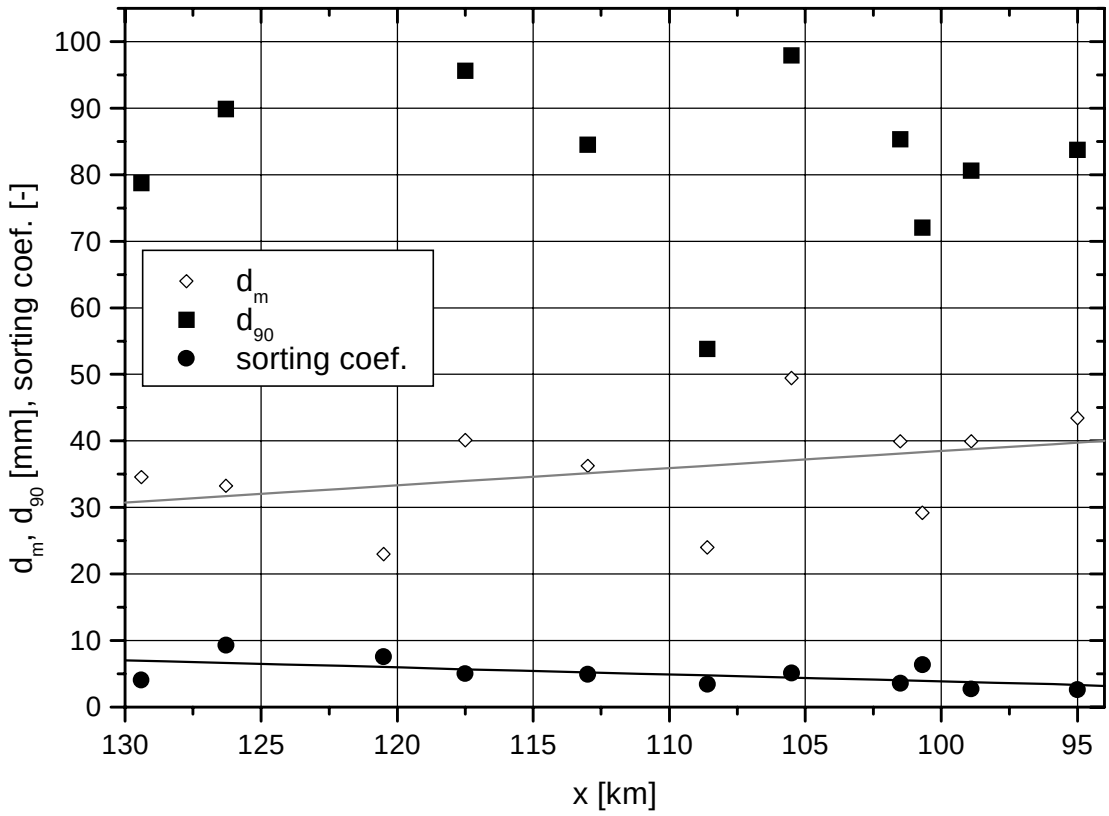

Fig. 3 Mean grain diameter d_m, d_{90}, and sorting coefficient of the analysed samples of river sediments taken versus river station of the Mura River (linear trends are also shown).

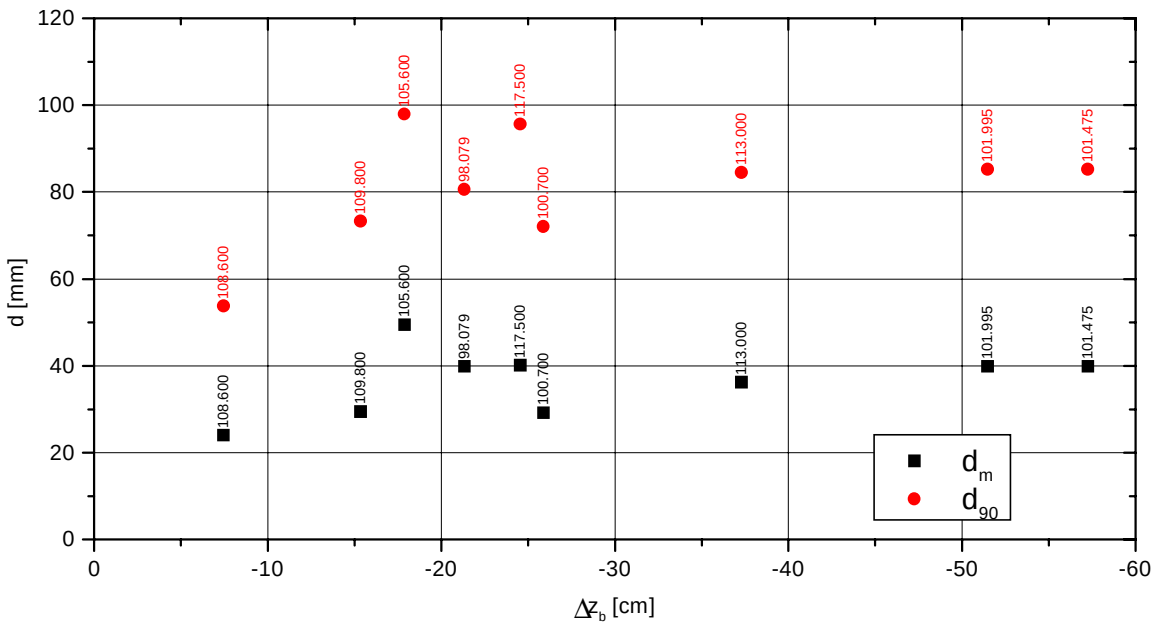

Fig. 4 Mean grain size d_m and d_{90} versus degradation depth Δz_b (above the data points also river stations are given).

We compared the granular composition of the river bed surface to the bed degradation data (see section 2). From Figure 4 it can be seen that there is no obvious trend between both parameters, which may be evidence that the surface layer on the river bottom is still active and not mature (fully immobile armour). This was also confirmed by the hydraulic computations for the discharge Q = 1200 m^3/s, which is between Q_5 = 1130 m^3/s and Q_{10} = 1270 m^3/s. It is evident from Figure 5 that computed shear stresses exceed the critical values for incipient motion.

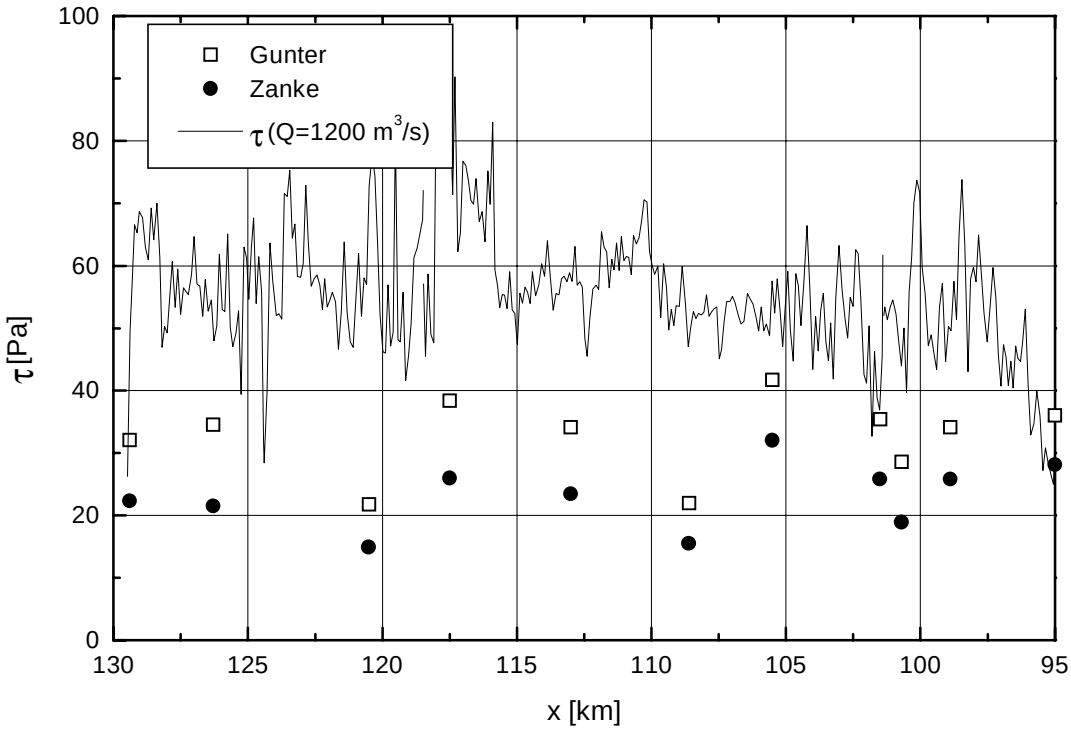

Fig. 5 Critical shear stresses calculated from mean grain diameter d_m using Günter's (squares) and Zanke's method (circles), compared to shear stresses corresponding to Q = 1200 m^3/s.

Further on, the mean grain size of the subsurface d_m was used to calculate critical shear stresses τ_{cr} (Figure 5), using on one hand Zanke's method (1982):

$$\tau_{cr} = 0.04 \cdot (\rho_s - \rho) \cdot g \cdot d_m$$

and on the other one Günter's approach (1971), which takes into account the increase of critical bed shear stress τ_{cr} due to armouring and the decrease due to turbulence:

$$\tau_{cr} = 0.033 \cdot (\rho_s - \rho) \cdot g \cdot d_{90}^{0.67} d_m^{0.33}$$

assuming that d_{90} is a reasonable estimate of the mean size of the surface layer. The critical shear stresses are shown in Figure 5. Their values are between 15 N/m^2 and 32 N/m^2 (after Zanke), and between 22 N/m^2 and 42 N/m^2 (after Günter), respectively.

4 Preliminary sediment budget analysis

For 100-year return period flood, we made a preliminary sediment budget analysis. First we calculated sediment transport capacity for this discharge along the border reach. We assumed erosion / deposition rates equal to transport capacity. In this case, the amount of eroded / deposited material between the two subsequent cross sections can be calculated using Exner's equation:

$$\frac{1}{1-p} \cdot B \cdot \frac{\partial z}{\partial t} + \frac{\partial Q_b}{\partial x} = 0$$

where B is bed width, Q_b is sediment transport capacity, z is bed elevation, and p is porosity, respectively. Sediment transport capacity was calculated using Meyer-Peter - Müller formula. Transforming this partial differential equation to a difference equation gives the following expression for bed elevation difference rate $\Delta z/\Delta t$:

$$\frac{\Delta z}{\Delta t} = -\frac{\Delta Q_b}{\overline{B} \cdot \Delta x} \cdot (1-p)$$

This sediment budget analysis was based on only two neighbouring cross sections, not taking into account dynamics of sediment transport. Figure 6 shows the bed degradation rate (in meters per hour) for the 100-year return period flood compared to measured bed degradation in the past 30 years. It can be seen that high flows may still erode the river bottom to certain extent.

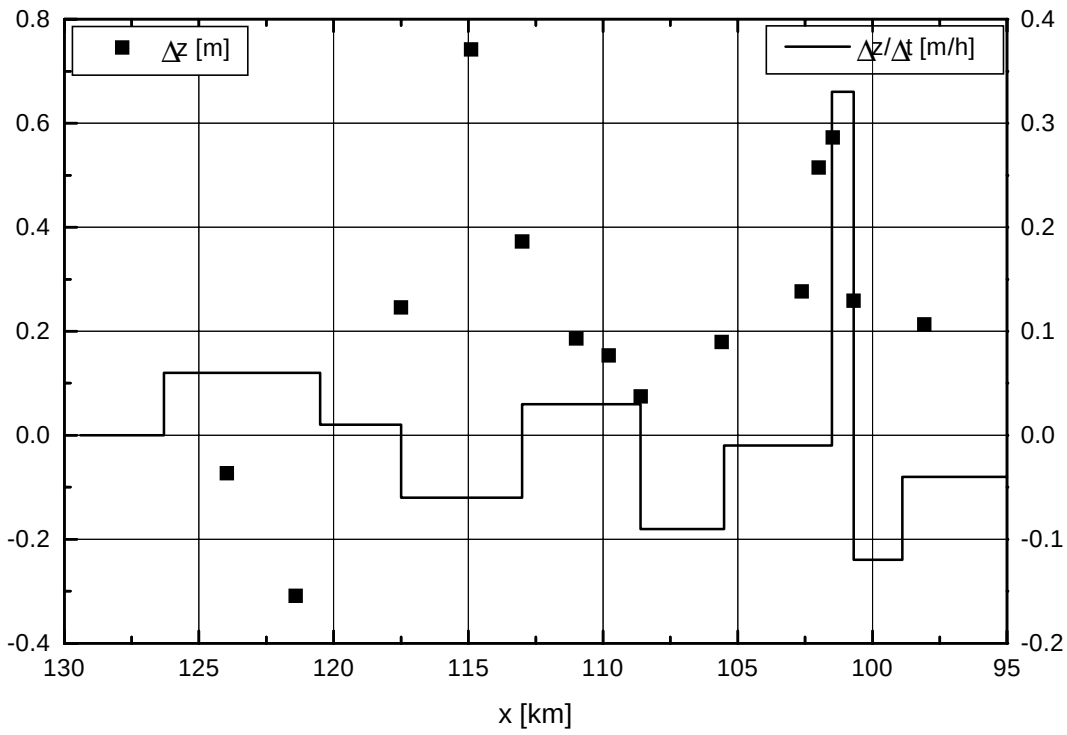

Fig. 6 Bed degradation rate for the 100- years' return period flood compared to measured bed degradation in the past 30 years.

5 Conclusions

Extensive morphologic and hydraulic analyses are being carried out within the first phase of the Conceptual Water Management Action Plan for the Border Reach of the Mura River, started in 1998. Among them, an analysis of river sediments was performed, which showed that the riverbed of the border reach of the Mura River is composed of mainly coarse gravel. The riverbed sediments are coarser and better sorted in the downstream direction. The main cause of such coarse river sediments in a fairly lowland river may be the fact, that the inflow of bed load has been interrupted for years and as a consequence extensive degradation of the riverbed below the last HPP in Austria occured. Along the border reach of the Mura River there are namely no important sediment sources which could counterbalance the lack of inflowing sediments from upstream. Nevertheless, a comparison between computed shear stresses from a one-dimensional hydraulic model and critical values showed that sediment transport might occur quite often.

A granulometric analysis of sediments deposited in alluvial plains near the Mura River is under way at the moment. The main purpose of this analysis is to get data relevant for the case of possible local widening of the river cross section as a counter measure against the river bed degradation. The influence of such a measure on sediment regime of the Mura River will be evaluated by the final sediment budget analysis, using a one-dimensional mathematical model of water and sediment flow. This analysis should also show to which extent this local widening could stop the degradational trends in the border reach.

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Renewed Collection of Sediment Data on the Dráva River

László Rákóczi, János Szekeres

Abstract: R. Dráva is an important tributary of R. Danube with a considerable sediment transport. Its lower course forms the border between Hungary and Croatia. Sediment data collection has been started here several decades ago at two stations on the Hungarian side, however, the process was repeatedly interrupted for various reasons. Recently, both countries decided to continue and extend the scope of sediment measurements. The paper deals with the first results of this project introducing new instruments and methods to sample the suspended sediment and bed load and to trace the movement of the latter.

Key words: anthropogen effects on sediment transport, field comparison of bed-load samplers, luminescent tracing.

Wiederaufnahme der Sammlung von Feststoffdaten an der Drau

Zusammenfassug: Die Drau ist ein wichtiger Zubringer der Donau, mit bedeutendem Feststofftransport. Ihre untere Strecke bildet die Staatsgrenze zwischen Ungarn und Kroatien. Die Sammlung von Feststoffdaten an zwei Stationen der ungarischen Seite wurde bereits vor mehreren Jahrzehnten begonnen, wurde jedoch, aus verschiedenen Gründen, mehrere Male unterbrochen. Neulich haben beide Länder beschlossen, die Feststoffmessungen fortzusetzen und erweitern. Der Beitrag schildert die ersten Ergebnisse dieses Projektes, in dessen Rahmen zur Beprobung des Schwebstoffes und des Geschiebes, bzw. Zur Verfolgung der Bewegung des letzteren, neue Geräte und Methoden eingesetzt wurden.

Schlüsselwörter: anthropogene Einflussfaktoren des Feststofftransports, Vergleich von Geschiebefängern vor Ort, lumineszierende Leitstoffe.

1 Introduction

River Drava, an important right-bank tributary of Danube River originates from the Austrian Alps *(Fig. 1)*. Its flow discharge varies between 200 and 2 200 m3/s with a multi-annual mean value of about 600 m3/s. From its 695-km length, about 130 km forms the border between Hungary and Croatia.

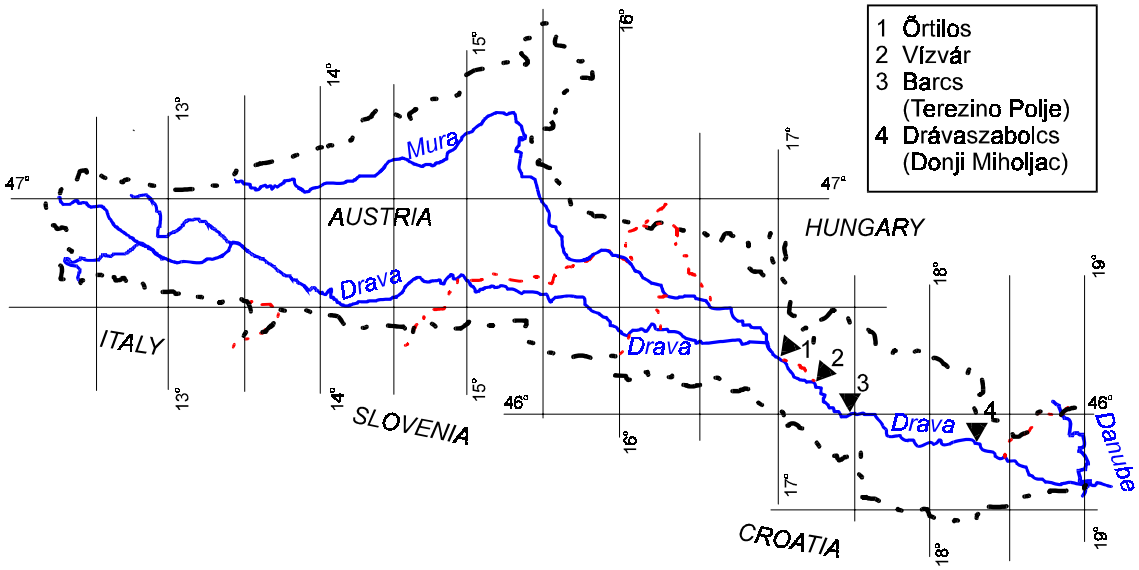

Fig 1 The catchment area of the River Drava

The sediment transport of Drava River is significant due to the size of its basin (40 150 km2 together with R. Mura) and high slope (0.0013) in the upper reaches. The two countries share the lower reach with a slope of about 0.00015. The river channel is overwidened and aggrading here requiring regular dredging. From the viewpoints of channel maintenance and planning of various development projects, it is important to improve both the quantity and quality of sediment data. Recently, the hydrographic authorities of Croatia and Hungary have decided to re-start and/or modernize the sediment sampling and measuring technique in order to supplement and review the existing database and to achieve a reliable picture of the sediment transport processes. The present paper gives a brief review of the applied methods and instruments and summarizes the first results obtained in Hungary between 1997 and 1999.

2 Suspended sediment transport

2.1 Evaluation of earlier data

The riparian countries have started the collection of hydrological data several decades ago, however, the method of the field measurements were not co-ordinated and the exchange of data was rather intermittent. Within the Hungarian river reach, regular suspended sediment sampling has been started in 1968 at *Barcs* (159 rkm) and *Drávaszabolcs* (76 rkm) gauge stations. Obviously, neither the number of stations nor the annual frequency of the measurements (about ten per year) can be regarded as sufficient to characterize the sediment regime of a more than 200 km long reach. Even considering the suspended sediment concentration and discharge data measured by the Croatian side since 1968, there were about 200 data available for establishing sediment-rating curves.

The scatter of plotted data being too high, they were re-grouped into five-years intervals and approximated by regression curves of the form:

$$C_k = A * Q^N,$$

where C_k is the concentration of suspended sediment and Q is the flow discharge. The curves (in logarithmic plotting: straight lines) show shifting and/or turning away from each other as depicted for station Barcs in *Fig. 2*. These discrepancies indicate that the data do not belong to the same statistical population, however, the scarce number of data belonging to the five-years long intervals as well as the questionable independence and limited homogeneity thereof make their exact mathematical statistical treatment impossible. The main reason for this lies in the intensive human intervention into the life of River Drava since 1942 by the construction of 15 river barrages (with hydropower plants) till 1990 on the Austrian reach alone. In the Slovenian reach there are 8 more barrages and in the Croatian one 3 with altogether 773 million m3 storage capacity. The latter three are situated only slightly upstream of the Hungarian-Croatian study reach and were built during the last sediment data-collection period (after 1975). Indeed, they significantly influence the sediment regime here, especially the last built Dubrava barrage.

The analysis of suspended sediment data obtained in the past and plotted in Fig. 2. showed that the regression lines shifted downward at high flows in the 1981-1985 period, i.e. during the construction of Cakovec and Dubrava barrages. This means that much higher sediment concentrations belonged at this time to the same flow discharges as presently. On the contrary, the lines representing the period between 1986 and 1996, are situated at the highest position on the graph proving a significant decrease of sediment transport in the studied river reach. The scatter of the plotted points is partially due to the natural flow regime of R. Drava, because during the passage of flood waves the barrages stay open. It could also be evidenced that various construction works affecting the river channel have temporarily increased the concentration of suspended sediment enhancing the scatter of data.

2.2 New data collection and evaluation of results

The new sediment data collection has started with the selection of two new measuring sites upstream of the existing two. The main aspects of the selection were to find a not too wide and unified channel reach (with no side-branches) for each station, i.e. *Őrtilos* (227 rkm) and *Vizvár* (190 rkm). Here the riverbed consists mainly of gravel and the slope is about 0.0004. The bed material easily and frequently becomes armoured by the coarsest fractions making the bed surface rather resistant against erosion.

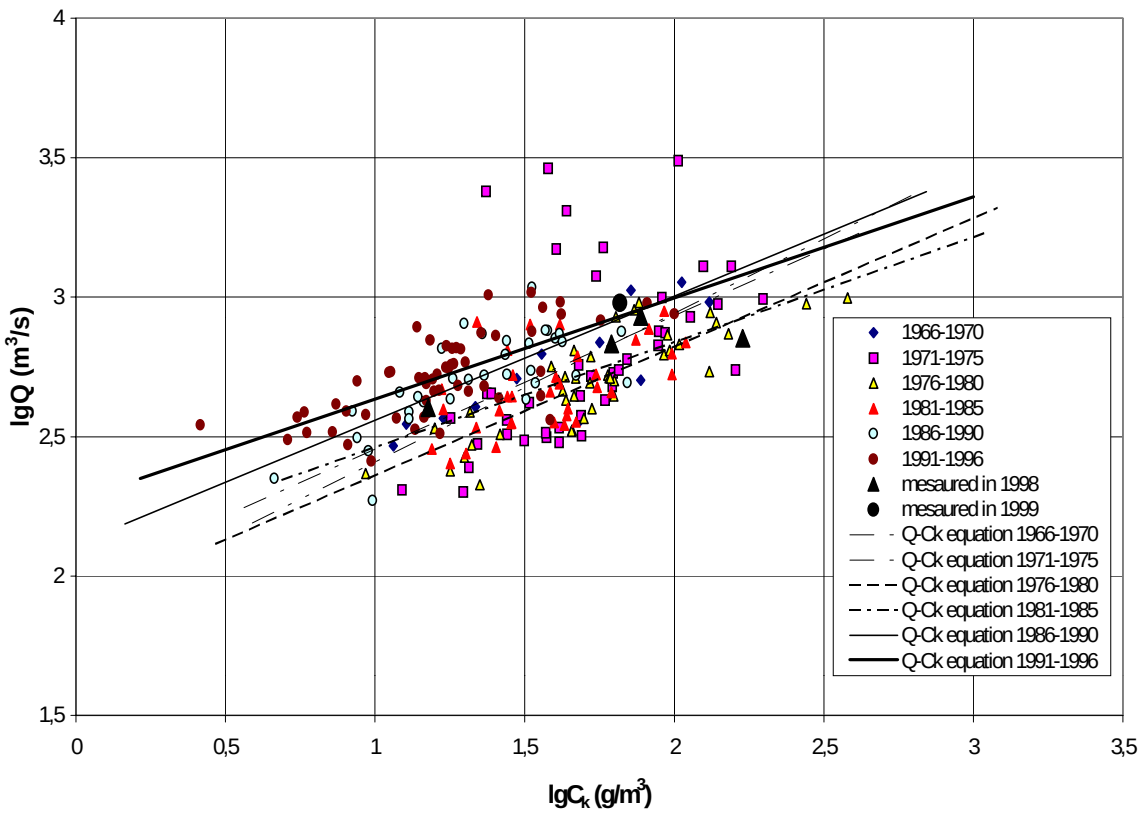

Fig. 2 Suspended sediment rating curves at station Barcs for the period 1966-1996. The data are grouped into intervals of 5 years each and supplemented by the results obtained 1998.

The sediment sampling and the accompanying flow-velocity measurements took place in 1998 already at all the four stations. After one pilot measurement in early July, three complete sampling programs were carried out, two of them in the *rising phases* of medium-sized floods, in the 600-700 m3/s discharge range. The sediment data collected at these above-average discharges were welcomed because most of the earlier data refer to low flows. 10-10 l suspended sediment samples were taken by pumping from every second velocity-measuring vertical in such a way that the sample volumes characterized the whole water depth.

The most important question by the evaluation of the new sediment data was, how well they fit to the groups of the earlier ones collected at Barcs and Drávaszabolcs between 1965 and 1996? In the case of the former station, reassuringly all the three new data fitted well to the regression line belonging to the period 1991-1996 (Fig. 2). In case of station Drávaszabolcs, only the sediment concentrations sampled during the higher flows fitted to the regression curve of the same time period, the one measured at the lower than average flow was best fitted to the group of data originating from the 1981-1985 years. The possible reason might be that the sudden drop of sediment concentration following the re-start of damming by closing the Croatian barrages at the end of the flood waves has reached the Drávaszabolcs station on the day of the sampling.

At the uppermost station, Őrtilos, the obtained sediment data could only be compared with the ones measured at the nearest Croatian station, Botovo. From among the results of the two samplings performed here, the data originating from the lower flow period (after the passage of the flood wave) fitted rather well to the regression line of the 1991-1996. The obtained flood concentration, however, joined the highly scattering Croatian data presumably due to the closeness of the operations performed at the Dubrava barrage. The sediment data measured at the other new Hungarian station, Vízvár, could not be compared with other data sets because of the absence of a nearby station

In 1999 the sediment measurements were carried out on the *recessing* limb of a flood wave, in the discharge range of 950 – 843 m3/s. The sediment concentrations obtained at the two new stations were remarkably lower than the ones measured in 1998 in the *rising* phase of a flood wave. This observation demonstrates the significant concentration differences due to the phases of floods in steep rivers enhanced here by the operational maneuvers of upstream barrages. The 1999 concentration data at the two other stations fit well to the ones measured in the 1991-1996 period similarly to the 1998 values. *Fig. 3* presents the regression line of this group together with the data from the last two years. For comparison, also the regression line of the sediment concentrations determined at the Croatian station Terezino Polje is shown. As to be seen, the coincidence of the two lines is satisfactory and the scatter of the plotted data is fair. All this proves that *the general decrease of suspended sediment concentration is continuing in the presently studied reach of the* River *Drava.*

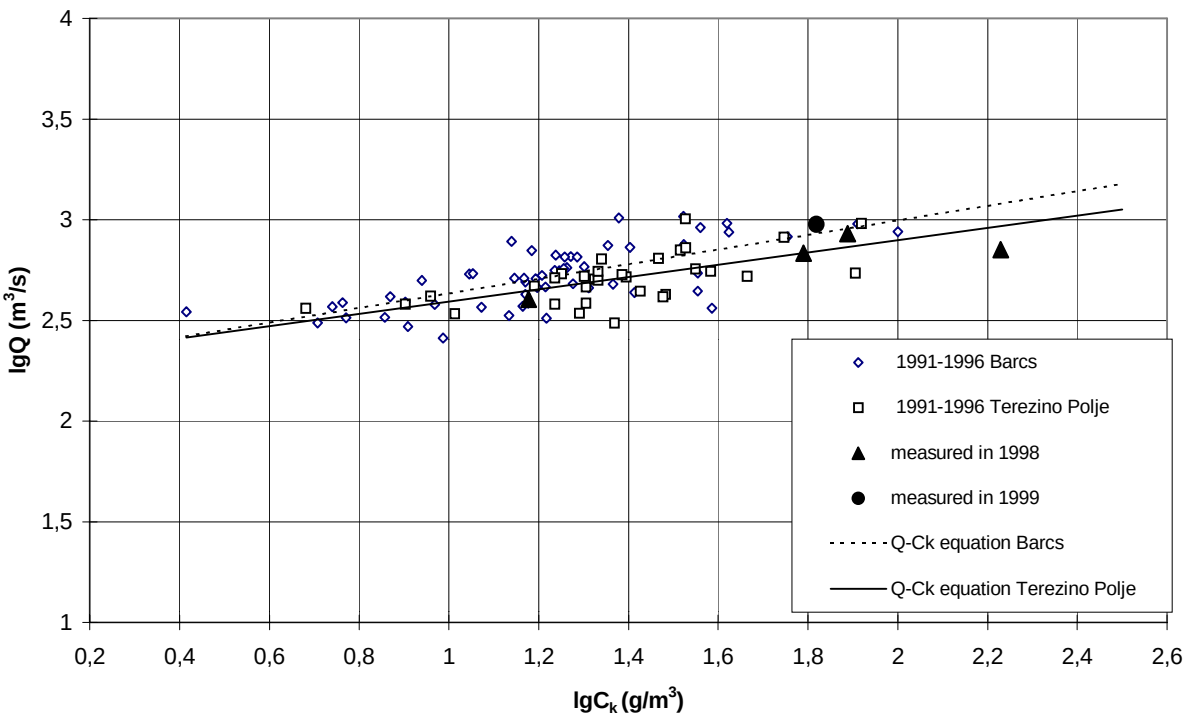

Fig. 3 Comparison of suspended sediment rating curves at stations Barcs and Terzino Polje for the years 1998-1999

3 Bed-load transport

3.1. History of data collection and preparations for re-starting it

The collection of bed-load data has started at the Hungarian hydrographic stations in 1969 with 4-measurements/year/station frequency. Intermittently, bed-load samplings were performed in the river training experimental section around Drávaszabolcs between 1969-1976. The Károlyi-type bed-load sampler was used on this sandy-bed reach of R. Drava, though it has originally been designed for gravel material. Unfortunately, the data collection was interrupted in 1983, thus, the inevitable sediment-transport modifying effects of the Dubrava (completed in 1989) and other Croatian barrages can not be reflected by the data. Bed-load discharge was also measured on the steep, gravel-bed Croatian river-reach in the seventies and eighties at three stations, mainly to provide data for the planning and construction of the mentioned barrages.

Due to the scarce number and low reliability of bed-load data collected before 1983, the plotted values were not subdivided according to shorter intervals as in the case of suspended sediment data. The higher scatter of data at Drávaszabolcs indicates that the discharge-sediment correlation is more influenced here by human interventions than at Barcs. Really, during the former data-collection period, more intensive river-training activities took place upstream of Drávaszabolcs than around Barcs. Most important of them was the narrowing several too wide channel sections by constructing long spur dikes and thus increasing the bed scouring potential of the flow.

In the spring of 1998, simultaneously with the selection of the new sediment measuring stations, the grain-size composition of the bed material was surveyed by sampling in a 10 km long around of each station. The steel pipe scraper device was used for this purpose, with one end closed and with a conic collar on the open end. The latter prevents the sampler from digging below the surface of the channel bed deeper than 4-5 cm. The measurements showed a coarse gravel bed material with mean diameter ranging up to 64 mm at the uppermost station (Őrtilos) and a medium to coarse gravel bed at Vizvár (up to 17 mm). The sampling has also demonstrated how stable the armoured coarse grave bed-surface might be. In some cases no scraped samples could be taken from the surfaces of such riverbed sections. The river bed sampling was carried out simultaneously with the suspended sediment and bed load sampling in all of measuring sections both in 1998 and 1999.

3.2. Bed-load sampling and tracing

It was supposed that the Károlyi-sampler could take bed-load samples in this gravelly reach provided the erosive capacity of a natural flood wave would break up the armoured surface layer of the bed, at least along stripwise portions of the river channel. On the other hand, some difficulties were envisaged concerning the lowering of the bulky sampler onto the bed at the expected 2-3 m/s flow velocities. On the sandy-bed reach of the studied river reach, the manufacturing and application of a Helley-Smith type bed load sampler was considered. For the sake of this, such an instrument was borrowed from the VUVH, Bratislava and after a couple of successful trials, the new device was built and completed in 1998 (*Fig. 4.*).

Preparations were carried out for a luminescent bed-load tracing measurement in the sand-bed reach of R. Drava. The methodology for surface labeling of natural sand grains, for injection and detection of tracer has already been developed by VITUKI in the sixties *(Rákóczi 1968).* In September 1998, bed material was collected around the stations Barcs and Drávaszabolcs with a mass of about 350 kg each. After drying, the sand grains were marked by a yellow luminescent dye, which shines brilliantly under UV light. In this way, even one single marked grain can be detected among thousands of unmarked ones. The grain-size distribution of the sand was laboratory checked before and after the marking procedure. According to the results, no significant granulometric changes could be observed, thus, the dynamic properties (settling, mobility, etc) of the sediment were not altered.

Bed-load was sampled at three stations in the *recessing phase* of a flood wave within the 950 – 843 m3/s discharge range. At the uppermost station the high flow velocity has hindered the lowering of the Károlyi sampler to the bottom. After fixing a 20 kg extra weight to it, the sampling was possible at Vízvár in nine points. The bed-load discharge was found much higher than the value in 1998, calculated from one single sample only. Interestingly, the average grain size of the nine samples was similar to the one in 1998. The much finer grain-size composition of bed load compared with that of the bed material indicates that in both years a fine gravel – sand mixture was transported over the stable, coarse gravel bed surface.

The sand-bed reach of Drava River was sampled at both stations in the same points as in 1998, however, in 1999 the Helley-Smith sampler was used. At Barcs the bed-load discharge, the average grain diameter surpassed the corresponding values obtained in 1998. From this first comparative measurement no final conclusions can be drawn yet concerning the sediment trapping efficiency, but it is obvious that the new sampler can more easily be handled than the bulkier Károlyi sampler. At Drávaszabolcs, the bed-load discharge was found to be about one third of that in 1998, while the average grain sizes remained very similar to each other in both years. The differences and possible contradictions have to be cleared up in the near future by several new measurements. One possible reason for them might be the relative position of the entrance of the lowered Helley-Smith sampler and the moving sand dunes on the riverbed. The application of an underwater video camera will presumably help to clarify this problem. This technique was already tested for gravel bed-load in the Hungarian-Slovakian Danube reach *(Rákóczi and Szekeres 1994).*

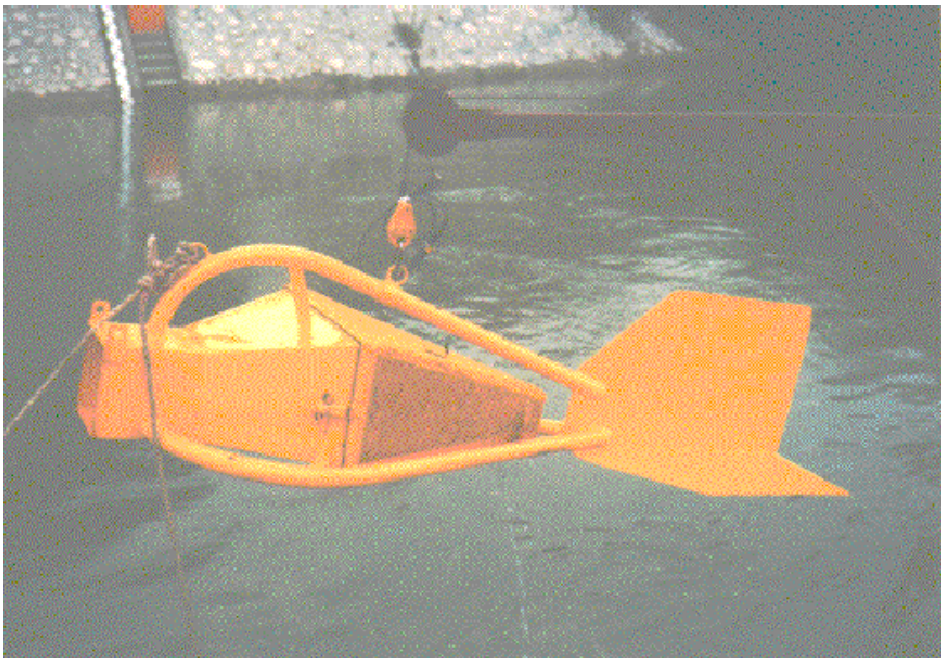

Fig .4 The Helley-Smith type bed-load sampler

In September 1999 successful tracer measurements were carried out in the vicinity of both stations within the sand-bed river reach. The flow discharges were somewhat lower than at the time of bed-load sampling (563 m3/s). The flow velocities ranged at the site of the tracer samplings between 0.6 and 0.8 m/s. About 130 kg marked sand was placed onto the riverbed at both places and the movement of it was followed by repeated bed-material sampling during two days after the start. The samples were analyzed under UV light right on the spot by placing

them in a special portable *luminoscope* equipped with UV filter-glass windows exposed to the sun (*Fig. 5*.). Thus, the transport of the samples to an UV laboratory was avoided.

Fig. 5 The portable luminoscope

From the daily displacement of the tracer grains the average velocity of the moving stripes of the bed could be determined. The bed-load discharge was then calculated as the product of the width, the depth, the velocity and the porosity of the moving stripe of the bed. The average velocity at Barcs was found to be 2 – 2.5 m/hr, while at Drávaszabolcs 1 – 1.5 m/hr. The corresponding specific bed-load discharges are 2.77 and 1.67 kg/s respectively. The latter two values are about twice the results obtained by samplers. The reasons for the differences might be manifold since the depth of the moving bed-layer was assumed and also the sampling has different sources of error. It is planned for 2000 to carry out *simultaneous* bed-load sampling and tracing measurements.

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Efficient Sampling for Estimating Suspended Sediment Loads - Case Studies from the River Elbe

Andreas Schmidt

Abstract: The main deficiency of most long-term sampling programmes is that they mostly are not well adapted to processes showing high variability, as they do not take account of the statistical character of the process observed. As a consequence a great number of unnecessary samples often are taken. To obtain load estimates within an acceptable range of accuracy and precision sampling strategies have to be applied. This paper describes the concept of stratified sampling and presents results of case studies from the River Elbe with regard to the estimation of yearly sediment loads.

Key words: sampling strategy, suspended sediment load, River Elbe

Effiziente Probenahme zur Schätzung von Schwebstofffrachten - Fallstudien an der Elbe

Zusammenfassung: Der größte Nachteil der meisten Langzeit-Probenahmeprogramme besteht darin, daß sie an Prozesse mit hoher Varianz nicht gut angepaßt sind, indem sie den statistischen Charakter des zugrunde liegenden Prozesses nicht angemessen berücksichtigen. Das hat zur Folge, dass oftmals eine Vielzahl unnötiger Probenahmen erfolgt. Um unverzerrte Frachtschätzungen mit definierter Genauigkeit zu erhalten, müssen Probenahmestrategien Anwendung finden. Im folgenden werden das Konzept der geschichteten Probenahme erläutert und deren Anwendung zur Schätzung jährlicher Schwebstofffrachten anhand zweier Fallstudien an der Elbe präsentiert.

Schlüsselworte: Probenahmestrategie, Schwebstofffracht, Elbe

1 Introduction

The knowledge of nature and behaviour of transported solids in rivers is fundamental to answer questions relating to navigation, water resources, and water quality and ecology aspects. As fine solids can serve as a transporting agent, measurements of suspended solids are a necessary basis for quantification of actual as well as potential loads of particle bound transport of organic micropollutants and heavy metals and further water quality assessment. Nowadays, these measurements are carried out at many rivers worldwide giving estimates of e.g. annual loads of sediments and pollutants.

As the often highly fluctuating suspended sediment concentration depends on many interdependent factors sediment discharge proves to be a complex dynamic process. In general water discharge and suspended sediment concentration do not correlate well as the variability of suspended sediment concentration is very high at instationary discharge conditions: for a given discharge concentrations can be several times greater on the rising limb of the hydrograph than on the falling limb. From numerous investigations it is well known that at least in smaller catchments the major part of the annual sediment yield is transported during short periods of high flows whereas in the most of time the sediment transport is comparatively low. Schmidt (1994) reported for a catchment in Germany with 101 km² that 80 % of the annual load was transported in 3 % of the time. Similar observations have been reported by Walling and Webb (1981).

As the discharge of suspended solids cannot be measured directly the common practice is to take discrete water samples, to determine the sediment concentration by means of filtration and to estimate the sediment discharge as a product of water discharge and sediment concentration. Beneath problems arising with filtration the main deficiency of this method is that no continuous monitoring is achieved. To get information about concentration continuously turbidity measurement frequently is used as this parameter can be related to sediment concentration sometimes to a high degree. As with this technique problems are involved as well (in addition to the dependency on concentration results of turbidity measurements depend on type of measuring system; size, shape, surface roughness and colour of grains; ratio of mineral to organic material, thus calibration often appears to be unstable) the traditional method of taking discrete water samples is still prevalent.

2 Aims and scope

To obtain load estimates within an acceptable range of accuracy and precision (i.e. unbiased estimates with low variance) under economical restrictions efficient and adequate sampling programmes have to be applied. Sampling is efficient if estimates with low variance are obtained even when sample sizes are small. The aim of all sampling strategies is to ensure a sampling procedure by which the required representation of the process is achieved at minimal expense. However, the main deficiency of most long-term sampling programmes is that they mostly are not well adapted to processes showing high variability, as they do not take account of the statistical character of the process observed. As a consequence a great number of unnecessary samples are taken at concentration conditions with low variance whereas the sampling frequency is inadequate at the rare significant events associated with high variance. Moreover the estimates are often biased and have no specified properties (no information about precision and accuracy). Thus they cannot be judged with regard to their deviation from the target value (e.g. true annual load).

Many authors have stressed the fact, that sampling frequency has significant effects on the accuracy and precision of load estimates and that a great need exists for adequate sampling programmes (Dickinson, 1981; Olive, Rieger, 1988).

The lack of a theoretical basis is the reason, why the application of ‘subjective’ sampling programmes is inefficient and does not give answers to the following questions:

- How many samples have to be taken to estimate sediment yield with defined precision ?
- How to distribute these samples in time in view of the high variability of the process ?
- What are the statistical properties of the estimates ?

To overcome these deficiencies strategies have to be based on sample survey theory.

The Federal Waterways and Shipping Administration (Wasser- und Schiffahrtsverwaltung des Bundes - WSV) maintains 69 measuring stations in the German waterways. At these sites water samples are taken by hand in a daily interval (in general only workdays) to determine suspended sediment concentration. The results of the analyses done by the Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde - BfG) allow estimation of sediment concentration, sediment transport and loads at each site. As most of these measuring stations are controlling great drainage basins the streams do not show very rapid event response at these sites and sample sizes of about 250 per year may give reliable load estimates. Taking into account the costs of collecting and analysing the huge amount of samples the operation of this monitoring network would greatly benefit from the application of well-adjusted sampling strategies. Moreover, errors introduced by inadequate sampling could be avoided. Therefore investigations have been done to define strategies which ensure an improved sampling efficiency, i.e. reducing the number of measurements in comparison with the operation today, with the aims of relating sampling effort to the desired precision of load estimates and getting unbiased estimates with

known statistical properties. The results of all simulations have been compared to estimates obtained by the sampling programme practised today. Among the strategies tested have been very simple ones, like simple random sampling, each sample having the same probability of being taken, sampling with probability proportional to the magnitude of estimated sediment transport and stratified sampling.

3 Principles of sampling

As they are a function of random variables results of estimation functions (e.g. $x = \alpha \Sigma x_i$) are random variables themselves. Therefore they are statistically distributed. For independent distributed random variables with expected value μ and variance σ^2 the variance of the sample mean is

$$V(x) = \sigma^2/n.$$

As the variance of the population σ^2 is given by the nature of the process sampled reducing the size of the sample means accepting a corresponding increase of the variance of estimate and vice versa. Therefore processes with high variance are badly estimated with a small sample size. However, the problem in sampling usually is that the sample size has to be small due to economical reasons while the variance of estimate is not allowed to exceed a predefined level due to the quality standard of the investigation. This can only be achieved by applying strategies that make use of statistical information regarding the nature of the process, i.e. differentiating the target population. Therefore that sampling strategy has to be applied by which the sample size is reduced the most for an accepted variance of estimate.

The precision of a sample is given by

$$d_x = k\,\sigma_x = k\,\sigma/\sqrt{n}$$

in which σ_x is the standard deviation of the sample mean, σ is the standard deviation of the population, *k* is the value of the standard normal distribution for a chosen level of confidence and *n* is the sample size (Leiner, 1994). By *k* the probability has to be defined that the unknown expected value of the population lies within the limits of confidence.

From this equation the number *n* of samples to be taken is determined as

$$n = (k^2\,\sigma^2) / d^2_x$$

i.e. the sample size increases as the level of confidence ($1-\alpha$) will be chosen higher, as more precise the estimate has to be (small allowed estimation error) and as higher the variance of the population units will be. If the standard deviation of the population σ is unknown the sample estimate *s* has to be used with *t* (value of the t-distribution) instead of *k*.

4 Stratified sampling

The concept of stratified sampling is to divide the population into several strata within which the subpopulations are relatively homogeneous (‘minimization of variance’), whereas the heterogeneity between the strata is stressed (‘maximization of variance’). To apply stratified sampling, the empirical distributions of the variables by which the strata are defined have to be known. In case of suspended sediment data useful variables could be e.g. water level or water discharge, tendency (rising or falling), rate of change (e.g. dQ/dt) and time (seasonal influences). Although using only one variable may lead to an appropriate stratification scheme careful stratification may require a combination of several variables.

The design of sampling strategies of course requires historical data. Records of e.g. water discharge and of concentration data of at least one year should be available to get some estimates of the statistical properties of the process. As the appropriate definition of the strata is decisive for satisfactory application it is advisable to use data of more than one year and to

analyse the characteristic of the parameter to be sampled carefully with respect to the parameter(s) defining the strata.

Strata are defined by calculating strata sizes and variances within these strata from historical records before sampling starts, thus the quality of estimates is very much dependent on the fact that the processes statistically behave similar in future as in past at the site monitored. The underlying assumption is that future hydrographs distribute to the different strata similar to the record used for calibration with regard to times spent in strata and to the variances within the strata. If the relationship between the sampled variable and the strata-defining variable changes (e.g. changes in sediment-streamflow relationship caused by changes in watershed characteristics) calibration by historical records is no longer valid for the future sampling scheme.

4.1 Stratification

Stratification is done by examining historical records and looking for time intervals in which the chosen variable (e.g. water discharge) and the sampled variable (e.g. sediment concentration) are of similar character. The data of all intervals showing similar character are lumped together and define one stratum. In case of suspended sediment data it is often observed that the concentration hydrograph peaks before the flow peak is reached (hysteresis effect). For this a definition of an event stratum having a boundary at higher flow on the recession limb compared to that on the rising limb may be successful. Of course the definition of strata boundaries is a subjective procedure, but if the underlying principles (e.g. discriminating between non-event and event data) are applied consequently and the historical record is long enough (several years) and has good quality, the definition of strata boundaries is not critical as variance estimates normally are not very sensitive to moderate differences. The main benefit comes from stratifying, not from optimising strata boundaries. A procedure for optimising strata boundaries was given by Cochran (1963) using sediment-rating curves.

Reducing the variance by stratifying historical hydrographs may lead to a great number of narrow strata. However, applying this sampling strategy to future unknown hydrographs it should be assured that each stratum gets enough samples to allow estimation.

In order to get estimates with desired statistical properties the population has to be approximately normally distributed. In general this is not the case for suspended sediment data, but it is nearly always possible to define subpopulations by stratification that more closely approach normality.

4.2 Allocation of samples

There are two different ways to allocate the samples to strata. If the samples are allocated depending on the sizes and variances of the strata it is called a *proportional allocation*, whereas if the samples are allocated depending on the sizes and variances of the strata and the costs of sampling in each stratum it is called an *optimal allocation* (Neyman, 1934). If the expected value $\mu_s \neq \mu$ at least for one stratum *s* proportional allocation does better compared to purely random sampling. If $\sigma^2_s \neq \sigma^2$ at least for one stratum *s* optimal allocation does better compared to proportional allocation.

In the case of stratified sampling with proportional allocation the total number of samples *n* to be taken is determined as

$$n = t^2 / d^2_x \sum_{s=1}^{S} (N_s/N \bullet s^2_s)$$

in which N_s is the time in stratum *s*, s_s is the sample estimate of the standard deviation in stratum *s*, and *N* is the total time in the period under consideration.

In the case of stratified sampling with optimal allocation the total number of samples *n* to be taken is determined as

$$n = t^2 / d^2_x \left(\sum_{s=1}^{S} N_s/N \cdot s_s \right)^2.$$

Provided the variable costs of taking samples are the same in all strata, the total number *n* of samples in case of optimal allocation is distributed amongst the strata according to

$$n_s = n \cdot N_s \cdot s_s / \sum_{s=1}^{S} (N_s \cdot s_s).$$

4.3 Sampling

In applying stratified sampling the samples can be taken either at constant rates or randomly distributed corresponding to these rates. Sampling rates can be calculated for each stratum by the ratio n_s/N_s (e.g. samples per day), which should be rounded for the sake of convenience. Minimal rates should be defined to assure that a reasonable number of samples are gathered. Though sampling at constant rates is the most convenient way of sampling it has a decisive disadvantage: if the process sampled shows any regular pattern that matches the sampling frequency (e.g. algal blooming corresponding to daylight) sampling at constant rate will not be representative producing biased estimates.

If stratified random sampling is used uniformly distributed random numbers [0,1] have to be calculated either before sampling starts or in real time. In the first case the times of sampling for each stratum are defined calculating n_s random numbers, sorting them in ascending order, and transforming them to random numbers [0, N_s] to match the expected time N_s in that stratum. However, as the future hydrograph is unknown when sampling starts it is advisable to calculate sufficient random numbers n_s^* (e.g. several times the number n_s) for each stratum to avoid running out of random numbers if the actual stratum size exceeds the expected size N_s. In that case the times of sampling of course have to be calculated by transformation to the corresponding time N_s^* (N_s times the chosen safety factor). The alternative way of using random numbers for stratified sampling is to assign an inclusion probability to each stratum reflecting the expected size and variance of the respective stratum. If a calculated random number is less than the inclusion probability of the current stratum a sample will be taken. This of course needs the calculation of uniformly distributed random numbers [0,1] for each time step, preferably in real time.

5 Case studies

The efficiency of stratified sampling with regard to the estimation of yearly loads was tested with two different data sets: a 6-year-record (1992-1997) of daily samples at *Pirna* (River Elbe, km 34.7) and a 2-year-record (6/1996-5/1998) of turbidity measurements at *Dommitzsch* (River Elbe, km 172.6). The turbidity data delivered in 10 min intervals have been averaged to hourly values and then transformed to concentration values by applying a good fitting turbidity-concentration relationship.

5.1 Results from Pirna

Analysing the flow and sediment data from the daily samples at Pirna a simple scheme of only three strata seemed to be adequate with flow as the only strata-defining variable (flow-stratified sampling): a non-event stratum with flow less than 400 m^3/s, a low-event stratum 400 to 700 m^3/s, and a high-event stratum with flow higher than 700 m^3/s. A confidence level of 90% and

an accepted deviation from true yearly mean load of ±15% were chosen. The methodology outlined above has been applied to a period of two years of this record (1994 and 1995) to define appropriate sampling frequencies for each of these three strata.

Table 1 Sampling frequencies for Pirna (precision ±15%; α=10%) calculated for 1994-1995

Stratum	Time	Time	Number of samples	Sampling rate	Sampling rate	Chosen sampling rate
	days	%	-	samples/day	days/sample	days/sample
Q ≤ 400 m³/s	215.5	59	9.91	0.046	21.76	22
400 < Q ≤ 700	102.0	28	14.18	0.139	7.20	7
Q > 700 m³/s	47.5	13	25.06	0.528	1.90	2
Totals	365	100	49.15	-	-	-

The calculated sampling rates for a time base of one year (Table 1) show that to get estimates with same precision the sampling effort differs considerably from stratum to stratum, a clear proof that stratifying this record makes sense. In the non-event stratum (more than half of the time in these two years) one sample in three weeks would be adequate (if this level of precision is accepted) as the variance of the concentration is low when water discharge is below 400 m³/s. Using these results sampling was simulated for the other four years (1992, 1993, 1996, 1997) at constant rates starting sampling on the first day in each stratum. Simulation results are presented in Table 2.

Table 2 Results of sampling simulations with flow-stratified sampling at Pirna

Stratum	Sampling rate	1992	1993	1996	1997	Mean
	days/sample	samples	samples	samples	samples	samples
Q ≤ 400 m³/s	22	14	16	11	12	13
400 < Q ≤ 700	7	8	3	14	13	10
Q > 700 m³/s	2	7	3	15	12	9
	Samples per year	29	22	40	37	32
	Percentage of daily sampling	8%	6%	11%	10%	9%
	Deviation from 'true' load	-1.6%	-0.7%	5.8%	0.2%	0.9%

5.2 Results from Dommitzsch

In the case of the 2-year-record from Dommitzsch again a simple scheme of only three strata was chosen with flow as the only strata-defining variable. Because the period following July 1997 has been comparably dry lower strata boundaries have been chosen: a non-event stratum with flow less than 300 m³/s, a low-event stratum 300 to 600 m³/s, and a high-event stratum with flow higher than 600 m³/s. Again the confidence level was 90% and the accepted deviation from true yearly mean load was ±15%. As in the case of the Pirna data most of the time in the year sampling could be reduced significantly if this level of precision is accepted: using the first time period for calibration one sample in three weeks would result to be adequate for the non-event stratum (nearly 50% of the time), and using the second time period for calibration one sample in five weeks would result to be adequate for the non-event stratum (about 80% of the time). As a consequence of the fact that the second part of the data set used for calibration

comes from a drier period compared to the first one the sampling rates in the non-event stratum differ significantly (Table 3).

Sampling was simulated applying the different calibration results to the other half of the 2-year-record respectively. Starting on the first day in each stratum sampling at constant rates was simulated. The results are presented in Table 4.

Table 3 Sampling frequencies for Dommitzsch (precision ±15%; α=10%) calculated with two different parts of the data set

Stratum	Time	Time	Number of samples	Sampling rate	Sampling rate	Chosen sampling rate
	hours	%	-	samples / h	h / sample	h / sample
Calculation for the period 6/1996 - 5/1997						
Q ≤ 300 m³/s	4190	47.8	8.217	0.0020	509.9	510
300 < Q ≤ 600	3314	37.8	11.131	0.0034	297.7	298
Q > 600 m³/s	1256	14.3	12.711	0.0101	98.8	99
Totals	8760	100	32.059	-	-	-
Calculation for the period 6/1997 - 5/1998						
Q ≤ 300 m³/s	7078	80.8	7.865	0.0011	899.9	900
300 < Q ≤ 600	1367	15.6	6.390	0.0047	213.9	214
Q > 600 m³/s	315	3.6	3.365	0.0107	93.6	94
Totals	8760	100	17.620	-	-	-

Table 4 Results of sampling simulations with flow-stratified sampling at Dommitzsch

Calibration data: 6/1996-5/1997			Calibration data: 6/1997-5/1998		
Stratum	Sampling rate	6/1997-5/1998	Stratum	Sampling rate	6/1996-5/1997
	h / sample	samples		h / sample	samples
Q ≤ 300 m³/s	510	14	Q ≤ 300 m³/s	900	5
300 < Q ≤ 600	298	5	300 < Q ≤ 600	214	16
Q > 600 m³/s	99	4	Q > 600 m³/s	94	14
	Sample size	23		Sample size	35
Percentage of daily sampling		6%	Percentage of daily sampling		10%
Deviation from ‘true’ load		-10.4%	Deviation from ‘true’ load		5.7%

6 Conclusions

The results of the investigations show that load estimation of flow related constituents may greatly benefit from the application of sampling strategies, in particular if the variance of the parameter sampled varies much with increasing flow. If strategies are applied that base on sampling theory load estimates within specified ranges of accuracy and precision can be obtained. The investigations reveal that in the case of flow-stratified sampling the main benefit comes from stratifying the record, not from optimising the strata boundaries. Nevertheless, the

results in the case of the data from Dommitzsch demonstrate that a good calibration generally requires a database of several years. From both case studies the conclusion can be drawn that the sampling rate in this part of the River Elbe - as far as yearly sediment loads are concerned - could be reduced significantly in comparison to daily sampling if a statistically based strategy is applied and the sampling scheme is well adjusted to the nature of the process by means of historical data.

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Prognose von flußmorphologisch bedingten Sohlunebenheiten in kiesführenden Flüssen im Hinblick auf mögliche Fahrrinnenquerschnitte

Bernhard Söhngen, Michael Möhling

Zusammenfassung: Die statistische Auswertung von Querprofilen aus Flusspeilungen im Ausbauabschnitt der Donau zwischen Straubing und Vilshofen sowie am Oberrhein zwischen Iffezheim und Au am Rhein, hinsichtlich der morphodynamisch bedingten Unebenheiten des Gewässerbettes, zeigt eine nahezu lineare Abhängigkeit von der mittleren Wassertiefe bei bettbildendem Abflusszustand, von der betrachteten Fahrwasserbreite und von der Krümmung des Strömungsfeldes. Die Unebenheitshöhe ist weiterhin linear proportional zum Shields-Wert. In Geraden tritt an die Stelle des Krümmungsradius als charakteristische Länge der Krümmung ein Vielfaches der Breite des Niedrigwasserbettes. Die Ergebnisse der statistischen Analyse werden für die Prognose von Fahrwassertiefen für Ausbauzustände an der Donau verwendet.

Schlüsselworte: Unebenheit, Fahrrinnentiefe, Flußmorphologie

Prognosis of Bed Unevenness in Gravel Bed Rivers, Caused by Bed Formig Processes, Regarding to Possible Navigable Depth

Abstract: The statistical evaluation of cross-section profiles of the Danube River reach between Straubing and Vilshofen and of the upper Rhine River between Iffezheim and Au, according to the unevenness of the river bed caused by morphodynamic processes, shows, that there is a nearly linear dependency on the average water depths for bankfull discharge, on the widths under consideration and on the curvature of the flow field. The height of the unevenness is also linear proportional to the Shields value. In straight river reaches the curvature has to be replaced by another characteristical length of the planform geometry, the width of the river bed at low water levels. The results of the statistical analysis will be used for the prognosis of fairway depths for the Danube River after improvement.

Keywords: unevenness, navigable depth, river morphology

Einführung

Der volkswirtschaftliche Nutzen von Regelungsmaßnahmen in schiffbaren Flüssen ist häufig bestimmt durch künftig größere mögliche Abladetiefen für die Schifffahrt. Dies ist z.B. im Donauabschnitt Straubing-Vilshofen der Fall, für den derzeit vergleichende Variantenanalysen unter Einschluss flussregelnder Ausbaumaßnahmen durchgeführt werden (Kellermann 1999, Söhngen 1999). Die hier beschriebenen Untersuchungen stehen in diesem Kontext. Die Abladetiefe ist dabei, neben den Querschnitts- und Strömungsverhältnissen sowie den verkehrlichen und schifffahrtlichen Randbedingungen, maßgeblich von den Tiefenverhältnissen im Bereich der Fahrrinne abhängig. Diese sind wiederum, bei (in der Regel) vorgegebener Fahrrinnenbreite, von den Abflussverhältnissen, dem Gefälle und der Sohlen- und Systemrauheit - diese Parameter definieren die mittlere Wassertiefe - sowie der morphologischen Gestalt des Flussbettes im Querprofil abhängig. Die Tiefenverhältnisse können im Bereich der Fahrrinne vereinfachend, neben der mittleren Tiefe h_m, durch ein weiteres Tiefenmaß, die Unebenheitshöhe u, beschrieben werden. Letztere wird im Folgenden definiert als Differenz von h_m zur kleinsten Wassertiefe im Bereich der Fahrrinne, wie dies auf Abbildung 1 skizziert ist. Im Hinblick auf die schifffahrtlichen Randbedingungen wird also nur die Unebenheitshöhe "nach oben" betrachtet.

Ist die Unebenheitshöhe klein, wie dies im Bereich von Furten, also den Übergängen zweier aufeinander folgender gegensinniger Kurven, der Fall ist, dann ist von h_m nur ein geringer Wert abzuziehen, um die nautisch nutzbare Tiefe bzw. die Fahrrinnentiefe zu erhalten. Dennoch ist es wichtig, diesen Wert und dessen Abhängigkeit, z. B. von Regelungsparametern oder von der Fahrrinnenbreite zu kennen, um die nautisch nutzbare Tiefe nach Durchführung von Ausbaumaßnahmen vorauszusagen oder/und optimieren zu können.

In Flusskrümmungen ist die Unebenheit viel größer als in Geraden. Die Querprofile weisen hier eine typische Dreieckgestalt auf, d. h. die Gewässersohle fällt als Folge der Sedimentumlagerungen durch die Sekundärströmung zum Außenufer hin ab (vgl. Abb. 4). In Krümmungen wird die Fahrrinne deshalb zum Prallhang hin verschoben, um trotz vergleichsweise großer Unebenheiten noch ausreichende Fahrrinnentiefen erreichen zu können. Dies geht allerdings häufig auf Kosten der möglichen Fahrrinnenbreite und damit der Sicherheit.

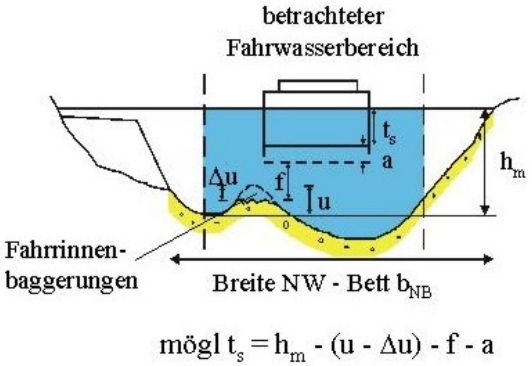

Abb. 1 Definitionsskizze zur Ermittlung der möglichen Abladetiefe t_s aus der mittleren Wassertiefe h_m , der Unebenheitshöhe u , der unterhaltungsbedingten Minderung der Unebenheit Δu , dem Mindestflottwasser f und dem fahrdynamischen Einsinken a

Die folgende Analyse bezieht sich auf weitgehend gestreckte und gleichzeitig stark geregelte Flussabschnitte, die in Gewässern mit beweglicher Sohle, wie im vorgenannten Donauabschnitt, in der Regel abladebestimmend sind. Die Flussregelung erfolgt dort überwiegend mit Buhnen, wobei, selbst in sonst geraden Flussabschnitten, durch wechselseitige Anordnung von Buhnengruppen darauf hingewirkt wurde, dem Niedrigwasserbett einen tendenziell mäanderförmigen Verlauf aufzuzwingen, wie dies auf Abbildung 2 skizziert ist.

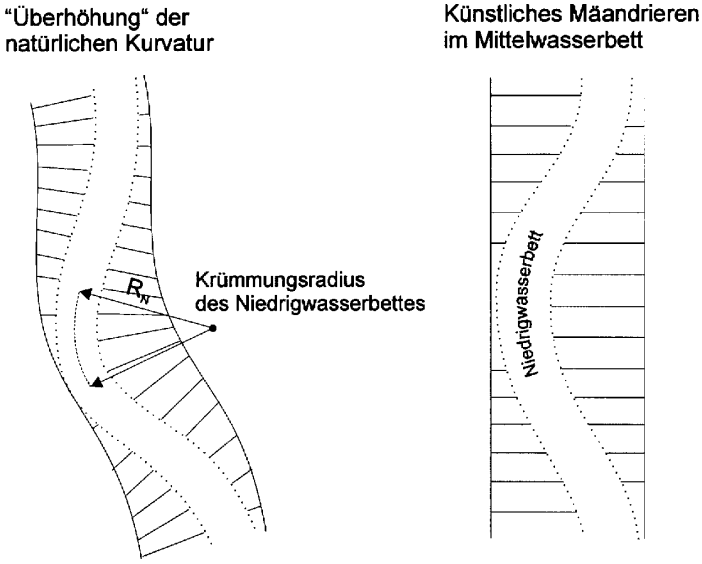

Abb. 2 Im Rahmen der vorliegenden Analyse betrachtete "weitgehend gestreckte" Flussabschnitte mit Niedrigwasserregelung.

Dadurch und durch Wahl einer angepassten Breite zwischen den Streichlinien gelang es, wandernde Kiesbänke zu vermeiden. Diese wurden gewissermaßen durch die erzwungene "innere Kurvatur" des Strömungsfeldes an der Stelle "eingefroren" und es wurde dadurch, wenn auch verbunden mit größeren Bettunebenheiten, ein weitgehend stabiler Gewässerzustand erreicht.

Mit der nachfolgenden Analyse wird versucht, diese Unebenheiten auf der Basis statistischer Untersuchungen abzuschätzen. Dabei wurden Daten vom Oberrhein zwischen Iffezheim und Au am Rhein sowie der Donau im o.g. Ausbauabschnitt ausgewertet. In diesen Flussabschnitten liegt das Verhältnis der Breite des Niedrigwasserbettes (b_{NB}) zu der des Mittelwasserbettes (i. d. R. die Wasserspiegelbreite bei bordvollem Abfluß b_{MB}) zwischen 0,5 und 0,7 (vgl. Tab. 1). Die relative, d. h. auf eine charakteristische Wassertiefe des Niedrigwasserbettes (h_{NB}), hier bei "bettbildenden Abflusszuständen", bezogene Kopfhöhe der Buhnen (h_B), liegt zwischen 0,6 und 0,7. Als "bettbildend" wurde, wegen der ausgeprägten Aus-uferung beider hier betrachteter Flüsse in den gewählten Abschnitten, der bordvolle Wasserstand gewählt. Auch das Verhältnis dieser mittleren Wassertiefe zur Breite der beweglichen Sohle des Niedrigwasserbettes (hier i. d. R. der Abstand zwischen den Streichlinien der Regelungsbauwerke), ist in allen betrachteten Flussabschnitten nahezu konstant und liegt zwischen 0,04 und 0,05. Die Buhnenabstände betragen ca. das 1- bis 2-fache der Buhnenlänge. Die Shield'schen Bewegungsintensitäten (bezogen auf d_{50} der Sohlendeckschicht), liegen zwischen ca. 0,06 am Oberrhein bzw. in der Teilstrecke des Donauabschnittes unterhalb der Isarmündung und ca. 0,04 oberhalb der Isarmündung. Diese geometrischen Randbedingungen ermöglichten es, die Unebenheitshöhe vom Oberrhein mit denen in der Teilstrecke unterhalb der Isarmündung der Donau zu vergleichen. Die nachfolgend genannten statistischen Parameter sind auf die vorgenannten Parameterbereiche beschränkt.

Ziel der Untersuchungen

Die vorliegende Analyse zielt vornehmlich auf die Prognose von möglichen Fahrrinnentiefen für solche Ausbauzustände, bei denen zuverlässige Aussagen nur über die **mittleren** Tiefenverhältnisse im Bereich der Fahrrinne getroffen werden können, bei denen die exakte morphologische Gestalt des Flusses jedoch nur grob angenähert voraussehbar ist. Dies ist z. B. für eine im Rahmen der vertieften Untersuchungen zum Donauausbau betrachtete Ausbauvariante (B) der Fall, mit der die Grenzen flussregelnder Maßnahmen im Hinblick auf die Maximierung der Fahrrinnentiefe - bei vorgegebener, größerer Breite als im Ist-Zustand - aufgezeigt werden sollen. Dabei werden sowohl die Grundrissgestalt des Flusses - durch eine deutlich veränderte Fahrrinnentrassierung -, die Gefälleverhältnisse - durch Entschärfung derzeitiger Steilstrecken -, als auch die morphologischen Randbedingungen - durch einen deutlich höheren "Regelungsgrad" gegenüber dem Ist-Zustand - verändert. Für die Analyse ist es allerdings nicht notwendig, vorauszusagen, an welcher Stelle exakt welche Regelungsmaßnahme welche strömungs- und fahrdynamischen Verhältnisse hervorrufen wird. Es reicht aus, eine Aussage über die **im Mittel** erreichbaren Tiefenverhältnisse, eingedenk der Bettunebenheiten, zu treffen. Es kann dabei angenommen werden, dass die **mittleren** Unebenheiten aus einer statistischen Analyse, wie sie nachfolgend vorgestellt wird, durch Optimierung der Regelungsmaßnahme auch örtlich erreicht werden können. Dadurch wird es möglich, auch für die Variante B das durch Flussregelungsmaßnahmen Erreichbare auszuzeigen.

Ursachen von Bettunebenheiten in kiesführenden Flüssen

Die größten Unebenheiten entstehen durch die **Krümmung des Strömungsfeldes**. Eine Krümmung tritt, wie vorher hinsichtlich der Anordnung der Regelungsbauwerke auf Abbildung 2 gezeigt wurde, auch in weitgehend gestreckten Flussabschnitten auf, siehe auch Abb. 4. Wird zunächst vereinfachend von einer konstanten Sohlenquerneigung S_F ausgegangen, dann ergibt sich die größte Unebenheitshöhe in Bezug auf die mittlere Tiefe aus dem Produkt der Sohlenquerneigung mit der halben betrachteten Breite b, z. B. der in der Fahrrinne. Wird weiterhin, in Analogie zur Vorgehensweise z. B. von Zimmermann (1978), davon ausgegangen, dass es sich um eine ausgebildete Kurvenströmung handelt, dann kann die Kurvenschrägneigung und damit die Unebenheitshöhe von geometrischen und

sedimentologischen Parametern des Gewässerbettes abhängig gemacht werden. Hierzu wird zunächst die Querneigung des Wasserspiegels in Kurven errechnet. Der dadurch bedingte Druckgradient hält der Zentrifugalkraft des gekrümmten Strömungsfeldes im Mittel das Gleichgewicht. Wegen der ungleichförmigen Fließgeschwindigkeitsverteilung über die Tiefe, mit größeren Fließgeschwindigkeiten an der Oberfläche, ist dort die örtliche Zentrifugalkraft jedoch größer als die Gegenkraft aus dem Druckgradienten. Deshalb wird an der Wasseroberfläche eine zum Prallufer hin gerichtete Kraftkomponente geweckt. An der Sohle ist dagegen die Kraft aus dem Druckgradienten größer als die aus der Zentrifugalkraft, woraus eine nach innen gerichtete Kraftkomponente resultiert. Die aus diesen beiden Kraftkomponenten gebildete Drehkraft beschleunigt ein in Bewegung befindliches Sohlenkorn zum Innenufer hin. Bei einer stationären, ausgebildeten Kurvenströmung, bei der sich die Sohlenquerneigung nicht mehr ändert, muss die zugehörige Kraft im Gleichgewicht sein mit der durch die Sohlenquerneigung bedingten Gewichtskomponente des Kornes, die zum Prallhang hin gerichtet ist. Mit diesen grob skizzierten Ansätzen ergibt sich schließlich die auf Abbildung 3 erläuterte Gleichung für die Unebenheitshöhe einer ausgebildeten Kurvenströmung mit den theoretischen Werten für die Konstanten C_1 von 14,5 und C_2 von 0,0.

Auch in völlig geraden Abschnitten von Flüssen, die unter natürlichen Bedingungen Mäander bilden würden, wobei z. B. das Kriterium von da Silva (vgl. Yalin, 1992) zur Charakterisierung der Flussgestalt verwendet werden kann, wird der Stromstrich nicht völlig gerade verlaufen, sondern mäanderförmig um die Flussachse pendeln. Da die zugehörige „Wellenlänge“ proportional ist zur Breite des Flussbettes, ist somit auch der zugehörige Krümmungsradius mit der Flussbreite skaliert. In der auf Abbildung 3 illustrierten Gleichung für die Unebenheitshöhe, ist deshalb im Bereich von geraden Flussabschnitten der Krümmungsradius durch ein Vielfaches (Konstante C*) der maßgebenden Gewässerbreite, hier der Breite des Niedrigwasserbettes b_{NB} , zu ersetzen. Die Unebenheitshöhe kann danach mit einem "effektiven Krümmungsradius" R_{eff} errechnet werden. Der tatsächliche Krümmungsradius ist dann zu verwenden, wenn dieser kleiner als das vorgenannte Vielfache der Breite des Niedrigwasserbettes ist.

Parameter aus der Theorie der Kurvenschrägneigung

äquivalente Sandrauhigkeit

betrachtete Sohlbreite

Unebenheitshöhe („nach oben“)

$$\frac{u}{h_{NB}} = C_1 \cdot \left(\frac{k_s}{h_{NB}}\right)^{-\frac{1}{6}} \cdot \Theta \cdot \frac{b}{R_{eff}} + C_2$$

Mittlere Wassertiefe des NW-Bettes bei bettbildendem Wasserstand

$$\frac{h_{NB} \cdot I}{\frac{\rho_s - \rho}{\rho} \cdot d_{50}}$$

Konstante, abhängig u.a. vom Regelungsgrad und von der Form des Gewässerbettes (dto. C_1)

In Geraden: Krümmung des „inneren Mäandrierens“ : $R_{eff} = R_M \approx 10\, b_{NB}$

In engen Kurven ($R < R_M$) : $R_M = R$

Breite des NW-Bettes

Abb. 3 Aus der Theorie für die ausgebildete Kurvenströmung abgeleitete Beziehung für die Unebenheitshöhe u in kiesführenden Flüssen mit der Tendenz zur Mäanderbildung.

Eine weitere Ursache von Unebenheiten in geregelten Flüssen sind **Buhnenkopfkolke**. Auf Abbildung 4 ist ein solcher Kolk am Beispiel eines Donau-Querprofils mit rechtsseitig

angeordneter Buhne dargestellt. Die dargestellte Buhne liegt im mittleren Bereich eines längeren Abschnittes, der durch Buhnen geregelt ist am Innenufer. Am Außenufer einer Kurve oder an der ersten Buhne eines längeren Buhnenbereiches können sich noch deutlich tiefere Kolke ausbilden. Die durch Buhnenkopfkolke verursachten Unebenheiten u können in Analogie zu Pfeiler- und Fundamentkolken abgeschätzt werden. Nach Kandasamy und Melville (1998) tritt dabei der Einfluss des Shields-Wertes gegenüber den allgemeinen geometrischen Randbedingungen zurück, d. h., wenn der Fluss den Wert des Bewegungsbeginns überschreitet, ändert sich mit steigendem Shields-Wert die Kolktiefe nur noch wenig. Skalierende Größe der Kolktiefe und damit in erster Näherung auch der Unebenheitshöhe u ist deshalb, bei großen Querabmessungen dieser "Störkörper" im Fluss, die **Wassertiefe.** Diese Bedingung kann für Buhnen vorausgesetzt werden. U ist danach in erster Näherung ein Vielfaches der Wassertiefe, multipliziert mit einem Faktor, der von den allgemeinen geometrischen Randbedingungen, die z. B. durch die Höhe und den Abstand der Buhnen in Relation zu h_{NB} ausgedrückt werden können, abhängig ist. Für ähnliche dimensionslose Kenngrößen der makroskopischen geometrischen Parameter des Gewässerbettes, wie sie hier in den betrachteten Abschnitten von Rhein und Donau vorliegen, beschreibt deshalb die auf Abbildung 3 angegebene Konstante C_2 in erster Näherung den Einfluss der zusätzlichen Unebenheiten aus lokaler Kolkbildung im Bereich von Buhnen.

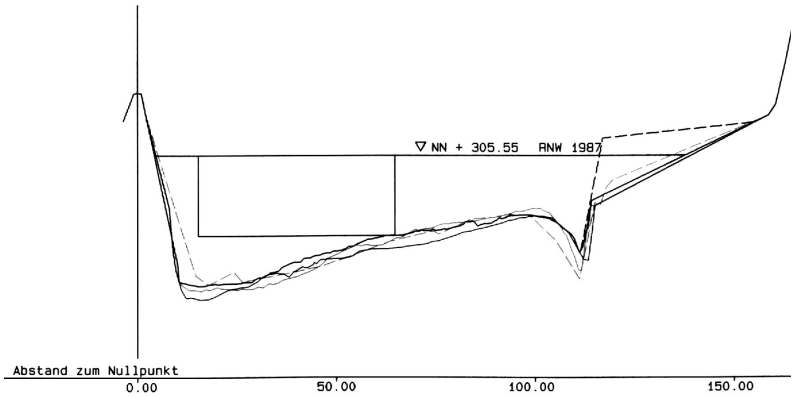

Abb. 4 Ausbildung von Buhnenkopfkolken am Beispiel des Donau-Querprofils, km 2271,4 in einer schwachen Rechtskrümmung.

Unterhaltungstechnisch besonders schwierig zu beherrschende Unebenheiten sind **Mittelgründe**. Sie sind zum einen Folge der generellen Flussgeometrie, z. B. im Bereich einer lokalen Aufweitung. Sie können aber auch bedingt sein durch turbulenzgetriebene Sekundärströmungen, die beispielsweise an Buhnenköpfen entstehen. Dies könnte den auf Abbildung 5 dargestellten Mittelgrund in einer Strecke der Donau mit beidseitig angeordneten Buhnen der Donau erklären, wobei die vergrößerte Systemrauheit an den Buhnenköpfen eine zur Mitte gerichtete Strömungskomponente an der Sohle generiert. Die Ursache könnte aber auch in der vermehrten Turbulenzproduktion an den Buhnenköpfen zu suchen sein, sodass an der Streichlinie entlang Kolke auftreten ("Kolkstraßen"), die zu einer Ausgleichsbewegung in der Flussmitte führen, damit sich das Transportgleichgewicht, das kleinere resultierende Querschnitte erfordert, wieder einstellen kann.

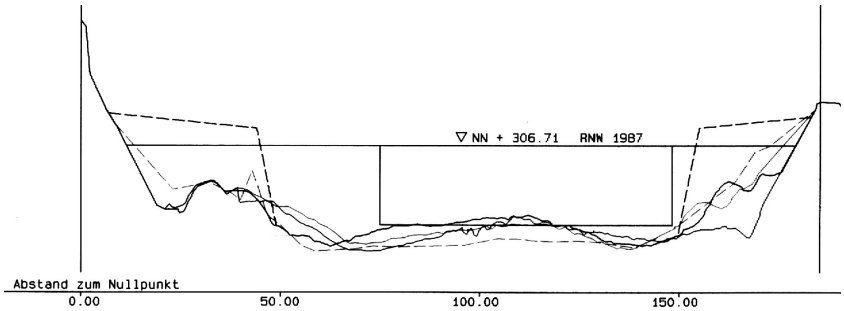

Abb. 5 Mittelgrundbildung in einem beidseitig durch Buhnen geregelten

Abschnitt der Donau bei km 2274,7.

Wenn die Mittelgrundbildung eine solche Ausgleichsbewegung für die Kolkstraßen ist, kann sie nach den vorher für Kopfkolke angestellten Betrachtungen gleichfalls durch die Konstante C_2 beschrieben werden. Auch wenn sie durch die generelle Morphologie des Flusses verursacht ist, ist voraussichtlich die Wassertiefe die maßgebende skalierende Größe. Diese Einschätzung folgt u. a. aus Erfahrungen mit höhenverzerrten, physikalischen flussbaulichen Modellen mit beweglicher Sohle. Dabei wird die Höhenkoordinate des zu modellierenden Flussbettes in der Regel weniger verkleinert als die Lagekoordinate. Die Querprofile sind damit im Modell überhöht. Dies gilt formal zunächst nur für die festen Berandungen, bei denen die Überhöhung modellseitig erzwungen werden kann. Es zeigt sich aber, dass auch die bewegliche Sohle Deformationen aufweist, die zu den überhöhten Wassertiefen proportional sind (Nestmann, Söhngen, 1993).

Abschließend seien die gleichfalls primär mit der Wassertiefe skalierten **Unebenheiten durch Transportkörper** genannt. Im betrachteten Donauabschnitt und auch am Rhein treten Transportkörper unterschiedlicher Höhe und Länge auf (Söhngen et al, 1992). Trotz vergleichsweise großer, singulärer Dünenhöhen von bis zu 0,7 m, die durch Längspeilungen in der Donau nachgewiesen wurden, können sie in den Querprofilen in der Regel nicht nachgewiesen werden. Dies gilt vor allem für die abladebestimmenden Furten. Ein Grund hierfür sind sicherlich die Unterhaltungsanstrengungen der Wasserstraßenverwaltung, die dort dafür sorgen, dass die Unebenheiten, auch aus Transportkörpern, begrenzt werden. Wie auf Abbildung 1 dargestellt, ist deshalb die maßgebende Unebenheitshöhe an den abladebestimmenden Stellen um ein Maß Δu zu reduzieren. Aus der Analyse der Bettunebenheiten für unterhaltungsintensive Querprofile kann dabei geschlossen werden, dass Δu ca. 0,15 m beträgt, betreffend den Ist-Zustand der Donau im Jahre 1998. Für die vorliegende Analyse sind deshalb solche Querprofile aus der Betrachtung auszuschließen, die einer intensiven Unterhaltung unterliegen, denn dort sind die beobachteten Unebenheiten signifikant durch anthropogene Einflüsse überprägt.

Auch Transportkörper können in erster Näherung im Parameter C_2 berücksichtigt werden, denn Dünen können unter ungestörten Bedingungen nicht größer werden als ein bestimmter Prozentsatz der Wassertiefe (vgl. z. B. Yalin, 1964). Verallgemeinernd erfasst somit die auf Abbildung 3 dargestellte Beziehung sowohl den Einfluss der Kurvatur des Strömungsfeldes, den der Flussregelung als auch den von Transportkörpern auf die durchschnittliche Unebenheitshöhe.

Statistische Auswertung

Ausgehend von Querprofilen in 100 m-Abständen wurden für die hier betrachteten Flussabschnitte die Unebenheitshöhen für verschiedene Sohlbreiten ermittelt. Da die Analyse auf die Fahrwasserverhältnisse zielt, wurden solche Sohlenbereiche mit zugehöriger Breite ausgewählt, die sich an fahrdynamischen Randbedingungen orientieren. Dies waren u. a. die Fahrspur zu Berge fahrender Schiffe, die gesamte Fahrrinne und die Breite des Niedrigwasserbettes. Da innerhalb der drei hier betrachteten Flussabschnitte:

- **Oberrhein zwischen Iffezheim** (Rhein-km 336) **und Au am Rhein** (Rhein-km 352)
- **Donau zwischen Straubing** (km 2319) **und Deggendorf** (Donau-km 2286) und
- **Donau unterhalb der Isarmündung bis zur Felsstrecke** (Donau-km 2281 – 2258)

in etwa gleichförmige Verhältnisse hinsichtlich der Shields-Werte sowie der Verhältnisse der Sohlenrauheit zur mittleren Wassertiefe des bettbildenden Abflusszustandes vorliegen, konnte die auf Abb. 3 genannte Gleichung, getrennt für die v.g. Abschnitte, durch die nachfolgend genannte, vereinfachte Beziehung ersetzt werden:

$$u/h = A\, b/R_{eff} + B, \text{ wobei } R_{eff} = C^* b_{NB} \text{ bzw. } R_{eff} = R \text{ für } R < C^* b_{NB}$$

Die Konstanten A und B wurden nun durch eine lineare Regressionsanalyse aus dem Datenkollektiv der Unebenheitshöhen und der zugehörigen charakteristischen Parameter des Strömungsfeldes errechnet. Geringe Standardabweichungen der Konstanten A und B errechneten sich dabei für das gewählte Vielfache der Breite des Niedrigwasserbettes von $C^* \approx 10$. Die dabei für die drei Flussabschnitte errechneten Zahlenwerte sind auf Tabelle 1 angegeben, zusammen mit den Durchschnittswerten für die mittlere Wassertiefe des Niedrigwasserbettes bei bordvollem Abflusszustand h_{NB}, den maßgebenden Mittelwerten der makroskopischen Parameter der Gewässertopographie, der relativen Breite des Niedrigwasserbettes b_{NB}/b_{MB}, der relativen Wassertiefe h_{NB}/b_{NB} und der relativen Buhnenhöhe h_B/h_{NB}, dem gewählten repräsentativen Korndurchmesser der Sohlendeckschicht (der im Korngemisch gleich häufig über- und unterschritten wird) d_{50}, dem mittleren Wasserspiegelgefälle I, dem mittleren Shields-Wert Θ_{d50}, dem aus Strömungsmodellen rückgerechneten Wert für die äquivalente Sandrauheit k_s des Gewässerbettes (beim bettbildenden Wasserstand) und der Konstante C_1, die sich nach Einsetzen der vorgenannten Kennwerte aus der Regressionskonstanten A ergibt. A bzw. C_1 können dabei mit einem Unsicherheitsbereich (Standard-Abweichung) von ca. 5 % errechnet werden. Die wesentlich kleinere Konstante C_2 konnte an der Donau mit einer Genauigkeit von rd. 10 % ermittelt werden. Trotz der unvermeidbar starken Streuung der Messdaten, die auf Abb. 6 deutlich wird, auf der Ergebnisse der Regressionsanalyse in logarithmischer Darstellung für die Donau unterhalb der Isarmündung dargestellt sind, ist somit im statistischen Sinne eine ausreichend genaue Parameterbestimmung ermöglicht worden. Die Modellansätze werden dadurch im Grundsatz bestätigt. Die Konstante C* konnte aus dem vorliegenden Datenkollektiv dagegen nur grob angenähert bestimmt werden. Hierzu werden ergänzende Untersuchungen empfohlen.

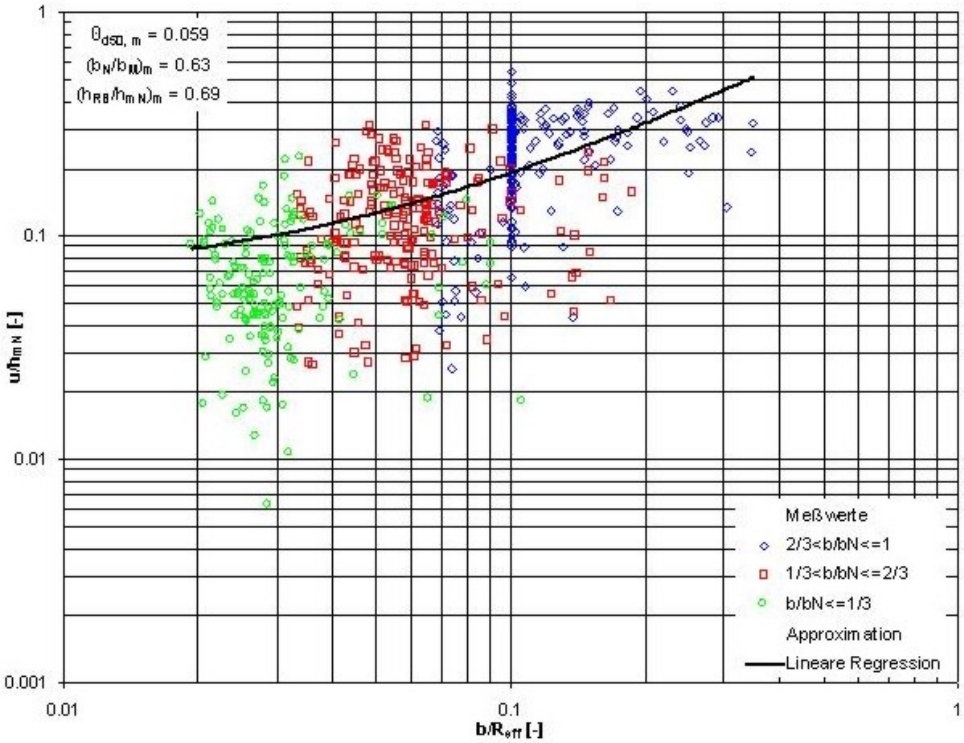

Abb. 6 Darstellung der Messwerte und der Ergebnisse der linearen Regression für die Teilstrecke unterhalb der Isarmündung.

Diskussion der Ergebnisse im Hinblick auf die Prognose von Ausbauwassertiefen

Unter gleichen flussmorphologischen Randbedingungen traten z. B. im Bereich von Furten die größten Unterschiede in den ermittelten Unebenheitshöhen auf. Die Werte liegen zwischen ca. 1 dm – 5 dm. Neben dem schon erwähnten Einfluss der Fahrrinnenunterhaltung sind als weitere Gründe die Art der Regelung und die Anordnung der Regelungsbauwerke zu nennen. Die erwähnte Anordnung von Buhnen im Außenuferbereich führt zu großen Konstanten C_2 für die Teilstrecken an der Donau, insbesondere im Abschnitt unterhalb der Isarmündung, der wegen der großen Gefälle die höchste Sohlmobilität aufweist. Im betrachteten Rheinabschnitt ist die Konstante C_2 dagegen sehr klein, d. h. zusätzliche Unebenheiten, die aus den Regelungsbauwerken resultieren, sind vernachlässigbar gering. Dort dominiert allein der regelungstechnisch erzwungene Einfluss der inneren Kurvatur des Strömungsfeldes. Für Ausbausituationen an der Donau, hierzu zählt auch der optimierte Ist-Zustand, kann aber vorausgesetzt werden, dass alle bestehenden Regelungsmaßnahmen angepasst werden und dass vor allem neue Regelungsmaßnahmen so ergriffen werden, dass Unebenheiten, die z. B. durch eine Buhnenkopfkolkbildung ausgelöst werden, vermieden oder begrenzt werden. Für die Prognose wurde deshalb davon ausgegangen, dass die Konstante C_2 gleich Null ist.

Flussabschnitt	h_{NB} (m)	b_{NB}/b_{MB}	h_{NB}/b_{NB}	h_B/h_{NB}	D_{50} (mm)	I (‰)	Θ_{d50}	k_S (m)	$A \pm s_A$	B bzw. $C_2 \pm s_{C2}$	C*	C_1
Rhein-km 330 – 352	6,1	0,50	0,048	0,57	22	0,40	0,065	0,081	1,40 ± 0,05	0,003 ± 0,003	10	10,5
Donau-km 2319 – 2286	5,2	0,63	0,042	0,58	8	0,11	0,045	0,089	1,24 ± 0,06	0,032 ± 0,005	10	14,0
Donau-km 2281 – 2258	5,1	0,63	0,046	0,61	16	0,31	0,059	0,199	1,30 ± 0,07	0,063 ± 0,006	10	12,8

h_{NB}: mittlere Wassertiefe im Niedrigwasserbett bei bettbildendem Abfluss, b_{NB}: mittlere Breite des Niedrigwasserbettes, b_{MB}: mittlere Breite des Mittelwasserbettes, h_B: mittlere Höhe der Buhnen über der mittleren Sohle, d_{50}: Korndurchmesser der Sohlendeckschicht bei 50% Siebdurchgang, I: mitteres Wasserspiegelgefälle, Θ_{d50}: mittlerer Shields-Wert, k_S: Äquivalente Sandrauhigkeit bei bettbildendem Abfluss

Tab. 1 Parameter der Rhein- und Donauabschnitte und Ergebnisse der Analyse zur Ermittlung der durchschnittlichen Unebenheiten des Gewässerbettes (Basis: Peilung 1990).

Der durchschnittliche Wert für die Konstante C_1 errechnet sich zu 12,4. Die zugehörige Standardabweichung beträgt 1,8. Der theoretische Wert beträgt 14,5 und ist damit um ca. 14 % größer als der ermittelte Durchschnittswert. Wegen dieser vergleichsweise geringen Abweichung wird für die Prognose der Bettunebenheiten der theoretische Wert verwendet. Die Ergebnisse liegen in diesem Falle auf der sicheren Seite, da die damit errechneten Unebenheiten in der Donau größer sind als die mit den Durchschnittswerten errechneten.

Ein mit diesen Parametern erzieltes Ergebnis ist auf Abbildung 7 dargestellt. Angegeben ist zunächst die mittlere Wassertiefe im zentralen Bereich der Fahrrinne h_m. Unten dargestellt ist der sich aus der Unebenheitshöhe errechnende Sohlabstand s (Mindestabstand zwischen Schiffsboden in Fahrt und der mittleren Sohlhöhe). Dabei wurde die „natürliche“ Unebenheitshöhe, entsprechend dem Einfluss der Fahrrinnenunterhaltung, um 0,15 m reduziert und es wurde ein Mindestflottwasser zwischen Schiffsbuhnen in Fahrt und Sohle von 0,2 m angesetzt (Sohlabstand = Unebenheitshöhe - Reduktion durch Unterhaltung +

Mindestflottwasser). Dargestellt ist schließlich die örtlich mögliche Abladetiefe eines durchschnittlichen Großmotorschiffes t_s, das bei dem bisher gültigen Abflusszustand zur Beurteilung der Schifffahrtsverhältnisse RNW_{87} zu Berge fährt. Sie ergibt sich nach den Beziehungen auf Abb. 1 aus den geometrischen Randbedingungen unter Berücksichtigung des fahrdynamischen Einsinkens der Schiffe in Fahrt a (mögl. $t_s = h_m - s - a$). Danach könnten die Schiffe ca. 1,7 m tief abladen. Dieser rechnerische Wert stimmt sehr gut mit Angaben der Schiffsführer zu "Abladeregeln" überein.

Schlussfolgerungen und Ausblick

Die Streuung der Messdaten zeigt zum einen, dass z. B. durch Teilverfüllung von Buhnenkopfkolken noch eine Reduktion der Unebenheiten erreicht werden könnte, wodurch sich, bei gleicher mittlerer Wassertiefe, größere Fahrrinnentiefen realisieren ließen. Die große Streuung der Messdaten zeigt aber auch, dass der Erfolg einer Regelungsmaßnahme nicht **garantiert** werden kann, wohl aber, dass die Unebenheiten **im Mittel** auf das durch die Formel errechnete Maß zu begrenzen sein sollten, wobei, wie der Hinweis auf die Buhnenkopfverfüllung gezeigt hat, Maßnahmen zur weiteren Reduktion der Unebenheiten zur Verfügung stehen. Hierzu gehört auch der Ersatz von Buhnen durch Parallelwerke, wenn die Außenuferlage des Regelungsbauwerkes nicht vermieden werden kann. Mit allem Vorbehalt hinsichtlich der Methodik der Ableitung der auf Abb. 3 angegebenen Gleichung, die durch weitere Untersuchungen an Flüssen, bei denen insbesondere die Parameter: Shields-Wert und Sohlenrauheit variiert werden sollten, zu überprüfen ist, zeigt die hier für den genannten Donauabschnitt abgeleitete Beziehung folgende Abhängigkeiten auf, die nochmals hervorgehoben werden sollten:

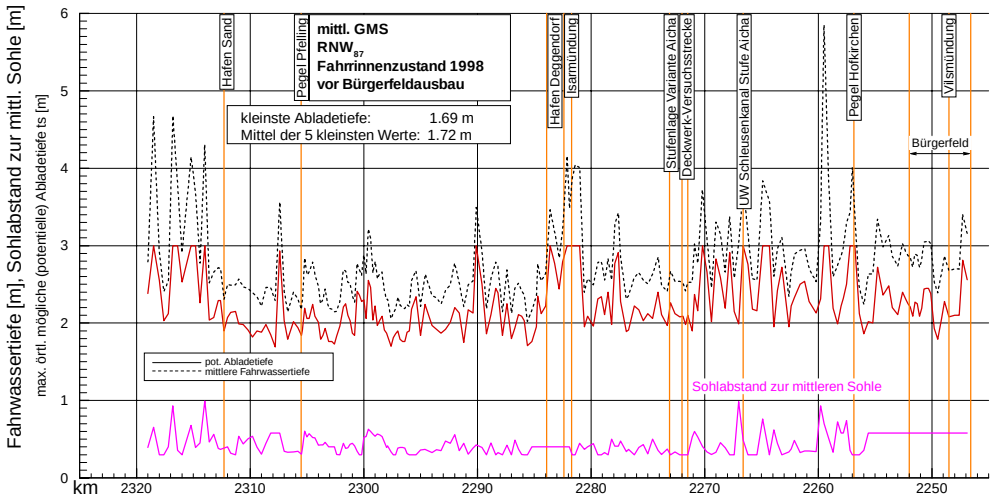

Abb. 7 Mögliche Abladetiefen eines durchschnittlichen GMS in der Bergfahrt bei $RNW_{87,}$ errechnet für den Ist-Zustand (Peilung 1998) auf der Basis mittlerer Wassertiefen und statistisch ermittelter Sohlunebenheiten bei vorgegebener Schiffsgeschwindigkeit

Die Unebenheitshöhe wird mit größerer mittlerer Tiefe, wie sie durch Regelungsmaßnahmen angestrebt wird, gleichfalls größer. Ein Teil der durch die Regelung gewonnenen größeren Tiefen geht also durch morphodynamische Anpassungsprozesse wieder verloren, es sei denn, es wird intensiver unterhalten, wodurch die Unebenheitshöhen weiter begrenzt werden können. Dies bedingt allerdings auch vermehrte Unterhaltungsbaggerungen.

Auch eine größere Fahrrinnenbreite, auf der die Unebenheiten zu ermitteln sind, wie sie für die erwähnte Variante B (im Hinblick auf die Erhöhung der Sicherheit des Schiffsverkehrs und die nahezu durchgängige Ermöglichung von Begegnungen von Schubverbänden) gewählt wurde, führt zu einer deutlichen Vergrößerung derselben. Die weitgehend ungestörte Unebenheitshöhe im Bereich von Furten (ohne intensive Unterhaltung) beträgt z. B. ca. 0,5 m in der Teilstrecke unterhalb der Isarmündung (bei im Mittel 70 m Fahrrinnenbreite). Würde nun eine größere Fahrrinnenbreite, z. B. von 85 m, realisiert, dann errechnete sich eine um rd. 0,1 m größere Unebenheitshöhe. Bei einer noch größeren, anzusetzenden Fahrrinnenbreite und vor allem in Kurven, träten weitere Reduktionen der möglichen Tiefen auf. Bei Variante B muss deshalb von erhöhten Unebenheiten ausgegangen werden, d. h. die durch die Regelungsmaßnahmen erzwungenen größeren mittleren Tiefen werden durch höhere Unebenheiten z. T. wieder aufgezehrt oder es sind viel größere Unterhaltungsaufwendungen anzusetzen.

Die auf Abbildung 3 dargestellte Gleichung kann natürlich auch verwendet werden, um, bei vorgegebenen zu erreichenden Tiefenverhältnissen, diejenigen Breiten zu ermitteln, mit denen möglichst geringe Unterhaltungsaufwendungen erreicht werden könnten. Wenn der u. a. für Abbildung 7 verwendete Wert für die Reduktion der Unebenheitshöhen durch Unterhaltungstätigkeit von 0,15 m nicht angesetzt würde, dann errechnete sich in Furten, ausgehend von den Tiefenverhältnissen, wie sie heute in der Strecke vorliegen, eine Fahrrinnenbreite von ca. 50 - 60 m, ausgehend von einem Sollwert der Fahrrinnentiefe von 2,0 m. Dies ist diejenige Breite, die geringe Unterhaltungsaufwendungen erfordern würde. Die im Mittel in der Donau vorliegende Fahrrinnenbreite beträgt durchschnittlich ca. 70 m. Um sie aufrechtzuerhalten sind Unterhaltungsbaggerungen, insbesondere in den Randbereichen der Fahrrinne, notwendig, deren Breite, entsprechend den oben angegebenen Werten mit ca. 10 – 20 m beziffert werden kann.

Entsprechend könnten "flussmorphologisch angepasst" Breiten für enge Kurven, deren Kurvenradius heute zwischen 300 und 400 m liegt, abgeleitet werden, wonach sich Werte zwischen 60 und 70 m errechnen. Der Vergleich mit den heute im Mittel in diesen Kurven vorliegenden Breiten zeigt, dass ziemlich genau die vorgenannten Werte gewählt wurden, um die Unterhaltungsaufwendungen, die dort - wegen der großen Querneigung des Gewässerbettes - viel intensiver sind, begrenzen zu können. Dies bedingt allerdings, dies sei hier ergänzend angemerkt, auch für die vorgenannten Werte für Geraden, Einschränkungen hinsichtlich derjenigen Fahrzeuge und Fahrzeugkombinationen, die in diesen engen Querschnitten verkehren können (Söhngen, 1999). Eine Erweiterung der Fahrrinnenbreite gegenüber den vorgenannten Werten, insbesondere in engen Kurven, würde jedoch zu deutlich vergrößerten Unterhaltungsaufwendungen führen.

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Comparison of Suspended Sediment Measuring Method in Slovakian and Hungarian Hydrologic Services

Peter Škoda, Mária Borodajkevyčová, János Szekeres

Abstract: This paper is an attempt to create a common (international) method for the suspended sediment measuring for Slovak Republic and Hungary, which could be used by the experts of the Crossborder Commission. By this method these countries would be able to compare the concentration and the transport of the suspended sediment in rivers like Danube, Ipel (Ipoly), etc. The paper gives a short overview of the suspended sediment transport measurement and calculation too. It is attempted to suggest a common method for the suspended sediment measurement, to be used in the future in the whole river basin of the Danube after detailed discussions with all concerned countries.

Vergleich der Schwebstoffmeßmethoden des Slowakischen und des Ungarischen Hydrologischen Dienstes

Zusammenfassung: Der vorliengende Beitrag ist ein Versuch, eine gemeinsame (internationale) Methode der Messung des Schwebstoffes für die Slowakische und die Ungarische Republik zu schaffen, welche durch die Experten der Grenzkommission angewandt werden könnte. Diese Methode würde den gennanten Ländern ermöglichen, die Konzentration und die Fracht des Schwebstoffes von Flüssen wie die Donau, Eipel, usw. untereinander zu vergleichen. Der Beitrag bietet auch einen kurzen Überblick über die Messung und die Berechnung des Schwebstoffes. Es wird versucht, eine gemeinsame Methode für die Messung des Schwebstoffes. Es wird versucht , eine gemeinsame Methode für die Messung des Schwebstoffes vorzuschlagen, welche in der Zukunft, nach ensprechender Abstimmung mit allen interessierten Ländern, im ganzen Donaueinzugsgebiet eingesetzt werden sollte.

1 Preface

The Slovak Republic and Hungary have 679 km long common border and this is formed in a length of 146 km by the River Danube and 181 km by the River Ipel (Ipoly). Other four ones the River Bodrog, Bodva (Bódva), Hornad (Hernad) and Slana (Sajó) cross the common border. The Hydrological Services of the two neighbouring countries, have very good connection concerning the exchange and comparison of the surface water data series. Regularly the stage, the water temperature and the discharge data series are checked up year by year. Depending on the distance between the compared border stations different permissible limits are pre-determined for the differences of the monthly or yearly characteristic values (max., min, average). In case of exceeding the limits the data sets are examined thoroughly again. The data comparison work have been performed for several decades in the frame of the Technical Scientific Co-operation Agreement between the Slovak Hydrometeorological Institute (SHMU, Bratislava) and the Water Resources Research Plc. (VITUKI, Budapest). Presently a new Agreement is adopted by the two governments concerning the exchange of hydrological information, forecasting and early warnings, so the task have been lifted up to the level of the Crossborder Commission.

On the basis of the good and effective work of the previous period the experts of the two countries plan to extend the co-operation in the field of sediment data exchange and their cross--checking.

The first step was to get acquainted with the sampling, analysing and processing method of the partner Service. An informal meeting was organised with the participation not only the

Slovakian and Hungarian but the Czech experts too, where the above mentioned practices were introduced.

The state of the sediment data collection can be summarised as follows:

2 Sediment sampling in the Slovak Republic

Most of the suspended sediment and bed-load measurements were done in the period 1930-1960. During the last decades the bed-load measurements was interrupted and the number of the suspended sediment measuring sections was decreased too.

2.1. Regular measurements

Sampling is provided by voluntary observers daily together with water stage observations, in the period of increased discharges even more frequently. Water sample is taken-off in integrated way from flow by suspended particles sampler, in one vertical representating the whole profile. Sampler consists of two parts: sampling device and sampler container. Sampling device consists of a hydrodynamic head with supply and ventilation tube screwed on the neck of sampler container and take-off holder with approx. 2 m handle. PE bottle with wide neck and 1,0 l volume which is used as sampler container and also for sample transport.

On the Danube river there are 3 hydroprognostic stations where sampling is made daily at 6 a.m.. The total number of suspended sediment sampling points in the Slovak Republic is 17.

With the aim to verify the sampling vertical representativeness there are also provided the whole profile suspended sediment measurements at various water discharges. The collection of the samples from voluntary observers are made at least once in month, in summer period two times, resp. more frequently.

An amount of insoluble matters (mud, resp. suspended sediment content) was given till 1996 by ČSN 30 530 (Czechoslovak standard) by filtration through filtering paper by white ribbon 389 in laboratory. Later (since May 1996) a new way of filtration has been put into operation by sampling suction by membrane filter SYNPOR with diameter 50 mm and density 0,450 μm (ČSN 850 530 recommendation is 0,6 - 0,3 μm).

2.2. Irregular (occasional) measurements - the whole profile measurements.

An aim of the whole profile measurements is to obtain a value of the whole profile suspended sediments concentration, to verify accuracy and reliability of the value of suspended sediments concentration from a representative vertical sample.

The whole profile measurements have been provided in dependence on flow and discharge by sampling equippment:

- VÚVH sampler, resp.
- OTT equipment for suspended sediment samples.

Samples are taken-off in several verticals in integrated, resp. point way. Measurements are provided by the SHMI technicians. At the beginning and the end of measurement there are also collected samples from a representative vertical. At the same time discharge measurement is realized together with the whole profile measurement. A number of the whole profile measurements ought to be on one profile minimum 2 - 3 times per year (mainly in case of low flow or flood occurence).

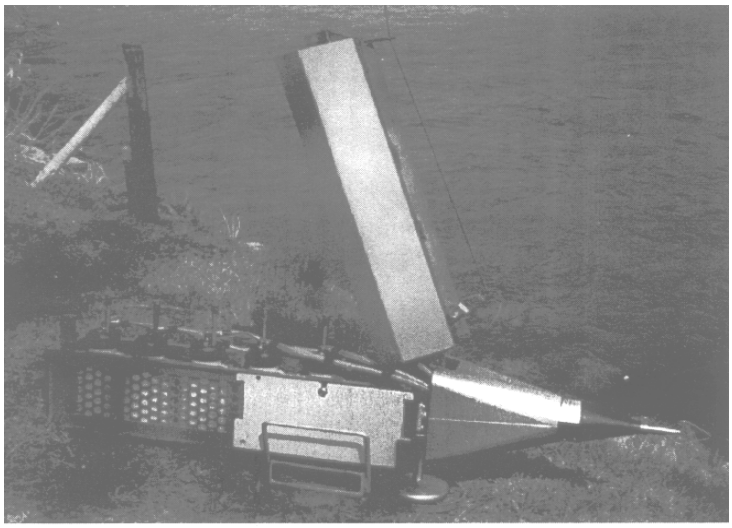

Fig. 1: The suspended sediment sampler made by the firm OTT.

2.3 Summary of the methodology

Suspended sediment sampling:	
instrument:	VUVH or OTT type sampler,
number of verticals:	five or six,
number of points in a vertical:	five (or integrating method),
volume and type of samples:	one litre samples per points,
method of samples analysing:	filtration by membrane filter,
grain-size distribution:	none,
suspended sediment discharge	specific sediment discharge multiplied by the velocities point by point

3 Sediment sampling in Hungary

The *suspended sediment* measurements were started in the first years of the fifties and practically there was no discontinuity in the series.

The *bed-load measurements* were started also in the beginning of the fifties, but they were suspended in the middle of the seventies caused partly by the large financial and manpower demand involved, and partly by the relatively high uncertainties of the obtained results.

3.1. Regular measurements

Hungary has established twenty five *suspended sediment* measuring stations. The frequency of the measurements varies between five to twenty per year. In any cases complete flow discharge measurement is carried out simultaneously with the suspended sediment sampling.

For a long time the milk bottle sampler (*Fig. 2.*) was used for the sampling, but from the beginning of the nineties the petrol engine driven pump (*Fig. 3.*) is used for this purpose. Three copies of the OTT-type sampler were bought but due to their unpractical handling and the frequent technical troubles they are not used in the daily practice.

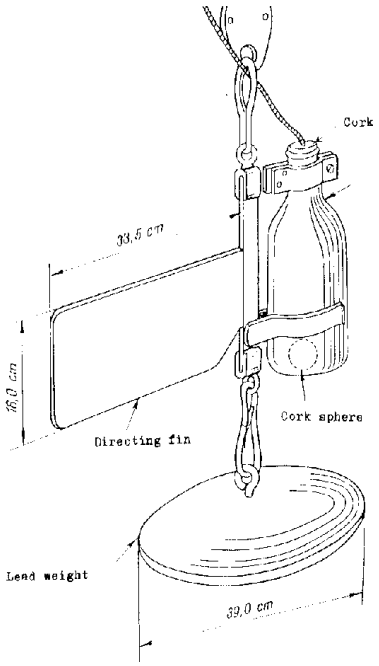

Fig. 2 The milk-bottle sampler

In case of pumping samplers the long suction tube causes the biggest trouble, because of maintenance and cleaning problems. The other disadvantage of the pumping samplers that the sampling is not possible from bridges in case of high suction elevation.

The *bed-load* is not measured regularly.

3.2. Occasional measurements

From 1988 several suspended sediment and bed-load discharge measuring projects were carried out on the common Slovak-Hungarian reach of the River Danube to determine the sediment transport characteristics of this river stretch preparing the operation the planned Gabcikovo-Nagymaros Hydroelectric Power System. The measurements covered the whole common river stretch from Rajka to Nagymaros. Simultaneous discharge, suspended sediment and bed-load discharge measurements and bed material samplings were performed in five [illegible] 2 the pressure-difference (Karolyi-type) bed-load sampler was completed with an underwater video camera, so the whole process of the sampling was visually studied in the field and the effective time of sampling was determined.

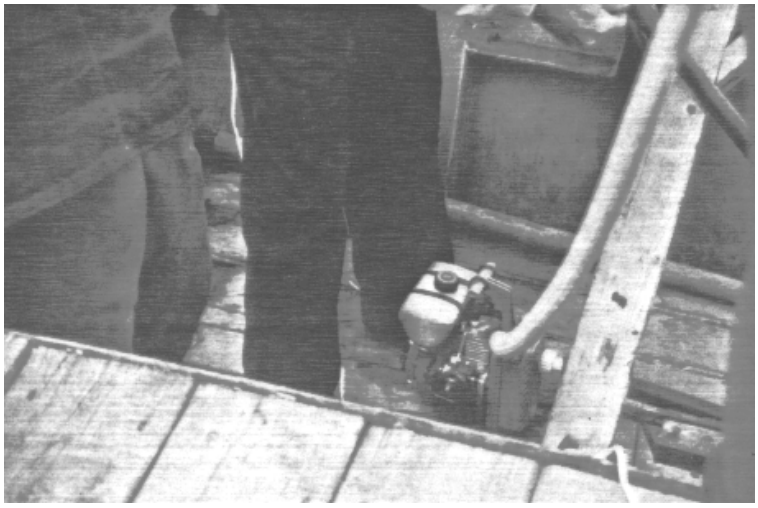

Fig. 3 The petrol engine driven pumping sampler

In 1998 a new project was started in Hungary aimed to determine the change of sediment transport of the River Drava as a result of the barrages constructed in the last decades on the upper reach of the river in Austria, Slovenia and Croatia. In this river besides the flow discharge, also the suspended sediment and bed-load discharge measured and the bed material sampled. Furthermore the propagation velocity of the sand dunes was detected by fluorescent tracing applying surface-coated sand material. The research work is planned to be completed in the year 2000, thereafter new flow discharge - sediment discharge correlation equations will be determined and the annual sediment transport will be computed. In the frame of this work the sediment data of the Croatian Hydrological Service will also be taken into account.

3.3. Summary of the methodology

Suspended sediment sampling:

instrument:	pumping equipment and OTT type sampler,
number of verticals:	five to seven,
number of points in a vertical:	ten or five,
volume and type of samples:	one or two litre samples collected in a ten litres container per sampling vertical
method of analysing the samples:	drying and weighting,
grain-size distribution:	in each vertical by densimetry,
suspended sediment discharge	sediment concentration multiplied by the flow discharge pertaining to the sampled vertical and summarised along the whole section,

Bed-load transport:

instrument:	Karolyi and Helley-Smith type sampler,
number of verticals:	five or nine,
number of sampling in a vertical:	one,
method of analysing the samples:	sieving,
grain-size distribution:	in each vertical,
bed-load transport	specific bed-load transport multiplied by the width pertaining to the sampled vertical and summarised along the whole section.

4 Summary of the advised methodology

The differences of the methods used by the two partner Institutes for the suspended sediment discharge measurements are as it follows:

there is only one commonly used sampler type, made by OTT, however, both Services have objections against it,

- they assign different number of verticals and sampling points in a vertical,
- the volumes of the sample, and the laboratory methods of the sediment content analysis are different too,
- the volume of the sample and the frequency of the determination differs in case of the grain size distribution.

To elaborate a commonly accepted method is possible only on the basis of the similarity. The most serious problem is the selection of the suspended sediment sampler. Theoretically the OTT type is the most accurate and the easiest to use, but its hydraulic shape and the reliability of its operation should be improved. This development is the most important part of the task and this should be executed together with the manufacturer of the instrument.

The basic characteristics of the common measuring method should be according to the followings:

number of verticals:	seven,
number of points in a vertical:	five, (or integrating),
volume and type of samples:	two litre (in case of integrating method ten litre) samples, individually analysed,
method of analysing the samples:	drying and weighting,
grain-size distribution:	in each vertical, determined by densimetry
suspended sediment discharge	specific sediment discharge multiplied by the flow velocities point by point.

Moreover, the detailed instructions for the execution of sediment measurements should be discussed by the experts of the partner Institutes taken into consideration of their existing experiences. The practical experiences collected after the introducing of the common instructions should be evaluated systematically and the eventual modifications should be determined and introduced.

The results of this project should be discussed with the Hydrological Services of the other neighbouring countries too, because of the unification of the suspended sediment sampling methods is not only the problem of the Slovak Republic and Hungary but the other Danubian countries too.

In case of successful co-operation, the next step would be the unification of the bed-load measuring method too, but it seems to be a more difficult task than the suspended sediment sampling.

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Environmental information under the UN/ECE Water Convention

Martin Adriaanse

Abstract: In **the text of** the **UN/ECE** Convention on Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 1992), **DRAWN UP UNDER THE AUSPICES OF THE UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE (UN/ECE)**, information **EXCHANGE** and the need **FOR of** monitoring play an important role. **THE DRAWING UP OF A** joint monitoring programme is often one of the first steps in transboundary co-operation on a river basin or international lake. Activities related to the monitoring and assessment are schematically shown in monitoring cycle (see Fig. Below).
In the work programme under the Convention, guidelines on monitoring and assessment of transboundary rivers have been developed in 1996. Since, pilot projects on a series of European river basins have started to implement these guidelines. **Recently** a first review of the river guidelines has been adopted at the 2nd Meeting of the Parties in March 2000.

Key words: Monitoring, assessment, Information Exchange, Transboundary water

Umweltinformationen im Rahmen der UN/ECE Wasserkonwention

Zusammenfassung: Im Übereinkommen zum Schutz und zur Nutzung grenzüberschreitender Wasserläufe und internationaler Seen (Helsinki, 1992), das unter der Schirmherrschaft der Wirtschaftskommission für Europa der Vereinten Nationen (UN/ECE) ausgearbeitet wurde, kommt dem Informationsaustausch und der Überwachung des Gewässerzustandes eine besondere Rolle zu. Die Erarbeitung eines Programmes zur gemeinsamen Gewässerüberwachung ist oftmals der erste Schritt in der grenzüberschreitenden Zusammenarbeit in Flussgebieten oder in Einzugsgebieten von internationalen Seen. Im Rahmen der Zusammenarbeit unter dem UN/ECE Übereinkommen wurden im Jahre 1996 Richtlinien zur Überwachung und Bewertung von grenzüberschreitenden Fliessgewässern fertiggestellt. Danach erfolgte ihre Anwendung in Form von Pilotprojekten in einer Reihe von Europäischen Flusseinzugsgebieten. Die zweite Tagung der Vertragsparteien nahm im März 2000 eine überarbeitete Fassung der Richtlinien an.

Schlűsselwőrter: Monitoring, Bewertung, Gewässerüberwachung, Grenzűberschretendes gewässer

The text of the UN/ECE Convention on Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 1992) refers to information and the need of monitoring at several places. It seems that a joint monitoring programme is often one of the first steps in transboundary co-operation on a river basin or international lake.

In 1994, a Task Force on Monitoring and Assessment has been established under the UN/ECE Convention. One of its first products was the guidelines on monitoring and assessment of transboundary rivers, adopted in 1996. Since, pilot projects on a series of European river basins have started to implement these guidelines. Recently a first review of the river guidelines has been drafted, to be adopted at the 2nd Meeting of the Parties in March 2000.

In the meantime guidelines for the monitoring and assessment of transboundary groundwaters have been developed and for international lakes the same process just started with Finland (Finnish Environment Institute) as lead country.

The guidelines have a strategic character and intend to be recommendations to governments on tailor-made approaches for monitoring and assessment on transboundary waters. In fact, the

principles of these river guidelines are applicable to transboundary watercourses in general (and for not transboundary waters as well). Therefore it may be useful to present them in the context of this conference.

1. The close link between policy making and environmental information should be emphasised.

Three core elements can be distinguished in water management: a) the functions and uses of the water system, b) the problems and threats (the issues) and c) the measures, including the policies and action plans. In fact, the need for information is connected to these core elements and their interaction (Fig. 1).

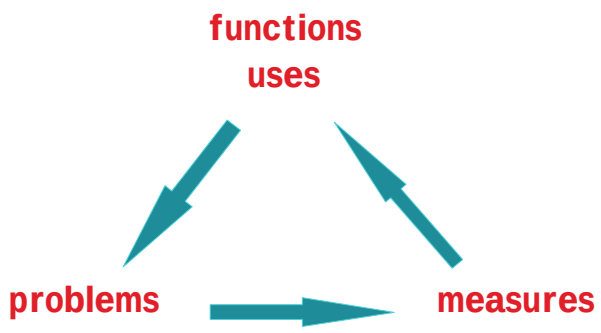

Fig. 1 Core element in water management

2. Different information is needed in the various stages of a problem and in the policy which is developed to encounter it.

The policy life-cycle (Fig. 2) makes clear that four phases can be distinguished, with varying political interest. First is the phase of problem recognition. This is the period of discord and quarrel; people even may ignore that there is a problem. After recognition of the problem, the political importance is increasing rapidly and the policy has to be formulated. The acceptance of a policy (law, strategic action plan) is the summit. In fact the implementation of the policy is a period of declining political interest. In the last phase the problem is under control and results are evaluated.

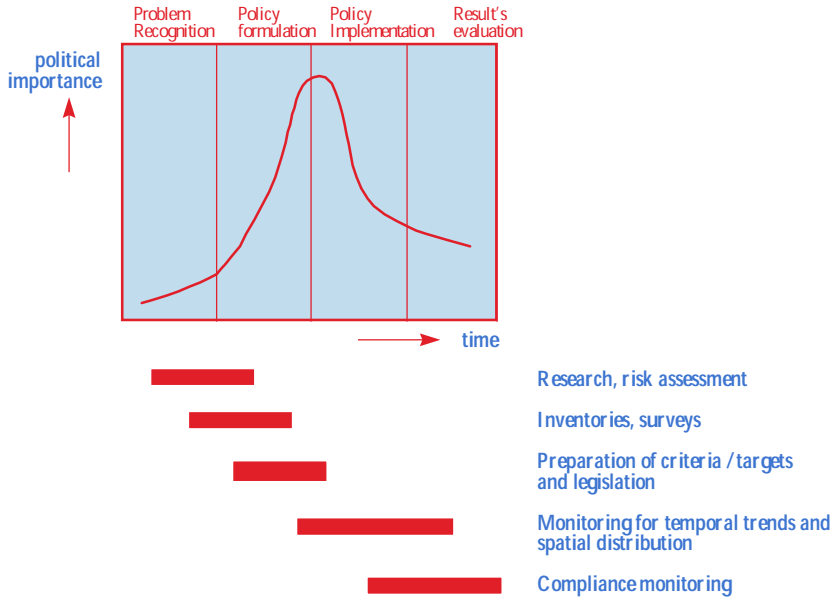

Fig. 2 Policy life-cycle

It is essential to realise that the various phases require different kinds of information. In the first phase investigations, risk assessments, inventories, in-depth surveys are needed to research, screen, estimate and define the problem. In the second phase, models can considerably help to compare alternatives/variants for solution.

The monitoring (as a routine activity) really starts with the third phase: to detect the temporal trends from the moment that policy implementation starts and onwards; to test the compliance with standards; to evaluate the effectiveness of a policy.

3. Back to the core elements in water management: a water management analysis is prerequisite to identify what are the information needs in the transboundary context.

In the pilot projects mentioned before a strategy has been developed for this. Five steps were recognised on which riparian countries have to agree (see box).

WATER MANAGEMENT ANALYSIS

..... riparian countries need to **individually** *identify and* **collectively** *agree upon:*

a) human USES and ecological FUNCTION of the river basin
b) PROBLEMS which have impact on uses and functions
c) existing and future PRESSURES
d) impact of state of river on RECEIVING WATER
e) identify MANAGEMENT TARGETS and quantify them

To identify a problem, a quantitative criterion for a use or function of the water system is needed as a reference. Such a criterion should preferably be based on risk assessment, and

could indicate a situation of acceptable risk. Besides, targets should be quantified to be able to evaluate the effectiveness of a measure or policy (Fig. 3).

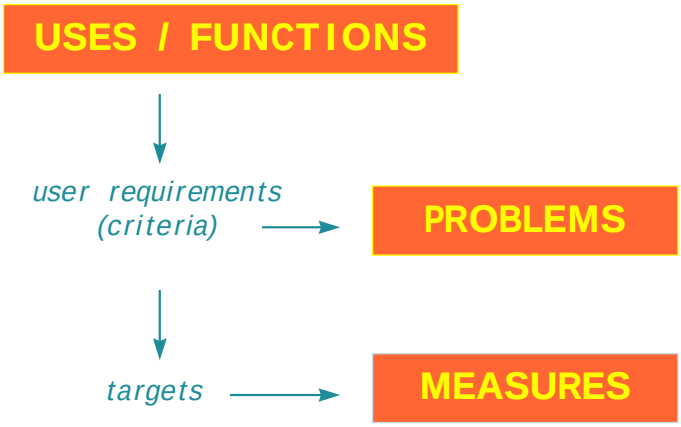

Fig. 3 Criteria and targets

In the pilot projects, five (partly parallel) activities have been chosen to support the water management analysis (Fig. 4). The evaluation of legislation includes the comparison of national systems for water legislation (incl. water classification systems) in riparian countries, comparison with international standards and with recent developments in EU legislation. The goal of these specific activities in the projects is to reach an agreed upon system of assessment, based on recognised targets.

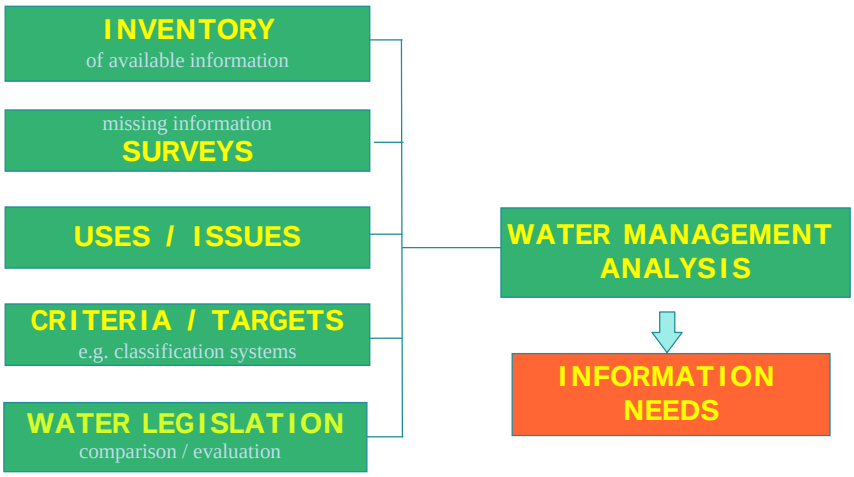

Fig. 4 Activities in water management analysis

4. Information needs should not only focus on the state of the watercourse. For policy making and policy evaluation it is essential that environmental information is given by indicators which are representative for cause- and effect relations in water management. The state is only one phase in the causality chain between the driving forces, the pressures, the impacts and the responses of the society (Fig. 5).

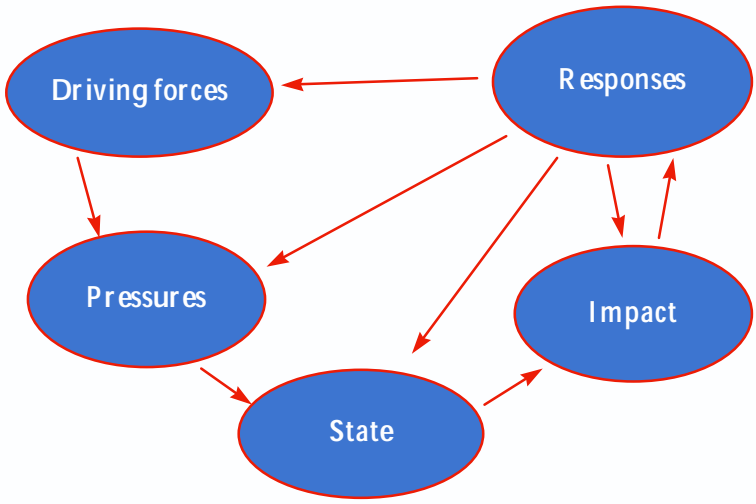

Fig. 5 DPSIR-framework

5. To assure a good quality of the monitoring and assessment, it is important to realise that monitoring and assessment includes a chain of related activities, which starts with specifying what questions are to be answered in the decision-making process, and ending up with the utilisation of the information in the management of the water system. Design criteria for the successive steps in the chain have to specified by the former steps. It should be realised that the chain is as weak as its weakest link (Fig. 6).

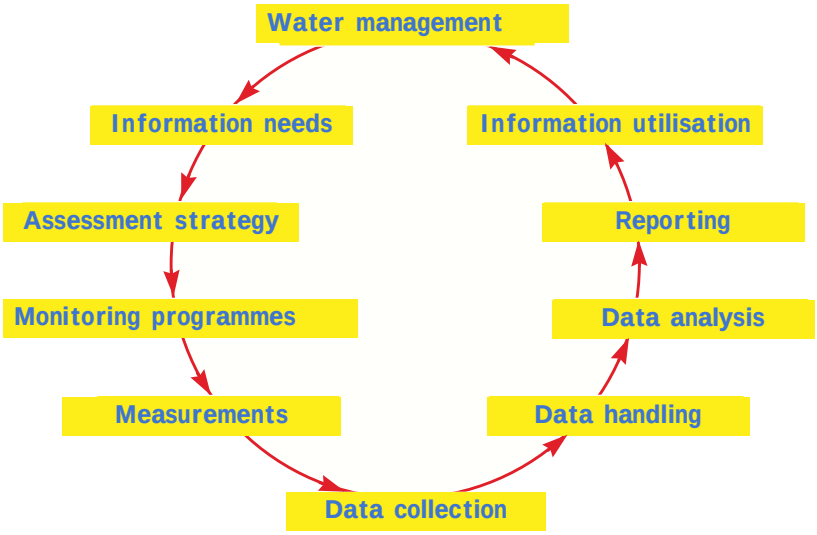

Fig. 6 Monitoring cycle

6. There is much more than technical aspects in improving the monitoring and assessment of a river or lake (transboundary or not-transboundary) (Fig. 7). Strategic aspects were already

mentioned before (information needs, assessment strategies, evaluation of legislation). Without these, the co-operation degrades to "exchange of data". But institutional aspects dominate the success of transboundary co-operation to a large extend. Does an official agreement on co-operation exist and what is the defined goal of the co-operation? What is the goal of information in the transboundary context? Is it intended to be the basis for decision making? Does policy plans and management targets exist? Is there a free access to data? Are responsibilities clearly defined? And last but not least, long lasting experiences of commissions on transboundary waters discovered that mutual understanding and trust, as a product of many years of co-operation, is a decisive factor in making the assessment and management successful.

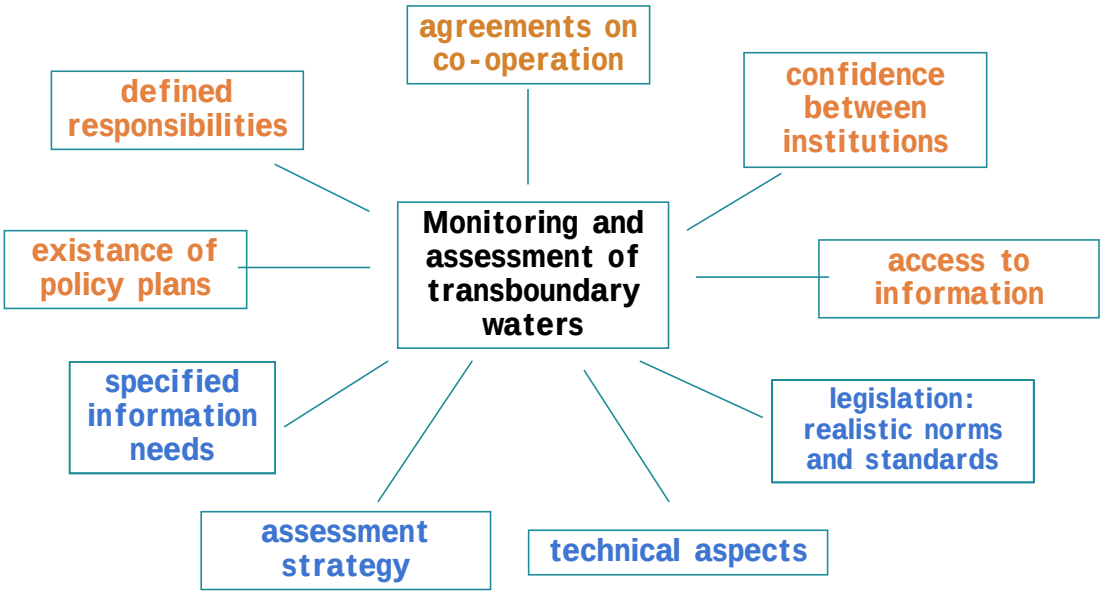

Fig. 7 Technical, strategical and institutional aspects

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The Fate of Cadmium in a Field Soil

Natália Babejová, Andrea Čipáková, Pavel Dlapa, Ľubomír Lichner, Vladimír Píš

Abstract: Three influences on the fate of cadmium in the field soil were studied: rapid macropore flow, cadmium binding on soil organic matter, and duration of cadmium contact with soil. Tracer measurements demonstrated a deep penetration of cadmium up to the depth of 60 cm in spite of prediction that all the Cd should be observed in the top 10 cm layer. Preferential flow in macropores caused penetration deeper than 10 cm of more than 40 % of applied $^{115}Cd^{2+}$ during the first infiltration of 14 cm of water. In case of the cadmium binding on soil organic matter (SOM) in acid conditions it was found out that increasing the SOM and dissolved humic acids content in soil resulted in an increasing of cadmium adsorption on solid phase. An influence of fulvic acid addition on the cadmium adsorption on soil sites was not registered. An impact of duration of cadmium contact with soil on a share of single physico-chemical forms of cadmium binding was assessed by means of comparison of the 1-day and 180-days contact. It was found that the percentage of easily available Cd decreased and the percentage of hardly available Cd as well as water soluble Cd increased for 180-days contact.

Key words: cadmium, soil organic matter, macropore flow.

Verhalten von Kadmium in dem Boden

Zusammenfassung: Drei Einflüsse auf Verhalten des Kadmiums in dem Boden waren studiert: schnelle Strömung in Makroporen, Bindung des Kadmiums auf bodenorganischem Material und Dauer des Kontaktes von Kadmium mit dem Boden. Die Tracermessungen entdeckten eine Penetration des Kadmiums bis zum 60 cm im Gegensatz zu Prognose, dass Kadmium wird in der 10 cm dicken Oberbodenschichte bleiben. Infolge der Präferenzströmung in Makroporen mehr als 40 % von applizierten $^{115}Cd^{2+}$ infiltrierte tiefer als 10 cm während der ersten Infiltration. In dem Fall von bodenorganischen Material (BOM), die Steigerung von BOM Inhalt und aüfgeslöste Humatesaüre Inhalt in der Boden, die Erhöhung von Adsorption des Kadmiums in der Boden verursachte. Die Erhöhung von Adsorption des Kadmiums in der Boden wurde registriert nicht in der Fall von aufgeslösten Fulvatesaüre. Der Einfluss von Dauer des Kontaktes von Kadmium mit dem Boden auf dem Anteil von einzelnen physikalisch-chemischen Formen, war aufrund des Vergleichs der am 1-Tag und 180-Tagen dauernden Kontaktes festgestellt. Der Anteil der leichtzugänglichen Cd-Form sank, aber Anteil der schwerzugänglichen Cd-Form und wasserlöslichen Cd-Form stieg mit Verlängerung der Dauer des Kontaktes.

Schlüsselworte: Kadmium, Bodenorganisches Material, Strömung in Makroporen.

1 Introduction

The Danubian Lowland, situated in the south-western part of Slovakia, is a large (1260 km^2) agriculturally utilized area. A shallow underlying aquifer contains about 10 km^3 of freshwater. In this decade, an increase of groundwater vulnerability to cadmium has been noticed in this area due to:

1. the transition from Soviet phosphate fertilizer (from the Kola peninsula) with a small amount of cadmium (1-3 mg Cd/kg of fertilizer) to Africa superphosphates with 18-24 mg Cd/kg of fertilizer),
2. reduced number of agrotechnical operations resulting in the formation of macropore systems,

3. inappropriate irrigation practice with a fast application of the necessary volume of water when the irrigation rate exceeds the saturated hydraulic conductivity of the soil matrix, and
4. the fact that major part of precipitation occurs in a small number of rain events with high rainfall intensity which can occur at any time during the vegetation period.

An influence of pH and time on adsorption of cadmium added to clayey and sandy soil was studied by Eriksson (1989). The objective of this study was to assess an influence of rapid macropore flow, organic matter content, and duration of the cadmium contact with soil on a behaviour of cadmium in soils of the Danubian Lowland.

2 Theoretical part

Humic and fulvic acids from different sources shows different physical and chemical properties. Formed in anaerobic conditions, humic and fulvic acids extracted from peat have higher molecular weight than acids which were formed in the top soil horizont in aerobic conditions (Babčan and Ševc, 1997). Less carbon and nitrogen content, higher oxygen content in fulvic acids together with less molecular weight cause higher polarity and mobility of fulvic acids in comparison with humic acids (Wander and Traina, 1996).

Humic acids extracted from brown coal were used as a selective ionex (sorbent) in the soil contaminated by cadmium. It was found out that the acid soil solution destroys the ionex very quickly, and therefore, this ionex is not suitable for acid soils (Kolář et al., 1998). Correlation between a content of carboxyl groups in humic acids and the quantity of sorbed cadmium was found out by Barančíková et al. (1997). Sorption of cadmium on isolated humic acids was approximately seven times greater than on soils from which the humic acids were isolated. The size of sorption and desorption of cadmium on humic acids was markedly affected by their chemical structure, particularly by the number of carboxyl groups and degree of humification

3 Materials and methods

3.1 Cadmium transport by a rapid macropore flow

The aim of this study was to give evidence for a deep Cd penetration and estimate the maximal portion of cadmium which moves preferentially along macropores at the site Kráľovská lúka (Bodíky). The study started after 17-days lasting warm and rainless period resulting in a crack formation. Hydrophysical characteristics of soil under study are given in Table 1.

Table 1 Hydrophysical characteristics of soil from the site Kráľovská lúka (Bodíky)

Depth, cm	Θ_s	Θ_r	α	n	K_s, cm d^{-1}
0 - 10	0,6222	0,1105	0,4694	1,1028	45,21
11 - 60	0,4939	0,0807	0,0891	1,1491	5,93
61 - 320	0,4516	0,0807	0,0202	1,8819	147,16

Radioactive tracer technique was used to follow the ^{115}Cd transport in the unsaturated zone of soil because of its ease and speed in comparison with soil or soil-solution sampling and analysis (Lichner, 1995). The probe, by means of which the transport of the radioactive tracer in the unsaturated zone of soil was monitored, consists of a duralumin tube in which a Geiger-Mueller (G-M) detector and analog interface unit, connected to the nuclear analyser with coaxial cable, can be placed in any desired position (cf. Fig. 1 in (Lichner, 2000)). Three tubes (10 mm O.D., 8 mm I.D.) were inserted vertically from the soil surface into the holes made by a 10-mm-diam. steel rod into the soil below a double-ring infiltrometer. Conical soil sealing was made for each vertical probe to prevent water and tracer from bypassing past the probe.

Relative Cd concentration *RC* distributions over depth were obtained by scanning the observation probe using G-M detector. The first measurement of RC_1 was made immediately after ponding infiltrations of 1 cm of water marked with $^{115}Cd^{2+}$ and 13 cm of pure water. The second measurement of RC_2 followed after 15 days in which 25.4 mm of rainfall was registered.

3.2 Cadmium binding on soil organic matter

Soil samples used in laboratory experiment were collected at the Experimental Basis of the Research Institute of Irrigation, Drainage, and Landscape Engineering in Most near Bratislava. Hydrophysical characteristics of the soil under study were presented by Štekauerová (1998). Humus content in samples was 0.76 %, and it was increased by addition of peat and sodium humate solution. In this way, soil samples with humus content 1.17, 2.95, 5.25 and 9.62 % were obtained. The sample with humus content 1.17 % contained sodium humate solution only, another three samples contained sodium humate solution and peat. Samples were dried at room temperature, crushed, sieved through 2 mm sieve, and than used for laboratory analyses. Humus content was determined oxidometrically by Tjurin´s method (Hraško et al., 1987).

Humic and fulvic acids were extracted from peat using the method described by Králová et al. (1991). The peat was dissolved in 0.1 M NaOH, and then sulphuric acid (pH = 2) was added. Humic acids coagulated and was separated, whereas the fulvic acids remained in solution. Physical and chemical properties of humic and fulvic acids obtained are presented in Table 2.

Table 2 Physical and chemical properties of humic and fulvic acids extracted from peat

Acid	Organic carbon content, %	Density, g cm^{-3}	Acid content in solution, %
Humic acids	44.1	1.091	92.4
Fulvic acids	10.3	1.037	97.7

Cadmium nitrate $Cd(NO_3)_2$ solutions with 43.8, 115.6, and 161.5 mg/l Cd were used for a study of Cd (II) sorption in acid conditions (pH = 4.5). One gram of fine-grained soil and 50 ml of $Cd(NO_3)_2$ solution were added into 100 ml plastic bottles, and this suspension was shaked on the laboratory shaker for 2 hours, leaved at rest for 24 hours, and then shaked once more for 2 hours. The solid phase was separated by centrifugation (30 min, 3500 rot/min) and filtration through paper filters. Amount of adsorbed cadmium is a difference between cadmium content in solution before and after reaction and it was determined by atomic absorption spectrophotometry method (analysator AA-6501 G SHIMADZU, Japan).

The same procedures were used in the second experiment where an influence of humic and fulvic acids on Cd (II) sorption was studied in acid conditions (pH = 4.5). Therefore, approximately 0.67 g of humic acids or the same amount of fulvic acids were added to 1 gram of fine-grained soil and 50 ml of $Cd(NO_3)_2$ solution with 43 mg/l Cd.

3.3 Duration of cadmium contact with soil

Modified Tessier sequential extraction method (Tessier et al., 1978) was used to estimate an impact of duration of cadmium contact with soil on a share of single physico-chemical forms of Cd. A change of forms share was assessed by means of comparison of the 1-day and 180-days contact of ^{109}Cd with black earth from the site Leopoldov and Dolná Seč.

4 Results and discussion

4.1 Cadmium transport by a rapid macropore flow

The first measurement was made immediately after ponding infiltrations of 1 cm of water marked with $^{115}Cd^{2+}$ and 13 cm of fresh water. Considering Cd adsorption only and solute transport in the soil without macropores (retardation factor R = 673), all the Cd should be observed in the top 10 cm layer. But the tracer distributions have shown that preferential flow in macropores caused the deeper penetration of more than 40 % of applied $^{115}Cd^{2+}$ during the first infiltration (Table 3). The second measurement followed after 15 days in which 25.4 mm of rainfall was registered. As a result, additional Cd displacement from the top 10-cm layer to the depth of 10-20 cm was measured.

Table 3 Results of relative Cd concentration *RC* in 10-cm-depth increments estimated from the counting rate vs depth distributions.

Depth, cm	0-10	10-20	20-30	30-40	40-50	50-60
RC_1, %	58.3	24.5	8.4	3.3	4.0	1.5
RC_2, %	52.6	34.1	5.8	3.6	2.5	1.4

4.2 Cadmium binding on soil organic matter

The Cd (II) adsorption in soil increased with increasing the total humus content and cadmium concentration in the soil solution, as it can be seen on Fig. 1. We cannot explain the drop in cadmium adsorption for the concentration 116 mg Cd/l and humus content 1.17 %.

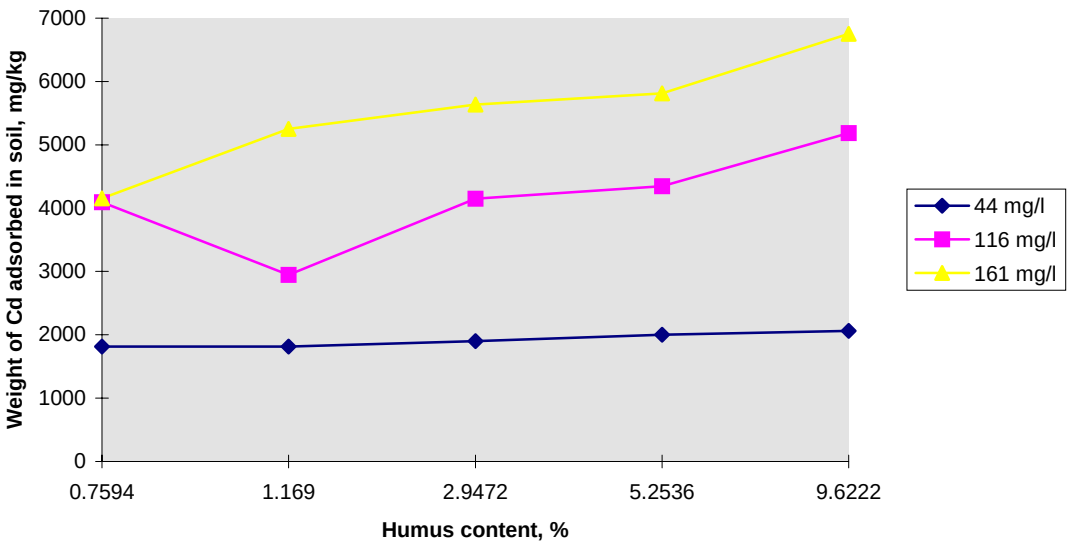

Fig. 1 Relationship between the Cd adsorbed in soil on humus content in soil

In the second experiment (Fig. 2), soil containing sodium humate adsorbed smaller amount of Cd than original soil. On the other hand, soil containing peat adsorbed larger amount of Cd than original soil. Addition of humic acids increased cadmium adsorption, but this increase depended on the initial humus content, e.g. addition of 0.67 g humic acids caused an increase of cadmium adsorption on solid phase by 15 % for the soil sample with 0.76 % of humus, but only by 5 % for the soil sample with 9.62 % of humus. An influence of fulvic acid addition on the cadmium adsorption on soil sites was not registered.

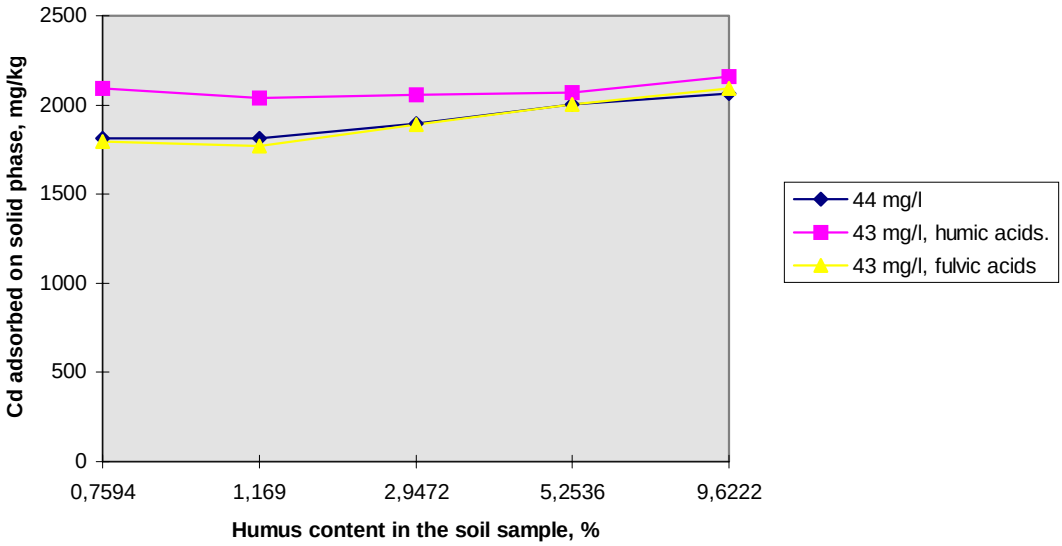

Fig. 2 Relationship between the Cd adsorbed on solid phase and initial humus content in the soil sample as influenced by the presence of humic and fulvic acids

4.3 Duration of cadmium contact with soil

An impact of duration of cadmium contact with soil on a share of single physico-chemical forms of cadmium binding was assessed by means of comparison of the 1-day and 180-days contact. It was found that the percentage of easily available Cd decreased, and the percentage of hardly available Cd as well as water soluble Cd increased for 180-days contact (Table 4).

Table 4 An influence of contact period of cadmium with soil on percentage of single forms of cadmium binding in soil

Locality	Leopoldov		Dolná Seč	
Duration of ontact period	1 day	180 days	1 day	180 days
Percentage of single forms of cadmium binding in soil	%	%	%	%
Non-available	0	0	0,3	0
Hardly available	15,2	42,8	19,6	47
Easily available	84,1	54,3	78,5	50,8
Watersoluble	0,7	2,9	0,6	2,2

5 Conclusions

It was found out that more than 40 % of applied $^{115}Cd^{2+}$ penetrated deeper than 10 cm as a result of rapid flow. Presence of soil organic matter such as peat and humic acids increase cadmium adsorption on soil sites. An influence of fulvic acid addition on the cadmium adsorption on soil sites was not registered. An increasing of contact period from 1 to 180 days resulted in approximately threefold increasing of percentage of hardly available cadmium forms and watersoluble fraction of cadmium, but the percentage of easily available forms of cadmium decreased by about 30 %.

Acknowledgement: The financial support from the Slovak Grant Agency Project 2/7065/20 is gratefully acknowledged.

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Frequent Observations on the Quality of the Danube's Water

Stefka Blaskova, Plamen Ninov, Konstantin Tzankov

Abstract: Frequent observations on the hydrochemical regime of the Danube river at Nikopol town (km 598.0) have been carried out during 7 months. These investigations are imposed by the war in Yugoslavia in order to observe the water quality alterations. The investigations are sponsored by NATO. On the base of the collected information the dynamics of the hydrochemical characteristics of the river water and tendency of time alterations were investigated. The relationship between the water discharge and chemical composition is studied. The results of the frequent observations are compared with the long term regularly monitoring data from 1989-1998 and no influence on the Danube water quality is registered.

Key words: water quality, pollution

Intensive Beobachtungen der Qualität der Donau Gewässer

Zuzammenfassung: Sieben Monate lang wurden intensive Beobachtungen des hydrochemischen Regimes vom Fluβ Donau in der Nähe von Nikopol (km 598.0) durchgeführt. Diese Untersuchungen haben sich infolge des Krieges in Yugoslawien als nötig erwiesen um die Wassergüte beobachtet zu werden und sind von NATO gefördet. Auf Grund der erhaltenen Auskunft sind die Dynamik der Änderung der phusikalisch-chemischen Eigenschaften der Fluβgewässer und die Tendenzen der Änderung im Laufe der Zeit übersehen worden. Man hat den Zusammenhang zwischen der chemischen Zusammensetzung der Gewässer und der Wassermenge gesucht. Man hat einen Vergleich mit den Ergebnissen von der Period 1989-1998 gemacht.

Schlüsselworte: die Wassergüte, die Verschmutzunng

In the present investigation a part of the results from the temporary air and surface water monitoring on the territory of Bulgaria imposed by the war in Yugoslavia is presented. The investigations are sponsored by NATO. More frequent Danube water quality observations have been carried out near Nikopol town (km 598.0) along the Bulgarian bank during the period from 01 June 1999 to 31 December 1999. Samples are gathered twice a week and about 60 analyses of river water quality are realized for the seven months period. The water quality composition is estimated regarding the following parameters: mineral content – dissolved substances or total mineralization (SUM), sulfates (SO_4), chlorides (Cl), hydrocarbonate ions (HCO_3), calcium (Ca), magnesium (Mg), sodium and potassium (Na+K); the parameter of organic pollution – permanganate oxidation (Ox); biogenic substances – nitrates (NO_3), nitrites (NO_2), ammonium ions (NH_4), phosphates (PO_4) and total iron (Fe); heavy metals content – arsenic (As), selenium (Se), cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), nickel (Ni), molybdenum (Mo), cobalt (Co).

The temporary monitoring information is compared with the data based on the long standing observations of the river water quality at Nikopol town (km 598.0) accomplished by the National Institute of Meteorology and Hydrology – Bulgarian Academy of Sciences (Tables 1, 2). The hydrological regime is one of the most important water quality factors. The water discharge is connected closely with the alterations of the surface water chemical composition and thence its impact on the biological regime. The relationships between water discharge and water quality parameters are examined. The relation Q = f (concentration) could be used for forecasting of different water pollution stages and/or filling up the missing data. The alterations of water quality parameters regarding the time show their seasonal distribution. The period June -December1999 does not spread over a full annual cycle. The relationships between water quality parameters and the time during the seven-month period (01.06-31.12.1999) illustrate

Table 1 Danube Water Quality Parameters at Nikopol Town (km 598) for the Two Compared Periods

period		pH	O_2	BOD5	Ox	HCO_3	SO_4	Cl	NO_3	NO_2	PO_4	Ca	Mg	NH_4	Na+k	SUM	Fe	H
		-	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	^oH
1989-1998	min	6,7	6,55	2,64	2,96	170,8	19,2	18,6	1,99	0,01	0,11	43,90	11,00	0,14	16,0	320,3	0,07	8,12
	max	8,4	10,65	8,32	11,20	454,4	99,6	42,3	12,00	0,32	0,35	59,40	16,50	3,60	98,0	610,1	0,33	10,32
	average	7,5	8,65	4,83	5,55	215,0	78,3	33,7	6,55	0,13	0,18	46,77	12,77	0,74	64,1	485,5	0,22	9,49
VI-XII 1999	min	6,7	-	-	0,96	133,8	7.8	19,5	0,87	0,02	0,01	28,90	3,40	0,03	16.3	273.1	0,01	2,52
	max	7,8	-	-	5,45	234,8	52,1	29,0	10,30	0,20	0,19	48,90	28,10	2,50	87.3	475.1	0,56	10,66
	average	7,0	-	-	3,58	195,2	21,4	23,6	4,21	0,08	0,07	39,27	9,82	0,29	55.2	350.5	0,16	7,29

Table 2 Heavy Metals Content in the Danube Water at Nikopol Town (km 598) for the Two Compared Periods

period		As	Se	Cd	Pb	Cu	Zn	Mn	Fe	Ni	Mo	Co
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1989-1998	min	0,01	0,008	0,001	0,002	0,001	0,001	0,001	0,36	0,001	0,001	0,001
	max	0,08	0,02	0,001	0,048	0,071	0,095	0,098	0.52	0,01	0,007	0,001
	average	0,05	0,01	0,001	0,008	0,018	0,02	0,038	0,45	0,005	0,004	0,001
VI-XII 1999	min	0,01	0,010	0,001	0,020	0,001	0,010	0,020	0,190	0,001	0,002	0,001
	max	0,01	0,020	0,004	0,025	0,005	0,030	0,030	0,250	0,004	0,004	0,003
	average	0,01	0,015	0,002	0,022	0,003	0,020	0,025	0,210	0,003	0,003	0,002

only the part of the seasonal distribution but the comparison with the natural seasonal distribution for the previous period does not indicate any differences.

The outcomes show gradually increase of the HCO_3, Cl and total mineralization content regarding the time (Fig.1 a, b, c)(the time is given in days from the beginning of the period - 01.06.1999). The SO_4 and Mg concentrations are comparatively constant (Table 1). This tendency leads to suggestion that SO_4 and Mg are linked mainly as $MgSO_4$. On the other hand there is a close correlation between Ca and HCO_3, which is an indication for increased content of $CaHCO_3$. The relationships between the mineral content parameters and the water discharge are satisfactory (correlation coefficient r = 0.55-0.87) (Fig.1 d, e, f). All relationships reveal the natural regularity of the Danube water mineral content changes. No influences caused by the war are noticed. The analyses of the results as a minimal, maximal and average values for the both periods are presented at the Table 1. Comparison of the results for the periods 1989-98 and 01.06-31.12.1999 does not show any negative deviations from the existing stage as a result of the war. Furthermore all concentrations measured in 1999 are lower than the concentrations measured in the previous ten years. For example the average value of the total mineralization decreases from 485.5 mg/l to 320.5 mg/l, the average content of sulfate ions decreases from 78.3 mg/l to 21.4 mg/l, the average content of chloride ions changes from 33.7 mg/l to 23.6 mg/l etc. (Table 1).

The permanganate oxidation (Ox) is a parameter determining the organic pollution. Its seasonal distribution depends on the hydrological regime, inflow of organic matter from the catchement area, hydrobiological regime of the river and waste water inflow. The alteration of the permanganate oxidation regarding the time in days for the period 01.06-31.12.1999 and the relationship between permanganate oxidation and water discharge are given in Fig.2 a, b. The values of permanganate oxidation are low for the two studied periods (Table 1) – Ox average = 5.55 mg/l for the period 1989-98 and Ox average =3.58 mg/l. It is obvious that there are no significant changes in the measured values for the two periods and there is no reason to consider that the war has caused any organic pollution in the Bulgarian part of the Danube.

The change of the biogenic substances concentrations with the time confirms the natural seasonal occurrence; NO_3 and NO_2 show an winter maximum (Fig.2 a, b) which is a result of the activity of the phitoplankton. This conclusion is confirmed by the relationships between the concentrations of NO_3 and NO_2 and the water temperature. The concentration of PO_4 reaches its maximum value in winter. The phosphates are the most stable biogenic compounds. They show a considerable correlation with the water discharge, the water temperature and the time for the period 01.06-31.12.1999 (Fig. 2 c, d) (the time is given in days from the beginning of the period). Iron concentrations are low and do not show tendency of changes with the time. The results at Table 1 show that concentrations of biogenic substances registered in the period June – December 1999 are similar to the concentrations from the ten years observations (1989-1998). The anthropogenic sources of biogenic contamination are agriculture activities in the catchment area and domestic waste water that is why the war can not be a reason for increasing of biogenic substances concentration. A decrease of concentrations of biogenic substances comparing the two studied periods is observed. For example the average values of nitrate ions decrease from 6.55 mg/l to 4.21 mg/l, the average values of nitrites change from 0.13 mg/l to 0.08 mg/l; the average values of ammonium ions change from 0.74 mg/l to 0.29 mg/l etc. (Table 1). The reason for the decrease is that the period 01.06-31.12.1999 does not spread over a full annual cycle.

The heavy metals concentrations are studied by several measurements during the period 01.06. - 31.12.1999. The results are shown at Table 2. Concentrations in studied period of 1999 do not vary considerably from the regular measurements for the investigated long-term period (1989-1998). The carried out investigations reveal that the heavy metals content is not changed as a result of the war.

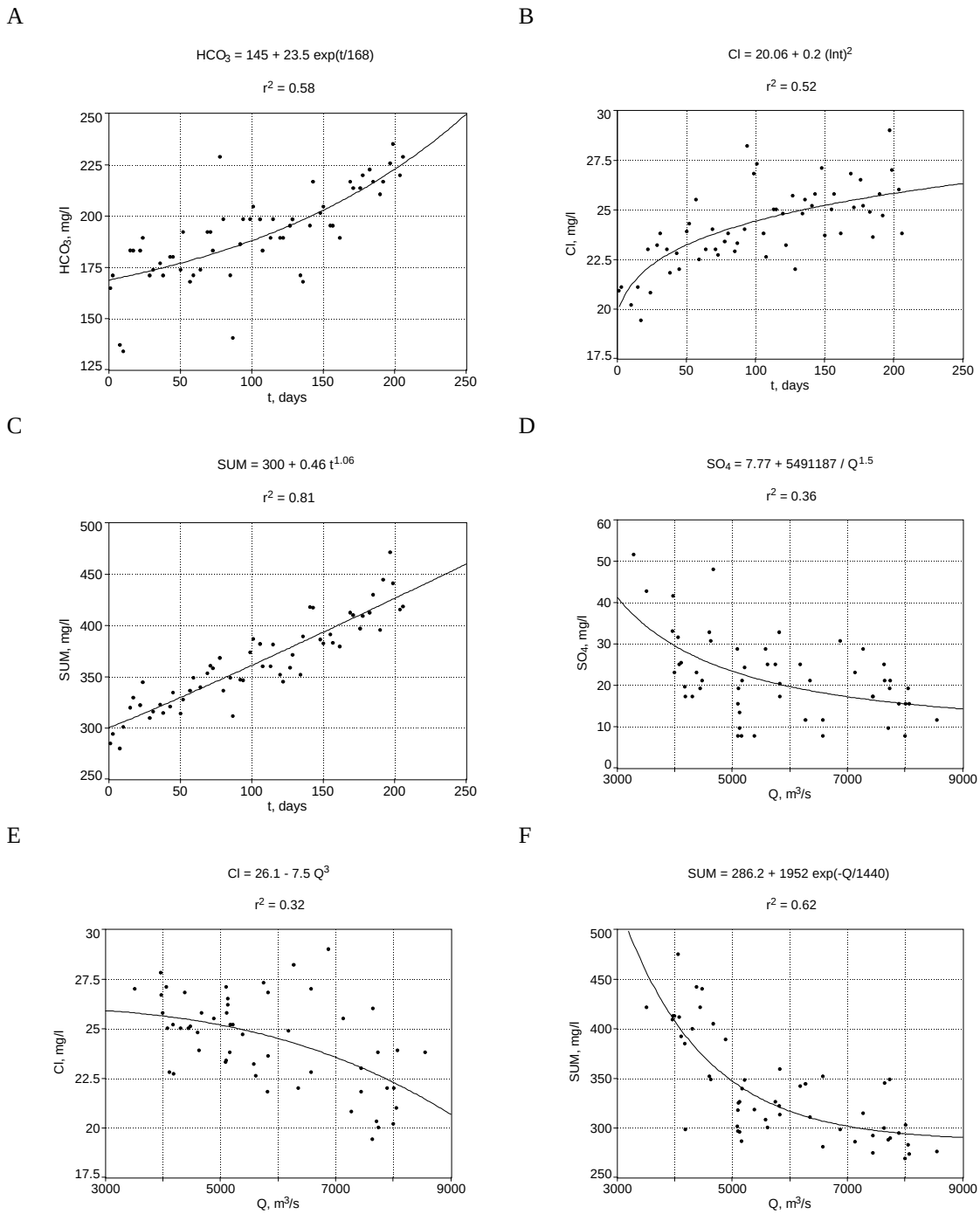

Fig.1 Relationships between water quality parameters and the time (t) (A,B,C) and between water quality parameters and water discharge Q (D,E,F) for the period 01.06-31.12.1999

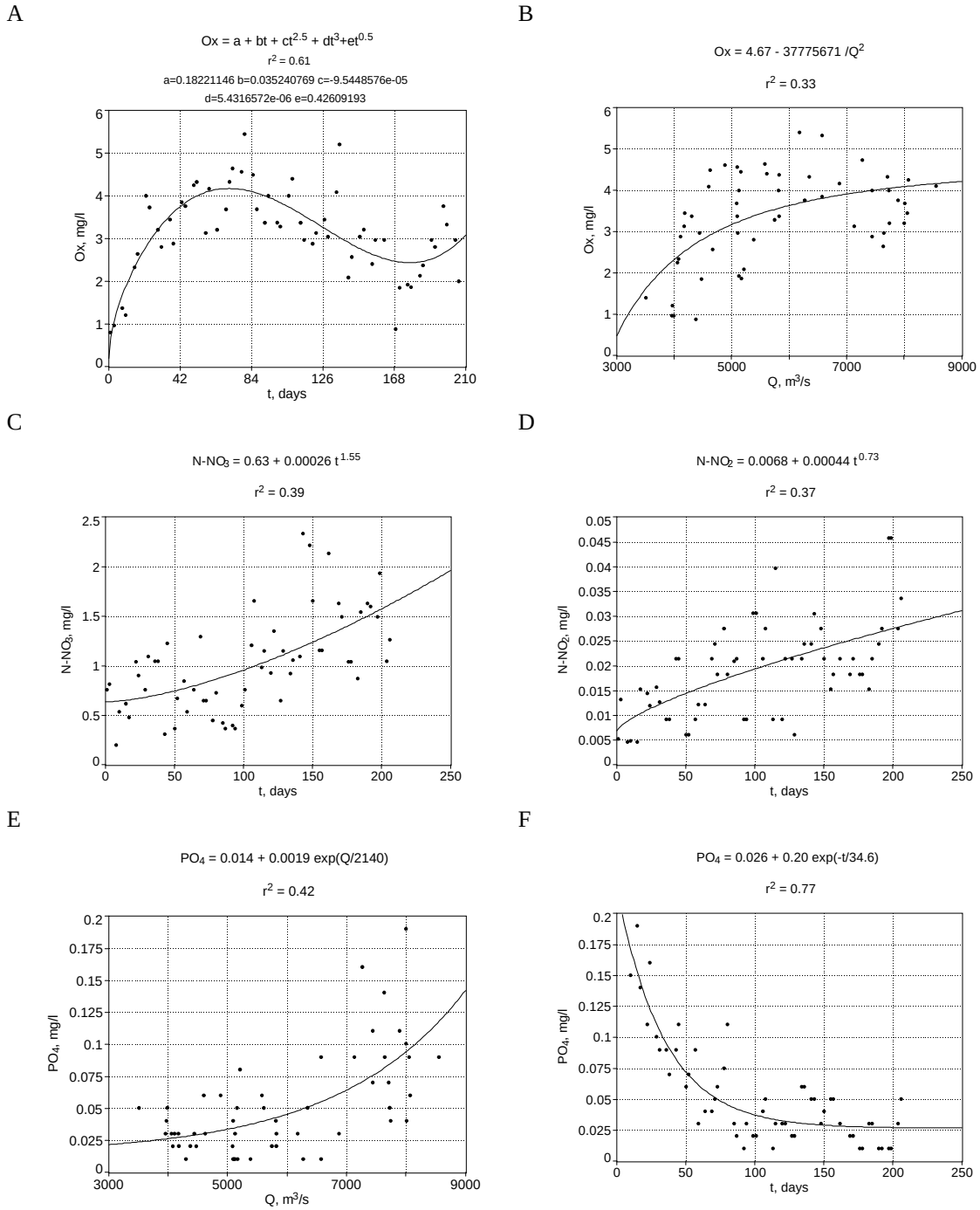

Fig.2 Relationships between water quality parameters and water discharge Q (B,E) and between water quality parameters and the time (t) for the period 01.06-31.12.1999 (A,C,D,F)

If the war has caused any additional increases of concentrations they are reduced in the river section between Bulgarian-Yugoslavian boundary (km 845) and town Nikopol (km 598.0). The concentrations measured at the monitoring point Nikopol in 1999 are low and are not dangerous for the environment and the human health.

Conclusions

1. The concentrations of the investigated water quality parameters during the period 01.06-31.12.1999 do not exceed the concentrations obtained from the regular measurements of the previous ten years period (1989-1998). The additional pollution as a result of the war in Yugoslavia concerning the studied water quality parameters is not registered.

2. The analyses carried out show that the natural seasonal distribution of the concentrations for the period June – December 1999 concerning the studied water quality parameters is not disturbed.

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Inventory of Transboundary Groundwaters in the ECE Region

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Abstract: The Convention on the Protection and Use of Transboundary Watercourses and International Lakes (so called Helsinki Convention) was drown up under the auspices of the UN/ECE and entered into force in October 1996. In the frame of this Convention was established the Task Force on Monitoring and assessment of Transboundary Waters for drafting guidelines on monitoring and assessment of transboundary waters, for rivers, groundwater, lakes and estuaries. The guidelines for groundwaters were accepted in March 2000. These guidelines were supported by four background documents, among them the Inventory of transboundary groundwaters. The Inventory report was based on a questionnaire concerning groundwater issues. Answers were received from 25 ECE-region countries. In this paper are reported the scope, the basic considerations, the methodology used, some recommendations and proposals for guidelines and some of the results of the Inventory report.

Key words: Helsinki Convention, transboundary groundwaters, monitoring and assessment

Bestandsaufnahme des grenzüberschreitenden Grundwassers in der ECE-Region

Zusammenfassung: Das Übereinkommen über den Schutz und die Verwendung grenzüberschreitender Wasserläufe und internationaler Seen (die sogenannte Helsinki-Konvention) wurde unter dem Patronat der UN/ECE ausgearbeitet und im Oktober 1996 in Kraft gesetzt. Im Rahmen dieses Übereinkommens wurde die Abteilung für die Überwachung und Abschätzung grenzüberschreitenden Wassers eingerichtet. Die Richtlinien für die Überwachung und Abschätzung grenzüberschreitenden Wassers, der Flüsse sowie des Grundwassers wurden im März 2000 angenommen. 4 Hintergrund-Dokumente stützen die Richtlinien, unter ihnen das Inventar für Grundwasserfragen. Die Bestandsaufnahme basiert auf einem Fragebogen, der sich mit der Grundwasserproblematik befaßt. Antworten hierauf kamen aus 25 Ländern der ECE-Region. Die Studie gibt Auskunft über den Umfang der Grundlagen, die angewandten Methoden sowie einige Ergebnisse der Bestandsaufnahme und enthält Vorschläge und Empfehlungen für Richtlinien.

Schlüsselworte: Helsinki-Konvention, grenzüberschreitende Grundwässer, Überwachnung und Abschätzung

The *Convention on the Protection and Use of Transboundary Watercourses and International Lakes* was drawn up under the auspices of the UN Economic Commission for Europe (ECE) and signed in Helsinki on 17 March 1992. The Convention entered into force in October 1996 and covers, amongst others, the *monitoring and assessment of transboundary waters*, the effectiveness of measures taken to prevent, control and reduce transboundary impacts, the exchange of information between riparian countries and public information on the results of water effluent sampling. Riparian countries shall also harmonise rules for setting up and operating monitoring programmes, including measurement systems and devices, analytical techniques, data processing and evaluation procedures.

In 1994, the ECE Working Party on Water Problems established the *Task Force on Monitoring and Assessment of Transboundary Waters* with the participation of 22 countries. At its eighth session in March 1995, the Working Party agreed upon a phased approach to the drafting of *guidelines on monitoring and assessment of transboundary waters*. This phased approach means that guidelines will be drafted for rivers, groundwater, lakes and estuaries successively. After finishing the guidelines for transboundary rivers, the Working Party requested the Task Force to draw up - as a second step of activities - draft guidelines on monitoring and assessment

of *transboundary groundwaters*. These guidelines will be considered at the second Meeting of the Parties in the year 2000.

The scope

The Guidelines on monitoring and assessment of transboundary groundwaters are supported by a series of 4 background documents dealing with the following themes:

1. Inventory of transboundary groundwaters
2. Problem-oriented approach and the use of indicators
3. Application of models
4. State of the art on monitoring and assessment of groundwaters

Here the activities and results under item number 1: *Inventory of transboundary groundwaters* are discussed in brief.

The main purpose of this sub/project as defined in its Working Programme is to highlight:

- the location, extension and type of transboundary groundwaters;
- the monitoring activities, pollution sources and contamination of transboundary groundwaters;
- the uses, problems and trends in the state of groundwater according to the observations up till now and
- the institutional- and international aspects in their management in the ECE region.

In the course of the preparation, it seemed useful to extend the scope for gaining information also on the position and significance of groundwaters in the relevant countries, on the legal and administrative background of managing with groundwaters, on the monitoring activities in the countries, on the bilateral agreements covering groundwater issues and the activities running under them.

Basic considerations

The basic considerations taken into account in the course of implementing the sub-project are as follows:

When considering groundwaters in general it should be taken into account that groundwaters are taking part together with surface waters in the same hydrological cycle, and the two kinds of water are in more or less close connection and interaction with each other. This is why the basic principle of *integrated water management* is being more and more accepted in a world-wide sense. Nevertheless there are considerable differences between the characteristics of surface water and groundwater to be taken into consideration both in managing with them and in their monitoring. The most important features among others are as they follow:

- groundwaters can be found also in regions where watercourses are not available at reasonable distance; watersheds of surface waters are in coincidence with the boundaries of aquifers in a few cases only,
- groundwater has a spatial extension linked with the extension of the aquifers sometimes in multilayered systems; its three-dimensional nature should be taken into consideration,
- groundwater moves relatively slowly (m/year) as compared with the movement of surface water (m/s), this is valid also for the variations in groundwater level/head,
- since the whole of groundwater resources are invisible, changes in the state of groundwater (both from quantitative and qualitative aspects) are proceeding also in an invisible way

- there is a considerable degree of physico-chemical interaction between the water and the containing aquifer; as a result, even the baseline quality of groundwater is subject to spatial and depth variations,
- as a consequence of the relatively slow physical movement, pollution processes are also relatively slow on one hand, their elimination (e.g. clean-up) is also a long process and successful only in few cases on the other,
- abstraction of groundwater is influencing the extension of the actual recharge area connected to the particular abstraction; as a consequence various groundwater horizons and bodies previously separate can be interconnected,
- both quantity- and quality monitoring of groundwater must be a three-dimensional system and it should be developed having a good knowledge of the hydrodynamic system of groundwater to be monitored; additionally future changes should be taken into account as far as possible.

Methodology

For the execution of the overall groundwater programme a Core Group was established on international level and a Guidance Committee was organised in Hungary as lead country of the sub-project No.1. The Committee supervised the whole process implemented under the sub-project. The data-base for the implementation of the sub/project was developed in VITUKI Plc. Budapest, Hungary.

For the implementation of the sub-project the *Questionnaire concerning groundwater issues* was elaborated and circulated by the lead-country to the 22 Task Force members and for information to the 30 focal points of Forum of European Geological Surveys (FOREGS) and to the members of the Core Group on Groundwater. The ECE Secretariat circulated it to the 14 ECE focal points other than the Task Force members. Answers were received from 25 countries.

The *objective* of the Questionnaire was to gain information

- on the significance of groundwaters, their kinds, functions and uses, on their monitoring within the country, data-bases, methods of licensing, institutions involved in the management with groundwaters,
- on each transboundary aquifer (shallow, deep, alluvial, bank-filtered, karstic and others) taking into account the quantity and quality characteristics, threats, contamination, monitoring and institutional aspects,
- on the experienced impacts originating from the neighbouring countries.

The countries were asked to use maps showing the locations of the transboundary aquifers providing them with the particular labels.

In the course of evaluating the information received some difficulties should be overcome, e.g.:

- the most serious difficulties have been experienced when trying to compare the data communicated by two (three or four) countries on the same transboundary aquifer; there have been serious discrepancies in the data received from the relevant countries,
- there have been cases when one of the relevant countries communicated the data of a transboundary aquifer in her territory (in certain cases detailed data according to the Questionnaire) while the other country did not indicate any counterpart in her territory neither in the Questionnaire nor in the maps,

- in other cases, there were serious differences in the types of the aquifers as communicated by the relevant countries (it occurred that two or more types were indicated by one of the countries and/or the length of intersection did not display the necessary consistency).

Thus the identification of transboundary aquifers became the most important difficulty. It should be clearly accepted that the identification of a transboundary aquifer is much more difficult than that of a transboundary river (e.g. in the latter case, no doubt can be experienced when identifying the name, location or length of the watercourse; nevertheless, some difficulties are occurring when the characteristic flows or the quality of water are being compared).

There was no consistency in labelling the aquifers on the maps used as each country applied the labelling according to her internal system.

The above difficulties are self-explanatory, considering the institutional differences, the ways, means and levels of hydrogeological explorations; differences in the criteria of classifying the aquifers and scientific/technical traditions prevailing in the respective countries.

Recommendations

An other outcome of the sub-project has been the formulation of some recommendations to the Guidelines. There are some well known *basic principles* relating to the monitoring of groundwaters in the technical-scientific literature. They should be taken into consideration also when developing the *guidelines specific to the monitoring and assessment of transboundary groundwaters.*

Basic principles

- *The three-dimensional nature of groundwaters should be taken into consideration*

  Not too many doubts are arising when a watercourse to be monitored should be identified: its bed, the movement of water and its direction, the name of such a watercourse brings no serious difficulty about. To establish the similar characteristics of groundwater is somewhat more complicated. The location, extension, depth, etc. of a transboundary groundwater body is less evident then a river-bed. Additionally several times multilayered systems should be monitored when the appropriate aquifers and the aquicludes are of different nature and the movement of waters contained by the aquifers together with their chemical character may be different. Above these, interactions can develop between the aquifers as the consequence of human interventions (e.g. abstractions). These features altogether are defining the movement and quality of groundwater in a given block of subsurface space where the water stored should be monitored according to the actual necessities.

- *Integration of surface- and groundwater monitoring is necessary*

  This is required to the extent as the changes and processes in one kind of waters are expected to induce changes and processes in the other under the prevailing hydrological/hydrogeological system taking also the consequence of human interventions (abstraction, pollution, etc.) into account. This is important not only because of the possible interactions between the two kinds of water but also from the point of view of the integrated water management the necessity of which is emphasised both in the technical-scientific literature and in several international documents on water management as well.

- *Time-requirement of detecting definitive processes in groundwaters and making the necessary counteractions should be taken into consideration*

  Movement of groundwaters and the processes taking place in the groundwater systems are rather slow as compared to those in surface waters. Adverse quantitative impacts as the result of human interventions may be more or less eliminated even if requiring longer time. Quality impacts can be hardly eliminated, the clean-up of aquifers is very expensive and time-consuming action. According to the general experience e.g. the safeguarding of the provision of drinking water (and other uses in particular cases) a critical change (e.g. the deterioration of quality of the abstracted water) must be foreseen at least 10-15 years earlier.

- *The groundwaters, the human interventions and their consequences in groundwaters should be monitored in an integrated way*

  Abstractions or artificial recharge of groundwaters are changing the movement of groundwater systems radically. Earlier isolated groundwater bodies become more or less interconnected. The impact of pollution sources is quite different under natural conditions an in the situations when the flow-system had been changed. Processes in the groundwater system (quantity- and quality ones) and the causes bringing them about should be evaluated together to gain a comprehensive picture and a basis to elaborate and to implement the necessary technical counteractions.

- *Monitoring and assessment of groundwaters should be executed in a phased way*

  The conviction is getting more and more accepted in the scientific/technical literature and in certain cases it is more or less realised in the practice that a particular groundwater monitoring system should be developed in a phased way. Without defining the number of phases here and now it seems to be advisable to accept that the first phase should be the *information analysis* when all the information direct and/or indirect on the groundwater to be monitored and its hydrogeological context should be collected and analysed (results of eventually existing monitoring activities, experiences and/or records/estimation on production wells and springs, information gained from geological/mineral explorations, experiences on eventual dewatering activities in mining industry, etc.). On the basis of the results an *exploration phase* should be implemented when target-oriented exploratory activities are being executed (mainly by drilling exploratory wells, taking samples from the layers and groundwaters penetrated, accomplishing hydrodynamic tests in them, etc.). It is of high probability that a considerable number of the exploration wells will remain as monitoring ones. The results of this phase may be a considerable contribution to a better understanding of the characteristics of the groundwater to be monitored and to *plan* the monitoring system itself. This leads to the *development of the monitoring system* (usually a network of monitoring wells) which produces numerous additional information on the aquifers, on the groundwaters contained by them, on the aquicludes and aquitards in the environment of the groundwater to be monitored. From this may start the *initial phase* of the monitoring activity itself together with the continuous evaluation of the results leading after a certain time to the *revision and optimisation* of the system. Later smaller improvement may occur, because frankly spoken no perfect and proof monitoring system can be developed at all. Above all, the whole process should be predetermined by the *objective* of the particular monitoring activity (safeguarding the quality of

drinking-water resources against deterioration/over-use, to control or close-up pollution sources, to provide long-term forecasts on levels/quality of groundwaters by modelling, etc.). *Modelling* with its requirements should be considered as a definitive factor from the beginning of the development of a monitoring system. This is at the time being such a common tool in describing, evaluating, assessment and forecasting of the processes in groundwater systems that the data-demand of modelling should be taken highly into account in each phase of development.

Proposals to the Guidelines, specific to transboundary groundwaters

- *The transboundary groundwaters (aquifers) should be identified*

  To develop any kind or level of monitoring all of the transboundary aquifers should be identified. According to the lessons learned in this sub-project it can be seen that transboundary aquifers are in a very low number which can be considered as identified ones (the type of groundwater, the length of intersection, etc. are the same or near the same reported from the two sides of the frontier), i.e. information available on the same aquifer on two sides of the frontiers are highly different. Evidently this comes not from any change in the characteristics of aquifers just at the frontier; the cause of discrepancies is the difference in the information available in the relevant countries on the same aquifer. The reason is that the particular countries have the knowledge of the aquifers at different level due to the different methods and extents of exploration made. To arrive at the identification of the aquifers the countries have to collect all the available information on the aquifers and evaluate them according to joint methodologies in compliance with what has been told above about the phased development of monitoring systems with reference to *information analysis*. As a next step the necessary *explorations* are recommended to be implemented to assure the same level of knowledge on both sides of the frontier. These steps can lead to the *identification of the aquifers* (transboundary groundwaters).

- *Monitoring systems on transboundary groundwaters should be developed jointly on the two sides of the frontier ("one aquifer, one monitoring system")*

  The approach is recommended in which the transboundary aquifer to be monitored should be considered as a single and uniform natural system. The frontier is something artificial having no influence on the characteristics of groundwaters and on the processes taking place in them crossed by it. Therefore *one* monitoring system should be developed per aquifer even if it is invested and operated by two countries. Thus all the principles listed as basic ones should be applied to the aquifer as a whole (phased development, integrated planning, the considerations on human interventions an its impact on the time-requirement, three-dimensional nature, etc.). This refers also to modelling: when using models in transboundary sense, a single model is recommended to be used per aquifer and waters in the aquifer/aquifer-system. It is perhaps not advisable to recommend to be used by all of the ECE countries (however not excluded), nevertheless the uniformity mentioned above is strictly recommended. This is coming not only from the nature of groundwaters but also from the provisions of the Convention and those of *The Commission Proposal for a Council Directive Establishing a Framework for Community Action in the Field of Water Policy* (the comprehensive framework-directive of the EU on water management). Latter goes so far that it recommends to assign River Basin Districts (also in international sense: International River Basin Districts), to ensure that application of the rules of the

Directive is co-ordinated, with a competence on monitoring activities, groundwaters included. It is advisable to take also this instrument into consideration when organising the joint monitoring and assessment of transboundary groundwaters.

- *Monitoring systems of transboundary groundwaters should be target-oriented/tailor made providing the countries involved with the necessary information to manage the appropriate groundwaters in a common way*

  There are cases when important abstractions are on one or both sides of the frontier together with potential pollution sources. Sometimes some pollution is detected already, in other cases the deterioration of groundwater can be established, incidentally together with some long-term trend of deterioration. Each case is differing from the other therefor no suggestion should be made e.g. on the frequency of observations/sampling, on the distribution of monitoring sites, etc.; they should be defined per aquifer. Nor the determinants in quality monitoring should be proposed with general validity as they are depending on the actual hydrogeological situation, the expected contamination, etc. Here again the question of modelling returns as a further factor giving requirements towards the appropriate monitoring system. However the information provided by the monitoring system should be compatible and this leads to the next proposal.

- *Observation, sampling, laboratory analysis, data storage and processing should be standardised*

  This standardisation should be valid for the whole of the monitoring system of a particular transboundary groundwater body. To serve this, the whole development of the monitoring system should be one continuous process as it has been discussed in connection with the phased character of development, from the information analysis to the operation of the system; furthermore its operation should be planned in advance with scheduling also the systematic updating upon the experiences gained.

Some of the results

Altogether 89 aquifers have been reported by at least one country. Each transboundary aquifer has been characterised with a *sheet* in the report on the sub-project, containing all information accumulated in the course of the implementation. There are 51 cases when only one of two or three countries have communicated some information on the same transboundary aquifer while the neighbouring countries have communicated no answer on it at all.

There are 11 transboundary aquifers where

- the types are indicated as the same or nearly the same by the relevant countries;
- the differences in the lengths of intersections are below 50% and;
- the extent of the particular aquifer is reported by both of the neighbouring countries.

These aquifers may be considered as *identified ones.*

This is the core issue of the present sub-project and this is why the process can not be considered as implemented. *The results of the sub-project can be considered as the assessment of the present knowledge on transboundary aquifers/groundwaters rather than as an inventory.* The process is recommended to be continued to come to a more or less equal level of knowledge on transboundary groundwaters/aquifers thus arriving at a comprehensive and reliable inventory and to make first steps towards the development of their uniform monitoring and assessment.

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UN/ECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes (done at Helsinki, on 17 March 1992.)

Übereinkommen von 1992 über den Schutz und die Nutzung grenzüberschreitender Wasserläufe

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The Development of the Salination of the Soil - Groundwater System on the Left Bank of the Danube River

Anežka Čelková

Abstract: Soil and groundwater quality research and monitoring results in the selected locations Veľké Kosihy and Čalovec in the east of the Žitný Island are presented in the paper. Groundwater was taken into consideration as it is a source of secondary salination of soil. In the course of 1989 and 1990 samples of soil from both locations were taken and analyzed and over the period of 1989 to 1996 also groundwater samples were taken and analyzed, and the concentration of salinating ions, the amount of dissolved substances (RL), pH-values and specific electric conductivity values (EC) were measured and the sodium adsorption ratio (SAR) was calculated. Based on these data the soil salination development trends were ascertained. Most of the monitored groundwater parameters displayed a growing tendency, according to which we may state, that the soil salination hazard due to mineralized groundwater increases in both locations.

Key words: Groundwater quality, salination hazard.

Entwicklung der Salinisation des Boden - Grundwassersystems auf der linken Seite der Donau

Zusammenfassung: In diesem Beitrag sind die Ergebnisse der Forschung und Überwachung der Boden- und Grundwasserqualität in den ausgewählten Orten - Veľké Kosihy und Čalovec im Osten von der Žitný Insel - präsentiert. Das Grundwasser wurde einbezogen, weil es als Quelle der sekundären Salinisation des Bodens gilt. In Jahren 1989 und 1990 wurden an beiden Orten Bodenproben und vom 1989 bis 1996 auch Grundwasserproben entnommen und analysiert. In den Grundwasserproben wurden die Konzentration der den Salzgehalt steigenden Ionen, die Menge der aufgelösten Stoffe (RL), gemessene pH-Werte und spezifische elektrische Leitfähigkeit (EC) festgestellt und die SAR-Werte (sodium adsorption ratio) kalkuliert. Aufgrund dieser Angaben wurden die Bodensalinisationtrends festgestellt. Die Werte der meisten überwachten Grundwasserparameter zeigten eine wachsende Tendenz, deshalb können wir sagen, dass das Bodensalinisationsrisiko aufgrund des mineralisierten Grundwassers an beiden Orten wächst.

Schlüsselworte: Grundwasserqualität, Bodensalinisationsrisiko.

1 Introduction

The exact description, forecast and quantitative characteristics of the soil water regime constitute the most important elements for the study of salination processes and development of soils affected by salination from the view-point of their rational agricultural utilization. Efficient salination control is possible only if the sources of salination have been determined, water and salt flows have been concisely and quantitatively described and the relation between factors affecting the salination process analyzed and quantified. The accumulation of salt from groundwater is of primary importance in areas, in which groundwater constitutes the main source of salts and plays the decisive role in the development of soils (Burger, Čelková 1994).

2 Characterization of emergence and development of saline soils

The increase in the soil and groundwater salination is caused by a whole range of natural factors, artificial factors (these include the effect of the construction and operation of waterworks) and agricultural techniques, which also include methods applied to regulate the water and salt regime of soils - irrigations and drainage (Shainberg et al. 1984). The groundwater regime on the adjacent land is affected by the completed and operated waterworks system on the Danube River. The forecasted alterations, i.e. fluctuation of water levels in the eastern part of the Žitný Island with natural occurrence of mineralized groundwater, generate presuppositions for a possible secondary soil salination on this territory. Mineralized groundwater is to be frequently found not very deep below the ground level and during the prevailing evapotranspiration salinating substances get to the upper layers of soil and become the main reason for soil salination.

The salination of soil, irrigation and groundwater is prevalently caused by anions: hydrogen carbonates, sulphates, chlorides, and cations: calcium, magnesium, sodium and potassium cations. The concentrations of the mentioned cations in groundwater determine the SAR (sodium adsorption ratio) values, i.e. the adsorbed sodium to calcium and magnesium ratio, they characterize the contamination of water and indicate the possibility of soil salination with sodium, which represents a cation with the worst salination effect with respect to the growth and development of plants, and which leads to a reduction of the soil permeability. Groundwater SAR values together with the specific electric conductivity (EC), which is an indicator of the overall water mineralization, constitute the main criteria characterizing the salination hazard degree according to the following levels (Richards et al. 1959, Kenneth 1990): EC: 100-250 μS/cm– low, 250-750 μS/cm - middle, 750-2250 μS/cm – high, 2250-5000 μS/cm – very high. The sodium hazard criterion based on the SAR value displays four levels: 0-10 – low, 10-18 – middle, 18-26 – high, SAR>26 – very high.

The specific electric conductivity of the saturated soil extract and the weight of the soil aquaeous lixivium evaporation residue obtained at a temperature of 105°C (RL - dissolved substances) constitute the main soil salination criterion. Soils having an EC>400 μS/cm, or weight of the evaporation residue exceeding 0.3% are considered to be salinated. A slight salination occurs already when the EC>200 μS/cm, or the weight of the evaporation residue amounts to 0.1%.

2.1. Balance of distribution of the salinating substances concentration in the soil and groundwater

The monitored locations Veľké Kosihy and Čalovec are situated in the east of the Žitný Island. Alterations in the groundwater levels were forecasted in this location after the construction of the waterworks was completed.

Veľké Kosihy: The location is situated near Veľké Kosihy on agricultural land about 1 km away from the Danube River. The Lel-Kosihy melioriation canal flows along the location at a distance of 200—220 m. Composition of the soil: 0-90 cm: clay soil, 90-160 cm: clay loam, 160-640 cm: sandy soil, 640 cm: gravel.

Čalovec: The location is situated in the eastern part of the Žitný Island near Čalovec on agricultural land at a distance of approximately 50 m from the Kolárovo-Kameničná melioration canal. The groundwater level is directly affected by the water level in the canal. Composition of the soil: 0-30 cm: clay soil, 30-40 cm: loamy sand, 40-75 cm: sandy soil.

In the course of 1989 and 1990 field measurements were carried out and soil samples were taken from selected locations. Soil samples were gradually taken from three or four soil depths over the entire year, and the contents of the individual salinating ions and physical-chemical

characteristics were determined in the soil aquaeous lixivium (at a 1:5 ratio). The results of chemical analyses of the soil lixivium from one sample taking in both 1989 and 1990 are just as illustration given in table 1. As for the anionic components hydrogen carbonates prevail over chloride and sulphate ions in both locations, which gives evidence of the bicarbonate nature of soil salination. As for the cationic components the Na^+ concentration prevails over the Ca^{2+} content in Veľké Kosihy, and this even increases proportionately to the depth of the soil layers. The EC values ranging from 189 to 396 μS/cm give evidence of the beginning soil salination process.

Over the period of 1989 to 1996 groundwater samples were taken and analyzed. The time courses of salinating ion concentrations, specific electric conductivity values (EC) and amount of dissolved substances (RL) in groundwater in the monitored locations are shown in figures 1-3. The SAR values were calculated on the basis of measured cation concentrations in groundwater. The SAR time course is given in figure 4. Most of the monitored groundwater parameters displayed a growing tendency. As for the anionic components the HCO_3^- content prevails over the SO_4^{2-} and Cl^- contents in both locations. As far as the cationic components are concerned, the Na^+ content prevailed over Ca^{2+} and Mg^{2+} contents in Veľké Kosihy. Such a chemical composition of groundwater is qualified as hazardous because of the possibility of sodium salination. By means of capillary action soluble salts get into the soil root zone, where they precipitate after water transpires, and accumulate in the soil layers, and Na^+ is bonded to soil. The Ca^{2+} content prevailed over Mg^{2+} and Na^+ contents in Čalovec. In Veľké Kosihy the EC values ranged from 1,100 to 1,800 μS/cm, SAR values ranged from 18 to 37, which bears evidence of the high groundwater mineralization degree and the high even very high degree of soil salination hazard due to sodium contained in groundwater. In Čalovec the EC values ranged from 1,340 to 2,800 μS/cm and the SAR values ranged from 6 to 18, which bears evidence of the high even very high mineralization degree and medium soil salination hazard due to sodium contained in groundwater.

3 Conclusion

Based on soil and groundwater monitoring results we may come to the conclusion, that the deteriorating groundwater quality - as far as salinity is concerned - increased the soil salination hazard in both locations over the monitored period due to seasonal fluctuations of the groundwater level and capillary action.

The concentrations of most of the salinating ions in groundwater, as well as the EC and SAR values showed a growing tendency over the period of 1989 to 1996. Based on criteria which characterize the soil salination hazard degree due to the effect of ground water, the salination hazard is high in Veľké Kosihy according to the EC value (750 <EC< 2,250) and the soil salination hazard due to sodium contained in groundwater is high even very high according to the SAR value (18<SAR<38). As for the second location - Čalovec - the salination hazard is high even very high (750<EC<3,000) and the soil salination hazard due to sodium contained in groundwater is medium (10<SAR<18).

Hydrogen carbonates prevail over sulphates and chlorides in the soil lixivium, which gives evidence of the bicarbonate nature of the salination. The weight of the evaporation residue at a temperature of 105º C ranges from 0.14 to 0.28% and the electric conductivity ranges from 189 to 396 μS/cm, which gives evidence of a slight or beginning soil salination process.

4 References

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Table 1 Results of soil lixivium analyses carried out for samples taken in Veľké Kosihy and Čalovec.

Location	Date	Depth	pH/ H_2O	pH/ KCl	Cl^- [mg/ 100g]	SO_4^{2-} [mg/ 100g]	HCO_3^- [mg/ 100g]	K^+ [mg/ 100g]	Na^+ [mg/ 100g]	Mg^{2+} [mg/ 100g]	Ca^{2+} [mg/ 100g]	evaporation residue at 105°C [%]	EC [µS/cm]
V.Kosihy	1989	0-30	7,25	7,02	8,90	3,4	29,0	6,8	2,05	6,65	23,3	0,17	240
	30.5.	30-60	7,14	6,85	10,3	3,9	33,0	3,05	26,4	6,95	12,35	0,15	208
		60-90	7,18	6,80	15,8	12,4	41,5	0,75	51,2	7,05	11,03	0,14	201
		90-150	7,28	6,85	12,4	15,2	45,8	0,7	58,6	7,3	9,2	0,14	195
V. Kosihy	1990	0-30	7,35	7,10	8,8	8,15	19,20	4,90	5,35	7,15	27,20	0,17	215
	24.5.	30-60	7,26	6,90	9,10	6,90	25,40	2,15	30,05	7,35	16,30	0,17	189
		60-90	7,20	6,89	12,40	10,10	34,0	1,05	40,20	7,30	10,50	0,16	190
		90-150	7,13	6,79	13,60	16,80	39,5	0,90	51,15	7,45	8,25	0,16	195
Čalovec	1989	0-30	7,35	7,15	22,5	39,2	91,5	1,1	9,5	6,5	27,4	0,20	284
	16.5.	30-60	7,09	6,8	18,4	48,5	86,5	0,8	10,4	8,7	20,1	0,26	362
		60-90	6,95	6,72	19,5	23,0	80,5	1,4	6,2	5,3	16,9	0,16	226
Čalovec	1990	0-30	7,28	6,90	26,2	49,0	85,0	0,95	9,3	5,9	23,6	0,29	394
	24.5.	30-60	7,10	6,70	20,5	38,5	81,0	0,80	8,2	9,6	19,8	0,28	350
		60-90	7,02	6,65	16,3	23,3	80,0	0,55	10,5	6,5	17,5	0,26	245

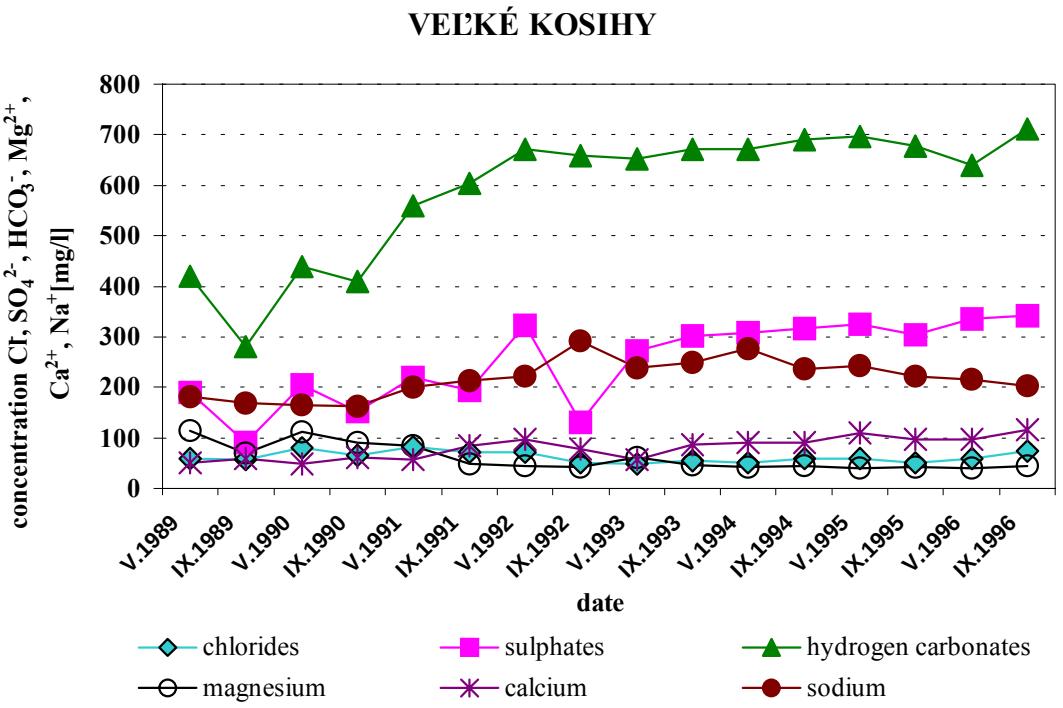


Fig.1 Time course of salinating ion concentrations of magnesium, calcium sodium, chlorides, sulphates and hydrogen carbonates in groundwater in Veľké Kosihy.

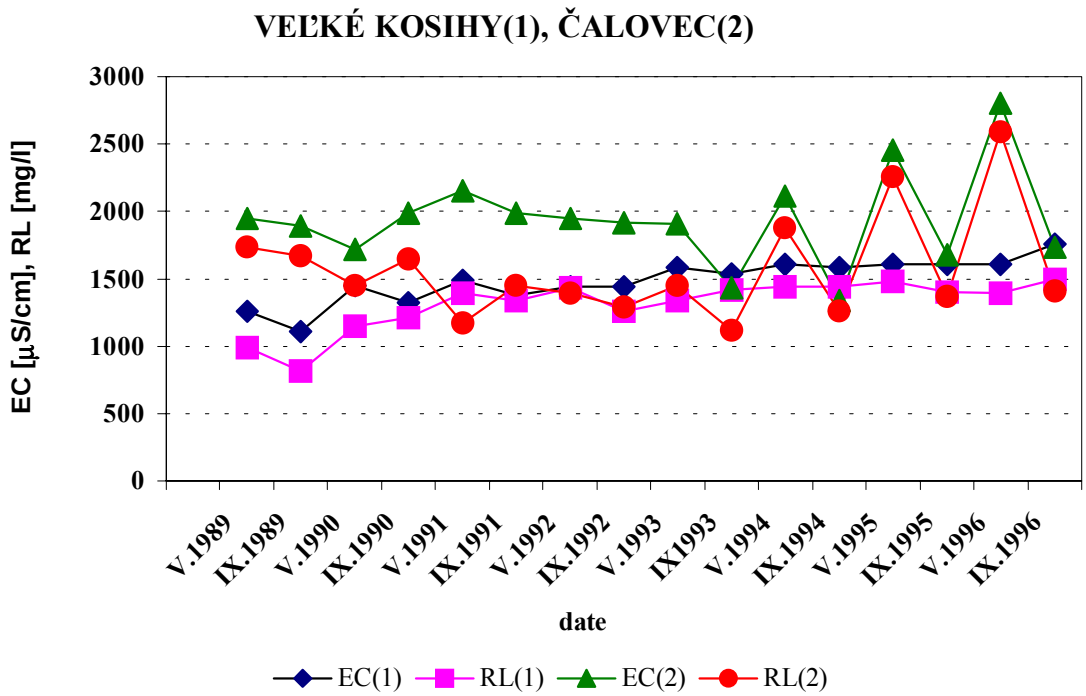


Fig. 2 Time course of specific electric conductivity (EC) and amount of dissolved substances (RL) in groundwater in the monitoring locations in Veľké Kosihy (1) and Čalovec (2).

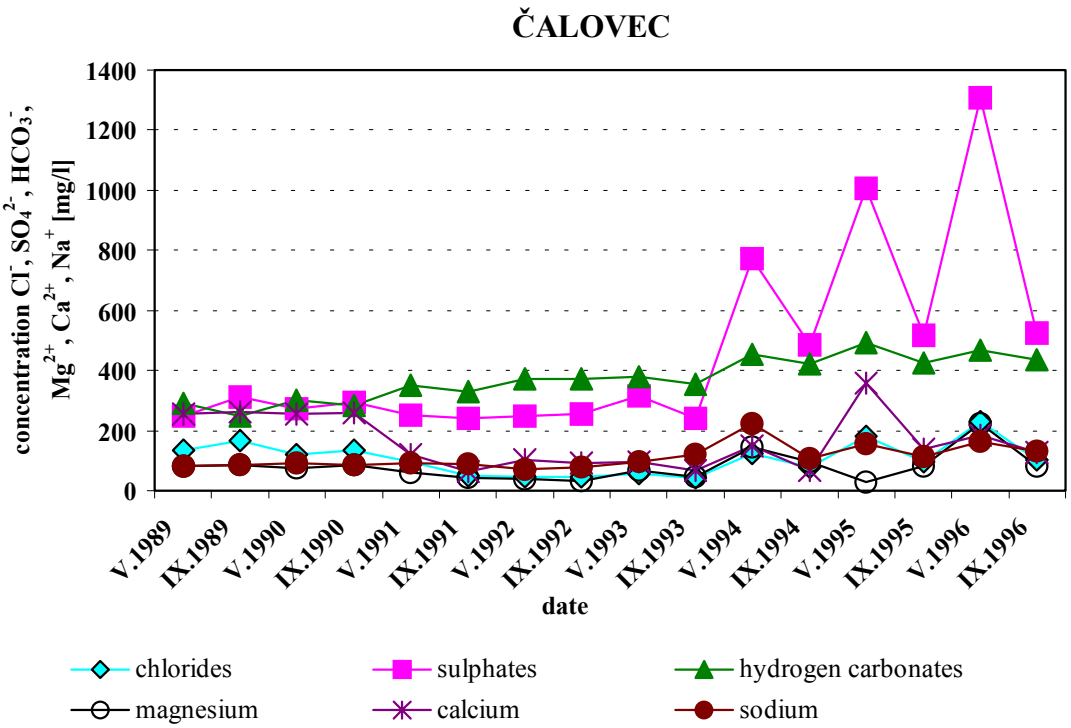


Fig.3. Time course of salinating ion concentrations of magnesium, calcium sodium, chlorides, sulphates and hydrogen carbonates in groundwater in Čalovec.

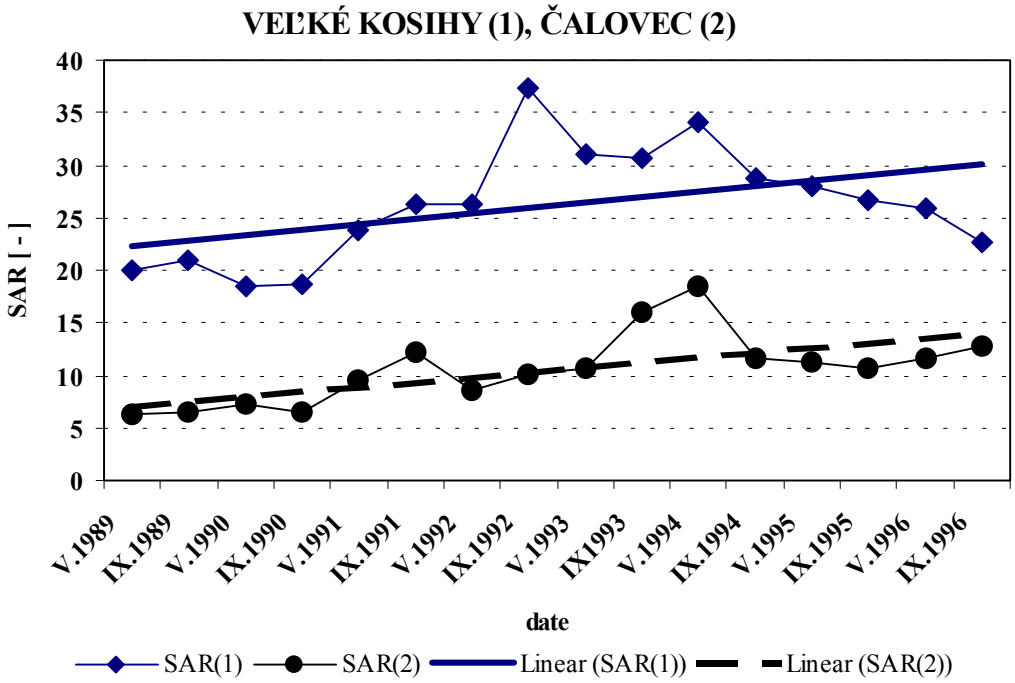


Fig. 4 Time course of SAR (sodium adsorption ratio) values in groundwater in Veľké Kosihy and Čalovec and trend lines for these values.

A Saprobiological Assessment of the Danube River

Emília Elexová, Jarmila Makovinská, Lívia Tóthová

Abstract: Taxa composition and diversity of three water communities - bioseston, periphyton (phytobenthon) and macrozoobenthon have been studied in longitudinal profile of the main Danube channel between Bratislava and Szob. Saprobic indices of all studied communities were calculated for a biological quality assessment. Species of the periphyton and macrozoobenthon communities, attached to the solid objects of littoral zone, are considered the suitable organisms namely for a long-term quality - saprobity assessment. They dispose of high indicative abilities, long development cycles and high abundance or biomass, and these properties allow the best reflection of water quality long-term status. In contrary the bioseston provides information about the current situation. Macrozoobenthon has been monitored since 1996. The investigation of periphyton started later - in 1997 and as well as the macrozoobenthon it was studied three times a year. Phytoplankton is included in a great deal in bioseston community, which contains the other organisms from consument and destruent trophic groups. They were sampled and studied regularly each two weeks or monthly. 10-years period was evaluated in this contribution from the determinants of saprobity and biological oxygen demand point of view by linear regression. The mentioned trend analyses and time series are presented from three selected sampling sites – Bratislava, Medveďov, and Szob. The slight gradual decreasing tendency in both determinants has been recorded. Macrozoobenthon and periphyton were sampled three times a year. Generally the bioseston saprobic indices were higher than the fyto- or zoobenthon saprobic indices. The total saprobity does not exceed beta-mesosaprobic limit. These results correspond to organic matter content increase, related to gradual eutrophication in longitudinal profile of the Danube river.

Key words: Danube, saprobic indeces, bioseston, periphyton, phytoplankton, macrozoobenthon

Saprobiologische Bewertung der Donau

Zusammenfassung: Taxonomische Abladung und Diversität drei Wassergemeinschaften (Bioseston, Periphyton, Makrozoobenhos) haben wir bei dem Längsschnitt der Donau zwischen Bratislave und Szob verfolgen. Von alle studierenden Gemeinschaften, haben wir Saprobien – Indexen berechnen für biologische Bewertung der Qualität. Die Kategorien der Gemeinscheften für Makrozoobenthos und Periphyton sind passende, besonders für die langfristige Bewertung der Qualität von Saprobien. Sie disponieren mit den Hoch – Indikationsfähigkeiten und mit den langfristigen Entwickelungen. Diese Eingenschaften können sehr gut langfristigen Stand zeigen. Umgekehrt Bioseston gibt uns die Informationen um die gegenwärtige Situation. Makrozoobenthos verfolgen wir von dem Jahr 1996. Forschung für Periphyton war ain Jahr später – 1997 und auch die Beobachtung war drei Mal im Jahr. Phytoplankton gehört mehr zu der Gemeinschaft von Bioseston, welche weiter Gruppen die Konsumenten und Destruenten bilden. Diese studierten wir immer jede zwei Wochen oder ein Mal im Monat. Zehn Jahren haben wir Saprobien und Biochemischer Sauwrstoffbedarf (BSB_5) mit der Hilfe der Regreβlinie bewerten. Und das bei drei ausgewählten Örte (Bratislava, Medveďov, und Szob). Bei der Zeiger BSB_5 und Saprobien – Indexen sehen wir das Sinken. Makrozoobenthos haben wir auch drei Mal im Jahr genommen. In der Allgemeinheit, können wir sagen, daβ Saprobien – Indexen von Bioseston mehr hoch als die Indexen von Phyto- und Zoobenthos waren. Die Bewertungen die Saprobien – Indexen waren im Bereich Beta – Mesosaprobien. Ergebnise der Forschung zeigen auf den Gewässereutrophierung bei dem Längschnitt der Donau.

Schlüsselworte: Donau, Saprobien – Indexen, Bioseston, Periphyton, Phytoplankton, Makrozoobenthos

Regarding the international and transboundary character of the Danube river Slovak section, taxa composition and diversity of three communities – bioseston, periphyton (phytobenthon) and macrozoobenthon, with quantitative determinant expressed as a relative abundance have been studied in longitudinal profile of the main Danube river between Bratislava and Szob. The map of monitored sampling stations is given on fig.1.

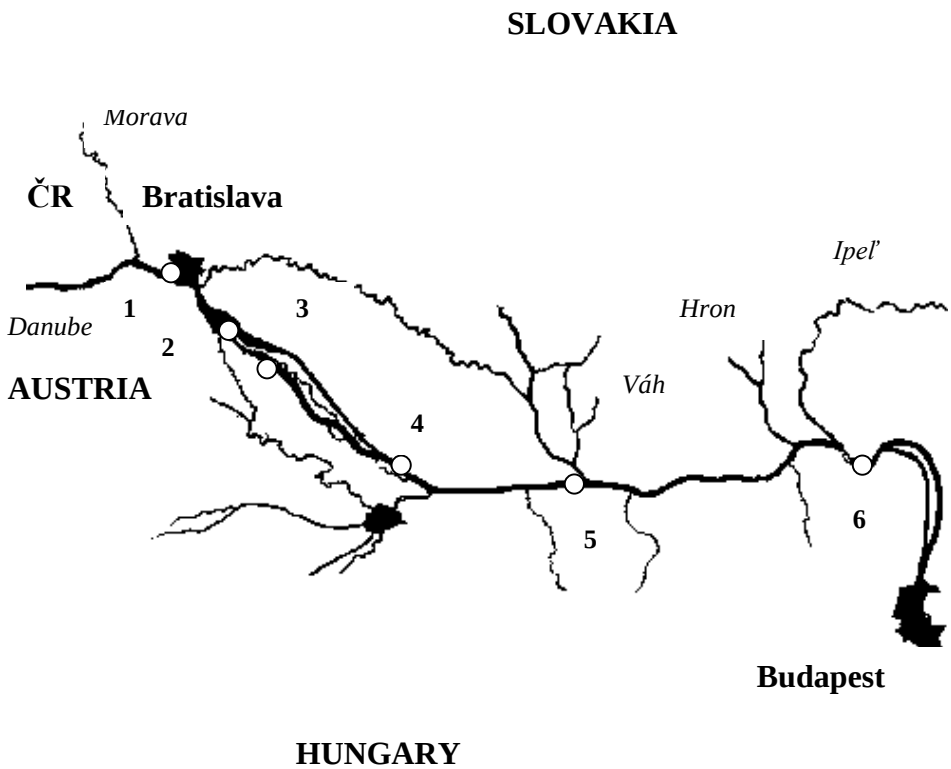


Fig. 1 Map of the monitored sampling sites: 1-Bratislava, 2-Rajka, 3-Hrušov, 4-Medveďov, 5-Komárno, 6-Szob

Saprobic indices of mentioned communities were calculated for a biological quality assessment. Species of the periphyton and macrozoobenthon communities, attached to the solid objects of littoral zone, are considered the suitable organisms namely for a long-term quality - saprobity assessment. They dispose of high indicative abilities, long development cycles and high abundance or biomass, and these properties allow the best reflection of water quality long-term status. Additionally, the benthic fauna community is considerably diversificated. In contrary the bioseston provides information about the current situation. Macrozoobenthon has been monitored since 1996, the investigation of periphyton started later - in 1997 and as well as the macrozoobenthon it was studied three times a year. Phytoplankton is included in a great deal in bioseston community, which contains the other organisms from consument and destruent trophic groups. They were sampled and studied regularly each two weeks till 1997 (in Bratislava till 1999), in 1998 and 1999 monthly. 10-years period was evaluated in this contribution from the determinants of saprobity and biological oxygen demand point of view by linear regression. The mentioned trend analyses and time series (Figs. 2a-f) are presented from three selected sampling sites - Bratislava, the input profile of Slovak section, Medveďov - station influenced by Gabčíkovo Power Plant and Szob - output from the Slovak section, influenced by the three slovak tributaries - Váh, Hron and Ipeľ rivers.

Fig. 2a-f 10-years trend analyses and time series of biological oxygen demand and bioseston saprobic index in sampling sites of the Dunube river

Fig. 2a

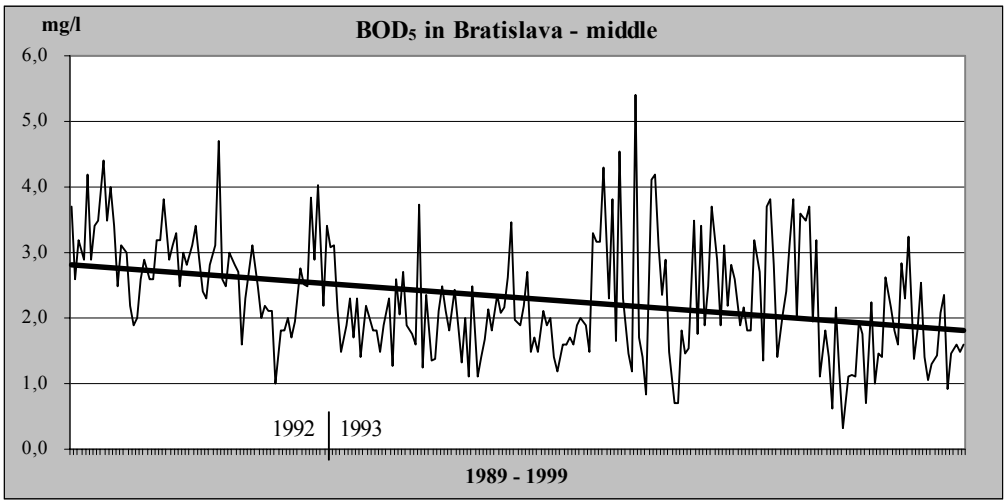


Fig. 2b

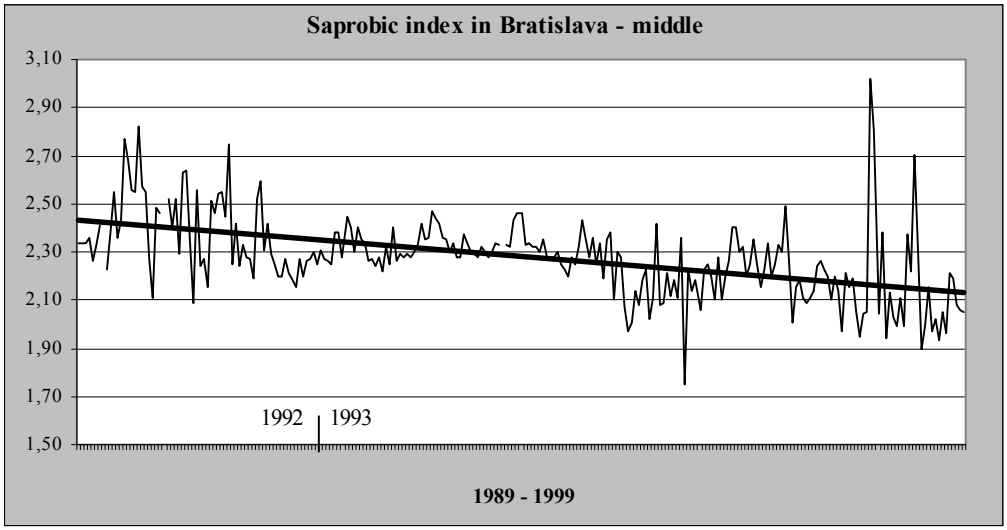


Fig. 2c

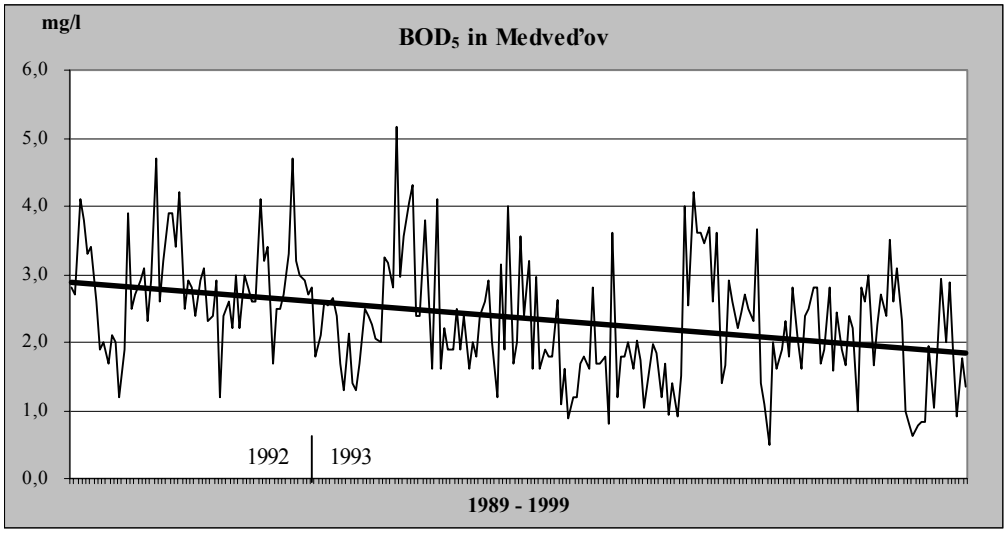


Fig. 2d

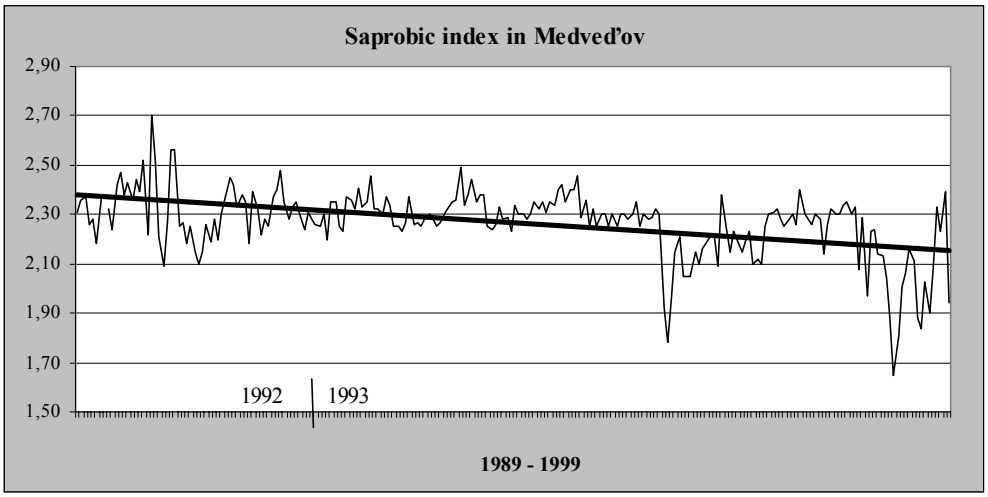


Fig. 2e

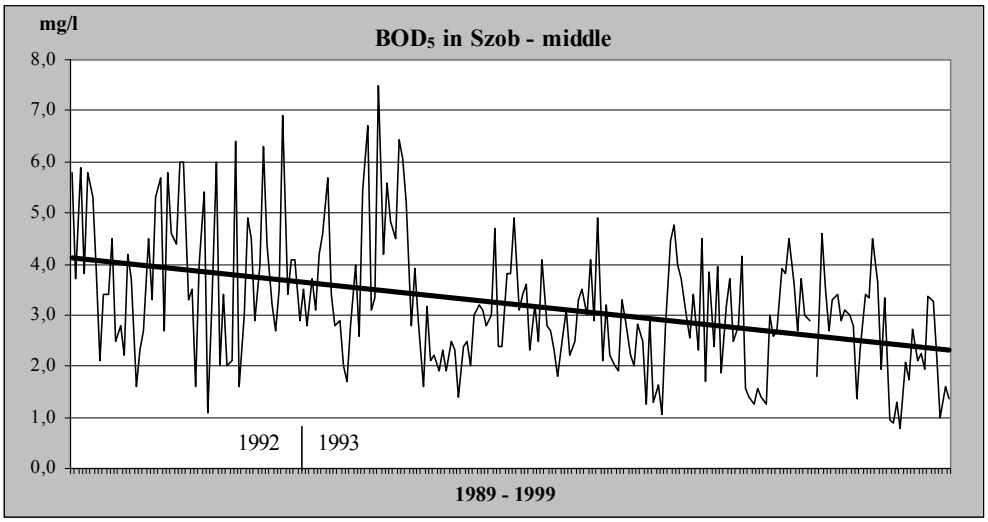
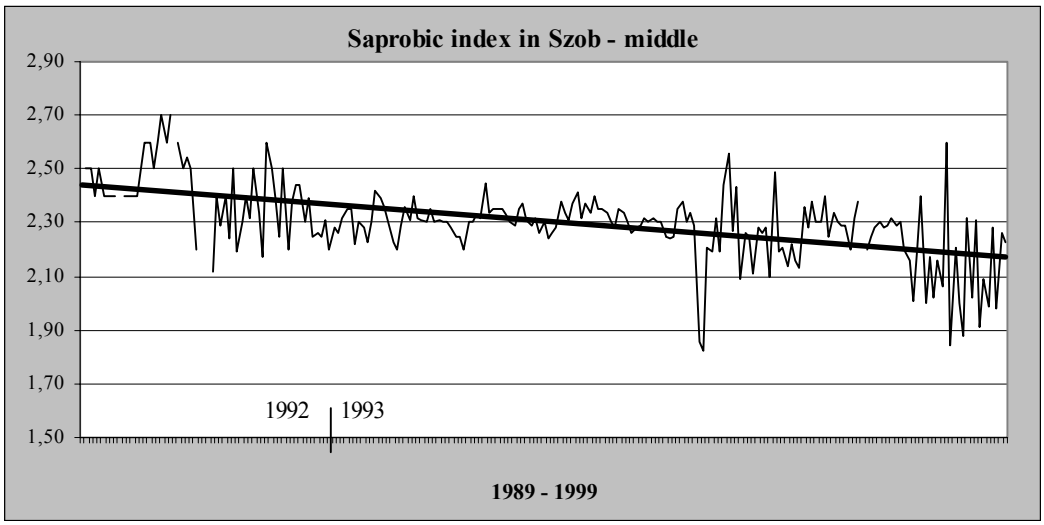


Fig. 2f



The measured data of BOD_5 and calculated data of bioseston saprobic indices are divided into two periods: 1989 - 1992, which respond to the period of the Danube damming and 1993 - 1999 after the damming. The trend line shows the slight gradual decreasing tendency in both determinants. However, according to the statistical calculation of two data sets from mentioned periods, this decline is not significant from the statistical point of view. The exception was examined only in the Szob BOD_5 mean value decrease, which went down approximately from 4 mg/l to almost 2 mg/l. In Szob sampling site the obtained saprobic indices values had a small deviations during our investigation period.

Macrozoobenthon and periphyton were sampled three times a year. Mean annual values of all studied communities were compared in the Danube longitudinal profile (Figs. 3a-c). Additionaly the determinants - dissolved oxygen and BOD_5 were evaluated as well.

Fig. 3a-c Mean annual values of selected water communities and oxygen determinants

Fig. 3a

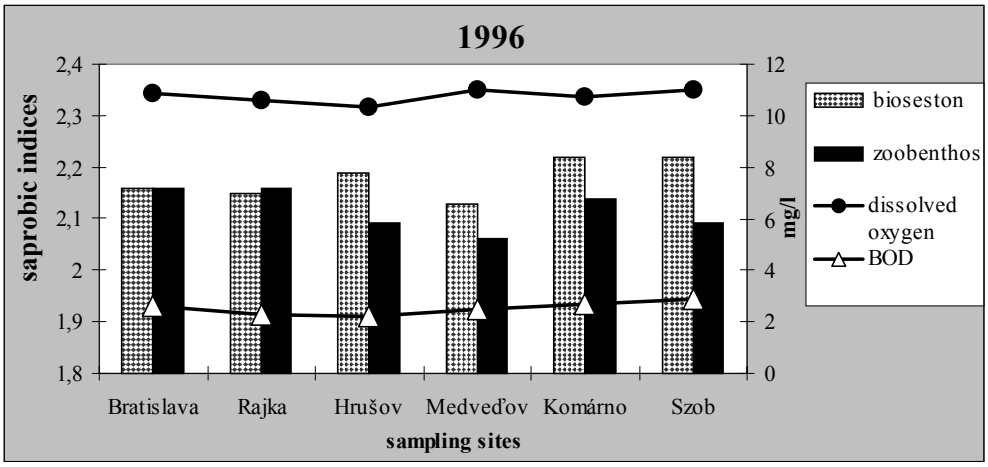


Fig. 3b

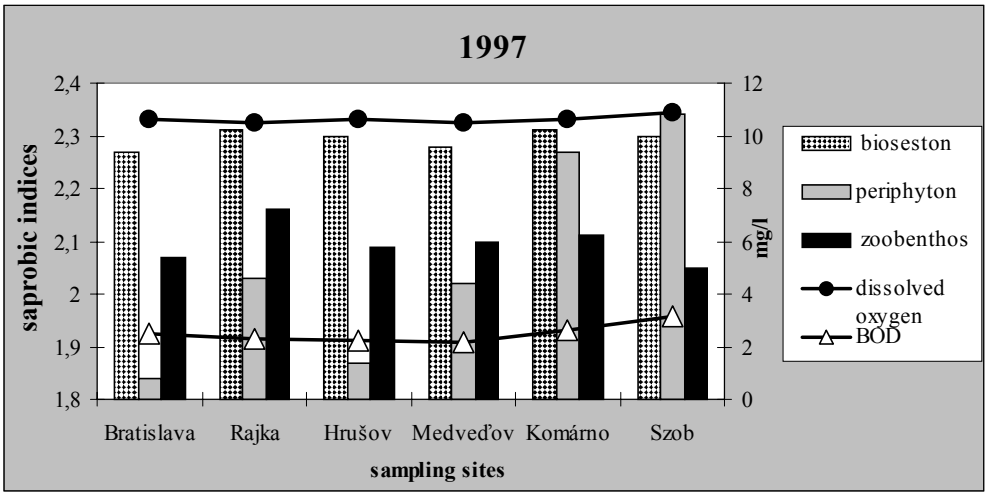
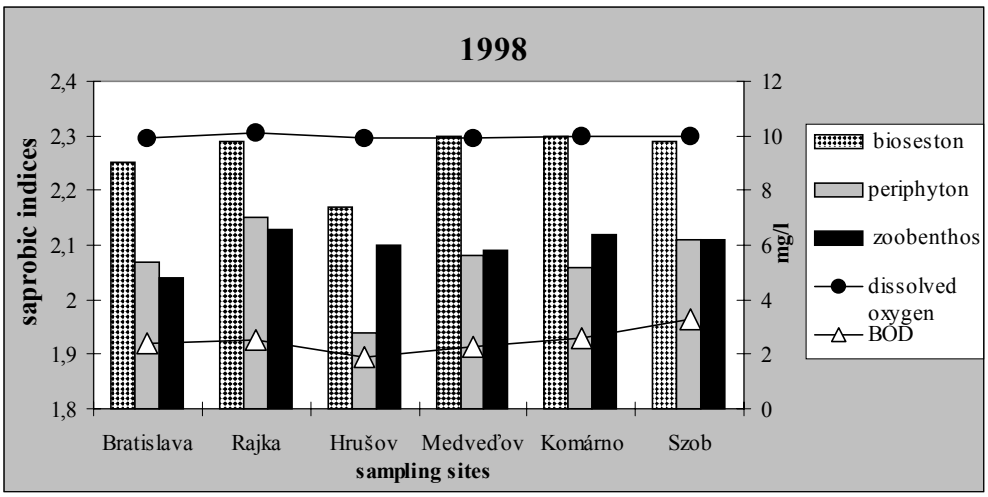


Fig. 3c



The mean values of oxygen determinants as well as the bioseston saprobic indices are based on two-weekly in 1996 and 1997 (in Bratislava also in 1998), and in 1998 on monthly sampling frequency. Generally the bioseston saprobic indices were higher than the fyto- or zoobenthon saprobic indices. Although in 1997 and 1998 they reached the higher values than in 1996 (even above 2,3), the total saprobity does not exceed beta-mesosaprobic limit. When consider the long-term status based on the benthic groups, slight increase of saprobic indices can be seen in the last two stations - Komárno and Szob, compared to Bratislava. The same effect is noticeable in BOD_5. These results correspond to organic matter content increase, related to gradual eutrophication in longitudinal profile of the Danube river.

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Dyanamics of the Hydrochemical Parameters of the Water Quality for the Rivers of the Tisa and Prut Basins

Hanna Gerasimenko, Viacheslav Manukalo, Olexander Kosovets, Lubov Zagoruiko

Abstract: The paper presents the data on long-term trends in the series of the hydrochemical parameters values for the main Ukrainian tributaries of the Danube - the Tissa and Prut rivers - for the period 1984 - 1997. The data of observation, used in the research, were granted by the network of the water quantity and quality monitoring which belongs to the Committee of Ukraine for Hydrometeorology. The study of long-term dynamics of the water quality have been carried out by 7 observation stations in the Tisa basin and 1 stations in the Prut basin. The water quality for the rivers has been estimated by combining such hydrochemical indicators as a mineral composition, biochemical oxygen demand, contents of nitrates, nitrites, oil products and toxic components (cooper, zinc, chromium). A comparison has been also made between the trends of the dynamics before and since 1990. The decline in industrial and agricultural activities in Ukraine since 1990 has not fawored the water quality improvement in the rivers. But some decrease of an intensity of the pollution have been observed.

Key words: rivers, hydrochemical parameters, dynamics of parameters, estimated water quality

Änderungeu von hydrochemischen Wassergüteparametern in den Flüssen der Theiss und Prut - Becken

Zusammenfassung: Im vorliegenden Bericht werden Angaben uber die Änderungen der hydrochemischen Parametergröben für Hauptnebenflüsse der Donau in den Grenzen der Ukraine (die Theib und der Prut) in den kren 1984 - 1997 dargelegt. Zugrunde der Untersuchungen wurden Beobachtungsangaben gelegt, die aus dem Monitoringnetz der qualitativen und quantitativen Wasserguteparameter eingehen. Dieser Messungsnetz ist dem Komitee der Ukraine für Hydrometeorologie untergeordnet. Die Wassergute wurde nach folgenden hydrochemischen Kennwerte abgeschatzt. Biochemischer Sauerstoffbedarf , Biogenelemente (Nitrate, Nitrite), Toxinkomponenten (Kupter, Zink, Chrom). Trotzdem die Aktivitat der Industrie und Landwirtschaft in der Ukraine nach 1990 heruntergegangen ist, wesentliche Verbesserung der Wassergute in der Theiss und dem Prut geschieht nicht.

Schlüsselworte: Flüsse, hydrochemische Parameter, Parameteranderung, Wasserguteschatzung

1 Introduction

The Tisa and Prut rivers are the largest tributaries of the Danube river within the territory of Ukraine. The length of the Tisa river within Ukraine is 233 km (24 % from the total one), the length of the Prut river is 272 km (28 %). The area of the Tisa basin within Ukraine is 11300 km^2 (7% from the total one), the area of the Prut basin is 8260 km^2 (30% from the total one). Within Ukraine both rivers represent typical mountain flows. They are characterized by frequent reiteration of flash floods of different origin (rain, snow, snow-rain) during all the year.

It is necessary to admit, that the Tisa river, its tributaries Latoritsa, Uz rivers and Prut river do not belong to the Ukrainian rivers, which are under the strong impact of the human activity. Within the basins of both rivers, only several large cities are situated: Uzhgorod (about 125.000 citizens) on the Tisa river, Mukachevo (about 90.000 citizens) on the Latoritsa river and Chernovtsy (about 260.000 citizens) on the Prut river. However, the ecological problems of Ukraine, resulting from irrational water consumption, land and forest resources, as well as from insufficient financing of environment protection measures, affect the quality of water in the Tisa basin rivers and Prut river.

The purpose of this paper is to present the data on long-term trends in the series of hydrochemical parameter values for the Tisa river, its tributaries Latoritsa and Uz, also for the Prut river for the period of 1984-1997.

2 Materials

This paper is based on:

- the data of observation, granted by the network of water quantity and quality monitoring, which belongs to the Committee of Ukraine for Hydrometeorology;
- the data on consumption of water resources and the data on recirculating waters, granted by the Committee of Ukraine for Water Management;
- National report on the environment condition in Ukraine, made by the Ministry for Ecology and Nature Resourses of Ukraine.

The study of long-term dynamics of the water quality have been carried out by seven observation stations on the Tisa basin rivers and and by one observation station on the Prut river (table.1).

Table.1 Characteristics of the river basins

River	Station	Basin area (km^2)	Area of forests (%)	Mean annual flow discharge (m^3/s)
Tisa	Rahiv	1070	68	21.8
Tisa	Vilok	9140	55	207
Tisa	Chop	11300	46	------
Latoritsa	Svaliava	680	61	14.8
Latoritsa	Mukacheve	1360	63	25.6
Latoritsa	Chop	2870	41	35.0
Uz	Uzgorod	1970	57	29.0
Prut	Chernivtsy	6890	42	73.5

3 Results

The water quality for the rivers has been estimated by combining such hydrochemical parameters as: a mineral composition Σ i (the sum of Cl^-, SO_4^-, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+), content of biogenic elements (nitrates, nitrites), oil products and toxic components (Cu, Zn, Cr).

As example of the dynamics of the selected hydrochemical parameters of the water of Tisa river at Chop and Latoritsa river at Mukachevo is presented at the Fig.1 and Fig.2. The figures illustrate the increase in the concentration of the pollutants in the water during late 1980-ies. The peak of the pollution was observed in the end of 1980-ies – in the beginning of 1990-ies. The same situation have been observed on others rivers. An irrational land use within the river basins and an increase of sewage waters from the urbanized areas near such cities as Uzgorod, Mukachevo, Chernivtsy are the main factors, affecting the growth of river water pollution. So far the rate of construction of village waste-water disposal systems has been very low for almost all area of the Tisa and Prut rivers basins.

Later, the economical problems of Ukraine, the stagnation of the industrial and agricultural production had led to the decrease in the water consumption, as well as in the recirculating water discharges. In general, within Ukraine the volumes of the recirculating water discharges into water objects have decreased from 17.026 million m^3 in 1992 to –11.648 million m^3 in 1997. The volume of discharges of pollutants into water objects has decreased from 6.558 million ton in 1992 to 3.267 million ton in 1997. The Zakarpattya administrative-territorial unit (the basin of the Tisa, Latoritsa and Uz rivers) stand out among the other regions by the increase in the recirculating water discharges till 1994, later there has been observed an insignificant decrease (to 5%). This fact give evidence for need in modernization of the water treatment plants.

The general estimation of the water quality of the rivers of Tisa and Prut basins has been carrying out according to the System of ecological classification of the surface water objects which has been adopted in Ukraine. According to this system, surface waters are divided into 5 classes: from I class (very clean) to V class (very contaminated). According to this classification, the Tisa, Latoritsa, Uz and Prut rivers belong to: a) in Σi - to the 1 class; b) in BOD_5 – to the III class (slightly contaminated); c) in the content of nitrates and nitrites – to the III class; d) in the content of oil products – to the IV class (contaminated); e) in the content of the toxic substances (Cu, Zn, Cr) – to the III class.

4.Conclusion

After analysing the water quality of the Tisa, Latoritsa, Uz and Prut rivers in a period between 1984 and 1997, it is obvious that the examined rivers are under the impact of the human activity. The decline in industrial and agricultural activities in Ukraine since 1990 has not fowored the significant water quality improvement in the rivers. The main concern is the presence in the water of oil products and of the toxic substances.

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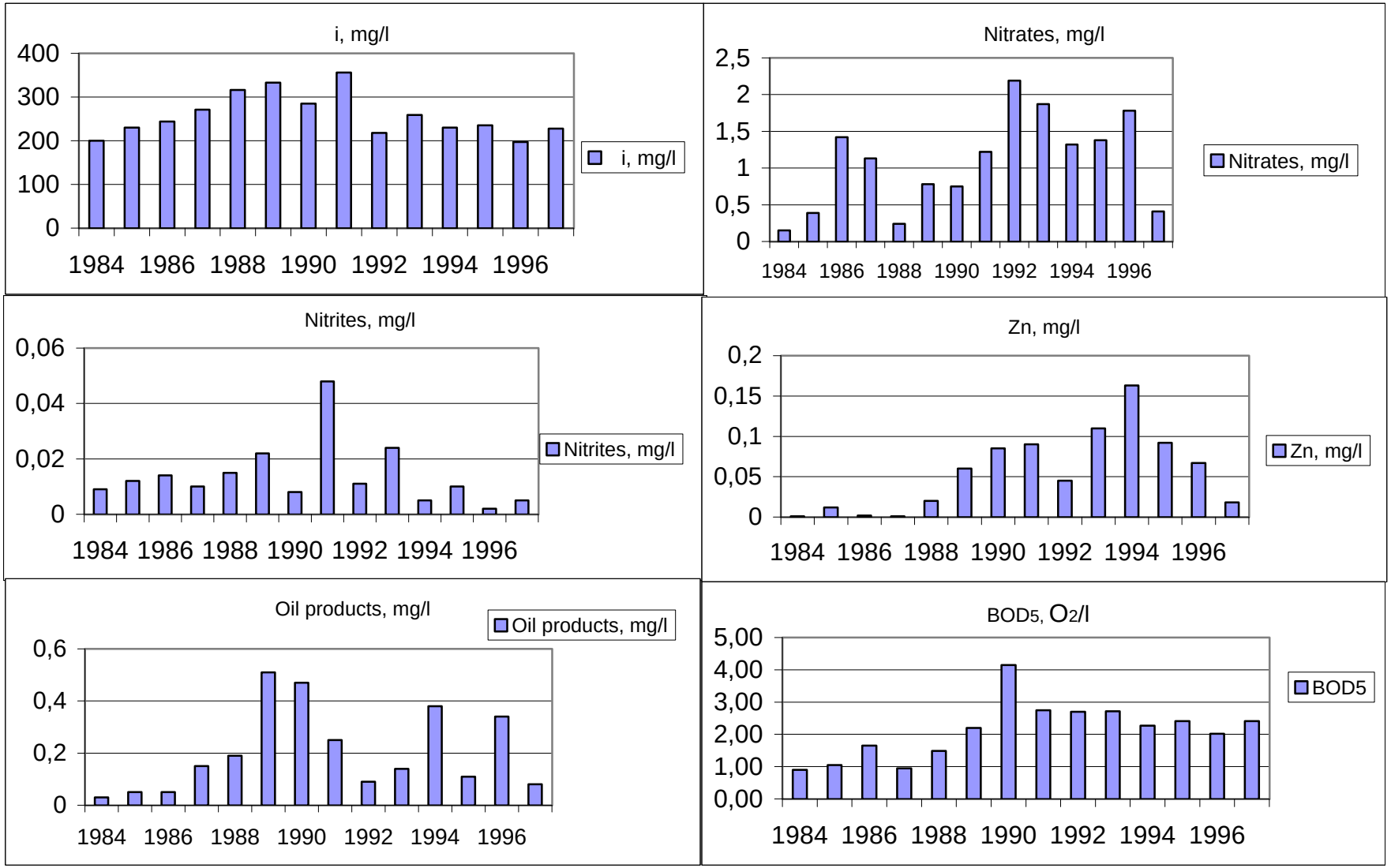

f hydrochemical parameters of the water quality for the Latoritsa river at Chop.

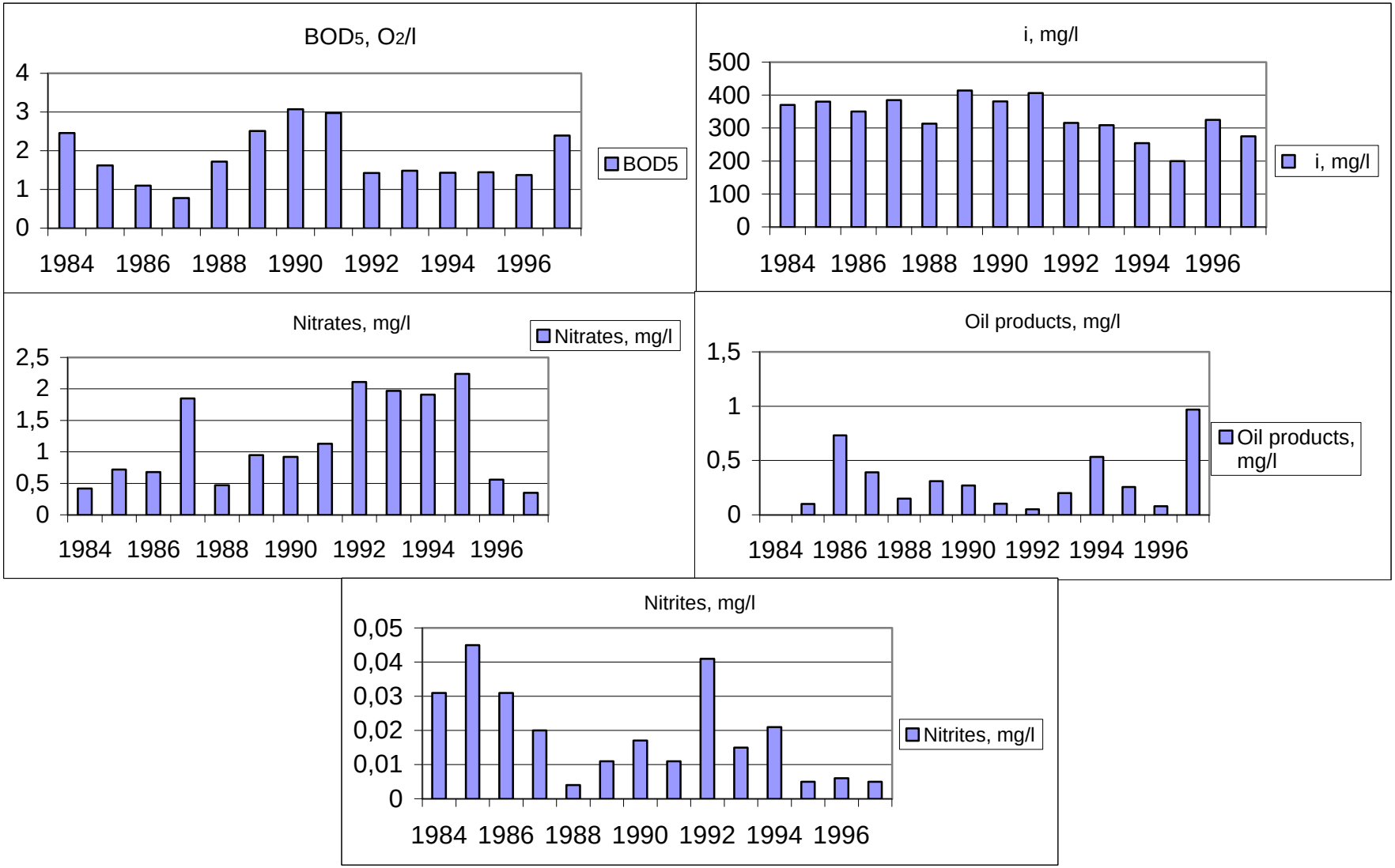

Fig.2. The dynamics of hydrochemical parameters of the water quality for the Tisa river at Chop.

The Danube Water Quality Model and Its Role in the Danube River Basin Pollution Reduction Programme

Jos van Gils, Joachim Bendow

Abstract: The Danube River Basin Pollution Reduction Programme is a project carried out by UNDP/GEF in 1997-1999. It studied among other things the current state of the Danube Basin and a concrete set of proposed measures aimed at reducing the trans-boundary transports of pollution. The work in this project was supported by the Danube Water Quality Model (DWQM). In particular, this model was used to quantify the Danube in-stream loads of N and P in the current conditions, and the effects on these loads of the implementation of the Pollution Reduction Programme. The current paper describes the objectives, the set-up, the validation and the application as well as the limits of the DWQM.

Keywords: Danube, nutrients, water management, modelling, in-stream loads, retention.

Das Donau Wasserqualitäts-Modell und seine Rolle in das Programm zur Verringerung der Wasserverschmutzung der Donau

Zusammenfassung: Das Programm zur Verringerung der Wasserverschmutzung der Donau ist ein Projekt, welches von 1997 bis 1999 mit finanzieller und technischer Hilfe des UNDP/GEF durchgeführt wurde. In diesem Projekt wurde die Situation der Wasserverschmutzung im Donaueinzugsgebiet, ihre Ursachen und ihre Folgen studiert und Maßnahmen vorgeschlagen um grenzübergreifende Gewässerverschmutzung zu reduzieren. Das Donau Wasserqualitäts-Modell (DWQM) wurde hierbei zur Erarbeitung einer Vergleichsanalyse eingesetzt. Das Modell wurde dazu benutzt, Nährstofffrachten in Fliessgewässern sowie die Auswirkungen von Maßnahmen zur Verringerung der Wasserverschmutzung darzustellen. Der vorliegende Bericht beschreibt die Ziele, die Voraussetzungen, die Erstellung, die Modelleichung und die Einsatzmöglichkeiten sowie auch die Grenzen der Anwendbarkeit des Modells.

Schlüsselworte: Donau, Nährstoffe, Wasserwirtschaft, Modellentwicklung, Frachten in Fliessgewässern, Rückhalt.

1 Introduction

The Danube River Protection Convention, created in the framework of the ECE-Convention for the protection of trans-boundary waters (Helsinki Convention 1992), became with its entry into force on 22 October 1998 the overall legal instrument for co-operation and trans-boundary water management in the Danube River Basin. The overall objective of the DRPC is to achieve and maintain the sustainable development and use of water resources in the Danube River Basin. The Contracting Parties are recommended to aim at an intensified regional co-operation, a due balance between ecology and economy, an integrated implementation as well as goal-oriented policies and strategies, executive structures and tools. In order to achieve substantial progress in the protection and sustainable use of the water resources, the following overall strategic goals and targets are defined:

- to maintain and improve the status of water resources as to quality and quantity;
- to prevent, reduce and control water pollution, including accidental pollution, in particular where hazardous substances and nutrients are involved;
- to improve the aquatic ecosystems and biodiversity;
- to contribute to the protection of the Black Sea from land-based pollution.

National and regional policies are based on common principles related to the protection and use of natural resources, in particular on the Precautionary and the Polluter Pays Principles, the best available technology (BAT) and the best environmental practice (BEP). The same applies to the Convention. Most of the Contracting Parties have developed a water management policy as a part of their national policy. Sector policies for reducing point sources of pollution are mostly in place whereas specific policies for reducing diffuse sources of pollution are partly under development; policies regarding wetland rehabilitation are emerging.

The protection of the Black Sea and its ecosystems from land-based pollution constitutes a multifaceted regional framework objective. Its realisation is to a considerable degree depending on the implementation of relevant objectives and policies in the Danube River Basin, in particular regarding eutrophication caused by nutrient discharges. Hence the Commissions responsible for the protection of the Danube River (ICPDR) and the protection of the Black Sea (ICPBS) jointly declare their policies and willingness to co-operate for achieving common strategic goals as specified in a ”Memorandum of Understanding” which shall be adopted in the year 2000. These goals particularly address assessment and urgent control measures regarding nutrients and hazardous substances. A defined ecological status is intended to be maintained and at a long-term scale recovered through ensuring appropriate practices and measures.

In the frame of the Danube Environmental Programme, the UNDP Global Environment Fund and the EU through its Phare and Tacis programs, have since 1992 provided international assistance to develop appropriate mechanisms and planning tools for the implementation of the Danube River Protection Convention. In the particular context of the Pollution Reduction Programme, the causes and the effects of water pollution have been analysed and policy guidelines, strategies, and projects for pollution reduction and water management have been developed. The project considers root causes for ”Inadequate Management of Water Resources”, referring primarily to the middle and lower Danube countries, taking into account problems related to socio-political transition, reforms and general economic recession; war and displacement of population; absence of national strategies for water management and inefficient environmental management, enforcement and compliance.

Concerning the direct causes, important sources of pollution or priority ”hot spots” where identified for the municipal, industrial and agricultural sectors. 51 ”Significant Impact Areas” have been identified in the Danube River Basin, which are in particular affected by industrial pollution, COD and toxic materials as well as by excessive nutrient loads. Special consideration was also given to the nutrient transports to the Black Sea, indicating a total of 551 kilotons of Nitrate and 48,9 kilotons of Phosphorus reaching annually the Black Sea.

Over 400 projects have been developed, responding generally to ”hot spots” or point sources of emission, representing national priorities and taking equally into account the obligation to mitigate trans-boundary effects. Particular attention was given to the identification of sites for wetland restoration, which play an important role not only as natural habitats, but also as nutrient sinks.

The total investment required to respond to the priority projects is estimated to be about 5,66 billion US$, covering the following sectors:

- Municipal waste water collection and treatment plants: 3,57 billion US$
- Industrial waste water treatment: 0,81 billion US$
- Agricultural projects and land use: 0,16 billion US$
- Rehabilitation of wetlands: 1,12 billion US$

The expected results of the Pollution Reduction Programme show a considerable decrease of pollution in terms of COD/BOD, respectively in terms of N and P. The implementation of the proposed priority projects in the municipal, industrial and agricultural sectors will lead to a reduction of about 640,000 tons of COD/BOD and of about 100.000 tons of N and P. The latter has a direct influence on the Black Sea and will contribute to achieve common Danube and Black Sea goals to restore marine ecosystems in the north-western shelf.

The Danube Water Quality Model (DWQM) was developed in the frame of the Danube Pollution Reduction Programme to simulate the actual in-stream nutrient load. Simulations have been conducted to support the Trans-boundary Analysis as well as to support the definition of priority measures of the Pollution Reduction Programme demonstrating nutrient reduction through implementation of the projects and policy measures. Details about the work can be found in the related report (GEF, 1999).

2 Materials and Methods

2.1 System description

The Danube Water Quality Model (DWQM) describes the fate of the nutrients nitrogen (N) and phosphorus (P) in the Danube catchment. These nutrients are discharged in the aquatic environment due to human activities and natural processes. The model contains a schematisation of the Danube river and its main tributaries, derived from (Vituki, 1996) and the National Reviews (GEF, 1998), called ”the network” from now on, see Fig. 1.

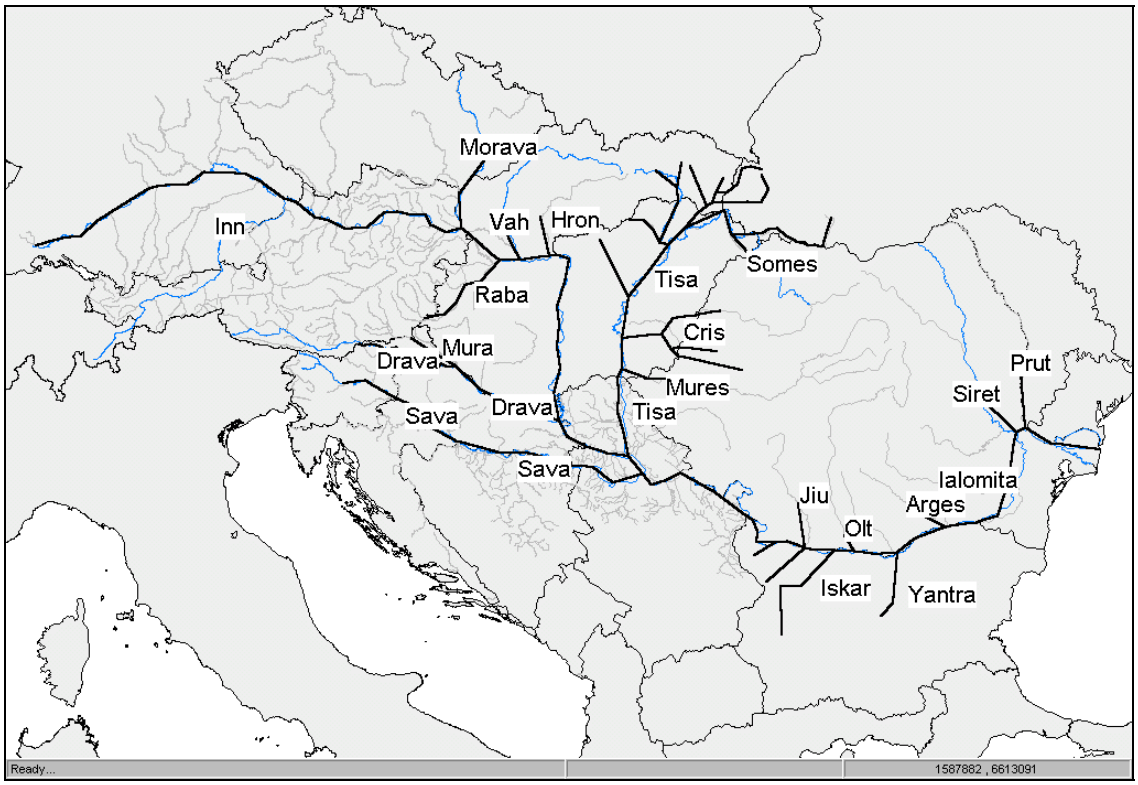

Fig. 1 The river network of the DWQM.

In the remainder of this paper, the word ”catchment” will refer to everything outside the network: land area, small tributaries, ground water, etc. The catchment is simply schematised as its surface area, as a function of the distance along the river.

With the DWQM's objectives in mind, the catchment has been subdivided over the 13 principal Danube countries (see Fig. 2).

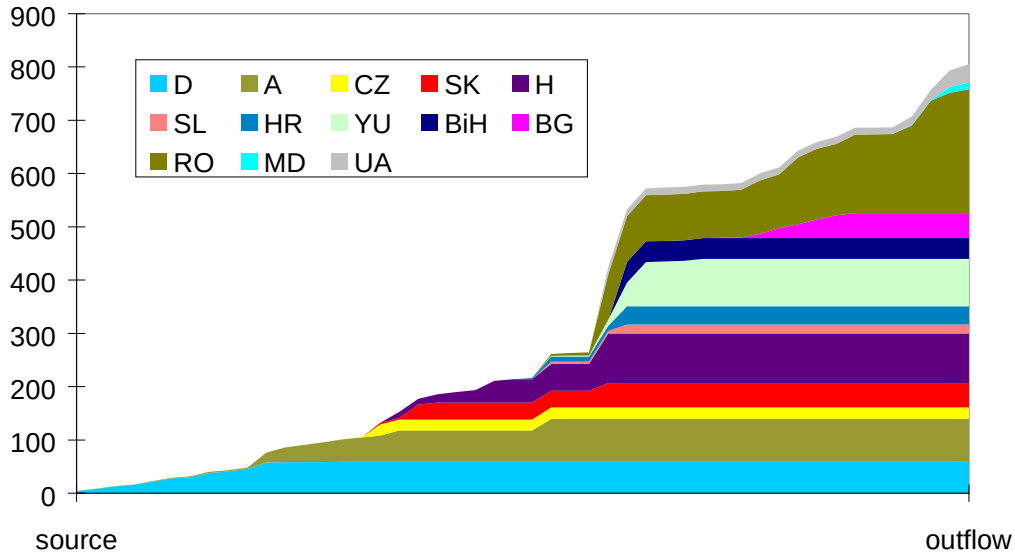

Fig. 2 The catchment profile along the Danube (in 1000 km^2), subdivided over the 13 principal Danube countries.

2.2 Conceptual model

The conceptual model of the DWQM is shown in Fig. 3. The emissions are split into two parts: the emissions directly to the river network and the remaining emissions. The remaining emissions are subject to retention in the catchment[1]. The word retention refers to any process which effectively removes nutrients from the catchment if we look at a period of several years, under the present conditions. Seasonal cycles of uptake and release are therefore not considered retention. Relevant retention processes of nitrogen are: (a) denitrification in the ground water and the surface water, (b) long term accumulation of nitrogen in the ground water. Retention processes of phosphorus include: (c) net storage in the sediments of lakes, flood plains and wetlands. The part of the remaining emissions not retained in the catchment reaches the network as effective emissions to the river.

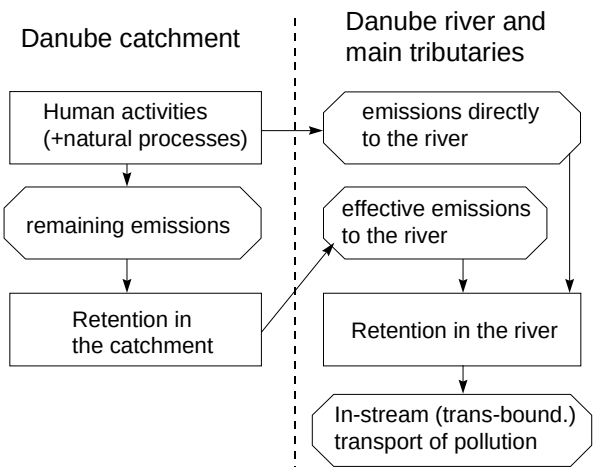

Fig. 3 Systems diagram

All emitted nutrients in the river are subject to retention in the river. The final result is the in-stream transport of nutrients which is equal to the trans-boundary nutrient loads at the borders between the Danube countries.

[1] The subject of retention of nutrients in the aquatic cycles of river catchments has been described in detail by many authors, e.g. Tonderski (1997), de Wit (1999).

2.3 Implementation

The total emissions have been computed for all the Danube countries based on the ”materials accounting method” (University of Vienna ea., 1997). The emissions estimates were originally made for the years 1988/1989 and 1992, but were later updated (University of Vienna, 1999) to 1994-1997 based on data collected in the National Reviews (GEF, 1998), see Fig. 4 and Fig. 5.
Large individual point sources of N and P discharging directly to the river network were identified based on the EMIS inventory (Mehlhorn, 1998) and the National Reviews (GEF, 1998). The remaining emissions (Fig. 3) were computed by subtracting these emissions directly to the river from the total emissions discussed above.

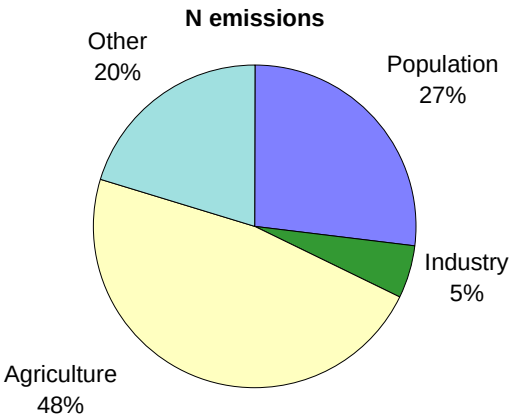

Fig. 4 Subdivision of N emissions.

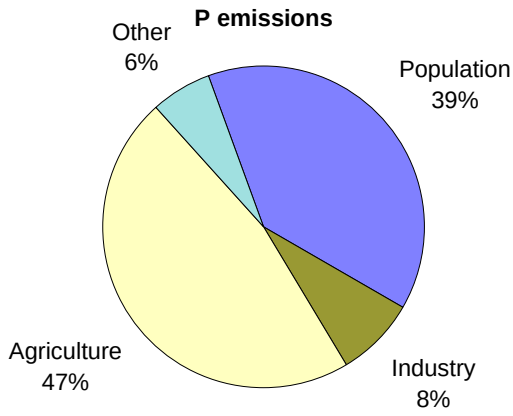

Fig. 5 Subdivision of P emissions.

The retention in the catchment is represented by an empirically derived "immission/emission-ratio". High (95% probability) and low (5% probability) estimates for this factors for N and P, as a function of the area specific run-off, were derived from Behrendt ea. (1999). The values for N range from 5-36% (low runoff) to 59-88% (high runoff), while the values for P range from 5-36% (low) to 72-100% (high).

Based on an analysis of the available data, two processes were identified which are expected to cause a non-negligible retention in the river: the denitrification (N) and the net sedimentation in the backwater area of the Iron Gates dams on the Yugoslavian-Romanian border (P), see Perišic ea. (1990).

The hydrology and the water balance are very relevant because water is the carrier of a large part of the emissions. The hydrology and water balance model was based on the observed river flow data for selected stations in the network. The diffuse inflows between two such stations were divided over the river stretch in between, proportional to the increase of the catchment area. Since the catchment increase along the river has been mapped per country (see Fig. 2), also the diffuse inflow can be divided over the different countries. The model is evaluated for subsequent steady states, with a time interval of 1 month for the period 1994-1997.

The effective emissions to the river (see Fig. 3) are discharged in close connection with the diffuse inflow. The emissions per country were divided in three categories: those with a constant discharge rate (typically point sources), those with a discharge rate proportional to the diffuse inflow (typically ground water inflows) and those with a discharge rate proportional to the square of the diffuse inflow (typically erosion related emissions), see (Jolankai, 1992). The diffuse inflow is known per country as a function of space and time. With the above considerations in mind, the concentration of N and P in the diffuse inflow is computed, again per country and as a function of space and time.

The final step in the computation procedure is the computation of the in-stream loads. This is done by solving the partial differential advection equation, including sources and sinks with the appropriate boundary conditions and initial conditions.

2.4 *Model Calibration/Validation*

The methodology for the calibration and validation was selected with the following main consideration in mind: there are so many uncertainties involved in the DWQM exercise, that it is not a sensible thing to tune certain model parameters to obtain a good fit between model predictions and field data. This would probably result in compensating one big error with another one, and would make the analysis of policy measures less reliable.

In stead, we tried to work with state-of-the-art knowledge and data, to quantify the largest uncertainties and to see if an agreement exists between model predictions and field data, taking into account these uncertainties. In particular, we used the following quantified uncertainties: (i) high and low estimates of the point sources part of emissions, (ii) 80% and 120% of best estimates of the diffuse part of the emissions, and (iii) 5% and 95% probability values of the immission/emission ratio representing the retention in the catchment.

Observed concentrations and in-stream loads were used to validate the DWQM. The in-stream loads are of course not really ”observed” but they are computed from observed concentrations and river discharges. The method proposed by Buys ea. (1998) for use in the Danube basin was adopted. In relation to the observed concentrations we had to accept the fact that the basin-wide uniformity of sampling, analysis and quality control procedures can never be perfect. Apart from that, the observed concentrations needed to be corrected before the validation exercise could be carried out. Total nitrogen concentrations could on many occasions only be obtained by estimating the organic nitrogen concentration. Total phosphorus concentrations were found not to be representative for the river load. Two systematic errors were defined: an underestimation because of the low sampling frequency (Zessner ea., 1998) and an underestimation because of the use of surface samples only. Both problems have not yet been investigated thoroughly on a basin-wide scale. We used an approximate correction factor of 2 for both problems together.

2.5 *Validation results*

Typical validation results for the concentrations of N and P are shown in Fig. 6 and Fig. 7.

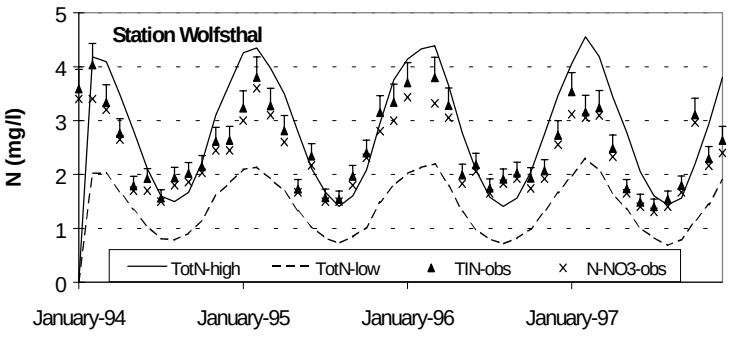

Fig. 6 Validation results: nitrogen at Wolfsthal (km 1874).

Fig. 6 shows the results for nitrogen at Wolfsthal (km. 1874). The solid and dotted lines represent the higher and lower computed concentrations. The triangles represent the measured concentrations of total inorganic nitrogen, with the error bars representing the estimated organic nitrogen concentration.

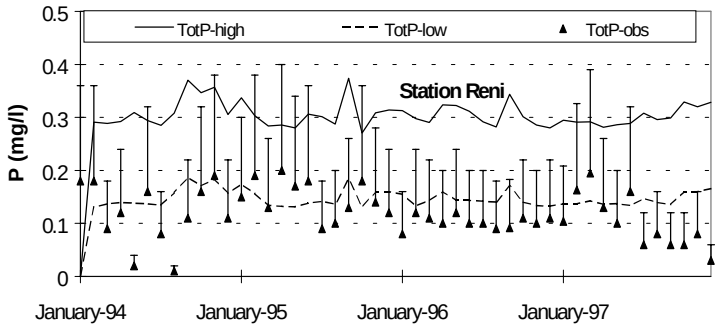

Fig. 7 Validation results: phosphorus at Reni (km 132).

Fig. 7 shows the results for phosphorus at Reni (km. 132). This time the error bars on the observed values represent the correction factor of 2 discussed above. Both graphs demonstrate the fact that the observed and the predicted values match well, taking into account the large uncertainties.

Typical validation results for the in-stream loads of N and P are shown in Fig. 8 and Fig. 9.

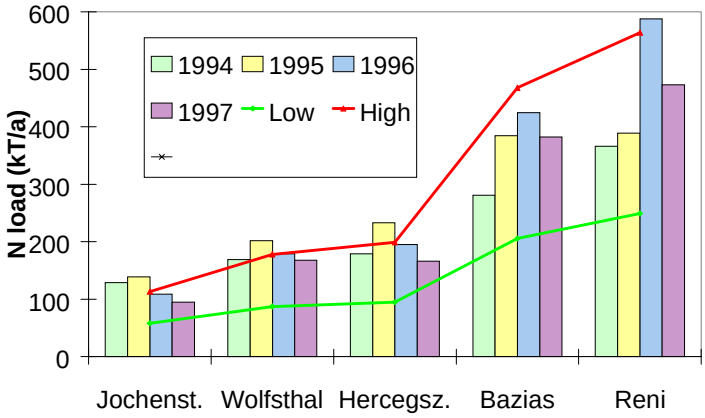

Fig. 8 Validation results for the in-stream loads of nitrogen.

Fig. 8 shows the results for nitrogen at various stations along the Danube. The solid lines represent the higher and lower computed values. The bars represent the values computed from measured concentrations and discharges for the years 1994-1997.

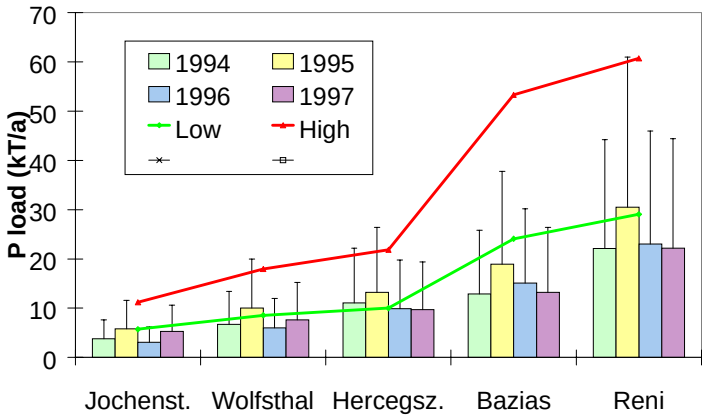

Fig. 9 Validation results for the in-stream loads of phosphorus.

Fig. 9 shows the results for phosphorus. This time the error bars on the observed values represent the correction factor of 2 discussed above.

Both graphs demonstrate the fact that the observed and the predicted values match well, taking into account the large uncertainties.

3 Results

3.1 The Trans-boundary Analysis

The Danube Water Quality model has been used to support the Trans-Boundary Analysis (TBA). To this end, a computation was carried out for a situation somewhere between the high and low estimates described in paragraph 2.4. The precise definition of the computation was made by matching the in-stream loads upstream of the Danube Delta with the best available load data derived from observed nutrient concentrations and water discharges.

The overall computation presented before was split into 13 different computations: each one of them with the emissions from one individual country. The results of the 13 computations per country were superimposed to obtain the overall result. Because all equations in the DWQM were strictly linear, this was a mathematically valid procedure.

The results are presented in Fig. 10 and Fig. 11. Both figures present the nutrient loads (vertical axis) as a function of the distance along the river (horizontal axis).

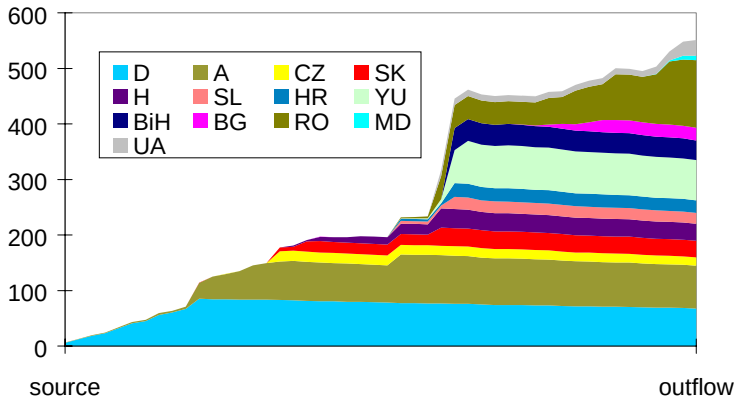

Fig. 10 In-stream loads of Nitrogen.

Fig. 10 shows the gradual increase of the in-stream nitrogen load from the source of the Danube up to the middle Danube area, where it increases very rapidly, due to the inflows of the Drava, Tisa and Sava tributaries. The gradual increase continues up to the outflow. The country contributions show a gradual or jump-wise build-up, similar to the build-up of their catchment contributions (see Fig. 2). Downstream, the country nitrogen load contributions decrease gradually. This is the result of the in-stream denitrification.

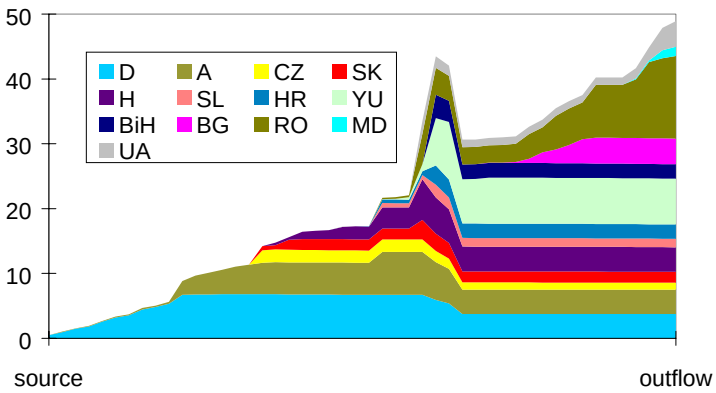

Fig. 11 In-stream loads of Phosphorus.

Fig. 11 shows a similar picture for phosphorus. In this case however, the in-stream removal is not distributed over the whole river as with nitrogen. Phosphorus is only removed from the river in the Iron Gates lakes area, downstream of the inflows of the Drava, Tisa and Sava tributaries. Therefore, the in-stream load sharply decreases just downstream of the strong increase at the locations of these tributaries.

3.2

The Pollution Reduction Programme

Taking into account the implementation of all projects and pollution reduction measures in the Danube River Basin countries, the expected pollution reduction in terms of N and P is presented per Country and Sector in Fig. 12 and summarised per Sector in Fig. 13.

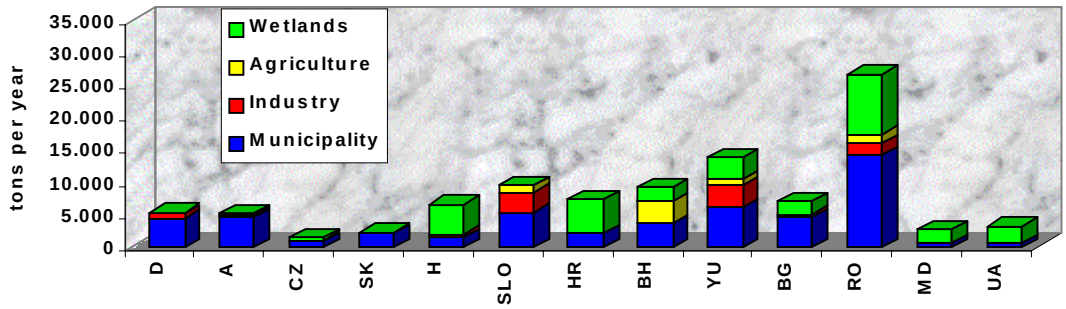

Fig. 12 Expected pollution reduction of N and P from proposed and ongoing national projects per country and per sector.

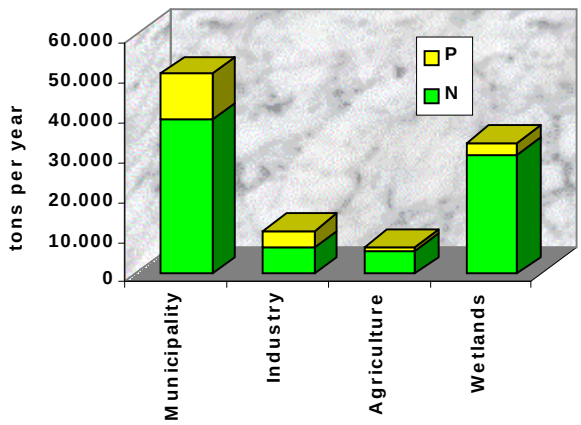

Fig. 13 Expected pollution reduction of N and P from proposed and ongoing national projects, summarised per sector.

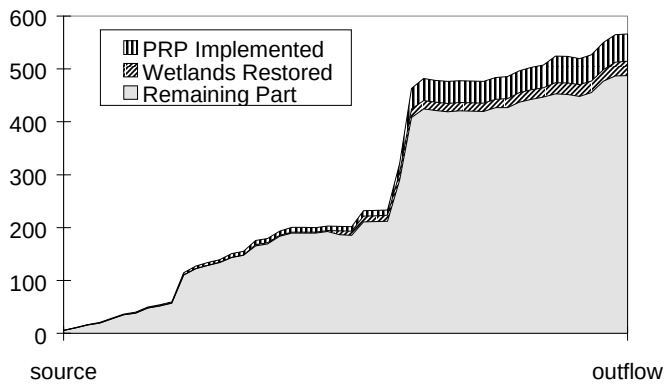

Fig. 14 In-stream nitrogen load profile for the Danube river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands.

The presentation shows the particular importance of N and P reduction through municipal waste water treatment facilities and through the restoration or rehabilitation of wetlands functioning as nutrient sinks. Concerning the relatively low reduction from the agricultural sector, it should be noted, that agricultural projects refer mainly to point sources of pollution (animal farms). The largest share of the nutrient pollution from agriculture however, are the diffuse emissions caused by fertiliser application, which have to be reduced through a change of agricultural practices and new policy instruments.

The positive impacts on the Black Sea are indicated in the results of the simulation within the Water Quality Model concerning the load reduction of phosphorus and nitrogen (see Fig. 14 and Fig. 15).

All together the load reduction of the nutrients to the Black sea is expected to reach the amount of 81,272 t/y for nitrogen and 20,371 t/y for phosphorus after the implementation of the proposed projects for municipal, industrial, agricultural waste water treatment plants and wetland restoration.

The highest concentration of hot spots is in the middle but also in the lower part of the Danube River Basin. As the DWQM results show, that P reduction in respect to the Black Sea might be more effective closer to the Black Sea, whereas N reduction does not appear to be so distance related, emphasis should be given to projects in the middle and lower Danube to reduce loads to the Black Sea. These considerations should be balanced with the responsibility of all countries who contribute nutrients to the Danube to take action (Polluter Pays Principle).

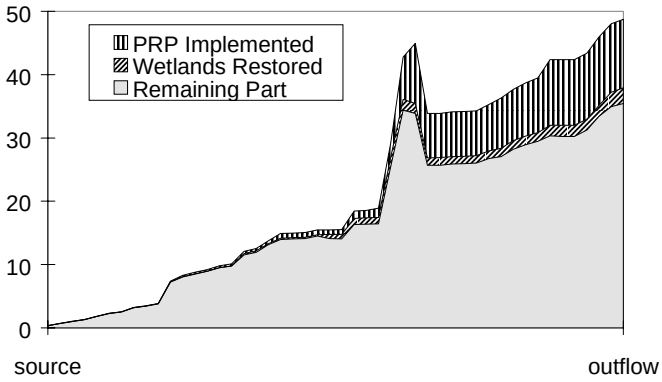

Fig. 15 In-stream phosphorus load profile for the Danube river, before and after implementation of the PRP, with the additional effect of the restoration of 17 wetlands.

Upstream countries have fewer hot spots, but they still remain significant suppliers of nutrient loads to the Black Sea. These countries should consider identifying and implementing wetlands rehabilitation projects as part of their own nutrient reduction strategies. Nutrient reduction for diffuse sources of pollution in the upstream countries Germany and Austria can merely by achieved through agricultural policy reforms and change of agricultural practices.

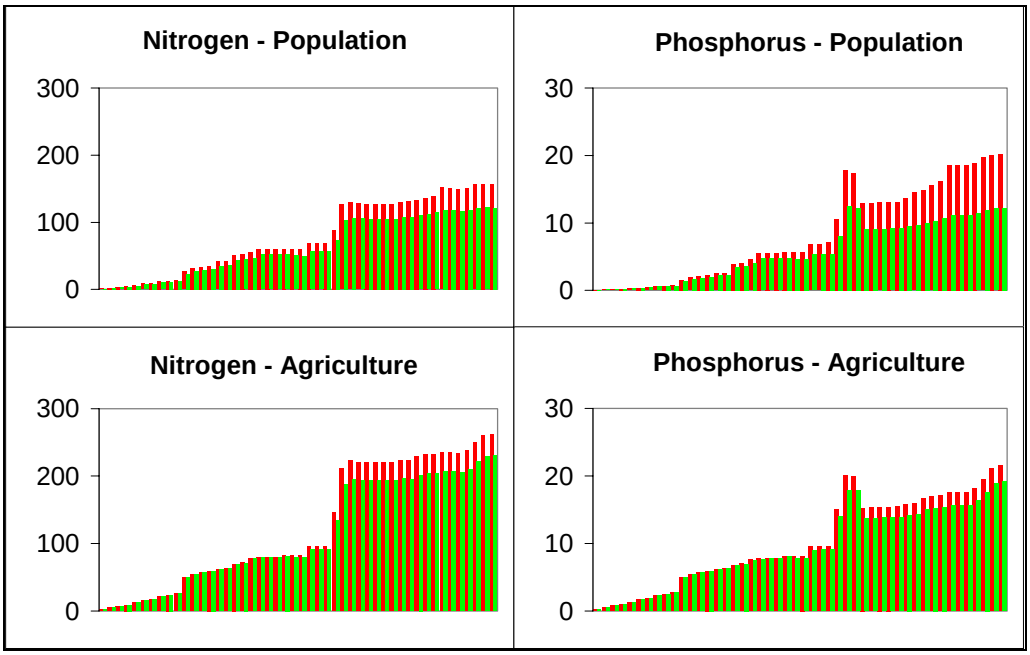

Fig. 16 Sectoral analysis of the effects of the PRP on the Danube in-stream nutrient loads: comparison of in-stream loads before (dark) and after implementation (light).

The analysis of the effects of emission reductions per sector (see Fig. 16) shows clearly the importance of actions to be undertaken in the central and downstream countries of the Danube River Basin. Projects developed for the urban sector (population) are leading to a considerable decrease of nutrient emissions in particular phosphorus, which reflects the result of important

investments in this sector. The industrial sector seems, in terms of nutrient emissions insignificant, but could have a devastating effect if old industries with outdated technologies would be put back to operation. The agricultural sector accounts for the highest contribution of the nutrient load and proposed measures are in fact too insignificant to produce a real remarkable effects. In the downstream countries the reduction of nutrients is merely due to the rehabilitation of wetlands then to the reduction of use of fertilisers and pesticides. Highest attention has therefore to be given to agricultural policy reforms and changes of agricultural practices.

4 Conclusions and Recommendations

The DWQM has provided a quantitative synthesis of all available knowledge regarding the fate of nutrients in the Danube basin. Even though many knowledge gaps exist, our understanding of the system has increased and a common basis was established for the evaluation of the current status of the basin and the assessment of the effects of the pollution reduction from point sources of emissions and of in-stream reduction of nutrient loads through the restoration of the wetlands. As such, the DWQM provided a vehicle to carry the discussion one step beyond just complaining about how much we do not know yet.

Important spin-off of the current exercise is a clear insight in the existing knowledge gaps, which can be summarised as follows:

- insufficient knowledge on a basin-wide scale of the in-stream transports of nutrients: in particular: (*) the organic part of nitrogen, and (*) the particulate part of phosphorus;
- insufficient knowledge on a basin-wide scale of the current emission levels, against the background of (*) the rapidly changing economical conditions in major parts of the basin, and (*) the residence time of the aquifers;
- insufficient knowledge on a basin-wide scale of the retention in the catchment: which physical and hydrological conditions affect this retention most?;
- insufficient knowledge on a basin-wide scale of the retention in the river: (*) the relevance of net sedimentation of phosphorus in other reaches than the Iron Gates, and (*) the relevance of denitrification in the river and the role of the organic carbon cycle in this respect.

Most of the identified gaps have been addressed in the DANUBS research proposal, which has been submitted to the EU for financial support. In this programme, 13 research institutes from different Danubian countries as well as from Greece and from the Netherlands participate. The programme is oriented towards the management of the nutrients balance in the biosphere. It not only deals with the Danube on itself, but also takes into account the effects of the Danube plume on the North-western Shelf of the Black Sea.

With its further development, the Danube Water Quality Model will become a valuable tool to monitor the effects of measures and actions applied by the various countries to reduce the nutrient loads to the Danube River and to control effectively the compliance with the EU Nitrate Directive. Thus, it can contribute to a controlled development which will allow the Black Sea ecosystems to recover and the economic conditions to improve through a sustainable management of resources.

5 Acknowledgements

The authors wish to express their gratitude towards the members of a Technical Working Group, which made an indispensable contribution to the results presented in the current paper. This group consisted of Helmut Fleckseder (ICPDR), Don Graybill (UNDP/GEF), Geza Jolankai, Helmut Kroiss, Bernd Mehlhorn (ICPDR, EMIS), Steffen Mueller, Ilya Natchkov (EU), Liviu Popescu (ICPDR, MLIM) and Matthias Zessner. Furthermore, the work presented would have been impossible without the data and expertise collected by the Danube countries under the guidance of the MLIM and EMIS Expert Groups of the ICPDR.

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Modelling of Suspended-Load Concentrations Related to Water Discharge in the Main Rivers of the Czech Republic

Radvan Hájek, Jarmila Halířová, Taťana Petrůjová, Miroslav Rudiš

Abstract: Three models representing the relation between suspended-load concentration or suspended-load discharge and water discharge as applicable to the main river basins of the Czech Republic are presented. These relationships are discussed in detail on the example of the Morava river (a tributary of Danube). The results of the comparison of the monitored suspended load transport and the transport computed from the models are evaluated.

Key words: water discharge, suspended load, suspended-load concentration, suspended-load discharge, suspended-load transport, modelling of transport

Modellierung der Beziehung zwischen der Schwebstoffkonzentration und dem Abfluß in den Hauptflüssen der Tschechischen Republik

Zusammenfassung: Drei Modellbeziehungen zwischen der Schwebstoffkonzentration und dem Abfluß ausgearbeitete für tschechischen Hauptflüsse sind vorgelegt. Die Beziehungen für Morava (March), der im Gewässer Donau liegt, werden ausführlich besprochen. Diese Resultate der modelliertenn jährlichen Schwebstofftransporte werden mit aktuelen Transporten, berechneten auf Grund der täglichen Beobachtungen, verglichen.

Schlüsselwörter: Wasserabfluß, Schwebstoffe, Schwebstoffkonzentration, Schwebstoff-transport, Schwebstofffracht, Modellierung der Schwebstofffracht

1 Introduction

The modelling of the relationship between the water discharge (Q) and the concentration of suspended load (c) has been investigated since the start of the planning of the Gabčíkovo-Nagymaros project. In this context, many measurements of suspended -load concentrations have been made on samples taken from the Danube. The problem of finding a suitable relationship has proven to be a very complicated one, and was solved by a method of two-dimensional mathematical statistics (Rudiš, M., Machek, J.,1963). After a twenty year break in this research, it has become obvious that it is necessary to evaluate the yearly transport of suspended load from the main river basins, and from the teritory of the Czech Republic at all. That was one of the reasons why the Czech Hydrometeorological Institute (CHMI) in 1984 started daily monitoring of suspended-load concentrations on the main watercourses of the Czech Republic, as well as on some of their tributaries.

Data from CHMI monitoring stations have been used for computations that have been carried out during this work, with the length of record for each station quoted in Tab. 1 (the monitoring of suspended-load concentrations within the CHMI network is going on). Using these data, the annual transports of suspended load have been evaluated on the Labe river (Petrůjová,T.,Kožnárek,Z., Vašátko,J.,Černá,L., 1993), (Rudiš, M.,1993) and (Rudiš, M., Trejtnar,K.,1997) and on the Morava river (Petrůjová, T., Dostál, I., Dydowiczová, D., 1993).

Futher on, the relationship between the suspeded-load concentration and water discharge was the subject of research on 11 monitoring stations (see Tab. 1), within the framework of a research grant from the Czech Ministry of Environment (Petrůjová, T., Rudiš, M., Halířová, J.,1998). Here, the problem of defining the relationship between the concentrations of pollutants and the concentrations of suspended load was considered, too, with work starting in this area. This problem is now being solved in the context of the „Complex Monitoring of Water Quality in Watercourses According to EU Directives“ programme, which has been undertaken by the CHMI within its monitoring station network.
This work is presenting the results of the application of three predictive models, described in the literature (Rudiš, M., Petrůjová, T., Hájek, R.,1999) in monitoring stations on the Morava river (which is a tributary to the Danube).

Table 1 Overview of the profiles with daily measurement of suspended load

gauging station	river	monitoring period
Němčice	Labe	1985 - 1997
Brandýs n.Labem	Labe	1985 - 1997
Mělník	Labe	1985 - 1996
Děčín	Labe	1985 - 1997
Vraňany	Vltava	1985 - 1997
Olomouc	**Morava**	**1985 - 1997**
Kroměříž	**Morava**	**1985 - 1997**
Uherské Hradiště	**Morava**	**1989 - 1997**
Strážnice	**Morava**	**1989 - 1997**
Ostrava - Svinov	Odra	1985 - 1997
Bohumín	Odra	1993 - 1997

2 Regression Relationship Between Water Discharge and Suspended Load Concentration

During the evaluation of the daily concentrations of suspended load and their changes in relation to water discharges (Rudiš, M., Machek, J., 1963), an extreme variability of the items evaluated was found, which did not make possible to use one-dimensional regression to describe the searched-for relationship. The values of water discharges were therefore divided into non-uniform class intervals, and further, suspended load concentration sub-sets were created, these having shown to follow the log-normal distribution. The mean values of these distributions were governed by the logarithmic regression:

$$\ln (c) = X + Y \cdot \ln (Q + Z) \qquad (1)$$

where X, Y and Z are constants.
During further elaboration of this topic, with new monitoring data (see Tab. 1, and also Petrůjová, T., Rudiš, M., Halířová J., 1998, and Rudiš, M., Petrůjová, T., Hájek, R., 1999), it became obvious that the above logarithmic model is not entirely suitable, especially in cases of extreme values of water discharges. We have therefore used two new methods of creating data subsets, ensuring that the evaluated sets were obtained as

the mean values of the suspended-load concentrations or the suspended-load discharges, in relation to the newly-determined water-discharge class intervals:

type „A“ - from 10 to 12 non-uniform class intervals of m-daily and N-yearly water discharges, valid for the period of 1930 - 1980 ;

type „B“ - in 50 non-uniform class intervals, determined from ordered values of water discharges for the period of 1985 - 1997 (i.e. including the July 1997 floods) in such a way, that each class interval contained approximately the same number of suspended-load concentration data items.

These methods of arrangement of the basic data sets were used for both the suspended-load concentration data and the suspended-load discharge (Q_{pl})data.

For sets adjusted in this way, we have already obtained the above usable regression relationship between the suspended-load concentration and the water discharge - see equation (1) (see also Fig. 1 and 2), and also a regression relationship, which expresses the suspended-load discharge as a function of water discharge, of a type

$$\ln Q_{pl} = B \,.\, \ln (Q/Q_o) \qquad (2)$$

where „B“ is a dimensionless factor and „Q_o“ a characteristic discharge, related to the area of the considered watershed (Rudiš, M., Petrůjová, T., Hájek, R., 1999). Regressions elaborated in this way can be seen in Fig. 3 and 4. Both figures show a better regression fit with the use of the above type „A“ method, which considers a longer period of discharge monitoring.

In some cases however, during extremely low and extremely high water discharges, significant deviations of the theoretical values from the experimental ones became evident. Therefore we have proposed a purely empirical model which is a relationship on the basis of a hyperbolical tangent better expressesing the concentration deviations during extreme water discharges:

$$\ln (c/c_o) = K\, ((Q/Q_o)^{\beta} - 1) \,/\, ((Q/Q_o)^{\beta} + 1) \qquad (3)$$

where c_o, K, Q_o and β are constants. Of these, c_o and Q_o are co-ordinates of the inflexion point of the fitting curve.

In case that we have at our disposal only a limited number of data for extreme water discharges, the computation of the constants is inaccurate. For this reason it was not possible to use this model in the cases of the Olomouc, Uherské Hradiště and Strážnice monitoring stations (short monitoring periods). The model was successfully verified in the Kroměříž monitoring station (see Fig. 5). Comparing Fig. 1 and 5, it is obvious that the regression curve in the latter case has a better fit during high water discharges. That is why, for high discharges, the annual transport estimates may be more accurate. The spread of data during low water discharges has little influence on the calculation of the total amount of the suspended-load transport.

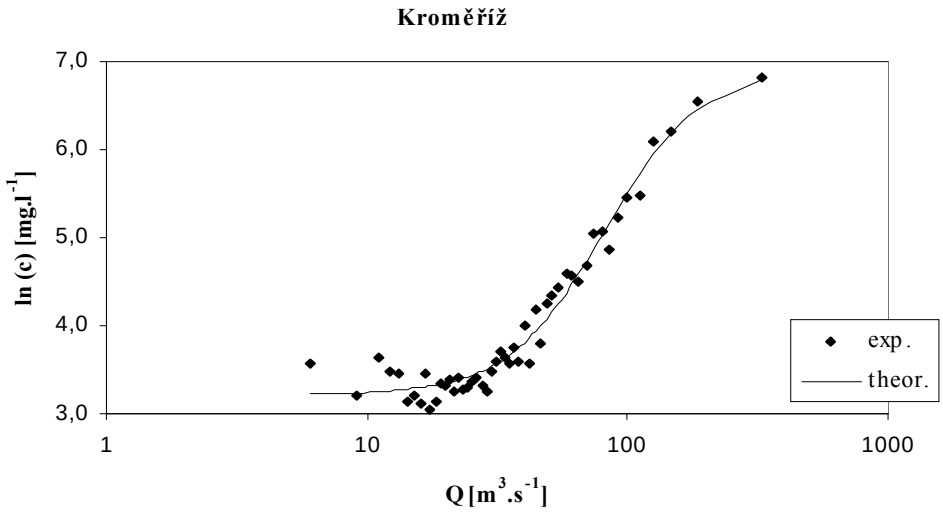

Fig. 5 Application of empirical model represented by hyperbolic tangent-set of experimental points type B, Q - water discharge [$m^3.s^{-1}$], c - concentration of suspended load [$mg.l^{-1}$]

3 Conclusion

We have used the discussed models for the theoretical computation of the yearly suspended-load transports, which we then compared with the transports evaluated from the daily monitoring of suspended-load concentrations and water discharges. We have found that, invariably, the lowest values of suspended-load transports (for a set of suspended-load discharges of a type „B“) are computed from the regression Eq. (2). On the other hand, the highest values of transports are given by this for a set of suspended-load discharges of a type „A“, and by the logarithmic regression Eq. (1) for a set of suspended-load concentrations of a type „B“. Model computations of transports in the Kroměříž monitoring station are the ones that are closest to the real monitored values. Here, the hyperbolic tangent model was applied for both types „A“ and „B“ suspended-load concentration sets. When using this model, the computed transports are very satisfactory for wet years, but the resultant values are underestimated for dry years.

The resulting annual transport values computed from all quoted models are equally affected by a common error, i.e. either an overestimation or an underestimation of suspended-load transport. The size of the deviations in the computation of suspended-load transports is influenced mainly by the irregular distribution of water discharges and suspended-load concentrations during the year, i.e. the occurrence of their extreme values, which will have the greatest impact during dry years, and which are hard for the models to account for.

The resultant computations may be continually made more accurate on the basis of further, regularly carried out daily monitoring of suspended-load concentrations.

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Methodological Approach to a Hydro-Ecological Evaluation of the Load of the Water Component in the Main Slovak River Basins

Ján Hanušin, Anna Grešková, Milan Lehotský

Abstract: In the context of continual increasing demands of water, particularly of its consumption, water resources in their time-spatial variability and dynamics (in quantitative as well as in qualitative sense) are increasingly influenced by various impacts. The rationality of treatment of water resources need to respect the dynamics equilibrium between existing water reserves which are accessible on the one side and protection and consumption on the other one. In addition to solving this difficult problem the research of load of water component of landscape by anthropic impacts must be done. Our study presents environmentally oriented methodological approach of assessment of load of water component with its application on main Slovak river basins in regional level i. e. in the scale 1:200 000.

Key words: main river basins, Slovakia, hydro-ecological evaluation, size of load, water component of landscape.

Ein methodischer Ansatz zur hydro-ökologischen Bewertung des Belastungsgrades der Wasserkomponente in den Haupteinzugsgebieten der Slowakei

Zusammenfassung: Im Zusammenhang mit ständig wachsenden Ansprüchen an das Wasser, besonders beim Wasserverbrauch, sind die Wasserressourcen in ihrer zeitlichen und räumlichen Variabilität und Dynamik, sowohl im qualitativen als auch im quantitativen Sinn, immer mehr durch unterschiedliche Einwirkungen beeinflusst. Eine rationelle Bewirtschaftung der Wasserressourcen muss das dynamische Gleichgewicht zwischen den vorhandenen Wasserressourcen auf der einen Seite und ihrem Schutz und Aufbrauch auf der anderen Seite berücksichtigen. Um zu einer Lösung dieser nicht leichten Aufgabe zu kommen, muss der anthropogene Belastungsgrad der Wasserkomponente in der Landschaft untersucht werden. Die vorliegende Studie präsentiert einen umweltbezogenen Ansatz zur Abschätzung des Belastungsgrades der Gewässer in den Haupteinzugsgebieten auf regionaler Ebene, d.h. im Maßstab 1 : 200 000.

Schlüsselworte: Haupteinzugsgebiete, Slowakei, hydro-ökologische Abschätzung, Belastungsgrad, Wasserkomponente der Landschaft

1 Introduction

Water should be understood as one of the landscape components penetrating and acting in all components of natural as well as cultural landscape. In the same time it is source and natural substance. This dialectic unity of its understanding is very clear manifested but in fact there is a lot of problems how to do “good management “ of it. Regarding the "universality" of the occurrence and function, or use of water in natural landscape and by population, we understand water as a complex medium moving in cultural landscape in a uniform, innerly differentiated cycle (Hanušin, 1983). The consequence of the movement of water in natural and social systems and the growing pressure on its use that is not always in agreement with rational management exercise an influences on its qualitative and quantitative properties. The rational management of water resources as the basic condition for the sustainability of other landscape components and human being comes out from searching the dynamic equilibrium between offer of existing accessible and renewable water supplies, their protection and consumption. For this reason as one of the tools the research of size of load of anthropic pressure on water

component is useful and inevitable. The aim of our contribution is to present environmentally draught procedure of the evaluation of size of load of water as the landscape component. Our methodological approach is applied on the regional level of main basins of Slovakia in the scale 1: 200 000.

2 Theoretical background and methods

Methodologically we came out from the complex and system conception of landscape. We recognise landscape as structuralised entity. The structuralization is expressed in space and time. The space structuralization of landscape is manifested by different types of areas abreast occuring, differ related to quality of components and processes and surface of spreading. The succession of states defines the structuralization of landscape types in time. Applying above mentioned reflections on natural landscape we identify in it areas-units, natural landscape types. When the water component is accepted as principal component of landscape type (it is our case) we can name such defined landscape types as hydro-ecological types (HET). HET-s represent homogeneous areas on each taxonomic level where dominate specific processes of hydrological cycle. In those spatial landscape structures the human activity is realised. Anthropic impacts have different appearance and intensity of transformation of natural landscape videlicet HET-s are loaded by anthropic impacts in different size (Fig. 1). Main methodological starting points we have formed in our works (Grešková et al. 1994, Hanušin et al. 1994, Hanušin, Lehotský 1998). They are as following:
i) typology of HET-s
ii) determination of the degree of HET´s vulnerability
iii) assessment of anthropic impact
iv) assessment of load of water component of landscape

2. 1 Typology of hydro-ecological units and determination of their degree of vulnerability

Based in dominating partial hydrological processes in overall water circulation within the landscape system three hydro-ecological types are identified (Grešková et al.1994):

a) initial or source-based

is such a natural unit where surface streams with maximum discharge below $1.m^3.s^{-1}$ exist though with ground water supply amounting to $6\ l.s^{-1}.km^{-2}$.

b) accumulative

is the one in which the ground water supply reach the values over $6\ l.s^{-1}.km^{-2}$ i.e. it represents a natural unit with a substrate allowing for accumulation of ground water. It has surface streams with alluvial plain no wider than 20 m.

c) accumulative-transitory

is such one representing area which does not comply with above quoted criteria, and the regime of surface stream immediately reacts with the close environs (alluvial plain) where groundwater accumulates.

We differentiated them at the lower taxonomic level by properties:

a) input-precipitations

is defined by climatic index of moisture as accumulated value of water regime in HET and properties of downpours (R-factor of USLE) as specific features of dynamism of water input in HET.

b) dynamism and reaction

energy, by coefficient of transmissivity.

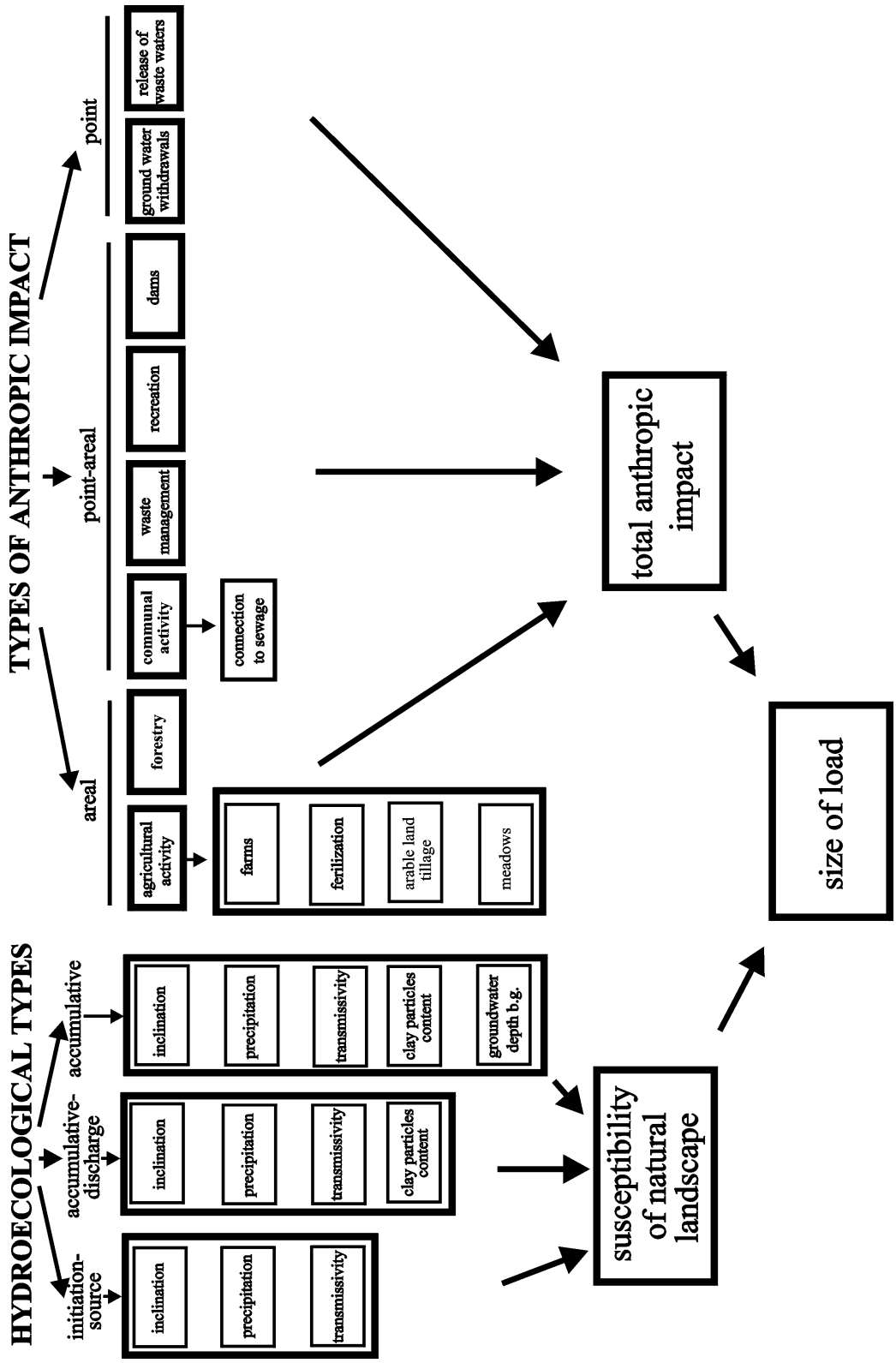

Fig. 1 The scheme of the hydroecological evaluation of load of water component on river basin

c) output-accumulation ability, discharge or initiality are defined by:
- the rate of water exchange i.e. by discharge
- rate of water retention, i.e. accumulation.

Degree of vulnerability of the HET is assessed by an expert estimate of the quoted parameters which are expressed in ordinary scale in bal units. Bal estimate is assessed following the formula:

$$V_{bal} = (\text{parameter value} \,.\, \text{coefficient}) + \text{value of climatic index of moisture}$$

Susceptibility degrees for the basic HET i.e. initial or source-based, accumulative, and accumulative-transitory is presented in a form of 5 degrees ordinar scale.

2.2 Evaluation of anthropic impact and size of load

Methodology of diagnosis of anthropic impact leans on determination and spatial identification of anthropic activity defined by the relation land use--land cover. We distinguished following anthropic impacts on water component of landscape:
- point impacts for the purpose of the study are the activities, effect of which is initially concentrated in the territory, with an area from several square metres or decimetres (discharge, drawing) to several ares or hectares.
- area-point impacts are the settlements, recreation areas and water reservoir areas.
- areal impacts include relatively less intensively acting ones, though operating on large areas and ensuing from the prevailingly areal use in form of arable land, meadow and forest management.

Each impact was aligned the coefficient of negative effect in scale from 1 to 5 so that impacts with the lowest coefficient exhibit the smallest conflict and vice versa. The coefficients are following:

1. coefficient “5” - communal activity, release of waste waters and waste management
2. coefficient “4” - arable land with fertilisation more then 240 kg/ha
3. coefficient “3” - arable land with fertilisation less then 240 kg/ha
4. coefficient “2” - areas of dams, meadows and pastures, recreation
5. coefficient “1” - ground water withdrawals, forestry.

Total value of anthropic impact-size of load of HET-s and magnitude of conflict represents the sum of partial impacts following the formula:

$$L_{bal} = V_{bal} \,.\, \text{value of impact} \,.\, \text{coefficient of impact}$$

Final evaluation with an outcome in form of map of the load grade of water component originated by superposition of the maps representing susceptibility degree and maps of anthropic impacts. Presented approach made possible to differentiate five grades of load of component water in landscape for the single basins at the national level and in scale 1:200 000.

3 Results (Fig. 2)

3.1 Lower Morava basin

The most conflictive area with the highest and very high anthropogenic load are in the territory of the low Morava flood plain and in the enclaves of intensive farming areas between Záhorská Ves and Suchohrad, north from Stupava and around Cerová. The highest and very high load is found in the territory of the settlments Holíč, Skalica, Myjava, Senica, Malacky, and Stupava. The territories with medium load neighbour with the highest load on the plains of the Morava and around Podmalokarpatská depression north from Rohožník. The medium load is typical for the settlements where several anthropogenic activities meet with water management on a comparatively small area. Low or the least loaded areas are on big surfaces around the Malé Karpaty Mts., Bor and Chvojnická pahorkatina hilly land.

3.2 Danube basin

Danube basin, a narrow strip of the Podunajská rovina plain in close vicinity of the Danube represents the most conflictive territories with high anthropogenic load and high HET sensitivity. The highest load is found mainly in the area of the settlements Bratislava and Gabčíkovo. Medium degree of load is found in smaller settlements on very to medium sensitive HET. Sparsely and the least loaded areas are the ones of the Vydrica basin in the Malé Karpaty Mts., an area east from Hurbanovo and Burda.

3.3 Váh basin

The most loaded territories with greatest conflict can be identified on the Podunajská rovina plain (Žitný ostrov). The greatest load besides the mentioned plain is found only in smaller enclaves SE from Čachtice, around Ilava and S from Námestovo. Very loaded territory is the N part of Žitný ostrov, environs of Trnava, Jaslovské Bohunice, environs of Dvory nad Žitavou, a strip of territory from Neded to Nesvady, Bytčianska kotlina, basin, E protuberance of the Žilinská kotlina basin and NE part of the Turčianska kotlina basin. The territories with medium load occur along the lower reach of the Váh S from Kolárovo, on moderately elevated positions of the Podunajská rovina plain, on the foothills of the adjacent hilly lands or plains (along the S and SE foothills of the Trnavská pahorkatina hilly land and in depressed swampy areas (N part of the Martovská mokraď, NW from Nové Zámky). Then there are the Dolnovážska niva flood plain, Trenčianska, Ilavská, Turčianska, Oravská and Liptovská kotlina basins and the S part of the Žilinská kotlina basin. The low load degrees are characterised by the wooded part of the mountain ranges. All settlements in the Podunajská rovina plain, regardless the size, represent the highest degree of load. Besides Podunajská rovina plain there are settlements with the greatest conflict all along the flood plain of the Váh, on the flood plains of the medium and lower reach of the Orava and Kysuce and in the mountain areas, where they are situated prevailingly within the most sensitive HET: the settlements in the Low Tatras, Kremnické vrchy Mts., Súľovské skaly Mts and in Žilinská kotlina basin.

3.4 Nitra basin

The most critical areas (very loaded) in the basin are around Nitra and Šurany. The same degree of load is to be found in the settlements of Topoľčany, Partizánske, Nováky, Prievidza. The medium degree of load is in rural settlements on the alluvial plain of the Nitra, Nitrica, south from Zlaté Moravce. The lowest degree of load are mostly represented by mountain forest compounds of Tríbeč and Považský Inovec.

3.5 Hron basin

The most conflictive areas in the draining area of the Hron and particularly in its lower stretch. Here belongs the whole of the alluvial plain of the Hron from Slovenská brána to Štúrovo. All settlements with population over 5,000 lying on the alluvial plain of the Hron represent a very high and high load for the landscape, especially its water component. Settlements out of the alluvial plain cause high load in very sensitive HET: settlements lying on the dividing line between the Veľká Fatra Mts. and Starohorské vrchy Mts. (Harmanec, Motyčky, Donovaly) in the infiltration area of high-yielding resources of ground water. A medium loaded area stretches on the part of the Hron alluvial plain from Kozárovce to the river spring and the recreation areas of Tále and Trangoška.

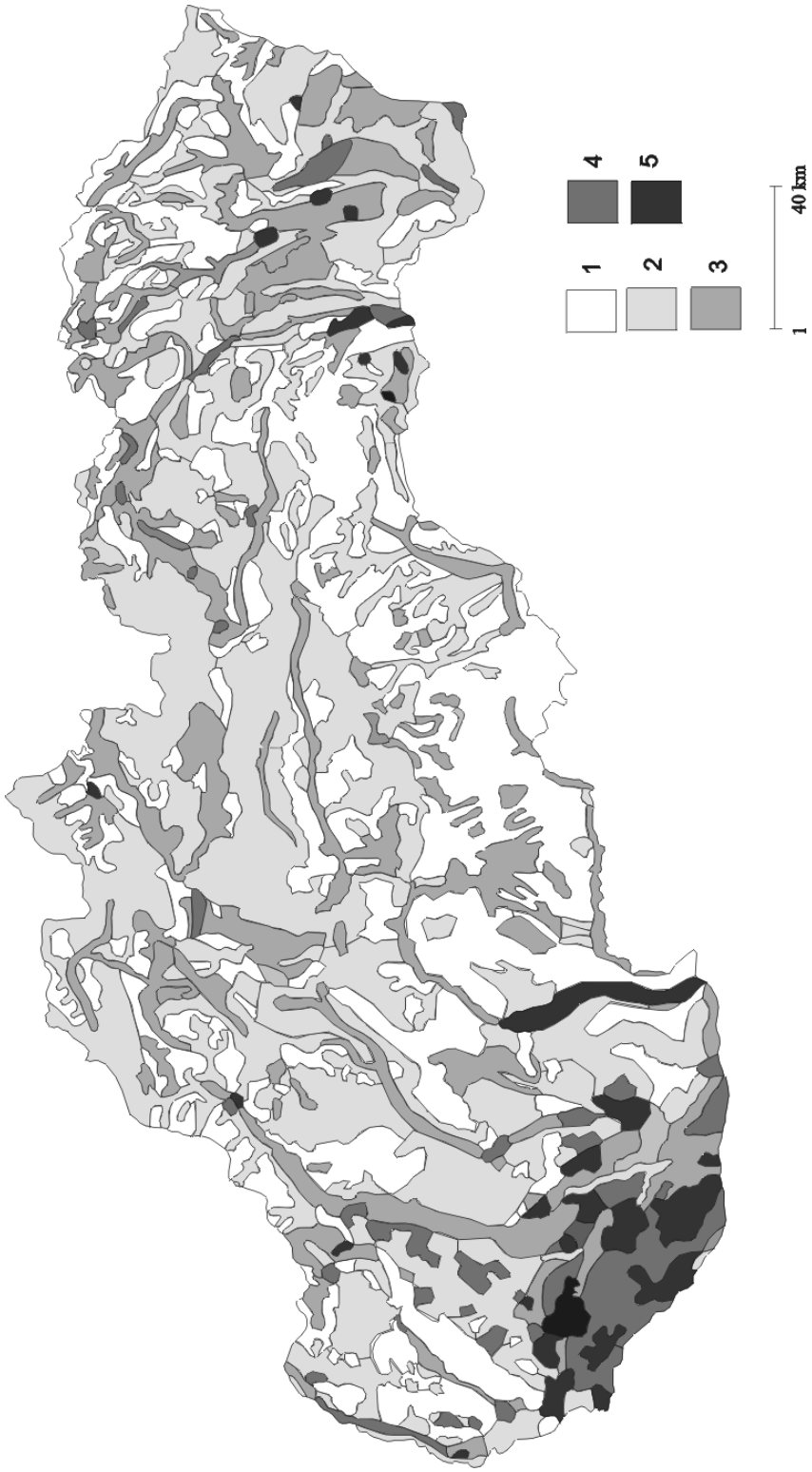

Fig. 2 The size of load of water component in main Slovak river basins. 1. the lowest load, 2. low load, 3. medium load, 4. very high load, 5. the highest load

3.6 Poprad and Dunajec basins

The highest anthropogenic loads are in the territory of settlements (alluvial plain of the Poprad, in its stretches between Kežmarok--Podolínec, Hniezdne--Stará Ľubovňa, and Plavnica--Orlov). The medium degree of load prevails in Popradská kotlina basin. The lowest load is in the forest and high-mountain areas.

3.7 Ipeľ basin

There are no cases of the highest load and conflict degree in this catchment. Very high load is represented only by the town of Šahy. The medium degree is typical for other settlements on the alluvial plain of the Ipeľ. Low or the lowest degree of load is in the most part of the territory.

3.8 Slaná basin

There are only three degrees of load in catchment of the Slaná with very low, low and medium loaded areas. The medium degree of load occupies compact territory on the alluval plain in the middle and lower reaches of the Slaná, south from Rožňava and on the lower reach of the Rimava starting in Jesenské. Larger areas with medium degree of load are found around Kokava n. Rimavicou, Tisovec, Ratková, Revúca and Rejdová.

3.9 Bodva basin

The highest and very high degree of load is represented by the space between Moldava nad Bodvou and Veľká Ida and W from VSŽ iron works in Košice. Medium and low degree of load is in the agriculturally intensively exploited territory of the Košická kotlina basin in the very sensitive area of Slovenský kras Mts with low anthropic load. The lowest degree of load is in the HET with minimum anthropic influence in the area of Slovenské rudohorie and Slovenský kras Mts.

3.10 Hornád basin

The most conflicting areas with high anthropogenic load on the one side and high susceptibility of the HET on the other, was found in the settlements of Košice, Spišská Nová Ves, Prešov, Sabinov, the mining towns of the Spiš region, and in smaller settlements between Prešov and Košice and on the alluvial plain of the Hornád in the southern part of the Košická kotlina basin. The centre of Košice, the towns of Rudňany and Spišská Nová Ves are especially conflictive. High load represented by the settlement of Vernár in extremely sensitive HET is also inadequate. Out of the areal influences the biggest conflict is caused by the farming using high doses of fertilizers on the alluvial plain of the Hornád in the southern part of Košická kotlina. Medium loaded HET are the alluvial plains of the Torysa and Hornád in Hornádska kotlina basin, environs of Levoča, Lipany, Prešov and the central part of the Šarišská vrchovina Mts.

3.12 Bodrog basin

The most conflictive territories with the highest and very high load are in Michalovce, Trebišov, Humenné, Stropkov, Bardejov, Vranov nad Topľou, and in Snina. The most extensive territories with very high load of environment can be found in the central part of the alluvial plain of the Laborec, south from Strážske. It is an agriculturally intensively exploited territory. Medium degree of load is typical for the prevailing majority of smaller rural settlements and the alluvial plains of the Ondava, Topľa, and Laborec. Less and least loaded areas are the ones of the HET in the Slanské and Zemplínske vrchy Mts. and the forested parts of the Nízke Beskydy Mts.

4 Conclusions

The results reached by the above mentioned approach can be generalised as follows:

1. the highest and medium degrees of load are linked to:

a) lowland (plain and hilly) areas with accumulation and accumulation-discharge HET characterised by good permeability and large supply of economically used ground and surface water. Activities demanding large amounts of water and simultaneously highly influencing the quality of water component of landscape are concentrated here.
b) all large settlements (population over 5000) mostly situated in highly sensitive HET (alluvial plains of big streams). Size of load is determined by the size of settlement and available facilities (sewage and WWT plants) and sensitivity of the HET where the settlement is situated.
c) almost all smaller (population below 5000) settlements situated in highly sensitive accumulation-discharge or source HET as local conflict nuclei in the consequence of poor amenities of public water works, sewage, WWT plants, especially where the dynamics of water circulation is low.
d) all intensively agriculturally used areas with high use of fertilisers and agro-chemicals on highly sensitive HET with a rich supply of ground water and presence of stream interacting with its environs.
e) point influences of discharges communal waste water and polluted water (industrial entities and large-scale raising of farm animals, etc.) directly into the recipients without cleansing.

2. Low to the lowest degree of load

a) low degree of load in high mountain, mountain-meadow, mountain-forest and meadow compounds is determined in the consequence of higher values of specific runoff and transmissivity of substrate, although the anthropic impact is almost negligible.
b) the least loaded water component of landscape is linked to forest and meadow complexes of mountains and partially also lowlands where it is determined by lower sensitivity of the territory in the consequence of relatively smaller value of specific runoff, low transmissivity of substrate and low values of climatic index of moisture.

Acknowledgement
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Applying GIS to Non-Point Source Pollution Modelling

Kamila Hlavčová

Abstract : Non-point source pollution results in the degradation of water quality from storm runoff, a process in which pollutants on land are released and transported during rain storms into water bodies. Unlike point sources of pollution such as factories, non-point source pollution occurs from multiple sources. In an urban area, it may occur simultaneously from residential, commercial, and industrial sources. In an agricultural setting, the pollution may occur from different land uses, the use of fertilizers, and livestock.

GIS has emerged as a valuable technology for assessing and managing non-point source pollution. In this paper non-point source pollution and the delivery process of non-point pollution using a GIS-based model in the basin of the Teplica River has been estimated. The research focuses on the delivery of two types of pollutants - sediments (soil particles) and nutrients, with a focus on nitrogen and phosphorus. Three input raster maps - a digital elevation model, a soil map and a landuse map were used in the modelling, and additional images of slopes in the watershed, the direction of the flow of the water and pollutants, and the length of the flow were created. The amounts of sediment and nutrients available for transport by water depend on the land use and soil and topographic conditions. The surface conditions of the basin define what proportion of sediments and nutrients will be trapped in situ and what proportion could be carried away by water. The proportion carried away by water is called the "delivery ratio", and it was calculated for each cell in the watershed. The path of the flow of pollutants from each cell to the watershed outlet was determined to be the "total flow-path delivery ratio", which expresses the amount of available load that actually reaches the stream. The final product of the model is the annual amount of sediments and nutrients in tons that are lost from the basin in a year.

Key words: non-point source pollution, GIS-based model, digital elevation model, sediments, nutrients

Die Applikation von GIS in Modelierung der flaechlichen Verschmutzung

Zusammenfassung: Der Artikel befasst sich mit der Transportmodelierung der flaechlichen Verschmutzung aus dem Eizugsgebiet Teplica, ausdruecklich an zwei Typen von Schadstoffkomponeten orientiert - Sedimenten und Naehrstoffe. Fuer die Modelierung wurde GIS orientiertes Model verwendet. Die Eingabedatei bestand von drei digitalen Rasterkarten - digitales Gelaendemodel, digitale Karte der Landnutzung, digitale Karte der Bodenarten und weitere Karten: die Karte der Abflussorientierung, der Haengenneigungen und der Abflusslaengen. Schrittweise wurden die Mengen von Schadstoffkomponeten fuer jedes Grid, bis zu dem Abschlussprofil simuliert. Das Resultat der Modelierung ist die Menge von Schadstoffkomponeten, die im einen Jahr aus dem Einzugsgebiet transportiert sein kann.

Schlüsselworte: die flaechliche Verschmutzung, GIS orientiertes Model, digitales Gelaendemodel, Sedimenten und Naehrstoffe

1 Input data

The Teplica River basin, which is in the western part of Slovakia and has an area of 93.81 km^2, was selected for the study. The elevation of the basin varies from 226 to 628 m a.s.l. and the average slope is about 14.7 %. The elevation (Fig.1), soil and land use (Fig.2) of the basin were used as input data in the form of digital raster maps with a resolution of 100 m. The raster maps were prepared by digitizing analog maps - a contour map with a scale of 1:10,000, a soil type map with a scale of 1:500,000 and a land-use map with a scale of 1:10,000. Three additional images were created from the digital elevation model - slopes in the basin (Fig 3), the direction of the flow of the water and pollutants, and the length of the flow. A geographic information system (GIS) was used for determining the slope gradients and the length of the flow through the cells. The direction of the flow and pollutants was determined by comparing the elevation of a cell with the elevation of the eight surrounding cells. The DIRECT program, which is from the public domain DEM Drainage Software containing programs for the extraction of hydrological information from DEMs (Jenson and Domingue, 1988) was used.

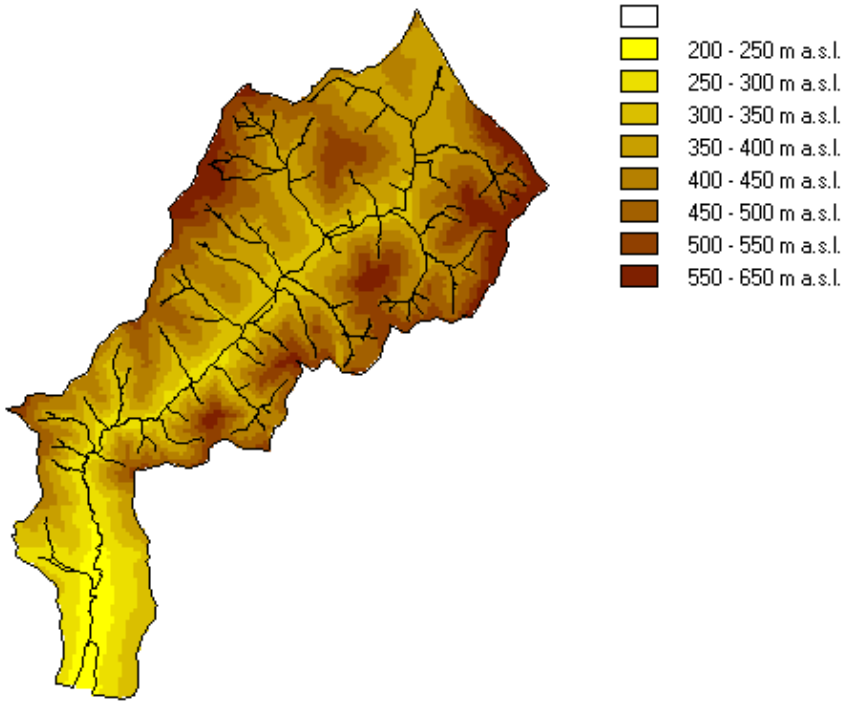

Fig. 1 Digital elevation model of the Teplica River basin

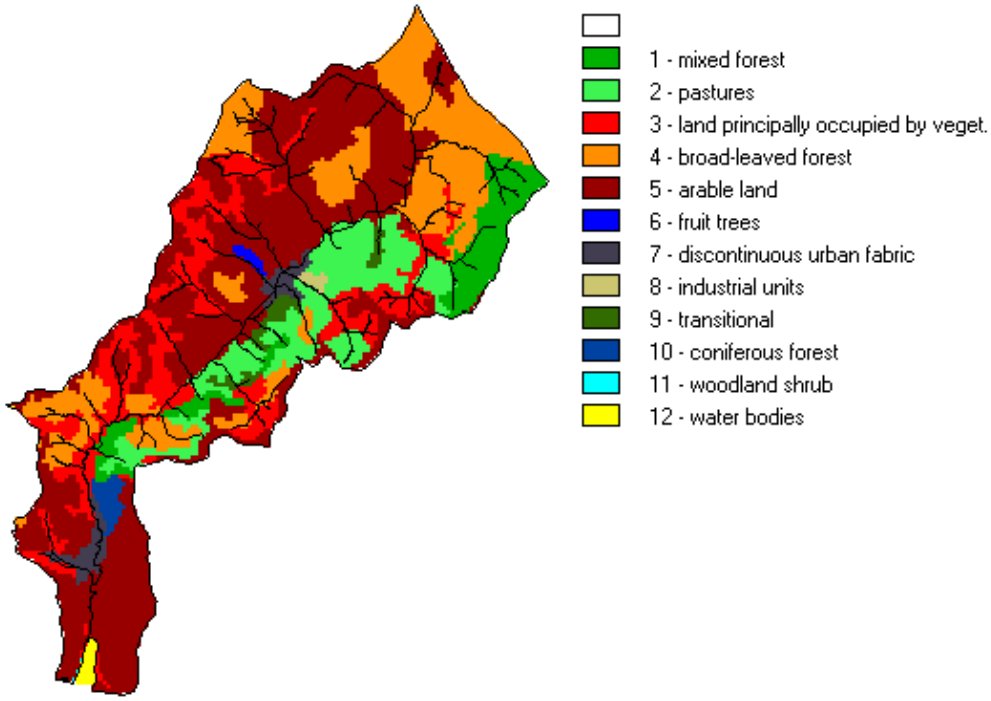

Fig. 2 Land use of the Teplica River basin

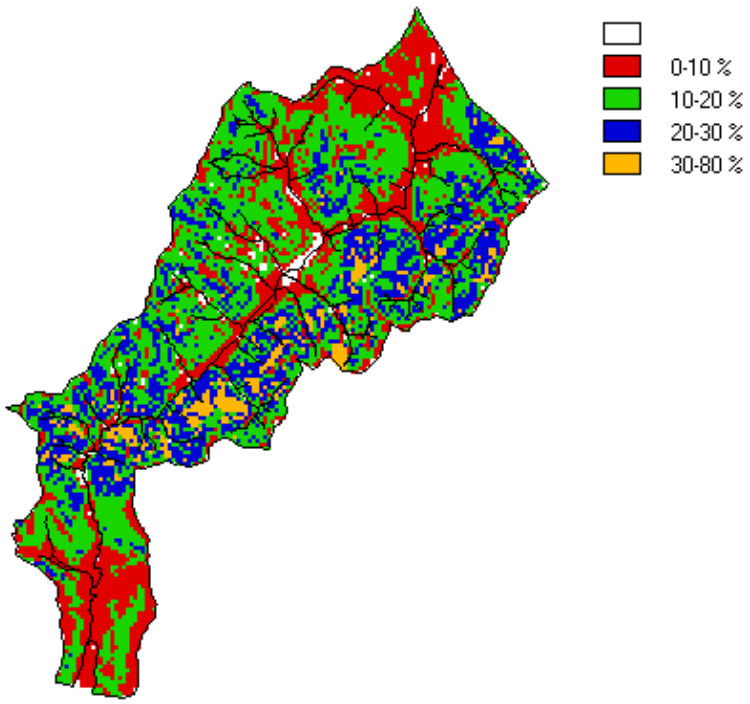

Fig. 3 Slopes of the Teplica River basin

2 Detachment of sediments and nutrients

The amount of sediments and nutrients available for transport by water depends on the land use and soil and topographic conditions. This is calculated in the model in the first step as the detachment of the sediments and nutrients.

The volume of nutrients was calculated using empirically-derived export coefficients for each nutrient. In this study, the export coefficients were drawn from tables compiled by Reckhow, et al. (1980), and they were selected based on the similarity of soils, rainfall, slopes, and land management characteristics. The export coefficients represent the amount of a nutrient (in kilograms) transported from an area (in hectares) per year for each use of the land (Table 1).

Table 1 Export coefficients for total potential phosphorus and nitrogen loads

Land use	Total phosphorus [kg/ha/year]	Total nitrogen [kg/ha/year]
Water	0	0
Barren	1.3	4.4
Pasture	1.46	6.125
Cultivated soil	2.2	9.3
Grassland	0.25	1.48
Forest	0.212	2.46

To calculate the initial mass of sediment available for transport, the Universal Soil Loss Equation (USLE) was used, because it is one of the most widely used empirical models for this purpose. USLE (Wischmeier, Smith, [8]) is defined as :

$$G = R\ K\ L\ S\ C\ P, \tag{1}$$

where :

G is the average annual loss of soil per unit area (tons per cell per year), R is the rainfall and runoff factor (tons per hectare), K is the soil erodibility factor, L is the slope length factor, S is the steepness factor, C is the cover and management factor, and P is the support practice factor.

3 The overland flow delivery process

This component of the model represents the influence of surface conditions, such as soil permeability, slope and vegetation density on the delivery of sediments and nutrients during movement towards a stream channel. The three non-linear empirical models (Levine, et al. [6]) for trapping efficiencies of phosphorus, nitrogen, and sediments through each cell in the watershed are :

$$TP_{trapped} = 1/\left(1+e^{(1.47-0.416d+0.012sqrd+0.296p-5.74n)}\right), \tag{2}$$

$$TN_{trapped} = 1/\left(1+e^{(-10.14+0.016d+26.83\theta-4.58\ln(n)+2.78\ln(mpd)+1.47dn-1.63d\theta)}\right), \tag{3}$$

$$TSS_{trapped} = 1/\left(1+e^{(-3.57-0.33d+0.011sqrd+22.82\theta+0.73p)}\right), \tag{4}$$

where :
TP is the trapping efficiency for the total amount of phosphorus, *TN* is the trapping efficiency for the total amount of nitrogen, *TSS* is the trapping efficiency for the total amount of suspended sediments, *d* is the distance of the flow (m), *sqrd* is the distance of the flow squares (meters^2), *p* is the soil permeability (inches/hour), *mpd* is the mean soil particle diameter (mm), *n* is the Manning's roughness coefficient (unitless), and θ is the slope angle (radians).

The models calculate the trapping efficiencies, which are then converted into delivery ratios. The trapping efficiencies show the percentage of sediments and nutrients which could be physically trapped in a cell, depending on the surface condition, such as vegetation, soil properties, slope and flow distance. The delivery ratios show the percentage that can escape from a cell. The sum of the trapping efficiency and the delivery ratio is one hundred percent.

4 Stream network delineation

The delivery ratio models described above do not make a distinction between cells that are outside a stream and cells that fall into a stream. In reality, when a storm occurs, overland water flows down a slope, forming storm sewers or drainage streams. It is assumed that all of the nutrients and sediments entering a stream cell are carried by water energy downstream to the next cell and that the delivery ratio in cells falling within a drainage stream is 100%. To delineate the stream network, the COUNT program from the DEM Drainage Software (Jenson and Domingue, 1988) was used. This program counts the number of cells that flow into any one cells based on the direction of flow in each cell. The result represents the number of cells flowing into each cell, and a threshold of 20 was applied to it to delineate the stream network.

5 Total flow path delivery ratios

The difference between the cell delivery ratio and the total delivery ratio is that the former refers to the percentage of pollutant load in a cell that can be transported to the next cell in the flow path, whereas the latter refers to that part of the load in a cell which actually reaches a watershed outlet. The FLOWPATH program from DEM Drainage Software (Jenson and Domingue, 1988) was used for determining the total delivery ratios. The calculation starts at the watershed outlet and identifies the flow path from each cell to the outlet cell. The delivery ratio for the receiving cell is multiplied by the delivery value of the neighboring cells that flow into it. The resulting image shows the proportion of the potential load of a pollutant in a cell that can actually reach the watershed outlet under certain topographic and surface conditions.

6 Total annual nutrient and sediment loadings

The actual amount of pollutants delivered to the watershed outlet from each cell was calculated as the product of the potential loadings for each cell of the watershed and the total flow path delivery ratios for the pollutants. The total annual mass of nutrients and sediments that passes through the watershed outlet as the sum of the values for all the cells was determined.

The results for the Teplica River basin are as follows :

- total sediment load = 738.805 t per year,
- total nitrogen load = 29.274 t per year,
- total phosphorus load = 1.428 t per year.

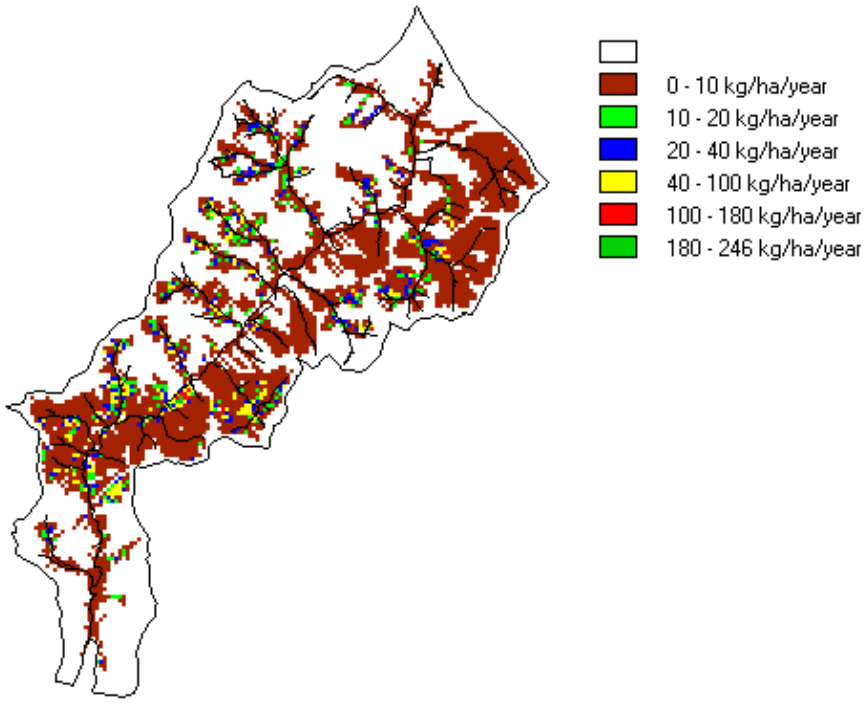

Fig. 4 Total annual sediment loadings in the Teplica River basin

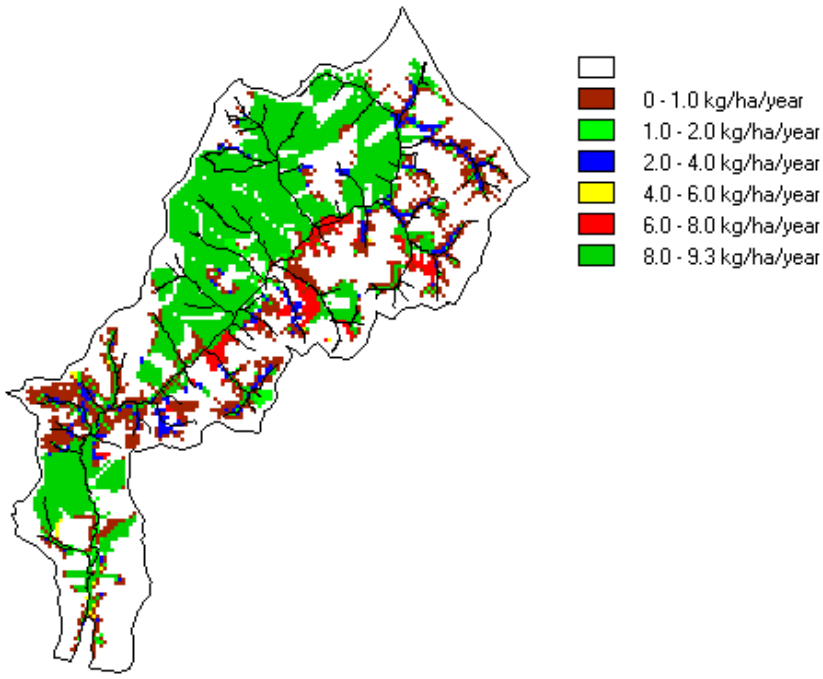

Fig. 5 Total annual nitrogen loadings in the Teplica River basin

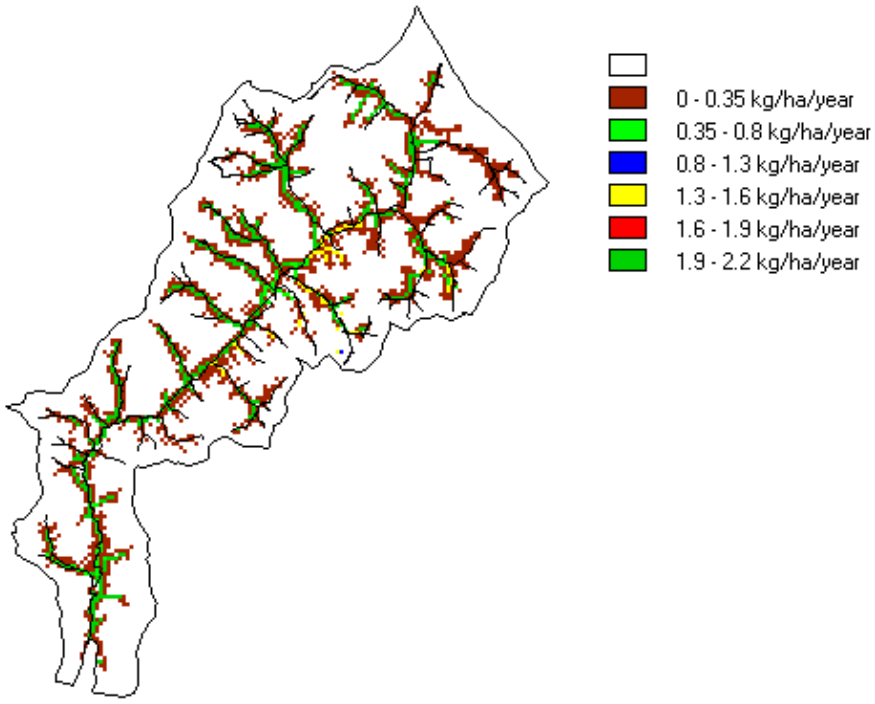

Fig. 6 Total annual phosphorus loadings in the Teplica River basin

7 Conclusion

The delivery process of non-point pollution from its source to the receiving waters was modelled in this study using a GIS-based model (Emani, 1996). The basin of the Teplica River was chosen as the model site. First, the amount of nutrients and sediments for transport from each cell was calculated. Then the proportion of this amount that could be carried away with surface water flow from each cell was estimated, depending on the surface condition (soil permeability, slope and vegetation density). The next step was the delineation of a network of permanent and temporary streams. Using this data, the individual path of the water flow from each cell towards the stream network was identified. This flow path information was used to calculate the total flow path delivery ratios, which express the part of the available load that actually reaches the stream. The final product of the model is the annual amount of sediments and nutrients in tons that are lost from the basin in a year.

The results can have important implications for the management of water resources in a basin, and the spatial character of the model permits the identification of pollutant-contributing areas. These areas could be targeted for management action. Approaches to soil conservation can include crop and vegetation management (rotation, cover crops, high density planting), soil management (tillage practise, soil stabilisers) and mechanical methods of erosion control (contouring, terraces, waterways and stabilisation structures).

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An Ecological Interaction Analysis of the Bahlui, Jijia and Prut Rivers

Serban Iliescu, Mihaela Nicolae, Ruxandra Maxim

Abstract: The aquatic ecosystems are dynamic systems preserve stability, due to the self-control function, by stability meaning the balance between the constituent populations. The dynamic of the balance the aquatic ecosystems are achieving not only to the connection between the species and the environmental factors, but also to the mutual connection among the existing populations. In this paper, we have studied the interactions among the water chemical composition, the bacterial microflora and plankton, the interactions among the sediments chemical composition and the zoobenthos, but also the interactions among the groups of main organisms on the Bahlui, Jijia and the Prut Rivers.

Key words: plankton ,fitoplankton, zooplankton zoobenthos and saprobic zone.

Betrachtungen über die ökologischen Wechselwirkungen an den Flüßen Bahlui, Jijia, Prut

Zusammenfassung Die Wasserökosysteme sind dynamische Systeme, die sich ihre Stabilität – als eine Konsequenz der Selbstkontrollfunktion aufbewahren. Durch Stabilität ist ein Gleichgewicht zwischen den zusammenfassenden Populationen zu verstehen. Das dynamische Gleichgewicht der Wasserökosystemen erfüllt sich sowhl durh die zwischen Spezies und Umweltfaktoren Zusammenhänge, als auch durch die gegenseitigen Zusammenhänge zwischen den vorhandenen Populationen.

Wir haben im vorliegenden Arbeit sowohl die Wechselwirkungen zwischen dem Wasserchemismus, der bakteriellen Mikroflora und dem Plankton, die Wechselwirkungen zwischen dem Sedimentenchemismus und dem Zoobenthos, als auch die Wechselwirkungen zwischen den Hauptgruppen der Organismenin die Flüßen Bahlui, Jijia und Prut behandelt.

Schlüsselworte: Plankton, Phytoplankton, Zooplankcton, Zoobenthos, Saprobitätsgrad.

Introduction

The Prut River, the last big tributary of the Danube, has a relatively small surface (27,5000 km) within the hydrographic basin is one of the main sources of drinkable water in the Eastern part of Romania. In our researches, we have focussed deeply on the evaluation of the water quality, and due to the fact that, until 1990 it couldn't be studied in an united way, and the results couldn't published, the Prut River have been considerate the border.

The Prut River has 952,9 km length, its spring is in Ukraina, in the Cernohova Mountains, the Goverla Mount, at 2061- m altitude. It has a 88 m^3/s flow. It crosses 211.9 km of Ukrainean territory and enters our country at Orofteiana, and a 742,2km section forms a common border with the Moldavia Republic. It flows into the Danube near Giurgiulesti Gura-Prut.

Its main tributaries are the Baseu, the Jijia, the Bahlui, the Elan and the Chineja.

1 Results and Discussions

In order to characterise the change occurred in the natural factors action (the flowing system, the forms of the relief crossed by, the geomorphic structure of the soil) and, especially the antropic factors action, the samples have been taken from 11 working stations (9 on the Prut River, one on the Bahlui River and one on the Jijia River).

On these samples have been done physical-chemical, biological and bacteriological analysis of the water and the sediments.

In order to characterise the evolution of the surface water temporal-spatial quality, besides the data analysis, regarding the physical-chemical characteristics, a great importance given the quantitative and quantitative analysis of the aquatic biocoenoses, which has led to evaluation of cleaning grade and also to the interactions between the biotic and abiotic factors and between the groups of characteristic organisms.

The present work has as main goal analysis of the interactions occurred in time and space between biotop-biocoenosa.

The analysis of the biotop-biocoenosa interactions and among the main groups of organisms has been done separately for the Bahlui, the Jijia and the Prut Rivers.

2 Bahlui River

2.1 Water chemical composition and the microbiota interactions on the Bahlui River.

At downstream – Tomesti Station, the Bahlui is characterised by a slow water flow, very low transparency, dark-brown colour, persistent and domestic smell. The temperature in the summer time reaches 26-28°C. At this station, after it assimilates the tributary of Local Purification Station of Iasi, water of River Bahlui is "degraded" category, having high organically load and ammonium values and the dissolved oxygen was absent or it reached very low values in summer time. The high organically load values (CCOCr, CBO_5) allowed, throughout the research years, to develop the total coliforms bacteria in a very great number, the bacterial impurification remaining the same, without any attempts of improving - fig. No. 1.

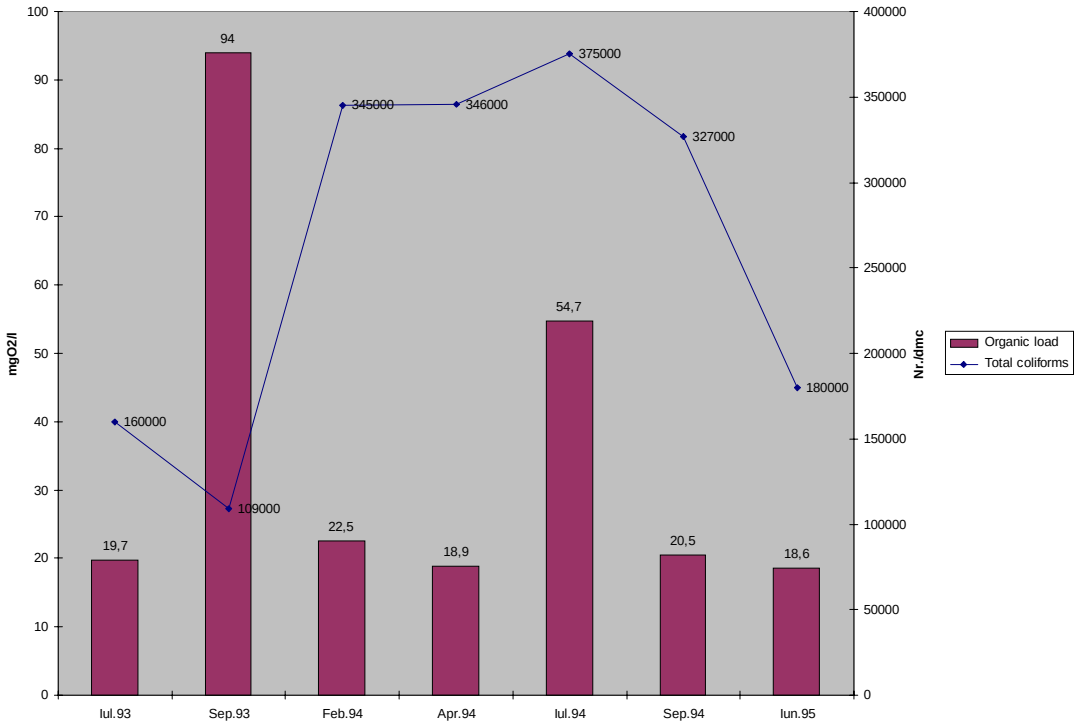

Fig. 1 The variation of the total coliform and saprophyte bacteria, taken from the River Bahlui at Tomesti section, from July 1993 to June 1995.

2.2 The chemical composition of water and the phytoplankton interactions on the Bahlui River

At this station, the very high water pollution led to the appearance and the development in Phytoplankton of some algae species, specific to high organically load and low dissolved oxygen composition waters, highly impurified polisaprobic level. Among the most frequent species, we can list the *Cyanobacteria*: *Aphanisomenon flos aquae, Anabaena flos-aquae, Oscillatoria limosa, Euglenophyta*: *Euglena viridis, Lepocinclis ovum, Strombomonas verrucosa, Bacillariophyta*: *Cyclotella meneghiniana, Navicula cryptocephala, Nitzschia palea.* In June, 1995 although found them in a high percent (25%) in Phytoplankton, the Chlorophyta (*Actinastrum Hantzschii, Crucigenia fenestrata, Pandorina morum, Scenedesmus dimorphus*), we can't appreciate an improving of the water quality, these algae being moved from the superior course due to the increasing of the flow, caused by frequent rains in this period - fig. no. 2.

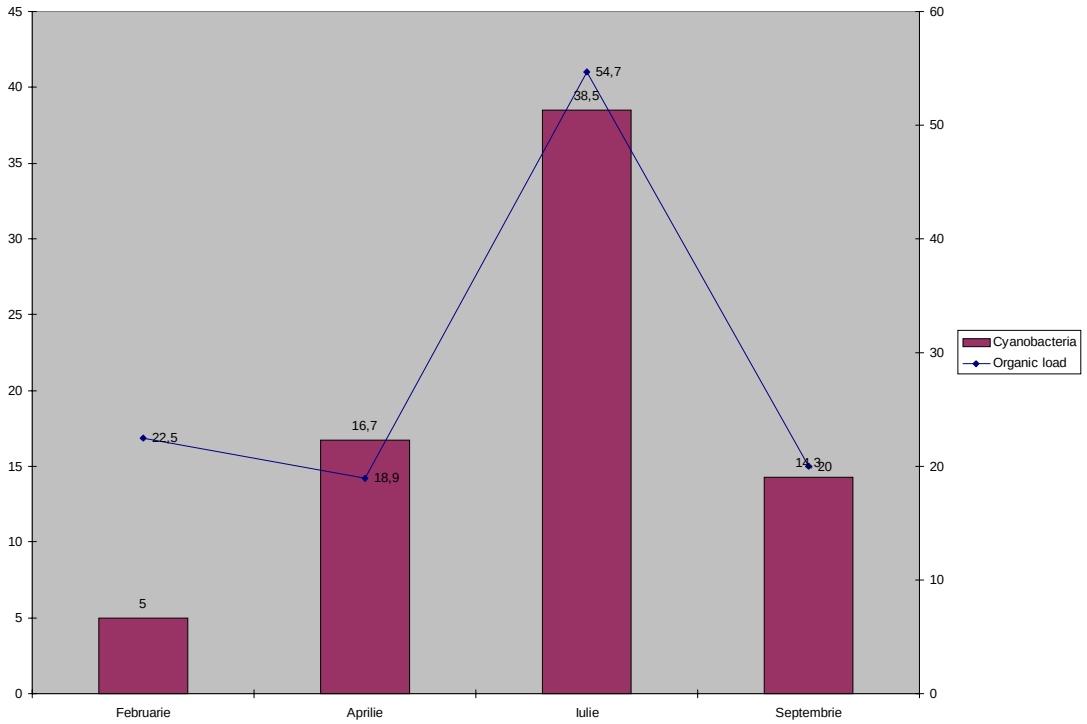

Fig. 2 The connection between the weight of Cyanobacteria number and the CBO_5 concentration on the Bahlui – Tomesti Section, 1994

2.3 Water chemical composition and the zooplankton interaction on the Bahlui River

The quantities low oxygen dissolve led to the appearance and the development on the Bahlui zooplankton of numerous *Ciliata* and *Rotatoria* (*Colpidium colpoda, Litonotus lamella,* namely *Rotaria citrina* si *Rotaria neptunia*), species specific to highly polluted polisaprobe water fig. no. 3.

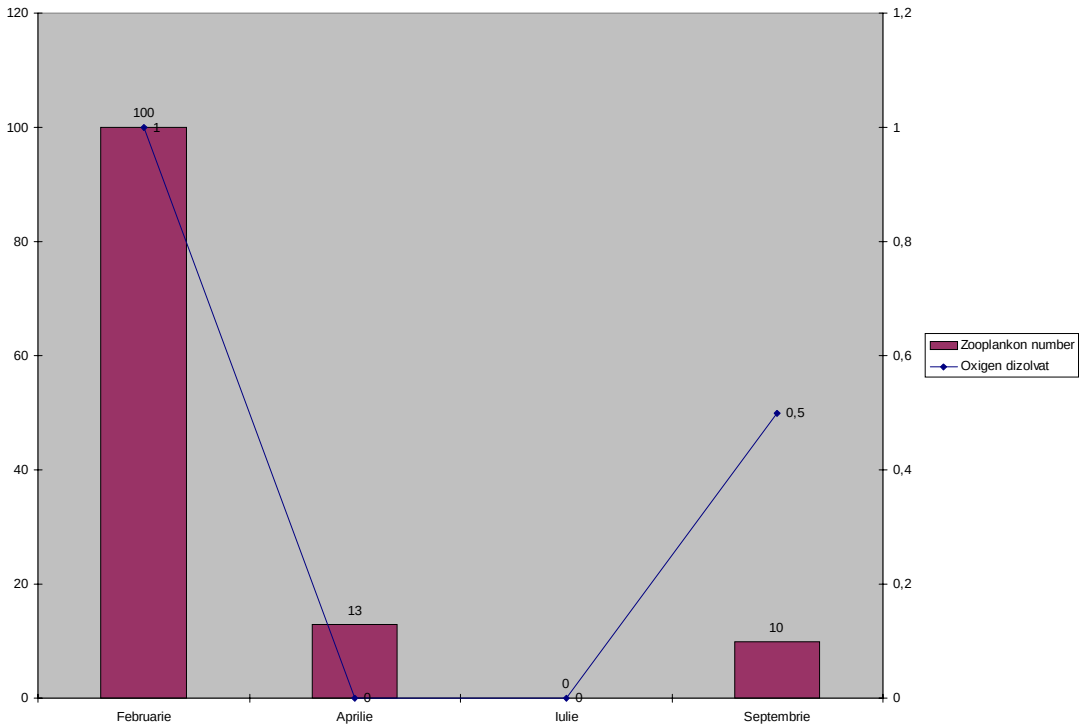

Fig. 3 The connection between the number of zooplankton and the oxygen concentration on the Bahlui – Tomesti Section, 1994

2.4 The chemical composition of the sediments and zoobenthos interactions on the Bahlui River

At this station, the Bahlui has a bed muddy river. The permanent deposits of suspensions coming mostly from the Purification Station of Iasi gave the black colour and the strong domestic smell to the sediments. Just as in case of zooplankton, in July, September, 1993 and July, 1995, it wasn't evidence the benthic fauna, due to the absence of dissolved oxygen for a long time

The zoobenthos qualitative analyses, in connection with the physical-chemical analyses, stated a poor fauna, made up of a limited number of species, Oligochaetae (*Limnodrilus hoffmeisterii*, *Limnodrilus udekemianus*, *Tubifex tubifex*) and the larvaes of chironomids: (*Chironomus plumosus*, *Chironomus thummi*), specific to high impurification polisaprobic level, dominating the whole period of research.

3 Jijia River

3.1 The chemical water composition and the microbiota interactions on the Jija River.

Jija River, at Chiperesti Station, similar to the Bahlui from the physical-chemical point of view, especially the organic substances, the dissolved oxygen, ammonium, nitrogen and total phosphorus contents, is characterised as a "degraded" category, the great number of total coliforms bacteria (over 100, 000/dmc), showing the characteristics of strongly polluted water fig. no. 4.

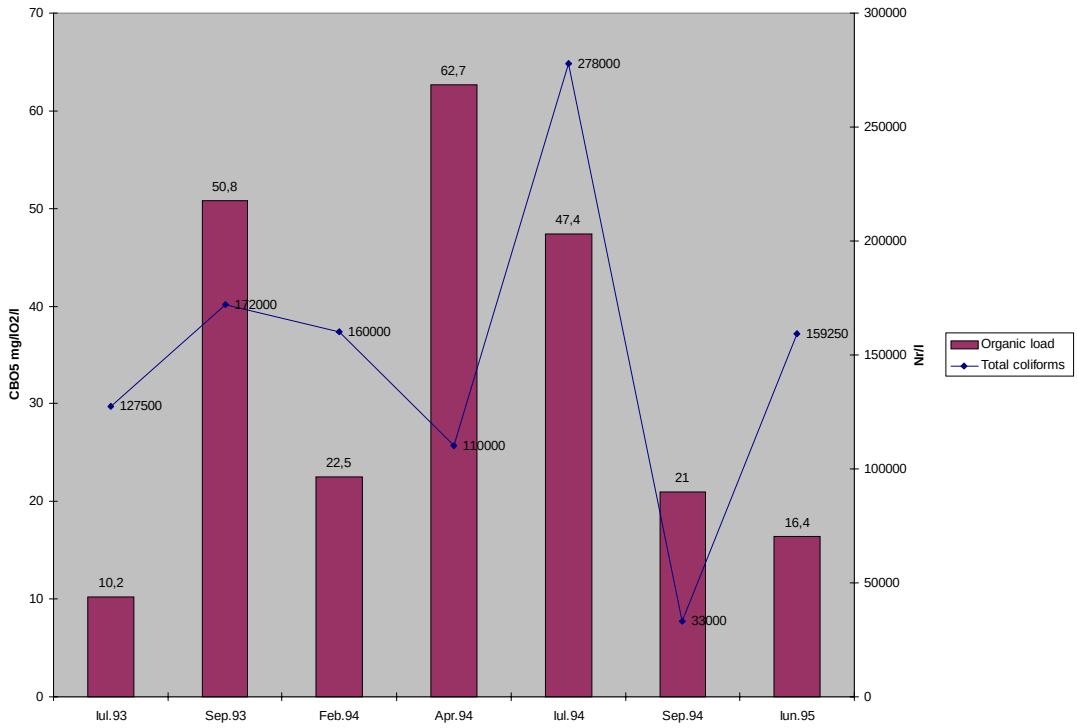

Fig. 4 The variation of the total coliforms and organic load of Jijia River at Chiperesti Section, from July 1993 to June 1995.

3.2 The chemical composition of water and the phytoplankton interactions on the Jijia River

Physical-chemical analyses of River Jijia, after it assimilate the strongly impurified waters of the Bahlui River, show big organic load, ammonium, nitrogen, total phosphorus values and dissolved oxygen is absent or can be found only in low concentrations. After the sampling in the winter time, due to the hot waters evacuated by the Steam Power Station Holboca, the temperature of the water was 2-3°C higher the Prut temperature, the freezing phenomenon didn't show up.

The relatively low organic load values (10.2-19.0 mgO_2/l CBO_5) throughout winter-summer period of 1993, led to the development in high percent (44.7-76.15%) of B*acillariophyta*, dominated by the species: *Cyclotella meneghiniana*, *Navicula cryptocephala*, *Nitzschia acicularis*, *Nitzschia palea*, specific to polluted waters. At the same time, together with the rising of organical load (21.0-62. mgO_2/l CBO_5) and the falling of the dissolved oxygen concentration, the B*acillariophyta* were replaced by *Cyanobacteria* and *Euglenophyta* represented by the species: *Aphanizomenon flos-aquae*, *Anabaena flos-aquae*, *Oscillatoria limosa* and *Lepocinclis ovum*, *Phacus caudatus*, *Phacus tortus*, *Strombomonas verrucosa*, specific to highly impurified λ-ρolisaprobic level. fig. nr. 5.

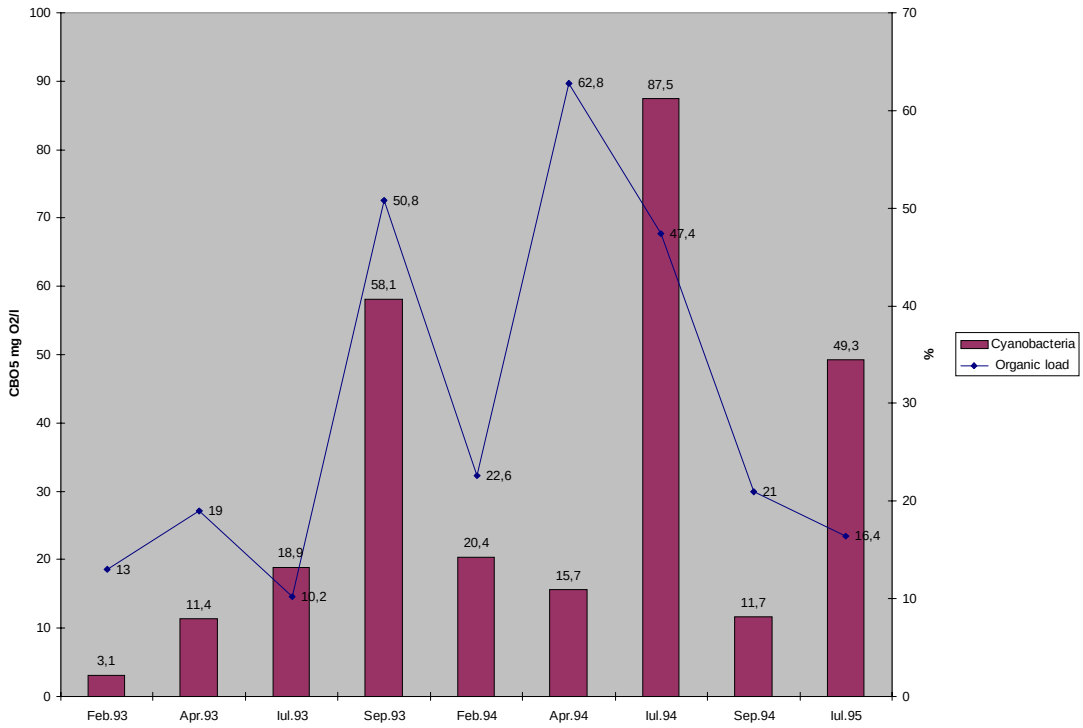

Fig. 5 The connection between the number of cyanobacteria and the CBO_5 concentration on the Jijia – Chiperesti Section, from 1993 to 1995

3.3 Water chemical composition and the zooplankton interaction at the Jijia River

The absence of dissolved oxygen influenced directly the development and the evolution of the Jijia zooplankton in summer time (July, 1993,1994,1995) causing the disappearance of organisms in the Jijia plankton, at this station. During the other sampling periods, the low dissolved oxygen quantities allowed the development in zooplankton of *Rotatoria* represented by: *Rotaria citrina* and *Rotaria neptunia* and the *Ciliata* represented by: *Colpidium colpoda* and *Litonotus fasciola*, species specific to strongly impurified ρolisaprobic level fig. no. 6.

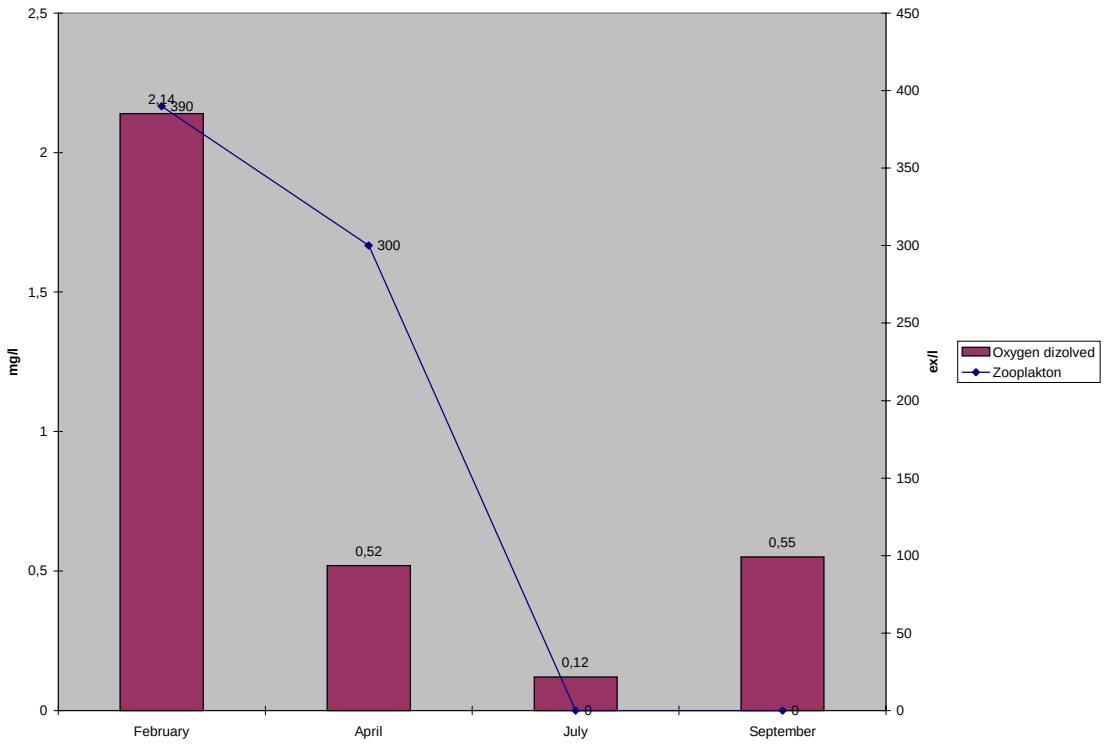

Fig. 6 The connection between the number of zooplankton and the dissolved oxygen concentration at the Jijia - Chiperesti Section, 1993.

3.4 The sediments chemical composition and zoobenthos interactions on the Jijia River

At Chiperesti Station, the Jija River specific is a muddy-sandy bed of the river, black colour and persistent domestic smell. The zoobenthos is dominated by a poor fauna, made up of *Oligochaeta*, represented by: *Limnodrilus hofmeisterii, Limnodrilus udekemianus,Tubificidae Tubifex tubifex* and *Chironomidae larvae* : *Chironomus plumosus, Chironomus thummi,* species specific to strongly impurified ρolisaprobic level. The zoobenthos sample analyses showed that, at 6 of the 9 sample, due to the evacuations of the heavy oil fractions from the Steam Power Station. Holboca and the absence of dissolved oxygen, the benthic organisms were absent.

4 Prut River

4.1 Water chemical composition and the microbiota interactions on the Prut River.

In order to understand the bacterioplankton and the chemical composition water interactions, we have studied from quantitative point of view, the total coliforms bacteria, ranged by the Romaniaan Standard, regarding the water quality, related to the variation of the main indicator for the oxygen status and the organic load (CBO_5).

The total coliform bacteria have a numerical evolution, similar to the organically load values, ranged in CBO_5. This matter can be explained by the fact that the main residual waters evacuations, which bring significant organic load, are the tributary of the Local Purification Station of Iasi (partially functioning) and the C.S. Comtom Tomesti drains. These evacuations are domestic waters, provided by the city inhabitants and the pigs farms, which normally contain a high number of coliforms bacteria.

The Prut, at the stations placed on the middle and inferior sections, exception the station placed downstream the confluence with the Jijia, has a low number of coliforms bacteria, in connection with the low organic load values, specific to clean waters. The highest values of coloforms

bacteria number were found all the time at the station placed downstream the confluence with the Jijia, this being loaded after the confluence with the Bahlui, a receptor of organic and bacterial loaded waters fig. No. 7.

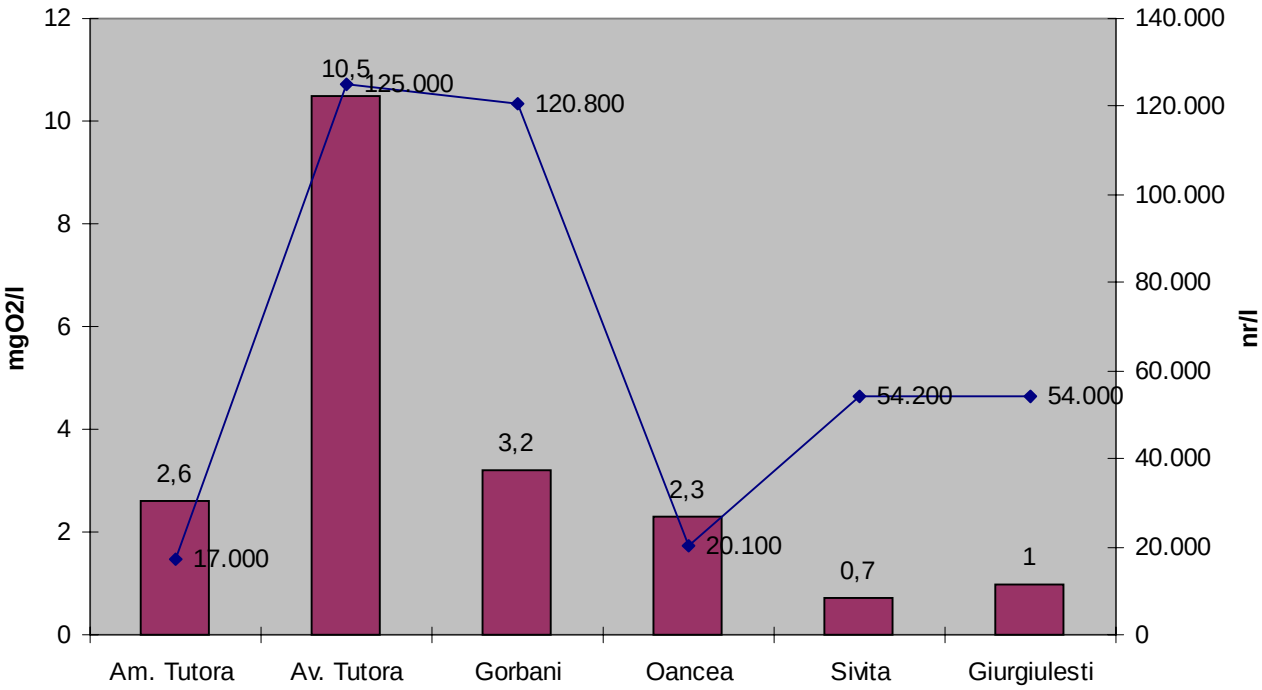

Fig. 7 The variation of the total coliforms number related to the organic load (CBO_5) on the Prut, during the September, 1992 research

4.2 Water chemical composition and the phytoplankton interaction on Prut River

From the physical-chemical point of view regarding the Prut, throughout the entire researched course, it has a static evolution, having certain properties which permit the development in phytoplancton of the species specific to clean waters. The station, where the Prut's River water was "degraded", due to the confluence with the Jijia, which flows highly impurity, is the station placed downstream Tutora. It is hard to link the water chemical composition to the biomass and the number of species, because the number of taxons can't be detected in the biomass, when in phytoplankton are existing *Cyanobacteria*, *Euglenophyta* and *Dynophyta* species, having a high volume, consequently chemical composition water and the phytoplancton interactions will be analysed searching the evolution of the organic load, dissolved oxygen, nitrogen, total phosphorus values, the total number of the phytoplankton and indicating species.

From a quantitative point of view, the Prut phytoplankton, throughout the 4-5 year researches, was dominated by *Bacillariophyta*, followed by *Chlorophyta*, *Euglennophyta* and *Cyanobacteria*. On the middle section between the Oroftiana-Darabani – Sculeni station and the downstream Tutora station, the organical load (CBO_5) has low values, specific to clean surface waters and in phytoplanton there are certain species, such as: *Amphora ovalis, Asterionella formosa, Ceratoneis arcus, Cymbella ventricosa, Melosira varians, Navicula rhynchocephala, Synedra acus, Actinastrum Hantzschii, Ankistrodesmus falcatus, Crucigenia rectangularis, Panorina morum, Pediastrum duplex, Scenedesmus quadricauda*, specific to oligo-β mezosaprobic waters. At the downstream Tutora Station, the impact of Jijia is obvious, which flows highly impurity (in 1993, the organically load shows the highest medium value - 47 mgO_2/l CBO_5) and middle impurity in the other years 6-10,5 mgO_2/l CBO_5 and low dissolved oxygen values, up to the Oancea station, in phytoplankton there are certain species of the:

Cyanobacteria, *Euglenophyta* and *Bacillariophyta Anabaena flos-aquae*, *Aphanizomenon flos-aquae*, *Oscillatoria limosa*, *Lepocinclis ovum*, *Phacus tortus*, *Strombomonas verrucosa*, *Cyclotella meneghiniana*, *Navicula cryptocephala*, *Nitzschia palea*, species specific to polluted waters. The last stations placed on the inferior section, the furthest owes from the confluence, with the Jijia, together with falling of the organic load values and with the rising of the dissolved oxygen, due to the process of self-purification and the permanent support of the upstream species, the biocoenotic balance is re-established and in phytoplankton there come again with a great abundance the *Chlorophytae*: *Crucigenia rectangularis*, *Pandorina morum*, *Scenedesmus abundans*, which together with the *Bacillariophyta* show an improving of the Prut water quality.

In June and September, throughout the whole research period, especially at the stations placed on the inferior section, where the river has a slower flow, together with the rising of temperature, the presence of nitrogen and total phosphorus, without to evidence the appearance of eutrophycation process, there is a numerical development in phytoplankton - fig. no. 8, 9, 10.

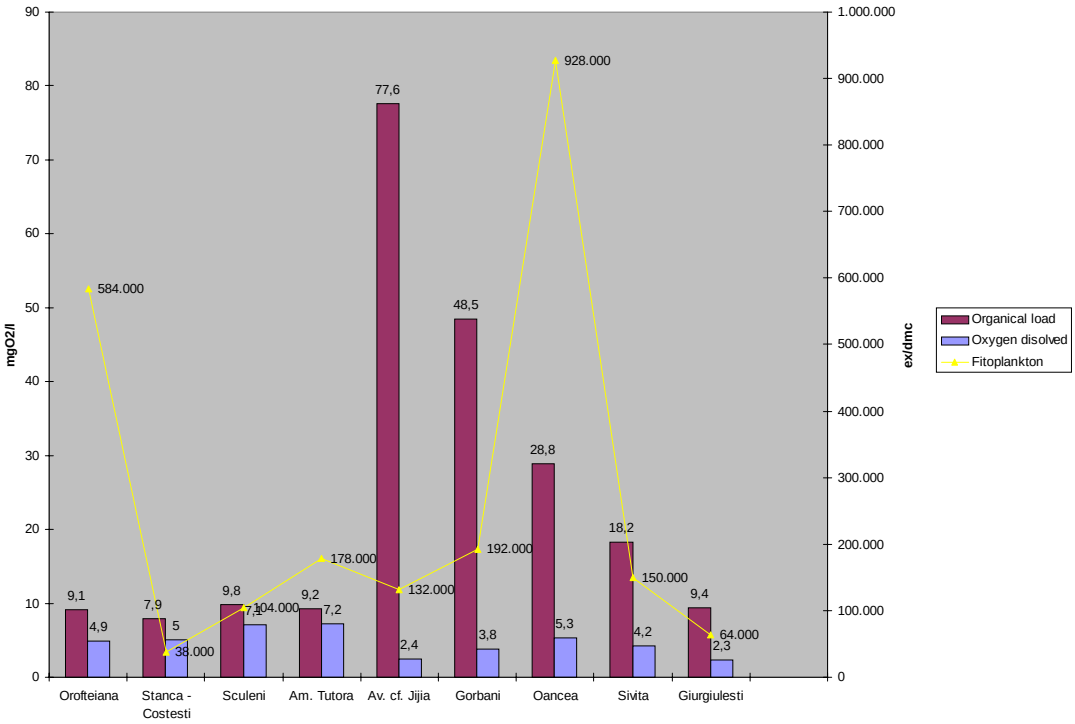

Fig. 8 The connection between the number of the phytoplanctons species and the dissolved oxygen and the CCO-Cr concentrations on the Prut, during the September, 1994 research

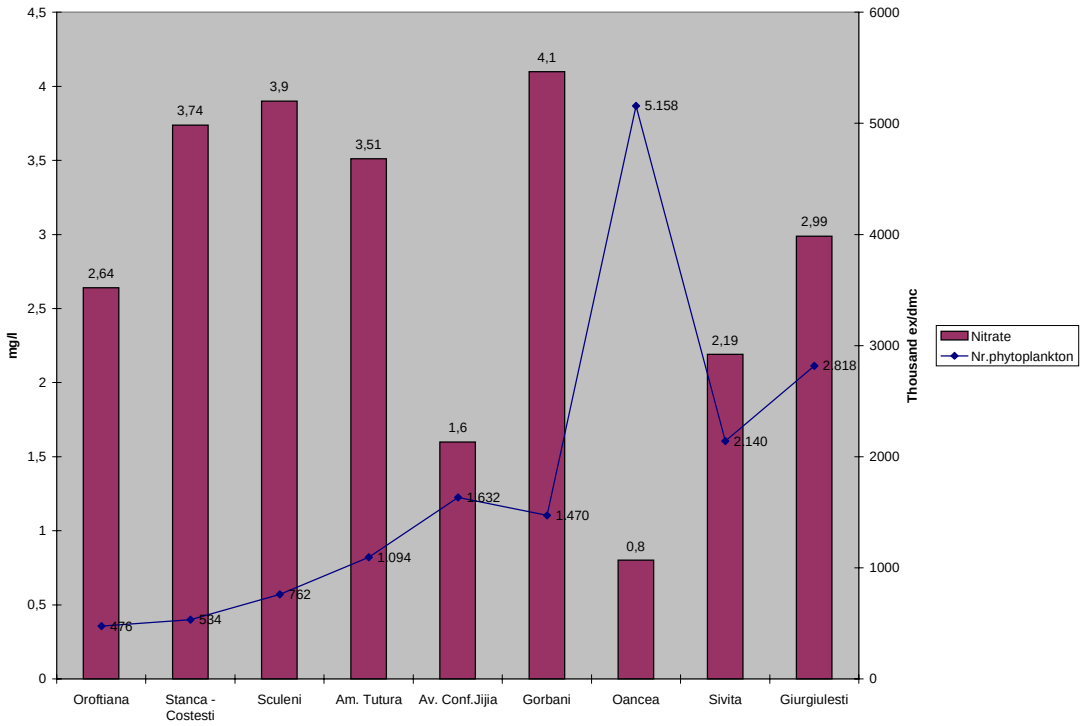

Fig. 9 The connection between the number of the phytoplanctons species and the nitrogen concentrations in the Prut River, during the April, 1994 research.

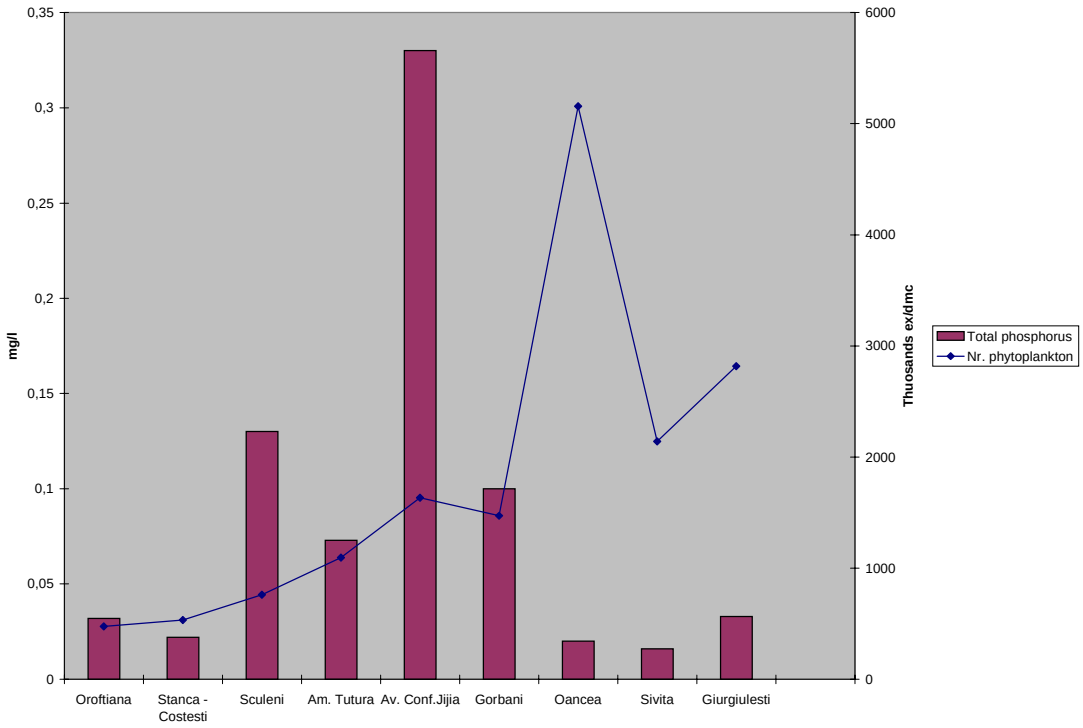

Fig. 10 The connection between the number of the phytoplanctons species and the total phosphorus concentrations on the Prut River, during the April, 1994 research.

4.3 Water chemical composition and the zooplankton interaction on the Prut River

The analysis on taxonomic groups of zooplankton showed, throughout the research period, a low number of zooplanktons, *Roratoria* having the highest percent, followed by *Copepoda*, *Cladocera* and *Ciliata*. On the middle section, similar to phytoplankton, in the Prut zooplankton there are certain species, such as: *Asplanchna priodonta*, *Keratella quadrata*, *Bosmina longirostris*, *Moina rectirostri*, specific to low polluted waters. On the inferior section, at the upstream station the confluence with the Jija, up to Oancea station, together with the rising of turbidity and the organic load and the falling of the dissolved oxygen concentration, even if *Rotatoria* remain the dominant group, the highly frequent species are: *Rotaria citrina* and *Rotaria neptunia*, which *Ciliata*: *Colpidium colpoda*, *Litonotus fasciola*, *Litonotus lamella* and *Paramaecium putrinum*, range the Prut River in the caregory of high pollution waters. At the other stations placed on this, Sivita and Giurgiulesti Gura Prut, even if the number of species remains the same, the zooplankton qualitative structure gets better and specific medium polluted waters species reappear in high percent fig. No. 11.

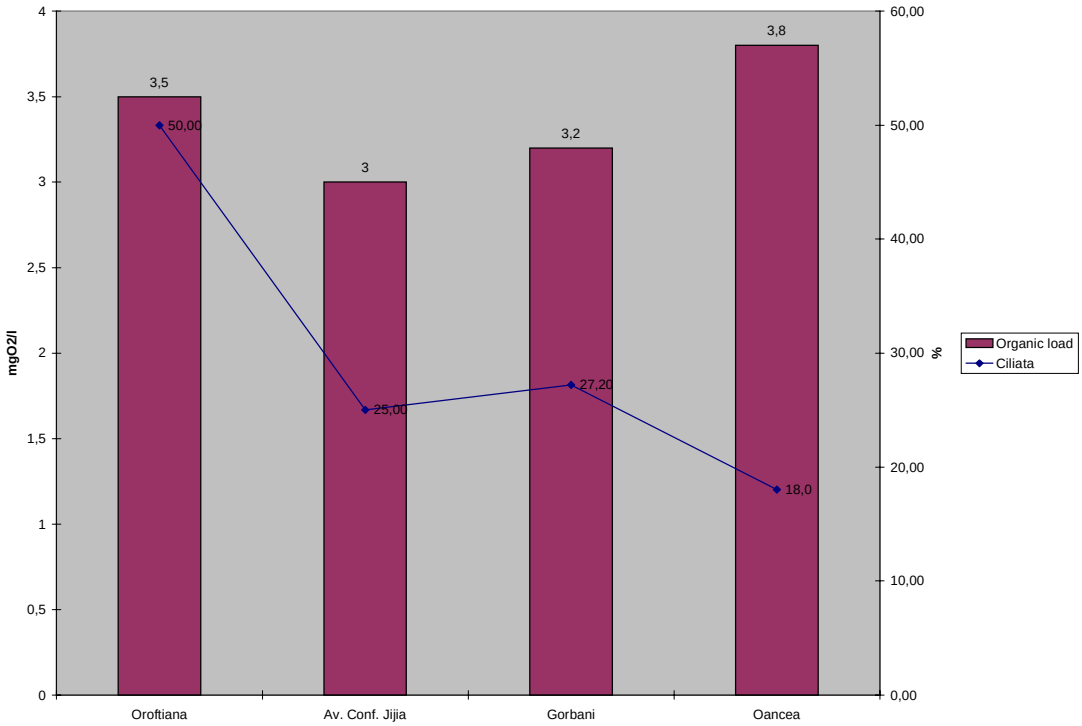

Fig. 11 The connection between the ciliates number and the organic load concentration of Prut River 1993.

4.4 The sediments chemical composition and zoobenthos interactions on the Prut River

The analysis of the benthonic biocenossis components has a representative role in establishing the water quality, the benthonic species are the ones ready to change immediately by the environment factors, being much more sensitive than the phytoplankton species.

The appreciation of changes benthonic biocoenosis was done in the same way as in the case of plankton biocenosis component, taking into consideration the section of the Prut River: middle and inferior.

The sediments samples were have taken from all the stations, and it has done physical-chemical analyses which didn't show high values of nitrogen, phosphates and heavy metals (Zn, Hg, Cu, Pb).

The quantitative and qualitative determinations of the zoobenthos, consequently are addicted to: the nature the bed of the river, the flow system and the presence of pollution sources.

The split of the benthonic organisms on the Prut River shows significant differences between the two sections.

The middle section, where the bed of the river is characterised by a substratum made up of rocks and pebbles, by the relatively powerful water current, by high transparency, the temperature in summer time reaches 20° C, the oxygen concentrations reach high values, and the organic load low values. The zoobenthos community structure is made up of the chriotherms, rheofile and polioxyfile species. The organisms associations are made up of a great numbers of systematic groups: *Coelenterata*, *Nematoda*, *Gastropoda*, *Bivalva*, *Oligochaeta*, *Amphypod*a and *Insecta*. Due to the low values of the organic level and high concentrations of dissolved oxygen, specific to low pollution waters, the benthonic organisms show obviously in this section the presence of the insects in high percents: *Baetis rhodani*, *Baetis buceratus*, *Caenis macrura*, *Ephemerella ignita*, *Amphypoda*: *Pseudogammarus balcanicus*, *Bivalvia - Dreissena polymorpha*, *Gastropoda - Ancylus fluviatilis*, *Nematoda*, *Oligochaeta* and larvs of *Chironomidae* being present in low percents. At the station placed downstream the accumulation lake Stefanesti Sanca Costesti and Sculeni, where hydrotehnical and craft works were done, in zoobenthos there are certain species such as: *Caenis macrura* and *Palingenia longicauda*, specific to disturbed ecosystems.

The inferior section is characterised by a low sided the bed river, faces, clay-sand nature, low current speed and low transparency. The water temperature is over 22° C. Organic load has higher values, comparing them to those recorded on the middle section. The station placed downstream Tutora shows throughout the research period, the highest values of organic load, specific to polluted waters. In July, at the most stations placed on section, the dissolved oxygen shows low concentrations.

The benthic community is part of the potamon and is made up of eurithermes, reotolerants species, specific to slow ecosystems. At the station placed downstream Tutora, the benthic biocoenosis has a composition similar to that found at the upstream stations, but noticing that the *Nematoda*, *Oligochaeta* and *Insecta* larvas are found in a greater number, the river being included in the β – mexosaprobic level (medium impurification). At the station placed downstream the confluence with Jijia River, together with rising of organic load values and the falling of dissolved oxygen concentrations, the zoobenthos is made up of predominant O*ligochaeta* and C*hironomidae* larvas: *Limnodrilus hofmeisteri*, *Limnodrilus udekemianus*, *Chironomus plumosus* and *Chironomus thummi* species specific to “degraded” waters. At the stations placed between Gorban-Albita and Oancea, the distance of the pollution source rises although, the low current velocity and sediment deposits slow down the self-purification, the benthic fauna keeping on being made up of the same organism groups mentioned above, but on some sample there are found also insects: *Baetis rhodani* and *Baetis buceratus*, species specific to the impurification waters. The last stations placed on this section Sivita and Giurgiulesti Gura Prut, in zoobenthos there come again *Gastropda*: *Planorbis planorbis*, *Viviparus viviparus*,, *Bivalvia-Anodonta cygnea*, *Amphypoda-Pseudogammarus balcanicus* and *Insecta*: *Baetis rhodani*, *Caenis macrura*, species specific to medium β-saprobic impurification waters fig. No. 12.

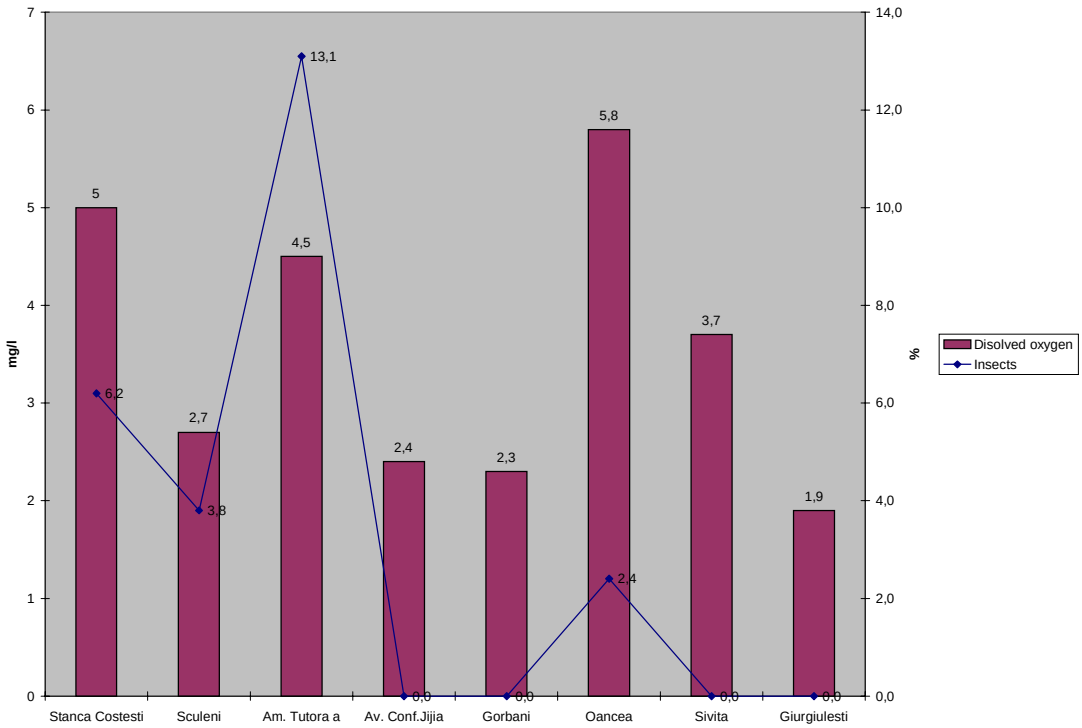

Fig. 12 The connection between of the insects number and the dissolved oxygen concentration on the Prut during July 1994 research.

Conclusion

Starting from the hypothesis the dynamic balance of ecosystems is based not only on the linking between species and environmental factors, bur also on the mutual connection among the species, the present work stated that the following facts:

The possible number of total coliform bacteria had a similar evolution to the organic load values, ranged on CBO_5. At the station placed on the middle and inferior sections excepting the station placed downstream the confluence with the Jijia River, the Prut River has a low number of total coliform bacteria, a fact that links to the low organic load values;

It is difficult to link the chemical composition of the water, to the biomass and to the number of species, because the number of taxons is not well detected in the biomass, when in the phytoplankton the species *Cyanobacteria*, *Euglenophyta* and *Dynophyta* appear, having a high volume;

The interaction of the chemical composition of the water and plankton and the benthic fauna showed a good correlation between the values of the main indicators for the quality water: the organic load, oxygen, nitrogen, total phosphorus and the total number and characteristic species.

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Some Ecological Interactions Between Biotic and Abiotic Factors from Aquatic Ecosystems

Graziella Jula

Abstract: Human interventions in hydrological, bio-geo-chemical cycles is necessary. As an inevitable part of social development, water is extracted from its natural system context and made accessible for various purposes and functions in society. Gradually water is returned to the environment but with other quality and quantity characteristics.
Thus the relationship between water resources development and productive capacity of ecosystems should be harmonised.
To achieve this purpose, to minimise the harmful effects on the life-support systems (which means to promote the sustainable development), the multidisciplinary framework of ecosystemic approach has been more and more promoted.
The paper presents the interactions between biotic and abiotic factors (hydrological, physical-chemical) in the light of ecosystem approach.

Key words: interactions, ecosystem ,biotic factors, abiotic factors, phytoplankton, zooplankton, zoobenthos

Einige ökologischen WechselWirkungen zwischen biotische und abiotische Faktoren die aquatischen Ökosystemen

Zusammenfassung: Menschliche Eingreifungen in den hydrolgischen Kreislaufen; die bio/geochemischen Kreislaufen sind notwendig. Als unvermeindlicher teil der gesellschaftlichen Entwicklung, ist das Wasser aus dem umgebenden Zusammenhang seiner natürlichen Systems gefördert, damit in den verschidenen Zwecken und Funktionen der Gesellschaft zugänglich werdend. Graduell, wiederkommt, das Wasser im Umwlt, aber mit anderen qualitativen und quantitativen Eingenschaften.
Demnach, sollte man die Beziehung von Wasser-bodenschätzeentwicklung zum produktiven Vermögen der Ökosystemen in Einklang gebracht werden.
Zum Erreichen dieses Zwecks, um die schödlichen Auswirkungen auf die Lebensstützesystemen zu vermindern (was eine Förderung der dauerhaften Entwicklung heißt), wurde immer mehr den vieldisziplinären Rahmen des ökosystemischen angenommen) holistischen Behandlung gefördert.
Die Arbeit stellt die Wechselwirkungen der biotischen und abiotischen (hydrologischen, physisch-chemischen) Faktoren dar, im Rahmen des ökosystemischen Behandlung.
Schlüßelworte: Wechselwirkungen, holistische ökosystemische Behandlung, Ökosystem, biotische Faktoren, abiotische Faktoren.

Introduction

The very many different aspects regarding water monitoring and water management strategies have been elaborated with increasing emphasis over the past decade on ecosystem approach, which is more capable of determining cause-effect relationships.

The ecosystem approach recognises the importance of taking into account all the ecological aspects of aquatic ecosystems, the guidelines of the [UN/ECE,1993] and [UN/ECE,1993,a] stating that " ecosystems assessment should be based on integrated criteria in terms of water quality and quantity as well as flora and fauna" and " the ecosystems approach has to rely more than usual on continuous liaison between disciplines involved in monitoring"./6./

Unlike the divergent, sectorial /simplistic approaches (promoted by the 1985s) which ignore the interdependency among different parameters, the ecosystem approach is possible without the explanation not only of direct relations, but also of those undirect among different components and on this base it is possible to predict some possible cumulated effects which could influence the equilibrium and the functionality of aquatic ecosystems on long-term.

To this point, in order to get a complex image on the effects of human pressure (respectively the construction of hydropower dams and subsequently of system reservoirs) on structure and functionality of aquatic ecosystems, the interactions between biotic and abiotic factors have to be presented within the ecosystem framework .

Aspects of the interactions among biotic and abiotic factors

The human interventions in hydrological, bio-geo-chemical cycles as an inevitable part of social development, expressed through the construction of hydropower dams and reservoir**s** lead to the modification of natural biotop and implicitly to the modification of the biocenosis.

Owing to the modifications of abiotic factors and closely correlated with their dynamics, life from reservoirs gets new valecies.In their turn, the components of biocenoses , through their activity, modulate in time and space the abiotic factors.

Thus the set-up (construction) of a reservoir doesn't assume only the replacement of a lothic biotop with a lenthic one, but also an ample diversification of the habitat which complicates the structure and the functionality of the new ecosystems.

Under these circumstances the interactions between hydrological, physical-chemical and biological elements play an important role in obtaining a comprehensive image of effects of water flow in set-up systems .

The intervention in hydrological cycle of river of origin (through its transformation into reservoirs) have led to the hydro-morphological and physical changes ,among which the most important are the following :

- the accentuated decrease of water flow velocity
- the appearance of stagnant or semistagnant water zones
- the local increase of depth and width of river bed of origin (near the dam)
- the reduction of water flow slope
- the disparition of shore areas suitable for the development of some ontogenetical stages of fish development and of other organisms
- the temporary installment of thermical stratification (where the case be)
- the accentuation of sedimentation
- the decrease of water turbidity which leads to the amplification of trophogenic zone

These changes will determine modifications of bio-geo-chemical cycles, having, in view , the permanent and mutual interactions and feed-back relations between biotic and abiotic factors., which has an important role in the organization and self-control of ecosystem.

Results and discussions

As a case study ,one of the major rivers of Romania (the Olt river) with a length of 670 km, a basin surface of 24010km2, an average multiannual flow of 6 billion m3 has been selected, being ,at the same time, one of the most developed watercourses towards hydroenergetical purpose. This development started in 1970 and will include finally 30 hydropower dams of small fall, which will use a total fall of 413 m ensuring the instalment of total power of 1095 MW and the production of average energy of 2775 GWh/year.

During the time, The Olt river has been subject to a complex anthropogenic intervention , expressed through the cumulative effect of a various range of disturbing factors (direct, undirect) from the upstream and from its own disturbing factors.

The repercutations of anthropogenic activity have occurred at the level of abiotic factors ,as well as at the level of biotic ones, between these existing mutual interactions and interconditionings.

From spatial point of view, there were chosen sampling points which belong both to the studied ecosystem and to the adjoining areas (upstream and downstream), named segment. The selected reservoir is situated in the middle third part of the Olt river, the morphologic and exploitation features of which are the following :

- the volume V_{NNR} = 8200000 m^3
- the depth (near the dam) = 12 m
- average flow = 93.45m^3/s
- installed power = 24.9 MW
- average energy = 58 GWh/year
- retention time = 24.48 hours ~1.02 day

For obtaining a more comlpex image, the interactions were studied at one hand at the level of biotop-biocenosis and on the other hand within the biocenosis.

Regarding the existing interactions between phytoplankton and abiotic factors the following aspects have resulted:

- the low retention time of the reservoir (about 24 hours) have determined the dominating development of the diatoms (which are reophile forms, confirming the data from literature)/5/.
- the solid (kg/s) and liquid flows (m^3/s) with higher values during the spring (when there is a high turbidity and a lower transparency) have determined the more reduced development of microalgal vegetation, in comparison with summer.(fig.1).

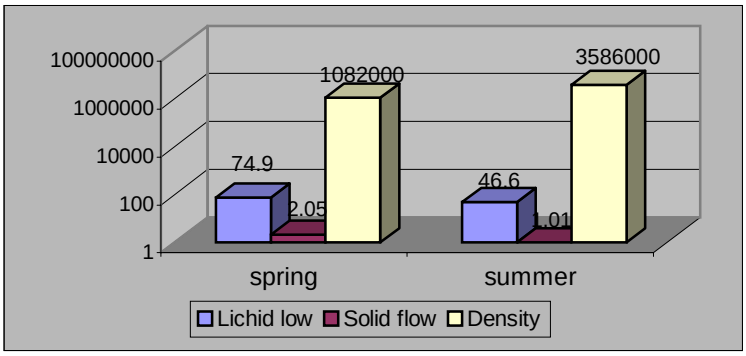

Fig.1 The variation of lichi,solid flows and density of phytoplankton -1996

- the increase of temperature (during the summer, corroborated with the increase of transparency and with other favorising and determining factors) has stimulated the phytoplankton development (tabel 1).

Table 1 The variations of temperature, transparency and density of phytoplankton-1996

Sampling point	Parameters		
	Temperature	Transparency -cm	Density–exp/l
Dam 0m-spring	1	90	1082000
Dam 0m-summer	21,5	120	3586000

- the ionic reaction of water has modified towards the increase of its values, subsequently of the algal development. The highest values were recorded in the sampling point Dam 0m (8.2), where the highest values of algal density were obtained, as well .

- the development of algal vegetation has determined an increase of oxygen concentration produced by photosynthesis process, sometimes reaching the situation of oxygen saturation (up to 16o mg O_2/l)
- the chemical oxygen demand (KMnO4) and the biodegradability of organic substances (BOD $_5$) have evolved from spatial and temporal point of view in accordance with the values of densiy and biomass, showing the existence of higher values in lentic areas, especially near the dam –0m, where the effects of water storage are best felt (fig.2).

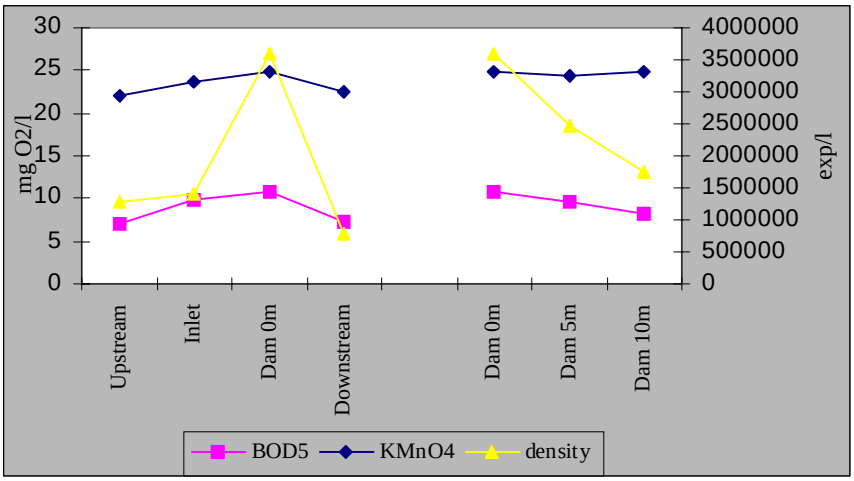

Fig.2 The variations of DBO_5, COD and density of phytoplankton

- regarding the correlations between the nutrient concentrations (total mineral nitrogen and total phosphorus) and the development of phytoplankton (this represents one of the recycling channels of mineral elements) the reduction of nutrient concentration has been noted during the summer, in comparison with recorded values from spring (consequence of their consumption in the vegetal neosyntesis process (fig.3)

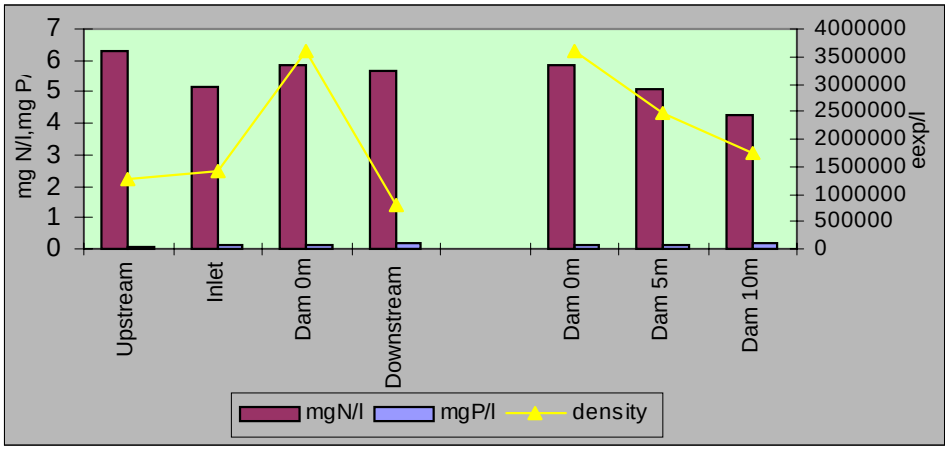

Fig.3 The correlations between nutrients and density of phytoplankton

- consequence of changes of biotop of origin, the biodiversity has presented a reduction of Simpson index values in lentic points, in comparison with those which work in the lotic regime. Temporary, the values of biodiversity index have presented a slight increasing tendency during the spring and autumn , in comparison with summer (fig.4).

- also, the similarity degree quantified through the Sorrenson index has highlighted the existence of higher values among the sections which works in the similar regime (65%- between lentic sections)

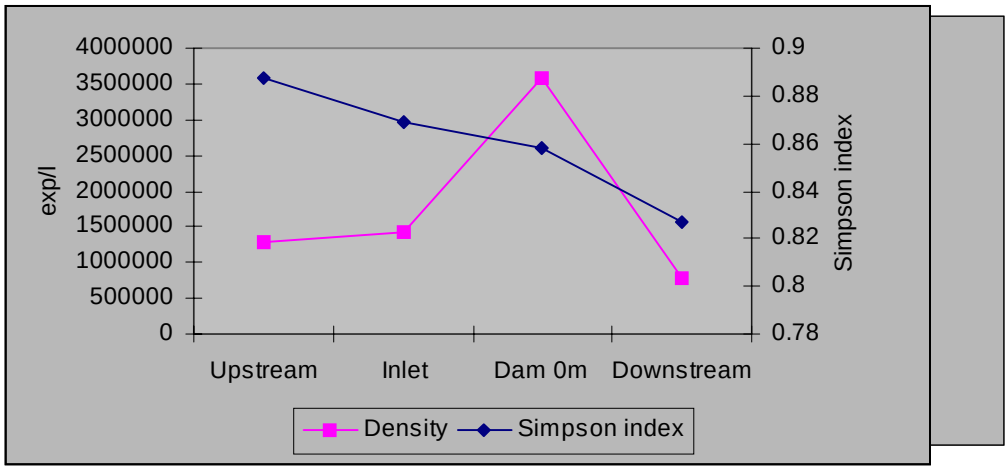

Fig.4 The variation of density of phytoplankton and Simpson index

At the level of zooplankton , the correlations between its representation, from qualitative and quantitative point of view and the effects of the change of biotop of origin, are less expressive owing to the a low general representation of zooplanktonic organisms (consequence of the low retention time of this reservoir), on one hand and, , and the tendency of anthopisated ecosystems to produce a primary production uncovered by consumption (P/C>1) on the other hand.

At the level of substratum, it has been observed a longitudinal zoning of sediment distribution, in the sense of a substratum represented by cobble, stone, gravel in lotic sections and sand and muddy-sandy in lentic sections. Thus, the existence of types of different substrata in these sections **.** The forms which belong to *Ephemeroptera*, *Plecoptera*, *Trichoptera* groups were observed only in the lotic areas, whereas the forms of Vermes (Oligocheta) and Diptera (Chironomida) have been recorded in the both types of zones (being constant forms).

Regarding the interactions at the *biocenotical level* the following have been noted:

- the microbiota (the probable number of heterotrophic bacteria) has indicated a direct correlation between the increase of its values and the increase of organic substance quantity (algal density and biomass) and its biodegradability –BOD_5 (fig.5).

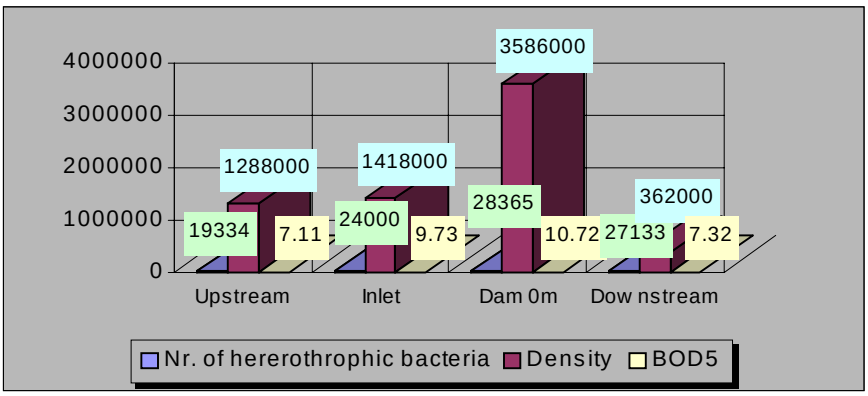

Fig 5 The variation of heterothrophic bacteria, density of phytoplankton and BOD_5

The structure and dynamics of algal associations is also influenced by the presence of zooplankton, by the ratio bewteen the algae which can be consumed by the primary consumers.

As previously shown, the phytoplankton is made up espeecially of diatoms, which (although in some period of year reach high biomass) they do not have high trophical value.

The decrease of trophical status has been corelated with the increase of taxonomical diversity indicating a higher stability of these**.**

Conclusions

- the multidisciplinary framework of ecosystem approach represents the basis of sustainable development
- the anthropogenic impact on aquatic ecosystems has produced changes at the level of biotop and biocenosys
- the analysis of interactions between biotic and abiotic factors expressed the changes of structure and functionality of ecosystem
- these interactions have highlighted the mutual and permanent interconditionings and feed-back relations which take place .in the maintaining of stability and self-control of the aquatic ecosystems.

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The Movement of Radionuclides of the Danube River in the Last Eight Years

Zoltán Kassai

Abstract: Being an international river, the Danube is loaded with waste water from nuclear power plants as well as nuclear research centres and hospitals.

Radiological monitoring of the Danube has been carried out in all countries along the Danube. There are a number of sources of radioactive pollutants of the water of the river Danube which may be measured.

A routine programme for monitoring the levels of radioactivity in the Danube in Slovakia has been carried out for many years by the Water Research Institute in Bratislava, at the Radiology laboratory, systematic observation quality where has been taking part in water since 1973.

The main sampling sites at which measurements were taken are Bratislava, Hrušovo, Medveďov, Čuňovo, Komárno, Szob. Takings are realized 12 times a year, total beta are measured and strontium-90, tritium, caesium-137 are analysed four times.

Furthermore, two times a year sediments are analysed; the total alpha, total beta and γ emitting nuclides are determined in the sediments.

All of the countries around the Danube are concerned about the smallest radiological loading of the Danube.

Key words: radioactivity, contamination, sediment, quality of water, radioactive elements

Radioaktivitätsentwicklung der Donau in den letzten acht Jahren

Zusammenfassung: Die Donau ist ein internationaler Fluss, in den sich Abwässer aus mehreren Kernkraftwerken, wissenschaftlichen Kernanlagen und Krankenhäusern ergießen.

Die Bestimmung der Radioaktivität der Donau, die Grundwassergüte von Žitný ostrov (des sogenannten binnenländischen Donaudeltas) beeinflusst, ist von Gesichtspunkt der Trinkwasserversorgung von Bratislava und Žitný ostrov von großer Bedeutung.

Routineüberwachung des Donauradioaktivitätsniveaus auf dem Gebiet der Slovakei wird in der Radiologieabteilung des Forschungsinstituts für Wasserwirtschaft schon mehr als drei Jahrzehnte durchgeführt. Die systematische Kontrolle verläuft seit dem Jahr 1973.

In dem slowakischen Donauabschnitt gibt es sechs Entnahmestellen, wo Wasserproben jeden Monat zur Bestimmung der Beta-Volumenaktivität und viermal jährlich zur Bestimmung weiterer radiologischen Kennziffern entnommen werden. Die Donausedimente werden zweimal jährlich in drei Lokalitäten entnommen.

Schlüsselworte: Radioaktivität, Kontamination, Sedimente, Wassergüte, radioaktive Elemente

Introduction

A point of view by supplying the population of Bratislava and Žitný Ostrov with drinking water is very important. The determined radioactivity of the river Danube influences the quality of underground water on Žitný Ostrov.

We must protect and care about these sources of water before contamination including radioactivity contamination, because Žitný ostrov is a unique supply of undergraund water.

Radioactive materials are considered besides of organic polutants and metals to be the most dangerous polutants. The influence of the contents of radioactive contaminants on the environment including hydrosfery is due mainly to the activity of nuclear power plants, places working with radioactivity and uranium mines.

The nuclear power plants produce a wide of spectrum of radioisotops. Waste water with low radioactivity is emited to the river Danube, which achieves a considerable diluteing.Tritium mainly characterises liquid emitted waste, ceasium-137, strontium-90 and cobalt-60 with long half-life charge. After the accident in Černobyl (1986) hydrosfere is contaminated by radioisotops as Cs - 134, Cs -137 and Sr – 90.

Water

The part of the river Danube is relatively short in Slovakia, and its length is 172,1 km. It hasn´t a uniform character. The upper part is the short part that has a character of a mountain river, the lower part has a lowland river character].

In this part are the tributaries: Váh, Hron and Ipeľ which flow into to Danube. The Danube is influenced by waste water from the nuclear power station in Germany (Gundremmingen and Isar) and from the Czech republic (Dukovany). The waste water from the nuclear power station of Jaslovské Bohunice and Mochovce flow into the Danube in Slovakia.

The radiology laboaratory on Water Research Institute has been taking part in systematic observation of quality water of the Danube since 1973. Gross beta activities are determined twelve times each year and concentrations of Sr-90, Cs-137 and tritium are determined four times per year

The main sites which represent measurements are shown on Figure 1. For this presentation we prepared only some sites, which are marked with a circle on Figure 1. It is Wolfstahl (1873,5 km), Karlová Ves (1873,0 km), the tributaries Váh – Komárno (1,4 river km), Hron (1,5 river km) and Ipeľ (10,0 river km) and side on the boundary with Hungary - Szob (1707,0 km).

Sediments

Sediments are sensitive indicators and register the contamination of surface water. Many contaminants are accumulated, which can be determinated in the case when concentration in the water phase is under the limit of applied method detection.

Among natural radionuklides belong: natural uran, Ra-226, K-40,Th-232, and among articifial radionuklids belong Cs-134, Cs-137, Sr-90, Co-60, tritium which result from human activity.

Within the monitoring of quality water of frontiery flows, which has been realised at the Water Research Institute for more than three decades, there are observed also the composition of sediments. Samples of sediments are taken from three profiles of the Danube: Bratislava (1869,2 km), Komarno (1768,0 km) and Szob (1768,0 km) also from the left and right river bank. Samples are taken two times a year, distance 1,5 m from the bank.

It was determined in the sediments after drying, crushing and sieving the gross alfa activity, the gross beta activity and gama spektormetria (Cs-134, Cs-137, Ra-226, Ac-228 and atc). For this presentation we prepared the results of sediments from Bratislava.

All results are middle values of the left and right bank and averages from all measurements in the year.

Results

Radioactive contamination of the river Danube had a decreasing trend until 1982 as a result of the moratorium on nuclear test explosions. Radioactivity in the Danube water did not change significantly from 1983 to April 1986 and varied around an arithmetic mean value. There was a sharp rise in radioactivity after the accident in the Chernobyl Nuclear Power Plant, especially in radiostroncium and radioceasium. The maximum value was recorded in May 1986. After May 1986 there was a gradual decrease of radioactivity, which has been monitored to the present time.

In the folloving figure are the present results of our experiments of water from the Danube, years 1992 to 1999. In the Figures 2,3,4 are results of gross beta activity. In the Figure 2 it is shown when water comes to Slovakia (Wolfsthal, Karlová Ves), in the Figure 3 are the present waters from the tributaries of the Danube: Váh, Hron and Ipeľ and in the Figure 4 are shown the results of water which flows away to Hungaria.

Analysis of data show that for all studied parameters and radionuklides the values are considerably under the limited values. Along classification of surface water quality by Slovak standards are valid for I. class value: for beta gross activity less than 1,0 Bq/l. On the Slovak territory is an increase of gross beta activity on the river Ipeľ, but these values are under the limited value too. The results show that radioactive contamination has a mild decreasing trend. The results of Ra-226 and Cs-137 of the rivers Váh, Hron and Ipeľ are shown in Figure 5 and Figure 6.

The results of gross alfa and beta activities of the river Danube sediment from Bratislava are shown in Figure 7 and the radionuklids Ra-226 and Cs-137 are shown in the Figure 8.

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STN 757221 Water quality. Classification of surface water quality

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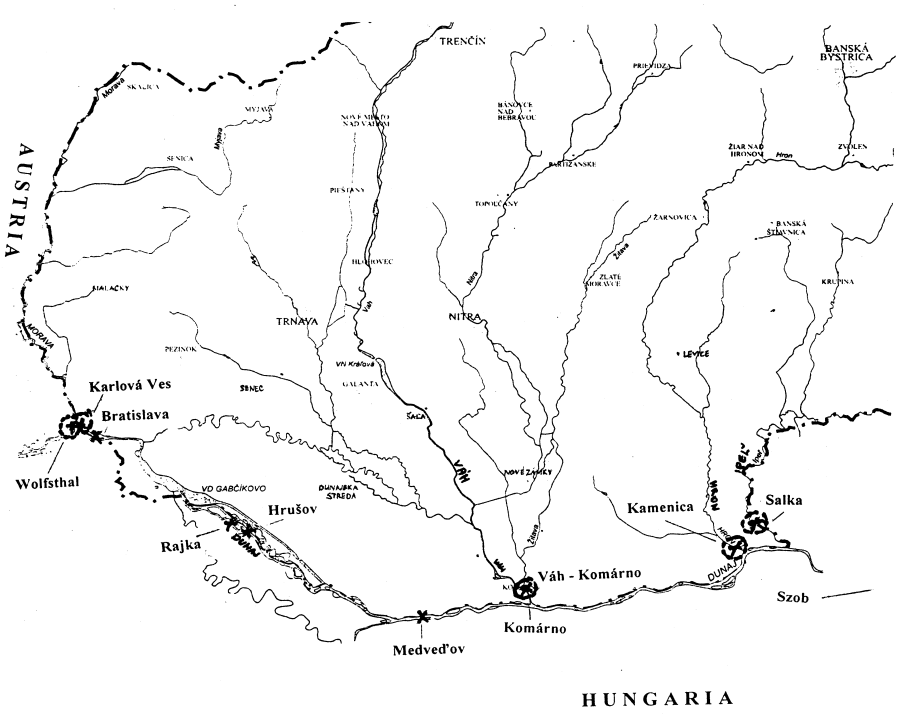

Fig. 1 Danube sampling sites

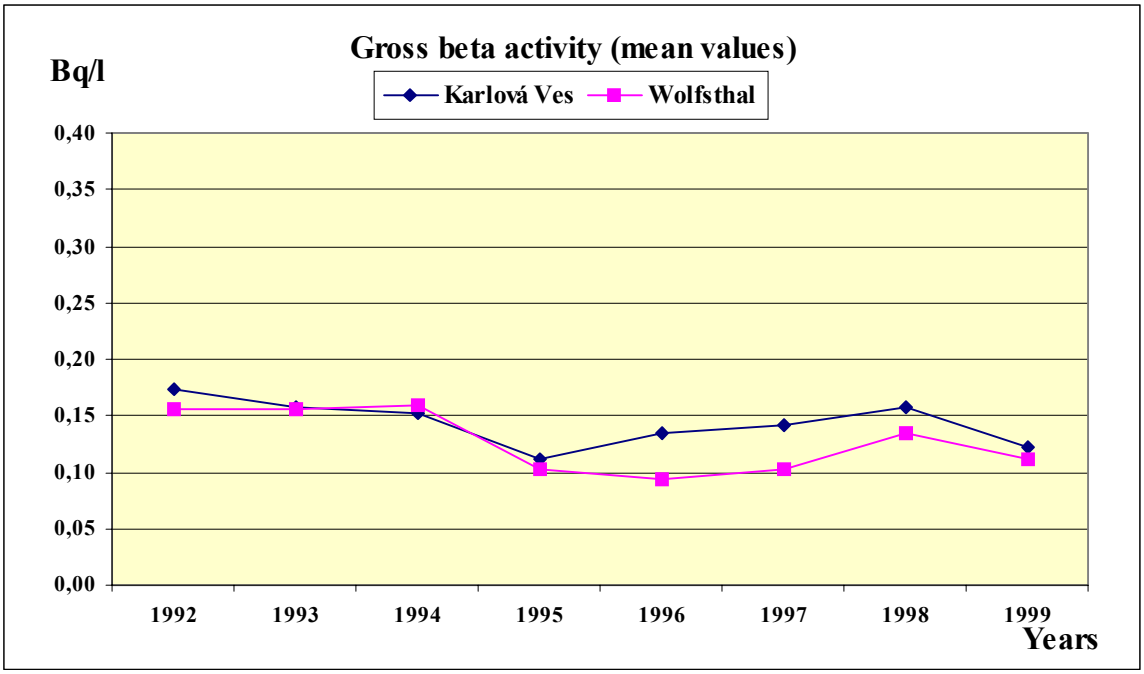

Fig. 2

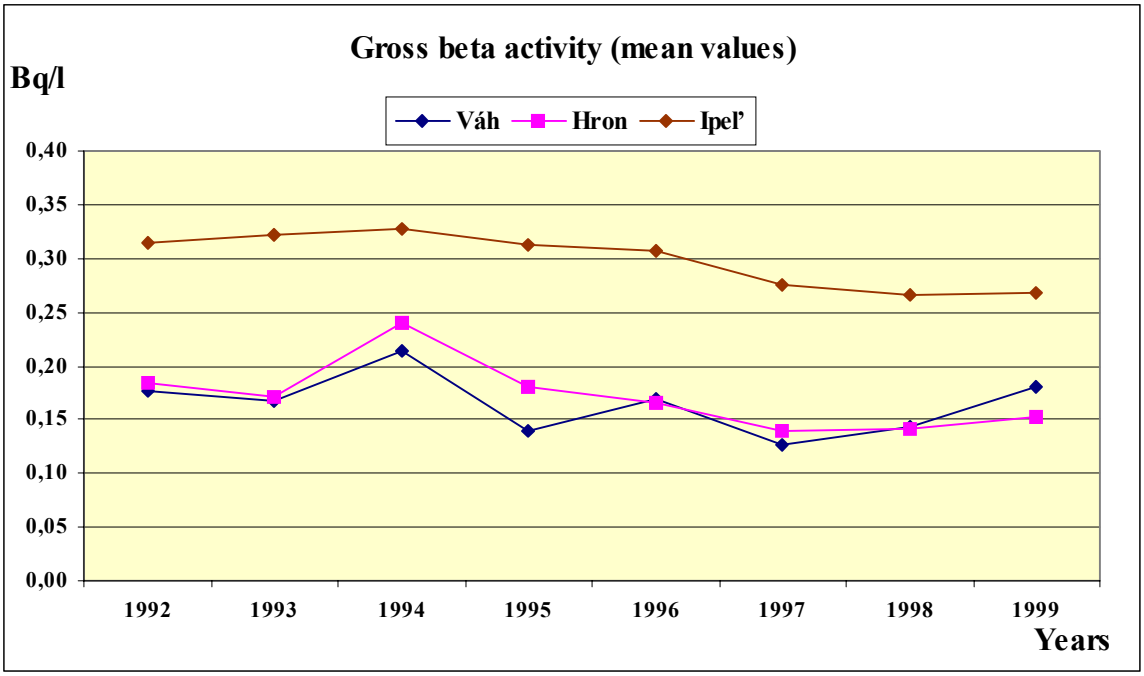
Gross beta activity (mean values)
Bq/l
Váh
Hron
Ipeľ
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
1992
1993
1994
1995
1996
1997
1998
1999
Years

Fig. 3

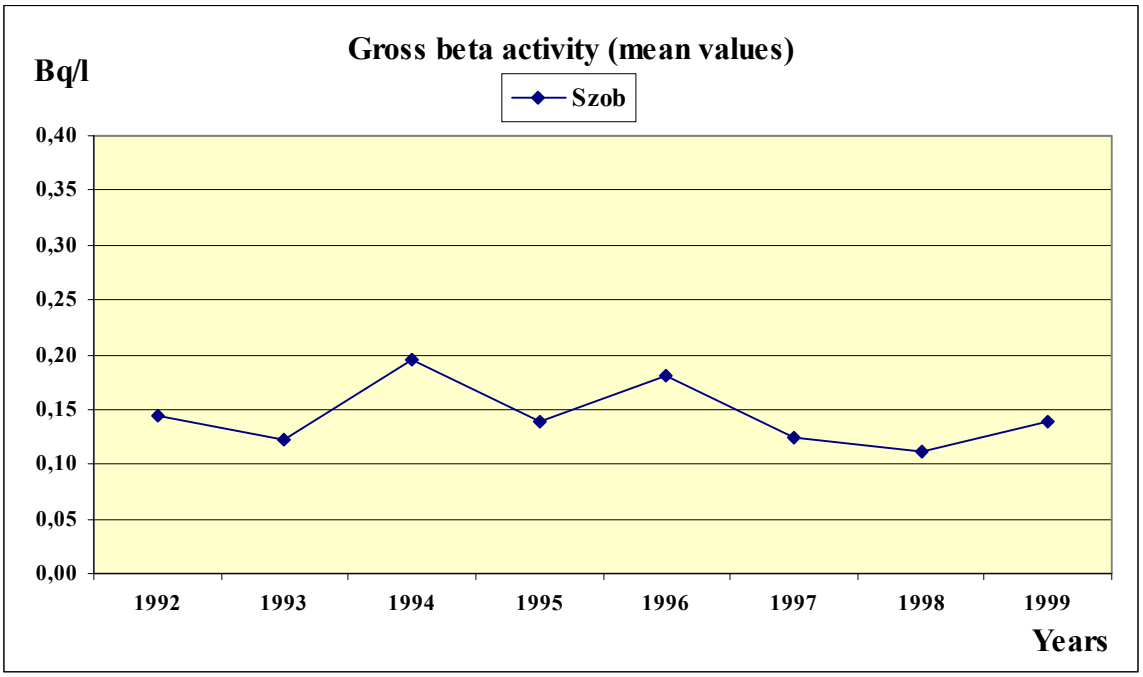
Gross beta activity (mean values)
Bq/l
Szob
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0,00
1992
1993
1994
1995
1996
1997
1998
1999
Years

Fig. 4

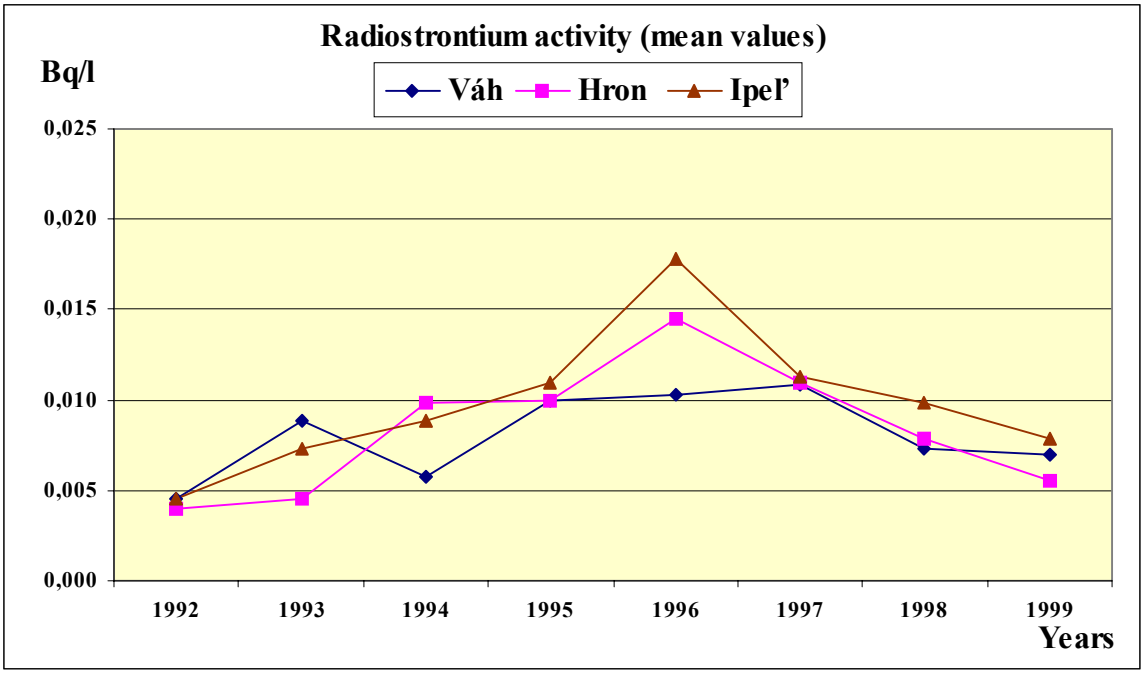
Radiostrontium activity (mean values)
Bq/l
Váh
Hron
Ipeľ
0,025
0,020
0,015
0,010
0,005
0,000
1992
1993
1994
1995
1996
1997
1998
1999
Years

Fig. 5

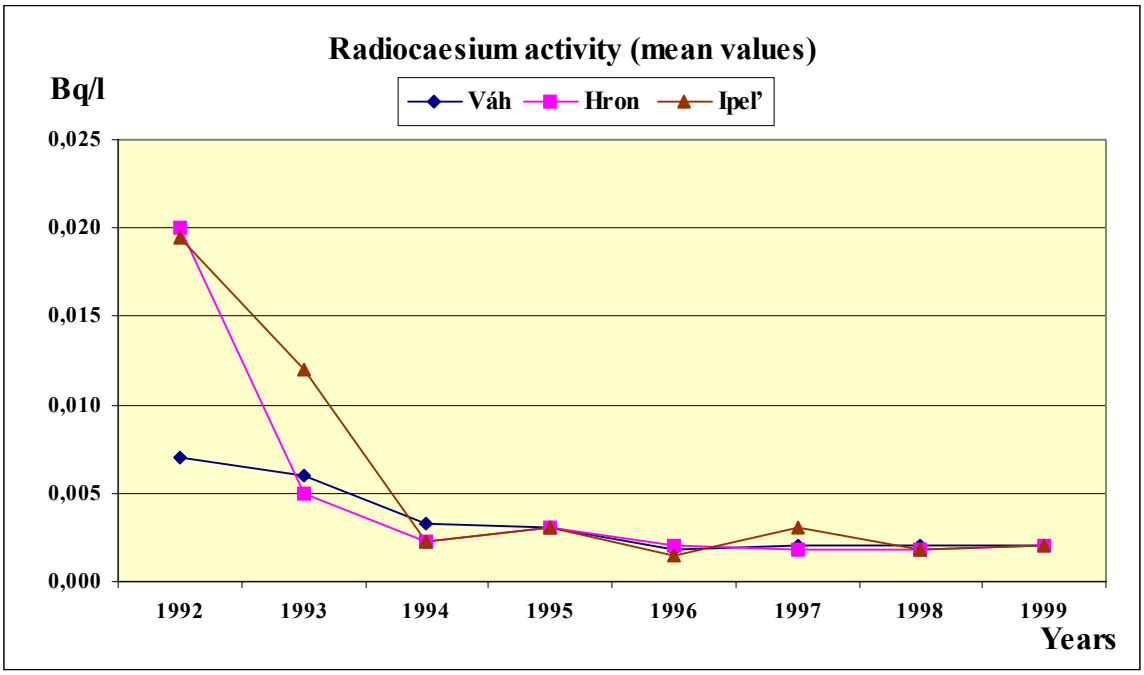
Radiocaesium activity (mean values)
Bq/l
Váh
Hron
Ipeľ
0,025
0,020
0,015
0,010
0,005
0,000
1992
1993
1994
1995
1996
1997
1998
1999
Years

Fig. 6

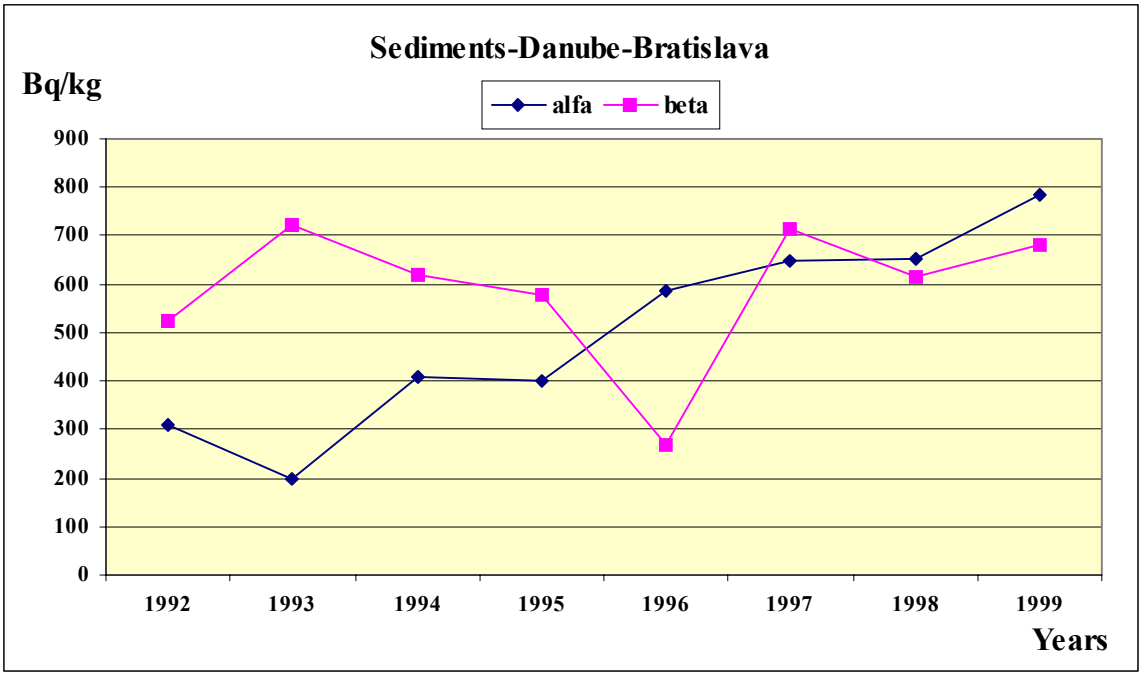
Sediments-Danube-Bratislava
Bq/kg
alfa
beta
900
800
700
600
500
400
300
200
100
0
1992
1993
1994
1995
1996
1997
1998
1999
Years

Fig. 7

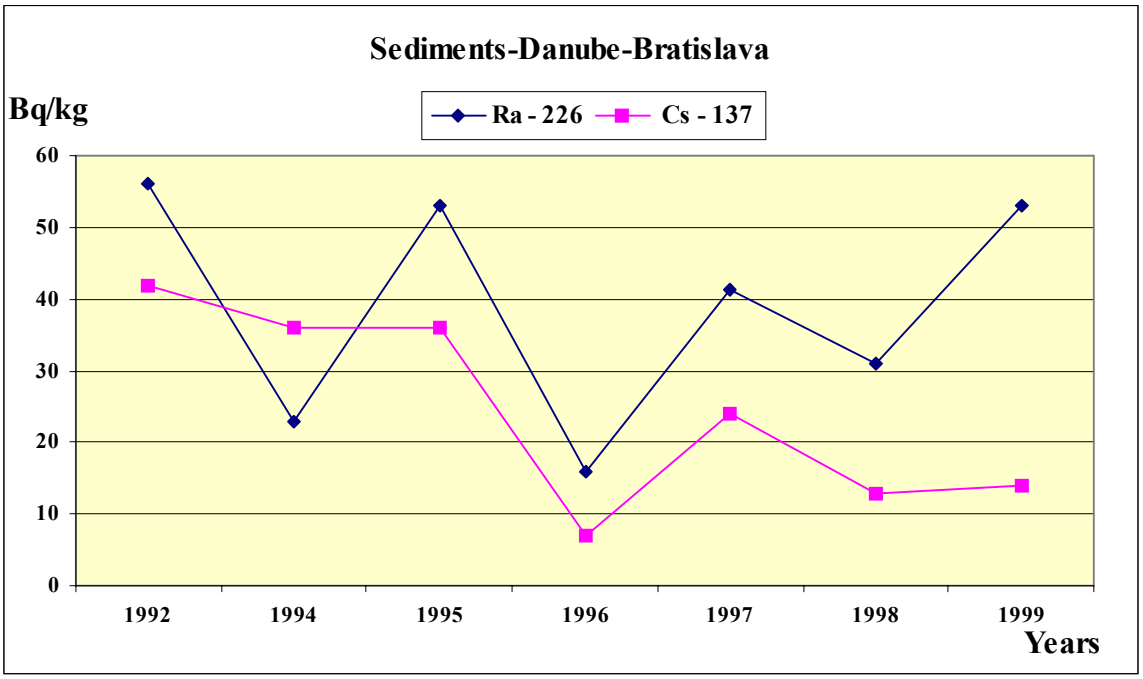
Sediments-Danube-Bratislava
Bq/kg
Ra - 226
Cs - 137
60
50
40
30
20
10
0
1992
1994
1995
1996
1997
1998
1999
Years

Fig. 8

The Impact of Macropore Flow on the Transport of Agrochemicals in Field Soil

Ľubomír Lichner

Abstract: Macropore flow can be the cause of rapid transport of agrochemicals (both non-reactive and reactive) through the soil, resulting in a groundwater pollution. Radioactive tracer measurements has shown that the macropore flow was about 49 % of the total flow in the barley field in the 1993 experiment, 19 % in the maize field in the 1995 experiment, and 55 % in the untilled soil covered with grass in the 1996 experiment. It can be seen that the warm and rainless second half of April 1993 resulted in nearly as high macropore flow in the barley field as that in the untilled soil. An impact of macropore flow (e.g., as a result of land use) is also to be seen in the area-averaged solute relative concentration vs depth distributions but for the small and medium cumulative infiltration only.

Key words: macropore flow, groundwater pollution, agrochemicals

Der Einfluss von Strömung in Makroporen auf Transport der Agrochemikalien in Boden

Zusammenfassung: Strömung in Makroporen kann einen schnelleren Transport von Agrochemikalien (nicht nur nichtreaktiv, sondern auch reaktiv) in der Bodenzone verursachen - mit einer Verunreinigung des Grundwassers als Folge. Wie Feldversuche mit radioaktiven Indikatoren in der Donauebene zeigen, beträgt der Anteil der Strömung in Makroporen etwa 49 % bei Anbau von Gerste (1993), 19 % bei Anbau von Mais (1995) und 55 % bei Grasbedeckung (1996). Infolge des warmen Wetters ohne Niederschläge in der zweiten Aprilhälfte ist die Strömung in den Makroporen bei Gerstenanbau beinahe ebenso hoch wie bei nichtbearbeitetem Grasland. Der Einfluss der schnelleren Strömung in den Makroporen, als Folge unterschiedlicher Landnutzung, zeigt sich auch bei der Verteilung der Chemikalienkonzentration in der Bodensäule, allerdings lediglich bei geringer oder mittlerer kumulativer Infiltrationen.

Schlüsselworte: Strömung in Makroporen, Grundwasserverschmutzung, Agrochemikalien

1 Introduction

Macropores in a field soil can allow water and surface-applied agricultural chemicals to move rapidly through the root zone, thereby being the cause of shallow groundwater pollution and drop in fertilization and irrigation efficiency. This type of preferential flow occurs if macropores have ports at the soil surface and water is applied to the soil surface at rates higher than the infiltration rate into the soil matrix. Experimental evidence has shown that the rapid part of water transports the reactive solutes through biopores and cracks without apreciable sorption.

In a concept of the two-domain flow of water and solutes in the unsaturated zone of soil, the slow part of water flow (matrix flow) is of great use for plants while the rapid part (macropore flow), bypassing the root zone of soil, is of no use for plants and increases the vulnerability of groundwater to pollutants. Macropore flow may occur with little or no solute retardation and the depth to which the reactive solute penetrated may exceed the depth it should have reached if ideal miscible displacement had occurred.

The objective of this study was to assess an impact of macropore flow on a transport of agrochemicals in a field soil by means of (a) estimating the bypassing ratio at the interface between the root zone and subsoil, and (b) monitoring the tracer relative concentration vs. depth distributions in the course of infiltration experiment following the tracer pulse application.

2 Materials and methods

The study field at the Experimental Basis of the Research Institute of Irrigation in Most near Bratislava is situated in the south-western part of a large (1260 km^2) agriculturally utilized area called the Danubian Lowland, with shallow underlying aquifer containing about 10 km^3 of freshwater. The soil is classified as a Chernozem (FAO: Chernozem, U.S. system: Mollisol Boroll). Hydrophysical characteristics of that soil are given in Table 1 where α and n are constants of the van Genuchten's equation, K_T is the matrix saturated hydraulic conductivity measured with tension infiltrometer, and K_G is the saturated hydraulic conductivity measured with Guelph permeameter.

Table 1 Hydrophysical characteristics of the soil under study (Štekauerová, 1998).

depth of soil layer (cm)	saturated water content θ_S ($cm^3\,cm^{-3}$)	residual water content θ_r ($cm^3\,cm^{-3}$)	parameter α (cm^{-1})	parameter n (-)	hydraulic conductivity K_T (cm s^{-1})	hydraulic conductivity K_G (cm s^{-1})
0 - 55	0.4890	0.0105	0.04875	1.20327	5.40×10^{-5}	4.30×10^{-4}
56 - 85	0.4908	0.0106	0.02809	1.29624	1.80×10^{-4}	4.00×10^{-4}
86 - 100	0.4875	0.0105	0.00654	1.28743	1.96×10^{-4}	2.44×10^{-4}

The plots 1.5 m x 3.5 m (1993) and 1 m x 1 m (1995-96) were used to study the non-reactive fertilizer transport and to estimate the bypassing ratio in that structured clay-loam soil. The radioactive iodide $^{131}I^-$ was used as a tracer of non-reactive fertilizer transport in cultivated (1993, 1995) and untilled (1996) clay-loam soil under spring barley (1993), maize (1995), and grass (1996). The $^{131}I^-$ transport investigation was made using 8 vertical (1993), 12 vertical (1995), 4 vertical and 3 horizontal (1996) probes depicted in Fig. 1.

Before the tracer application, soil surface was wetted by sprinkling irrigation of 10 mm (1993), 27 mm (1995), and 18 mm (1996) of water solution of NaI to minimize extracellular oxidation with subsequent incorporation of the radioactive iodide into organic compounds (Behrens, 1982). Then the radioactive iodide $^{131}I^-$ was applied by drops at the 10-cm diam. circle around each of 8 probes with following sprinkling irrigation of 10 mm of water (1993), and by sprinkling irrigation of 27 mm (1995) and 18 mm (1996) of the $^{131}I^-$ tagged water. After the tracer application, the 10-mm (1993), 27-mm (1995), and 18-mm (1996) doses of non-tagged water were applied by sprinkling irrigation with the intensity of 15-20 mm hr^{-1} (1993), 9.2-20.3 mm hr^{-1} (1995), and approximately 20 mm hr^{-1} (1996). Bypassing ratio was measured after a cumulative infiltration of 200 mm (1993), 108 mm (1995), and 198 mm (1996) of water. Tracer relative concentration vs depth distributions were measured after a cumulative infiltration of 40, 100, and 200 mm (1993), 27, 54, 81, and 108 mm (1995), and 18, 36, 54, 72, 90, 108, 126, 144, 162, 180, and 198 mm (1996) of water.

Radioactive tracer technique (Lichner, 1995) was used to estimate the bypassing ratio at the interface between the root zone and subsoil, and to monitor the non-reactive nutrient relative concentration vs depth distributions in a structured clay-loam soil. The probe (Fig. 1) consists of a duralumin tube (3) in which a Geiger-Mueller (G-M) detector and analog interface unit (1), connected to the nuclear analyser (2) with coaxial cable, can be placed in any desired position.

The tubes (10-mm O.D., 8-mm I.D., and 1500-mm length) are inserted vertically from the soil surface into the holes made by a 10-mm-diam. steel rod into the soil below the 1-m^2 square infiltrometer (4). Conical soil sealing (5) made for each vertical probe prevents water from bypassing past the probe, as it was proved by a dye test with Methylene Blue. Owing to its small size (21-mm length and 6.3-mm O.D.) the G-M detector can be considered as a point detector.

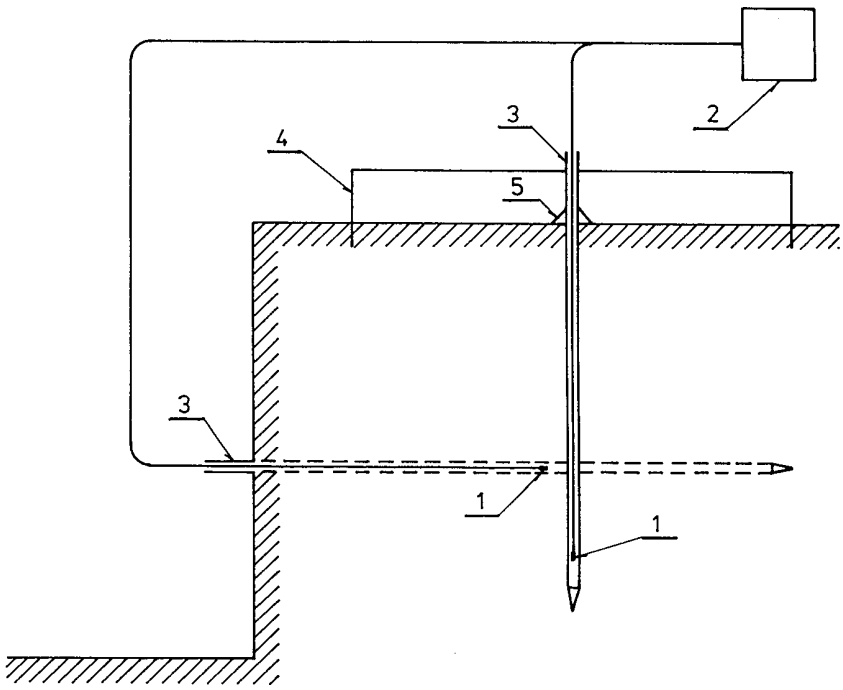

Fig. 1 Schematic arrangement for radioactive tracer technique.
(1) G-M detector and analog interface unit, (2) nuclear analyzer (counting rate-meter), (3) duralumin tube, (4) square infiltrometer of 1-m^2 area, (5) conical soil sealing.

In the first part of our study, the radioactive tracer technique was used to estimate the bypassing ratio in the field soil. After the $^{131}I^-$ tracer application at the rate i_0 slightly higher than the matrix saturated hydraulic conductivity K_{sh}, an easily detectable infiltration front IF is formed in the soil matrix (Fig. 2a). It is assumed that no tracer occurs in the macropores after redistribution. The upper part of soil under study was water saturated before the tracer application and, therefore, soil water content equal to the saturated water content Θ_s of the soil matrix is assumed above IF. Additional infiltration of the non-tagged water at a rate higher than the matrix saturated hydraulic conductivity ($i > K_{sh}$) results in a displacement of IF at the rate i_h which is dependent upon the hydraulic properties of both macropore and matrix domain (Fig. 2b). The tagged water ponding at the soil surface (with a depth exceeding a threshold value) as well as the film flow of tagged water down the macropores are depicted as the black areas in the Fig. 2a.

In a soil without macropores, the cumulative infiltration I of the non-tagged water results in the displacement I/n of the front, where n is the effective porosity of soil.

In a macroporous soil with two-domain flow, the cumulative infiltration I of the non-tagged water is divided into two parts, viz. $I = I_m + I_h$, where I_m is the unknown cumulative

infiltration into macropores and I_h is the unknown cumulative infiltration into matrix. Considering the facts that the radioactive tracer occurs in the soil matrix only and that some part of matrix water (expressed by Θ_r) is immobile (van Genuchten and Wierenga, 1976), the cumulative infiltration I results in an infiltration front displacement $h = I_h/n_{ef}$, where $n_{ef} = \Theta_s - \Theta_r$ is the effective porosity, Θ_s is the saturated water content, and Θ_r is the residual water content of the soil matrix. The infiltration front displacement h is then used to estimate the cumulative infiltration into matrix $I_h = h\, n_{ef}$ and the cumulative infiltration into macropores $I_m = I - h\, n_{ef}$. The bypassing ratio BR can then be expressed as $BR = I_m/I = 1 - hn_{ef}/I$.

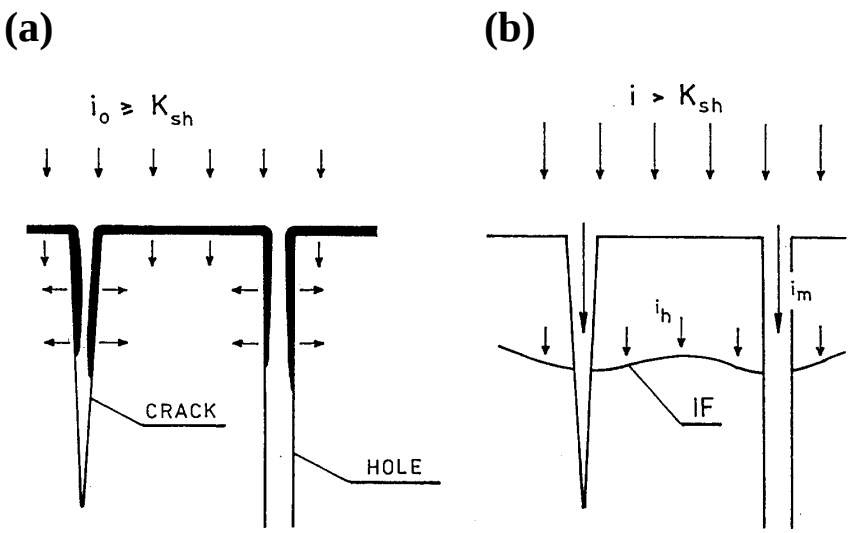

Fig. 2 Two-domain flow of water in macroporous soil
(a) infiltration of the water tagged with $^{131}I^-$ into the soil matrix from the soil surface and from macropores (crack, earthworm/ant hole)
(b) movement of the $^{131}I^-$ infiltration front IF in the soil matrix at the rate i_h, induced by sprinkled irrigation with the intensity $i > K_{sh}$

As it was set down for our measurements, the infiltration front of a radioactive tracer is the maximal depth in the tracer concentration vs. depth distribution where the measured radiotracer plus background counting rate is higher than $2(n_b + \sigma_b)$, where n_b - background counting rate, and σ_b - standard deviation of the measured background counting rate. Considering that 90 % of the water uptake by agriculture plants takes place in the depth of 0 - 50 cm (Novák, 1995), the infiltration front of the radioactive iodide was tried to locate below the maximum uptake area.

In the second part of study, scanning the probe was used with 10-cm distance between measuring points. Since counting rate can be considered to be proportional to the tracer concentration (IAEA, 1975, p. 78), the area-averaged relative concentration of a non-reactive nutrient in a soil layer was established in the way as it follows. The counting rate in the soil layer from $10a$ [cm] to $10(a + 1)$ [cm] (for a = 0, 1, 2, ...) was estimated as the mean of counting rates measured by a probe in these two depths. Then the nutrient relative concentration in soil layers surrounding the probe was estimated from the counting rate in the same soil layers so that the sum of relative concentrations in all layers was equal to 1. Finally, the nutrient relative concentration in soil layers obtained in a plot were area-averaged in the way described by Butters and Jury (1989), i.e. the area-averaged nutrient relative concentration

in a soil layer in the plot is the mean of relative concentrations obtained in this layer by all the probes.

3 Results

During the 1993-96 tracer experiments, the bypassing ratio was estimated in the clay loam soil using $n_{ef} \approx 0.3$ obtained from the laboratory measurements. The background counting rate, obtained from 40 measurements in the depths from 0 to 100 cm, was $n_b \pm \sigma_b = (4 \pm 2)$ cpm.

In the 1993 experiment (performed in cooperation with E. Lichnerová and P. Rafaj from 28 April to 2 May 1993), the tracer measurements were made in the field sown with spring barley (Lichner, 1995). They started after two weeks of a warm and rainless period which resulted in the formation of cracks and, therefore, in the high value of the bypassing ratio $BR_1 = 0.49$ in the depth of 48 cm.

In the 1995 experiment (performed in cooperation with P. Germann, A. Mdaghri Alaoui, V. Novák, M. Šír, and M. Kubu from 20 to 25 July 1995), the tracer measurements were made in the maize field (Mdaghri Alaoui et al., 1997). The bypassing ratio $BR_2 = 0.19$ in the depth of 56 cm.

In the 1996 experiment (performed in cooperation with M. Šír from 5 to 9 August 1996), measurements were made in the untilled soil under grass. Well-developed biopore system resulted in the bypassing ratio $BR_3 = 0.55$ in the depth of 78 cm.

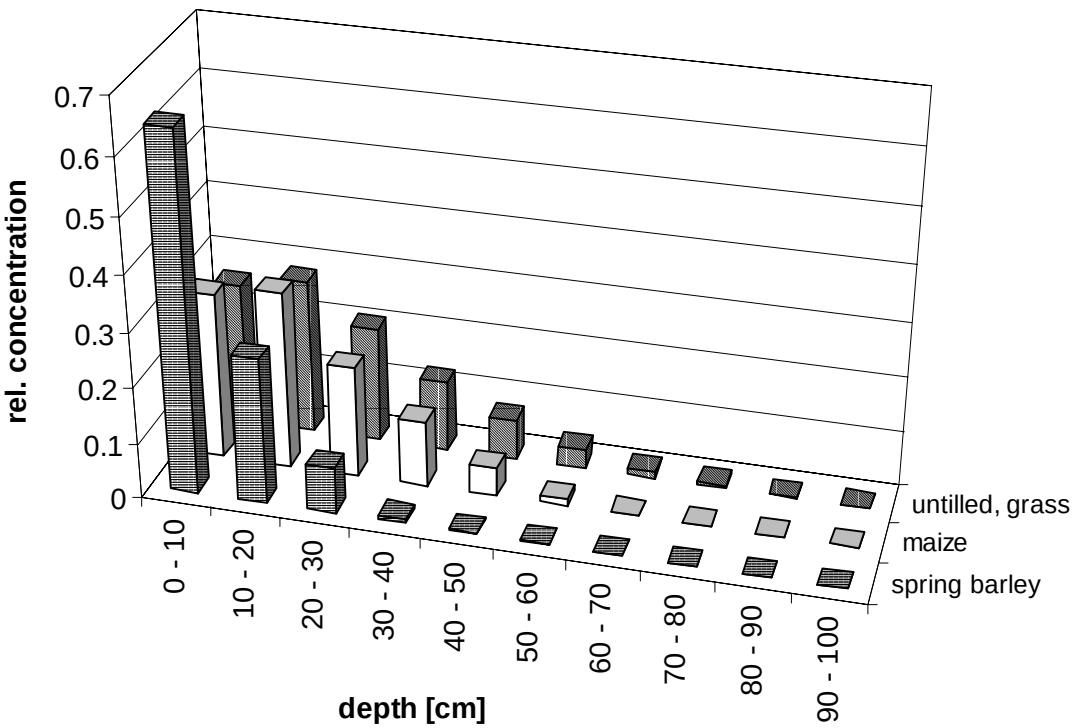

Fig. 3 Non-reactive fertilizer penetration into the soil after cumulative infiltration of I = 40-54 mm of the tagged and non-tagged water

The area-averaged nutrient relative concentration vs depth distributions for small and medium cumulative infiltration (I = 40 mm in 1993, and I = 54 mm in 1995 and 1996) are quite different in terms of visual examination (Fig. 3). For example, 60-70 % of applied chemical occurs in the layer 0-10 cm in the 1993 spring barley field, 0-20 cm in the 1995 maize field, and 0-30 cm in

the 1996 untilled field covered with grass. Tracer leading edge is in the depth of 60 cm in the spring barley field, 70 cm in the maize field, and 100 cm in the untilled field covered with grass. In case of the bigger cumulative infiltration (I = 100 mm in 1993, and I = 108 mm in 1995 and 1996) the relative concentration vs depth distributions are near the same in terms of visual examination (Fig. 4). For example, 82-92 % of applied chemical occurs in the layer 0-50 cm in all the fields. Tracer leading edge is in the depth of 90 cm in the spring barley field, 80 cm in the maize field, and 100 cm in the untilled field covered with grass.

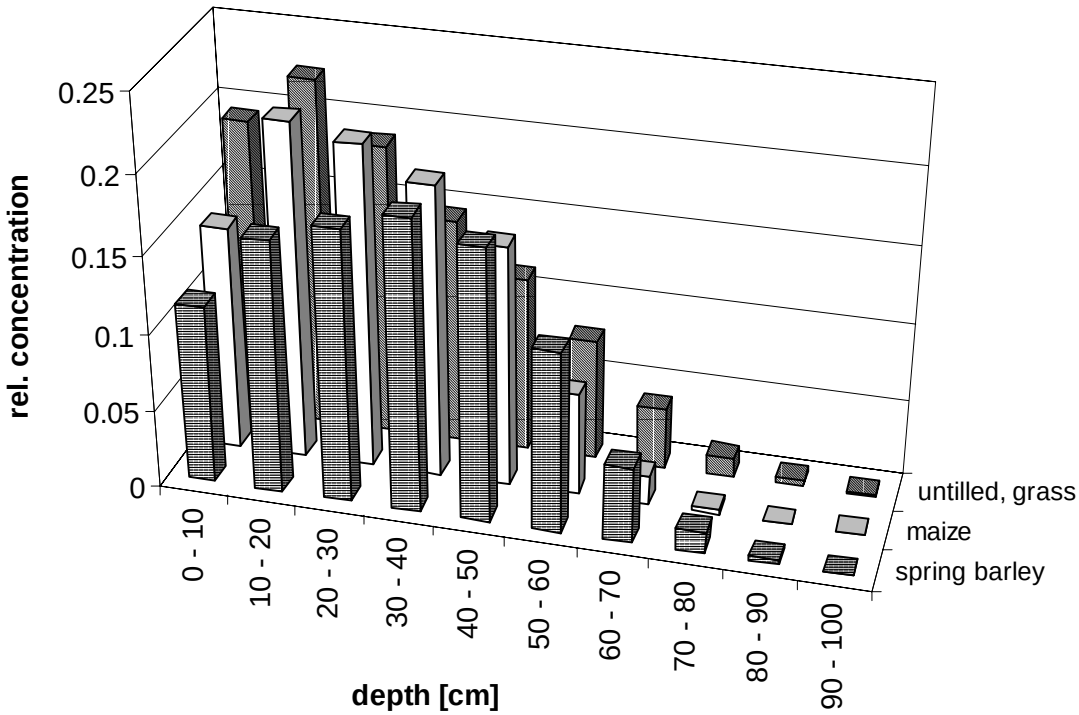

Fig. 4 Non-reactive fertilizer penetration into the soil after cumulative infiltration of I = 100-108 mm of the tagged and non-tagged water

With regard to the above-mentioned results it can be said that there exists a threshold cumulative infiltration similar to the minimum mixing length L (also referred to as Lagrangean length scale). Minimum mixing length is an intrinsic property of any diffusion-type process and it is the length in the flow direction required to arrange all pores participating in the flow process according to their size and relative abundance. It means that after travelling along L a water parcel has a chance to move through all pore-size categories (Germann, 1990). If cumulative infiltration gets over this threshold value, then considerable decrease in a spatial variability of area-averaged distributions of relative concentration vs depth in case of the measurement of solute transport in a scale of representative elementary volume.

4 Conclusions

The radioactive tracer measurements has shown that the macropore flow was about 49 % of the total flow in the barley field in the 1993 experiment, 19 % in the maize field in the 1995 experiment, and 55 % in the untilled soil covered with grass in the 1996 experiment. It can be

seen that the warm and rainless second half of April 1993 resulted in nearly as high macropore flow in the barley field as that in the untilled soil.

From above-mentioned results it follows that macropore flow occurs in that field with all the consequences when water is applied to the soil surface at rates higher than 2 mm hr^{-1} (Table 1). The saturated hydraulic conductivity less than 2 mm hr^{-1} was measured (with falling head method) in 37 % of undisturbed soil samples taken in the central part of the Danubian Lowland (Šútor, 1986). As it can be seen in Table 2, probability of the rain with intensity higher than 2 mm hr^{-1} and duration more than 1 hr is high in the south-western Slovakia during vegetation season (April - October) and, therefore, some special agrotechnical operations, e.g. the fertilizer applicator (Ressler et al., 1997) should be used to reduce nutrient losses and minimize groundwater pollution.

Table 2 Frequency of rains with intensity higher than 2 mm hr^{-1} and duration more than 1 hr as measured in the 1990-98 vegetation seasons at the meteorological stations in the south-western Slovakia (Lichner et al., 1999)

Year Station	1990	1991	1992	1993	1994	1995	1996	1997	1998
Hurbanovo	22	17	16	23	31	23	25	22	32
Mochovce	20	28	22	15	29	30	30	25	30
Jaslovské Bohunice	23	17	23	23	30	26	26	15	28
Piešťany	26	18	26	28	26	22	26	19	18

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Developments in Water Quality of the Danube from 1980-1998

Marta Machkova, Pavol Miklánek, Pavla Pekárová

Abstract: The contribution deals with the long-term tendencies in Danube water quality (Wolf, 1996; and Velikov et al, 1996; Pekárová et al, 1998). The trend analysis was based on monthly or forthnightly data measured at Danube-Bratislava cross-section (Slovak part) and Danube-Silistra (Bulgarian part) during the period 1980-1998. The following data were used for analysis $N\text{-}NO_3^-$, Cl^-, SO_4^{2-}, O_2, BOD, COD, Cd, Pb, Cr, Cu, Zn, Ni, and As. The relationships between discharges and instantaneous concentrations of the main selected pollutants were elaborated. The annual pollutant loads were estimated by two methods. The first one is based on daily discharges and daily concentrations calculated by the empirical relations. The second one is based on mean monthly discharges and concentrations measured once per month. Comparison of the results according both approaches is presented.

Key words: Water Quality, Danube, Yearly Loads, Empirical Relationships

Die Entwicklung der Donauwasserqualität während 1980-1998

Zusammenfassung: In dem Artikel sind die langfristige Trenden der Wasserqualität im Donau präsentiert. Die Trendanalyse ist auf den monatlichen Zeitreihen von zwei Stationen: Donau in Bratislava (Slowakischer Teil) und Donau in Silistra (Bulgarischer Teil) gegründet. Die 18-jährige Zeitreihe für die Periode 1980-1998 wurden analysiert. Folgende Daten wurden studiert: $N\text{-}NO_3^-$, Cl^-, SO_4^{2-}, O_2, BOD, COD, Cd, Pb, Cr, Cu, Zn, Ni und As. Empirische Beziehungen zwischen den Abflüssen und Stoffkonzentrationen wurden entwickelt. Die jährliche Stoffbelastungen der Donau wurden identifiziert mit zwei Methoden. Die erste kam aus der täglichen Durchflüsse und täglichen Stoffkonzentrationen. Konzentrationen wurden mit den empirischen Beziehungen errechnet. Die zweite Methode kam aus mittleren monatlichen Durchflüsse und Stoffkonzentrationen, die einmall pro Monat gemessen wurden. Im Beitrag ist der Vergleich der Ergebnisse präsentiert.

Schlüsselworte: Wasserqualität, Donau, jährliche Stoffbelastungen, empirische Beziehungen

1 Comparison of the long-term water quality development in the middle and downstream part of the Danube

Measured concentrations of selected water quality parameters were used for the assessment of water quality of Danube in Bratislava (Slovakia) and Silistra (Bulgaria) during 1980 – 1998. The data were provided by the Slovak Hydrometeorological Institute in Bratislava, and the Ministry of Environment and Water – Sofia, as well as by the Danube TNMN (Trans National Monitoring Network).

The measured concentrations of sulphate, chloride and nitrogen nitrate in both stations are in Fig. 1.

Sulphates. The sulphate concentrations were higher in the middle part of the Danube in 1980-1991, while in 1991-1995 the concentrations were significantly higher in the downstream part. In 1996-1998 were the sulphate concentrations surprisingly similar in both stations. Generally, the trend of the sulphate concentrations is decreasing in both stations.

Chlorides. The chloride concentrations were slightly higher in the downstream part through the whole period. In 1985-1993 the concentrations were higher than in other years of the period.

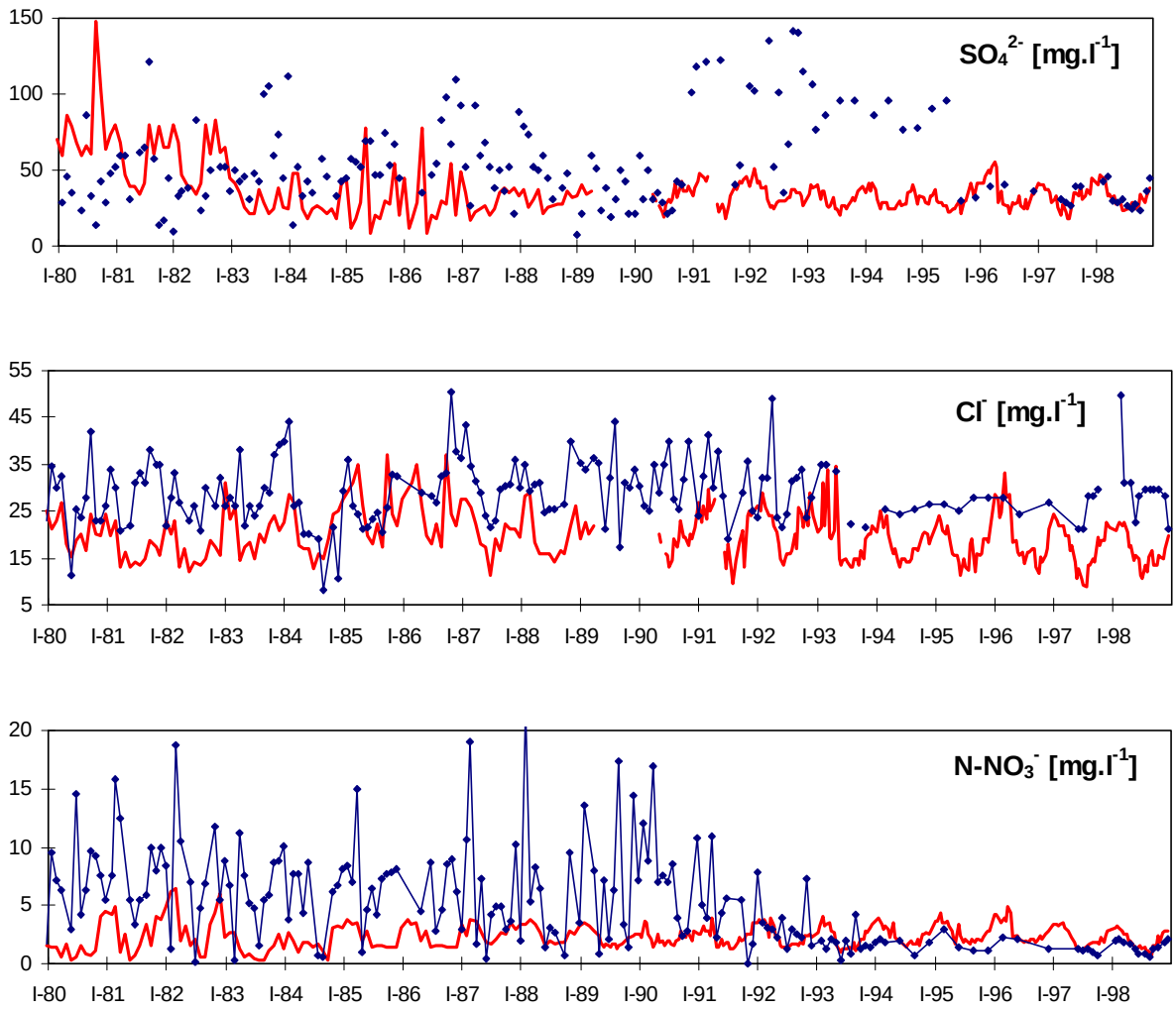

Fig. 1 Monthly concentrations of sulphate, chloride and nitrogen nitrate in two stations: Danube in Bratislava (bold line) and Danube in Silistra (points), period 1980-1998.

Nitrogen nitrates. The changes in nitrogen nitrate concentrations are very marked after 1993 in the downstream part of the Danube. The concentrations did not exceed the value of 20 mg.l^{-1} in 1980-1991, and value of 5 mg.l^{-1} after 1993 and are lower in the downstream part of Danube after 1993. The nitrogen nitrate concentrations are stable in Bratislava during the whole period.

Generally the Lower Danube waters are of quite low mineralization, normally less then 400 mg.l^{-1}. It was already shown in Pekárová et al (1998) that during the last ten years the concentration of certain macro-components is decreasing due to the economic decrease in the former socialist countries.

Oxygen parameters. Basic oxygen related parameters are in Fig. 2. The amount of dissolved oxygen in Bratislava station is typical with regular annual courses and no significant trend can be observed diring the whole period. In Silistra, significant increase of the dissolved oxygen can be observed after 1993. The biological oxygen demand is higher in the downstream part of the Danube through the whole period.

Metal concentrations. The metal concentrations in Danube in Bratislava were analysed during 10-years period 1989 – 1998. The length of the series is 91 values. Basic statistical characteristics (average, min, max, c10, c50, c90) of the measured parameters during 10- and 5-years period are in Tables 1a, 1b.

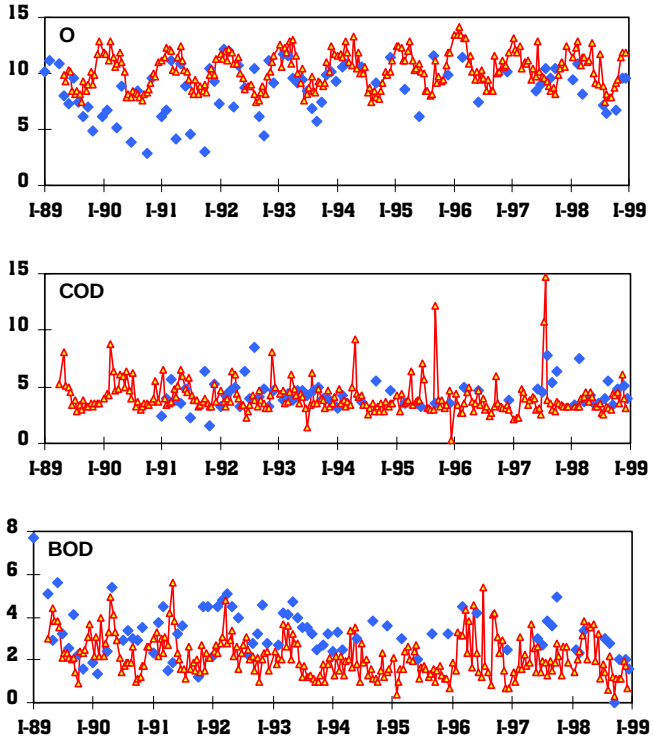

Fig. 2 Comparison of the dissolved oxygen (O) concentrations, BOD a COD [mg.l^{-1}] in Bratislava (line with points) and in Silistra (points).

The measured concentrations of the metals are in Fig. 3 together with the mean daily discharge during the day of sampling. The maximal concentration of all the metals was measured on August 5, 1991 during the flood of 8970 m^{3}s^{-1}.

Generally, the metal concentration is higher with the higher flow. No trend (increasing or decreasing) in metal concentrations was observed during the analysed 10-years period. The instantaneous discharge during the water quality sampling influences significantly the concentrations.

Table 1a Basic statistical characteristics of selected heavy metals concentrations in Danube – Bratislava during 10-years period 1989 – 1998

	Ni µg.l^{-1}	Cu µg.l^{-1}	Cd µg.l^{-1}	Pb µg.l^{-1}	Zn µg.l^{-1}	As µg.l^{-1}	Hg µg.l^{-1}	Cr µg.l^{-1}
mean	2.69	4.06	0.07	2.41	27.70	1.26	0.19	1.42
min	0.20	0.30	0.01	0.10	20.00	0.50	0.10	0.07
max	21.90	42.60	0.39	47.40	247.00	3.30	1.00	15.20
c_{50}	2.10	2.80	0.05	1.06	20.00	1.10	0.10	0.70
c_{10}	0.96	1.11	0.01	0.30	20.00	0.71	0.10	0.20
c_{90}	5.16	5.79	0.17	4.63	33.20	1.99	0.40	3.40

Table 1b Basic statistical characteristics of selected metals concentrations in Danube – Bratislava during 5-years period 1994 – 1998.

	Ni µg.l^{-1}	Cu µg.l^{-1}	Cd µg.l^{-1}	Pb µg.l^{-1}	Zn µg.l^{-1}	As µg.l^{-1}	Hg µg.l^{-1}	Cr µg.l^{-1}
mean	2.66	3.66	0.05	1.72	27.70	1.26	0.17	0.93
min	0.60	0.30	0.01	0.10	20.00	0.70	0.10	0.07
max	7.50	20.60	0.20	20.30	247.00	3.30	0.80	5.90
c_{50}	2.20	2.80	0.04	0.80	20.00	1.05	0.10	0.50
c_{10}	1.20	1.40	0.01	0.20	20.00	0.79	0.10	0.20
c_{90}	4.80	5.70	0.10	3.80	33.20	2.08	0.39	1.50

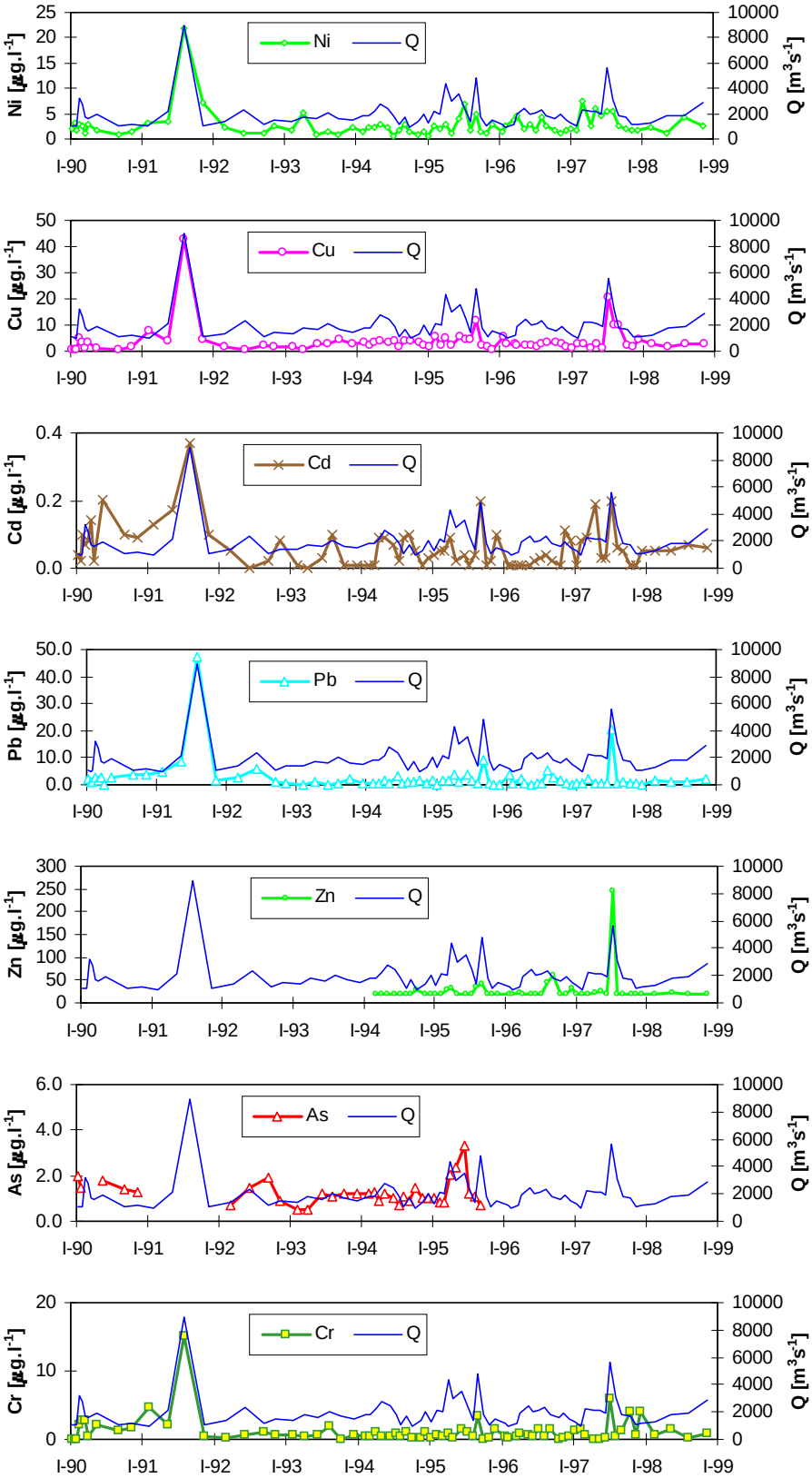

Fig. 3 Measured concentrations of Ni, Cu, Cd, Pb, Zn, As and Cr, and mean daily discharge (Q) in the day of sampling during January 1990 – December 1998. Station Danube in Bratislava – middle.

Table 2 Basic statistical characteristics of selected metals concentrations in Danube – Silistra during 5-years period 1994 – 1998.

	Ni $\mu g.l^{-1}$	Cu $\mu g.l^{-1}$	Cd $\mu g.l^{-1}$	Pb $\mu g.l^{-1}$	Zn $\mu g.l^{-1}$	As $\mu g.l^{-1}$
mean	2.94	26.14	0.79	6.50	45.84	0.85
min	0.00	4.00	0.00	0.00	10.00	0.50
max	8.00	100.00	5.00	11.00	117.00	3.00
c_{50}	4.00	22.00	0.50	8.00	42.00	0.50
c_{10}	0.00	10.00	0.00	1.60	15.40	0.50
c_{90}	5.50	36.00	1.00	10.00	84.00	1.00

In Table 2, there are the basic statistical characteristics of selected metals concentrations in Danube – Silistra during 5-years period 1994 – 1998.

Relatively regular determinations of certain heavy metals are available in Bulgaria only after 1993. Analysing the available information we can say that the average concentrations of the heavy metals are higher at the Lower Danube except for the arsenic As. Most likely that is because of the continuous release of polluted waters by the Serbian mining complex "BOR" situated at the Timok river basin (the border river between Bulgaria and Serbia). According to the present investigations, the industrial activities in Bulgaria and Romania are also polluting Danube by heavy metals despite of the production decrease.

These facts indicate the higher pollution of Danube in the downstream part compared to the middle part.

2 Indirect determination of the heavy metal concentrations from daily discharge in Danube - Bratislava

Monitoring of the water quality parameters, particularly heavy metals, has not such long series as runoff monitoring. The estimation of the pollutant loads transported by the river depends on accuracy and frequency of water quality sampling. The instantaneous concentrations of pollutants depend on instantaneous runoff. The load of pollutants is in fact the product of concentration and runoff volume. The reliability of the estimate is therefore directly relative to the reliability of both the runoff and concentration estimates.

There are two possibilities how to estimate the monthly and annual loads:

1. To use the monthly runoff volume derived from continuous runoff records and to substitute the mean monthly concentration by the instantaneous concentration measured once in month. The results are only approximate and do not represent the actual conditions due to obvious reasons.
2. To use the daily runoff volume derived from mean daily discharge and to identify the mean daily concentration with the measured instantaneous concentration in days of sampling and to complete the series of daily concentrations indirectly from relations between runoff and concentration. These relations can be derived from series measured once in month. The results are expected to represent the actual conditions more reliably.

The relations for the indirect estimation of heavy metal concentrations from mean daily discharge were derived for Danube in Bratislava profile. The relations were derived from data series summarised in Table 1a. The results and derived relations are in Fig. 4.

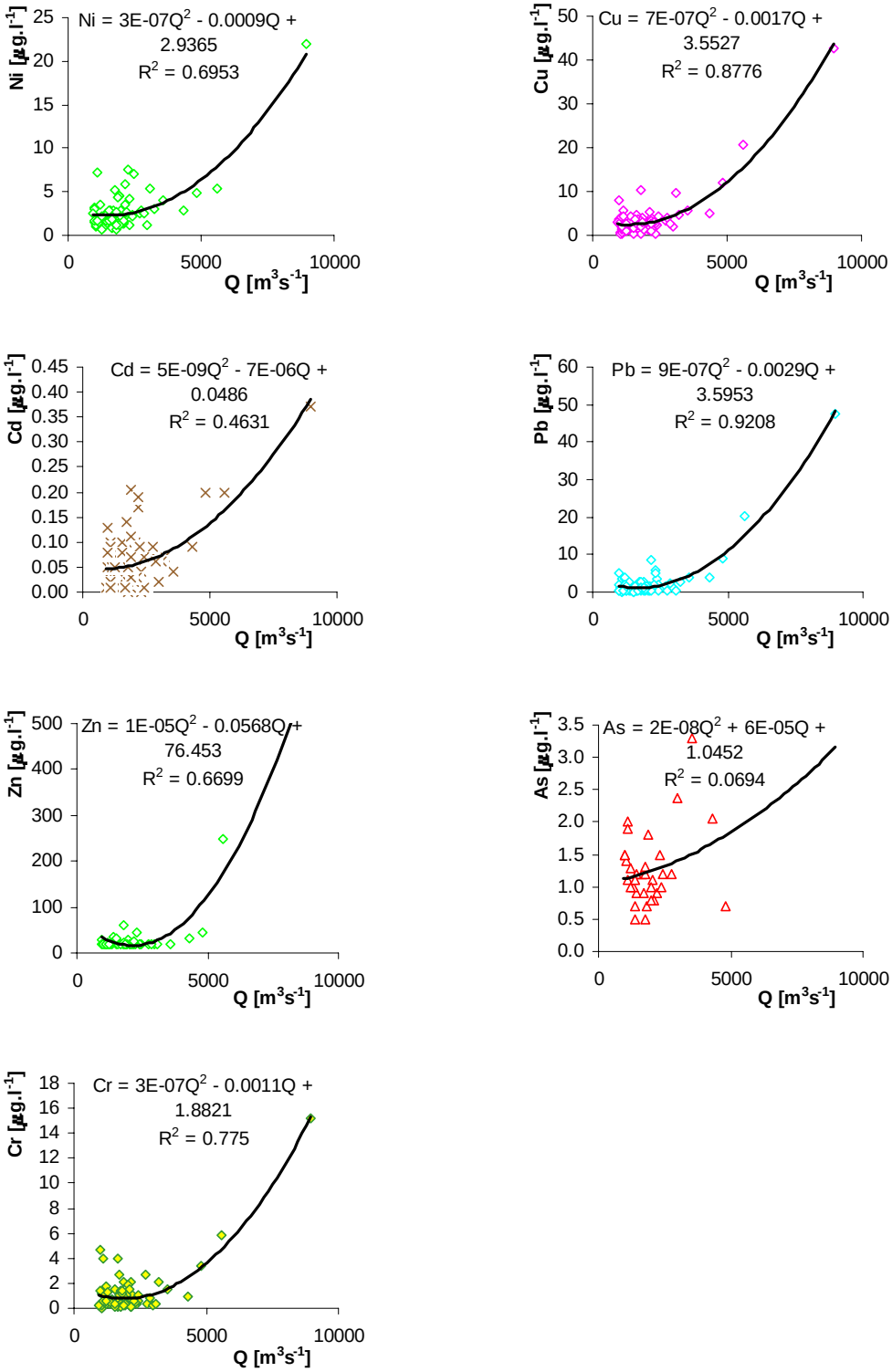

Fig. 4 Relation between metal concentrations and mean daily discharge, period 1990-1998, Danube - Bratislava.

Table 3 Comparison of the loads [t y^{-1}] in Danube-Bratislava calculated from the monthly and daily values in 1996

Yearly load in tons	Ni	Cu	Cd	Pb	Zn	As	Hg	Cr
monthly data	160	178	1.904	93	1687	-	6.3	37.6
daily data	173	253	4.040	158	1254	83	-	76.0

The series of daily heavy metal concentrations for Danube in Bratislava in 1996 were completed using relations between mean daily discharge and concentration listed in Fig. 4.

The completed concentration time series were used for estimation of the annual loads of heavy metals in Danube in Bratislava according the second approach described in previous paragraphs. Results are in Table 3 in “daily data” row”. Results are compared with loads estimated according first approach using monthly data (one sampling per month). Results are also in Table 3 in “monthly data” row. The load estimates based on “daily data” are higher for all the components, except for zinc Zn.

The presented results attempt to estimate the loads of heavy metals in Danube water. The study is based on available data series which are not of sufficient temporal resolution. It was shown that the reliability of the estimate depends highly on accuracy and frequency of water quality sampling. The differences between estimates presented in Table 3 are significant and demonstrate the possible uncertainty of the estimates and the need for more detailed monitoring.

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Bacterial Pollution of the Danube River and Its Tributaries

Elena Mogoňová, Jozef Augustín

Abstract: In 1995-1999 an extensive investigation was carried out in the Danube River. Special attention was paid to the monitoring of microbial pollution of the regulated and non regulated parts of the river and tributaries. A significant self-cleaning effect was observed both in the original and in the canalised part of the Danube (from 1869.2 to 1806.2 river km). Microbial contamination increases again downstream the urban areas in the region of the towns Komárno/Komárom (1 768,0) and Štúrovo/Esztergom (1 720.0). The bacterial pollution of the river water taken at the true left bank, the true right bank and in the middle of the river differs considerably. The Váh and the Hron as tributaries from Slovakia account for 9 % and 1.7 % respectively and the Ipeľ, which forms the Slovak-Hungarian border account for about 0.4 % of the Danube flow at 1869.2 river km (Bratislava). Their contribution to the bacterial contamination of the Danube river plays a less significant role.

Key words: Danube river, bacterial pollution, self-cleaning effect

Bakterielle Verunreinigung der Donau und ihrer Zubringer

Zusammenfassung: In den Jahren 1996-1999 wurde eine umfangreiche Forschung der Donau durchgeführt. Eine spezielle Aufmerksamkeit wurde der Überwachung der mikrobialen Verunreinigung des regulierten und unregulierten Flussteiles und seiner Zubringer gewidmet. Ein wichtiger Selbstreinigungseffekt wurde im ursprünglichen so wie im neuen Flussbett der Donau (vom Fkm 1869.2 bis 1806.2) festgestellt. Die mikrobiale Verschmulzung erhőht sich erneut flussabwärts durch bewohnte Gebiete im der Region der Städte Komárno/Komárom (Fkm 1768.0) und Štúrovo/Esztergom (Fkm 1720.0). Die bakterielle Verunreinigung des vom linken und rechten Ufer und aus der Flussmitte entnimenen Wassers ist in Szob ziemlich verschiedenartig. Die flűsse Váh und Hron als Zubringer aus der Slowakei stellen um 9%, bzw. 1,7 % dar und der die slovakisch - ungarische Grenze bildende Fluss Ipeľ stellt um 0.4 % des Donauabflusses im Fkm 1869.2 (Bratislava) dar. Der Anteil dieser Zubringer an der mikrobiologischen Verunreinigung der Donau ist wenig bedeutsam.

Schluusselworte: Donau, bakteriologische Verunreinigung, Selbstreinigungseffekt

1 Introduction

A substantial part of the catchment area of the Danube is in the Alps. After passing through the Vienna Basin, the Danube splits into one main channel and two minor branches forming two islands: Žitný ostrov in Slovakia and Szigetkóz in Hungary (Fig. 1). Until 1992 the main river channel (Old Danube) forming the border between Hungary and Slovakia, carried more than 95 % of the total flow, which averaged about 2 075 m^3/s (ranging from 750-7 500 m^3/s) in the period 1980-1989 (Liebe, 1994). When damming the Danube near Čunovo in Slovakia (river km 1 851,7) at the end of October 1992 part of the discharge was shifted into a parallel canal. In the area between the new canal and the old riverbed the hydrological regime was changed (Svobodová et Lisický, 1995). Environmental impacts were expected. To evaluate the potential effects a series of hydrogeological, zoological, botanical, algological and other studies were undertaken and the results published in many original papers (Báldi et al., 1998, Illyová, 1995, Krumpálová, 1996, 1997, Lisický et al.,1997, Makovinská, 1994, Matis et Tirjaková, 1995, Šporka et Krno, 1995, Vranovský, 1995, 1997). However little atttention has been paid to the microbial pollution and self-cleaning effects of the intact and regulated parts of the river.

The goals of this study were to assess whether the canalised part of the river and basin formed can change the microbial biocenosis compared with the biocenosis of the intact parts of the river.

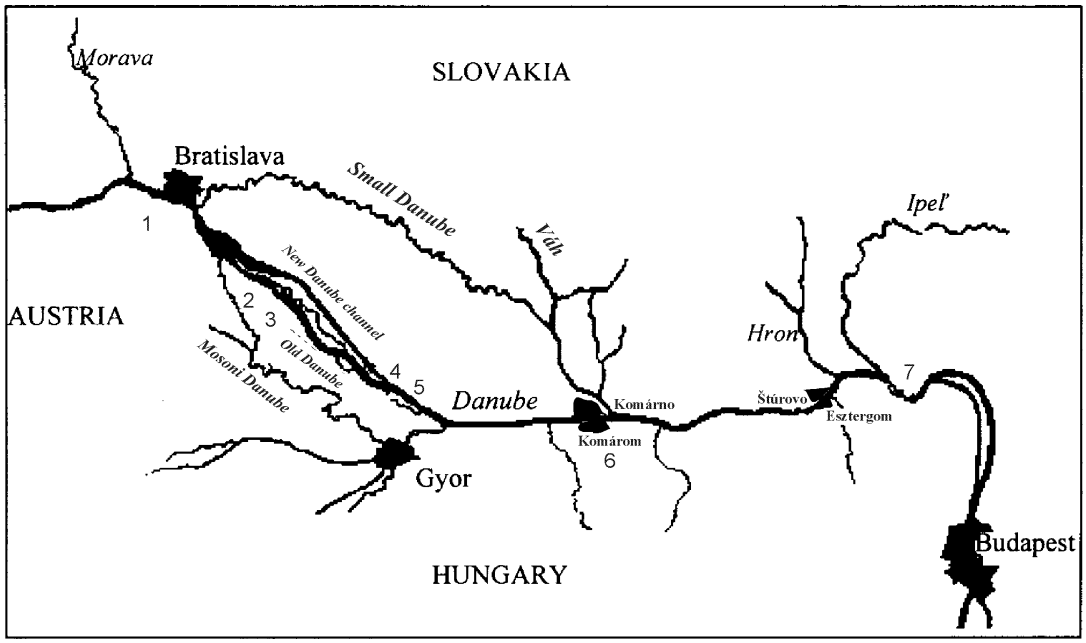

Fig. 1 Location of sampling sites in the Danube downstream from Bratislava to Szob (river km 1869.2 – 1707.0):1 – Bratislava , 2 - Rajka, 3 - Hrušov, 4 - Sap, 5 - Medveďov, 6 - Komárno, 7 - Szob.)

2 Methods

Bacterial contamination was evaluated as the number of colony forming units (CFU/ml) of five indicator bacterial groups (coliform bacteria, thermotolerant coliform bacteria, faecal enterococci, mesophilic bacteria and psychrophilic bacteria) obtained by cultivation methods. In 1996 the procedure described in Slovak technical standard STN 830531 was used. In the following years procedures described in the new Slovak technical standard STN ISO 7899-2, STN ISO 9308-1 and the Interational standard ISO 6222 were used.

In 1996 and 1997 samples were taken at two-week intervals, i.e. 25 tests each year. In 1998 and 1999 samples were taken at four week intervals, i. e. 12 tests each year, the only exception being Bratislava, where samples were taken at two-week intervals. Obtained data were expressed as the mean values and the value of 90 percentile calculated according to the equations in STN 757221.

2.1 Sampling sites

Sampling site No. 1 is in level with the second Bratislava bridge (1 869.2 river km). The microbial quality of the water is only slightly influenced by the urban pollution of Bratislava and the data represent water quality before Gabčíkovo hydroelectric power plant.

Sampling sites No. 2 and No. 3 are located on the old Danube riverbed forming Slovakia-Hungary border. Sampling site No. 2 is near Rajka village (1 848.0 river km) on the true right bank in Hungary 3 km downstream from the weir at Čunovo. Sampling site No. 3 Hrušov (1 842.0 river km) is on the true left bank in Slovakia 9 km downstream from the weir at Čunovo.Sampling site No. 4 is located on the new canal at the village of Sap (1 810,0 river km), 8 km downstream of the outflow from the Gabčíkovo hydroelectic power plant and just before junction of the canal with the old Danube riverbed.

Sampling site No. 5 is near Medveďov village (1 806.2 river km) under the bridge in the middle of the river forming Slovakia-Hungary border. Sampling site No. 6 is in the middle of the river

under the bridge (1 768.0 river km) connecting Komárno town (Slovakia) and Komárom town (Hungary). Samples were taken from the permanently anchored platform. Sampling site No. 7 is in Hungary 0,9 km downstream from the state border at Szob village. Samples were taken from ferry on the true left bank, the true right bank and in the middle of the river (1 707.0 river km).

3 Results and discussion

The microbial contamination of the Danube in Bratislava (1 869.2 river km) reflects the contamination of the river where it flows into Slovakia plus contamination from the Morava, the tributary reaching the Danube at 1 882 river km.

At approximately 1 856 river km the Danube enters the Čunovo Reservoir. Here sedimentation occurs as a consequence of the reduced flow-rate. At 1 851 river km the Danube splits into the new channel of the inlet canal of the hydroelectric power plant at Gabčíkovo and into the old Danube riverbed. The streams are re-united at 1810 river km at Sap. This part of the river in both channels is not affected by intense anthropogenic activity. The Danube in its original riverbed flows through undeveloped inland river delta. The new branch flows through the artificial watercourse. Our results show that in both channels a very significant decrease in microbial contamination occurs, in some cases even less than 10 % of the bacterial content of Bratislava sampling site (Tab. 1). The observed self-cleaning effect can be caused by sedimentation processes of certain particles of suspended matter colonized by microorganisms, as well as the decreased bacterial viability in the given water environment. There is no further contamination from the neighbouring country. The Danube in its original riverbed from 1 851 to 1 810 river km flows through the undeveloped land of the inland river delta without any significant anthropogenic activity. The new artificial channel protects the water from bacterial contamination.

Microbial contamination increases again when the river flows through the urbanized part of the country (Tab. 1), as is evident from the microbial content at 1 768,0 and 1 707.0 river km. The first sampling site is situated right in the centre of Komárno (approx. 25 000 inhabitants) on the true left bank and Komárom (approx. 25 000 inhabitants) on the true right bank. The second sampling site is situated 13 km downstream from Štúrovo (approx. 20 000 inhabitants) on the true left bank and Esztergom (approx. 38 000 inhabitants) on the true right bank.

3.1 The influence of tributaries

The results presented in Table 3 show that the Váh, the Hron (tributaries from Slovakia) and the Ipeľ/Ipoly river (which forms the Slovak-Hungarian border) play a less significant role in the microbial contamination of the Danube. The total discharge of these three rivers (Q = 187.7, 36.1 and 8.09 m^3/s) to the Danube represents 9 %, 1.7 % and 0.4 % (in total 11.4 %) of the total Danube discharge Q = 2 106.4 m^3/s at its entry-point into Slovakia (Bratislava).

Table 1 Changes of bacterial content of the Danube river between 1869,2 and 1707,0 river km. ThCf - Thermotolerant coliform bacteria , FS - Faecal streptococci , Cf - coliform bacteria, Mph - mesophilic bacteria, Phsp - psychrophilic bacteria. Relative values of microbial content in Table 1are calculated on the basis of values given in Table 2 which represents 100 %.

			1996					1997				
No	River km	Station	ThCf	FS	Cf	Mph	Psph	ThCf	FS	Cf	Mph	Psph
1	1869.2	Bratislava	100	100	100	100	100	100	100	100	100	100
2	1848.0	Rajka	68	36	69	100	58	73	42	71	58	95
3	1842.0	Hrušov	54	21	59	67	33	66	68	47	62	97
4	1810*	Sap	19	13	15	50	22	24	26	21	29	64
5	1806.2	Medveďov	22	12	22	47	21	39	32	41	62	77
6	1768.0	Komárno	452	134	813	597	304	290	160	419	224	118
7	1707.0	Szob	117	44	185	443	211	90	71	165	216	143

Table 1 Continue

			1998					1999				
No	River km	Station	ThCf	FS	Cf	Mph	Psph	ThCf	FS	Cf	Mph	Psph
1	1869.2	Bratislava	100	100	100	100	100	100	100	100	100	100
2	1848.0	Rajka	51	24	38	59	37	58	64	49	62	23
3	1842.0	Hrušov	39	20	22	50	33	43	50	42	125	74
4	1810*	Sap	13	8	18	85	58	18	14	11	73	42
5	1806.2	Medveďov	13	12	21	82	59	18	29	19	44	26
6	1768.0	Komárno	113	60	279	144	101	96	50	118	129	74
7	1707.0	Szob	96	68	124	278	152	58	86	117	1394 **	208

* Outlet canal of Gabčíkovo hydroelectric power plant before entering the old Danube riverbed.

** Characteristic value was affected by sporadic extreme values in the course of the year probably originating from local source of contamination.

Table 2 The value s of 90 percentile of bacterial contents in the Danube at 1869.2 river km (Bratislava) taken as 100 % values for Table 1.

	c_{90} [CFU/ ml]				
Year	ThCf	FS	Cf	Mph	Psph
1996	103	73	350	1 650	7 328
1997	70	38	190	3 532	9 572
1998	67	25	180	2 845	6 075
1999	67	14	183	2 017	14 793

Table 3 Discharge [m^3/s], bacterial content N [CFU/ml] and bacterial discharge Q_{bact} [CFU/s] of the Danube and the tributaries in 1997. In the table are given the percentage of Q_{bact} values of tributaries. As 100 % values were taken discharge and bacterial contents of the Danube at 1869,2 river km (about 12 km into Slovakia). ThCf - thermotolerant coliform bacteria, FS - faecal streptococci, Cf - coliform bacteria, Mph - mesophilic bacteria, Psph - psychrophilic bacteria.

River	Q [m^3/s]	Station	Parameter	ThCf	FS	Cf	Mph	Psph
Danube	2106,4	Bratislava	N	30,84	14,76	93,84	1 485,2	5 917,2
			Qbact	$64,9.10^9$	$31,1.10^9$	$197,6.10^9$	$3,13.10^{12}$	$12,5.10^{12}$
			[%]	100	100	100	100	100
Váh	187,7	Komárno	N	430	99	827	12 318	20 268
			Qbact	$80,7.10^3$	$18,6.10^9$	$155,2.10^3$	$2,31.10^6$	$3,8.10^6$
			[%]	124	60	78	74	30
Hron	36,1	Kamenica	N	11	7	32	1 095	6 073
			Qbact	397.10^6	253.10^6	$1,155.10^9$	$39,5.10^9$	219.10^9
			[%]	0,6	0,8	0,6	1,3	1,7
Ipeľ	8,1	Salka	N	17	14	30	851	8675
			Qbact	$137,5.10^6$	$113,3.10^6$	$242,9.10^6$	$6,88.10^9$	$70,18.10^9$
			[%]	0,2	0,4	0,1	0,2	0,6

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The Danubian Countries' Contribution to the Technogenic Pollution of the Black Sea's Drainage Surface: Hydrographic and Ecological Statistics

Valeria Prokacheva & Vladimir Usachev

Abstract: On the basis of field experiments and satellite images analysis an original methodology has been developed to determine the permanently polluted areas around urban settlements and along roads. The polluted lands distribution in the countries of the Black Sea drainage area has been discovered. One third (33%) of such lands are located in the Danube river basin.

Key words: methodology, urban halo, watershed, polluted area

Rolle der Donauanliegerstaaten in die technogenische Oberflächenverunreinigung des Schwarzmeerquellgebietes: hydrographische-ökologische Statistik.

Zusammenfassung: Auf der Grundlage der feld-experimental und Expeditionsforschungen, mit Hilfe der kosmischen Aufnahmen, ist die originelle Methodik der Feststellung der verunreinigten Flachen um die Stadten herum und die Landstraßen entlang ausarbeiten. Es ist die Verteilung der verschmutzen Erdboden nach den Staaten des Schwarzmeerquellgebietes aufgeklärt. Im Donaueinzugsgebiet wird der dritte Teil (33%) dieser Erdboden enthalten.

Schlüsselworte: Methodik, städtische Aureole, Quellgebiet, verschmutzte Gebiet

Introduction

Statistical characteristics of watersheds (forested area, swamp area, lake area, ploughed areas, etc.) are used not only for a geographical descriptions but also for hydrological computations and for river runoff modelling. At present, in majority of cases it is necessary to take the account of watershed urbanisation indices, too. Area occupied by different constructions in the watershed is one of such indices. But the sizes of polluted areas are much greater. Urban areas and roads are supposed to be the main sources of the terrain pollution. Technogenic dust and aerosols are spread by atmospheric fluxes and by traffic over great distances and are gradually settled onto the land surface. They are permanently deposited around cities and finally produce contaminated zones in the form of spots (around towns) and stripes (along roads).

We suggest using a new characteristic for this purpose, i.e. the size of continuously polluted areas within the limits of towns and roads effect. Until recently it was impossible to determine the contours and to put it in the map. Opportunities were extended when data of regular satellite surveys were made. Satellite images provided for the first time to see dark spots of polluted haloes extended far beyond the urban areas on the background of melting snow cover. It was the snow cover, which served as the background on which the principles of polluted areas were investigated; indication indices of urban haloes from satellite images were estimated. As a result, the areas of cumulative pollution within the limits of the technogenic influence of urban settlements and roads are determined.

Several contours may be selected in the urban halo according to the pollution density. We decided to determine the size of the area within the contour of the two-fold pollution rate, if compared with the nearest background. It should be noted, however, that not each urban halo could be interpreted from satellite images: cloudiness, forested areas and snow cover ephemerality prevent from interpretation. But information collected for many towns, which haloes were seen in the images, make it possible to apply methods of the correlation analysis with the account of the ecological analogy on a regional scale.

Methodology

Methodology for mapping the polluted zones has been developed on the basis of subsatellite experiments near numerous industrial centres with the use of field and stationary observations from land and from aircraft. The process was modelled on experimental plots by artificial dusting of the snow cover by various rates of pollutants. The possibility of determining the polluted boundaries around cities has been finally validated from the available images, at the levels several times exceeding the background values.

The elaboration of methods was executed by a complex way:
1). Analysis of urban haloes in satellite images has been made in detail for the territory of the former USSR. The problem was to supply for the territories by up-dated information on the size of permanently polluted (2 or 3 times higher than the background) areas. Information has been received from “METEOR” & “COSMOS” satellites with images of medium (200 m) and high (40 m) resolution. These images were interpreted mainly visually. It turns out that there are stable and regular principles in the seasonal and annual rhythms of urban halo formation. The problem of determination of the pollution rate at different distances from the centre in the sphere of the urban effect is solved by analysing of satellite images obtained in the characteristic suitable times (Temporal methodological recommendations 1984).

2). The situation has been studied by a field team in the polar tundra, in the forest and steppe zones around cities with different industries causing pollution. The supervision were carried out on routes crossing urban haloes, and on perimeter of urban territories with the help of aerial photography, airborne and automobile survey mapping polluted snow surface and snow cover areas. The ground observations on routes were made systematically on stationary plots located in places with various pollution extents. The contents of polluting particles in thickness of snow cover was measured, the share of organic and mineral components (after burning filters) was estimated, the samples of snow for laboratory determination of structure pollutants and ***pH*** of the snowmelt were collected, the stratigraphy of snow cover was investigated. The main goal of such studies was to discover difference in snow melting within the limits of the urban effect and on background territories, to compare them with the haloes interpreted from the images. It has been discovered, that there is a general trend of the reduced total pollution from the urban centre to periphery and then to background values. Moreover, an exponential law here dominates, similar to that, which forms the urban halo density in the image.

3). Imitative modelling of the pollution rate of the snow cover has been made on field experimental plots dusting these plots by different substances (wood ashes, coal dust, cement powder, etc.) at various doses (5-1500 g/sq. m). Dusty substances were selected by the brightness and the sizes of particles identical of them that met in real situation around inspected cities. The works were carried out in conditions of the Karelian Isthmus (Ilichevo, 1977 - 1987 years), on Aldan Upland (Mogot, 1978) and in Germany (Harzgerode, 1984 - 1987). The goal was to check the experimental effect of the pollutants on snow melting and to compare the results with those effects observed in real situations, within the limits of urban influence.

As a result of experiments, field studies and interpretation of urban haloes from satellite images a great massive of empirical data has been collected. These data are available in relative values and graphically analysed; different relations and dependencies have been estimated relative to the determining reasons; the results have been published (Prokacheva and Usachev 1989). Correlation has been determined between the sizes of polluted area and population number and density, with the account of the economic function, structure of employment of the population and predominant industry.

The working graphs are of a regional nature, they are not given here, but a generalised scheme of such assessment is given in Fig. 1. Polluted areas along roads have been computed with the account of highways & railways length within the appropriate region and width of the polluted stripe (0.1-0.3 km). The accuracy of this method is about 10-15%.

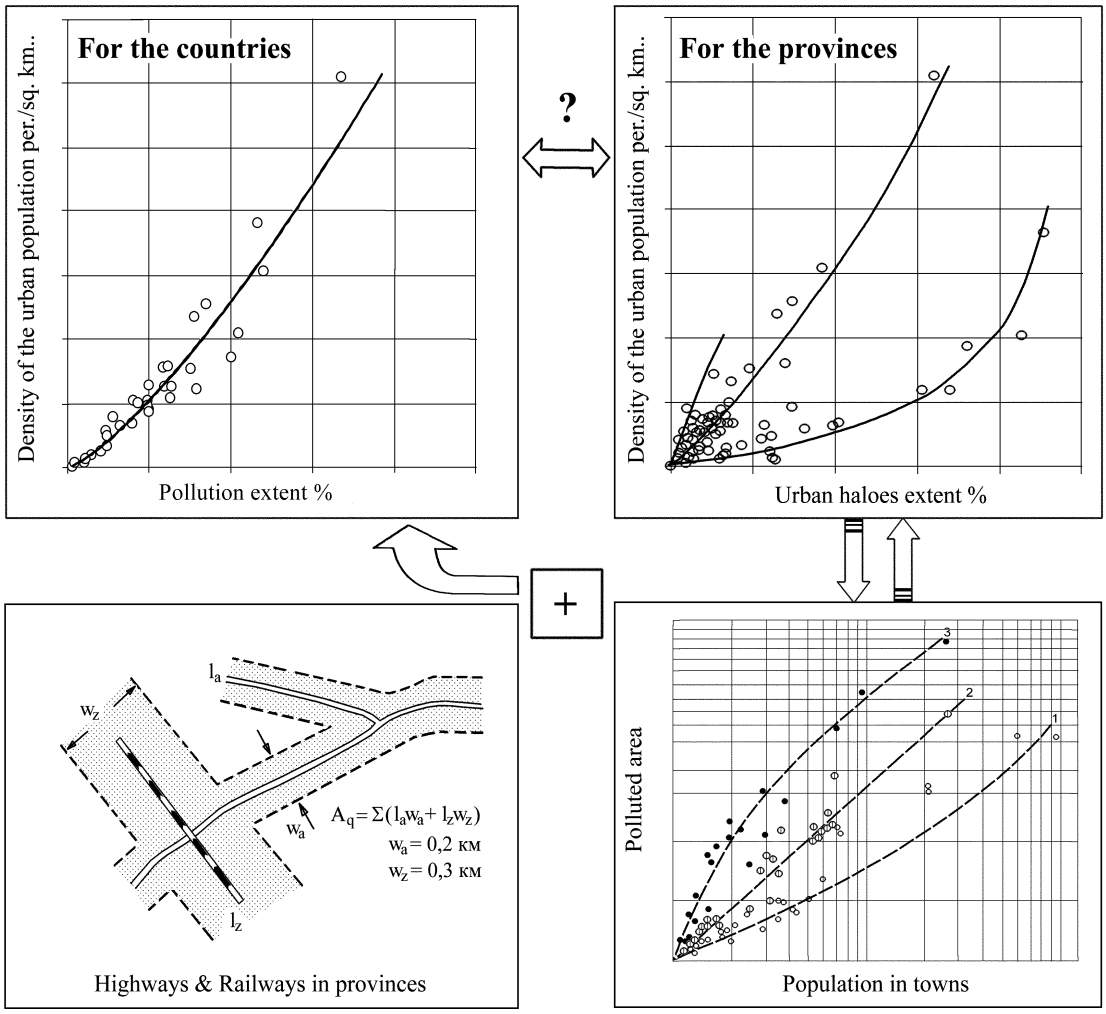

Fig. 1 Scheme of determination of the polluted areas around urban settlement and along roads in case of missing survey data

Results

This method to determine the areas of permanent pollution has been applied for the territories of Russia and of the adjacent countries. All computations are made according to the administrative & territorial division of each country (regions, republics, provinces etc). The generalised characteristics are given in Table 1.

Detailed statistical data make it possible to calculate the sizes of technogenically dusted areas in river basins, in lake and Inland Sea drainage areas. To translate these data to natural boundaries of river basins within the administrative boundaries it is sufficient to calculate the total polluted area within the contour of the required watershed. These calculations have been made, for instance, for the Black Sea drainage area covering the territories of 21 countries (Fig. 2).

Data obtained for the territories of Russia (Reference book 1992) and for other countries of the Black Sea drainage area (Prokacheva & Usachev 1994, 1997, 1999) have been used as the basis with the account of information on the Danube basin (Hydrology of the river Danube 1988).

The total polluted areas in the Black Sea drainage basin occupy 494,000 sq.km, i.e. 21 % of its territory. Most polluted lands (77%) are observed within the Danube, Dnieper and Don rivers basins. 33% of these lands are located in the Danube basin, 27% - in the Dnieper basin, and 17 % - in the Don basin.

Table 1 Averaged characteristics of the polluted areas in some countries

Country	Polluted area 1000 sq. km		Pollution extent %	Polluted area per capita sq. km / 1000 persons	Role of roads in the pollution %
	around towns	along roads			
Armenia	6.3	0.8	23.5	2.7	2.4
Austria	15.7	4.2	23.7	3.0	5.0
Azerbaijan	14.5	2.7	19.9	3.7	3.1
Belarus	15.2	11.7	12.9	2.2	6.1
Bosnia & Herzegovina	6.1	2.0	15.9	3.4	4.0
Bulgaria	14.8	7.1	19.7	2.5	6.3
Croatia	6.8	4.5	20.0	2.8	8.0
Czechia	21.1	10.4	40.0	3.1	13.2
Denmark	9.1	9.3	41.9	2.2	21.6
Estonia	2.6	1.8	9.7	2.2	4.1
Finland	18.4	9.1	8.2	4.2	2.7
Georgia	11.7	1.9	19.6	3.4	2.8
Germany	128.2	38.1	46.6	1.9	10.7
Hungary	19.0	4.0	24.7	2.6	4.4
Kazakhstan	90.9	23.4	4.2	9.4	0.9
Latvia	3.2	2.9	9.5	1.7	4.6
Lithuania	4.4	2.9	11.2	1.8	4.4
Moldova	4.5	2.2	19.8	2.1	6.6
Mongolia	9.7	9.8	1.2	7.9	0.6
Norway	12.6	6.4	5.9	3.8	2.0
Poland	52.4	41.9	30.2	2.2	13.4
Romania	30.4	8.0	16.1	2.4	3.4
Russia	619.8	123.4	4.3	5.6	0.8
Slovakia	8.6	3.7	25.3	2.8	7.6
Slovenia	3.3	1.8	25.2	3.0	8.9
Sweden	26.2	16.7	9.7	3.5	3.8
Turkmenistan	6.0	3.0	1.8	3.0	0.6
Ukraine	158.1	33.5	31.7	4.3	7.6
Yugoslavia	12.3	5.2	17.2	2.4	5.1

Polluted area distribution in the Danube river basin, over the territories of all 17 Danubian countries are presented in Table 2. The total polluted area in the Danube river basin occupies 122,000 sq.km; though the distribution of the polluted lands in different countries is not even (Fig. 3). The pollution extent in the appropriate parts of the Danube river basin in different countries ranges within wide limits from 1.6% in Switzerland up to 28.2 % in Czechia. A relative pollution extent in some parts of the Danube basin in different countries is also variable: in Czechia, Germany, Slovenia, Slovakia, Austria and Bulgaria it exceeds 20 %; in Switzerland, Albania and Poland – less than 3 %.

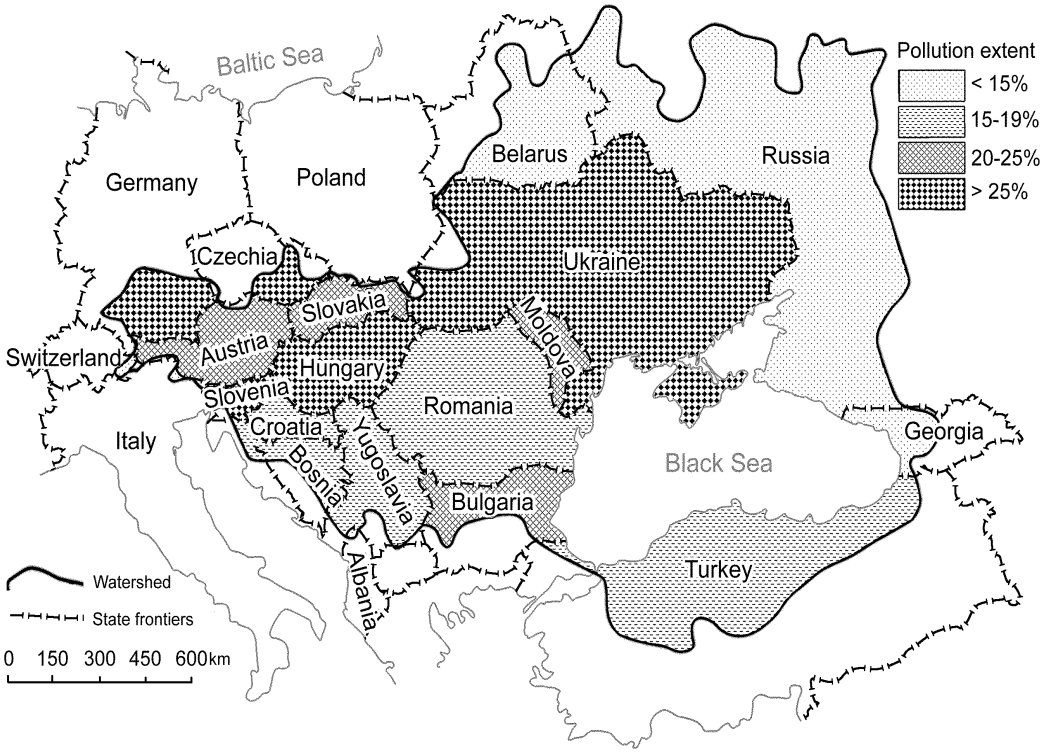

Fig.2 Pollution extent of the Black Sea drainage basin

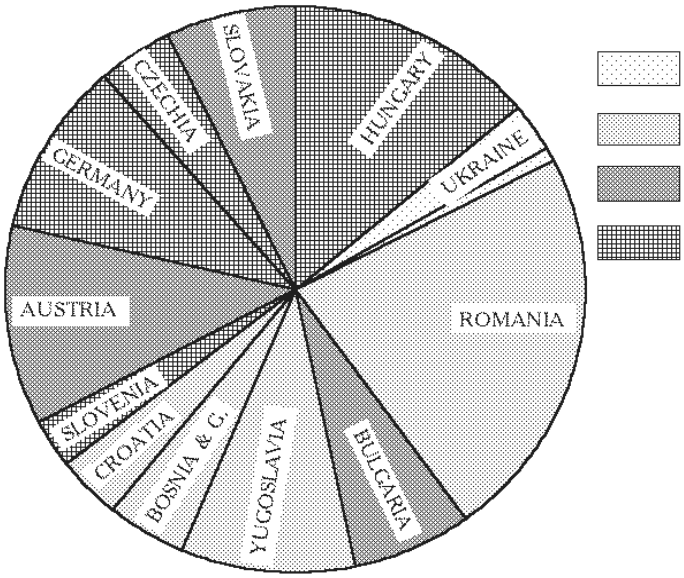

Fig.3 Percentage distribution of polluted lands on the Danube river basin.

Table 2 Polluted lands in the countries located in the Danube river basin

Country	Catchments area		Polluted area			Pollution extent in the river basin %
	1000 sq. km	%	around towns 1000 sq. km	with the account of roads 1000 sq. km	portion of the catchments %	
Albania	0.10	0.01	…	0.002	< 0,01	2.0
Austria	80.73	9.9	15.0	19.0	11.5	23.5
Bosnia & Herz.	39.50	4.8	5.7	7.2	4.4	18.2
Bulgaria	48.18	5.9	7.4	11.0	6.7	22.8
Croatia	35.00	4.3	3.8	6.3	3.8	18.0
Czechia	23.04	2.8	4.4	6.5	4.0	28.2
Germany	59.63	7.3	11.5	16.5	10.0	27.7
Hungary	93.03	11.4	19.0	23.0	14.0	24.7
Italy	0.47	0.06	…	0.015	0.01	3.2
Moldova	14.00	1.7	0.9	1.2	0.7	8.6
Poland	0.27	0.03	…	0.007	< 0.01	2.6
Romania	232.25	28.4	29.2	37.0	22.5	15.9
Slovakia	50.00	6.1	8.3	12.0	7.3	24.0
Slovenia	16.70	2.0	3.0	4.5	2.7	27.0
Switzerland	1.82	0.2	…	0.030	0.02	1.6
Ukraine	30.27	3.7	2.4	4.5	2.7	14.9
Yugoslavia	92.00	11.3	11.1	15.9	9.7	17.3
The Danube basin	817.00	100.	121.7	164.6	100.	20.2

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Complex Radio-Environmental Regionalization (CRER) of the Ukrainian River Basins

Victor M. Samoylenko, Yuriy S. Tavrov

Abstract: The new computerized procedure for complex radio-environmental regionalization (CRER) of river basins was elaborated and implemented on example of 30 Ukrainian test river basins in impact zone of the Chernobyl accident. The CRER procedure is applicable for other continental river basins during water management development.

Key words: test river basins, radio-environmental regionalization, radio-ecological risk, internal radiation dose, hydrological and landscape conditions

Die komplexe radioecologische Rayonierung (KRR) der ukrainischen Wasserbecken

Zusammenfassung: Die neue computerische Versuchs der komplexe radioecologische Rayonierung (KRR) war enwickelt und eingefahren am Beispiel der 30 ukrainishen Probewasserbecken in der Zone der Wirkung der Chernobylkatastrophe. Die Versuchs der KRR ist anwendbar für anderen Wasserbecken während der Wasserverwendung.

Schlüsselworte: die Probewasserbecken, die radioecologische Rayonierung, das radioecologische Risiko, die Innerstrahlendosis, die hydrologische und landschaftische Bedingungen

1 Introduction

According to the previous conclusions (Samoylenko, 1998), local water bodies (WB) (rivers, natural & manmade lakes, ponds etc.) in the most radio-polluted zones (primarily the Ukrainian Polissya and north-eastern Forest-Steppe) are very important for local water use and water consumption for economic and population purposes (drinking and industrial water supply, agricultural water consumption and melioration, fish-breeding and fisheries, water stock-breeding etc.). The location and resource utilization peculiarities of the WB in the Chernobyl accident impact zone directly influence the formation of the population internal radiation dozes (IRD) and human radio-ecological risk level because of the primary role of water in living organisms and communities, including their immunity. That's why this paper is devoted to the scientific-practical implementation of experience gained within 1986-1999 by Ukrainian Environmental Center "SIC WEMOW" during creation and development of computerized information system (IS) for generation, acquisition, computation and interpretation of field data bases on Ukrainian WB radioisotope pollution.

2 Procedure

In order to develop foregoing inventory IS (Samoylenko, 1998) special new stochastic computerized procedure (with radio-ecological risk assessment) was elaborated and called 'the procedure for complex radio-environmental regionalization (CRER) of river basins (RB)'. Such procedure is based on the theses of stochastic environmental hydrology as a new scientific sphere (Samoylenko, 1996, 1998).

CRER procedure foresees complex probability environmental RB sructurization aimed to distinguish parts of river basins, where hydrological & landscape conditions and possible consequences of radio-ecological/hydro-environmental processes are homogenous for population during consumption of local water fond resources (water, biological, land resources etc.).

CRER-procedure was executed on example of selected investigated region (the Ukrainian Polissya and north-eastern Forest-Steppe, Fig.1) as two-dimensional environmental general system (IREGS). IREGS was defined by the determinate-random and random fields' presentation (DRF and RF, Samoylenko, 1998) as the combination of three main DRF/RF – hydrological (*HL*), landscape (*LS*) and radio-ecological (*RE*):

$$(\text{IREGS}) \in [(HL); (LS); (RE)] \quad (1)$$

Hydrological DRF was preliminarily divided into 30 test river basins (TRB) according to the watershed lines of TRB principal rivers or reservoirs (Fig.1). Landscape DRF consisted of sub-fields, which were respondent to definite genetic type of landscape. Foregoing landscape types essentially predestine the conditions of Chernobyl radionuclide migration and redistribution in river basin sub-systems.

The definition of radio-ecological random fields was based on design internal radiation doses (DIRD) to inhabitants-abstractors (Samoylenko, 1998). In accordance with DIRD values new classified scheme for degree classes and degrees of possible radio-ecological risk in consequence of local water use (PRR LWU) was developed and proposed (Table 1).

Table 1 Classified scheme for degree classes and degrees of possible radio-ecological risk in consequence of local water use (PRR LWU), based on design internal radiation doses (DIRD) to inhabitants-abstractors (Samoylenko, 1998, 2000)

DIRD intervals, mSv•yr^{-1}	**PRR LWU categories**		
	Degree classes of PRR	**Degrees of PRR**	
		Indications (with symbols)	**Numerical indexes**
DIRD ≥ 0,200	Increased	High (H1)	1
0,100 ≤ DIRD < 0,200		Increased (I2)	2
0,050 ≤ DIRD < 0,100	Moderated	Moderated (M3)	3
0 ≤ DIRD < 0,050	Low	Low (L4)	4

Proper CRER by hydrological-landscape conditions and possible radio-ecological consequences of local water use was aimed to create two different but interrelated structures of investigated region's environmental general system:

(a) initial simulated functional structure of IREGS by PRR LWU (ISFS IREGS);
(b) secondary (integral) simulated functional structure of IREGS by PRR LWU (SSFS IREGS).

ISFS IREGS was simulated and formed by interpolation of defined DIRD intervals within limited homogeneous hydrological-landscape sections of TRB. Such sections, marked by corresponding to DIRD interval degrees of PRR (Table 1), constituted already quasi-stationary and quasi-uniform combined random sub-fields (inside TRB) and fields (inside IREGM) of PRR LWU – as elements of ISFS IREGS (Fig.2).

In order to distinguish secondary structure of IREGS – SSFS – special CRER taxonomic classification was elaborated with such hierarchical division: test river basin (TRB) – area of test river basin (ATRB) – local maximum of increased degree class of PRR (LM, inside ATRB).

Test river basin, already as a CRER-taxon of the highest location, was regarded as hydrological macro-system with uniform property by water flow regime, which makes for similar features of macro-dynamics of secondary radioactive pollution by water flow processes against the

background of aqua-terrestrial ecosystems' primary radio-contamination. Different from preliminary TRB division (Fig.1), test river basin like a CRER-compartment can be tested on design integral level of PRR LWU (Samoylenko, 1998, 2000). TRB involve their areas – the lowest CRER-taxons.

Area of test river basins (ATRB) was mentioned as hydrological-landscape meso-system inside TRB with specific target conditions and consequences of local water use and principal taxon substructure of CRER. Such meso-system is distinguished spatially by integral index – predominant indication of PRR degrees (Table 1) or combinations of those indications (no more than two) taking into consideration the ATRB compilation position with respect to TRB river valley or elements of this valley. ATRB is excelled by set of main consolidated (by river network etc.) landscape complexes, which have uniform property to possible radio-ecological consequences of LWU. Areas of TRB can involve local maximums of increased PRR LWU.

Local maximum of increased degree class of PRR (LM) was qualified as hydrological-landscape micro-system, which is defined in ATRB with more than one predominant indication of PRR degrees and belongs, as a rule, to only one type of landscape.

In that way, secondary (integral) simulated structure of IREGS was created by stochastic system modeling of ISFS IREGS division according to the multi-criteria of foregoing CRER taxonomic classification and transformation/attribution of ISFS random fields into fixed CRER-taxons (TRB, ATRB, LM).

3 Principal Results

Principal results of CRER procedure realization were implemented in computerized GIS maps of the most radioisotope polluted 30 Ukrainian test river basins. Their CRER-taxons (124 areas of TRB, Fig.3, and 70 local maximums in ATRB), with simulated level of possible radio-ecological risk in consequence of local water use (Samoylenko, 2000), point to the paramount environmental systems for counter-measures towards radiology situation mitigation with increasing of theoretical knowledge in sphere of radio-ecological and hydrological-landscape interaction and monitoring optimization. The CRER procedure is applicable for other continental river basins, not only for radioactive pollutants, during water management development.

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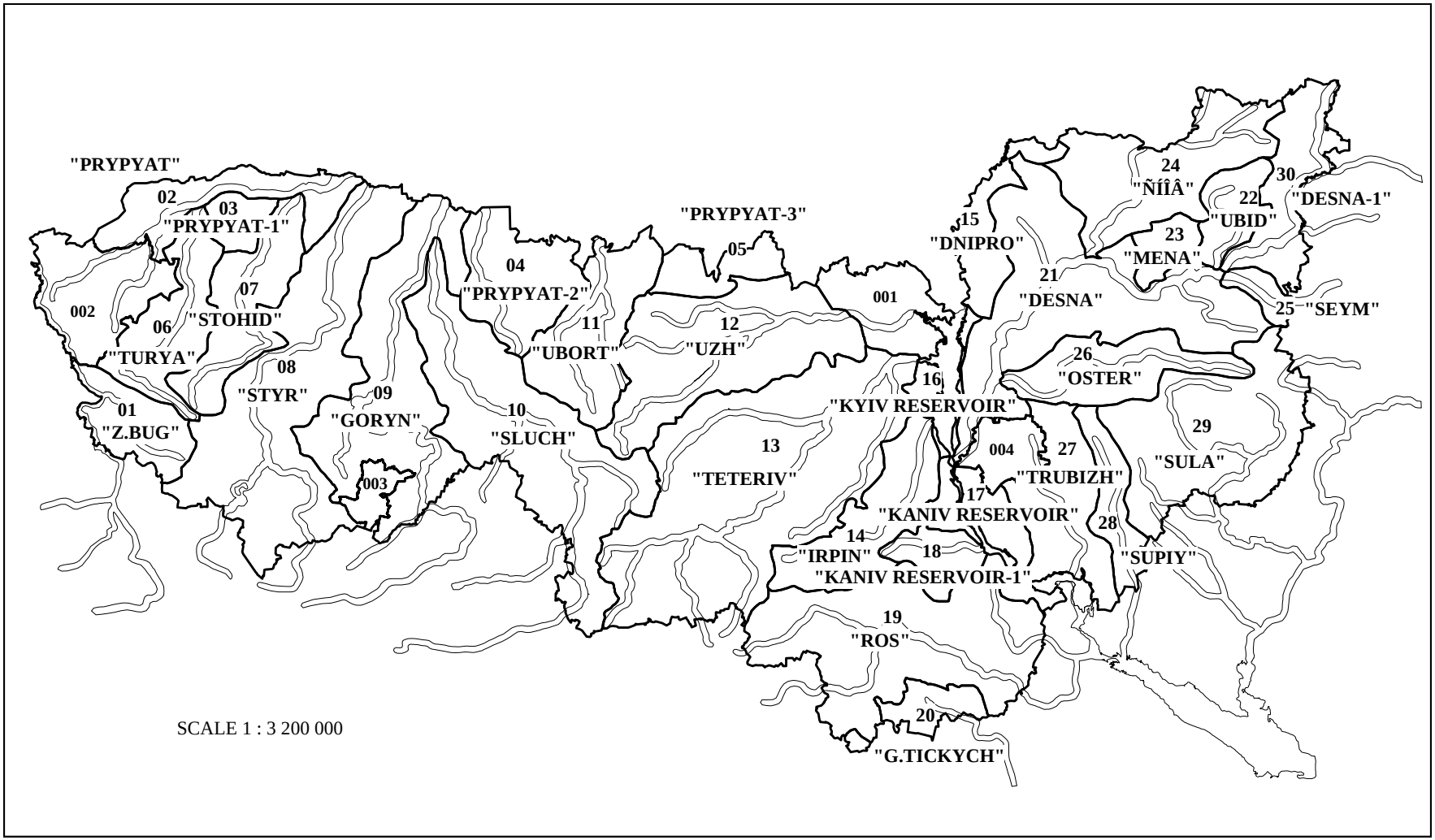
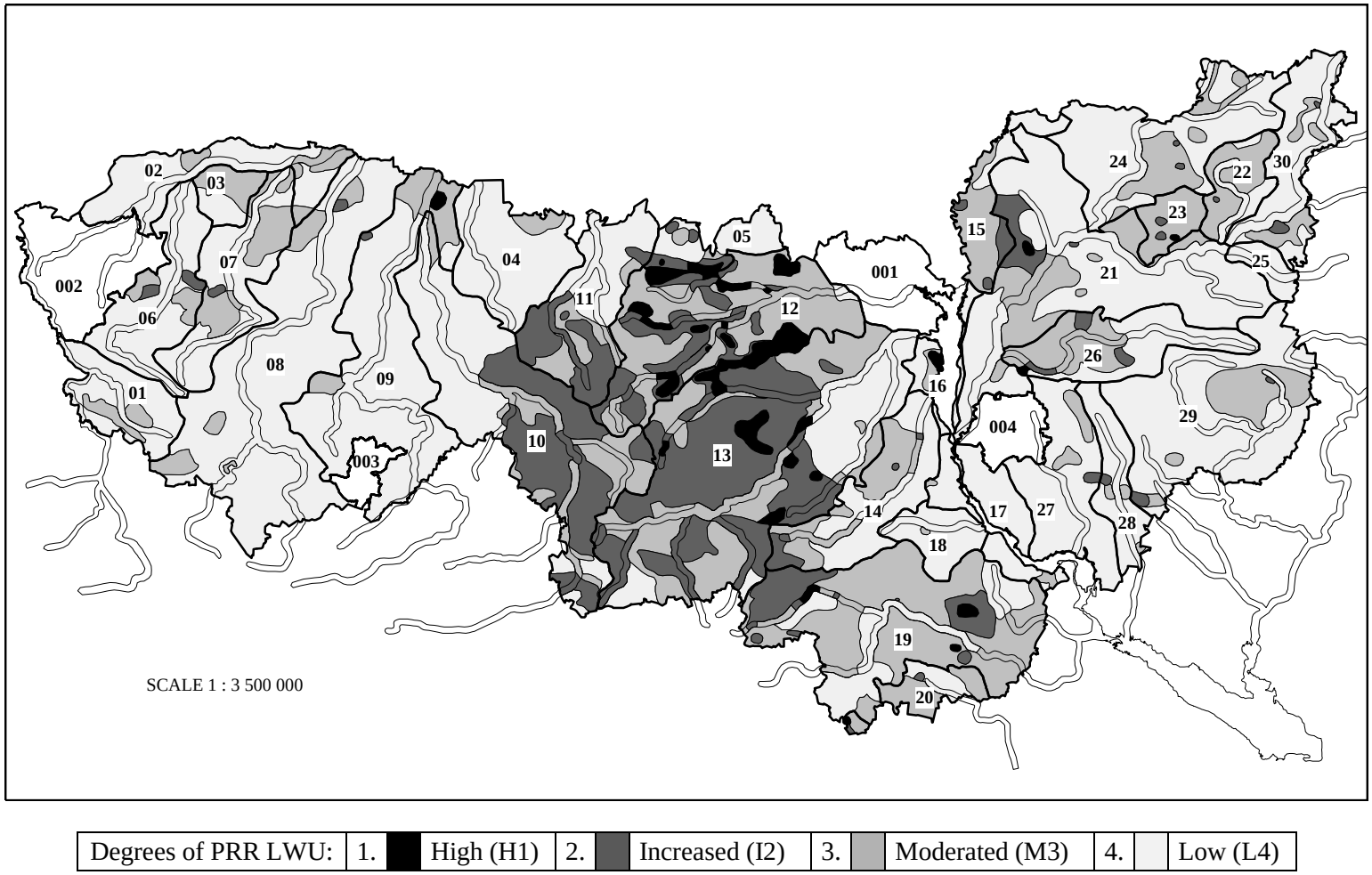


Fig. 1 Codes, names and borders of test river basins (TRB) (001…004 – non-investigated territories, including the Chernobyl Alienable Zone)



Degrees of PRR LWU:	1.	High (H1)	2.	Increased (I2)	3.	Moderated (M3)	4.	Low (L4)

Fig. 2 Fields for degrees of possible radio-ecological risk in consequence of local water use (PRR LWU, Table 1) in 30 test river basins [chart of initial simulated functional structure of investigated region's environmental general system by PRR LWU (ISFS IREGS)] (01…30 – codes of TRB, 001…004 – non-investigated territories, including the Chernobyl Alienable Zone, fig.1)

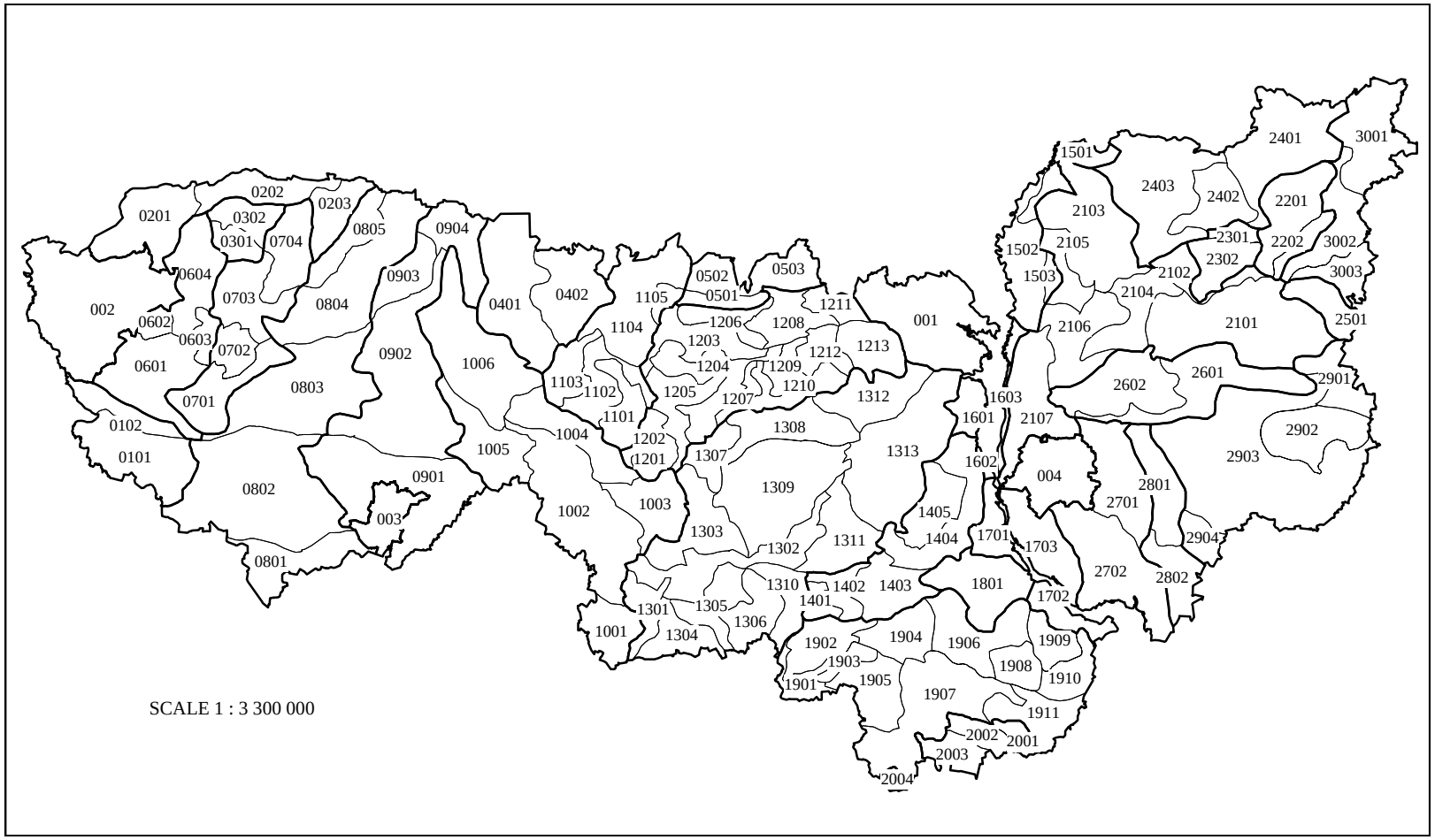


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Fig. 3 Boundaries of areas of test river basins (ATRB) as taxons of complex radio-environmental regionalization (CRER-taxons) [chart of secondary (integral) simulated functional structure of investigated region's environmental general system by PRR LWU (SSFS IREGS)] (0101…3003 – codes of ATRB, in which first two digits – codes of TRB, fig.1)

Water Quality of the Danube River and Its Impact on the Danube Delta and the Black Sea

Petru Serban, Aurel Varduca, Lucian Constantinescu

Abstract: In the first part of the paper it's presented the time evolution of the water quality parameters and the water quality-monitoring network of the Danube River.
In the second part it's presented the impact on the Danube Delta and the Black Sea ecosystems of the water quality of the Danube River.
A special reference is made on the effect of the war from Yugoslavia (Kosovo) on the water quality of the Danube River.

Key words: water quality, monitoring, pollution, self-purification, loads, nutrients, heavy metals, sediments.

Donau-Wasserqualität und der Einfluss gegen das Öko-system der Donaudelta und dem Schwarzen Meer

Zusammenfassung: Der erste Teil stellt die zeitliche Entwicklung von Wasserqualität Parameters und die Tätigkeit von Überwachungsnetz für die Donau dar.
Der zweite Teil stellt den Einfluss gegen das Öko-system der Donaudelta und dem Schwarzen Meer von der Wasserqualität Donaus dar.
Eine Spezialbezichung auf die Wirkung des Krieges im Kosovo gegen die Wasserqualität Donaus wird dargestellt.

Schlusselworte: Wasserqualität, Überwachungsnetz, Verschmutzung, Selbstreinigung, Belastung, Nährstoffen, schwere Metalle, Sedimenten.

1 Temporal trend of the water quality of Danube River.

The Bucharest Declaration (1985) and the Danube River Protection Convention created the legal frame of the activity of knowing and protection of the quantity and quality of the transboundaries waters.

Yearly are carried out a number of about 25000 - 26000 physical - chemical, biological, microbiological and radioactivity analyses.
The monitoring program of the Danube River includes: 11 control sections, 26 sampling points, 12 sampling frequencies and 50 quality parameters.

The Danube water quality characterisation, made by means of the mean annual parameter values, established for each control section, is presented in the following:

a) Referring to the oxygen and the organic regime parameters:

- Dissolved oxygen DO % has shown an evident decreasing spatial-temporal trend. While at reference section Jochenstein (Germany) the DO % values for 1988 year were about 100%, at the Danube mouth, DO % values reached only 78 %;

- Organic parameters COD-Mn, COD-Cr and BOD_5 presents a constant spatial evolution because of the self-purification process, being visible a decreasing trend after the 1992 year, both upstream and downstream of Bazias, at the entrance of the Danube on the Romanian territory.

Table 1 Danube water quality monitoring network provided in Bucharest Declaration

No	Section Name	Borders	Km	No. sampling points / section
1.	Jochenstein	Germany/Austria	2208.3	1
2.	Wolfsthal - Bratislava	Austria/Slovakia	1873	2
3.	Medvedev - Medvede	Slovakia/Hungary	1806	1
4.	Cob - Szob	Slovakia/Hungary	1707	3
5.	Mohacs - Bezdan	Hungary /Croatia	1433	1
6.	Banatska Palanka - Bazias	Yugoslavia/Romania	1075	3
7.	Gruia - Radujevac	Romania/ Yugoslavia	851	3
8.	Pristol - Novoselo	Romania/ Bulgaria	833	3
9.	Chiciu - Silistra	Romania/ Bulgaria	375	3
10.	Reni - mila 7	Ukraine /Romania	166	3
11.	Vilkov - km 18	Romania/ Ukraine	18	3

b) Referring the nutrients regime (fig. 1, 2) it was presented a decreasing trend after the 1992, both upstream and downstream of Bazias. This decreasing is more pronounced for the downstream countries (table 2), taking into account that the nitrogen (N) and phosphorus (P) concentration values in the 1994 year, in comparison with the 1988 year, present a decreased trend at the control section S_{10} - Reni, at the entrance of the Danube Delta, respectively 27 % for N and 65 % for P, in comparison with the values of 12 % for N and 63 % for P, at the control section S_6 - Banatska Palanka - Bazias.

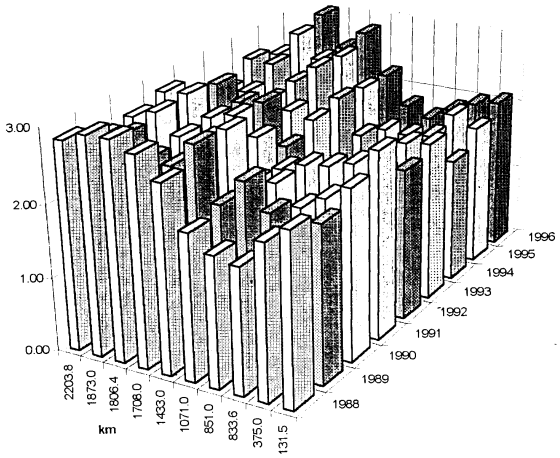

Fig.1 Spatial-temporal trend of the mean annual concentrations of total mineral Nitrogen (mg/l), for different stretches of the Danube - period 1988-1996-

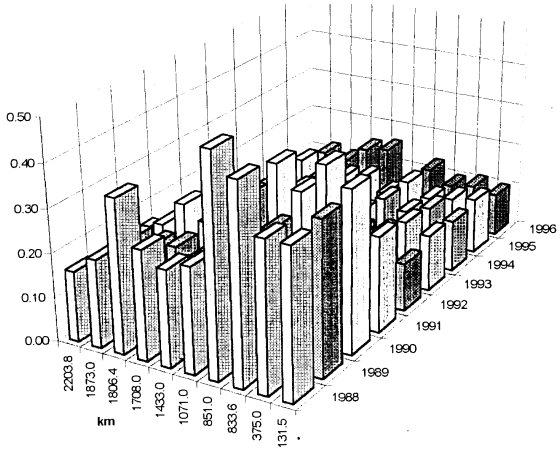

Fig.2 Spatial-temporal trend of the mean annual concentrations of total Phosphorous (mg/l), for different stretches of the Danube - period 1988-1996-

c) Referring the TDS parameters regime it was evident an increase of the salt content, from the reference section S_1 towards the final section S_{10}

Table 2 Spatial evolution of the nutrient pollution in 1994 year, in comparison with 1988 year

% decreasing	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	Mean %
N (mg/l)	6	10	12	?	9	12	15	?	8	27	9.5
P (mg/l)	44	35	66	36	41	63	74	78	59	65	56.1

d) Referring other parameters, excepting slightly differences for chlorides, there are not observed evident spatial and temporal variations. But there are remarked concentrations, beyond the usual limits, of heavy metals, in the sediments of the Iron Gate reservoir, observed also by the Cousteau Mission, which explained this situation as a “chemical bomb with effect in time”. These heavy metals are mostly originated from the upstream Danube countries.

We can consider the water quality of the Danube River is satisfactory, the most of the parameters complying the sanitary needs and the aquatic environment specific norms. The oxygen regime parameters, TDS parameters and some of specific pollutant parameters, are situated below the admissible limits for the water users.
For the integrated evaluation of the Danube water quality it has been used the classification proposed in the EC Project CES 668/1990, referring to the quality of the watercourses.
The variables taken in consideration for this classification are the following:

Table 3 The global balance for nitrogen load-the trend of contribution of the Danube countries

Year	Contribution				
	Input section Bazias (kt)	Output section Reni (kt)	Difference Reni-Bazias (kt)	upstream countries Bazias %	downstream countries Bazias %
1976	63	65	+2	96.9	3.1
1989	313	500	+187	62.6	37.4
1990	261	294	+33	88.8	11.2
1991	369	440	+71	83.9	16.1
1992	288	342	+54	84.2	15.8
1993	284	338	+54	84.0	16.0
1994	240	278	+38	86.3	13.7
1997	349	383	+34	91.1	8.9
average	270.9	330	+59.1	84.7	15.3

- oxygen regime (DO, BOD_5, COD)
- eutrophication (TP, TN)
- buffer capacity (pH, alkalinity)
- dangerous substances (heavy metals and cyanides)
- pesticides
- radioactivity
- microbiological pollution

Regarding the evolution of the water quality of the Danube River, the general tendency is the decreasing of the water quality, in accordance with the different analysed parameters:

- referring the oxygen regime, 331 km (15.3 %) of the upstream sector of Danube belongs to the class "excellent" and the rest of 1873 km (84.7 %) belongs to class "good";
- referring the eutrophication parameters, because of high concentration of nitrogen and phosphorous, even the first upstream sector of 550 km (24.3 %) is situated in the class "weak". A slight improvement is detected on the downstream sector where 497 km (22 %) is situated in the class "moderate"; but the most of the Danube River sector - 1175 km (53.7 %) belongs to class "weak";
- regarding the buffer capacity, all the Danube sector belongs to the class "excellent";
- heavy metals have an important role in the judgement of the water quality class, especially downstream of the control section Banatska Palanka - Bazias. Only 331 km (15.3 %) from the upstream sector is situated in the class "moderate", the rest of 1855 km (84.7 % is situated in the class "weak";
- almost the same situation occur for the pesticides: 152 km (6.9 %) of the Danube sector is situated in the class "moderate" and 2034 km (93.1 %) is in the class "weak". The decreasing of the water quality amplifies gradually downstream.

As a global figure, excepting the oxygen regime and the buffer capacity, the Danube water quality, according the EC Project criteria, belongs to the class "weak".

Table 4 The global balance for phosphorus load-the trend of contribution of the Danube countries

Year	Contribution				
	Input section Bazias (kt)	Output section Reni (kt)	Difference Reni-Bazias (kt)	upstream countries Bazias %	downstream countries Bazias %
1976	15	19	+4	79	21
1989	37.6	49.3	+11.7	76.3	23.7
1990	23	37	+14	62.2	37.8
1991	26	38	+12	68.4	31.6
1992	12.4	18.2	+5.8	68.2	31.8
1993	11.7	17.1	+5.4	68.4	31.6
1994	13	23	+10	56.5	43.5
1997	14.6	18.1	+3.5	80.7	19.3
average	19.2	27.5	+8.3	70 %	30 %

2 Specific problems of the downstream sector of the Danube River.

2.1. Nutrient pollution

The downstream Danube countries, Romania, Bulgaria, Moldavia and Ukraine are confronted with the nutrient pollution, exported from upstream countries.
This is shown in tables 2 - 4, where is presented an analysis for the Danube downstream sector, with the nutrients input and output, the internal contribution, as percent of the total nutrients loads transported to the Danube Delta and to the Black Sea.
In the case of nitrogen, the mean contribution of the downstream countries is about 15.3%, while their afferent catchement is 29 % of the total Danube catchement, meaning that the real undesirable “import” of pollution with nitrogen from the upstream countries is about 84.7 %.
It must be shown that after a maximum of 16.1 % recorded in the year 1991, it occurred a decreasing trend, referring to the internal contribution of Danube downstream countries. In the last period of time this was approximately 13.7 % in the year 1994 and 8.9 % in 1997.
For phosphorous, the “import” of pollution from the upstream countries is about 70 %., while the mean contribution of the downstream countries is about 30%. It occurred also a decreasing trend, referring to the internal contribution of Danube downstream countries.
The nutrient concentration / load entering in the Danube Delta and the Black Sea decreased in the year 1994 in comparison with the year 1988, with the following values: regarding the concentrations, 27 % for nitrogen and 65 % for phosphorous, and regarding loads, 39 % for nitrogen and 66 % for phosphorous.
The positive process mentioned above doesn’t reflect only the water quality protection measures, taken in the last period of time, but also show the declining of the industrial activities and of the quantities of fertilisers applied in agriculture in the transition countries from the Eastern Europe.

2.2. Pollution with non-biodegradable organic substances.

The organic non-biodegradable substances can’t be “filtered” by the Danube Delta and it represent an import from the upstream countries.
The general time trend of the concentration of the organic substance, evaluated firstly as COD-Cr, is the diminishing, both in the upstream countries and in Romania. An important decrease occurred for the Romanian sector, where the COD-Cr load in the year 1997 represents approximately 60 - 65 % from the load in the year 1988.

Despite of this, the spatial distribution of the “R” ratio, which represent the concentration of COD-Cr (non-biodegradable + biodegradable organic substance) recorded at control section S_{10} (Reni), towards with the concentration measured at the upstream sections, presents a maximum at section S_3 (Medvedev), before the entry on Romanian territory, maximum which differs as location, in comparison with the afferent maximum for BOD_5 (biodegradable substance). In this sector exists a pollution source which transfers downstream "heavy biodegradable organic substances". For Romania the “R” ratio presents constant values around 0.6. This confirms the hypothesis that the Danube transports towards the downstream sector a load of heavy degradable chemical substances, "imported" from the upstream sector to the Danube Delta and to the Black Sea, without representative local contributions.

Table 5 Changes in the North-Western side of the Black Sea

Indicator	1960	1989	1997
Quality of the ecosystem	good	heavy deteriorate	stationary
Fish stock	excellent	heavy reduced	stationary
Eutrophication	minor	periodic algal blooming	declining of algal blooming
Nitrogen load transported by the Danube in the Delta	50 kT/year	500 kT/year	383 kT/an
Phosphorus load transported by the Danube in the Delta	14 kT/year	49.3 kT/year	18.1 kT/an

2.3. Pollution with heavy metals

It occurred relatively reduce concentrations of heavy metals transported from the upstream countries, excepting the control sections S_5 and S_6 (Mohacs-Bezdan and Banatska-Palanka - Bazias), which presents a significant "export" of Cd, Pb, Hg and Cr towards the downstream countries. The associated sediment pollution illustrates better this process.

Table 6 The impact of priority pollutants upon the key functions of the Danube Delta and the Black Sea

Functions	Priority pollutants				
	nutrients	metals	pesticides	bacteria and viruses	petroleum substances
ecosystem	+++	++	++	-	++
recreation	++	-	-	+++	+
ecotourism	++	-	-	+++	+
fishery	+++	++	++	-	+
hydraulic structures	-	++	++	-	-

2.4. Pollution with petroleum substances

For the control section Bazias, during the period 1988-1992, frequently were recorded concentrations of petroleum substances of 0.6 - 0.7 mg/l. Since the year 1992 the pollution with petroleum substances declined at 0.3 mg/l.

2.5. Associated sediment pollution

The Research Institute for Environmental Engineering from Bucharest and the Cousteau Mission did a systematic evaluation of the sediments during the period 1991-1992. The sediments from the Iron Gate reservoir present an important pollution owing to the upstream industrial discharges with heavy metals and other chemical substances. The heavy metals (Hg, Cu, Pb, Zn and Cr) constitute the most representative accumulation of pollutants in sediments at

concentrations of 1.76 (Pb) till 3.05 (Hg) times greater than the concentrations recorded in the Rhine Delta. Owing to these considerations, the situation was characterised by the Cousteau Mission as "chemical bomb with effect in time".

3 The impact on the Danube Delta and the Black Sea ecosystems of the water quality of the Danube River.

The **eutrophication** of the Danube Delta and the Black is the environmental problem which probably drawn mostly the attention as a result of the use of fertilisers in the Danube basin. The River Danube transported 49.300 tonnes of phosphorus and 500.000 tonnes of nitrogen in the year 1989, quantity which is ten times greater in comparison with the year 1960 in the case of nitrogen and 3.5 times greater in the case of phosphorus. Despite the fact that in the year 1997 this impact declined to 383.000 tonnes of nitrogen/year and about 18.000 tonnes of phosphorus/year, the "impression " of the Danube on the downstream sector still remains at high level (table 5). The eutrophication, as a result of the high loads of nutrients, contributed to drastic changes and to global perturbations of the natural balances of the ecosystems (table 5 and 6). The first algal blooming occurred in the year 1975. After this date, as a direct consequence of the accentuation of the human activity, this process repeated with a different amplitude and frequency. So, until the year 1992, it has been founded an increase of phytoplankton concentration. After 1992, this process diminished, as a result of declining of nutrients load transported by the Danube. Some characteristics of this process are significant:
- till 1980 eutrophication phenomena appeared only in some cases, but in the period 1985-1992 it occurred in all seasons, excepting winter;
- the increase of process of “algal blooming” after the year 1975 is shown for the period maximum incidence by the following values of the biomass: 52 g/m3 in 1961, 310 g/m3 in 1980 and 461 g/m3 in 1985.

As a result of the increase of the nutrients load discharged in the Black Sea, in parallel occurred an **induced development of other species**, so as in the period:

- 1960 -1970, in phytoplankton were presented 38 species with a density under 100.000 cells/l;
- 1971 - 1980, in phytoplankton were presented a number of 61 species with densities of millions of cells/l.

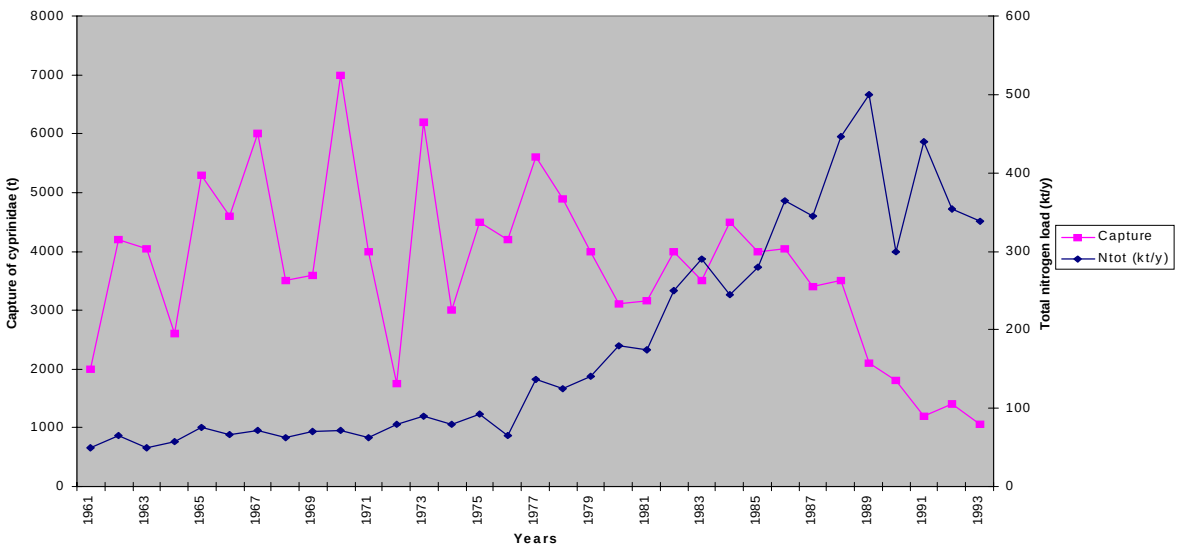

Fig.3 Evolution of the total nitrogen load and of the quantities of captured cyprinidae in the Danube Delta

The ecosystem modified during the period 1985-1990, the result being the increase of the anoxia, reducing of biodiversity and the development of opportunist algae with adverse effects on the aquatic environment.
The deterioration of the quality of the Danube, in correlation with the embankment of important land surfaces in the Danube Delta, for agricultural use, had as result the **declining of the fish species** from a number of 110 to 64 and the **diminishing of the quantities of cyprinidae** (carp), captured during the period 1961-1993, in the Danube Delta (fig.3 and 4).
For the period 1961-1973, it appears in figures 3 and 4 a natural evolution of cyprinidae captures, because the water quality of Danube was very good and the embankment of 24000 ha was done slowly and the impact on the fish population was insignificant. This situation changed completely after the year 1973, together with the deterioration of the quality of the Danube and the acceleration of the dynamic of the embanked surfaces (with the increase of the losses from the reproduction habitats) which exceeded 100.000 ha after 1988. After the year 1991 the fish catching stabilised, with a slightly increase in 1992, owing to the improvement of the water quality of Danube. This process will continue owing to the river restoration of some polders in the Danube Delta: Babina, Cernovca, Dunavat, Hobina I and II.

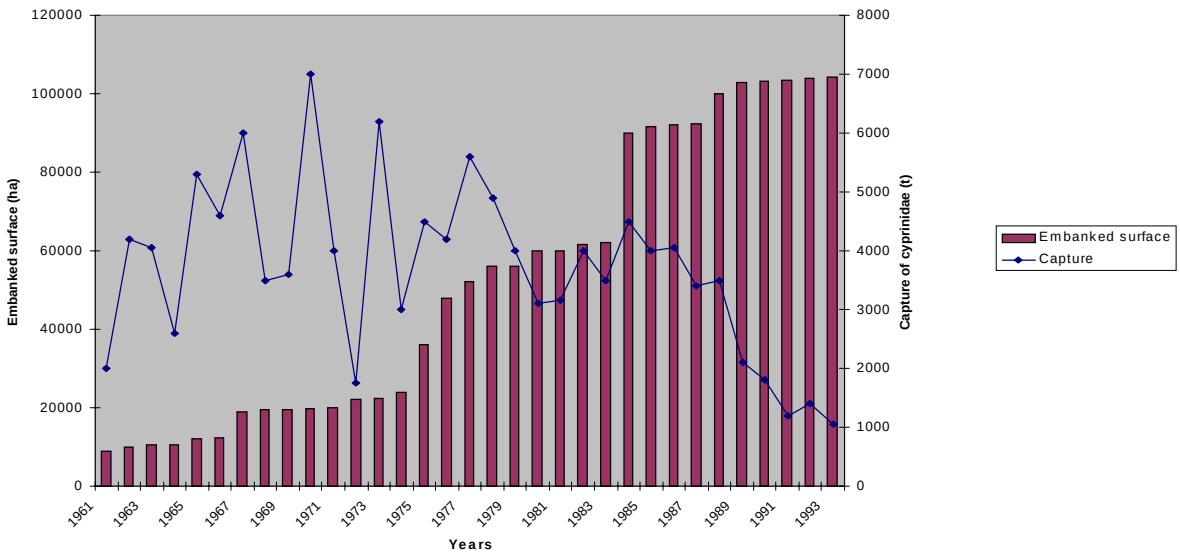

Fig.4 Evolution of the embanked surfaces and of the quantities of captured cyprinidae in the Danube Delta

4 The impact of the war from Yugoslavia on the water quality of the Danube River.

Just after the beginning of the war from Yugoslavia (24 March 1999), it were taken samples of water, sediments, fish and shells, with an increasing frequency, in comparison with the standard monitoring program, from several control sections from Danube, on the sector Bazias-Reni.
For emphasising the impact of the war from Yugoslavia (Kosovo) it were analysed comparatively:

- the concentrations of different chemical parameters measured in the same period of time at the control section Bazias (km 1071) and at the upstream section Hercegszanto (km 1435), considered as a witness control section, uninfluenced by the war (table 7).
- the concentrations of different chemical parameters, measured during the war, and the concentrations of the same parameters measured during the period 1996-1998 (tables 8-10).

Analysing the data presented in the tables 7-10, results the following conclusions regarding the **water and the sediments**:

a) The maximum magnitude of the impact, from the point of view of the temporal and spatial evolution, was distinguished in April 1999. The maximum incidence zone was the Iron Gate I reservoir, especially the section Bazias. Downstream of the control section S_7 (Gruia) the effect of the impact diminished;
b) The biggest ratios, for water, of the heavy metals concentrations at Bazias, with the concentrations at Hercegszanto were recorded in the month of April so as: Cd (144), Cr (12), Zn (44), Pb (36) and Cu (9);
c) The significant increase of the concentrations of heavy metals in water, with exceeding of the admissible limits of the Romanian standard STAS 4706/1988, on the sector Bazias-Iron Gate II, during April 1999, in comparison with the reference period 1996-1998;
d) The heavy metal concentrations hadn't significant leaps on the sector Gruia-Reni, in the same period of time, in comparison with the reference period 1996-1998 and the effect of the pollution in the zone of Bazias, haven't been observed in the Danube sector, situated downstream of the Iron Gate II reservoir;
e) Declining of the content of heavy metals in water, on the sector Bazias-Gruia, in the period following the war, respectively in August 1999, with returns of the heavy metal concentrations, to the values measured in the previous years; at the same time, haven't been observed significant changes in the sector Gruia-Reni, the recorded concentrations in August 1999, being comparable with the values measured during the reference time period 1996-1998;

Table 7 Heavy metals concentrations measured in the year 1996 in sections Hercegszanto and Bazias

Heavy Metals :g/l	Bazias km 1071		Hercegszanto km 1435		Ratio Bazias/Hercegszanto	
	average	max.	average	max.	average	max.
Zn	37	190	12	12	3.1	16
Cu	24	112	3	3	8	37
Cr	14	28	0.5	0.5	28	56
Cd	0.4	0.6	0.2	0.2	2	3
Pb	13	35	1.5	1.5	8.7	23

f) The increase, in April 1999, of the concentrations of the heavy metals (Zn, Cu, Cr, Cd, Pb) in sediments on the sector Bazias-Gruia, situation which maintains also in August 1999 for Pb and at a smaller extent for Zn and Cd;
g) The heavy metals concentrations measured during April - August 1999 have been 2 -7 times smaller in the sector Gruia-Reni, in comparison with the concentrations measured in the same period in the sector Bazias-Gruia for Zn, Cu, Cr and Pb, and comparable for Cd;
h) The exceeding of about 4 times, respectively 2 times of the admissible value limits of the Belgium Standard for heavy metals in sediments (table 10) in the sector Bazias-Gruia and respectively in the sector Gruia-Reni;
i) Referring to the temporal evolution, it has been observed a significant increase of heavy metals concentrations in sediments in the period April-July 1999, comparatively with the previous years, in the sector Bazias-Gruia. In August 1999, for Zn, Cu, Cd and at a smaller extent for Pb it has been remarked a return tendency to reducer heavy metals concentrations in sediments. For the sector Gruia-Reni the range of the concentrations measured for the year 1999 is comparable with the range of the concentrations measured during reference period, excepting Pb, for which appears an increasing trend in the year 1999.

Table 8 Concentrations of heavy metal in the year 1999 at the sections Hercegszanto and Bazias

Metals :g/l	Bazias km 1071						Hercegszanto km 1435						Ratio Bazias/Hercegszanto					
month	J	F	M	A	M	J	J	F	M	A	M	J	J	F	M	A	M	J
Zn	17	-	-	353	99	20	4	9	3	8	15		4	-	-	**44**	7	-
Cu	2.2	-	-	65	17	23	5	6	3	7	6		0.4	-	-	9	2	-
Cr	76	-	-	50	7.8	22	1	1	0.7	0.4	0.1		76	-	-	**125**	78	-
Cd	6	-	-	7.2	6.3	2.5	0.05	0.05	0.05	0.05	0.05		120	-	-	**144**	126	-
Pb	1.4	-	-	36	34	50	1.7	1.0	0.5	1.0	1.2		0.8	-	-	**36**	28	-

Table 9 Spatial-temporal evolution of the heavy-metals concentrations in water

Analysed sector	Period	:g/l				
		Zn	**Cu**	**Cr**	**Cd**	**Pb**
Bazias-Gruia	1996-1998	19-96	10-26	8-17.6	0.2-22.4	4.3-55.8
	April-June 1999	38.5-**1155**	8.2-**74.6**	23.2-**78.7**	1.1-5.6	16-**72**
	August 1999	20-33	15.4-26.8	8.3-15.9	0.2-3.4	14.5-21.1
Gruia-Reni	1996-1998	22-81.6	11.5-32.5	7.5-21.8	0.58-8.2	8.7-33.2
	April-June 1999	20-72.7	10.5-53	8.9-62	0.25-10.4	7.4-62.8
	August 1999	11-70	19-32.3	7.9-25.1	0.8-2.7	11.4-26.5
Max. admissible concentration according STAS 4706/188		30	50	50	3	50

The content of the heavy metals for the aquatic organisms has been determined in the **muscles and livers of fish** (table 11). The species more frequently analysed in August 1999, have been:

Cyprinus carpio (carp)
Abramis brama (bream)
Exos lucius (pike)
Lucioperca sandra (sander)

The maximum admissible concentrations in the muscles and livers of fishes (table 11) have been exceeded of maximum:

- 2 times for Zn, both on the sector Bazias-Gruia and on the sector Gruia-Reni;
- 2 times for Cu, on the sector Bazias-Gruia;
- 6 times for Cd, on the sector Bazias-Gruia and respectively 3 times on the sector Gruia-Reni;
- 6 times for Pb, on the sector Bazias-Gruia and respectively 5 times on the sector Gruia-Reni.

For the characterisation of the toxic and dangerous potential of heavy metals, it has been used also the ecological classification system of Dr. Bodo Wachs, which take into account criteria referring the heavy metals concentrations in fish tissues. This is presented in table 12.

The following aspects can be mentioned:

- the sector Bazias-Gruia belong to class IV, according to the classification system of Dr. B.Wachs;

- the sector Gruia-Reni belong to a better class in comparison with the sector Bazias-Gruia , referring to Cu, Cr and Cd , the sections Pristol and upstream Arges being situated in class III-IV, and the sections upstream Ialomita and downstream Siret being in class II-III or III-IV;
- regarding the class of the downstream sector of the Danube River, have been remarked the tendency to move to a more unfavourable class referring to Zn, Cu, Cr, Pb, especially on the sector Bazias-Gruia, respectively from the classes II, II-III, during the reference period (1994-1996), to the classes III, III-IV in August 1999.

Table 10 Spatial-temporal evolution of the heavy metals concentrations in sediments

Analysed sector	Period	:g/l				
		Zn	**Cu**	**Cr**	**Cd**	**Pb**
Bazias-Gruia	1997	58	38	26	0.7	32.4
	April-July 1999	122-**417** Bazias	72-**144** Gruia	64-**114** km.956	2.0-**8.5** Mold.Noua	35.5-**153** Bazias
	August 1999	162-**346** Bazias	61-**74** Bazias	69-**77** Bazias	2.3-**3.3** Gruia	19.5-**137** Bazias
Gruia-Reni	1997-1998	46.5-**299** am.Arges	42-**56** am.Arges	22-**76** am.Arges	0.3-**4.7** am.Arges	13-**37.5** Pristol
	April-July 1999	69-**143** am.Arges	24-**109** am.Arges	15-**76** km.490	1.2-**7.3** km.554	23-**69.8** am.Arges
	August 1999	55.8-**235** Pristol	28-**102** am.Ialomita	34-**100** Pristol	1.0-**4.5** am.Siret	18.2-**69.8** am.Arges
Belgium Standard		150	36	380	2.0	530
Canada Standard		820	110	110	10	250

Table 11 Spatial-temporal evolution of the heavy metals concentrations in fish tissue

Analysed sector	Period	:g/kg				
		Zn	**Cu**	**Cr**	**Cd**	**Pb**
Bazias-Gruia	July 1999	13.8-65.6	2.2-10.3	0.5-1.7	0.13-0.3	0.21-3.1
	August 1999	36.88 - 129.71	2.57-6.09	0.289-6.1	0.198-0.67	0.318 - 1.028
Gruia-Reni	August 1999	24.29 - 111.83	1.68-4.26	0.252-1.304	0.005-0.319	0.138 - 2.508
Limits according the Order of the Ministry of Health no.975/1988 (mg/kg)		50.0	5.0	-	0.1	0.5
Ratios having as reference the hygienic sanitary norms	Bazias-Gruia	> 2.0	2.0	-	3-6	2.0-6.0
	Gruia-Reni	2.0	-	-	max.3	max.5

Table 12 Water quality of the Danube in the year 1999, in comparison with the years 1994-1996, according to the ecological classification system of Dr. B. Wachs, referring to the contamination of fishes with heavy metals

Period	Danube sector	**Zn**	**Cu**	**Cr**	**Cd**	**Pb**
August 1999	Bazias-Gruia	IV	IV	IV	IV	III - IV
	Pristol	IV	IV	III - IV	III - IV	III - IV
	Am.Arges	IV	IV	III - IV	III - IV	III - IV
	Am.Ialomita	IV	III - IV	III	II - III	IV
	Am.Siret	IV	III - IV	III	II - III	IV
	Av.Prut-Reni	IV	IV	III	II - III	III - IV
1994-1996		II - III; II	III; II - III	II - III; II	III; III - IV	II - III; II

5 Conclusions

a) The evolution of the water quality of the Danube River shows a slight improvement, mainly because of to the declining of the industrial activities in the former communist countries from the Eastern Europe;

b) The most significant pollution of the Danube Delta and the Black Sea is the nutrient pollution. In the case of nitrogen, the mean contribution of the upstream countries is about 84.7 % and about 70 % for phosphorous, while their afferent catchement is 71 % of the total Danube catchement . The mean contribution of the downstream countries is about 15.1 % for nitrogen and respectively 30% for phosphorous;

c) The Danube transports to the downstream sector a load of non bio-degradable chemical substances, "imported" from the upstream sector towards the Danube Delta and the Black Sea, without representative local contributions;

d) The sediments from the Iron Gate I reservoir present an important accumulation of heavy metals (Hg, Cu, Pb, Zn and Cr). The heavy metal concentrations are from 1.76 (for Pb) till 3.05 (for Hg) times greater than the same concentrations recorded in the Rhine Delta;

e) • Declining of the fish species from the Danube Delta from a number of 110 in the period 1965-1975 to a number of 64 in the period 1988-1990 and the decreasing to a quarter of the quantities of cyprinidae captured in the above mentioned periods, owing to the deterioration of the quality of the Danube, in correlation with the embankment of important land surfaces in the Danube Delta for agricultural use;
• Declining with 60-80% in the period 1960-1992 of the number of fishes sensitive to pollution (sander, sheat fish, tench, etc.) which populate the Danube Delta;
• Decreasing of the number of dolphins from the Black Sea from 1 million in the year 1968 to 20.000 in the year 1990, because of the pollution and irrational fishing;

f) The concentrations of different parameters for water, sediments, fish and shells increased during the war from Yugoslavia. Some parameters, especially the heavy metals, exceeded mainly in April 1999 the admissible values limits from the Romanian and international standard and norms;

g) For the reduction of the pollution in the Danube River basin, the riparian countries have to join theirs efforts for the implementation of the Danube Pollution Reduction Programme (DPRP). The support of some Programmes and International Financial Institutions is absolutely necessary for the achievement of the DPRP.

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Rational Water Management of the Mediterranean Rižana River – the Importance of an Ecologically Acceptable Flow

Nataša Smolar-Žvanut, Ciril Krušnik, Gorazd Kosi, Danijel Vrhovšek

Abstract: In the period from 1995 to 1997, a list of all water users and an inventory of polluters were made. Hydrological and biological analyses were carried out for the Rižana river – from its source to its mouth. The river ecosystem was evaluated according to analyses of periphytic algae and macroinvertebrates in different hydrological habitats. Changes in diversity of macroinvertebrates, in diversity of periphytic algae, and in biomass were established, and attributed to water abstraction and river pollution. In order to maintain the ecological balance, an ecologically acceptable flow (EAF) was determined according to the ecological method for summer months.

Key words: ecologically acceptable flow, periphytic algae, macroinvertebrates, water quality, quality of aquatic environment

Rationale Bewirtschaftung des Mittelmeerflusses Rižana – Bedeutung der Restwassermenge

Zusammenfassung: Im Zeitraum von 1995 bis 1997 wurde eine Liste aller Wasserverbraucher zusammengestellt und die Wasserverunreiniger inventarisiert. Hydrologische und biologische Analysen wurden für Rižana – Fluss durchgeführt und zwar von der Quelle bis zur Mündung. Das Ökosystem des Flusses wurde hinsichtlich den Periphytic algae und Macroinvertebrates in verschiedenen Habitaten bewertet. Änderungen in der Diversität von Macroinvertebrates, Periphytic algae und Biomasse wurden festgestellt und der Wasserverunreinigung zugeschrieben. Zur Erhaltung des ökologischen Gleichgewichtes wurde nach der ökologischen Methode für die Sommermonate die Restwassermenge festgelegt.

Schlüsselworte: Restwasser, Periphytic algae, Macroinvertebrates, Wassergüte, Qualität der aquatischen Umwelt

Introduction

Like most of the Mediterranean, the area of Slovenian Istria has limited water sources. The only major spring is the karst spring of the Rižana River, which is the most important source of water supply for the Slovenian coastal area. Downstream, the increasing density of population, and related negative impacts, such as settlements, agriculture, industry, trade, traffic, and landfill-sites can be observed. The demand for drinking water, as well as the industrial and agricultural exploitation of the Rižana River exceed the water supply of the river.

There are various methods available for the determination of minimum acceptable flows: hydrological methods, river assessment methods and PHABSIM (Petts and Maddock, 1995). Based on the hydrological, hydraulic, morphological and ecological criteria, the hydrological and ecological method is currently being applied in Slovenia (Vrhovšek et al, 1994, Vrhovšek & Smolar, 1997, Smolar and Vrhovšek, 1998).

Because of a major water exploitation and an almost complete absence of water in summer in the lower parts of the Rižana River, the relevant ecologically acceptable flow (EAF) value was evaluated by means of the interdisciplinary approach (ecological method) in order to achieve the improvement of conditions for water organisms (Smolar et al., 1997). As EAF we determined the quantity and quality of water, which is assuring the preservation of ecological balance in the stream and in the riparian zone.

This paper describes specifically the role of macroinvertebrates and periphytic algae in determining the EAF in the Rižana River.

Study sites

With its 14 km of length, the Rižana River drains a watershed area of 204,5 km^2. The Rižana River features karstic hinterland with predominantly flysch area, with the estuary in the Adriatic over brachial wetland.Typical of the area, is a relatively mild submediterranean climate with mild winters and relatively high summer temperatures occurring primarily from the beginning of May until the end of September. During this period droughts are quite frequent.

The Rižana River has been the source of water supply since 1935. Directly below the settlements there is water abstraction for a fish-farm and for irrigation requirements. There are further 15 water abstractions downstream, and in summer some uncontrolled irragation abstractions. The consequences can be observed primarily in the summer period when, due to the deterioration of the aquatic environment, there were several cases of fish kill. Downstream, numerous hydrotechnical interventions were also carried out.

Along the watercourse, the riverbed structure is characterised by various substrates which, upstream, are composed of large stones while downstream, the stone structure changes from gravel into silt. The riparian vegetation along the watercourse is degraded due to land cultivation and the proximity of roads.

Four relevant sections of the Rižana River have been selected: the first, R1, was selected near the spring, and the last, R4, was selected near the estuary in the Adriatic.

Hydrological Characteristics of the Rižana River

The hinterland of the Rižana River is primarily composed of karst characterised by specific hydrogeological features, which is reflected by the annual hydrographs. The quantity of water feeding the Rižana River depends on groundwater levels, the precipitation and the flows in the Rižana River tributaries. The tributaries of the river, located in the karst region, are short and steep, having all the characteristics of torrents drying in summer periods (Peroša et al., 1993). Minor water abstractions along the watercourse during the period of high flows (i.e. in spring and autumn) do not essentially change the hydrology of the river, whereas in drought periods the water quantity along the watercourse decreases due to abstractions.

One of the basic parameters in determining the EAF are the flow values. The water quantity data refer to the Kubed gauge station which is located below the abstraction for water supply system, has a maximum delivery of 0.35 $m^3 s^{-1}$. The hydrological characteristics of the Rižana River flows at the Kubed gauge station for the thirty years period (1966 - 1995) are presented in Table 1.

Table 1. Hydrological data for the Rižana River at the gauge station Kubed, for period 1966 - 1995

parameter	value
Catchment area	204.5 km^2
Mean annual flow	4.10 $m^3 s^{-1}$
Mean minimum flow	0.22 $m^3 s^{-1}$
Minimum flow	0.01 $m^3 s^{-1}$
Q300d	0.50 $m^3 s^{-1}$
Q347d	0.16 $m^3 s^{-1}$

Materials and methods

In four sections (R1, R2, R3, R4) of the Rižana River, up to four samples of periphyton and macroinvertebrates were taken for quantitative and qualitative analyses. They were designated R1.1 - R1.4 from the left to the right bank.

Quantitative samples of macroinvertebrates were collected with the Surber sampler (square 21.5 by 17.5 cm, mesh size 0.3 mm). The samples of periphyton and macroinvertebrates for qualitative analyses were preserved in the field with 36 % formaldehyde and returned to the laboratory for sorting and identifying. After surveying organisms, abundance of individual taxa of algae and macroinvertebrates was assessed, marked by 1 - rare, occasional, 3 - frequent, 5 - dominant. The samples for quantitative analysis of periphyton community were collected from 5 - 7 boulders. A certain surface of periphyton was scraped off and dissolved in water. Subsequently, dry weight (DW) and ash free dry weight (AFDW) were evaluated according to the APHA method (1992) in the laboratory. Concentration of chlorophyll a (chl a) by filtration through the Watman GF/C filters and extraction with hot methanol was also evaluated. In all sections, samples were taken in the period of low flow in summer 1996 and in winter 1997. During the sampling period, the flow and the maximum current velocity in the sections were measured by SEBA Mini Current Meter MI.

Data analysis

The differences in AFDW averages, DW averages and chl a averages were tested in various sampling sections. The percentage of species deficit by Kothé, 1962 (Wegl, 1983) was calculated from the number of periphytic algae and macroinvertebrates taxa between individual sections of the river. The quality of water was evaluated using Pantle - Buck saprobic index (SI), the quality of aquatic environment was evaluated by the Biological Monitoring Working Party - BMWP score system (Armitage et al., 1983) and Extended Biotic Index - EBI (modified by Ghetti, 1986).

Results and discussion

Current velocity and discharge

The discharge in summer 1996 decreased along the river as a result of water abstraction for irrigation, industry and subsurface drainage due to intergranular porosity of substrata. The results of the measurements carried out on 28 August 1996 indicated the following values of the water flow: R1 section 0.284 m^3s^{-1} and R4 section 0.040 m^3s^{-1}. In winter 1997, the discharge increased from section R1 to section R4.

Maximum mean velocity always reached its highest value in the R1 section; the lowest was in summer 1996 in the R4 section (see Fig. 1). The result of natural and anthropogenically induced changes in discharge in summer, is a nearly dry river bed. The determination of EAF requires the absence of the extreme accumulation of soft sediments and the periodical maintenance of high water flows and the diversity of watercourse velocity, as well as the maintenance of the specific water level (Bundi & Eichenberger, 1989)

In evaluating the EAF, it is important to ensure the distribution of organisms in various habitats within the river sections. The consequence of the reduction of the water flow is the decrease in the number of different habitats and their quality.

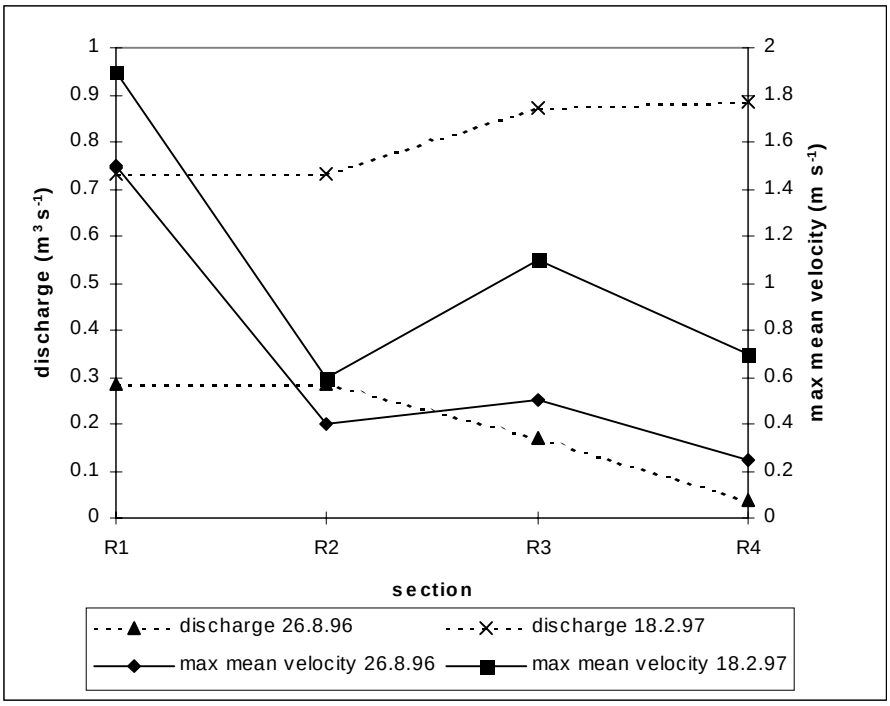

Fig.1 Discharge and flow velocity for the investigated sections on dates of sampling

Periphyton biomass

In comparison with downstream sites, the highest values of DW, AFDW and chl a were measured in the R1 section, notably in summer 1996 (see Table 2). We may assume that the reason for this phenomenon can be found in stable sediments, in the morphological diversity of the river bed and in the predominance of green algae mats. The lowest values of periphyton biomass were measured in the R3 section as the result of small moving substrata, which enable the development of a stable periphyton community. The same conditions were established in the R4 section, where the organic pollution was higher. The periphyton biomass was very high in the R4 section measured on 10 June 1995 (i.e. DW = 780 g m^{-2}). Due to the impact of other environmental factors, it was not possible to explain a massive growth of algae only through the low level of water flow, but also through the high nutrient level, the light impact and the structure of substrata. (Vrhovšek et al., 1995). The values of periphyton biomass were lower in winter 1997 than in summer 1996; the same was the case of the Slovenian streams Tržiška Bistrica, Dravinja and Branica (Smolar et al, 1998) and Sava Bohinjka (Kosi, 1988). With 95 % probability we can affirm that the average values of chl a were in winter 1997 statistically significantly different between the R1 and R3 and R1 and R4 sections ($p < 0.05$). The average values of AFDW in summer 1996 differed statistically significantly between the R1 and R2 sections and between the R1 and R3 sections (95 % probability). The knowledge of the natural dynamics of periphyton biomass in determining the EAF has enabled us to establish conditions for the maintenance of natural dynamics of flows, and for an adequate quantity of the flow during the drought period preventing the proliferation of the algae biomass.

Table 2. Minimum (min), maximum (max) and average (x) values of DW, AFDW and chl a for the sections in the Rižana River.

	DW	(g m^{-2})	_	AFDW	(g m^{-2})	_	chl a	(mg m^{-2})	_
	min	max	x	min	max	x	min	max	x
R1	152	327	237	30	181	86	191	773	374
R2	44	220	139	13	78	44	65	329	200
R3	19	227	140	5	79	42	10	218	113
R4	125	210	172	5	34	19	96	181	146

Periphytic algae and macroinvertebrates

A total of 70 taxa of periphytic algae were recorded in summer 1996, and 58 taxa in winter 1997. The majority of them belonged to Bacillariophyta, whereas the species of Cyanophyta, Chlorophyta, Xanthophyta and Rhodophyta were less pronounced, e.g. in the karst river Unica (Vrhovšek et al., 1996). Periphytic algae found in sections discussed consisted of several frequently occurring species, while in the R1 section, *Tribonema vulgare* and *Microspora amoena* were dominant in summer 1996. The most frequent species are representatives originating from karst rivers. Because of the morphological and discharge changes in the Rižana River in the R3 and R4 sections, epipelic and epipsamic algae were more frequent compared to the R1 and R2 sections, where epilithic algae were dominant. Had the EAF been maintained, such major changes in periphyton community would not have occured.

The majority of 61 taxa of macroinvertebrates were present in the R1 and R2 sections. We found more than 30 taxa per sample, while at other two sites the number of taxa per sample was lower (from 10 to 24), with the exception of R4 featuring 35 taxa in winter 1997.

The dominant taxa of macroinvertebrates in the sections in both seasons were species *Gammarus fossarum*, genus *Baetis* and family Elmidae. The average density of *Gammarus fossarum* increased downstream from 25.4 per sample in the R1 section to 277 in the R3 section in summer 1996. Due to the reduction in discharge and a low quality of aquatic environment along the river in summer 1996, a high deficit of macroinvertebrates taxa was recorded.

Consequently, a lower quality of aquatic environment had a large effect on the macroinvertebrate community. In spite of a very low water flow in the R4 section in summer 1996, there was no deficit of periphytic algae, indicating the deficiency of the applied index, as the latter does not provide for the evidence on the structural changes, including the reduction of the number of periphytic algae.

Water quality

The water quality and quality of aquatic environment are one of the most important criteria in the determing of EAF.

The values of saprobic index slightly increased along the river, nevertheless it was classified in all sections as I.-II. quality class. Similar were the results of the investigations in the R4 section in 1995 (Vrhovšek et al., 1995). The comparison of the results of the regular National Monitoring Programme in the R2 and below R4 section between 1987 and 1993 (Peroša et al., 1993) showed higher values of the saprobic index below R4 section, thus classifying water below this section into the II - III quality class.

In summer 1996, the EBI values classified sections R3 and R4 into the IV quality class, whereas, based on the BMWP values (see Fig.2) the R3 and R4 sections could be classified as V quality class. Both the BMWP and EBI indices showed in winter 1997 a lower quality of the aquatic environment in the R3 and R4 sections. Based on the results thus obtained we may conclude, that the EBI and BMWP indices indicate the deterioration of the aquatic environment

quality, while the SI shows the pollution degree of water. Similar results were obtained in analysing the Dravinja River (Krušnik & Černač, 1996).

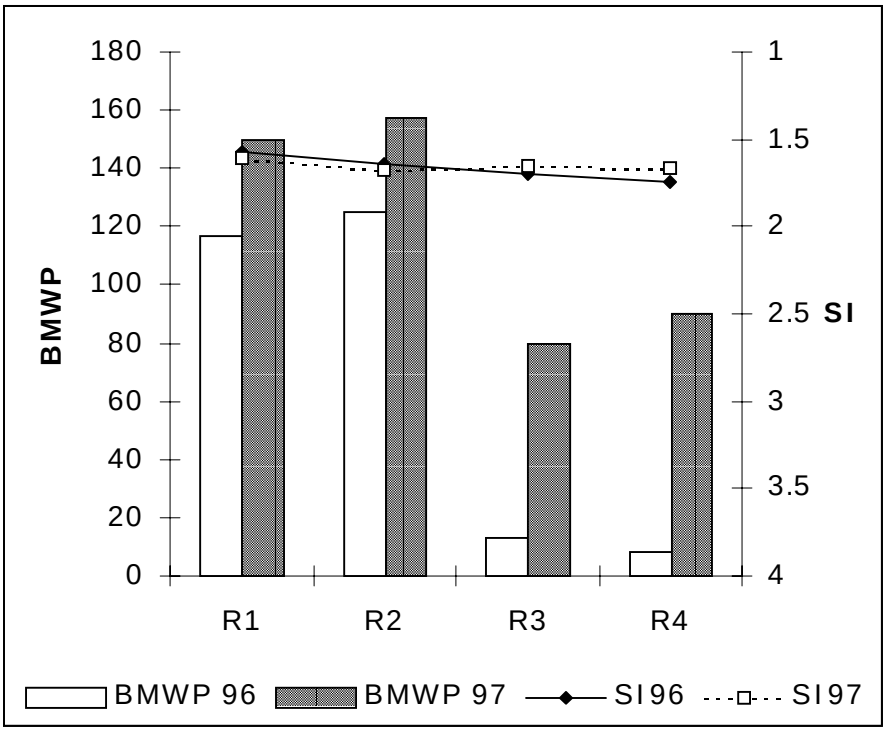

Fig.2 The values of BMWP in comparison with the values of SI for the Rižana River

Conclusions

With the regard to the water abstraction for the water supply purposes, the results of the hydrological analyses showed that due to extremely high water abstractions along the watercourse and the intergranular porosity of substrata in the lower part of the Rižana River, the flows were very low during the summer period. This has been reflected in the deterioration of the aquatic environment relevant to macroinvertebrates and periphytic algae. Taking into consideration the hydrological, ecological, landscape, morphological and ichthyological characteristics and habitat evaluation, we proposed the EAF values for dry summer period amounting to 0.160 $m^{-3}s$, which, by reducing the pollution level, will enable the maintenance of the ecological balance both in the river and in the riparian zone.

The rational use of water, the search for new sources of drinking-water, the waste water treatment, the control of water pollution, the evaluation of outflow from the planned accumulation and the provision of the ecologically acceptable flow are the most important arrangements we suggested.

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Die Wahrscheinlichkeit der Erscheinung der gefaehrlichen Schadstoffkonzentrationen im Wasser der Bergfluessen des ukrainischen Teiles des Einzugsgebietes von Tisa bei extremen Hochwassersituationen

Sergej Snishko

Zusammenfassung: Die Wahrscheinlichkeit der Erscheinung von gefaehrlichen Schadstoffkonzentrationen im Wasser der Bergfluesse des ukrainischen Teiles des Einzugsgebietes von Tisa bei katastrophalen Ueberflutungen wurde untersucht. Die Hauptergebnisse der Untersuchungen, die fuer die Prognostizierung der Gewaesserqualitaet und fuer die Entwicklung der neue Strategie des Wasserqualitaetsmonitoring benutzt werden koennen, wurden besprochen.

Schluesselworte: Wahrscheinlichkeit, Schadstoffkonzentrationen, katastrophale Ueberflutungen, Prognostizierung, Wasserqualitaetsmonitoring

Research of Probability of Occurrence of Dangerous Concentration of Polluting Substances in Water of the Mountain Rivers of the Ukrainian Part of Tisa River Basin at Catastrophic Flooding

Abstract: There are the results of probabilistic analysis of appearance of dangerous values of concentrations of polluting matters in the mountain rivers of the Ukrainian Carpathians. Main results can be used for the operative water quality forecasting.

Key words: probability, concentration of polluting substances, catastrophic flooding, forecasting, water quality monitoring

1 Ueberschwemmungen als die Ursache der Verunreinigung der Fluessgewaesser

Die schwankenden Wasserregime sind typisch fuer die Bergfluesse in den Ukrainischen Karpaten, die zum Donaueinzugsgebiet gehoeren. Mehr als 20 mal pro Jahr kann man hier Ueberschwemmungen beobachten. Die letzten groessen Ueberschwemmungen waren am 4-5. November 1998 an den Fluessen Tisa, Ush, Latoriza, Rika, Tereblja, Tereswa und Borshawa. Der Hochwasseranstieg betrug in kurzer Zeit fuer die naechsten Fluesse: Tisa bei Rachiw – 499 cm, Tisa bei Tjatschiw – 700 cm, Ush bei Ushgorod – 270 cm, Latoriza bei Mukatschewo – 677 cm. Als Folge wurden 28 Kanalisationspumpenanlagen, 20 Abwasserreinigungsanlagen, 4,0 km der Kanalisations-rohrleitungen zerstoert. Auch wurden 2 grosse Oelverteilungslager, 11 kleine Oellager, 14 Tankstellen, 6 Duengemittels- und PSM-Lager uebergeschwemmt. Es wurden auch einige Strecken der Gasrohrleitungen “Sojuz” und ”Urengoj-Pomary-Ushgorod” beschaedigt (Snishko,1999).

Solche Ueberschwemmung-Situationen fuehren u.a. zu den hohen Verunreinigungen des Flusswassers durch die Flaechenspuellungprozesse. Man muss bemerken, dass nur bei internationalem Verkehr in diesem Gebiet man rund 1700 Autos pro Tag rechnet. Das ist auch eine potenzielle Verunreinigungsquelle fuer die Fluesse (Oelprodukte, Schwermetalle).

In einigen Arbeiten wurden schon die Verunreinigung der Fluessgewaesser in diesen Region als Ergebniss des gemeinsamen Einfluesses der natuerlichen und anthropogenen Faktoren gezeigt. Oksijuk et al.(1995) haben die hohen Konzentrationen der Schwermetalle (Ueberschreitung der natuerlichen Werten um das 40-fache bis 118-fache), Phenolen und Oelprodukte (um 20-fache) im Wasser des Fluesses Tisa und ihren Nebenfluessen beobachtet.

Nach Informationen des Staatlichen Komitees der Ukraine fuer Hydrometeorologie (Nationaler Bericht (1994) wurden auch die Ueberschreitungen der Grenzwerten fuer NH_4^+

(Latoriza bei Mukatschiw, um 12-fache), fuer Oelprodukte (Latoriza bei Pidpolozzja, um 58-fache), fuer Cu (Latoriza bei Mukatschiw, um 46-fache), fuer Zn (um 58-fache) und fuer Mn (um 67-fache) im Wasser des Fluesses Tisa bei Rachiw beobachtet.

In vielen Arbeiten (Delfino, 1977; Hellmann, 1977; Lewis, Grant, 1979; Zakrewski, Snishko et.al., 1989; Snishko, 1996, 2000) wird die Abhaengigkeit der Konzentrationen mehrerer chemischer Komponenten vom Wasserabfluss nachgewiesen.

Die chemischen Komponenten wurden fuer 3 Gruppen nach dem Charakter der Beziehungen zwischen den Konzentrationen und den Wasserabflussmengen differenziert (Snishko, 1996 und 1996a):

1) Die chemischen Komponenten, deren anthropogenen Bestandteil kleiner als der natuerliche Bestandteil ist. Fuer diese Komponente ist die Wahrscheinlichkeit der engen Korrelationsbeziehungen mit der Wasserabflussmenge sehr gross.

2) Die chemischen Komponenten des gemischten Ursprungs (organische Verbindungen, N- und P-Mineralverbindungen, Schwermetalle, Phenole). Den anthropogenen Anteil an der Konzentration dieser Komponenten kann man noch mit dem natuerlichen Anteil vergleichen. Die Wahrscheinlichkeit der Bestimmung der zuverlaessigen Korrelationsbeziehungen kann etwa 30-40% erreichen.

3)Die chemischen Komponenten anthropogenen Ursprungs (Pestizide, Detergentien, Erdoelprodukte usw.). Der anthropogene Anteil der Konzentrationen an diesen Komponenten ist viel groesser als der natuerliche Anteil. Die Wahrscheinlichkeit der Bestimmung der zuverlaessigen Korrelationsbeziehungen ist sehr jedoch niedrig.

Auch in unserem Fall zeigen die Ergebnisse der Korrelationsanalyse deutlich, dass der Wasserabfluss auf die Hauptionen, Naehrstoffe, organische Schadstoffe Einfluss hat (Tab.1).

Tabelle 1 Zusammenhang zwischen den Wasserabfluess und den Konzentrationen der chemischen Substanzen im Wasser der Bergfluesse(Alle Korelationskoefiziente wurden bei $p< 0,050$ signifikant)

Fluss/ Probenahmeort	HCO_3^-	Ca_2^+	Cl^-	NH_4^-	NO_2^-	COD	OEL	Fe	Zn	Cu
Schwarze Tisa/Jasynja	-0,78	-0,77				0,60		0,50		
Tisa/Rachiw	-0,68	-0,57		0,51	0,70			0,56		
Weisse Tisa/ Lyhu			0,64					0,48		
Rika/Mishhirja	-0,56	-0,45								
Latoriza/Pid-polozzja	-0,47					0,47				
Latoriza/Tschop	-0,58						0,56	0,52	0,46	0,51

Diese Tabelle zeigt, dass man durch Hochwasseranstieg verschiedene Prozesse der Formierung der chemischen Zusammensetzung beobachten kann. In solchen Situationen dominieren die Loesungsprozesse(negative Korrelation) fuer Hauptionen (HCO_3^-, Ca_2^+) und die Flaechenspuellungprozessen fuer die resten Schadstoffen (positive Korrelation).

Durch schnellen Wasseranstieg aendert sich der Inhalt der wasserloeslichen chemischen Stoffen. Wie gross sind diese Veraenderungen und wie gefaehrlich koennen sie fuer die verschiedenen Wasserverbraucher und Wasserbenutzer sein? Um diese Frage zu beantworten,musste die Wahrscheinlichkeit der Erscheinungen der grenzueberschreitenden Hochkonzentrationen im Flusswasser bei den Ueberschwemmungen untergesucht werden.

2 Warscheinlichkeitsanalyse der Konzentrationsschwankungen bei extremen Hochwassersituationen

Dafuer wurden die Beobachtungsdaten des Staatlichen Komitees fuer Hydrometeorologie an den 14 Probenahmepunkten fuer die letzten 45 Jahre benutzt.

Durch die Warscheinlichkeitsanalyse der Datenreihen, der dem Hochwasserstand oder den maximalen Abflusswerten mit der Haeufigkeit von 1 bis 5% entsprechenden Konzentrationswerten, wurden die statistische Parameter der Konzentrationsschwankungen bei Ueberschwemmungssituationen untergesucht. Zuerst wurden die Wahrscheinlichkeitskurven fuer alle chemischen Stoffe und fuer jeden einzelnen Fluss entwickelt. Danach wurde die Verallgemeinerung aller Kurven gemacht und die verallgemeinerten Kurven fuer das ganze Tisa-Einzugsgebiet und fuer jeden chemischen Stoff neu aufgetragen (Abb.1).

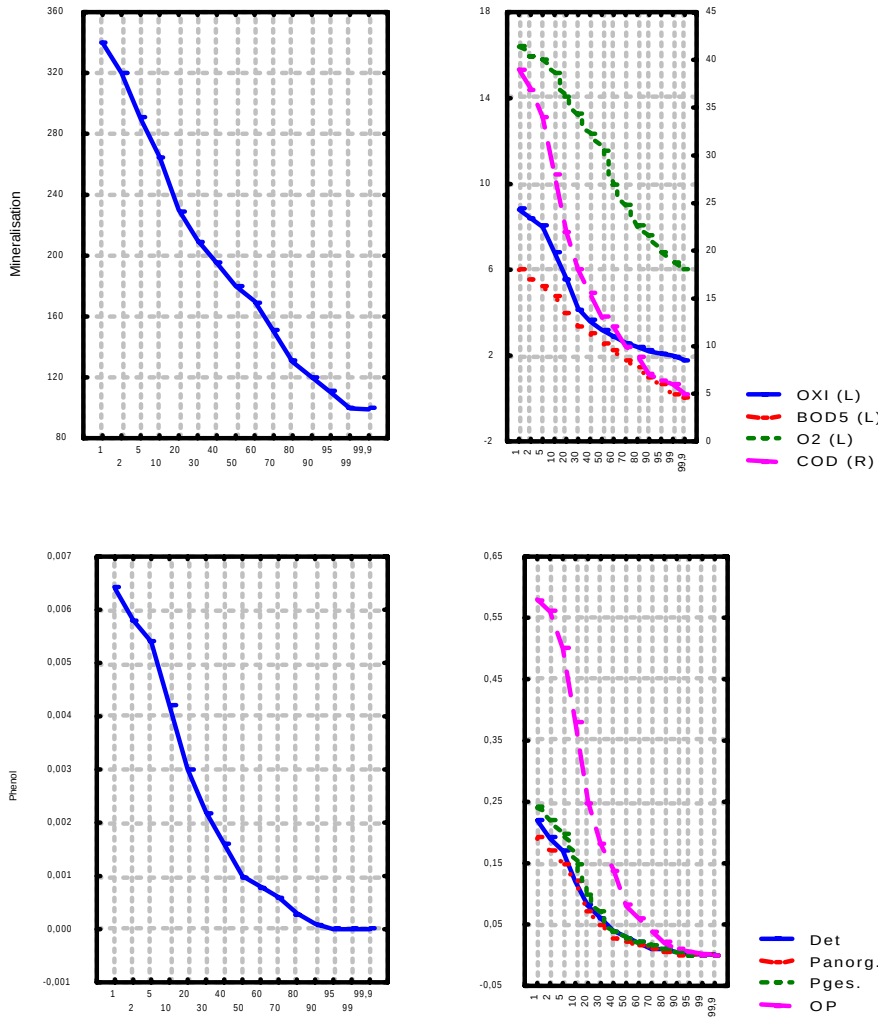

Abb.1 Die veralgemeinerten Wahrscheinlichkeitskurven der Konzentrationen der chemischen Parameter des Wassers bei der Hochwassersituation (Tisa-Einzugsgebiet): OXI- Oxidation

($KMnO_4$), BOD_5 – biologische Sauerstoffbedarf, O2- Sauerstoff, COD-chemische Sauerstoffbedarf, Det – Detergenten, $P_{anorg.}$ und $P_{ges.}$- Phosphor anorg.und ges., OP-Oelprodukte.

Die gesamte Ergebnisse diesen Untersuchungen stellt die Tabelle 2 dar.

Tabelle 2 Die Warscheinlichkeit der Erscheinung der gefaehrlichen Schadstoffkonzentrationen im Wasser der Bergfluessen von Tisa-Einzugsgebiet (Ukrainischer Teil) bei sehr starken Ueberschwemmungen

Chemische Parameter	Intervall der Haeufigkeit der Konzentrationen, %		Mittlere Probezahl mit den grenzueberschreitenden Konzentrationen, %	Ueberschreitung des Grenzwertes von maximalen Konzentrationen (Multiplikant)	Fluesse mit der anomalen Verteilung der Schadstoff-Konzentrationen
	Ueberschreitung des Grenzwertes	Ohne Ueberschreitung des Grenzwertes			
Mineralisation	-	0,01-99,9	-	-	-
NH_4^+	0,01-40	40-99,9	70	11,5	Wjetscha/Nelepino
$Fe_{ges.}$	0,01-20	20 –99,9	40	28	Schwarze Tisa/Jasynja
$P_{anorg.}$	0,01-20	20 –99,9	30	5,6	-
$P_{ges.}$	0,01-20	20-99,9	36	12	Tisa /Tschop/
Oxidation($KMnO_4$)	-	0,01-99,9	-	-	-
BSB_5	0,01-24	24-99,9	40	2,8	Tisa/Rachiw
Phenole	0,01-30	80-99,9	50	10	Tisa/ Tschop, Tjatschiw
Oelprodukte	0,01-50	60-99,9	62	16	
Detergentien	0,01-10	30-99,9	15	3,6	Tisa/Wilok Latoriza/Tschop
O_2	-	0,01-99,9	-	-	Rika/Mishhirja
Cu	0,01-60	92-99,9	95	55	Tisa/Tjatschiw
Zn	0,01-90	95-99.9	95	56	-
Cr	0,01-80	90,0-99.9	80	29	Latoriza /Pidpolozzja

Diese Ergebnisse zeigen deutlich ueber die hoche Erscheinungsmoeglichkeit der kritischen (ueber den Grenzwert) Konzentrationen von Schwermetallen (Cu, Zn, Cr) im Wasser der Bergfluesse. Bei den Ueberschwemmungen koennen die grenzueberschreitende Konzentrationen bei 95% allen Faellen, oder fast in der jede Wasserprobe erscheinen.

Die Wahrscheinlichkeit der Erscheinung der gefaerlichen Konzentrationen von NH_4^+, Phenole, Oelprodukte ist auch sehr hoch. Diese Stoffe koennen in der jede zweite Wasserprobe mit den grenzueberschreitenden Konzentrationen bestimmen werden.

Die Detergentien-, Phosphor- und hohe BSB_5 –Konzentrationen koenen in jeder dritten-fuenften Wasserprobe den Grenzwert ueberschreiten.

In allen Faellen des Wasseranstieges bleiben nur die Sauerstoffkonzentrationen und die Mineralisation des Wassers unter den Grenzwert.

Die Ergebnisse dieser Untersuchungen koennen fuer die Prognostizierung der Wasserqualitaet der Bergfluesse bei Ueberschwemmungen und fuer die Entwicklung neuer Strategien des Wasserqualitaetsmonitoring benutzt werden.

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Abflussmengen der Gewaesser als integrierte Charakteristik des Einflusses natuerlicher Prozesse auf die chemische Zusammensetzung der Gewaesser und auf die Wasserguete

Sergej Snishko

Zusammenfassung: Die Analyse der Wasserabflussdaten zeigt, dass der Abfluss langfristigen zyklischen Schwankungen des Wasserabflusses hat. Er schwankt durch die Einfluesse der dominanten abflussbildenden klimatischen Faktoren und zwar: staendige Schwankungen der Niederschlagsmenge und der Lufttemperatur. Die Konzentrationen mehrerer chemischer Komponenten und ihre Frachten sind vom Wasserabfluss abhaengig. Man muss die Abflussschwankungen bei den Untersuchungen der Evolution der chemischen Zusammensetzung des Flusswassers und bei den Berechnungen der Charakteristika der Frachten chemischer Komponenten beruecksichtigen.

Schluesselworte: Wasserabfluss, Zyklizitaet, chemische Zusammensetzung, Fracht der Naehrstoffe

Runoff as the Integrated Characteristic of Influence of Natural Processes on Chemical Composition and Quality of Water

Abstract: The analysis of the runoffs data shows, that the runoff is characterized by long-term cyclic fluctuations. It changes under influence of dominant climatic and other factors. The concentration of the majority of chemical components and sizes of their transport depend on a runoff. It is necessary to take into account fluctuation of a runoff at researches changes of chemical composition of river waters and at accounts of the characteristics of a pollutions transport in the rivers.

Key words: runoff, cyclic fluctuation, chemical composition, transport of nutrient matter

1 Abflussschwankungen und ihre Ursache

Der Abfluss der Gewaesser wird - wie auch andere Elemente des Klimaregimes - nicht nur durch die geographische Lage und durch die Morphologie gesteuert. Durch die atmosphaerische Zirkulation wird der Wasserabfluss an solche Prozesse des globalen Systems wie die Gletscherdynamik und die vulkanische Taetigkeit, die oceanische Zirkulation, die Sonnenaktivitaet, die Bewegung der magnetischen Pole der Erde, die Fluten und die Ebben gekoppelt. Eine detaillierte Analyse der Wasserabflussdaten zeigt, dass der Abfluss ueber einen laengeren Zeitraum nicht stabil ist. Er schwankt um einen Mittelwert (mittlerer Jahresabfluss). Diese Schwankungen werden durch die Einfluesse der dominanten abflussbildenden klimatischen Faktoren hervorgerufen und zwar: staendige Schwankungen der Niederschlagsmenge und der Lufttemperatur.

Die Hauptursache der Klima- und Abflussschwankungen ist offenbar die Aenderung der Sonnenaktivitaet (Herman, Goldberg, 1978; Wischinski, 1973; Kwadijk, 1993).

Die Erscheinung der zyklischen Fluktuation des energetischen Stroms der Sonne wurde zum ersten Mal vom Astronom A.Schwalbe 1843 beobachtet und vom Direktor des astronomischen Observatoriums in Zuerich R.Wolf untersucht. Sie haben die Dauer des Sonnenzyklus (11 Jahre) bestimmt. Spezielle Untersuchungen des langfristigen Regimes des Gewaesser-Abflusses haben gezeigt, dass er auch gesetzmaessigen zyklischen Aenderungen unterliegt (Kusin, 1970; Worontschuk, 1972; Leonow, 1990; Snishko, 1988 und 1989). Die langfristigen zyklischen

Schwankungen des Wasserabflusses sind aehnlich den 11-jaehrigen Schwankungen der Sonnenaktivitaet.

2 Einfluess der Abfluessschwankungen auf die zeitliche Veraenderung der chemischen Komponenten

In vielen Arbeiten (Delfino, 1977; Hellmann, 1977; Lewis, Grant, 1979; Holmes et al., 1980; Fadejew, 1983; Grieve 1984; Snishko, 1987; Zakrewski, Snishko et.al., 1989; Snishko, 1996) wird die Abhaengigkeit der Konzentrationen mehrerer chemischer Komponenten vom Wasserabfluss nachgewiesen.

Derartige Wasserguteschwankungen koennen als dreiteiliges Modell eines Warscheinlichkeitsprozesses vorgestellt werden (Peleschenko et al.,1988).

Das Modell besteht aus folgenden Teilen:

- determinierter Teil (charakterisiert den Einfluss der Hauptfaktoren, meistens die natuerlichen Hauptfaktoren);
- zufaelliger Teil (der Einfluss der zweitrangigen Faktoren, meistens anthropogene Faktoren);
- zufaelliger Teil (Fehler bei der Probenahme und bei der Wasseranalyse).

Die Evolution der chemischen Zusammensetzung der Oberflaechengewaesser ist lange Zeit - im Laufe der historischen Entwicklung der Hydrosphaere - hauptsaechlich nur unter dem Einfluss der natuerlichen Faktoren abgelaufen. Die Wasserabflussmenge war als integrierte Charakteristik des Einflusses dieser Faktoren in das Modell eingebracht worden. Kurz- und langfristige Veraenderungen der Wasserguetecharakteristiken wurden von den Wasserabflussveraenderungen gepraegt.

Seit der Verstaerkung des wirtschaftlichen Einflusses sind die Beziehungen zwischen die Konzentrationen und Abfluss schwaecher oder gar nicht ausgepraegt. Der determinierende Konzentrationsteil der chemischen Komponenten hatte abgenommen und der zufaellige Teil durch anthropogene Einfluesse hatte zugenommen.

Meybeck, Helmer (1992) haben 5 Haupttypen der Wasserguete-Aenderungen in Abhaengigkeit vom Intervall der Konzentrationsschwankung untersucht. Sie zeigte, dass die Wasserguete sich im Laufe einer Minute, eines Tages, einer Saison und eines Jahres veraendern kann.

In eigenen Arbeiten (Snishko, 1988; 1989 und 1998) gibt es Forschungsergebnisse ueber zyklische zeitliche Veraenderungen der Konzentration der Naehrstoffe (Stickstoff und Phosphor) in den Fluessen des Dniprobeckens (Abb.1) und in den Niederschlaegen. Gleichzeitig wurden auch zyklische Schwankungen langjaehriger Stickstoff- und Phosphor-Frachten in die Dnipro-Stauseen nachgewiesen.

Daraus wird deutlich, dass man die Abflussschwankungen bei den Untersuchungen der Evolution der chemischen Zusammensetzung des Flusswassers beruecksichtigen muss.

Die Beruecksichtigung der Abflusszyklizitaet ist notwendig fuer die Berechnungen des mittleren Jahresabflusses. Damit ergibt sich die Moeglichkeit, die Genauigkeit der Berechnungen im Fall von nur kurzen Beobachtungsperioden (unter Beruecksichtigung der gleichen Zahl von wasserarmen und wasserreichen Perioden, bzw dem “ganzen Zyklus” der Wasserabflussschwankungen) zu verbessern (Snishko, 1988). Dazu ist die gleiche Anzahl an wasserarme und wasserreiche Perioden bzw der “ganze Zyklus” zu beruecksichtige. Diese Methode ist auch bei den Berechnungen der Charakteristika der Frachten chemischer Komponenten zu empfehlen.

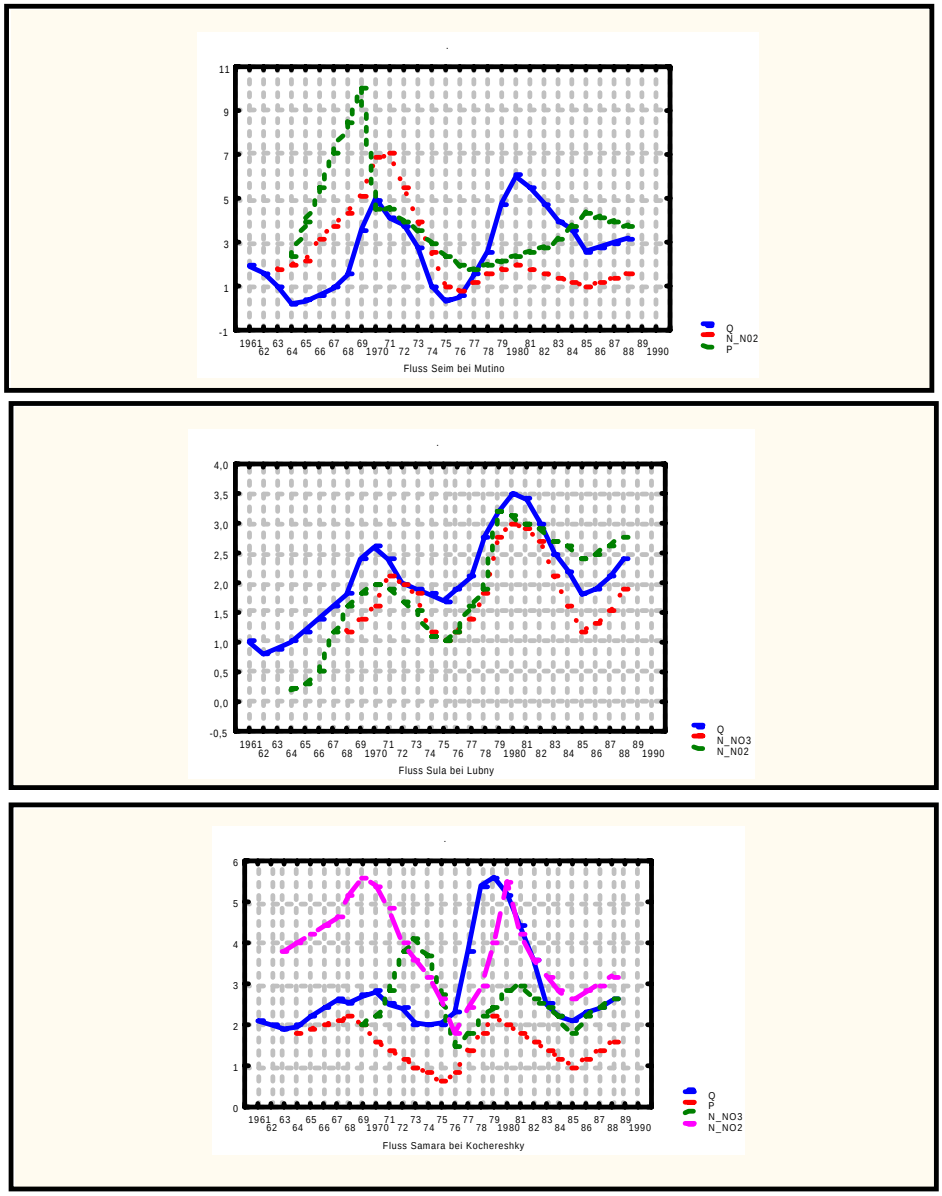

Abb.1 Zeitliche Veraenderungen des Wasserabflusses und der Konzentration der Naehrstoffe (Stickstoff und Phosphor) in den Fluessen des Dniprobeckens

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Langzeitentwicklung des Makrozoobenthos der Donau

Thomas Tittizer, Mechthild Banning

Kurzfassung: Das Makrozoobenthos der Donau wird von einer Vielzahl von biotischen und abiotischen Faktoren beeinflusst. Ein Vergleich der Daten aus den 40er bis Mitte der 60er Jahren mit den Befunden aus den 80er und 90er Jahren ermöglicht eine Beschreibung der biozönotischen Entwicklung. Zugleich werden die Ursachen, welche für die Veränderungen verantwortlich sind, beschrieben.

Schlagwörter: Donau, Fauna, Makrozoobenthos, Neozoa, Ökosystem

Long-Term Development of the Macroinvertebrate Community of the Danube

Abstract: The macroinvertebrate community of the Danube are influenced by many natural and anthropogenic factors. A comparison of the results of the 40th till middle of the 60th with results of the 80th and 90th, enable to describe the development of the biocenosis. Herewith the causes wich are responsible for this changes, are described.

Key words: Danube, fauna, benthic macroinvertebrates, Neozoa, Ecosystem

1 Einleitung

In Fließgewässern stehen Wasserkörper und Sediment, Tier- und Pflanzenwelt im freien Wasser und Gewässerbett durch die hier ablaufenden Prozesse physikalisch/hydrodynamischer, chemisch/biochemischer sowie biologischer Natur ständig und mit häufig wechselnder Intensität in Kontakt. Wechselwirkungen zwischen den einzelnen Komponenten des Fließgewässerökosystems sind außerordentlich vielfältig und bisher nur unzureichend erforscht.

Als Komponente des Ökosystems Fließgewässer wird auch das Makrozoobenthos (= Gesamtheit der im und am Gewässerboden lebenden Kleintiere) von einer Vielzahl von biotischen und abiotischen Faktoren beeinflusst. Umgekehrt spielt das Makrozoobenthos im Energie- und Stofftransport eines Gewässers eine bedeutende Rolle (Umwälzung, Mineralisierung und Stabilisierung feinkörniger Sedimente, Elimination organischer Substanzen aus dem Gewässer, Anreicherung schwer und nicht abbaubarer Substanzen im Zellgewebe, Nahrungskette etc.).

2 Methoden

Die Ermittlung der Langzeitentwicklung einer Lebensgemeinschaft setzt die Festlegung eines Referenz- oder Ausgangszustandes voraus. In der Regel wird hierzu ein zeitlich weit zurückliegender, vom Menschen "unbeeinflusster Zustand" (= Naturzustand) gewählt (TITTIZER et al. 1991). Diesem vom Menschen unbeeinflussten Zustand entspricht eine "natürliche Fauna". Da jedoch heute viele der anthropogen bedingten Veränderungen der Fließgewässer nicht mehr rückgängig gemacht werden können, ist man gezwungen, statt des Naturzustandes einen "potentiell natürlichen Zustand" als Referenz zu nehmen. Diesem "potentiell natürlichen Zustand" entspricht eine "potentiell natürliche Fauna".

Eine Rekonstruktion der "potentiell natürlichen Fauna" der Donau ist aber auch nicht möglich, da biozönotische Daten aus der Zeit vor den großen wasserbaulichen Eingriffen (Begradigungen, Bau von Wehren im 18. und 19. Jh.) fehlen. Aus diesem Grund beschränkt sich die vorliegende Arbeit auf einem Vergleich der Daten aus den

40er, 50er und bis Mitte der 60er Jahren (DUDICH 1967) mit Befunden aus den 80er und 90er Jahren (FRANK et al. 1990, CSANYI 1994, HUMPESCH 1994, LEUCHS et al. 1991, MOOG et al. 1994, MARTEN 1995, SCHÖLL & BANNING 1998, RUSSEV 1998, TITTIZER et al. 1994).

3 Ergebnisse

3.1 Ursachen der Faunenveränderungen

Das Makrozoobenthos eines Fließgewässers wird von einer Vielzahl von natürlichen und anthropogen bedingten Faktoren beeinflusst. Zu den wichtigsten Faktoren, die das Makrozoobenthos beeinflussen, gehören: Wasser- und Sedimentqualität, Fließgeschwindigkeit, Temperaturregime, anthropogene Nutzungen (Trink- und Brauchwassergewinnung, Energiegewinnung, Schifffahrt, Gewässerausbau- und Unterhaltungsmaßnahmen, Erholungs- und Freizeitaktivitäten des Menschen, fischereiliche Bewirtschaftung des Gewässers) sowie die Einwanderung und Ausbreitung fremder Tierarten (Neozoa) in dem Gewässer (REINHOLD & TITTIZER 1997, TITTIZER 1990, 1996).

3.2 Vergleich "gestern / heute"

Ein Vergleich der Daten von DUDICH (1967) mit den Ergebnissen der letzten 20 Jahre zeigt im Längsverlauf der Donau ein sehr uneinheitliches Bild (siehe Abb. 1).

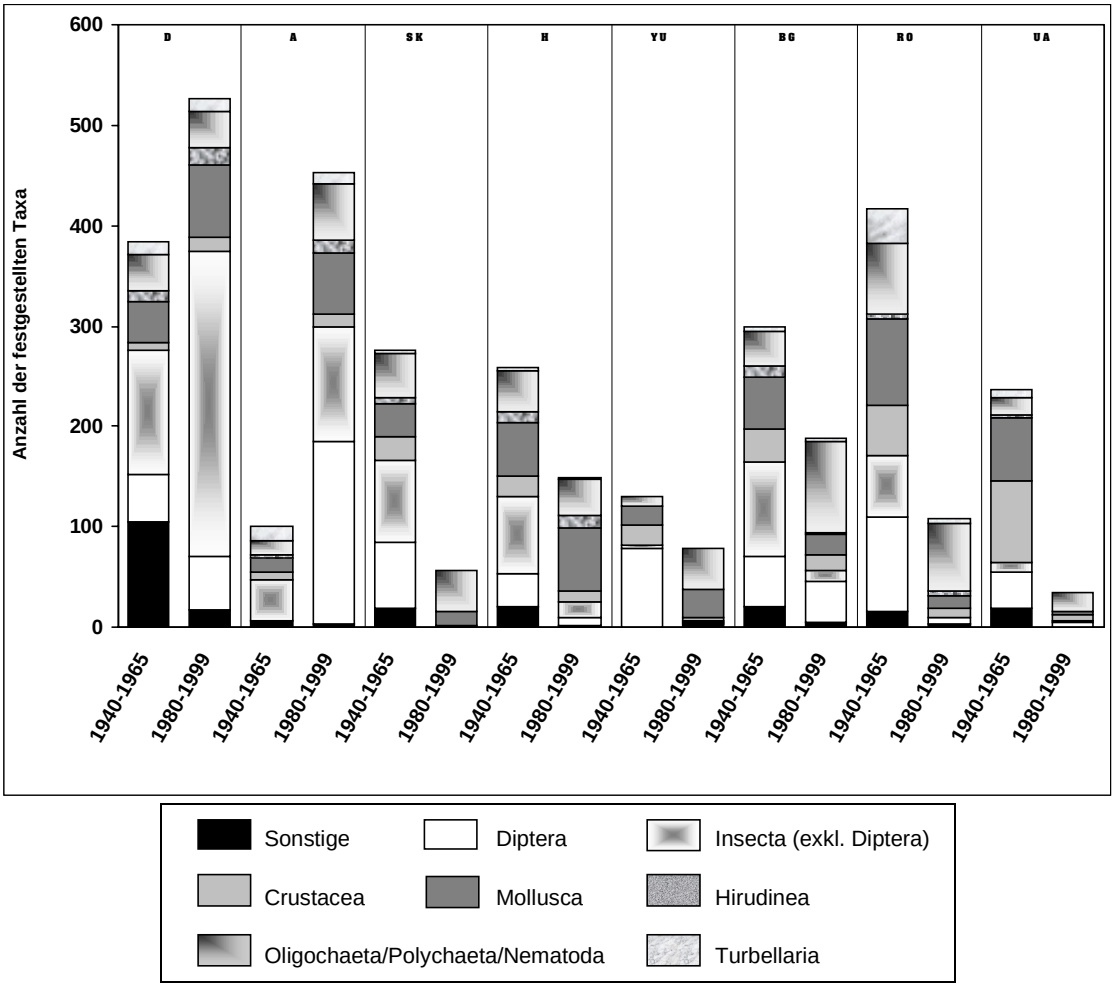

Abb. 1 Entwicklung des Makrozoobenthos der Donau in den einzelnen Donauländern

Der in Deutschland und Österreich festgestellte deutliche Anstieg der Artenzahlen in den letzten 20 Jahren ist nicht allein auf die Verbesserung der Gewässergüte in diesem Donauabschnitt zurückzuführen, sondern vielmehr auf die zeitlich und räumlich sehr intensive Untersuchung der Donau in diesen Ländern (LEUCHS et al. 1991, HUMPESCH 1994, TITTIZER et al. 1994, MOOG et al. 1994, MARTEN 1995, SCHÖLL & BANNING 1998). Sicherlich spielen dabei die verbesserten Untersuchungstechniken, die Fortschritte in der Taxonomie sowie auch die Einwanderung fremder Tierarten in dieser Region eine bedeutende Rolle (BANNING 1998).

In der schiffbaren deutschen Donau kann in jüngster Zeit die Ausbreitung, insbesondere von zahlreichen Arten mit pontokaspischer Herkunft verzeichnet werden (z. B. die Kleinkrebse *Jaera istri, Dikerogammarus haemobaphes, D. villosus, Echinogammarus trichiatus, Obesogammarus obesus, Limnomysis benedeni, Hemimysis anomala* und der Strudelwurm *Dendrocoelum romanodanubiale*). Gleichzeitig haben sich aus dem hydrographischen Einzugsgebiet des Rheins beispielsweise die Süßwassergarnele *Athyaephyra desmaresti* und die Körbchenmuschel *Corbicula spp*. (TITTIZER & TAXACHER 1997) bereits in der Donau angesiedelt. Als wesentlicher Transportmechanismus haben sich dabei inzwischen die Kühlwassersysteme der Motorschiffe herausgestellt (REINHOLD & TITTIZER 1997).

Ein Vergleich der früheren mit den heutigen Artenlisten aus dem deutsch-österreichischen Abschnitt der Donau zeigt, dass viele stenöke Potamalarten aus dem Faunenspektrum der Donau verschwunden sind. Dabei wurden insbesondere jene Insektenarten betroffen, welche streng an sommerwarme, große Fließgewässer gebunden sind. Hierzu gehören *Theodoxus danubialis, Theodoxus transversalis, Pseudanodonta complanata, Ephoron virgo, Gomphus vulgatissimus* und *Macronychus quadrituberculatus*. Einige von ihnen wurden inzwischen durch Schiffe aus weit entfernten Regionen wieder eingeschleppt, andere konnten aus noch vorhandenen Refugialräumen (z. B. Gewässer der Aue, Zuflüsse) ihre angestammten Lebensräume in der Donau wiederbesiedeln. Wiederum andere stoßen auf unüberwindbare Schwierigkeiten, die dem fortgeschrittenen Ausbau der Donau zu "verdanken" sind. Zu dieser Gruppe gehören *Isogenus nubecula, Perla bipunctata* und *Taenioptery nebulosa* aus der Gruppe der Plecoptera sowie *Oligoneuriella rhenana* und *Palingenia longicauda* aus der Gruppe der Ephemeroptera.

De facto fehlen heute in dem deutsch-österreichischen Abschnitt der Donau die Muschel *Unio crassus* und die Eintagsfliegen *Ecdyonurus dispar, Ecdyonurus insignis, Ephemerella mucronata, Heptagenia fuscogrisea, Oligoneuriella rhenana, Brachyptera risi* und *Rhithrogena semicolorata*-Gruppe. Sowohl für diese als auch für zahlreiche weitere, derzeit zwar in diesem Donauabschnitt nachgewiesene Arten (z. B. *Borysthenia naticina, Theodoxus danubialis, Theodoxus transversalis, Pseudanodonta complanata, Sphaerium rivicola, Gomphus vulgatissimus, Ecdyonurus venosus, Heptagenia flava, Helochares obscurus, Macronychus tuberculatus, Normandia nitens, Riolus cupreus, Lasiochephala basalis, Lepodistoma hirtum, Oligopectrum maculatum*) ist der Aufbau einer stabilen Population nach wie vor unsicher (BANNING 1998).

Die in den slowakischen, ungarischen und jugoslawischen Abschnitten der Donau festgestellten Artenrückgänge sind teils auf die verschlechterten Lebensbedingungen (Gewässerverschmutzung) für die aquatischen Makroinvertebraten zurückzuführen, im Wesentlichen jedoch auf die oft nur sporadisch durchgeführten Untersuchungen dieses Donauabschnittes in den letzten 20 Jahren.

Im Gegensatz dazu sind die geminderten Artenzahlen im bulgarischen und teils auch im rumänischen Donauabschnitt anzusehen. In diesem Donauabschnitt wurden in den letzten Jahren mehrere Längs- und Querprofiluntersuchungen durchgeführt und dabei eine Abnahme der Artenzahl infolge der Auswirkung übermäßig stark belasteter Zuflüsse wie Jiu, Olt und Arges von rumänischer Seite sowie Ogosta, Ossam und Russenski Lom von bulgarischer Seite festgestellt. Hierzu tragen auch die "nur" stark verschmutzten Zuflüsse wie Jalomița und Prut (Rumänien) sowie Iskar, Vit und Jentra (Bulgarien) bei. Alarmierend ist der deutliche Rückgang der Zahl der Insekten (z. B. Plecoptera, Ephemeroptera, Odonata) in diesem Donauabschnitt, welche auf Gewässerverunreinigungen sehr empfindlich reagieren. So wird z. B. das Erlöschen der Population der Eintagsfliegenarten *Palingenia longicauda, Ephoron virgo, Ametropus fragilis, Brachycentrus harisella* und *Cercobrachis minutus* sowie der Plecopterenarten *Isogenus nubecula, Perla bipunctata* und *Taeniopteryx nebulosa* auf die erhöhte Gewässerverunreinigung zurückgeführt (RUSSEV 1998).

Zugleich konnte eine Zunahme der Zahl der gegenüber Abwasserbelastung toleranten Arten aus der Gruppe der Oligochaeta und Chironomidae in diesem Donauabschnitt festgestellt werden. Eine erneute Zunahme der Artenzahl und eine Wiederkehr ehemaliger donautypischer Arten könnte nur noch durch eine drastische Verbesserung der Wasserqualität erfolgen.

Zusammenfassend kann folgendes festgestellt werden: Das Makrozoobenthos im deutschen, österreichischen und slowakischen Abschnitt der Donau wurde in den letzten 60 Jahre lediglich lokal durch die Verschlechterung der Wasserqualität beeinträchtigt. Die gravierendsten und zugleich irreversiblen Veränderungen erfuhr das Makrozoobenthos durch den Ausbau und Aufstau der Donau (RUSSEV et al. 1983, TITTIZER 1998). Im Bereich der staugeregelten Strecken wurden die strömungsliebenden Arten durch Stillwasserarten verdrängt (TITTIZER et al. 1990). Außerdem traten im Oberwasser der Stauwehre aufgrund erhöhter Sedimentation typische Kies- und Steinbewohner zugunsten einer ausgeprägten Sand- und Schlufffauna zurück. Diese Feststellung trifft auch auf den rumänisch-jugoslawischen Abschnitt der Donau im Bereich der Stauhaltungen Eisernes Tor I und II zu (POPESCU-MARINESCU 1987).

In der ungarischen und jugoslawischen Strecke der Donau nimmt der Einfluss der Gewässerverschmutzung auf das Makrozoobenthos zu und erreicht seinen Höhepunkt in dem bulgarischen, rumänischen und ukrainischen Abschnitt. Vormals typische Faunenelemente der Donau, insbesondere aus der Gruppe der Insekten, verschwanden für unbestimmte Zeit aus dem Besiedlungsbild. An ihre Stelle traten einige Arten aus der Gruppe der Zuckmücken und der Würmer. Ein wesentlicher Rückgang der Artenzahl bei gleichzeitiger Verschiebung des Artenspektrums zugunsten euryöker und abwassertoleranter Arten waren die Folgen.

4 Schlussfolgerungen

Strebt man die Wiederherstellung einer "potentiell natürlichen Fauna" für die Donau an (vgl. 2), so wird rasch deutlich, dass in den staugeregelten Strecken wegen der hier vollzogenen wasserbaulichen Maßnahmen dies nicht mehr möglich ist. Die hier vorherrschenden hydrologischen und morphologischen Verhältnisse erlauben die Rückkehr und die Etablierung stenöker, rheophiler Aten nicht mehr. Die einzig möglichen Maßnahmen zur Erhöhung der Biodiversität in diesen Strecken sind lokale

Gewässerstrukturverbesserungen. Zur Erhöhung der Artenvielfalt trägt in gewissem Umfang auch die Einwanderung/Einschleppung fremder Arten (Neozoa) aus weit entfernten Regionen bei. Hierbei kommt der Rheinfauna eine besonders wichtige Rolle zu (TITTIZER 1997, TITTIZER & TAXACHER 1997). In den übrigen, nicht staugeregelten Strecken kann eine wesentliche Erhöhung der Artendiversität durch Maßnahmen, die eine Verbesserung der Wasserqualität zur Folge haben, erreicht werden.

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Microscopic micromycetes monitoring in the Slovak section of the Danube river during years 1994 - 1999

Lívia Tóthová

Abstract: During 1994-1999 altogether 292 samples of Danube water were investigated. Microscopic fungi were identified in 100 % samples. Abundancy and specific diversity of microscopic fungi can oscillate during seasons in surface water. This seasonal variability depends on availability and amount of substrate. In the Danube river was fungi abundance ranged within 1 CFU.mL^{-1} to 45 CFU.mL^{-1} (Colony forming units) with maximmum in summer sampling time. Interaction between fungus colony number and water discharge was evident in all monitored sampling sites. This interaction could relate with higher concentration of organic compounds beacuse of runoff. Two genera of the subdivisio *Ascomycotina*, five genera of the subdivisio *Zygomycotina* and 34 genera of the subdivisio *Deuteromycotina* were identified by routine isolation and cultivation methods with prolonged cultivation time to 7 - 30 days at room temperature and day light. The most frequently isolated species belong to the genera *Penicillium, Acremonium, Alternaria, Cladosporium, Fusarium, Paecilomyces, Trichoderma* and *Mucor*.

The reported data refer to importance of further microscopic fungi monitoring, because these organisms represent an important part of the surface water environment.

Key words: microscopic fungi, *Deuteromycotina*, *Zygomycotina*, *Ascomycotina*, surface water, Danube river, Slovakia.

Mikroskopische Pilze in slowakischem Abschnitte der Donau.

Zusammenfassung: In der vorliegenden Arbeit werden die Ergebnisse mykologischer Untersuchung Der Donau aus den Jahren 1994 - 1999 präsentiert. Mikroskopische Pilze gehören zu organotrphenen Organismen mit der relativ anspruchslos Bedinungen für das Leben. Durch die Jahre 1994 - 1999 haben wir 292 Proben aus der Donau geanalysieren. Wir identifizierten mikroskopische Pilze in den 100 % Proben. Die Anzahl der Kolonienzahl (KBE), welche angewachsen haben, durch die Saison hat geschankeln. Aber wir müssen sagen daß die Variabiltät ein Zusammenhang mit der Menge des Substrates hat, welche für die Organismen passend ist Die Kolonienzahl die mikroskopischen Pilzen in slowakischem Abschnitte der Donau war in der Dimension von 1,0 bis 45,0 KBE.ml^{-1} mit Maximum im Sommer. Die Pfilzenzahl in slowakischem Abschnitte der Donau war dem Durchfluss direct proportionel.

Zusammen haben wir zwei Genera der *Ascomycotina*, fünf Genera der *Zygomycotina* und 34 Genera der *Deuteromycotina*. Sehr oft isolierte Arten haben bis Genera *Penicillium, Acremonium, Alternaria, Cladosporium, Fusarium, Paecilomyces, Trichoderma* and *Mucor* gehören. Selten haben wir Die Arten des Genera von *Mortierella, Rhizopus, Candida, Aspergillus, Beauveria, Geotrichum, Gliocladium, Phialophora, Stachybotrys, Stemphyllium, Trichophyton, Verticillium* geidentifizieren. Vereinzelt isolierten wir Genera *Absidia, Zygorhynchus, Arthrinium* und andere.

Schlüsselworte: mikroskopische Pilze, Donau, *Deuteromycotina, Zygomycotina, Ascomycotina*, Slovakia

1. Introduction

The pollutants inducing human diseases may by chemical substances or pathogenic microorganisms, such as viruses, bacteria, fungi, protozoa and helmins, while not truly waterborne. Their quality and quantity dependet on vectors which are aquatic habitants (Ben, 1974). Microscopic fungi are of a different species, which can have allergenic and toxinogenic effects. In surface water samples were *Deuteromycotina* and *Zygomycotina* determinated relatively rarely (Ben, 1974; Apas, 1988; Franková, 1993; Jesenská and Hrdinová, 1982; Jesenská, 1987; Niemi et al., 1982; Toetz, 1974; Tóthová and Franková, 1995; Tóthová, 1999). Regarding the international and transboundary character of the Danube river, only few studies have dealt with the genera or species composition and numbers of the microscopic fungi. The microscopic micromycetes in the main stream of the Danube have been investigated only in few researches (Apas, 1988; Franková, 1993; Jesenská, 1980; Jesenská, 1987; Tóthová, 1999). Apas (1988) investigated microscopic fungi species in the Danube delta. Franková (1993), Jesenská (1980), Jesenská and Hrdinová (1982) and Jesenská (1987) detected these organisms in the Danube water samples at the Bratislava sampling sites. Franková (in: Onderíková, 1995) was determinated microscopic micromycetes in Čunovo reservoir. Tóthová (1999) published microscopic fungi occurrence in Danube from Bratislava to Szob.

The aim of this paper is to investigate the numbers of *Deuteromycotina*, *Zygomycotina* and *Ascomycotina* genera, species composition respectively and diversity at selected sites of the Danube river.

2. Study area

The study site was situated in the lowland area along the Danube river and represents a large inland delta. The description of the study sites with their characteristics is given in Fig. 1. Site 1 is situated in Bratislava as imput to the slovak - hungarian section of the river. On the other hand site Szob (site 4) is consider as output of the mentioned section.

Investigation of the microscopic fungi was provided in the years 1994 - 1999. Sampling frequency was monthly.

3. Material and methods

The samples were collected in sterile containers. For the purpose of microscopic micromycetes isolation peptone - glucose agar with bengal red, SEVAC Sabouraud agar, Czapek - Dox agar and Malt extract agar supplemented with streptomycin 20 $\mu g.L^{-1}$ were used. Spread plate technique for obtaining quantitative data on colony-forming units (CFU) was used. When discrete colonies could not be identified directly cultivation on the Czapek yeast (autolysate) extract agar (CYA), Malt yeast-extract agar (MEYA), Syntetic nutrient agar (SNA) or water agar (HOOG AND GUARRO, 1995) was used.

The genera and species identification were made by means of macro- and micromorphological characteristics of primocultures and pure cultures. The total amount of micromycetes was identified by spread plate technique, applying on four types of agar nurtient media (peptone - glucose agar with bengal red, SEVAC Sabouraud agar, Czapek - Dox agar and Malt extract agar supplemented with streptomycin 20 $\mu g.L^{-1}$). All grown colonies were scored on inoculated media after 5 - 7 day cultivation time. The number of fungus colony per millilitre of original samples was equalled from the average number of colonies on all inoculated plates.

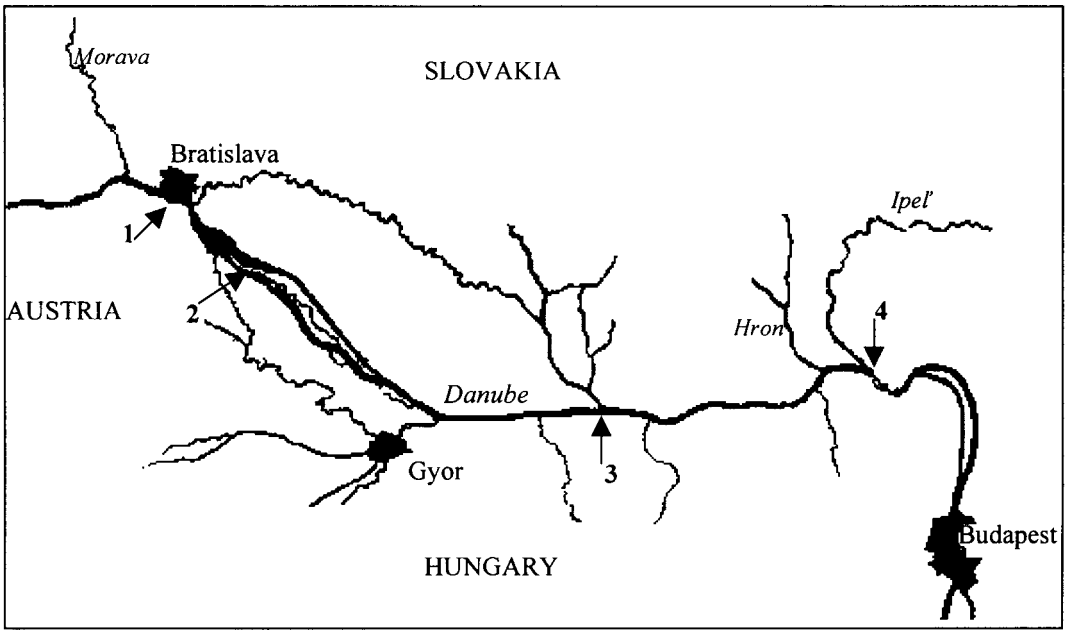

Fig. 1: Map of study sites in the Danube river (1 - Bratislava, r.km - 1869,2; 2 - Rajka, r. km - 1848,0; 3 - Komárno, r.km. - 1768,0; 4 - Szob, r.km - 1707,0).

4. Results and discussion

During the period 1994 - 1999 altogether 292 samples of Danube surface water were investigated. Microscopic fungi were found in the 100 % samples. Microscopic fungi identified in the Danube water samples belonged to the class of the *Deuteromycetes* and *Zygomycetes* (family *Mucoraceae*) prevailingly. Many *Deuteromycetes* isolated from surface water grown as white cotton wool like sterile mycelia. These mycelia sporulated scarcely on peptone - glucose agar with bengal red, SEVAC Sabouraoud agar, Czapek - Dox agar and Malt extract agar, CYA, MEYA, SNA and water agar too. Therefore 8,47 % colonies of investigated water samples could not be identified. Presence of cotton wool like sterile mycelia confirmed the results given in Franková (1993), Jesenská and Hrdinová (1982), Jesenská (1987), Tóthová and Franková (1995) and Tóthová (1999).

From the isolated microscopic fungi 2 genera from the subdivisio *Ascomycotina, 5* genera from the subdivisio *Zygomycotina* and 34 genera from the subdivisio *Deuteromycotina* were identified. In total, *Ascomycotina, Zygomycotina* and *Deuteromycotina* representatives of the 88 taxa were isolated. This documents the relatively high diversity of the investigated microscopic fungi in the Slovak section of the Danube. At site 1 (Bratislava) 56 taxa was found. Species diversity within genera *Alternaria, Aspergillus, Fusarium, Mucor* and *Penicillium* dominated. The lowest number of taxa was found at site 2 (53 taxa). Species diversity within genera *Alternaria, Aspergillus, Fusarium, Mucor, Penicillium, Trichoderma and Verticillium* prevailed. In the third sampling site 55 taxa and at the fourth site 58 taxa were identified. In the samples from Komárno site species diversity within genera *Alternaria, Aspergillus, Cladosporium, Fusarium, Penicillium Trichoderma* and *Verticillium* dominated. The highest species diversity was found at the site Szob. Species diversity within genera *Mortierella, Alternaria, Aspergillus, Fusarium, Paecilomyces, Penicillium* and *Trichoderma* were dominant.

The most commonly genera isolated from Danube water samples were: *Penicillium, Acremonium, Alternaria, Cladosporium, Fusarium, Paecilomyces, Trichoderma* and *Mucor*. Regarding *Penicillium* genus the most taxa (12) was determined. Of genera *Aspergillus* (7 taxa)

and *Fusarium* (7 taxa) slightly lower abundance was examined. Among these micromycetes less frequented genera from the investigated water samples were isolated. In some samples were identified species which belong to the genera *Mortierella, Rhizopus, Candida, Aspergillus, Beauveria, Doratomyces, Geotrichum, Gliocladium, Monilia, Phialophora, Stachybotrys, Stemphyllium, Trichophyton* and *Verticillium*. Rarely isolated species belong to genera *Absidia, Zygorhynchus, Arthrinium, Botrytis, Curvullaria, Epicoccum, Helminthosporium, Oidium, Oidodendron* and *Ulocladium.* In contrast to Jesenská (1987) research of microscopic fungi presence the genera diversity in our samples was quite different. Higher numbers of determinated genera in this study were connected with study area probably. Franková (1993) found out the most frequently genera *Penicillium, Fusarium, Trichoderma, Cladosporium, Aspergillus, Beauveria, Stachybotrys, Paecilomyces, Acremonium, Geotrichum and Trichophyton* in investigated Danube water samples. Our results confirmed the comprehensive list of genera given in Franková (1993) and Tóthová (1999). Franková (1993) determined species of 44 genera. Species of 39 genera identified in Danube water in investigated sampling sites were in good corelation with about mentioned author (Franková, 1993).

In the Danube river samples fungi abundance was ranged within 1 CFU.mL^{-1} to 45 CFU.mL^{-1} (colony forming units). The fungal population exhibited seasonal variation. As it was supposed seasonal dynamic indicated higher number of grown colonies in summer sampling time prevailingly (Fig. 2).

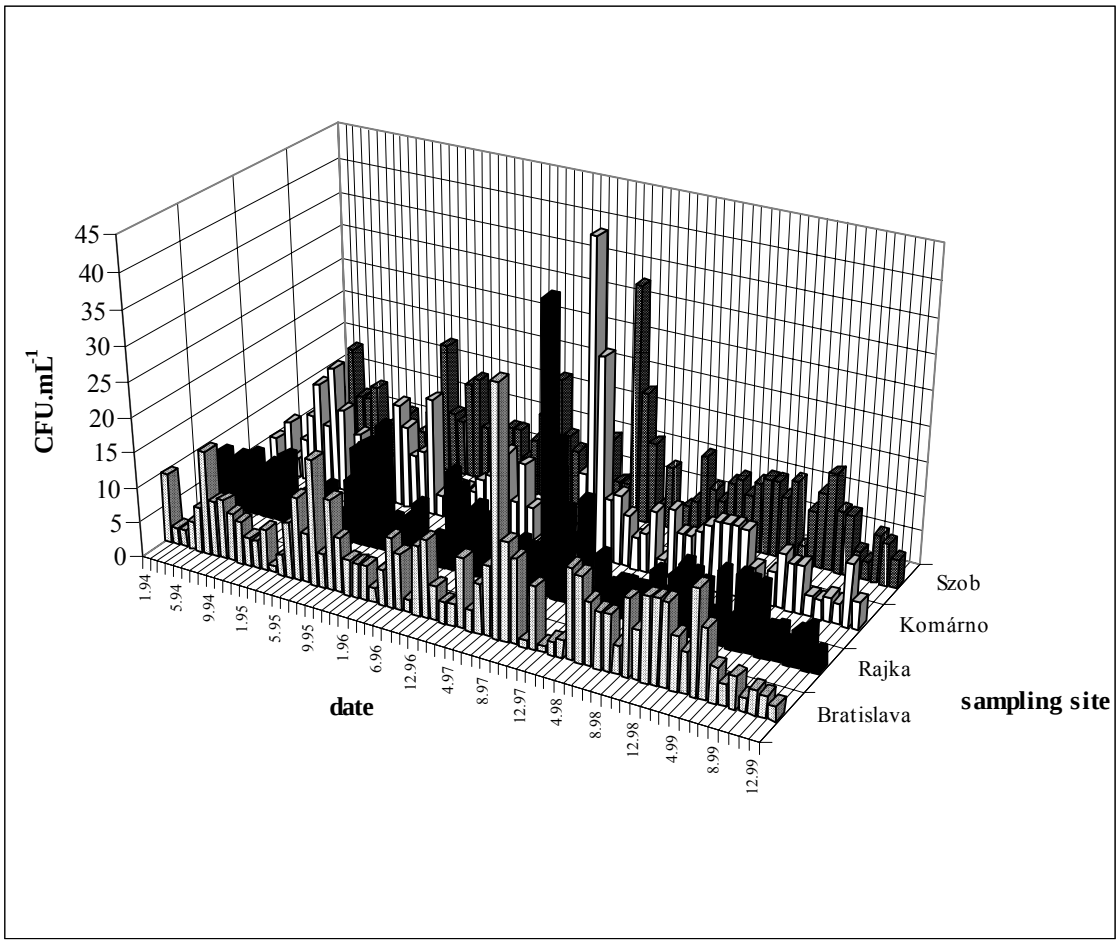

Fig. 2 Seasonal variability of microscopic fungi abundance in the years 1994 - 1999

The highest values were found in June and July previously during the monitored period. The highest colony numbers were observed at site Komárno and Szob mostly.. Mean annual values of the fungi numbers in the longitudinal Danube profile (Fig. 3) suggested smooth tendency of gradual growth in the direction from Bratislava to Komárno. In contrast to years 1994 - 1998 in the year 1999 was annual mean number at the Komárno site the lowest.

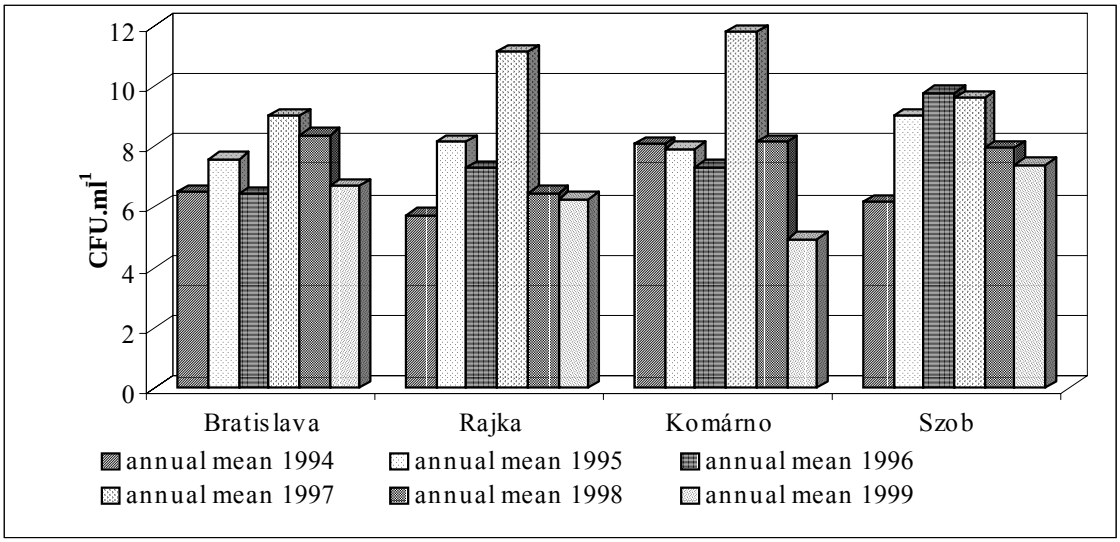

Fig. 3 Annual mean values of fungi numbers in the years 1994 - 1999

Numbers of micromycetes colonies relativelly depended on the water discharge (Fig. 4, 5). Number of fungi colonies increased with water discharge increasing. The mentioned differences in the numbers of micromycetes are assumed to be affected considerably by the water discharge and content of organic substances.

Our results on abundance confirmed the fungus colony numbers given in Jesenská and Hrdinová (1982) and Jesenská (1987).

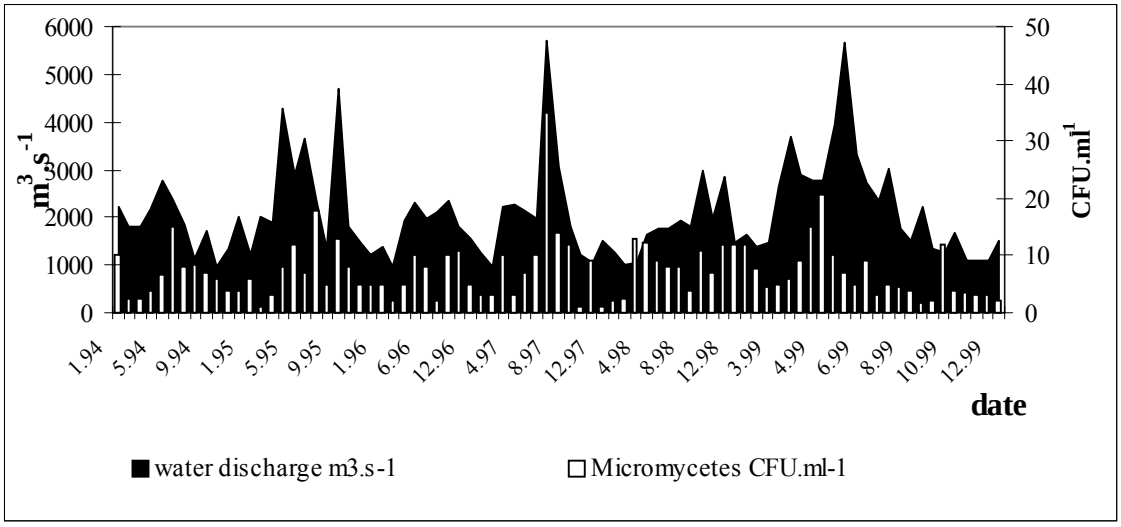

Fig. 4 Interaction between micromycetes and water discharge in the sampling site Bratislava (1994 - 1999)

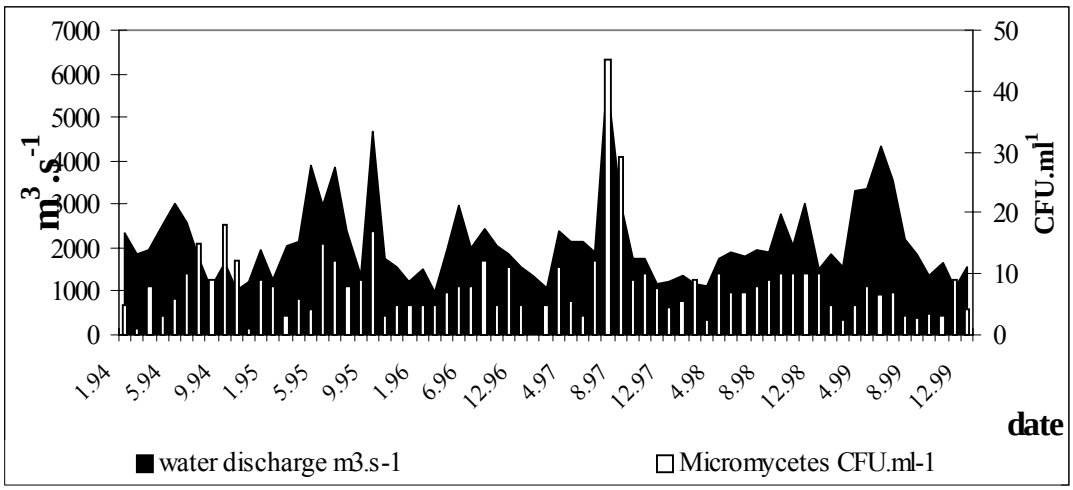

Fig. 5 Interaction between micromycetes and water discharge in the sampling site Komárno (1994 - 1999)

5. Conclusions

Pollution of natural environment with different industrial waste can have impact to the distribution of micromycetes as universal destruents of organic mass in nontypical environment like surface water.

It was shown that microscopic fungi in the Danube river water were relatively common organisms. Colony numbers and species diversity of microscopic fungi can oscillate during seasons in biotop. This seasonal variability depends on availability and amount of substrate.

Interaction between fungus colony number and water discharge was evident in all monitored sampling sites. This interaction could relate with higher concentration of organic compounds beacuse of runoff. The association between fungal occurrence and organic loading suggests that fungi may be usefull indicators of pollution. However, these organisms can survive in common and extreme habitats and no single species or genera has been identified as important in pollution indicator.

In all sampling sites toxinogenic, allergenic and potentially pathogenic species of microscopic fungi were identified, e.g. *Aspergillus fumigatus* and *Aspergillus flavus.*

The Danube water serve as drinking water source indirectly in Slovakia. Infiltrated groundwater form drinking water sources and could be influenced by these organisms. From this point of view it is important to investigate micromycetes in Danube water.

The reported data refer to importance of further microscopic fungi monitoring, because these organisms represent an important part of the surface water environment.

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Modelling the Role of Reservoirs in the Transfer and Retention of the Nutrients: Application to the Olt River (Danube Basin)

Maria Cristina Trifu, Josette Garnier, Gilles Billen

Abstract: A modelling approach was developed for the Danube River to establish how land use and management of the whole watershed determine nutrients (N, P, Si) delivery and retention by the river. The approach uses an adaptation of the RIVERSTRAHLER model (Billen *et al*., 1994; Garnier *et al*., 1995; Garnier et al., in press), which results from the coupling of an hydrological model with a biogeochemical model (RIVE) which takes into account the main ecological processes. A focus is made on the Olt River comprising a cascade of many reservoirs, known to influence both hydrological regime and nutrient transfer. The structure of the model should allow to take into account future management plan in the hydrographical network.

Key words: ecological modelling, nutrient retention, reservoirs, hydrobiology

Formung der Rolle der Vorratsbehälter in der Übertragung und in der Speicherung der Nährstoffe: Anwendung auf dem Fluß Olt (der Donauflüssbassin)

Zusammenfassung: Eine formenannäherung wurde entwickelt, damit der Donaufluß herstellt, wie Flächennutzung und Management des vollständigen Bassin Nährstoffanlieferung und –speicherung durch den Fluß feststellen. Die Annähering verwendet eine Anpassung des RIVERSTRAHLER Modells, das aus der Koppelung eines hydrologischen Modells mit einem biogeochemischen Modell (RIVE) resultiert und in Betracht zieht die ökologischen hauptsächlichprozesse. Ein Fokuswird auf dem Fluß Olt gebildet, der eine Kaskade von vielen Vorratsbehälter enthält, bekannt um hydrologisches regime und Nährübertragung zu beeinflussen. Die Struktur des Modells darf zukünftigen Managementsplan im hydrographical Netz in Betracht ziehen.

Schlüsselworte: ökologische Modell, Nährstoffspeicherung, Vorratsbehälter, Hydrobiologie

1 Introduction

In the scope of a comprehensive study of the Danube river system, the RIVERSTRAHLER model (Billen *et al*., 1994; Garnier *et al*., 1995) has been implemented for predicting the transfer and the retention of the nutrients, in its whole system of tributaries at the scale of the whatershed, in relation with human activities (Garnier et al., in press).

The model is based on the coupling of an idealised hydrological model that describes the hydrological constraints by stream-order (HYDROSTRAHLER), with an ecological model (RIVE) of the dynamics of phytoplankton and main biological processes of the ecosystem (bacterial degradation, zooplankton grazing, benthic processes). The whole Danube River catchment was divided into 11 sub-basin (taken into account by their own characteristics) and a main branch of the Danube (from Linz to the mouth) as one sub-system. Each of the sub-basins is considered an independent STRAHLER system. The model was used to simulate the major water quality variables involved in eutrophication problems for the period from 1988 to 1991. In this previous stage, the many reservoirs of the Olt basin (about 24, see Figures 1 & 2) were not taken into account.

In this paper, the aim is to apply the model for a more recent period than 1991, in order to better understand the response of the Danube basin to new constraints based on documented changes of human activity in the watershed. In this framework the role of the reservoirs is analysed regarding nutrient retention and transfer. We used the data base gathered for the year 1997.

2 Site description

The RIVERSTRAHLER model was applied to the Olt River (Danube basin), comprising a cascade of 24 reservoirs, necessarily influencing both hydrological regime and nutrient transfer.

The Olt River, located in the central and south part of the Romania country, between 43°47' - 46°45' North latitude and 23°35' - 26°24' East longitude (Figure 1). The Olt watershed is 24.050 km^2 and the river is long of 615-km . From its size point of view, the Olt basin is the fourth in Romania. There are 30 % mountains, 53 % hills and 17 % plains. Besides groundwater and direct precipitation, the Olt reservoirs receive rainwater runoff, domestic and industrial sewage brought by the pipes or the tributary draining the urbanised areas. The major part of the river main course comprises hydrotechnical constructions, leading to a succession of sites for decantation. Water samples taken from the main lakes-reservoirs at different depths, have shown that the amount of organic load is larger in deeper layers than at the surface; in a majority of reservoirs, an accumulation of non-biodegradable organic matter was shown (Water Romanian Authority, 1997). The major sources of pollution originate from the tributaries of the Olt River draining developed industrial areas, such as Risnov, Codlea, Victoria, Zarnesti, Fagaras, etc. (Water Romanian Authority, 1997).

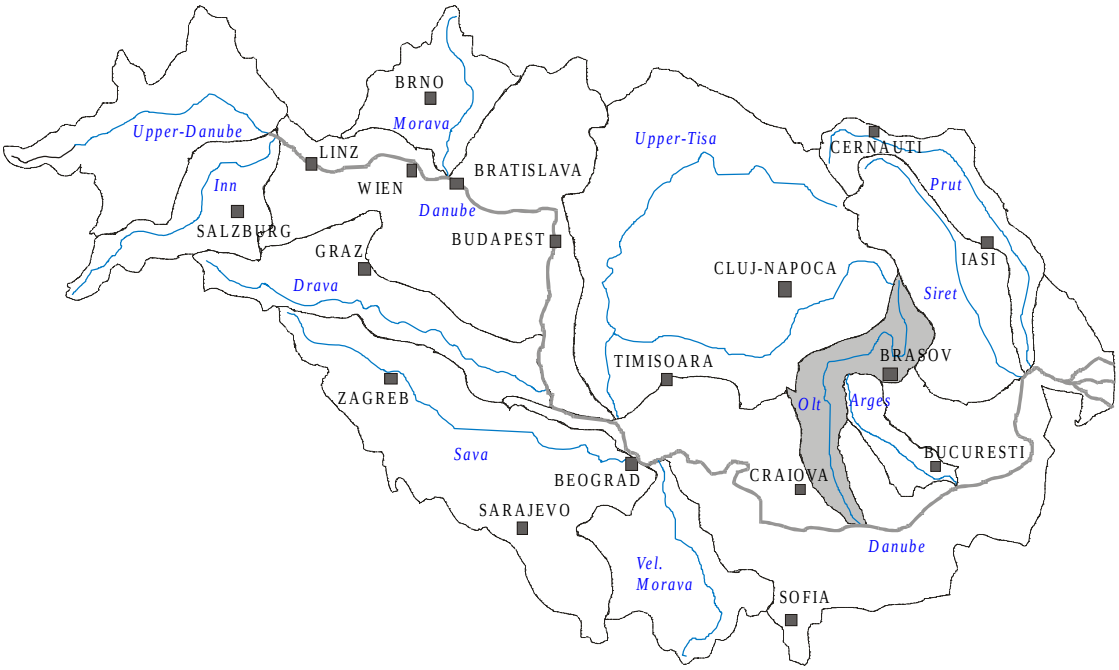


Fig. 1 RIVERSTRAHLER model applied to the Danube Basin. The Olt sub – basins is shown by a shaded area.

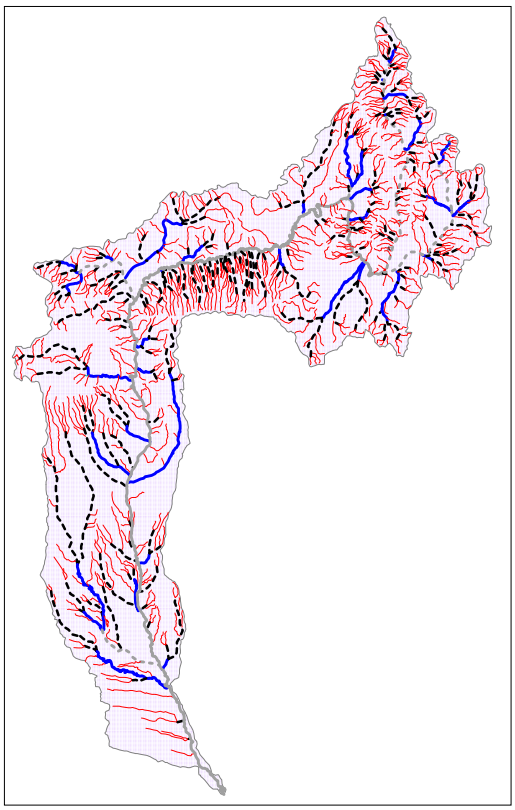


Fig. 2 Olt Basin : drainage network analysis. The stream ordering is: ord. 3 (gray line), ord.4 (black dotted line), ord. 5 (black bold line), ord.6 (grey dotted line), ord.7 (grey bold line); the stream-orders 1 and 2 are obtained by extrapolation and they a not contained on the map.

3 Model description

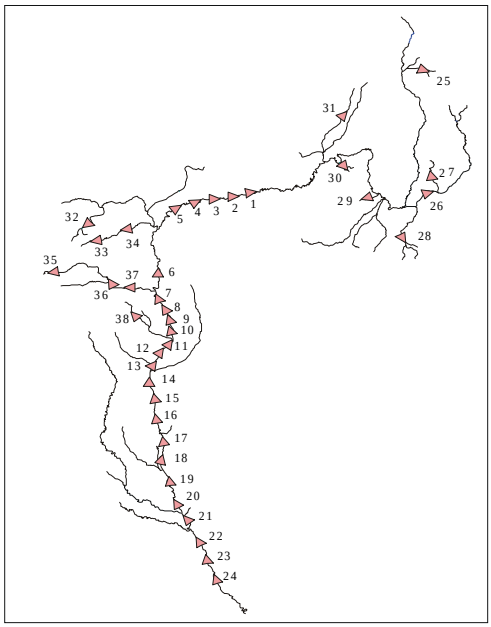
The approach lies on the concept of stream-order introduced by geographs (Strahler, 1957) which provides a generalised description of the morphology of drainage networks. Thus the complex network of tributaries is represented by a regular scheme of confluence of rivers with increasing stream-order (figure 2). Morphological characteristics, like watershed area, length, width and slope are related to the stream-orders. Using classical formulation of rain – discharge relationship, it makes possible to calculate discharge, flow velocity and depth in each stream-order, from the seasonal variations of rainfall and evapotranspiration, taking into account the role of the soil reservoir and of the water table (Billen et al., 1994; Garnier et al., in press). In order to represent the reservoirs along the Olt River, the mean width and depth of the whole succession of reservoirs were considered for the last order of the Olt drainage network. The morphology of 24 reservoirs on the main branch (order 7) and the other 14 located on the smaller stream orders was therefore analysed (figure 3). Besides this idealised description of the morphological constraints, the forcing functions driving the RIVERSTRAHLER model are:

• the hydro-meteorological constraints (seasonal variations of temperature, light intensity, pluviometry and potential evapotraspiration), by ten days period

• the inputs of material from the watershed, that means point sources (*treated and not treated domestic effluents* directly discharged, and *industrial effluents* for the sub-basins and main branch) and non point sources of organic matter and nutrients from the watershed (land use must be known for the whole system in terms of % area of cultures, meadows, forests, etc.).

The model allows to link the kinetics of the *microscopic* processes involved in the ecological functioning of the hydrosystem (RIVE model) and their *macroscopic* manifestations at the scale

of the whole drainage network, given these hydrological, morphological and climatic constraints and inputs. The RIVE model consists in a series of equations describing: • the processes of phytoplankton photosynthesis and growth in response to light and nutrients; • the processes of bacterial utilisation of organic matter in response to autochthonous and allochtonous sources of organic matter; • the processes of grazing and growth of zooplankton; • the processes of benthic nutrient recycling; • the nitrification, phosphate adsorption and oxygen



exchanges. In total, the model takes into account the kinetics of C, N, P, Si exchange between the different compartments of the system.

No.	Name of the reservoir	Volume (mil. m^3)	Surface (ha)	Order Strahler
1	Voila	12.25	412	7
2	Vistea	4.25	200	7
3	Arpas	7.35	275	7
4	Scoreiu	5.2	190	7
5	Avrig	10.8	330	7
6	Gura Lotrului	8.2	166	7
7	Turnu	13.11	154	7
8	Calimanesti	5	84	7
9	Daesti	11.2	209	7
10	Rimnicu Vilcea	19	319	7
11	Riureni	7.3	174	7
12	Govora	18.5	477	7
13	Babeni	59.6	905	7
14	Ionesti	24.9	466	7
15	Zavideni	45	839	7
16	Dragasani	48	825	7
17	Strejesti	202.7	2204	7
18	Arcesti	43.4	837	7
19	Slatina	19.2	540	7

No.	Name of the reservoir	Volume (mil. m^3)	Surface (ha)	Order Strahler
20	Ipotesti	110	1692	7
21	Draganesti	76	1080	7
22	Frunzaru	96	1280	7
23	Rusanesti	78	1100	7
24	Izbiceni	74	1095	7
25	Frumoasa	7.6	70	5
26	Reci	1.08	24	6
27	Moacsa Padureni	2.7	27	3
28	Sacele	15	122	5
29	Dumbravita	3.64	164	3
30	Bogata	0.9	4	3
31	Sinpaul	1.75	173	4
32	Gura Raului	15.5	65	5
33	Negovanu	6.4	50	4
34	Sadu II	0.4	35	4
35	Vidra	340	950	4
36	Malaia	3.4	47	5
37	Bradisor	38	230	5
38	Vlaesti	1.8	30	3

Fig. 3 The reservoir situation in the Olt basin and their main characteristics (name, volume, surface area and stream order situation)

4 Results

4.1 Olt Basin description

The lithology alone determine the silica content of the surface and ground water, while land cover and agricultural practices are important for determining nitrogen and to a lesser extent phosphorus concentration. Whereas phosphorus and nitrogen are brought to the drainage network by human activity in the watershed, silica input remains constant as it results only from rock weathering. A silica concentration was assigned to the important types of rocks from the Olt watershed, on the basis of the compilation by Meybeck (1986). A mean silica concentration was thus calculated from the distribution of each lithological type (table 1).

Table 1 Distribution of the lithological units in the Olt River system and estimated silica concentration in headwater

total area ***km²***	**læss & alluv.*** ***%***	**flysh*** ***%***	**secondary limestone*** ***%***	**magmatic rocks.** ***%***	**SiO_2** ***µM***
24 050	26	48	0	26	89

*Headwater concentration in SiO_2 in the different lithological units (Meybeck, 1986). Læss & alluvium: 100 µM; flysch: 50 µM; secondary limestone: 60 µM; magmatic rocks: 150 µM.

Considering the geographical distribution of land use types, a similar approach was followed for nitrogen and phosphorous, on the basis of the compilation by Howarth et al. (1996) and Billen & Garnier (2000) (table 2).

Table 2 Distribution of land use in the Olt River system and estimated mean nitrate concentration in headwater

total area ***km²***	**forest*** ***%***	**grassland*** ***%***	**arable land*** ***%***	**NO_3** ***µM***
24 050	29	54	17	151.8

*Headwater concentration in NO_3 in the different land use types. Forest: 20 µM; grassland: 50 µM; arable land: 700 µM

4.2 Simulations by the model

The model was run with the forcing functions analysed for the year 1997 and validated, with available discharge and water quality data. The simulations by the HYDROSTRAHLER model are generally in good agreement with measured data of discharge (figure 4a). Unfortunately, we were only able, at this stage, to validate the RIVERSTRAHLER model on the values of nitrate; the simulations gave values in the same order than the observations and similar seasonal trend (figure 4b).

a **b**

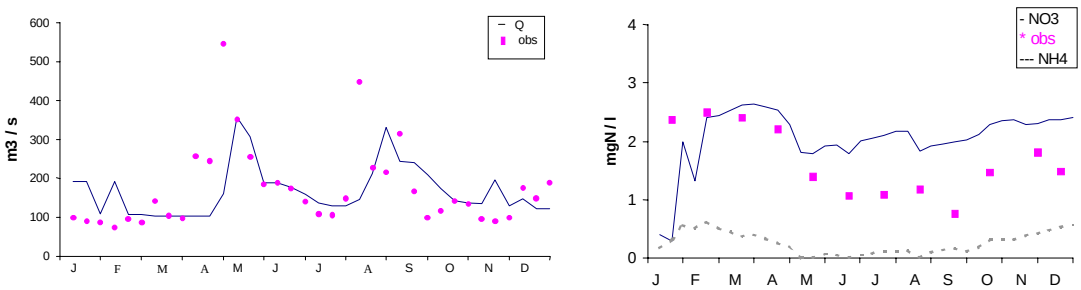


Fig. 4 Simulations by the model and comparison with experimental data for the year 1997: a) simulation by the HYDROSTRAHLER model of the seasonal variations of water discharges at

the outlet of the Olt River, b) simulation by the RIVERSTRAHLER model of the seasonal variations of nitrates.

In order to analyse the impact of the reservoirs on the quality river, simulations were made with and without reservoirs, i.e. with or without morphological regulation,. Both situations are compared at the basin outlet (about 20 km downstream from the last dam). The regulation notably modifies the values of discharge (Figure 5a); and the phytoplancton biomass, as well as their distributions in time (Figure 5b); the nutrients concentrations are also modified (figure 5c, d & e). The phosphates concentrations are very low in both cases and there is no doubt that they represent a limiting factor for the phytoplankton growth. With reservoir, phytoplankton limitation appears to be greater, due to bottom up control (nutrients), and probably also under top down effect (Garnier et al., 2000). A severe depletion in silica occurs in May with the reservoirs, necessarily due to diatom growth, but not shown by the variations in phytoplankton biomass that must be explained by losses (figure 5). Retention of silica by the reservoirs, as calculated by the model, would represent about 27 % of the Olt River flux in the presence of reservoirs .To go further in the understanding of retention in the reservoirs, the model was used to analyse the combine effect of damming (with and without reservoirs) and eutrophication (by increasing the phosphorous load). In agreement with the Redfield Si:P ratio, we can expect that an increasing load of phosphorus would increase silica retention (see conley et al., 1993). This hypothesis was tested by multiplying the phosphorus load by a factor of 2 and 5, the actual situation with reservoirs (figure 6, table 3). Compared to the reference simulation, silica retention can be increased from about 27% to 35%.

Nutrient delivery (as N, P) to coastal zones has dramatically increased in the past 30 years (Officer & Ryther, 1980; Conley, 2000). Before the 1990's, the Danube River used to deliver to the Black Sea an unbalanced silica load regarding nitrate and phosphorous, that must be the reason for eutrophication at the coastal zone (Lancelot & Martin, ECSS special volume, in press). Whereas the role of the Iron Gates impoundment's was said to be a major site for this retention, -(Humborg et al., 1997), the results by the model -(Garnier et al., in press) suggested that silica retention in the Danube river would be more evenly distributed throughout the drainage network. This preliminary study on the Olt River, which is exemplary by the number of reservoirs present, tends to confirm here that the many weirs in the Danube Basin can have a significant effect on silica retention, which can be more important as the phosphorous load increases.

An obvious limitations of the RIVERSTRAHLER model, as used here, is that it only provides simulation of the mean behaviour of tributaries of given order, instead of describing a particular river with its local peculiarities. Also, the reservoirs are taken into account in a simple way, as a depth and width regulation of the river stream order. The structure of the model however allows to improve the geographical realism of each of the sub-basin by splitting it into several sub-basin, each of them being described by a RIVERSTRAHLER model and a main branch, the results of the sub-basins models being used as limit conditions for the model of the main branch. For the Olt River, it could be possible to precisely describe the morphology of the main branch with its 24 reservoirs. A major limit to the approach lies on the data availability.

Table 3 Calculated transfer and retention by the Olt River system for a scenario of P load increase. Percentage retention is calculated by reference to the flux in the presence of reservoirs.

	Si fluxes KTSi y^{-1}	**retention by reservoirs** %
Output without reservoirs		
P load ref	23.8	-
Output with reservoirs		
P load ref	18	27
P load x 2	16.5	34
P load x 5	16.4	35

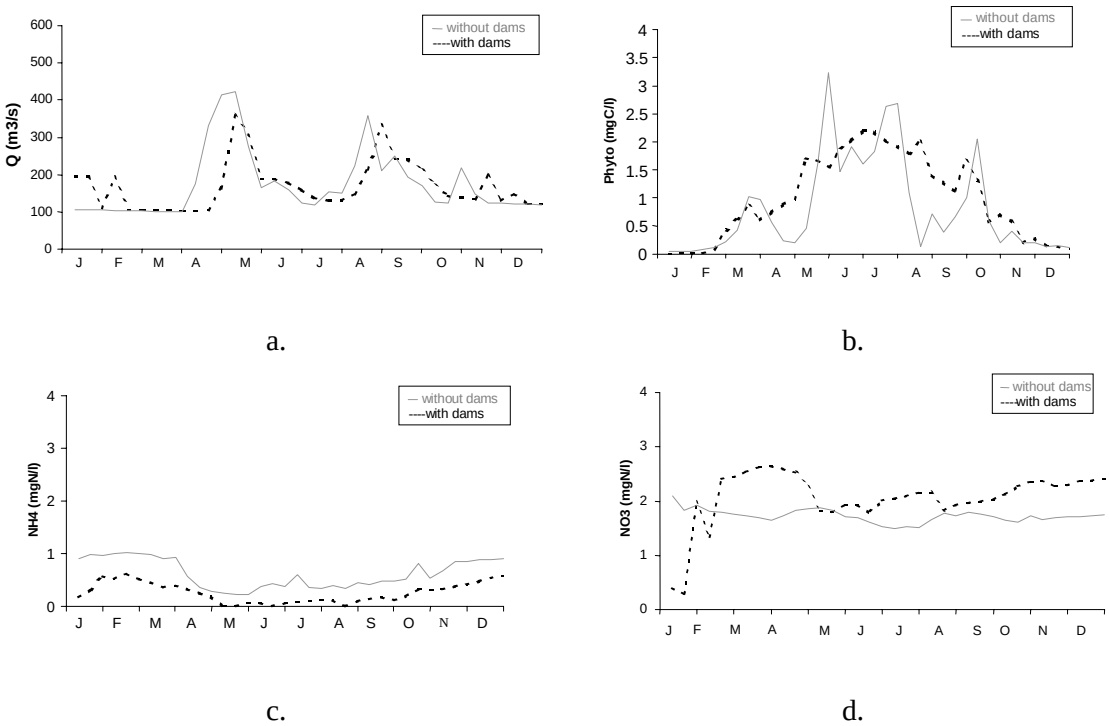


Fig. 5a - d Simulations by the RIVERSTRAHLER model of discharge (m^3 s^{-1}), phytoplankton biomass (Chl*a*), ammonia (mgN l^{-1}), nitrates (mgN l^{-1}), concentrations at the outlet of the Olt River in a scenario without reservoirs (solid line). Results for the reference situation (dotted line) are given for comparison.

e. f.

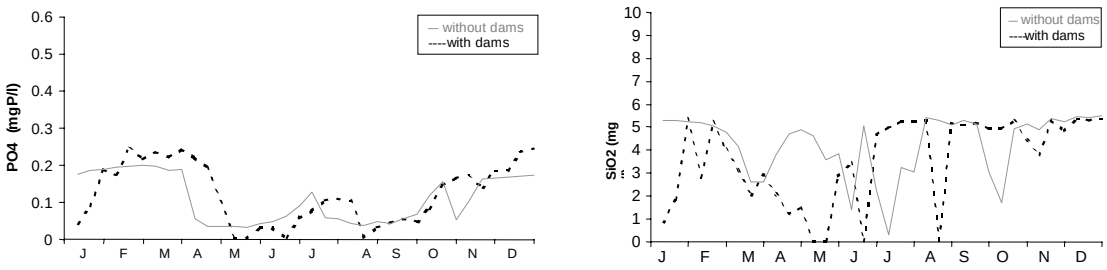


Fig. 5e - f Simulations by the RIVERSTRAHLER model of phosphates (mgP l^{-1}) and silica (SiO_2) concentrations at the outlet of the Olt River in a scenario without reservoirs(solid line). Results for the reference situation (dotted line) are given for comparison.

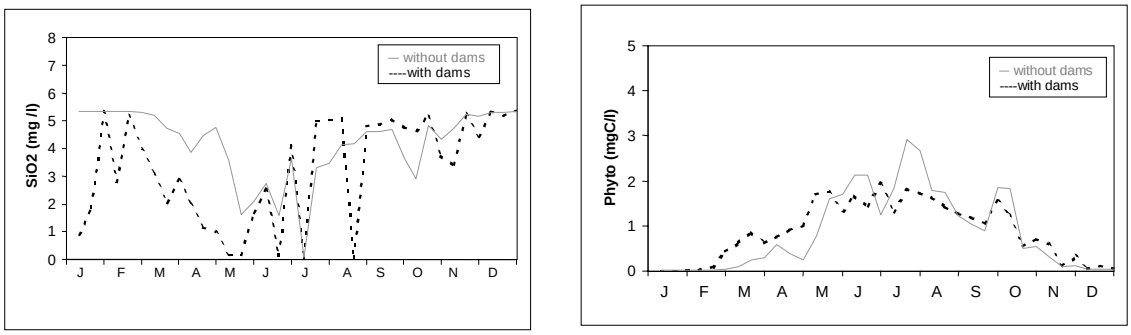


Fig. 6 Simulations by the RIVERSTRAHLER model of silica concentrations (SiO_2) and phytoplankton biomass (Chl*a*) at the outlet of the Olt River, in a scenario with an increase of total phosphorus load by a factor 5 (solid line). Results for the reference situation (dotted line) are given for comparison.

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The Occurrence of Heavy Metals in the Danube

Eva Třebenská, Adriana Čelková, Eduard Martiny

Abstract: The Water Research Institute Bratislava has been involved in the monitoring programme of the Danube for more than 20 years.The original examinations which started in the seventies included the determination of elements commonly occurring in surface waters such as Ca, Mg, Na, K, Mn and Fe utilizing especially titrimetry and flame atomic absorption spectrometry (FAAS). In 1989 this programme was extended and potential inorganic contaminants present in the waters in trace amounts such as As, Cd, Cr, Cu, Hg, Ni, Pb and Zn were included in the monitoring scheme. Since then the examinations of the Danubian surface waters and its tributaries have been carried out on a regular basis in the Laboratory of trace inorganic analysis on samples collected from 16 sampling sites along both banks of the Danube every two months using more sophisticated analytical equipment working on the principles of atomic absorption and fluorescence spectrometry (GF AAS and AFS) and atomic mass spectrometry (ICP MS).

Key words: trace elements, surface water, atomic absorption spectrometry

Vorkommen von Schwermetalle im Donauwasser

Zusammenfassung: Im Forschunginstitut fűr die Wasserwirtschaft Bratislava folgen wir Oberflächenwasserűberwachung der Donau mehr als 20 Jahren. Ursprűngliche Prűfungen (70 - Jahren) haben wir die Stoffe gefolgt, welche im laufenden Oberflächenwasser sind (z.b. Ca, Mg, Na, K, Mn, und Fe) - bei der Benűtzung die Methoden als Titrationsmetrie und auch bei der Flammen-Atomabsorptions-Spektroskopie (F AAS). Im Jahr 1989 es war diese Oberflächenwasserűberwachung - Programm mehr breiter um weitere Űberwachung. Und sicher um die potentionellen organischen Shmutzstoffen, welche in diesem Wasser in den spuren Mengen sind (z.b. As, Cd, Cr, Cu, Hg, Ni, Pb und Zn). Von dieser Zeit das Labor der spuren anorganischen Analyse regelmäβig analysiert der Dessine der Oberflächenwasser der Donau und seinen Zuflűsse. Von 16 orte bei der Donau, jeder zwei Monaten wir diese Dessine analysieren. Wir benűtzen dabei modernen Meβinstrumenten bei den Principien der Atomabsorptions- und Atomfluoreszenzs-Spektrometrie (GF AAS und AFS) und Atommassen-Spektrometrie (ICP MS).

Schlűsselworte: Spurenstoffe, Oberflächenwasser, Atomabsorptions-Spektroskopie

1 Introduction

The nature and properties of surface waters are affected by climatic conditions, the composition of geological stratum in contact with the waters and constituents present in their tributaries. In addition to major components such as common cations, anions and nutrients, trace components such as organic compounds and trace metals play a critical role in establishing the overall water chemistry. The presence of these trace constituents can also result in substantial modification of the ecosystem based upon their specific toxicity (Taylor, 1991).

Unlike most organic pollutants, heavy metals occur naturally in rock-forming minerals and so there is a range of normal background concentrations of these elements in soils, sediments, waters and living organisms. Pollution gives rise to anomalously high concentrations of the metals relative to the normal background levels.

The content of metals in water and their availability to terrestrial and aquatic organisms (i.e. their bioavailability) is determined by their solubilization and release from rock-forming minerals as well as the processes of their immobilization (precipitation, ion-exchange and

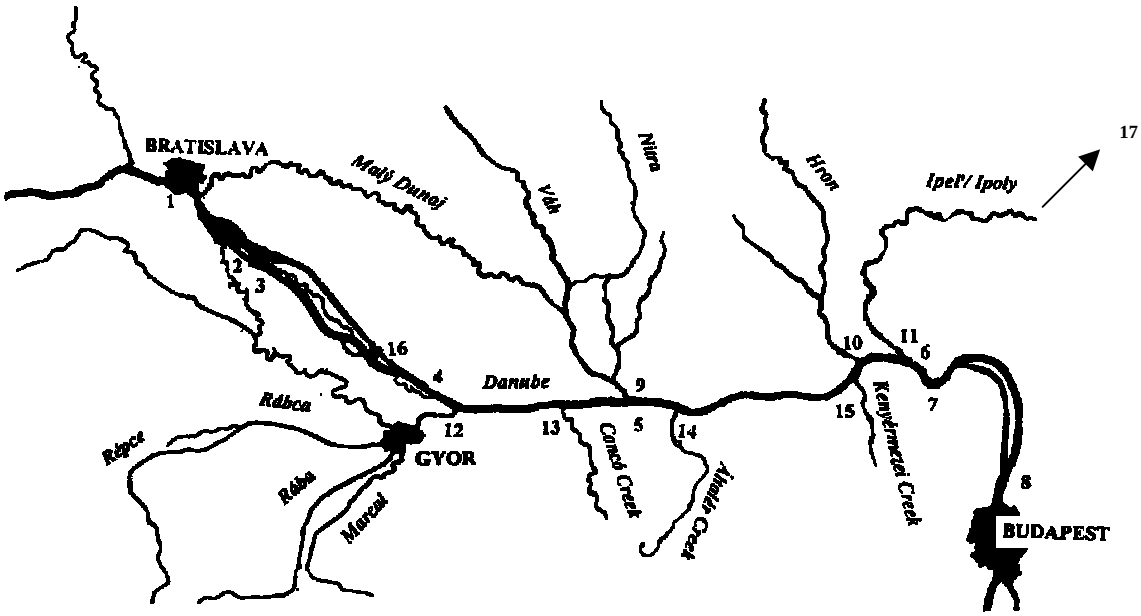
sorption on soils and sediments). Dissolved are especially inorganic complexes of metals with sulphate, carbonate, hydrocarbonate and phosphate and organic complexes with humic-, fulvo- and aminoacids (Manahan, 1991).

Some of these elements (Cu, Mn, Fe, Zn, Co, Cr, Se, B, Mo) being constituents of enzymes and other important proteins are required by most living organisms in small but critical concentrations for normal healthy growth (referred to as “micronutrients” or “essential trace elements”).

The excess concentrations of some elements with no known essential function (so called non-essential elements: As, Cd, Hg, Sb, Tl and U) as well as some of essential elements cause toxicity which at the biochemical level includes competition for sites with essential metabolites, replacement of essential ions, reaction with –SH groups of aminoacids/proteins, damage to cell membranes and reactions with the phosphate groups of ADP and ATP (Alloway et al., 1993).

2 Experimental

Sampling sites of the Danubian surface water and its tributaries are depicted in figure 1.



Explanations:
1 - Bratislava 2 - Rajka 3 - Hrušov 4 - Medveďov
5 - Komárno 6 - Szob 9 - Komárno (the Váh)
10 - Kamenica (the Hron) 11 - Salka (the Ipeľ) 17 - Kalonda (the Ipeľ)

Fig. 1 A map of the sampling sites on the Danube and its tributaries. The Danubian waters in Bratislava, Komárno and Szob were taken from true left and true right banks and in the midstream.

Samples of the riverine waters were collected 4-6 times a year. The total content of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn in the waters was determined in samples collected into 500 ml polyethylene bottles and preserved with high purity HNO_3 (Merck, Germany) by various techniques of atomic absorption spectrometry (AAS) under conditions specified in table 1.

Table 1 Performance characteristics of trace element determinations in surface waters

Element	Analytical technique	Method	LOD*	Instrumentation
arsenic	hydride generation AAS	Celkova et al.(1997)	1	Solaar 939
cadmium	graphite furnace AAS	DIN 38 406, časť 19	0.05	Perkin Elmer 3030
chromium	graphite furnace AAS	ISO 9174	0.2	Perkin Elmer 3030
copper	graphite furnace AAS	Fishman (1989)	0.5	Perkin Elmer 3030
mercury	cold vapour AAS	ČSN 830530, časť 43	0.1	Perkin Elmer 403
nickel	graphite furnace AAS	Fishman (1989)	1	Perkin Elmer 3030
lead	graphite furnace AAS	DIN 38 406, časť 6	1	Perkin Elmer 3030
zinc	flame AAS	ISO 8288 (1988)	0.2	Perkin Elmer 403

*limit of determination in ug/L

3 Results and Discussion

Large sets of results of concentrations of total contents of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn in the Danubian surface waters and its tributaries collected from 16 sampling sites as a rule 6 times a year within 1989 - 1999 have been statistically processed and evaluated. Concentrations of the metals have been shown to fall below limits declared in Nariadenie vlády Slovenskej republiky (1993)**- see the line entitled "limit" in table 2. Contents of Cd, Cr, Cu and Ni within this period have usually been one order of magnitude lower than the accepted limits. Even the maximum observed concentrations which are given for a particular year in table 2 have not exceeded the required limits and the frequency in which they appear is low and rather occasional - accidental. However, mercury and zinc are the exceptions. The fluctuations in concentrations of these elements in the Danube have been freqent, exceeding the permitted limits by a factor of up to 6 for Hg 17 times in 10 years and by a factor of up to 10 for Zn 8 times in 10 years. These figures are well documented in table 2. On the other hand, however, of all determinations of Hg and Zn performed on the Danubian waters 75 % and 80 % , resp. have been below the limits of determination (0,1 µg Hg/L and 0,02 mg Zn/L, resp.).

Table 2 Maximum concentrations of metals in the Danube and its Slovak tributaries in particular localities during 1989-1999 as compared with maximum values for surface waters limited by Nariadenie vlády Slovenskej republiky (1993)**

	As (µg/L)	**Cd** (µg/L)	**Cr** (µg/L)	**Cu** (µg/L)	**Hg** (µg/L)	**Ni** (µg/L)	**Pb** (µg/L)	**Zn** (µg/L)
limit	**50****	**10****	**100****	**200****	**0,5****	**100****	**50****	**100****
1989	**12** Hron 7.9.	**5** Hron 16.5.	**18** Hron 16.10.	**85** I-Sal 24.7.	**0,9** Kom 14.11.	**10** Hron 27.11.	**21** Váh 18.9.	**140** Váh 18.9.
1990	**13** Hron 21.3.	**1,6** Kom 6.2.	**8,6** Brat. 5.3.	**18** Brat. 19.2.	**2** Váh 21.3.	**8** Hruš 6.3.	**5** Med 15.5.	**230** Raj 4.9.
1991	**4** Szob 20.8.	**2,7** Hro 11.11.	**15** Brat. 5.8.	**43** Brat. 5.8.	**0,6** Brat. 13.5.	**22** Brat. 5.8.	**47** Brat. 5.8.	**160** Brat 5.8.
1992	**23** Hron 2.3.	**1,1** I-Sal 8.6.	**14** Kom. 15.9.	**3,8** Hro 9.11.	**1** Hron 14.9.	**6** I-Sal 14.9.	**22** I-Sal 8.6.	**960**I-Sal 8.6.
1993	**23** Hron 9.8.	**0,5** I-Sal 13.12.	**4,3** Hro 8.2.	**12** Szob 15.12.	**1** Raj 1.6.	**14** I-Sal 5.4.	**9** Szob 6.10.	**90** Szob 6.10.
1994	**29** Hron 8.8.	**0,8** I-Sal 12.12.	**2,5** Hro 12.12.	**190** Hru 11.1.	**1,1** Brat. 12.12.	**5** Brat. 11.7.	**16** Váh 6.9.	**185** Hru 11.1.

Table 2 - continuation. Maximum concentrations of metals in the Danube and its Slovak tributaries in particular localities during 1989-1999 as compared with maximum values for surface waters limited by Nariadenie vlády Slovenskej republiky (1993)**

	As (µg/L)	**Cd** (µg/L)	**Cr** (µg/L)	**Cu** (µg/L)	**Hg** (µg/L)	**Ni** (µg/L)	**Pb** (µg/L)	**Zn** (µg/L)
limit	**50****	**10****	**100****	**200****	**0,5****	**100****	**50****	**100****
1995	**20** Hron 6.2.	**3** I-Sal. 12.6.	**17** I-Sal. 12.6.	**39** I-Sal. 12.6.	**3** Kom. 10.1.	**44** I-Sal 12.6.	**42** I-Sal. 12.6.	**460**I-Sal 12.6.
1996	**5** Hron 5.8.	**0,8** Brat. 9.12.	**2,6** Hro 5.2.	**32** Szob 12.6.	**0,9** Brat. 13.5.	**8** Brat. 22.1.	**45** Szob 7.8.	**480** Szo 7.8.
1997	**13** Hron 13.10.	**0,7** Hro 3.2.	**5,9** Brat. 7.7.	**21** Brat. 7.7.	**1,5**I-Kal 3.2.	**8,7** Váh 4.8.	**74** Brat. 7.7.	**440** Brat 7.7.
1998	**13** Hron 3.8.	**0,4** I-Sal 16.2.	**4,8** Váh 11.5.	**4,5** Brat. 9.11.	**0,8** Raj. 12.5.	**8** I-Sal 3.8.	**4,4** Raj. 10.11.	**47** I-Sal 16.12.
1999	**10** Hron 8.11.	**1,3**I-Kal 10.5.	**5,1** Hro 8.11.	**19** Hruš 3.8.	-	**5** I-Kal 2.8.	**7** I-Sal. 2.8.	**40** I-Sal 1.2.

Abbreviations:

Brat (the Danube in Bratislava)	Kom (the Danube in Komárno)
Hro (the Hron in Kamenica)	Med (the Danube in Medveďov)
Hru (the Danube in Hrušovo)	Raj (the Danube in Rajka)
I-Sal (the Ipeľ in Salka)	Szob (the Danube in Szob)
I-Kal (the Ipeľ in Kalonda)	Váh (the Váh in Komárno)

An interesting finding has been observed from the statistical evaluation of the occurrence and distribution of arsenic in the Danube and the Hron. The Hron is one of main contributors of this element to the Danube. Its background arsenic level is relatively high in comparison with other Danubian tributaries as is documented in figure 2.s

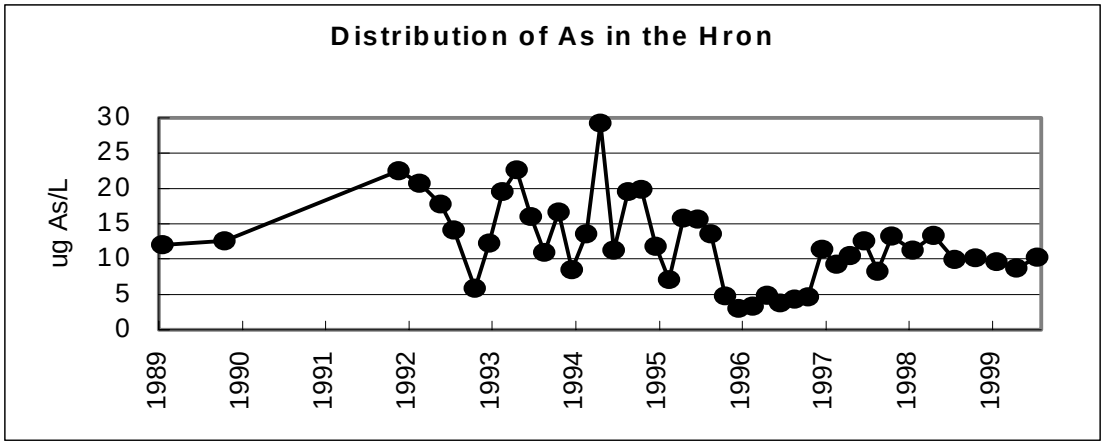


Fig. 2 Variations in the distribution of arsenic in the Hron during the period of 1989 - 1999.

The Hron is a true left bank of the Danube and the mean concentration of As in it varies approximately between 10 and 20 µg/L. This relatively high background level is related to the Jaseniansky stream running from an area famous for antimony ores (Zimnikovalová). Antimony and arsenic are similar in their chemical properties, the one being usually accompanied with the

other. Arsenic, however, is more mobile and less prone to hydrolysis than antimony. It was interesting therefore to investigate the influence and distribution of As in the Danubian waters in Szob the next downstream sampling site which is 10 km from the cofluence of the Hron and the Danube. The concentrations of As in the Danubian waters in Szob are substantially lower than those found in the Hron. Despite a 10-km distance of Szob from this confluence there is still an evident difference in concentrations of As in the waters collected from the true left bank sampling site - Szob L ● (maximum 12 and the mean concentration about 3-4 μg As/L) vs. midstream and true right bank sampling sites - Szob M and Szob R ■ with maximum concentration of 7-8 and the mean less than 2 μg As/L. These findings are shown in figure 3.

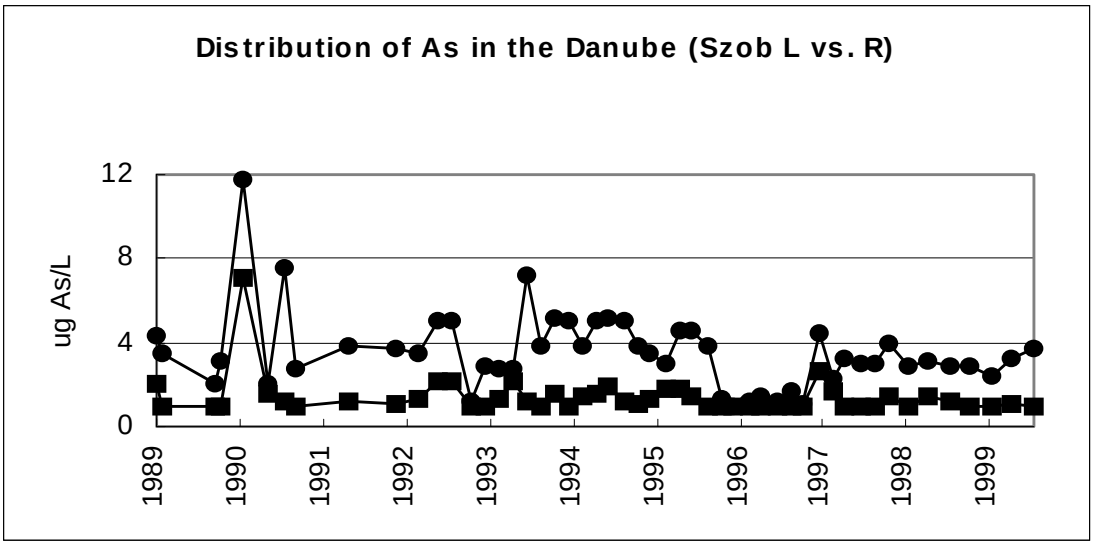


Fig. 3 Variations in the distribution of arsenic in the Danube in Szob within 1989 - 1999.

Figure 4 illustrates the distribution of As in the Danube in Komárno (the true left bank sampling site) which is about 80 km upstream from Szob and serves as a reference.

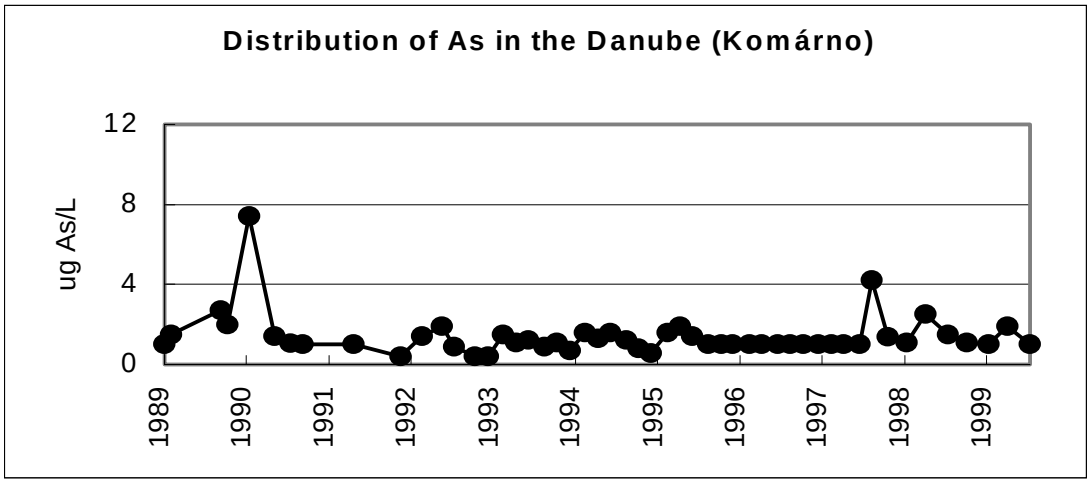


Fig. 4 Variations in the distribution of arsenic in the Danube in Komárno over 1989 - 1999.

Here the average concentration of As varies between 1 and 2 μg/L.

Another task of this work was to find out if there is a correlation between the seasons and the occurrence of the elements under study in the riverine waters. On the basis of the data available we have discovered that there is no strong correlation. However, there are some indications of a slight increase in concentrations of the metals in January-February and in September-October which can probably be related to the reduced water-level of the Danube at the end of winter and the end of summer.

Conclusion

The following conclusions can be drawn from statistical evaluation of the data of the occurrence of some elements in the Danube river and its tributaries the Hron, the Ipeľ and the Váh in the sampling sites located at the mouths of the last three rivers:

- The surface waters of these rivers at the examined sampling sites are relatively unpolluted with heavy metals. Some occasional local maximum concentrations of As, Cd, Cr, Cu, Ni and Pb can be observed but they do not exceed the limit set in Nariadenie vlády of Slovak Republic 242 (1993). Zn and Hg are the only elements that more frequently than the other metals do not meet these limits and exceed the set values by factors of up to 6 for Hg and up to 10 for Zn. The most recent analyses of filtered and unfiltered water samples from these localities suggest that the studied elements exist in a dissolved state
- Moderately increased concentrations of As in the Hron originate from the Jaseniansky stream and are attributed to geological structure of this area known for antimony mines
- Statistical evaluation of the data has not proved any strong correlation between the seasons and the occurrence of metals under investigation. There are some indications of negligible increase in the concentrations of these metals at the end of winter and the end of summer
- Analytical methods used in the analysis of surface waters: flame and graphite furnace AAS and more recently AFS and ICP MS are sufficiently sensitive and reliable. The internal quality control system comprises the utilization of certified reference materials and control charts, the external one participation in international interlaboratory tests.

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The Water Quality of Multipurpose Accumulations

Božena Tušar, Tatjana Mijušković-Svetinović

Abstract: Construction of complex hydrotechnical systems, such as multipurpose accumulations, causes many problems. One of the main ones, that scientists have been trying to resolve for years, is the change of water quality in a new water system.
The dam construction, especially at a watercourse, causes change in the water regime as well as ecological change, what in most cases leads to a hastened proces of the eutrophication imperilling the water quality.
The work presents the River Drava's flow, the plans for construction of new water systems, and estimates positive and negative aspects of such construction, stressing the problem of water quality.

Key words: water quality, multipurpose accumulations, river,

Wasserqualität in Akkumulationen mit mehrfachen Anwendungen

Zusammenfassung: Bauen komplizierte hydrotechnische Systeme wie Akkumulationen mit mehrfachen Anwendungen verursacht viele Probleme. Einer der für Wissenschaftler wichtigsten ist die Änderung der Wasserqualität in neuen Wassersysteme.
Ein Staudammbau, besonders am Wasserlauf, ändert das Wasserregime und verursacht öekologische Änderungen die meistens zur akzelerierter Eutrofikazion leiten und damit Wasserqualität bedrohen.
Der Artikel präsentiert der Wasserlauf der Drau Fluss, Pläne fur Wassersystemeneubau und prognosiert positive und negative Aspekte solch einer Bau an der Wasserqualität.

Schlüsselworte: Wasserqualität, Akkumulationen mit mehrfachen Anwendungen, Fluss, Eutrofikation

1 Introduction

River Drava is rich with water, has a specific water regime (main maximum flows from May to July, and secondary in October and November) and a substantial longitudinal decline. Because of all described previously Drava is suitable for use in energy production, respectively for building water steps, and for creating accumulations and hydroelectric power plants.

The upstream section of the river Drava has a great number of dams. There are 23 hydroelectric power plants on the Drava River that completely uses up its hydroelectric potential upstream from Mura. Its downstream section flows from the Mura river's mouth (Legrad, 236 rkm) forms the border between Croatia and Hungary for 170 km that has acted as an iron curtain for almost five decades, has therefore been protected from human activities and has become a unique oasis of numerous plant and animal species. Lower Drava is suitable for hydroelectric use for approx. 60 more meters of water decline. A greater interest for Drava's potential emerged at the end of 1950s when a joint Yugoslav - Hungarian water management was created and co-ordinated gathering of hydrographic and hydrological data started. A complex joint solution of Drava's regulation that consists of four interventions including water steps and has a multifunctional character was planned in the 1980s. Lately the Hungarian side partly abandoned these plans while the Croatian side adapted them for a possible realisation.

In order to regulate and use the waters of Drava and its biggest tributary Mura, the construction of new multifunctional water systems is being planned at Croatian territory. The regulation and use of Drava implicits primarily the use of its energy potential on chosen sections for the production of electricity, further the protection of its banks from the destructive influence of the river flow and flood protection of the surrounding area when high waters arise. Plans also include forming necessary conditions for the use of Drava water for farming purposes as well as for the drainage regulation of surface and subterranean waters of the basin that are expected to be affected by planned constructions on the river and its shores. And, finally, solving the problem of regulation and use of Drava should create terms of upgrading and developing the surrounding area.

Three water steps have been constructed on the river Drava and four more are yet to be built:
- HE Varaždin – already built
- HE Čakovec - already built
- HE Dubrava – already built
- HE Novo Virje
- HE Barcs
- HE Donji Miholjac
- HE Osijek

With a substantial part of project documentation ready, a complete preliminary design and ecological study, the first new water system to be constructed is probably HE Novo Virje [1,2].

2 The Water Quality of the River Drava

The complex problem of water protection in the Republic of Croatia, including the anti-pollution protection, has been regulated in the Water Act (NN 107/95), Regulation of Waters' Classification (NN 77/98) and State Water Protection Plan (NN 8/99).

In compliance with the Regulation of Waters' Classification (waterflows, natural lakes and accumulations) subterranean and seawaters are divided in five categories according to their purpose and purity grade. Water classification evaluates water quality and categorises waters based on maximal allowed quantities of certain parameters that designate sources and causes of water pollution.

According to State Water Protection Plan and the Regulation of Waters' Classification, Drava river should be a class II water within Croatian borders, meaning that its waters could, in their natural state, be used for bathing, recreation and water sports as well as fish breeding (except quality food fish). Following a purification procedure, it could also be used for drinking and in industry that needs purified water, while it must meet limiting values of water quality parameters for a class II water as shown Table 1.

River Drava's water quality evaluation is based on existing data on water quality research conducted between 1980 and 1998 in sampling stations on Lower Drava: Donji Miholjac (77+725 rkm), Bistrinci (54+000 rkm), Visnjevac (23+600 rkm) and Nemetin (10+900 rkm). Extreme and average values of selected water quality markers, with a positive or negative tendency displayed, are shown in Table 2.

This table, as well as [4,5], demonstrates that nitrates, ammonia, the number of coliform bacteria and BOD_5 present the biggest problem for Drava's water quality. In the whole 16 years of water quality observations, nitrate values have not once met the criteria for a class II water. Similar as ammonia that met the criteria for 4 (5) years. The number of coliform bacteria as well as BOD_5 has also often exceeded limiting values, especially at Nemetin sampling station. Other water quality

markers - oxygen saturation (supersaturation), KPK-Mn and saprobity index - are also critical for water quality, although to a lesser degree. Worst water quality measured was in 1984 and 1985, while best occurred in 1988, 1990 and 1997.

A general tendency of improving water quality can be observed but it is disturbing that parameters presenting greatest problems, like BOD_5, nitrates and phosphates, show a tendency of growth at all sampling stations, while saprobity index deteriorates at sampling stations Visnjevac and Nemetin. Parameters like ammonia, the number of coliform bacteria, suspended solids and KPK-Mn are in decline.

The tendency of water quality improvement is a result of water purification plant built lately in the Drava basin as well as of using upgraded industrial technologies. It must be also mentioned that, due to war and recession, negative industrial influence has been substantially diminished.

Table 1 Limiting values of selected water quality parameters for specific surface waters according to Regulation of Waters' Classification and State Water Protection Plan. [6]

N°	WATER QUALITY PARAMETERS	II CLASS	
1	pH value	6,5-6,3	8,5-9,0
2	Dissolved oxygen in mg/L O_2	7-6	
3	Saturated oxygen in %	70-80	110-120
4	Biochemical oxygen demand (BOD_5) in mg/L O_2	2-4	
5	Chemical oxygen demand (COD - Mn) in mg/L O_2	4-8	
6	Nitrates in mg/L N	0,5-1,5	
7	Nitrites in mg/L N	0,01-0,03	
8	Total phosphorus in mg/L P	0,10-0,25	
9	Ammonia in mg/L N	0,10-0,25	
10	Number of coliforms bacteria UK/L	$5x10^2$-$5x10^3$	
11	P-B saprobity index (S)	1,8-2,3	

Table 2 Extreme and average values of selected water quality parameters with displayed tendencies at sampling stations Donji Miholjac, Bistrinci, Visnjevac and Nemetin for the 1980 - 1998 period.

SAMPLING STATION		DONJI MIHOLJAC						BISTRINCI					
QUALITY PARAMETER		min		max		average		min		max		average	
WATER TEMPERATURE	^{O}C	0,00	+	26,00	+	12,02	+	0,00	+	26,00	+	12,10	+
pH VALUE		7,00	+	9,00	+	7,69	+	6,90	-	9,50	+	7,70	+
ELECTRICAL CONDUCTIVITY	µs/cm	104,00	-	469,00	+	319,37	+	200,00	+	526,00	+	318,16	+
DISSOLVED OXYGEN	mg/L O_2	5,60	-	24,70	+	9,78	+	4,70	+	24,40	+	9,83	+
SATURATED OXYGEN	%	42,62	+	201,00	+	89,24	+	45,17	+	177,00	+	89,75	+
BOD_5	mg/L O_2	0,02	+	28,16	+	2,89	+	0,03	+	25,13	+	2,84	+
COD ($KMnO_4$)	mg/L O_2	0,47	-	21,60	-	5,25	-	1,00	-	16,70	-	5,20	-
COD ($K_2Cr_2O_7$)	mg/L O_2	2,26	-	81,56	-	13,35	-	0,64	-	83,78	-	13,10	-
SUSPENDED SOLIDS	mg/L	10,00	-	350,00	-	61,05	-	10,00	-	240,00	-	60,58	-
MPNC	/100 mL	9	-	160000	+	7516	-	5	-	54000	-	7161	-
NUMBER OF BACTERIA	u 1 mL	80	+	153600	+	4069	+	60	-	68400	+	3703	+
SAPROBITY INDEX	S	2,00	-	3,00	-	2,38	-	2,10	+	3,30	-	2,33	-
NITRITES	mg/L N	0,001	+	0,050	+	0,011	+	0,001	+	0,140	+	0,011	+
NITRATES	mg/L N	0,450	+	13,800	+	2,110	+	0,014	-	9,600	+	2,074	+
PHOPHORUS	mg/L PO_4	0,011	-	1,920	+	0,191	+	0,010	-	1,300	+	0,191	+
AMMNONIA	mg/L N	0,019	-	0,890	-	0,204	-	0,007	-	0,970	-	0,209	-
SAMPLING STATION		VIŠNJEVAC						NEMETIN					
QUALITY PARAMETER		min		max		average		min		max		average	
WATER TEMPERATURE	^{O}C	0,00	+	26,00	+	12,90	+	0,00	+	26,00	+	12,11	+
pH VALUE		6,90	+	9,60	+	7,70	+	6,90	+	9,20	+	7,70	+
ELECTRICAL CONDUCTIVITY	µs/cm	206,00	-	618,00	+	323,89	+	200,00	-	565,00	+	324,32	+
DISSOLVED OXYGEN	mg/L O_2	4,40	+	23,10	+	9,78	+	4,10	+	24,20	+	9,76	+
SATURATED OXYGEN	%	40,89	+	195,00	+	89,39	+	38,41	+	181,00	+	89,37	+
BOD_5	mg/L O_2	0,03	+	17,50	+	2,99	+	0,08	+	18,70	+	3,17	+
COD ($KMnO_4$)	mg/L O_2	0,92	-	79,00	-	5,58	-	1,26	-	79,00	-	5,70	-
COD ($K_2Cr_2O_7$)	mg/L O_2	0,67	-	97,00	-	13,94	-	0,48	-	102,00	-	13,99	-
SUSPENDED SOLIDS	mg/L	10,00	-	250,00	-	67,63	-	10	-	250,00	-	68,53	-
MPNC	/100 mL	4	-	67000	-	8234	-	13	-	160000	+	11843	-
NUMBER OF BACTERIA	u 1 mL	100	+	155600	+	9629	+	2,00	+	230400	+	14098	+
SAPROBITY INDEX	S	2,00	+	3,00	-	2,34	+	2,00	+	3,00	-	2,32	+
NITRITES	mg/L N	0,001	+	0,250	+	0,011	+	0,001	+	0,050	+	0,005	+
NITRATES	mg/L N	0,260	+	9,900	+	2,123	+	0,450	+	9,500	+	2,222	+
PHOPHORUS	mg/L PO_4	0,010	-	1,150	+	0,198	+	0,018	-	0,890	-	0,206	+
AMMNONIA	mg/L N	0,020	-	0,890	-	0,210	-	0,029	-	1,160	-	0,211	-

3 The Impact of Hydroelectric Power Plants - Accumulations on Environment

Every hydroelectric power plant or a multipurpose accumulation will have an impact on the environment proportional to its size and function. Construction planner must maximise positive influences and, to a maximum degree, minimise disturbing effects on nature and life environment.

Accumulation environment impacts can be divided into positive and negative.

Positive impacts can be
- economic effects,
- flood protection,
- flow management,
- fish breeding,
- recreation (fishing, walking),
- water sports.

Negative impacts can be

- *physical*
  - change in hydrological regime (depending on the size of accumulation),
  - impacts on climate (fog, precipitation),
  - water quality change (temperature),
  - seismic impacts,
  - river bed erosion under the dam,
  - accumulation swerving (shortens lifespan),
  - change in subterranean water regime.
- *biological*
  - impact on plant and animal life,
  - spreading of diseases.
- *environmental*
  - aesthetic,
  - population migration (area flooding),
  - noise (during construction),
  - water, air and soil pollution (during construction),
  - sociological impact.

Building an accumulation requires a prognosis on the future water quality in the accumulation and downstream from it as well as in all other parts of the new water system, in order to establish the possibility of water use for planned purposes. Changes that occur inside the accumulation are usually followed by substantial change of physical and chemical water properties downstream from the accumulation such as water temperature, water turbidity, saturated oxygen, water hardness, possible appearance of ammonia and hydrogen sulphide etc.

Of great importance for water status in a water system, besides expected biochemical processes in a ecosystem, is waste material brought in through precipitation and waste waters from the banks and system’s catchment area. Therefore, when building a new water system, one must plan the location and the mode of releasing waste and precipitation waters. It is also important to establish if proposed changes in waterflow regime (new water system) cause additional expenses in wastewaters release because of a higher purity grade or their elevation to a higher plane.

By building a dam an accumulation is created that changes that waterflow’s hydrological and hydraulic properties. Water flow velocity is being diminished, water depth is increasing, and water temperature and transparency is changing. Living habitat conditions are therefore transformed and the existing plant and animal world must adapt to it, destroying certain species and presenting new ones, able to survive in changed surroundings. Intervening in nature by building new elements, man

changes and transforms biocenosis and existing relations in them and, at in the same time, accelerates and changes the process of matter circle.

Water quality of the Novo Virje hydroelectric plant watersystem and other planned hydroelectric plant watersystems, can be presumed based on research results (they give insight into processes taking place in a newly formed lake) on the Cakovec hydroelectric plant watersystem. Water quality of Cakovec accumulation depends on the water status in Varazdin accumulation as well as on the impact Varazdin's wastewaters that are, following primary and secondary (biological) purification, released into Cakovec accumulation. [1,2]

After building the Cakovec hydroelectric plant, research activities are being conducted on water samples at following locations [7]:

1a. Cakovec accumulation lake - accumulation tail around 700m downstream from Varazdin railway bridge: surface and bed;

1b. Cakovec accumulation lake near the recreational centre;

2. Cakovec accumulation lake in the middle: surface, middle and bed:
3. left drainage ditch in km 1+260 of embankment;
4. right drainage ditch in km 7+500 of embankment;
5. drainage derivation canal Cakovec in km 8+150 (Prolog bridge);
6. Drava's HE Cakovec biological minimum in km at around 1,5 before joining the drainage canal;
7. right drainage ditch 500m after the release of Varazdin's waste waters (physical, chemical and bacteriological analysis only);
8. little stream Jezercica.

Table 3. demonstrates the results of water quality observations for selected parameters in 1990. Similar observation results were acquired in the 1985 - 1989 period.

As shown in the table, water of the HE Cakovec water system is a II to III class water, except in the right and left drainage canal where it is a III to IV class water. Worst water quality can be observed in the right drainage canal 500m after the release of Varazdin's wastewaters. Displayed data shows that the eurtophication process has already begun in peripheral canals. [1,2]

Water quality in new water systems is directly dependent on the state of water systems of already built hydroelectric plants and, if nothing is done to stop the eurtophication process in existing water systems, the water quality of planned water systems could be expected to be even worse. It is also evident that it is necessary to position Drava in the required class II quality grade. Good will, financial resources and active participation of all beneficiaries of that certain waterflow (especially those who use Drava as a wastewater recipient) are necessary in order to uphold the water quality grade after building new water systems.

4 Measures intended to protect the accumulation and water quality of the Drava River

A basic assumption for a new water system's normal functioning is to bring Drava and her tributaries into a water quality class as required by the Regulation of Waters' Classification.

Known measures intended to stop eutrophication are:
- eliminating eutrophication causes and
- eliminating eutrophication effects.

Eutrofication is a complex of biogeochemical and ecological processes that result in the formation of a larger quantity of organic material that exceeds the trophic capacity of a certain unadjusted

ecosystem. Therefore, measures meant to prevent eutrophication use procedures that control mentioned processes. Described causes of eutrophication also point to possible courses of action.

Limiting the input of phosphorus, one of necessary biogene elements, in an accumulation prevents growth and development of algae that are the main source of biogene elements in residential, industrial and agricultural wastewater. Eliminating phosphorus in these waters can reduce eutrophication.

A further measure is controlling the use of artificial fertilisers in farming and limiting the use of poliphosphate detergents. Eutrophication can also be prevented by intensified elimination (by choice) of secondary productivity and the surplus of organic material with it.

Introducing different biological poisons (algaecides; copper sulphate, for example) into water is a way of preventing eutrophication, but with additional care not to destroy other biological species.

Technical measures include the choice of appropriate locations for an accumulation in the design phase in order to evade eutrophication morphometric factors.

Hydrotechnical measures are, of course, also available like introducing oligotrophic waters for dilution, introducing air into deeper accumulation levels and pumping. They all are expensive and difficult to implement.

Due to specific nature of every water system there are no universal solutions; every case must be observed and solved uniquely, using ecomathematical models and experimental verification of obtained results.[1,3]

5 Conclusion

Building new hydroelectric power plants and their water systems on the Drava River will cause morphological and hydrological change. Change in physical and chemical as well as biochemical processes will result in water quality transformation. In addition to parts of new water systems, the quality of the Drava River water downstream from the future construction will also be endangered. In order to prevent or reduce eutrophication of the Drava River certain protective measures must be implemented.

First and most important is to position the river Drava into a class II water, as required by the law. Further measures include partly eliminating the causes for eutrophication and partly eliminating eutrophication impacts.

The sustainment of required water quality for the Drava River includes decreasing the concentration of harmful and dangerous materials as well as organic load by purifying residential and industrial waste waters, or reducing pollution at its very source. It is also necessary to implement protective measures to coastlands by regulating abandoned gravel pits and wild waste deposits.

Eliminating the effects of an already started eutrophication process in existing water systems employs the use of biological methods: fish-stocking and overfishing, meaning depleting organic load.

If stated preconditions are not fulfilled one can expect an even worse water quality in the new water systems.

Table 3 Results of water quality observations at the Cakovec hydroelectric plant water system in 1990.

SAMPLING STATION	O_2 mg/L	SATU-RATION %	BOD_5 mg/L O_2	$KMnO_4$ mg/L O_2	COD mg/L O_2	MPNC b.c./L	CLASS
1a	8,48-11,69	90,15-103,18	1,36-3,21	7,59-13,28	2,62-4,58	1.500-24.000	II.-III.
1b	8,46-9,23	90,41-92,41	5,80-6,15	8,22-8,85	2,83-3,05	24.000	II.-III.
2a	8,94-11,57	89,85-102,22	1,21-3,22	8,53-12,64	2,94-4,36	0-1.500	I.-II.
2b	9,01-11,48	89,21-101,32	3,09-5,39	8,85-13,91	3,05-4,80	0-1.500	I.-II.
2c	8,66-12,16	89,46-107,33	2,11-6,71	9,43-10,12	3,25-3,49	750-3.800	II.-III.
3	3,97-4,42	39,72-40,81	0,20-2,66	5,06-8,22	1,77-2,86	0-3.800	III.-IV.
4	4,13-4,68	35,63-48,05	1,87-4,00	5,06-9,43	1,74-3,19	0-880	III.-IV.
5	8,74-10,46	91,06-97,22	2,53-4,80	7,59-15,80	2,57-5,51	220-24.000	II.-III.
6	4,80-6,97	47,29-74,55	4,06-4,87	8,53-22,12	2,94-7,47	24.000	II.-III.
7	2,01-2,94	19,85-28,35	199,8-315,2	8,22-81,64	2,77-27,30	2.700-24.000	-
8	10,45	94,31	6,95	12,64	4,37	24.000	II.-III.

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Water Quality Alterations of the Danube River in the Region of "Kozlodui"Nuclear Power Station

Konstantin Tzankov, Plamen Ninov, Stefka Blaskova

Abstract: On the base of the regular expeditionary investigations for the period 1989-1999 is assessed the influence of the cooling water of the Nuclear Power Station "Kozlodui" (km 686.6) over the temperature regime and water quality characteristics of the Danube river. The alterations of the temperature ingredient from the water of the cooling system do not change the mineral content and heavy metals concentrations in the Danube water. The content of the organic substances, biogenic elements and dissolved oxygen is changed insignificantly. The thermal pollution from the warm water channel of the Nuclear Power Station is spread no more than 200 m across and about 12 km along the river.

Key words: water quality, nuclear power station, pollution

Anderung der Qualität der Donau Gewässer im Bezirk vom AEW Kozlodui

Zuzammenfassung: Auf Grund von Expeditionsforschungen für die Period 1989-1999 ist die Einwirkung der Abkühlgewässer vom AEW Kozlodui auf dasTemperaturregime und die Charakteristik der Zuzammensetzung der Donau Gewässer abgechnet worden. Die Anderung des Temperaturingradients der Gewässer des warmen Kanals führt nicht zur Anderung des Mineralinhalts der Fluβgewässer und der Konzentration von Schwermetallen. Der Inhalt von organischen Stoffen und Biogenelemente unterliegt einer schwachen Abweichung. Die thermische Verschmutzung des warmen AEW Kozlodui Kanals bis 200 m in Querrichtung und bis 12 km längsm des Flusses begrenzt.

Schlüsselworte: die Wassergüte, das Atomkraftwerk, die Verschmutzunng

1 Intrudaction

The assessment of the Nuclear Power Station (NPS) "Kozlodui" impact on the surface water in the adjacent region is mainly connected with the major recipient and source for industrial water supply - the Danube river. This impact concerns the "cold" and "hot" channels - part of the technological cycle of the NPS "Kozlodui" which links the Station directly with the Danube river (Fig.1.). Because of the big volume of used cooling water taken from the river with a big water discharge as the Danube any comparisons to other Bulgarian tributaries are impossible.

The natural conditions in the investigated region could not influence significantly over the quantitative and qualitative characteristics of the Danube water. It is necessary to recall the well-known fact that the Danube forms its qualitative and quantitative discharge mainly above the Bulgarian part.

The National Institute of Meteorology and Hydrology has a full hydrochemical information obtained from regular expeditions in the Kozlodui region at the profiles: town Kozlodui (km 703.5), before the inflow of the Jiul river (km 691.6), before the "hot" channel (km 687.0), after the "hot" channel (km 686.0) and after the inflow of the Ogosta river (km 682.0). Simultaneously additional information concerning water quality is collected for the "hot" channel of NPS "Kozlodui" and the biggest Bulgarian tributary in the region – Ogosta river. Especially for the present investigation an expedition with a ship "Hidrolog" was held on 4-6 August 1999 between Kozlodui town and Ogosta river. During the expedition was gathered detailed information that enriched and actualized the existing database.

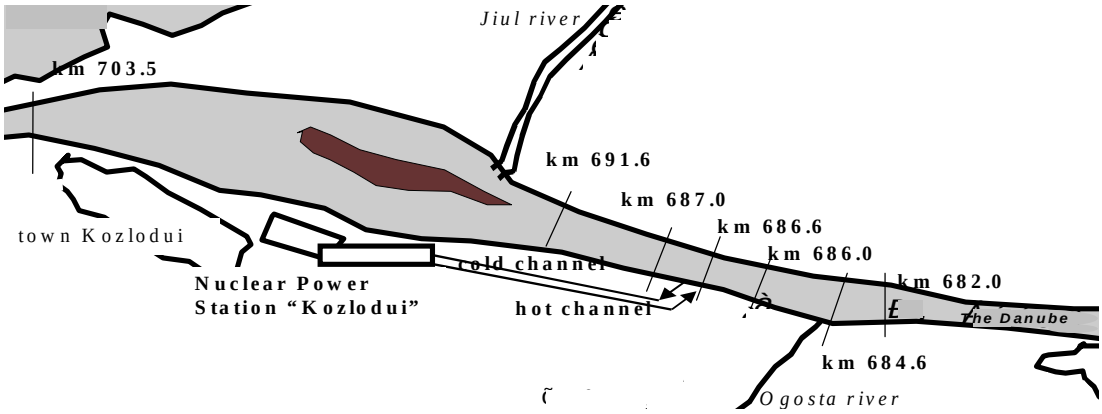

Fig. 1 Situation of the Danube in the region of the Nuclear Power Station "Kozlodui", monitoring profiles

2 Water quality characteristics of the "hot" channel (km. 686.5)

The strongest impact of the "hot" channel on the Danube river should be expected in the case of high air temperature and low water level. For the studied period 1989-1999 the expeditions were held between June and September – not always in the most unfavorable conditions. Nevertheless the water temperature in the "hot" channel changes from 26.4 ^{o}C to 35.0 ^{o}C while in the "cold" channel from 17.7 ^{o}C to 25.4 ^{o}C with a temperature differences more than 10 ^{o}C.

The oxygen content (O_2) of the "hot" channel is comparatively high and alters between 5.88 – 8.92 mg/l with an average value $O_{2average}$ = 7.35 mg/l. The organic content in the water of the "hot" channel expressed by the permanganate oxidation (Ox) is not high and changes between 4.12 – 10.08 mg/l with a average value Ox $_{average}$ = 5.46 mg/l. However there are significant deviations of the maximum and minimum measured values compare with the average values - 84.8% for the maximum and 24.5% for the minimum value. Very weak, almost insignificant are the alterations of the organic content at the inflow of the "hot" channel compare to the organic content in the "cold" channel - Ox = 4.81 mg/l.

The mineral content (Σi) on the way "cold" channel – Nuclear Power Station – "hot" channel – the Danube - remains unchangeable: Σi $_{average}$ entrance = 432.21 mg/l, Σi $_{average}$ inflow = 425.69 mg/l. Considering the biogenic elements content the same conclusion could be done. The nitrate ions $NO_{3average}$ remain absolutely constant – 0.78 mg/l. Very small alterations are registered for nitrite ions (from $NO_{2\ average}$ =0.26 mg/l in the "cold" channel to $NO_{2\ average}$ = 0.28 mg/l in the "hot" channel) and phosphates (from $PO_{4average}$=0.15 mg/l in the "cold" channel to $PO_{4average}$= 0.16 mg/l in the "hot" channel). Only considering the ammonium ions NH_4 bigger differences and comparatively higher values are noticed at the inflow of the "hot" channel ($NH_{4average}$=0.50 mg/l) than at the entrance of the "cold" channel ($NH_{4average}$=0.41 mg/l). This fact could not be explained without additional explorations but perhaps some small supplementary pollution exists.

The "hot" channel water contains not dangerous concentration of heavy metals. Practically there are not possibilities for some serious increase or decrease of the heavy metals content due to the cooling process. The temperature factor would not influence on the heavy metals concentrations. That is way the heavy metal concentration in the "hot" channel is the same as in the Danube river.

The presence of phenols, oil or other petroleum products in the "hot" channel has not been observed since the beginning of the monitoring.

3 Water quality characteristics of the Danube river in the region of the Nuclear Power Station "Kozlodui"

The Danube water quality characteristics in the studied region, rendering an account of the "hot" channel of the NPS "Kozlodui", will be examined in transversal as well as longitudinal direction. In longitudinal direction the water quality characteristics will be traced noting the "hot" channel influence. In transversal direction the goal is to be verified any possible water quality alterations to Romanian bank due to the NPS "Kozlodui".

3.1. Mineral content

Activities, mainly connected with the yield and treatment of inert materials, porcelain and faience industry, chemical industry etc. influence on the mineral content in the Danube water. The concentration of dissolved materials (total mineralization - Σi) in the studied section of the Danube river is comparatively low (Fig.2, 3). The average values for the observed three cross sections above the "hot" channel vary between 301.71 – 328.64 mg/l while in the "hot" channel this concentration is 325.69 mg/l. After the "hot" channel the limits of alterations are 347.24 mg/l – 357.91 mg/l. The higher values are not caused by the "hot" channel but by the water of the Bulgarian tributary Ogosta inflowing after the Nuclear Power Station with an average concentration - 404.19 mg/l**.** The mineral content in the studied section remains low and is not influenced by the "hot" channel. Average values of the total mineralization and of some ions as HCO_3, Cl, SO_4, Ca, Mg, Na and K are shown on the Figures 2 and 3.

3.2. Organic content

Additional inflow of organic compounds on the way - "cold" channel – "hot" channel – the Danube river - is not observed (Fig.2). Because of the higher temperature of the water in the "hot" channel the transformation processes of decomposition accelerate. But they are insignificant because of the lack of time. The water of the "hot" channel practically has the organic content equal to the Danube water and does not impact on it. Following the longitudinal distribution of the dissolved oxygen (O_2) along the Bulgarian bank some decrease after the inflow of the "hot" channel could be observed. That is a result of the higher temperature of the water. For example the average concentration of dissolved oxygen above the "hot" channel is $O_{2\ average}$ = 8.45 mg/l, at the inflow- $O_{2\ average}$ = 7.35 mg/l and after the inflow - $O_{2\ average}$ = 8.20 mg/l. The transversal distribution of parameters dissolved oxygen, BOD5 and permanganate oxidation above and after the "hot" channel is shown on the Figure 2.

3.3. Biogenic elements

The content of nitrate nitrogen ($N\text{-}NO_3$) in the water of the studied Danube section is low. The average values vary between 0.81 – 1.05 mg/l (Fig2). Nevertheless the concentration of nitrate nitrogen near Bulgarian bank is a little higher. However the quantity of nitrite nitrogen ($N\text{-}NO_2$) is comparatively big. The nitrite nitrogen is an interstitial product of the nitrification process. In the studied section from Kozlodui town till the Ogosta river the average values near the Bulgarian bank alter between 0.09 – 0.13 mg/l. This range of alteration is small. The distribution of the ammonium nitrogen ($N\text{-}NH_4$) in the studied section is similar as the nitrite nitrogen with average values between 0.25 – 0.59 mg/l. Surprisingly some small increase of ammonium nitrogen concentration along the Bulgarian bank because of the "hot" channel is noticed. The concentration of phosphate ions along the Bulgarian bank vary in very close limits – 0.13-0.17.mg/l. The concentration of iron ions (Fe) in the water of the studied section is low with average values between 0.15-0.20 mg/l (fig.2).

Finally, excluding some insignificant increase of the ammonium nitrogen, any other alterations of biogenic elements concentration in the Danube water because of the NPS "Kozlodui" were not found (Fig.2).

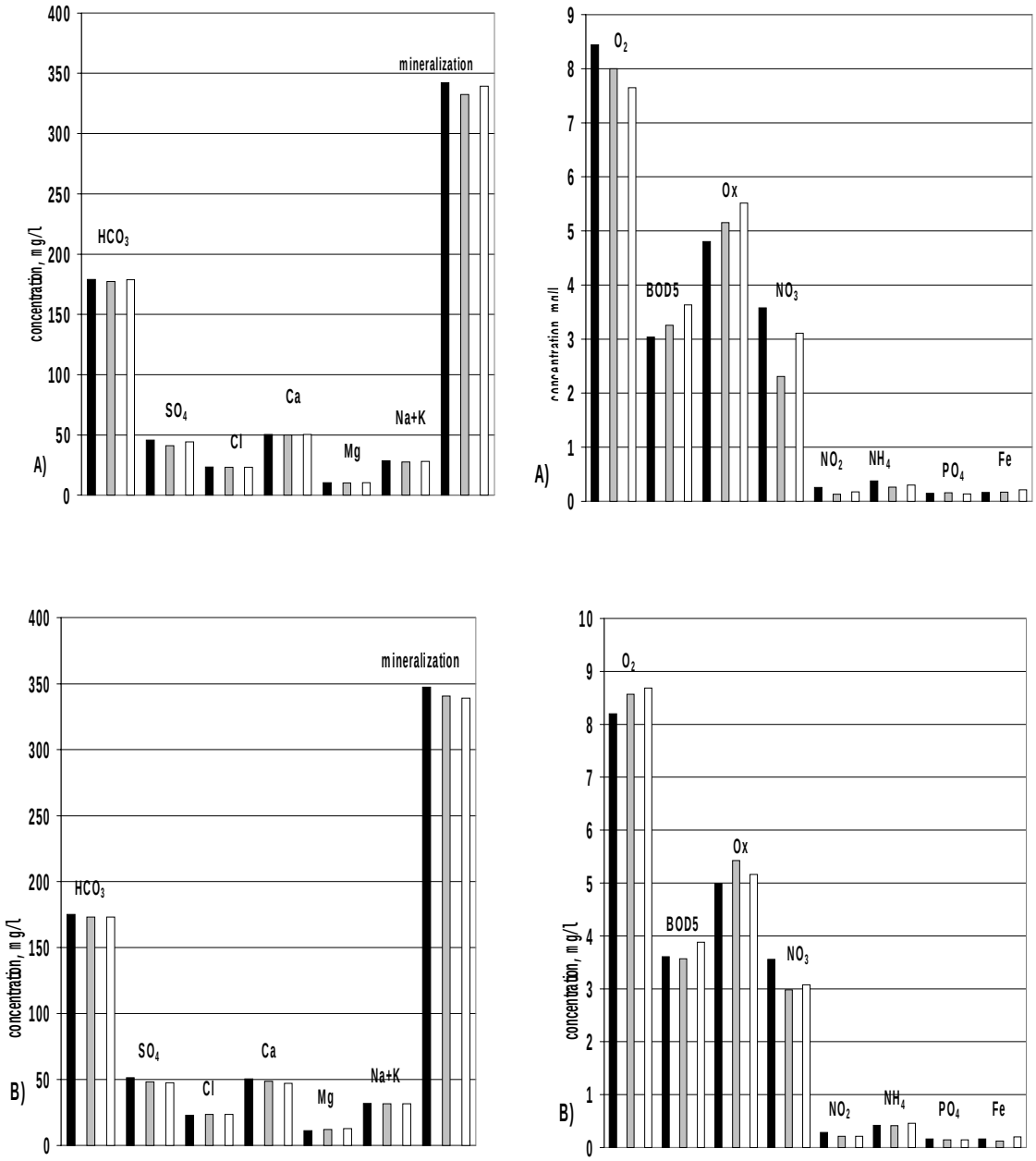

Fig. 2 Transversal distribution of water quality parameters - A) before "hot channel"; B) after "hot channel"

-Bulgarian bank, -midstream, -Romanian bank

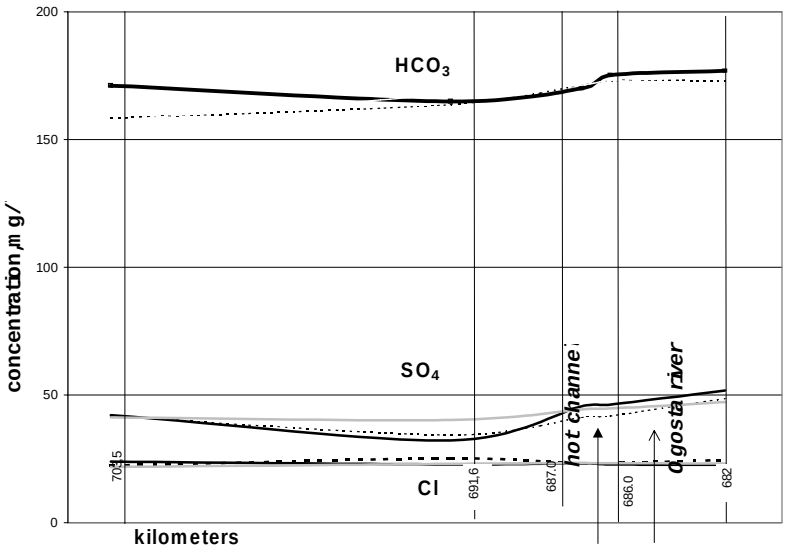

Fig. 3 Longitudinal distribution of some water quality parameters between km 703.5 (town Kozlodui) and km 680.0

—— -Bulgarian bank, ... -midstream, —— -Romanian bank

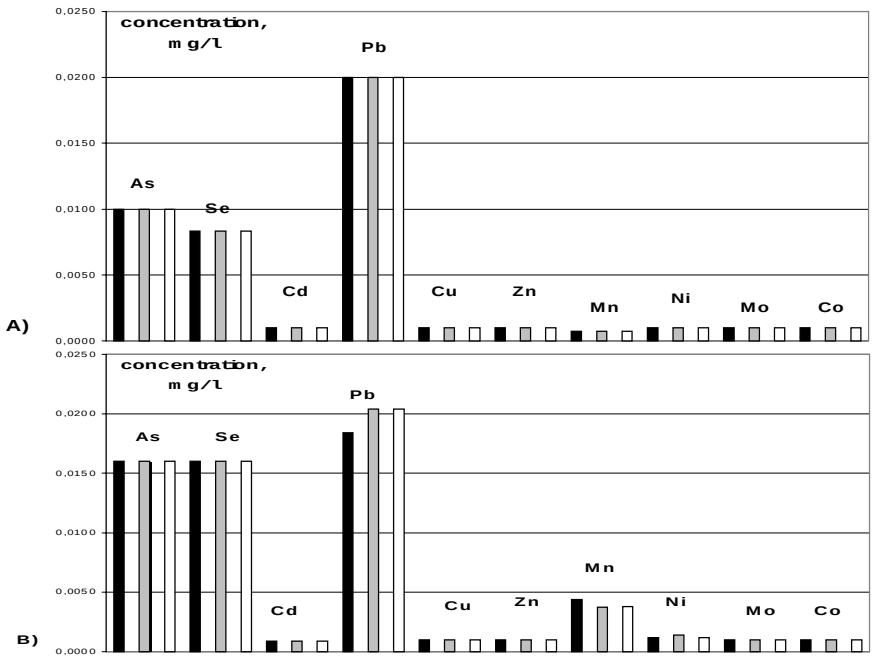

Fig. 4 Transversal distribution of water quality parameters -(heavy metals)- A) before "hot channel"; B) after "hot channel"

■ -Bulgarian bank, ▒ -midstream, □ -Romanian bank

3.4 Heavy metals pollution

The carried out investigations did not discover high concentrations of heavy metals or other toxic elements in the Danube water near the NPS “Kozlodui”. All measured concentrations of arsenic (As), cadmium (Cd), copper (Co), zinc (Zn), selenium (Se), nickel (Ni), molybdenum (Mo), lead (Pb) are in acceptable limits (according to Bulgarian legislation) without serious harmful effect over the habitat or human health (fig.4).

3.5 Temperature regime

The results of the last expedition (4-6.08.1999) show that the Danube water temperature was about 23.5^{o}C while in the “hot” channel. The temperature was 34.5^{o}C. In this case the influence of the higher temperature is located only 200 m from the Bulgarian bank and 12 km down the river (Table 1).

Table 1 Measured temperatures in the Danube water near the Nuclear Power Station “Kozlodui” – 4 August 1999

number	kilometers	L	hour	Water temperature	number	kilometers	L	hour	Water temperature
	km	m		^{o}C		km	m		^{o}C
1	687,3	BB	12,15	23,5	15		100	13,32	26,5
2		50	12,20	23,5	16		150	13,37	26,0
3		100	12,25	23,3	17		200	13,40	26,0
4		250	12,30	23,5	18	685,5	BB	14,00	26,5
hc			14,37	34,5	19		50	14,06	26,5
4	686,6	BB	12,46	25,0	20		100	14,10	25,0
5		50	12,49	24,0	21	685,0	BB	14,20	26,5
6		100	12,54	23,2	22		50	14,25	26,0
7		150	13,08	23,1	23		100	14,31	26,0
8	686,4	BB	13,45	29,0	24		150	14,36	25,5
9		50	13,48	27,0	25		200	14,42	25,2
10		100	13,50	25,8	26	682,0	BB	15,15	24,1
11		150	13,52	25,0	27		50	15,18	23,8
12		200	13,56	25,0	28		100	15,25	23,6
13	686,0	BB	13,25	28,0	29		200	15,35	23,6
14		50	13,28	26,5	30		250	15.47	23.5

Remarks: kilometers – distance from the delta of the Danube river (km);
L – distance from the Bulgarian bank (m);
hour – time of measurement;
BB – Bulgarian bank;
hc – “hot” channel

3.6 Special parameters

The active reaction pH is neutral, stable and varies in very close limits – pH = 7.32-7.40.

Principally the Danube water is hard water in the Bulgarian part of the river. The total hardness (H) depends on the natural factors. In the studied region the average values near the Bulgarian bank alter between 9.33-10.43 ^{o}H. It is important to emphasis that the hard water is not very suitable for cooling processes because of the fur accumulation.

The presence of phenols in the Danube water near the NPS “Kozlodui” has not been observed since the beginning of the monitoring.

The presence of oil and petroleum products could be registered only in the case of damages and breakdowns – as during the war in Yugoslavia in 1999. The oil pollution is dangerous for NPS

“Kozlodui” that is way since 1992 special fences have been built against petroleum products and floating objects.

The suspended matter content in the Danube water near the NPS “Kozlodui” varies between 8-20 mg/l as well as in the “cold” and “hot” channels from the NPS “Kozlodui” cooling system. This content is not dangerous. Usually Bulgarians rivers have bigger suspended matter content. For example the Ogosta tributary inflowing several kilometers down the Nuclear Power Station “Kozlodui” has average suspended matter content – 0.35 mg/l.

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Chemistry of Groundwater in Eastern Slavonia: Sava River Catchment – Croatia

Tatjana Vlahović and Andrea Bačani

Abstract: Groundwater chemistry of Quaternary aquifers has been studied in main water-well fields of Eastern Slavonia, Croatia. These alluvial sediments were deposited in the shallow lakes and swamps during the Middle and Upper Pleistocene. The reductive conditions of sedimentation prevailed. The groundwater composition shows the spatial and the temporal variations of basic cations and anions and of the concentrations of groundwater constituents (iron, manganese, arsenic, ammonia).

Key words: groundwater chemistry, Quaternary aquifer, Sava river catchment

Grundwasserchemie von Ost - Slavonien: Einzugsgebiet von Sava-Fluβ, Kroatien

Zusammenfassung: Die Grundwasserchemie von quartären Aquifer wurde an den grösseren Grundwasserförderungsgebieten in Ost - Slavonien in Kroatien analysiert. Die alluviale Aquifer wurden in dem seichten See und in den Sümpfen während der Mittel- und Oberpleistozän abgelagert. Die Sedimentation wurde durch reduzierenden Bedingungen karakterisiert. Die chemische Zusammensetzung des Grundwassers ist sowohl durch die zeitlichen und örtlichen Veränderungen der Hauptionen als auch durch die Konzentrationsschwankungen von Fe, Mn, As und NH_3 gekennzeichnet.

Schlüsselworte: Grundwasserchemie, quartären Aquifer, Einzugsgebiet von Sava-Fluβ

1 Introduction

Eastern Slavonia region, in Croatia comprises two drainage areas, the Drava river catchment in the north and the Sava river catchment in the south. The area under research is the Sava drainage basin. The southern boundary is the Sava River, the western boundary constitute the hillslope of the Mt. Dilj, the northern boundary is Đakovo-Vinkovci plateau and the position of the eastern boundary has not been clearly defined so far. The first 150 m of Quaternary deposits are saturated with fresh water which has been analysed in this study. The samples were taken on the main water – well fields Vinkovci, Đakovo, Velika Kopanica, Cerna and Županja (Fig. 1).

2 Geology and hydrogeological setting

The Sava drainage basin in Eastern Slavonia geotectonically belongs to the Slavonia-Srijem depression in the southern part of Pannonian basin. The first 150 m of the hydrogeologically interesting permeable sediments were deposited during the Middle and Upper Pleistocene. The eastern Slavonia area was then covered by shallow lakes and swamps and the neighbouring Bosnian and Slavonian mountains were land areas exposed to strong denudation. The transport and deposition of clastic material, respectfully several cycles of redeposition, was very dependent on the palaeoclimate. The most significant palaeoclimate characteristic was the alternation of the warm and humid periods with cold and very dry periods. During the warmer interglacial periods, the high waters of surface streams transported a lot of the coarse-grained clastic material and deposited it in the swamps and lakes. At the same time, the level of stagnant waters rose, so the swamps and lakes grew and covered a bigger area, until eventually they became interconnected. In contrast, the glacial periods are characterised by a draw-back of the surface streams into their river-beds, a reduction of their transport capabilities, and by the shallowing of the depositional area. The wind forces took the dominant role in the transport of sedimentary material, while silt and clay were deposited in the remaining lakes and swamps.

Each sedimentation cycle of the permeable layers starts as a rule with coarse-grained, poorly sorted particles, and ends with fine-grained uniform sands, followed by silt and clay.

The majority of the clastic material was transported in the Slavonia-Srijem depression by the rivers and streams from the Bosnian mountains and from Mt. Dilj. This is confirmed by the mineral composition of fluvial sediments which originated from the serpentine zone in Bosnia (Mutić, 1993). The main direction of transport was from the south to the north, correlates with reducing proportions of the coarse-grained clasts and grain size in the same direction (Urumović et al., 1978). In this way, in the southern part, along the Sava river, gravel was predominantly deposited, and in the northern sections sand (Miletić et al., 1986).

Apart from the palaeoclimate conditions, sedimentation was influenced by tectonic movements which are still active in eastern Slavonia.

These depositional conditions resulted in pronounced lithological heterogeneity in both the vertical and horizontal directions. Layers keep thinning out and lapping out, but it is possible to correlate the thicker layers over the whole area.

The gravel along the Sava River forms single aquifer with a thickness exceeding 100 m. The lithological composition is dominated by fine- to medium-grained gravel with 10-50 wt% of sand. This layer has the most favourable hydrogeological characteristics in the triangle between the Velika Kopanica, Gundinci and Kruševica. In this area, the gravel rarely contains more than 20 wt% of sand, and the thinner beds of finer material appear only sporadically. The more pronounced lithological inhomogeneity is found in the area between the Babina Greda and Štitar and further to the east, where the gravel contains frequent interbeds of silty sand and clay. The mentioned aquifer has a hydraulic conductivity in the range of 30 – ≥ 200 m/day, the transmissivity is between 423-7344 m^2/day, and storativity between $1{,}7\times10^{-4}$ and 8×10^{-3}.

To the north and east of the gravel aquifer, lies the a system of sand aquifers that can number from 2 to 11 in the shallowest 150 m of sediments. The thickness of individual layers rarely exceeds 30 m. Layers are mostly composed of fine- to medium-grained sand and occasionally of coarse-grained sand. The thicker layers of sand contain some gravel in their basal parts. The hydraulic conductivity of these layers is in the range of 5.5-37 m/day, the transmissivity is between 52-706 m^2/day, and storativity between $1{,}3\times10^{-4}$ - $4{,}3\times10^{-3}$.

The thickness of deposits that cover the eastern Slavonia aquifer system is between 10 and 40 m. The cover sediments are composed of silty-clayey deposits with lenses and interbeds of sand. The low-permeability sediments between the aquifers at depth are of the same lithological composition. The leakage coefficient there is in the wide range of $1{,}3\times10^{-5}$-$4{,}3\times10^{-3}$ day^{-1}.

Main water-well fields in study area are Vinkovci, Đakovo, Cerna, Županja and Velika Kopanica.

2.1 Vinkovci water-well field

The Vinkovci water-well field consists of 12 wells with pumping rate 2,5 to 18,5 l/s. The wells tap first two aquifers. The average depth of the first and the second aquifer is on 35 to 60 m, and 75 to 110 m, respectively. They consist of fine- to medium grained sands and are over- and underlain by clayey-silt aquitards.

2.2 Đakovo water-well field

The Đakovo water-well field consists of six wells pumping the water from two aquifers with total pumping rate of 50 l/s. The average depth of the first aquifer is 35 to 50 m. It consists of medium- to coarse grained sands with some gravel in its basal part. The second aquifer is made of fine- to medium grained sands and includes interlayers of silt. It is at a depth of about 75 and is about 30 m thick. The aquifers are over- and underlain by clayey-silt aquitards.

2.3 Velika Kopanica water-well field

Velika Kopanica water-well field is situated on the area of hydrologically highly favorable gravel aquifer. It has been evaluated that this waterwell field can produce 1 m^3/s with ten wells and can supply with water the whole region of Eastern Slavonia. There are two wells till now. The aquifer consists of fine- to coarse grained gravel with addition of 20 wt% of sand and the thinner beds of finer material appear only sporadically. Its tickness is over 90 m and is overlain by clayey-silt sediments of about 15 m thick.

2.4 Cerna water-well field

Cerna water-well field consists of six wells which tap first two aquifers. Anticipated water-well field yield is 120 l/s. The average depth of the first aquifer is 40 to 65 m. It consists of medium- to coarse grained sands with some gravel in its basal part. The second aquifer is made of fine grained sands and its average depth is 80 to 130 m. The aquifers are over- and underlain by clayey-silt aquitards.

2.5 Županja water-well field

Županja water-well field consists of five wells with pumping rate 20 to 25 l/s each. The wells tap aquifer on average depth 70 to 105 m. It consists of gravel to sand material and is over- and underlain by clayey-silty aquitards.

3 Groundwater composition

Groundwater composition is one of essential characteristics of aquifer which determines the suitability of water for water supply, but also reveals its origin and conditions in the aquifer. In that purpose samples were collected during pumping tests of the water-wells in Vinkovci (V-B1, V-B2, V-B6, V-B8), Đakovo (Đ-B3, Đ-B61), Velika Kopanica (VK-B1, VK-B2), Cerna (Cr-B1, Cr-B2, Cr-B3, Cr-B4, Cr-B5), and Županja (Ž-B1, ŽB-3).

Chemistry of groundwater primarily depends on the mineral composition of deposits and mineral's dissolubility. The main minerals of the Eastern Slavonia Quaternary deposits are epidote, pyroxenes, amphiboles, feldspars and micas that originate from basic and ultrabasic rocks of the serpentine zone in the south, but there are also the calcite and dolomite as well as limestone concretions which originate from carbonate rocks or are autochthonous in a sedimentary basin (Mutić, 1993). Consequently, the most common anions are HCO_3^-, than SO_4^{2-} and Cl^-. Cations are represented by Ca^{2+}, $Mg^{2+}$and Na^+. The waters of Eastern Slavonia aquifer system are of HCO_3 - CaMg - type (Fig. 2). Sporadically, these relations might vary because of the presence of some other minerals, which even in the small concentrations, change the groundwater composition. For example, the waters in water-wells VB-1, VB-8 in Vinkovci and Cr-B4, CrB-5 in Cerna are of HCO_3 - CaNa - type what can be explained by hydrolysis of Na-Ca plagioclase, feldsphatoides and clay minerals (Hem, 1985). Concerning the anions, waters of wells VK-B1 and VK-B2 in Velika Kopanica show considerable content of sulfates and chlorides, while the waters of wells Ž-B3 in Županja contain more chlorides. Increased concentrations of these anions are connected with minerals of the feldspathoid group and apatite, respectively which are common in the mineral composition of deposits but their ratio is variable.

The ground waters of Eastern Slavonia aquifer system contain increased concentrations of iron, manganese, arsenic and ammonium which are variable in space (Fig. 3, 4, 5, 6) and time (Fig. 7, 8). The increased concentrations of these constituents are result of both mineral composition of deposits and reduction conditions in sedimentary environment. Amphiboles and pyroxenes in a sandy aquifer showed distinct dissolution features which indicate that such minerals may be an important source of Fe^{2+} in groundwater (Postma & Brockenhuus - Schack, 1987), but of manganese also. The presence of these constituents is widespread in the ground waters of Quaternary deposits on the area of Pannonian basin (Drava river valley, Hungary) and their occurrences are frequently associated. They are related to formations of fluviatile, floodplain

and marshy origin. They occur at shallow to moderate depths. Bacterial processes played a great role in their formation.

The temporal variations of the iron concentrations during the pumping tests in Đakovo (Fig. 7) and Velika Kopanica (Fig. 8) were recorded. That can be explained with the spreading of cone of depression and withdrawal the water from different part of the aquifer which is of variable mineral composition and was deposited in the changeable conditions of the sedimentary basin. The temporal variations of the iron concentrations in Đakovo are small because of the small pumping rate.

4 Conclusions

From the analyses of groundwater chemistry and depositional environment of Eastern Slavonia aquifer system as well as it's mineral composition, the following conclusions are drawn:

1. The ground waters of Eastern Slavonia aquifer system are predominantly of HCO_3 - CaMg type, but there are also HCO_3 – CaNa, HCO_3Cl CaMg and HCO_3SO_4 – CaMg types of water.
2. The ground waters of Eastern Slavonia aquifer system contain increased concentrations of iron, manganese, arsenic and ammonium.
3. The chemical composition of ground waters shows spatial and temporal variations.
4. This chemical composition of ground waters is primarily the result of mineral composition of deposits and reductive conditions in sedimentary basin. Deposits predominantly originate from basic and ultrabasic rocks of the serpentine zone in the Bosnia, but also from carbonate rocks.

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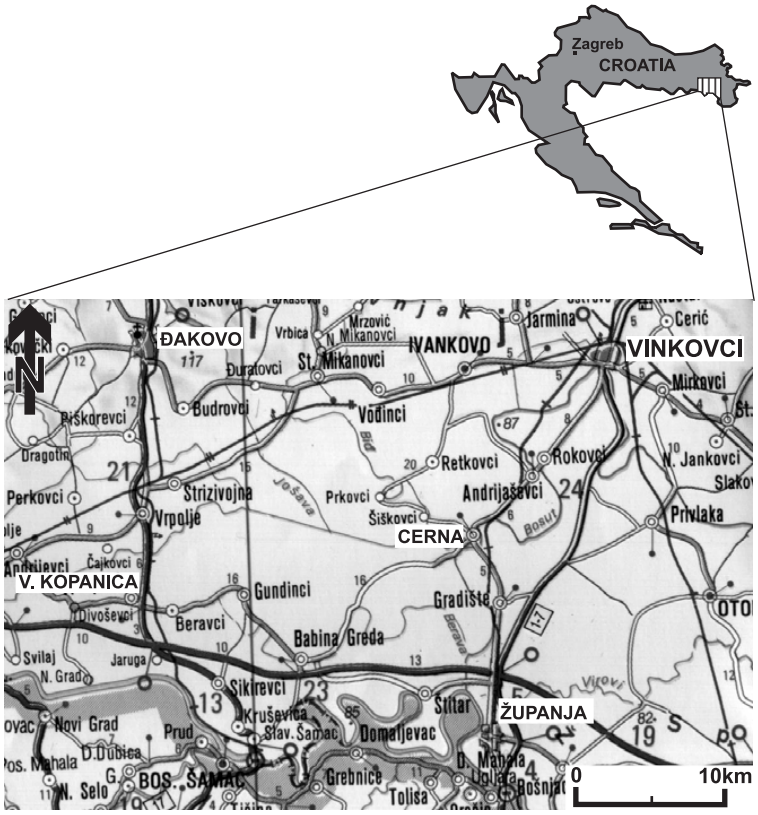


Fig. 1 Location map of the Water - Well Fields

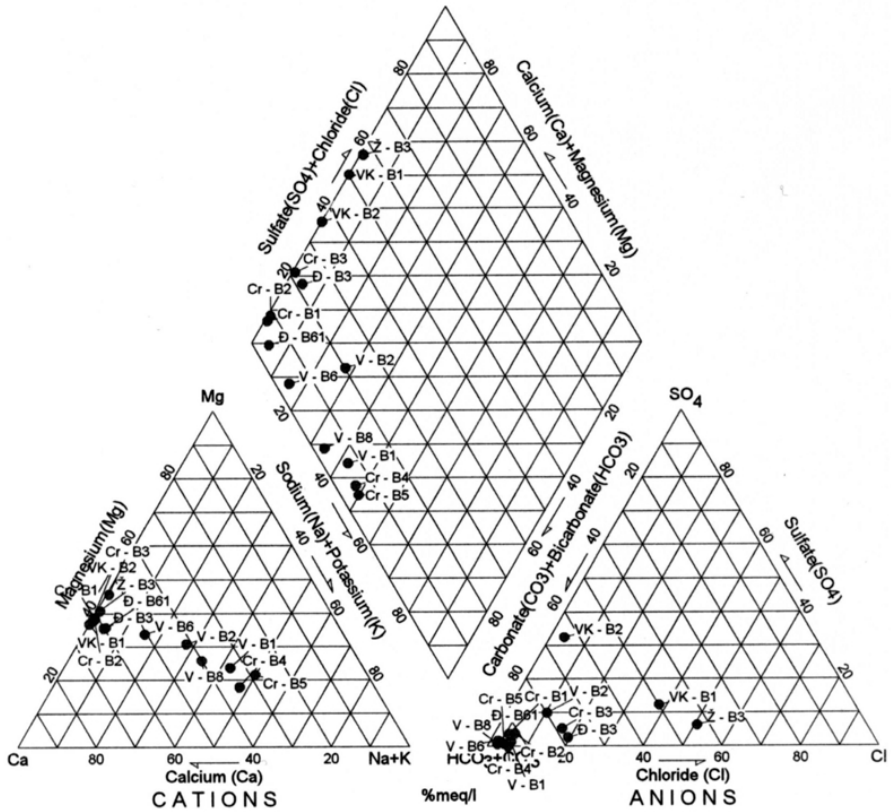


Fig. 2 Piper diagram of hydrochemical data in the sava river catchment

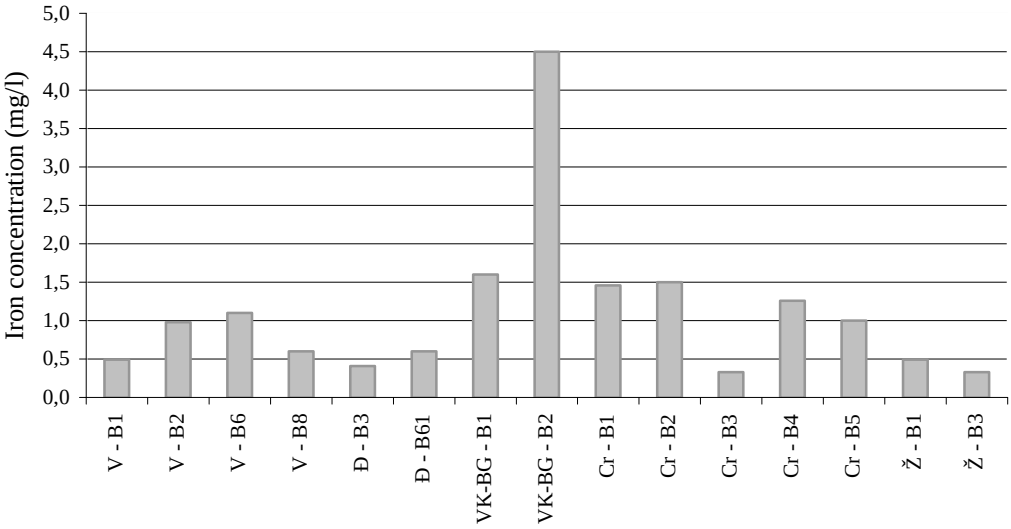


Fig. 3 Spatial variations of iron concentration on the area of Eastern Slavonia

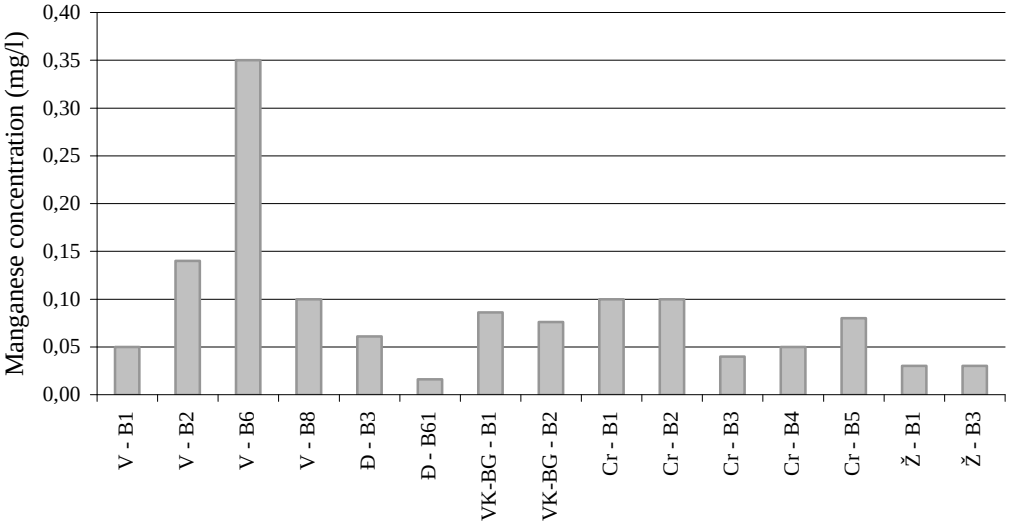


Fig. 4 Spatial variations of manganese concentration on the area of Eastern Slavonia

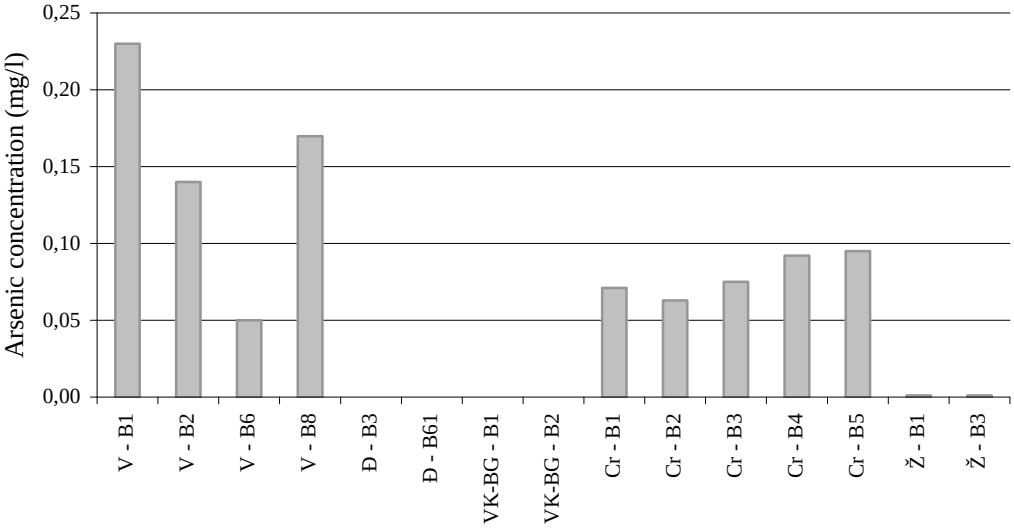


Fig. 5 Spatial variations of arsenic concentration on the area of Eastern Slavonia

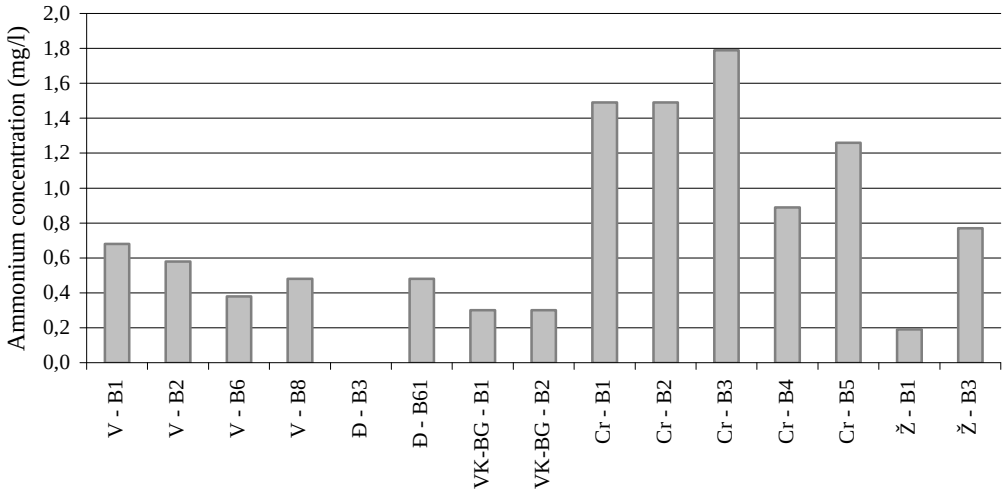


Fig. 6 Spatial variations of ammonium concentration on the area of Eastern Slavonia

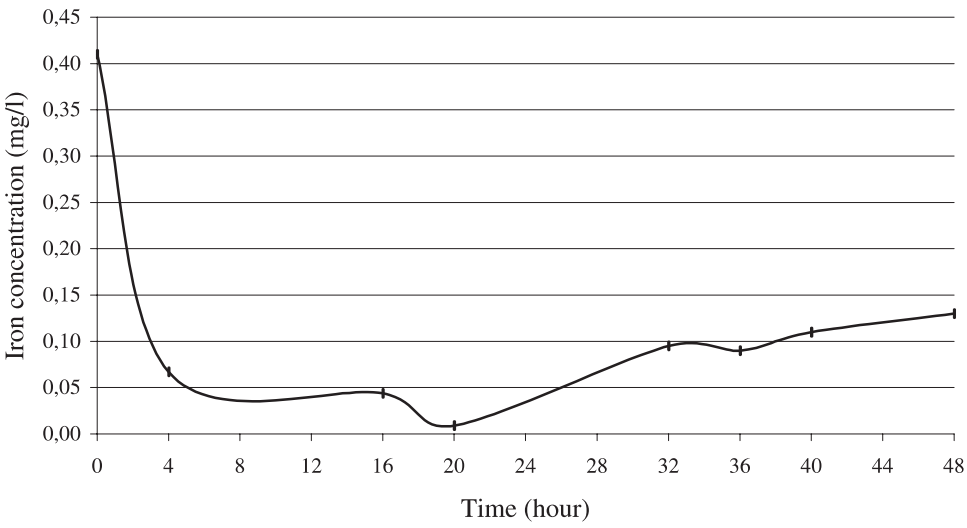


Fig. 7 Temporal variations of iron concentration in the groundwater of the water – well field Đakovo (Đ-B3)

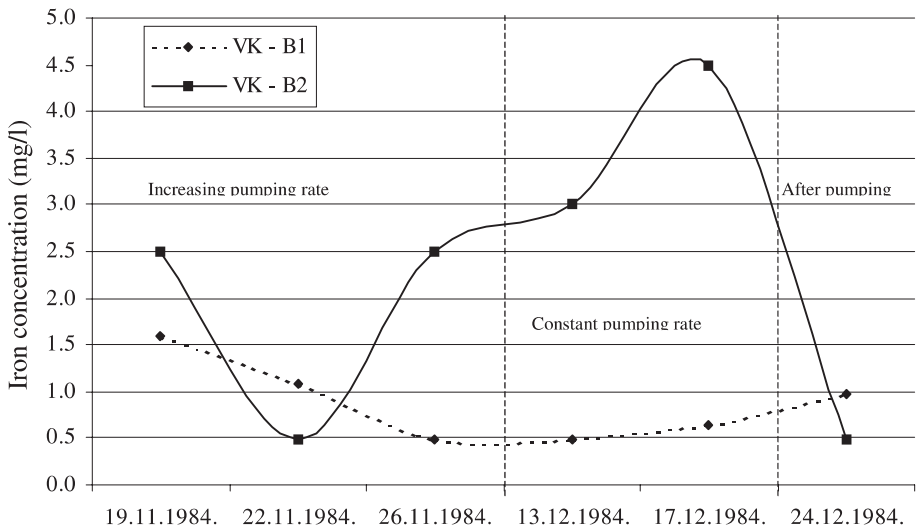


Fig. 8 Temporal variations of iron concentration in the groundwater of the water – well field Velika Kopanica

Miteinander arbeiten, voneinander lernen – Erfahrungen einer Donaubefahrung

Birgit Wolf

Zusammenfassung: Im Frühjahr 1998 fand auf dem Donauabschnitt von Deutschland bis Ungarn eine internationale Donaubefahrung zur Erstellung eines Gütelängsschnittes statt. Ziele und Durchführung der Messfahrt wurden von Anrainerstaaten, Eigentümer und Besatzung des Messschiffes einvernehmlich festgelegt, gemeinschaftlich erfolgte die Auswertung der Ergebnisse. Es konnte nicht nur eine qualitativ wertvolle Datenbasis erzielt, sondern auch eine vertrauensvolle Atmosphäre zwischen den Partnern geschaffen werden.

Schlüsselworte: Donaubefahrung, Gütelängsschnitt, Zusammenarbeit, Partnerschaft

Learning from Each Other by Cooperation – Experiences from a Joint Danube Survey

Abstract: For getting a water quality profile of the River Danube an international survey took place in spring of the year 1998. Danubian countries, the owner and the crew of the vessel agreed on targets and realisation of the trip and interpreted the results in a mutual way. Not only valuable data was archieved but also an atmosphere of common trust was borne.

Key words: Joint Danube Survey, Water Quality Profile, Cooperation, Partnership

1 Das Projekt

Die Donau ändert auf dem Weg zum Schwarzen Meer mehrfach ihr Gesicht. Ihre Beschaffenheit wandelt sich mit den durchflossenen Naturräumen, an den Mündungen der großen Nebenflüsse, durch die Einleitungen von Abwasser aus Siedlungen, Industrie und Landwirtschaft und durch Aufstau und Ausbau für Energiegewinnung und Schifffahrt. Der Frage wie sich der Charakter der Donau auf der rund 1500km langen Fliesstrecke in Deutschland bis Ungarn verändert, konnte bei einer Flussbefahrung im Mai 1998 mit dem Mess- und Laborschiff MS BURGUND nachgegangen werden. Diese Donaubereisung begann am Rhein und war Teil eines größeren Projektes, bei dem auch Main und Main-Donau-Kanal untersucht wurden. An der Aktion waren für Gewässerbeschaffenheit zuständige Behörden aus Deutschland, Österreich, der Slowakei und Ungarn beteiligt. Als wichtige Eckpfeiler für das Gelingen der Unternehmung waren vereinbart worden: ein möglichst alle Kompartimente umfassender Längsschnitt, Probenahme und Analytik aus einer Hand, gemeinsame Auswertung und Interpretation der Befunde. Anfang des Jahres 2000 war das Projekt erfolgreich abgeschlossen, die beteiligten Staaten konnten zwei Broschüren (einen Text- und einen Datenband) vorstellen, die ein informatives Bild des Zustandes der Donau zum Zeitpunkt der Befahrung zeichnen. Aus der zweijährigen intensiven Zusammenarbeit war ein vertrauensvolles Verhältnis zwischen den beteiligten Behörden entstanden, eine gute Grundlage für weitere Projekte im Gewässerschutz.

2 Die Planung

Für die erfolgreiche Durchführung der geplanten Meßfahrt war ein detailliertes Konzept erforderlich. Zu lösen waren Fragen zu Probennahmestellen, Untersuchungsumfang, Analytik und Logistik. Im Rahmen mehrerer Vorbesprechungen erarbeiteten Experten aus den beteiligten Staaten und Ländern gemeinsam eine Strategie zu diesen Themen. Von Anfang an wurden aber auch die nautische Besatzung und das Fachpersonal des Mess- und Laborschiffs MS Burgund eingebunden.

Die Planung der Messfahrt begann mit der Aufstellung eines Untersuchungsprogramms, das mit der Festlegung von Probenahmestellen und Meßprogramm einen fixen Rahmen vorgibt. Es ist die Grundlage für den Zeitplan, bei welchem vor allem auch Fahrt-, Liege-, Schleusungs- und Beladungszeiten berücksichtigt werden müssen. Bei einem Flusslängsschnitt ist es wichtig einerseits ein festgelegtes Untersuchungsprogramm zu verfolgen, andererseits flexibel auf Besonderheiten reagieren zu können. Sowohl bei dem festgelegten Untersuchungsprogramm, vor allem aber auch bei den ergänzenden Messungen ist das Messprotokoll, in dem die Bezeichnung der Messstelle, Flusskilometer und Besonderheiten verbindlich festgehalten werden, für die Zuordnung und Auswertung der Proben ganz entscheidend.

Chemisches Messprogramm

Wasser	Temperatur Sichttiefe, Sauerstoff, Leitfähigkeit, Trübung, pH-Wert, NH4-N, NO3-N, N gesamt, o-PO4-P, SiO2, Chlorid, Chlorophyll, Pestizide, BTX, LHKW, Tritium
Schwebstoff	Glühverlust, TOC, N gesamt, P gesamt, Schwermetalle, organische Schadstoffe, (PCB, DDT, HCB, PAH)
Sediment	Glühverlust, zinnorganische Verbindungen

Biologisches Messprogramm

Phytoplankton, Makrozoobenthon, Gesamtkoliforme Keime, Fäkalkoliforme Keime, Fäkalstreptokokken, Koloniezahl

Fig. 1 Untersuchungsprogramm für die Messfahrt auf der Donau

Für die Probenahme wurden bevorzugt Stellen gewählt, von denen bereits Untersuchungen vorlagen, zu welchen die Ergebnisse der Messfahrt in Beziehung gesetzt werden konnten. Von besonderem Interesse waren dabei Stellen an den Mündungen großer Nebenflüsse und im Einflussbereich größerer Einleitungen. Insgesamt wurden rund 30 Messstellen festgelegt, dies entspricht etwa einer Dichte von einer Messstelle pro 50 km Fließstrecke. Das Messprogramm umfasste die üblichen chemischen Messgrößen wie Wassertemperatur, pH-Wert, Leitfähigkeit, Sauerstoff und Nährstoffe, dazu eine Reihe von Pflanzenschutzmitteln, für die Schwebstoffphase Schwermetalle und ausgewählte organische Schadstoffe wie DDT, PCB und PAH, für das Sediment zinnorganische Verbindungen. Im biotischen Bereich wurden Phytoplankton, Makrozoobenthos und koliforme Keime bestimmt. Auch Radioaktivitätsmessungen waren Teil des Programms. Diese Fülle von Untersuchungen konnte nicht mehr an Bord allein erfolgen. Ergänzend sollten daher Proben in vorher gemeinsam ausgewählte Labors an Land gebracht werden. Es wurde vereinbart, daß jeweils ein bestimmtes Labor eine Parametergruppe für die ganze Messfahrt übernimmt, so daß homogene, vergleichbare Datensätze produziert werden. Zur Qualitätsssicherung sollte an einigen Messstellen doppelt analysiert werden. Diese Vorgehensweise erforderte eine sorgfältig geplante Logistik.

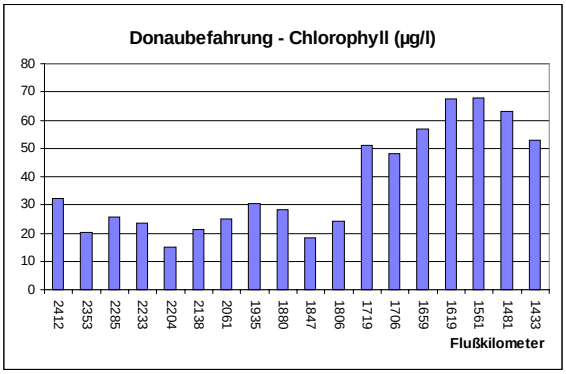
3 Die Durchführung

Da das Schiff von seinem Eigentümer, dem Bundesland Rheinland Pfalz, im Routinebetrieb auf den Flüssen Rhein, Mosel und Saar eingesetzt ist, hat die Besatzung bereits langjährige

Erfahrungen für eine standardisierte und problembezogene Probenahme, Vorbehandlung, Lagerung und Analytik der Proben an Bord und konnte diese Aufgaben auch bei der Donaubefahrung übernehmen. Das Schiffspersonal wurde jeweils verstärkt durch Experten der durchfahrenen Donaustaaten. Mit deren Sachverstand und durch die automatische Registrierung einiger Grundmessgrößen mit Hilfe einer Messstation an Bord des Schiffes ließen sich Belastungen des Wassers unmittelbar aufspüren und eingrenzen. Dieses Konzept garantierte sowohl gleichbleibende, reproduzierbare Arbeitsabläufe als auch eine Berücksichtigung lokaler Besonderheiten. Die Experten vor Ort stiegen vor ihrem Einsatzgebiet zu und wurden von Besatzung und Vorgängern eingewiesen. Die Arbeit konnte so kontinuierlich fortgesetzt werden. Eine Reihe chemischer Messgrößen wurde bereits an Bord des Schiffes analysiert. Auch im Bereich der Biologie konnten nach einer Vorbestimmung von Plankton und Makrozoobenthos erste Ergebnisse bereits am Schiff diskutiert werden. Diese Aktualität der Messergebnisse förderte den gegenseitigen Austausch und ermöglichte eine gezielte Pressearbeit, für eine fundierte Aussage war jedoch eine gründliche Analyse und Interpretation der Befunde an Land unerlässlich. Eine enge Zusammenarbeit zwischen Labors und Schiffsbesatzung war hierzu notwendig. Probengefäße für die gesamte Messfahrt mussten vorbereitet und nach der Befüllung entweder gelagert oder abtransportiert werden. Zur Interpretation der Daten wurden die Untersuchungsergebnisse der verschiedenen Labors zunächst zwischen allen Beteiligten ausgetauscht und dann in mehreren Besprechungen gemeinsam ausgewertet.

4 Ausgewählte Ergebnisse

Die Messfahrt zeigte: die Donau zwischen Kelheim/Deutschland und Mohacs/Ungarn weist in Wasser, Schwebstoff und Sediment verhältnismäßig niedrige Gehalte an Schadstoffen auf. Der Chemische Index, ein in der Bayerischen Wasserwirtschaftsverwaltung eingeführtes Maß für die allgemeine Wassergüte, deutet auf eine gute bis sehr gute Wasserqualität hin. Die Verhältnisse während der Messfahrt waren durch überwiegend trockene, warme Witterung und stabile Abflüsse geprägt. Bei diesen Bedingungen konnte sich das Phytoplankton gut entwickeln. In diesem Zusammenhang ist vor allem der Anteil des organischen Stickstoffs am Gesamtstickstoff interessant. Dieser Anteil stieg unterhalb des Donauknies bei Esztergom von rund 20% auf bis zu 60% an der ungarischen Südgrenze an. Auch der TOC stieg im genannten Abschnitt deutlich. Inwieweit diese Werte typisch und eventuell durch die Phytoplanktonentwicklung bedingt sind, müsste in nachfolgenden Untersuchungen geklärt werden. Festgestellt wurde, dass sich auch die Zusammensetzung des Phytoplanktons im Längsverlauf der Donau veränderte. Dominierten zunächst die Kieselalgen, waren unterhalb Bratislava auch die Grünlagen maßgeblich vertreten.



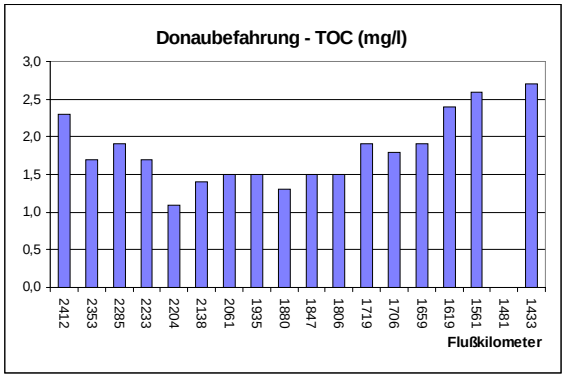


Fig. 2 Chlorophyll (in µg/l) und TOC (in mg/l) im Verlauf der Messfahrt

Weiterhin interessant war die Untersuchung auf Pflanzenschutzmittel: abhängig von landwirtschaftlichen Kulturen, Anwendungsbeschränkungen und Vermarktungspraxis konnten

hier auf einzelnen Gewässerabschnitten ganz unterschiedliche Wirkstoffe identifiziert werden. Dies ist für die Auswahl der Meßgrößen bei künftigen Untersuchungen von Bedeutung.
Relativ wenig differenziert stellten sich hingegen die Belastungen der Schwebstoffe und Sedimente dar. Auf der gesamten Donaustrecke lagen diese Werte recht gleichmäßig in einem niedrigen Bereich. Lediglich auf dem kurzen Abschnitt zwischen Kelheim und Regensburg (Deutschland, Fluss-km 2410 bis 2370) war HCB überraschend deutlich erhöht. Dies wies auf eine punktförmige Einleitung hin. Der verantwortliche Einleiter wurde von den bayerischen Behörden gefunden und die Belastung abgestellt.
Im Bereich der Mikrobiologie traten im slowakischen und ungarischen Donauabschnitt erwartungsgemäß höhere Werte unterhalb der grossen Städte auf.
Zur Untersuchung des Makrozoobenthos konnten mit Hilfe des auf der MS Burgund installierten langen Greifarmes vom Schiff aus unterschiedlichste Habitate, auch in Strommitte, beprobt werden. So ließen sich Artenlisten vervollständigen und Betrachtungen über eine biozönotische Zoonierungen wagen.
Eine Messfahrt bietet immer nur eine Momentaufnahme des befahrenen Gewässers. Dafür können aber Veränderungen im Längsverlauf sehr genau erfasst werden. Bei der durchgeführten Bereisung konnten die Ergebnisse der Donau mit Werten für Rhein, Main und Main-Donau-Kanal verglichen werden. Hier schneidet die Donau mit ihrer reichlichen Wasserführung und überwiegend geringeren Konzentrationen an Inhaltsstoffen sehr gut ab. Die Befunde der Messfahrt können bei der Fortschreibung des Untersuchungsprogramms des seit 1996 im Donauraum implementierten Trans National Monitoring Network herangezogen werden. Auch für die von der Internationalen Kommission zum Schutz der Donau (IKSD) geplante Befahrung der gesamten Donau bis zur Mündung können die Erfahrungen mit dem Meßschiff BURGUND sehr wertvoll sein.

5 Resümee

Die Meßfahrt kann sowohl hinsichtlich der Datenausbeute als auch im Hinblick auf die internationale Zusammenarbeit als Erfolg gewertet werden. Es zeigte sich, dass es möglich ist eine solche grenzüberschreitende Aktion gemeinsam zu planen und durchzuführen, wenn alle Beteiligten ihren Beitrag zum Gelingen leisten. Hier ist besonders das Miteinander auf dem Schiff und die Verteilung der Analysenpakete auf die verschiedenen Labors ein wichtiger Faktor. Zu empfehlen wäre aber für eine ähnliche Unternehmung die Benennung eines Koordinators, der während der gesamten Messfahrt auf dem Schiff bleibt. Seine Aufgabe sollte die Führung des Messprotokolls und eines Bordtagebuches sein, in dem besondere Vorkommnisse und außergewöhnliche Situationen (Witterung, Gewässerstruktur, Verbauungen...) festgehalten werden.

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An Approach to Irrigation Planing and Management of a Maize Crop in North Bulgaria

Vesselin Alexandrov, Josef Eitzinger

Abstract: The GENERIC CERES maize model, which has been integrated into a decision-support system for agrotechnology transfer (DSSAT), was adapted to the soil and climatic conditions in North Bulgaria using meteorological, agrometeorological and biological data from 1980 to 1993 at irrigated and rainfed experimental crop variety stations. A simulation approach, based on the DSSAT and GENERIC CERES maize model, was used to determine the appropriate amounts and dates of irrigation and the choice of most efficient strategy of irrigation in North Bulgaria under current and expected climate conditions. The strategic analysis, which was carried out by the DSSAT Seasonal Analysis program, was done in respect to the value of harvest yield of maize and net return. The studied method could be used by individual farmers, researchers, governmental or private organizations to determine an irrigation strategy for particular soil and climatic conditions in North Bulgaria.

Keywords: maize, DSSAT, irrigation, climate change

Eine Methode zur Bewaesserungsplanung und zum produktionstechnischen Management von Mais im Norden Bulgariens

Zusammenfassung: Das CERES MAIZE Modell, welches im Entscheidungshilfesystem fuer agrarische Produktionstechnik (DSSAT) integriert ist, wurde fuer die klimatischen und pedologischen Bedingungen im Norden Bulgariens adaptiert. Dazu wurden wurden agrarmeteorologische, meteorologische und physiologische Daten von pflanzenbaulichen Versuchsstationen aus den Jahren 1980 bis 1993 genutzt. Durch Simulationen des DSSAT bzw. CERES Modellsystems wurde die effizienteste Bewaesserungsstrategie wie optimierte Bewaesserungsmengen und deren zeitliche Verteilung unter gegenwaertigen und zukuenftigen Klimaszenarien im Norden Bulgariens bestimmt. Die strategische Analyse beruecksichtigte die Maisertraege und deren Deckungsbeitraege und wurde mit dem "DSSAT Seasonal Analysis Program" durchgefuehrt. Die erarbeitete Methode koennte fuer Landwirte, Wissenschafter, oeffentliche und private Institutionen genutzt werden um eine Strategie zur Bewaesserungsplanung fuer die spezifische Boden- und Klimabedingungen im Norden Bulgariens zu erarbeiten.

Schluesselworte: Mais, DSSAT, Bewaesserung, Klimaaenderung

1 Introduction

Agriculture, like most business, is a decision-making enterprise. Farmers and policy makers are constantly faced with the task of matching and allocating time and resources to efforts that are likely to produce desired outcomes. Deviations from expected outcomes are often caused by random environmental variables, such as weather, over which the decision maker has little or no control. Thus chance, and therefore risk, enters the decision-making process, and farmers and policy makers are unwillingly forced to gamble with nature.

Changes in greenhouse gases and aerosols, taken together, are projected to lead to regional and global changes in temperature, precipitation and other climate variables resulting in global changes in soil moisture, and prospects for more severe extreme high-temperature events, floods and droughts in some places. Global climate change will influence on all economic sectors to some degree, but agricultural production is perhaps the most sensitive and vulnerable to climate change and fluctuations. Agroecosystems in Southern Europe would be threatened mainly by

reduced precipitation and subsequent increases in water scarcity (IPCC 1997). Although measures are being taken to reduce greenhouse gas emissions, and these measures will probably reduce the rate and magnitude of climate change, it is unlikely that greenhouse gas emissions can be reduced enough to stabilize climate; therefore, adaptation will be necessary. Adaptation to a changing climate will occur in several forms, including for example technical innovations, changes in agricultural land areas, and changes in use of irrigation.

The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Project has developed a computerized Decision Support System for Agrotechnology Transfer (DSSAT) which integrates soil, weather and crop data bases with dynamic crop simulation models (Tsuji et al., 1994). System analysis and validated crop simulation models provide an alternative method for representing the crop production problem. Using models, crop growth and development can be readily evaluated under a wide range of management and environmental conditions. Strategy evaluation of timing and amount of irrigation is one of the most obvious applications. Strategy assessments related to climate change impacts on agricultural crops and agrotechnological management (such as irrigation) are also among the most helpful applications.

2 Material and Method

Meteorological, agrometeorological and biological maize data from twelve irrigated and rainfed experimental crop variety stations in North Bulgaria with elevation below 800 m from 1980 to 1994 were used for the simulation study (Fig. 1). The greatest part of the maize production in North Bulgaria is concentrated in the areas with elevation below 800 m. The Bulgarian standard maize hybrid "Knezha 611" was planted every year of the investigation. Different soil types (e.g., typical chernozems; leached chernozem-smolnitza; grey forest, moderately loamy; leached cinnamonic forest; delluvial-meadow, sandy; alluvial, clayey-sandy; etc.) were used. The major fertilizers incorporated were nitrogen, phosphorus and potassium. The average grain yield of maize was 7080 kg/ha at the rainfed stations and 10550 kg/ha at the stations with irrigation. The maximum and minimum amounts in a given location were 14950 and 1300 kg/ha, respectively or 0 kg/ha due to drought.

Fig. 1 Distribution of the experimental crop variety stations in Bulgaria (the underlined stations are irrigated).

The 30-year baseline climate data were based in this study on the period 1961-1990, recommended by the World Meteorological Organization (WMO). Several climate change scenarios were created by changing observed data from the current climate (1961-1990) according to doubled CO_2 simulations of seven global circulation models (GCMs). The GCMs which were used are those from the Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL R-30), Canadian Climatic Centre (CCC), Oregon State University (OSU), United Kingdom Meteorological Office (UK89) and Hadley Centre (HCGG and HCGS which integrates the negative forcing effect from sulfate aerosols). The GCM outputs were provided by the US Country Studies Program.

The single levels of CO_2 ($1xCO_2$) outputs from the GCMs were compared with averaged database of observed climate. The $1xCO_2$ OSU, HCGG and HCGS outputs could be considered as the most appropriate global circulation models for monthly air temperature in Bulgaria (except April and May) among the GCMs used in the study. The $1xCO_2$ CCC and GFDL R-30 models simulate relatively well current precipitation throughout the period from November to April. According to the GCMs used in the study annual temperatures in North Bulgaria are predicted to rise between 2.9°(HCGS) and 5.8°C (UK89) under an effective doubling of CO_2 ($2xCO_2$). In general, precipitation is expected to increase during the winter and to decrease during the warm half-year (CCC, GISS, GFDL R-30, OSU). The $2xCO_2$ UK89 and HCGS models even project minor increasing only in November and July and October, respectively (Alexandrov, 1997).

DSSAT is essentially a computer software shell designed to accommodate standardized crop models. A database-management system provides user-friendly entry and editing of several types of data. Retrieval programs are designed to extract the data from the centralized database and create files for running the crop models. Output from the models can then be printed or graphically displayed and compared with observed results. A validated crop model may be used to evaluate alternative strategies for improving farm performance using computer programs especially designed for this purpose. These programs facilitate running crop models for different soil types, planting dates, planting densities, varieties, irrigation amounts, dates, strategies, fertilizing timing, depth, and type, over several seasons to determine the most promising and least risky combinations of site management (Tsuji et al., 1994).

The CERES (Crop-Environment Resource Synthesis) family of crop models is used in DSSAT to predict the performance of several grain crops. The two most tested models include maize and wheat. These models, designed to use the IBSNAT minimum data set, are daily incrementing and require daily weather data consisting of maximum and minimum air temperature, solar radiation, precipitation and eventually wind speed. They calculate crop phasic and morphological development using temperature, daylength, genetic characteristics, and vernalization where appropriate. Leaf expansion, growth, and plant population provide information for determining the amount of light intercepted, which is assumed to be proportional to biomass production. The biomass is partitioned into various growing organs in the plant using a priority system. A water and nitrogen balance submodel provides feedback that influences the development of growth processes (Ritchie et al., 1990).

The Seasonal Analysis program allows the user to perform comparisons of simulations obtained by running the DSSAT CERES model of maize with different combinations of inputs. A simulation experiment, which may be made up of many treatments and may be replicated through time using different weather years, is set up by the user, the maize model is run, and the user can then analyze the results using the seasonal program. Seasonal Analysis is useful for comparing methods of managing a crop in particular environments, such as different planting dates, varieties, fertilizer and irrigation application regimes, etc. (Tsuji et al., 1994).

3 Results and discussion

The CERES GENERIC maize model was calibrated using phenological dates and grain yield from the experimental crop variety stations in North Bulgaria during the period 1984-1990. The procedure developed by Rosenbrok (Himeblau, 1975) was applied, that is, the optimized parameters were adjusted until there was good agreement between simulated and measured values. Experimental weather and agrometeorological data from 1980-1983 and 1991-1993 at the same locations were use to conduct a validation of the model. Simulated grain yield of maize was in good agreement with the measured yield, with simulated value points lying mainly within 20 % of the measured data for every year of validation (Fig. 2).

Generally, the results obtained in this study indicate relatively satisfactory performance of the CERES GENERIC maize model in a fully specified environment. An attempt was made using the model to predict the phenological development and final grain yield of maize across the country in 1994 and 1995. The obtained results showed the difference between predicted and observed dates of physiological maturity was no more than a week. Predicted grain yield of maize was again in accord with the measured yield, with predicted data points lying in most cases within 20 % of the measured values for each treatment.

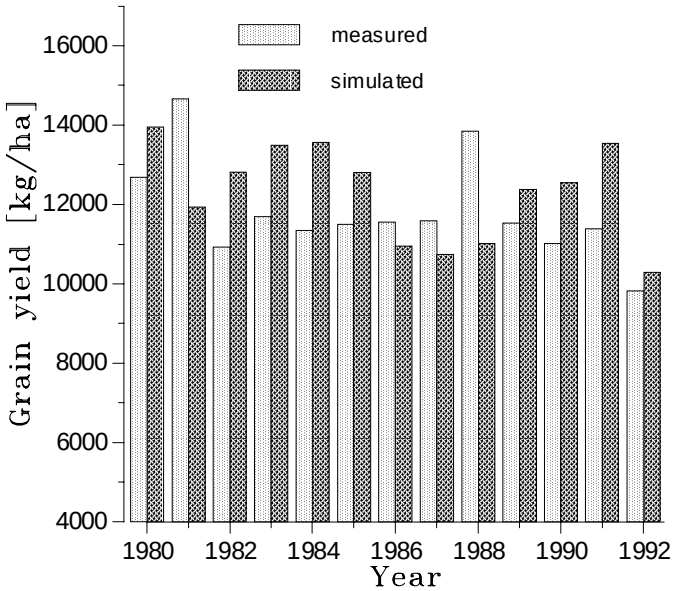

Fig. 2 Comparison between measured and simulated grain yield of maize during the periods of calibration (1984-1990) and verification (1980-1983 and 1991-1992) in Kojnare.

When the CERES GENERIC model of maize crop had been adapted for agrometeorological conditions in North Bulgaria the Seasonal Analysis program was run. Historical weather data from 1961 to 1990 were used. The major goal was to determine the most appropriate timing and water amount of irrigation applications for every experimental crop variety station under current climate during the growing season of maize. Both biophysical and economic analyses were done. The strategic analysis was done in respect to the simulated value of harvest maize yield and net return.

An example for crop variety station Kojnare is given below. The tested treatments of the irrigation numerical experiment assumed maize growth and development under rainfed conditions, different date (dates) and water amount of irrigation (Table 1).

Table 1 Description of the treatments examined in Kojnare.

Treat-Ment	Dates of irrigation	Water applied [mm]
1	rainfed	-
2	8.VIII	40
3	29.VI	40
4	29.VI, 14.VII	80
5	29.VI, 14.VII, 8.VIII	120
6	29.VI, 14.VII, 8.VIII	240

Some statistics of the simulated harvest yield of maize calculated by means of the Seasonal Analysis program are presented in Fig. 3. The box plot shown in this figure is a way of assessing visually the variability of the output variable under consideration (i.e., harvest yield of maize). For the distribution of the harvest yield of maize for each treatment selected the 0th (the lowest single short line), 25th (the lower of the short lines connected by the vertical bar), and 100th (the upper single short line) percentiles are plotted (Fig. 3). The simulated harvest yield of maize may be also plotted in mean-variance space. The calculated mean is plotted against the variance for the above output variable of interest, and the treatment numbers themselves are drawn on the graph (Fig. 3). Such graphs are another way of giving an indication of the relative variability associated which each treatment, and are useful for visualizing the tradeoffs. High variance and comparatively low mean for the rainfed treatment can be seen in Fig. 3. There is little to choose between treatments 5 and 6 in terms of their mean and variance.

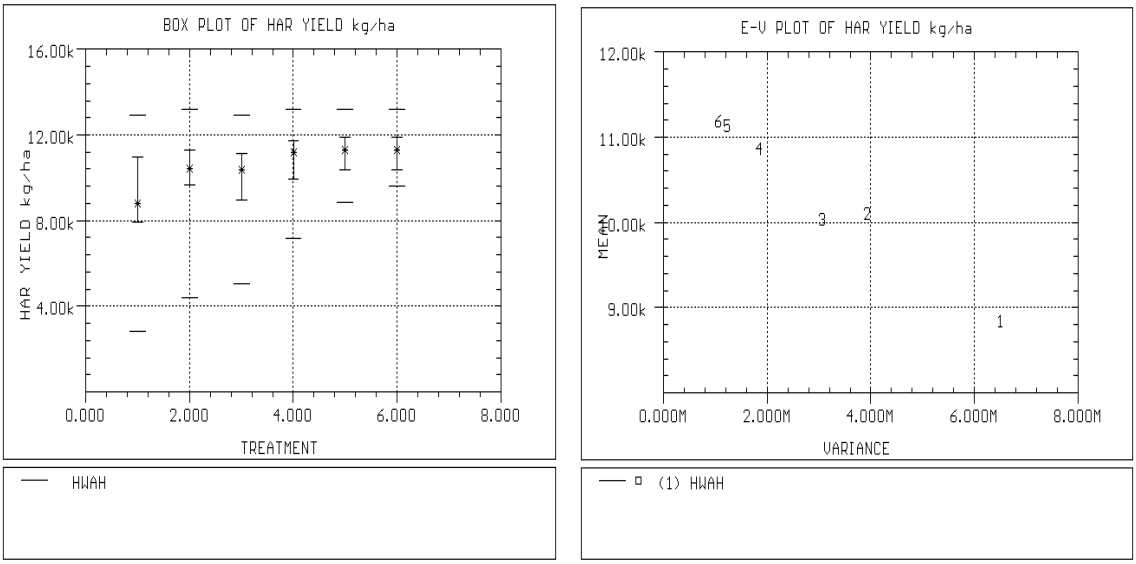

Fig. 3 Box (left) and mean-variance (right) plots of the simulated harvest yield (HWAH) of maize in Kojnare.

Visually, these box plots are sometimes clearer than cumulative probability curves if there are many treatments. When a cumulative function plot is using, output variables by treatment are plotted as cumulative functions plots (Fig. 4). Here, the output distribution for each treatment is plotted against equal increments of cumulative probability. The strategy with a cumulative probability function (CPF) to the right is considered the "best". In this case, the 6th treatment concerning 3 times of irrigation and water amount of 80 mm per application could be considered as the most appropriate irrigation strategy. The 5th treatment assuming half amount of water applied (relative to the 6th treatment) is also a good approach for high maize yield under irrigation. Naturally, when growth, development and yield formation of maize had been

simulated under rainfed conditions the calculated harvest yield was lowest and the relevant CPF was to the left (Fig. 4). Generally, using an irrigation application for a day or 2 times increased maize yield.

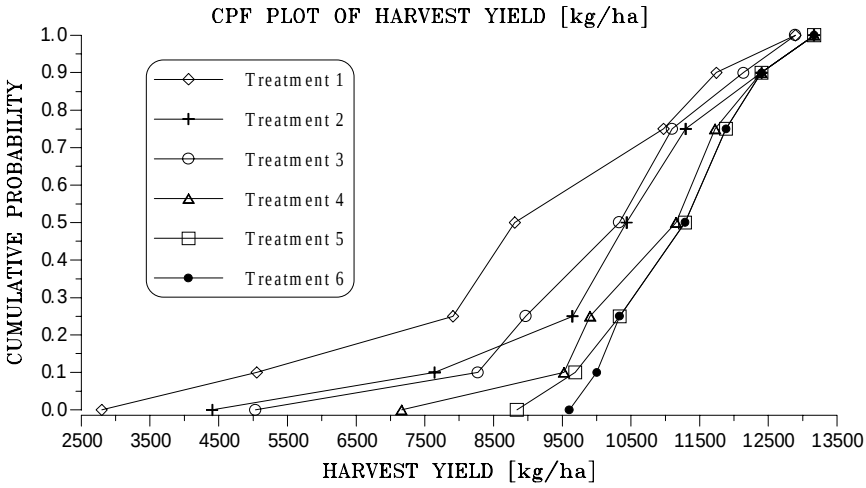

Fig. 4 Cumulative probability function plot of the simulated harvest maize yield in Kojnare.

In a similar way, the economic analysis of the Seasonal Analysis computer program calculates means, standard deviations, maxima and minima of the economic returns, and plots these as box plots, cumulative function plots, or mean-variance diagrams. Formal strategy evaluation of all treatments is carried out using mean-Gini stochastic dominance (Tsuji et al., 1994). In contrast to the biophysical analysis returns per hectare of the 6th treatment are lower than returns of the 4th and 5th treatments due to more water being applied. By running the "Strategy Analysis" option of the Seasonal Analysis program, the mean-Gini dominant treatment of the irrigated experiment can be calculated, in terms of the costs and prices used to analyze it (Table 2). Actually, the dominant treatment was the treatment 5 - 40 mm water applied per every day (total 3 days) of irrigation.

Table 2 Strategy analysis determining the dominant numerical treatment examined for Kojnare.

Treat-ment	E(x)-G(x) [money/ha]	Efficient [Yes/No]
1	906.1	No
2	1111.4	No
3	1119.2	No
4	1236.5	No
5	1265.3	Yes
6	1219.3	No

Legend: E(x) - mean return; G(x) - Gini coefficient.

The altered temperature and precipitation databases corresponding to each of the climate change scenarios were used to run the CERES GENERIC simulation model of maize. Crop management, technology, and distribution of cultivated land were assumed to be constant. All scenarios projected a shorter vegetative (sowing-silking) and reproductive (silking-full maturity) growing season of maize. These changes were driven by the temperature increases of the scenarios. Simulated grain maize yield decreases in North Bulgaria were caused primarily by warming and precipitation deficit during the growing season of this crop. Maize grain yield was more vulnerable under the CCC, GFDL and especially UK89 scenarios: yield reductions were near 30 % and 50-60 %, respectively. Under the GISS, OSU and HCGS scenarios, losses were

projected to be bellow 20 %. In comparison with the rest GCMs outputs for North Bulgaria the $2xCO_2$ GISS scenario did not have as great of a negative effect on yields. This is because the GISS model simulated increases of rainfall during the vegetative period of maize. The GISS, OSU and HCGS scenarios also had the lowest warming in this part of the year. Some changes were observed when the direct effect of increased CO_2 had been assumed in the study. In this case the reduction of maize grain yield decreased. The reason of these changed results was the influence of increased levels of CO_2 acting as a fertilizer.

The DSSAT Seasonal Analysis program was again run in order to determine the most appropriate timing and water amount of irrigation applications under the expected climate change during the growing season of maize. Both biophysical and economic analyses were done. The tested treatments of the irrigated numerical experiment were the same like these in Table 1. Some statistics of the simulated harvest yield of maize calculated by means of the Seasonal Analysis program under the $2xCO_2$ HCGS climate change scenario are presented in Table 3.

In the same way, the economic analysis of the Seasonal Analysis computer program calculated means, standard deviations, maximum and minimum of the economic returns, and plots these as box plots, cumulative function plots, or mean-variance diagrams. In contrast to the biophysical analysis returns per hectare of the 6th treatment are lower than returns of the 4th and 5th treatments due to more water being applied. These results were obtained using the relevant plots in Fig. 5 and 6. According to the Seasonal Analysis program the Gini dominant treatment was again the 5th treatment (40 mm water applied per every day of irrigation).

Table 3 Simulated harvest yield of maize in Kojnare under $2xCO_2$ HCGS climate.

Treat-ment	Mean [kg/ha]	St.Dev. [kg]	Min [kg/ha]	Max [kg/ha]
1	7107	1768	3356	9735
2	7876	1278	5059	10286
3	7967	1268	5194	10136
4	8494	943	6403	10525
5	8683	766	7081	10525
6	8794	738	7301	10525

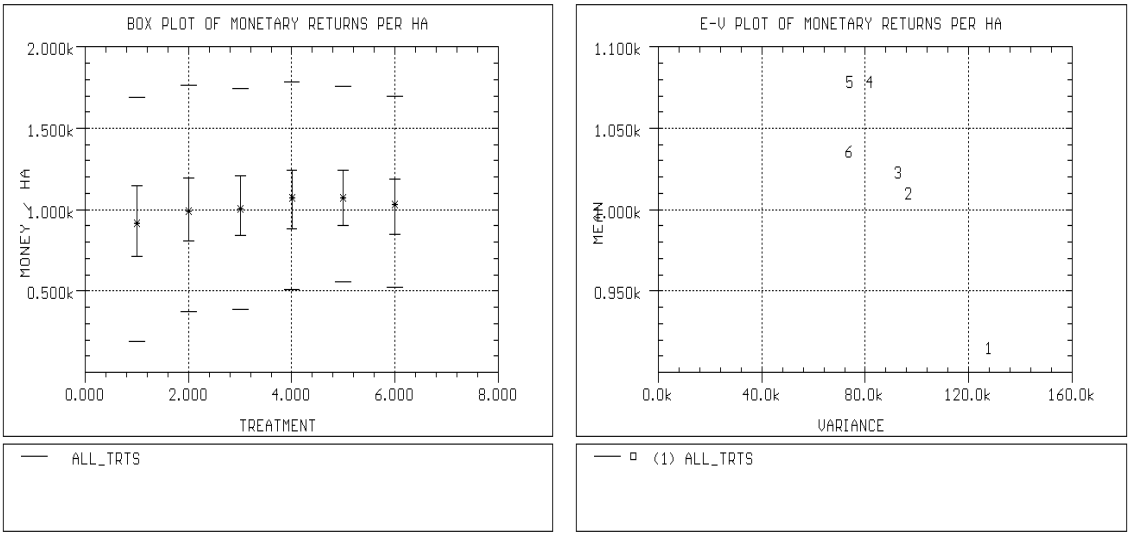

Fig. 5 Box (left) and mean-variance plot of monetary returns per hectare in Kojnare under $2xCO_2$ HCGS climate.

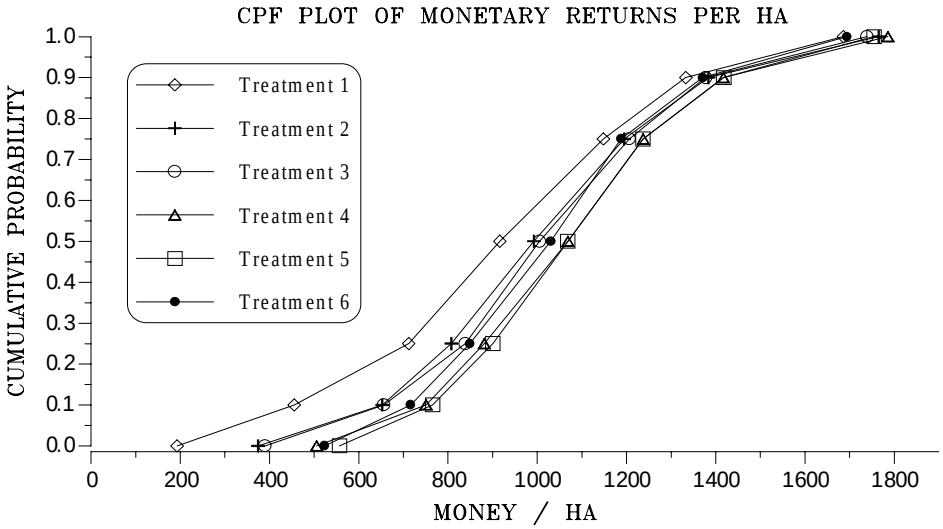

Fig. 6 Cumulative probability function plot of monetary returns per hectare in Kojnare under $2xCO_2$ HCGS climate.

4 Conclusions

The results obtained in this study indicate relatively satisfactory performance of the CERES GENERIC maize model in a fully specified environment in North Bulgaria.

The DSSAT could be used by individual farmers, governmental or private organizations to determine an irrigation strategy for particular soil and climatic conditions in North Bulgaria. The DSSAT could be also used by researchers to determine an irrigation strategy for maize crop under expected climate change in Bulgaria.

One should be careful in interpreting the DSSAT strategy evaluation outputs, as the assumptions may not always be valid. They are, however, a useful tool for helping decision-makers to "pre-screen" a wide variety of options and identifying those options or treatments that merit further investigation. Further analyses outside the confines of the DSSAT will always be required before much can be said about the feasibility of particular situation.

Acknowledgments

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Multifractal Based Determination of a PMF (Probable Maximum Flood)

Peter Bakucz

Abstract: This contribution is a review of a method based on dynamic scaling and multifractal statistics of discharge time series. The ultimate aim is to estimate the probable maximum flood (PMF) for the river Modau, Germany. The used method dealt with the multifractal properties of the discharge time series. It is demonstrated that based on the multifractal theory can be developed an useful searching method for analogous statistical time series with similar multifractal spectra as the original series.

Key words: Probable Maximum Flood, Multifractal Analysis

Ermittlung des PMF Mittels Multifraktaler Analyse

Zusammenfassung: Dieser Beitrag ist eine Zusammenfassung einer Methode**,** die auf der dynamischen Skalierung und den Multifraktalen Statistiken den Abfluss Zeitreihe basiert. Das utlimative Ziel ist die PMF (Probable Maximum Flood) für den Fluss Modau zu schätzen. Die verwendete Methode beschäftigte die Multifraktale Eigenschaften der Input Zeitreihe. Es wird demonstriert, dass mittels auf der Multifraktalen Theorie einer nützlichen Methode entwickelt werden kann.

Schlüsselworte: PMF, Multifraktale Analyse

1 Introduction

Models to forecast probable maximum flood values for natural rivers are principally based on hydrological, hydraulic and atmospheric weather interactions. They are often combined with probabilities of possible water resources system failure damages. Recently risk analysis procedures have been used to estimate both probabilities of extreme hydrologic events and related likely consequences such as incremental damages from water resources system failure (Thompson et al. 1997).

Safety studies have found that some existing water resources systems do not satisfy the latest estimates of PMF (Haimes et al. 1988). PMF is a maximum discharge value that might occur in the future. Several statistical techniques (Davis, 1991) have been used to predict probable maximum precipitation (PMP) values from extreme rainfall conditions. In possession of the maximum precipitation value it is feasible to apply a transformation receiving the PMF value. In spite of these attempts, it has not been possible to quantify PMF with great accuracy. A reason for these failures could be that the methods used are based onstandard linear statistical techniques which do not fit when the phenomenon to be analyzed is essentially non-linear.

One of the previous analysis of the non-linear characteristics of discharge time-series of natural river was developed by Krasovskaia et al. (1999) through the study of dimensionality of Scandinavian river flow regimes. The dimension found was a low and non integer value, which indicates that the flow system may be described by a nonlinear function of just a few variables. The fact that the dimension found was fractal predicts that this function, also called map in nonlinear dynamics can display chaotic behavior under certain circumstances. The existence of a low dimensional map suggests possibilities for short-term prediction through the use of a nonlinear model. This contribution will be a review and discussion of an idea behind the nonlinear statistical analysis of discharge time-series: the multifractal formalism. Due to importance of discharge time-series analysis, developing an effective approach based on these methods for characterizing probable maximum value of time series and its dynamics and understanding how time-series are formed is a challenging task. The method of characterization

the maximum discharge values would be to study what kind of correlation is associated with ist fluctuations. The Hurst exponent (H) is broadly used as a measure of the persistence of a statistical phenomenon. H<0.5 points at an antipersistent time-series.
It characterizes a system that reverses itself more frequently and covers less distance than random walk. 0.5<H<1 implies that we are analyzing a persistent time-series. This system has long memory effects: what happens now will influence the future, so there is a very deep dependence with the initial conditions. Persistent processes are common in nature. If the distribution is homogeneous there is an unique H, but if it is not there are several exponents. The most frequent exponent α will characterize the series and will play as Hurst eponent H. A very efficient method to obtain the f(α) singularity spectrum of a discharge values of natural rivers relies on the use of a tool introduced in the early eighties: the multifractal analysis (Peitgen et al. 1992, Grassberger and Procaccia, 1983). Theoretical evidence gathered during the past years indicates that the discharge time-series possess multifractal scaling properties such as high variability, intermittency and multiscaling (Turcotte 1992). These studies suggest that the multifractal scaling of discharge time-series can be valuable tool for characterization of the maximum discharge value, looking for similar time-series much higher values but the same multifractal spectrum.
To illustrate the application of this idea we will then use the data base of Modau river.

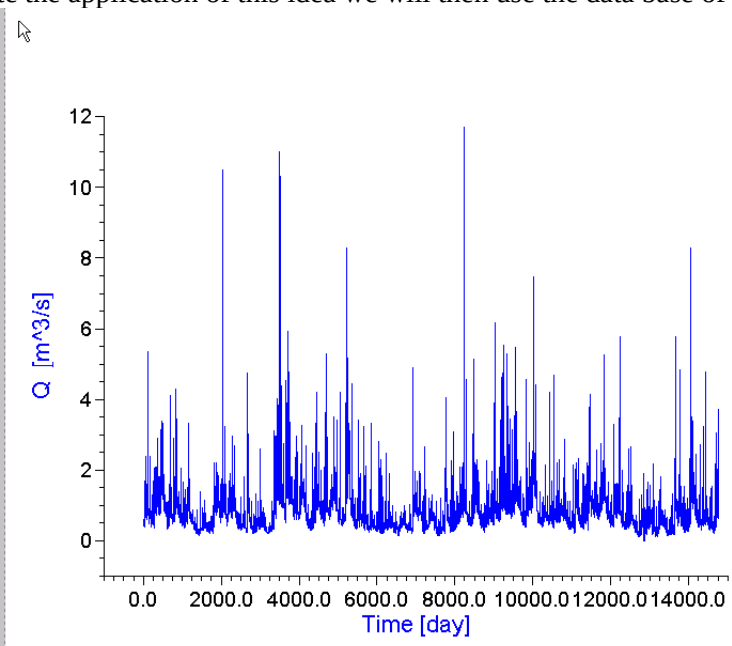

Fig.1 Discharge time series of river Modau

2 Multifractal Analysis

The dynamics of natural river discharge fluctuations can be described as a mechanical dissipative multi-body system, which is fundamentally non-linear (Turcotte 1992). The fundamental nonlinearity stems from the hydrological, hydraulic and weather interactions, and from imprecise measured discharge data-series. General non-linear parameter dependent dynamical dissipative systems very often have parameter ranges, in which the dynamics is chaotic (Raidl, 1996). Chaotic behaviour in the sense of a fully deterministic evolution of the systems in time bounded in phase space with sensitive dependence on initial conditions, might therefore be expected to occur also in natural river discharge systems. Dissipative non-linear systems typically have a long term behaviour which is described by an attractor in
phase space. Since the natural river discharge regime is unknown we cannot reconstruct the original attractor that gave rise to the observed time-series. Instead, we seek an textit{embedding space} where we

can reconstruct an attractor from the scalar data that preserves the invariant characteristic of the original attractor. The embedding dimension m of the reconstructed state space will in general be different from the unknown attractor dimension. An attractor is called strange attractor if its dimension is non-integer, i.e. fractal. Non-linear systems with chaotic behaviour often possess a strange attractor. The major characteristic of fractal objects like interfaces or time-series is their scaling property related to invariance under magnification. For uniform fractals, the scaling is uniquely described by one fractal exponent, the so-called fractal dimension. However, most fractal objects occurring in nature are nonuniform and multifractal. These objects can be more completely characterized by a spectrum of D(q) fractal exponents, where q is a real number, the so-called generalized dimension, where the fractal dimension is equal to D(0) and the function D(q) is generally referred to as a multifractal spectrum (Grassberger and Procaccia 1989). Mathematically, the general aim of the multifractal formalism is to determinate the f(α) singularity spectrum of a measure μ. It associates the Haussdorff dimension of each point with the singularity exponent α, which gives us an idea of the strength of the singularity

$$N_\alpha(\varepsilon) \approx \varepsilon^{-f(\alpha)}$$

where $N_\alpha(\varepsilon)$ is the number of boxes needed to cover the measure and ε the size of each box. A partition function Z can be defined from this spectrum:

$$Z(q,\varepsilon) = \sum_{i=1}^{N(\varepsilon)} \mu_i^q(\varepsilon) \approx \varepsilon^{\tau(q)} \text{ for } \varepsilon \to 0$$

where $\tau(q)$ is a spectrum which arouses by Legendre transforming the $f(\alpha)$ singularity spectrum. The spectrum of generalized fractal dimensions is obtained from the spectrum $\tau(q)$:

$$D_q = \frac{\tau(q)}{(q-1)}$$

The practical procedure for calculating a multifractal spectrum is carried out with q in range usually from 0 to 30. In this range the error bars of multifractal spectra of the river Modau discharge values are quite small, and therefore this range q is suitable for characterizing the river discharge time-series with multifractal exponents (Fig.2.).

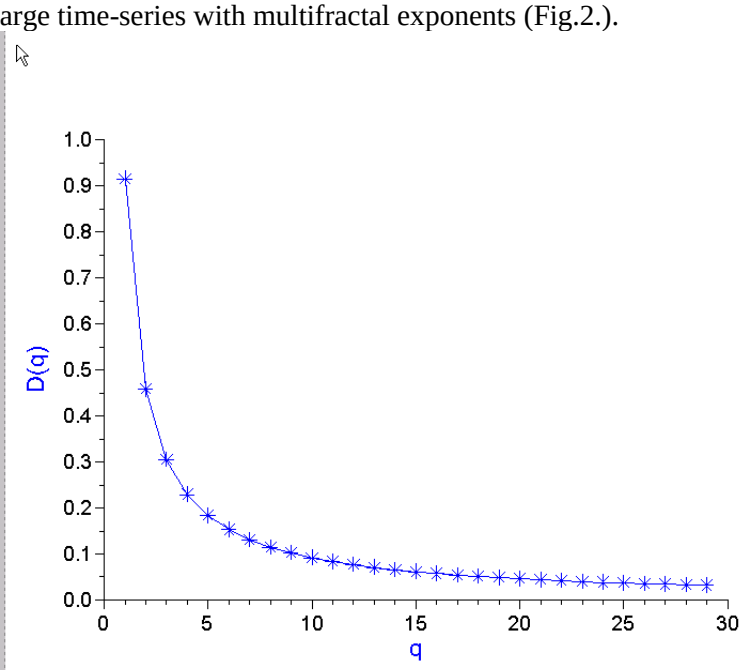

Fig.2 Multifractal spectrum of original discharge time series (Modau)

3 Results

The Modau discharge time-series is generally non-linear parameter dependent and has parameter ranges, in which the dynamics is chaotic. Chaotic behaviour, in the sense of a fully deterministic evolution of the system in time, yet erratically looking behaviour, bounded in phase space with sensitive dependence on initial conditions, might therefore be expected to occur also in discharge time-series. The multifractal behaviour is investigated by systematically changed discharge values at randomly choosed time-positions, then the maximum value can be derived looking the maximum difference between the original multifractal spectrum of Modau discharge time-series and the modified versions with help of
a powerful computer hardware.

Table 1 Modified discharge values

Discharge values		
	Time [sec]	Discharge [$\frac{m^3}{\sec}$]
Original	125	5.35
Modified	125	50
Modified	125	150
Limit	125	312.7

If the D(q) values difference between the original and the derived spectrums was greater than 1% then the computer program finished. Systematically changed the discharge values at t=125 sec, the maximum discharge value is 312.7 $\frac{m^3}{\sec}$. The computer time need to solve this question is very high. The greatest number received changing the whole database up to now is 407.1 $\frac{m^3}{\sec}$. However this results is received without parallel changing, and ithout cutting the original data series.

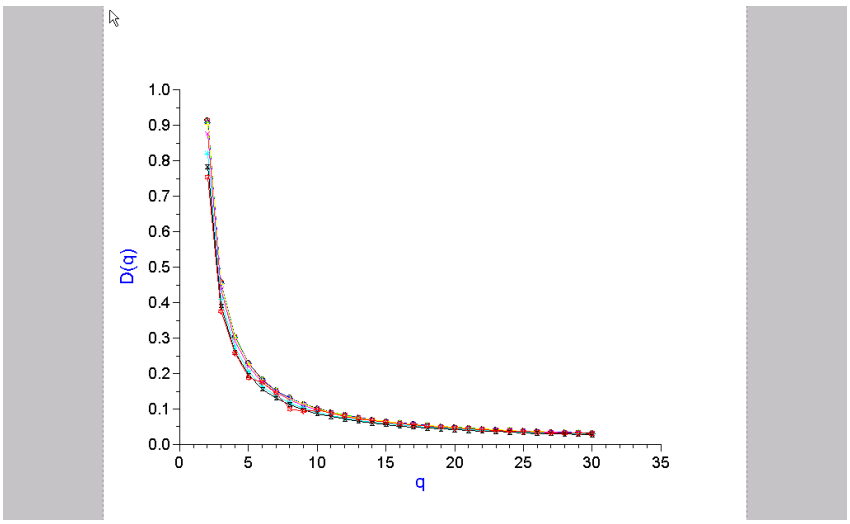

Fig.3 Multifractal spectrums of modified discharge time series

4 Summary

This contribution was a review and discussion of an idea behind the nonlinear statistical analysis of discharge time-series: the multifractal formalism. The ultimate aim was to determine the probable maximum flood PMF value for river Modau, Germany.
Probable maximum flood could be analyzed by the multifractal formalism to determine PMF value presume that the Modau discharge time-series is multifractal. This conclusion is supported by performing a multifractal analysis on Modau discharge time-series looking for the PMF value. The multifractal behaviour is investigated by systematically changed discharge values at randomly choosed time-positions, then the maximum value can be derived looking the maximum difference between the original multifractal spectrum of Modau discharge time-series and the modified versions with help of a powerful computer hardware. We have found that the probable maximum flood of discharge time-series when multifractal searching algorithms was applied is 312.7 which correspond to the original PMF value determined by dynamic scaling.

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Flash Floods, their Analysis and Frequency

(Learning of Case Studies in Northern Hungary)

Gábor Bálint, Lajos Szlávik

Summary: Under climatic conditions of the Central Danube Basin flash floods are relatively rare phenomena. The majority of floods go almost unnoticed on most of small ungauged creeks in hilly and undulating regions of Hungary. Only the extreme events causing substantial damage to slopes and valleys have been recorded to some extent. Case studies of recent years flash flood events in Central Europe (Czech Republic, Hungary, Slovakia, Rumania) are reviewed. The June 22-23, 1999 flood on Kemence creek 70 km North East of Budapest is analysed in details together with some similar events in July 1999 in the Mátra Hills. The role of slope conditions and antecedent moistening, high intensity of short period precipitation was clearly shown. Meteorological conditions of different events show some parallels, but these findings have only limited prognostic value. This fact also underlines that beside (or instead of) real time forecasting and warning wherever it is possible, proper planning and building codes, construction standards should be enforced.

Key words: flash flood, storm intensity, frequency of flash floods, building codes

Rasche Hochwässer, ihre Analyse und Häuigkeitet

(Fallstudien aus Nordungarn)

Zusammenfassung: Unter den klimatischen Bedingungen des Mittleren Karpatenbeckens gehören die raschen Hochwässer zu den seltenen Phänomena. Die meitsen Hochwässerwellen laufen in den meisten unbeachteten Kleingewässern von Ungarns Hügel- und Bergland fast unbemerkbar ab. Allein die mit bedeutenden Schäden der Häge und der Täler einhergehenden extremen Geschehnisse werden einigermaβen aufgezeichnet. Er werden einige, in den letzten Jahren in Mitteleuropa (Tschechien, Ungarn, Slowakei, Rumänien) verzeichnten rasche Hochwässer überblickt. Danach werden das am 22-23. Juni 1999 am Kemece-Bach (70 km nordöstlich von Budapest) beobachtete, sowie einige ähnliche, im Juli 1999 im Mátra-Gebirge beobachteten Fälle ausführlicher analysiert. Es zeigten sich dabei die ausschlaggebenden Einflüsse der Hangverhältnisse, Intensität des Starkregens. Die meteorologischen Bedingungen verschiedener Ereignisse zeigten gewisse Änlichkeiten, doch haben diese Befunde nur einen begrenzten Wert für die Vorhersage. Diese Tatsache weist auch darauf hin, daβ anstatt (oder neben) einer Echtzeit-Vorersage, eine zielbewuβte Planung und die der Bauausführung zielbewuβt geltend gemacht werden soll.

Schlüsselworte: rasche Hochwasser, Intensität des Starkregens, Häuigkeitet, Bau-ausführung

1 Introduction

Under climatic conditions of the Carpathian Danube Basin flash floods are relatively rare phenomena. The term ‘flood’ in Hungary very much connected with flatland rivers flowing between artificially constructed flood embankments. Hydrological events of headwaters usually bring some attention only up to the extent they influence flood conditions at lower reaches. The majority of floods go almost unnoticed on most of small ungauged creeks in hilly and undulating regions of Hungary. Only the extreme events causing substantial damage to slopes and valleys have been recorded to some extent. Such events are rather rare. They were mostly absent in the mostly dry 1980s and early 90s. Urban development in the last two decades

combined with well spread carelessness contributed to the severity of certain flash flood events in the last years in Hungary. Summer cottages mushroomed in valleys earlier left open, small wooden or cable bridges hanging over small streams have been replaced by undersized culverts. In extreme cases dried out channels were dammed in the rush of motorization to create access routes to newly obtained or old properties.

The danger presented by flash floods is considerable in hilly and undulating regions. Torrential floods may occur almost independently from the overall hydrological situation on extended catchments. Sudden increase of discharges and quick rises of water levels characteristic for the phenomenon are associated by intensive transport of all kind of sediment, debris and floating matter. At certain natural or artificial barriers temporary blockage of the channel occurs. The jamming caused by the accumulation of debris subsequently is destroyed by rising upstream water levels through the impact of pressure or in rare occasions breaching is the result of overtopping. Periodical repetition and downward movement of these processes along the channel result strong fluctuation of water levels and discharges. Periodically changing strong flow velocities may enhance scouring of the channel and destruction of banks and buildings and structures along those.

Investigations concern relatively small catchments with drainage area usually less or around 100 km^2 (in some cases up to 500 km^2 were considered). These catchments have usually a single raingauge or hydrological station if at all. Flash floods are rare phenomena and experimental basins operated in earlier decades gathered very small amount of information concerning these events, which are usually not sufficient for statistically well based frequency analysis. In most cases direct observations have to be replaced or supplemented by post flood investigations to reconstruct complete flood hydrographs.

2 Flash flood case studies

2.1 Central Europe in recent years

Major floods in Central Europe and associated publicity in July 1997 blocked the spreading of the news on some tragic events which would brought otherwise considerable professional and public interest toward flash floods in countries were these events are seldom. Some of those caused several dozen death tolls – almost measurable in these consequences with disasters covering vast areas and large river systems.

Flash floods in Romania in the Bereteu Valley near the Hungarian border (Szlávik and Bálint, 1998), in Czech Republic (ČHMU, 1999) , in Slovakia on Mala Svinka (Hajtášova, 1998; Majerčakova 1998), also in 1999 in Modra and several other places (*Ivicsics L*, 2000) may serve as valuable information to study flash flood behaviour. Also these events called the attention on the possibilities of dangerous phenomena in otherwise moderate regions.

2.2 Flash floods in Hungary in the summer of 1999

Significant floods occurred in recent years on small streams of hilly and undulating regions. The year 1999 was kind of typical, when the number of such events was much higher than usual. Torrential floods passed already in February on creeks of Bakony Hills and istreams of Fejér County. The month March brought major floods in Hernád Valley, Szerencs Creek and in the Valley of Bódva and Hejő.

June floods were caused by wet air masses circulating in a stagnant cyclonic low pressure field over the Carpathian Basin. Storm precipitation was rather intensive and often was accompanied with hail. The period of intensive precipitation starting from 13 June 1999 yielded rainfall depths equal or higher than multi annual monthly averages. A new rainfall producing cyclone reached the region between 17 – 22 June. Daily precipitation locally often reached average June totals and weekly values already as an areal mean exceeded monthly averages by 50 – 200 %.

(For example 24-hour values: Györe – 255 mm, region of Székesfehérvár – 212 mm, Perőcsény – 200 mm, Cece – 197 mm, Kurd – 187 mm, Kemence – 186 mm, Vámosmikola – 165 mm etc.)

Resulting floods caused strong scouring, erosion of channels and destruction of banks, inundation of valleys. Flash floods ending up with documented damage were recorded on streams:

- *In Northern Transdanubia Region:* Által-ér, Cuhai Bakony-ér, Concó-patak, Bornát-ér, Szőny-Füzitői-vízfolyás, Nagy-Pándzsa, Bikol-patak, Kenyérmezei-patak, Vezseny-ér;
- *In Central Transdanubia Region:*Kapos, Koppány, Gonozdi-, Szentmártoni-, Kulcsár-vízfolyások, Völgységi-patak, Tita-patak;
- *In Southern Transdanubia Region:* Baranya-csatorna, Hábi-patak, Gödrei-vízfolyás, Karasica, Okor-vízfolyás, Baté-Magyaratád, Orci-vízfolyás, Határkülvíz-csatorna;
- *In northern part of the Central Danube Region:* Galga, Tápió, Kemence, Zagyva, Benta;
- *In Northern Hungary:* Bene-patak, Tarna-völgy, Hejő-, Szarvágy-, Ágói-, Csincse-, Hór-, Laskó-, Vadász-, Tarnóca-patak.

A well-developed frontal system had decisive impact on weather conditions of the country after 7 July. Storms and rain showers appeared with daily regularity. Big rain depths covered large regions; several hundred square kilometres received precipitation exceeding 100 mm within a short time. Torrential floods appeared in the stream network of Zagyva, Tarna catchment, on creeks Tardi, Kácsi, Sályi, Geszti at the foothills of Bükk.

The sequence of precipitation on 16 – 17 August caused major floods on streams of Northern Hungary and in the Region of Northern Transdanubia.

Large damage in public and private property was associated with the series of flash floods. 12,000 buildings were in danger during June-July floods. The number of severely damaged homes exceeded 400. 3000 people were evacuated during flood events. The loss local governments suffered was estimated at 17 thousand million Hungarian Forints (approx. EUR 70 million).

2.3 Flood of the Kemence Creek

The 17 – 22 June rainfall events have been mentioned above. The last spills of this sequence of storms caused an extreme flood on Kemence creek (a tributary of Ipoly/Ipel') 70 km North East of Budapest on the Northern slopes of the Börzsöny Hills. The upper part of the creek with 51.6 km^2 drainage area entered into a reservoir serving mostly for flood retention and irrigation purposes. The 9 m high 445 m long earth dam was constructed in 1995. Floods of 1995 and in 1996 proved that the capacity of water release structures of the dam had been insufficient and an additional spillway was constructed. Based on 50.3 m^3/s.200-year design flood estimate, with the new spillway the capacity of release structures was risen up to 125 m^3/s.

Reconstruction of the June 1999 flood event was possible because of the hydrometric station of Bernecebaráti 1600 m downstream of the dam supplied with a recording pressure gauge. The gauge recorded water levels throughout the event, although it was destroyed by a small landslide of the under-scoured bank just after the flood wave passed.

Rainfall observations were available from 10 rain gauges of the wider surrounding of the drainage basin. Only one station situated at the lower edge of the catchment the rest are more distant. Daily observation totals were distributed to hourly values using the observations of the meteorological radar of Budapest. No significant inhomogeneity was observed during rainfall events over the Kemence catchment. An estimated rise of precipitation with elevation was taken

into account when areal mean rainfall depths were estimated over the catchment with elevation range around 800 m. Good coincidence was found with the nearest recording rain gauge; parallels of temporal distribution of rainfall were evident despite of the differences in total rainfall depths.

June rains contributed to considerable antecedent moistening (Fig. 1) over the forested catchment. The immediate cause of the flood was two consecutive storms producing 135 mm of rainfall within 36 hours. (Fig.2).. Available gauge records on Kemence creek together post flood investigations proved the significant role of sediment and floating matter transport and jamming. Heavy erosion and associated destruction and losses of property cannot be fully assigned to the natural flood wave owing to the failure of an upstream reservoir dam.

The flood wave to the reservoir had a peak around 169 m^3/s. The water level in the reservoir was 0.9 m above the forced flood level foreseen in the design. Failure of the dam was caused by distruction of the spillway which started with washing out of the downstream edge of the paved outlet canal. Within a few hours the water level of the reservoir depleted by 6 m releasing around 1 million m^3 of water. Around 20 % of the total 4,934,000 m^3 flood volume. The superposition of the natural flood (with a peak of 115 m^3/s) and the sudden wave caused by instant reservoir release lead to the highest flow velocities (Fig. 2).

The hundred year June-July daily rainfall over Kemence catchment is estimated at 86 mm. (based on Goda 1965). Owing to the extreme antecedent precipitation conditions

Flood frequency analysis was mostly based on disaster records of this century, and frequency analysis of precipitation events. In case of the Mátra Hills flood records at lower reaches of the Zagyva catchment were also used. Investigations in most cases proved the seemingly exaggerated media reports and public judgement: recent event were rare, extraordinary phenomena for the region with return periods 40-130 (and more) years.

3 Meteorological conditions, investigation flash flood inducing precipitation

The utilitarian approach towards the investigation of flash floods, suggest the investigation of causes and processes of flood formation in sake of protection and defence. Precipitation is one of the main components, rainfall depth, its temporal and spatial distribution, length of rainy period can be analysed.

Evidently rainfall events with duration equal to concentration time are significant. In case of the investigated catchments it equals around 24 hours or less. 1 and 2-day precipitation has extensively studied for the territory of Hungary. Recording raingauges are required for shorter duration rainfall. The number of such stations is much less and their period of record is shorter. The experience gained with Much

Asymmetric distributions (most frequently Lognormal) have been used to describe statistical distribution of precipitation. Distributions of extreme rainfall of the four warmest months do not differ significantly. Recent attempts follow internationally recognised approaches partial duration or Peak over Threshold (POT) models are applied with Gumbel or Generalised Extreme Value (GEV) distributions. No significant difference has been revealed between different station results for short duration precipitation in Hungary. That is why uniform relationships are applied for the calculation of design values throughout the country. Naturally it does not mean complete coincidence, just in the absence of large differences in elevations limited data sets and associated uncertainties do not allow to evaluate spatial distribution.

Duration of extremely intensive rainfall usually remains within 3 hours. Results of the analysis suggest that no significant difference exists results derived from shorter and longer observation (sampling) periods. As it concerns short duration rainfall only preliminary results are available for depth - area relationships and their temporal structure. Generally it should be always kept in mind that precipitation is an element which has considerable spatial and temporal variability.

A detailed listing of ireferences on investigations in Hungary is given in References.

4 Conclusions

Losses suffered during investigated flood events could have been significantly lessened if actors of local water management, first of all, self-governments of communities, could follow the prescriptions of the new Water Act: modified rights and responsibilities.

It would be important to invest more into flood defence of flash flood prone regions, also research and development in this field should be strengthened.

This fact also emphasise that beside (or instead of) real time forecasting and warning wherever it is possible, proper planning and building codes, construction standards should be emphasised.

The necessity of regional tackling of frequency issues was recognised. Limitations of empirical relationships used for the estimation of design floods were clearly revealed. Meteorological conditions of different events show some parallels, but these findings have only limited prognostic value. This fact also emphasise that beside (or instead of) real time forecasting and warning wherever it is possible, proper planning and building codes, construction standards should be emphasised.

Better knowledge of flash floods may contribute to flood protection and defence in hilly regions, channel regulation and landuse management in valleys may receive useful design data.

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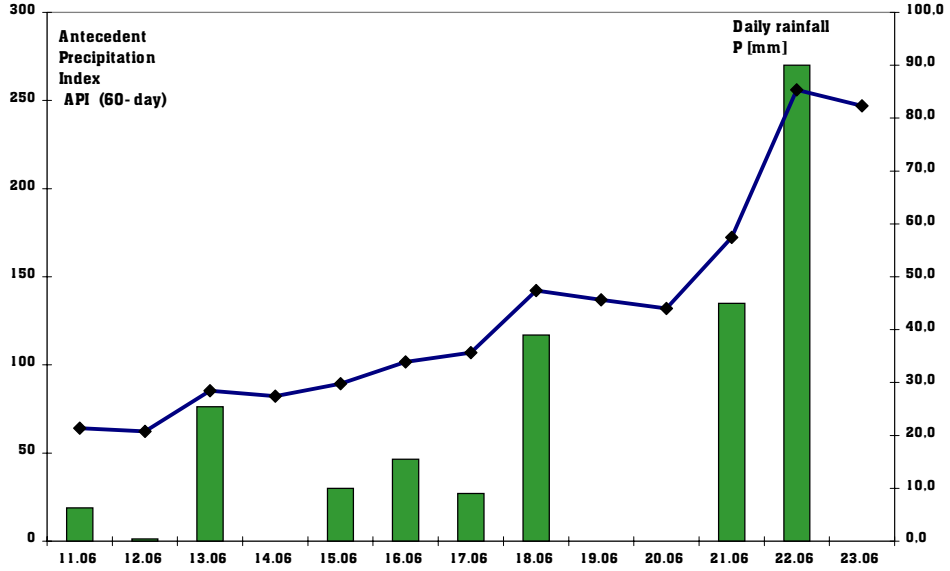

Fig. 1 Antecedent rainfall conditions in the Kemence catchment represented by Antecent Precipitation Index (API) of 60-day memory and daily rainfall values.

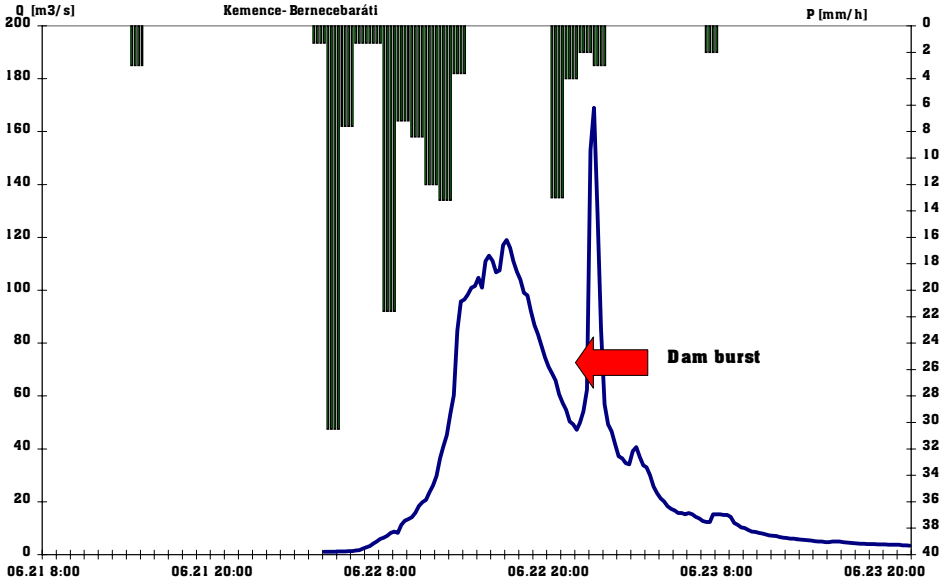

Fig. 2 July 1999 hydrograph of the of the Kemence Creek at Bernecebaráti with indication of the time of an upstream dam failure at Kemence Village causing the second superimposed flood wave

A Natural Approach to Design and Management of the Drainage System in Voivodina

Pavel Benka, Radovan Savic, Atila Salvai

Abstract: The projects of natural river engineering concerning specially agricultural land drainage systems represent a novelty in our country but also in some other countries. Some recommendations from the aspect of land reclamation and hydraulics that have been proposed could be used whenever correct planning and defining concrete research are to be carried out. The results of the presented analysis can be useful in designing a new or reconstructing an old drainage system, especially taking into account contemporary conceptions and possibilities of natural river engineering systems.

Key words: environment, drainage, hydraulics, channel, drain pipe.

Eine natürliches Herangehen an Entwurf und Management des Entwässerungs-systems in der Voivodina

Zusammenfassung: Projekte eines „natürlichen Flussingenieurwesens“, die sich insbesondere mit Ackerland-Entwässerungssystemen befassen, sind eine Neuheit für unser Land aber auch für einige andere Länder. Einige Empfehlungen aus der Sicht der Landgewinnung und der Hydraulik konnten genutzt werden, wann immer korrekte Planung und konkrete Forschung durchzuführen waren. Die Resultate der dargestellten Analyse können hilfreich sein für Neuentwürfe oder bei der Erneuerung alter Entwässerungssysteme – vor allem unter dem Aspekt zeitgerechter Konzepte und Möglichkeiten „natürlicher Flussingenieur-Systeme“.

Schlüsselwörter: Umwelt, Entwässerung, Hydraulik, Wasserlauf, Dränrohr.

1 Introduction

From the beginnings of civilization, man has striven to make alterations in his environment and thus ensure his own future. In the domain of agriculture, which is one of the first human activities, his endeavour to make sustainable or increased yields, has been directed towards to the drainage of agricultural land. New advancements in the field, i.e. a modern approach to the problem of natural river engineering using the natural concept, presuppose an integral research of all the complex processes involved and an interdisciplinary co-operation of the experts. In view of this, the development of practical reclamation, stabilization and improvement of rivers for an effective design and maintenance of the favourable hydrological, morphological, pedological, ecological, and other characteristics of water streams, assuming an interdisciplinary co-operation of the experts from all the pertinent domains (agronomy, forestry, ecology, biology, geology, etc.), is of essential importance from the point of view of both the environmental protection and modern agricultural production (Salvai, 1994).

The future agricultural development, and especially the production of healthy food will be almost impossible without the natural river engineering. In essence, natural watercourse engineering involves two major aspects when its influence on the environment and agricultural production is considered – direct, that are observed in the zone of the watercourse (the effect on the hydrological elements, protection of water from pollution, etc.) and indirect, observed outside the coastal belt of the watercourse (influence on climatic characteristics, soil erosion, etc.).

2 Protecting belt along the high-level drainage channel

It is accustomed that the high-level drainage channel of an agricultural land drainage system is either of a trapezoidal cross-section and steep slopes, or, prismatic, which means that there is no change of flow, mean water rate, water depth, etc., along the direction of water streaming. The maintenance of the designed physical state of thus constructed channels, which is often unstable and prone to changes, is very costly. In these channels, great seasonal variations of the water depth are frequently observed. Their aquatic ecosystems are characterized by a lower degree of biodiversity, especially in view of the floristic diversity, although they represent one of the fragile types of ecosystems. The land adjacent to the channel banks is usually used for the agricultural production (Salvai, 1994).

The widened channel of the drainage system may be used as the space for stabilizing water delivery toward the pumping stations and for a better management of the drainage system. In addition to the "functionalistic" conception of the drainage system engineering, the more recent "natural" approach has been introduced, in which is supposed the existence of the harmony between the criteria of functionality, safety, ecology, aesthetics, sociology, etc., suggesting the need for reconstructing the existing drainage systems with the aim of enlarging the channel storage capacity (detention reservoir).

The land belt adjacent to the high-level drainage channel represents one of key elements in natural river engineering. This land belt ensures protection of the channel from destructive actions of the negative factors of industry, agriculture, traffic, etc. Besides, it allows the existence of a greater diversity of plants and animals. This protecting belt with most diverse conditions in the biotope (humid soil, underbrush, etc.) allows the establishment of diverse biocenoses, which directly enhances the quality of the ecosystem in respect of the habitat protection through the overall biodiversity. Therefore, the protection of these ecosystems through the protection of the habitats and their mutual connection through the ecotones, enables preservation of the genetic and species diversity of the ecosystem. Numerous animal species living along the rivers can find here the space for food, reproduction, and a rather protected habitat.

Such a naturally regulated watercourse with its protection belt of land, where an autochthonous or planted forest is formed, can influence the agricultural production in several ways. First, it serves as a wind protection belt, it decreases evapotranspiration (by lowering wind speed), i.e. it diminishes the needs for irrigation. Further, it prevents the soil from erosion, especially from wind erosion. The protection belt reduces extreme oscillations in precipitation, temperature, soil and air moisture, etc., which has a positive effect on the agricultural production. The benefits of forests and forest belts are also significant in protecting the soil from erosion and flood, as well as in purification of wastewaters, etc., and these are only some of a number of polyvalent functions they have in particular branches of economy and society in general.

3 A new approach to the technical solution of drainage

As far as the environmental protection is concerned it could be said that solving the problem of concentrated pollution sources is much simpler than the problem of diffuse pollution sources, the reason being that diffuse pollutants reach the environment without the possibility of their pretreatment or an appropriate disposal. An extremely massive source of diffuse pollution is agriculture, which, among the others, is caused by the use of different fertilizers, pesticides, herbicides, and other chemical agents. In the long run, the greatest risk of diffuse pollutants that takes place despite of undertaking complex protective measures (rational and restricted use of fertilizers, optimal use of chemical agents, etc.) consists just in the fact that these substances still reach the soil, and then, by water (surface and ground) flow, come to ground waters and water streams. Besides, by constructing a system for irrigation and drainage, the transportation

processes influencing the degree of environmental pollution are only accelerated (Salvai and Batinic, 1995).

As reported by Vajagic and Belic (1990), on the basis of an analysis of the changes of water quality parameters on small plain watersheds in the 1980-1989 period, an increased content of nitrogen fertilizers in these surface waters was observed, which coincided with the increased quantities of mineral fertilizers applied. A special problem represent the agricultural areas with the drainage and irrigation systems involving water recycling, on which some negative effects on water quality may also appear, affecting thus the agricultural production (Loehr, 1974).

The water from a drainage system is usually directly conducted to the canals, so that the transport of harmful matter from the agricultural production is accelerated, and the water load in the stream increased. The more recent ideas in drainage system design start from the fact that drain pipes end up several meters before reaching the stream. In that case the drainage water is filtered through the soil in the protecting belt. The area between the pipe drain and water stream remains wet for a longer time, which has a positive effect on the components of the biodiversity of the ecosystems of watter-logged soil, marshes, swamps, etc. Besides, the passage of water through the protection layer brings about an improvement of its chemical quality, as the contents of nutrients from the drainage water get reduced by this process, as well as by biological purification. Therefore, in addition to the simultaneous enrichment of the watercourse surrounding in nutritive matter, this reclamation measure yields the improvement of the hydrological regime, physical and water-air characteristics, as well as of the productive characteristics of the soil on the inundated part of the water stream, which has a favourable effect on the development of the planted trees and other plant species.

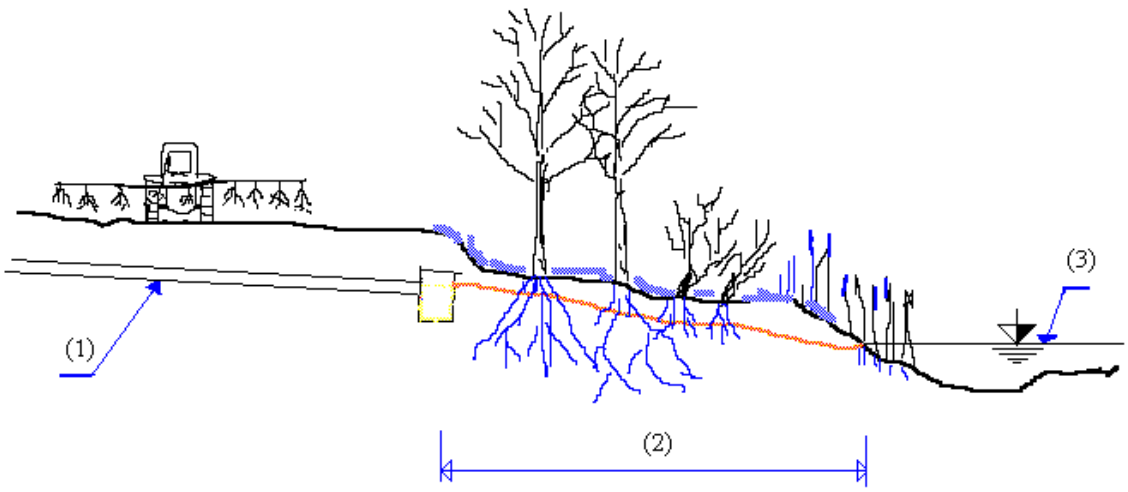

Fig. 1 Drainage position in natural river engineering circumstances, (1) - drain pipe, (2) - protection belt, and (3) - drainage channel (Salvai and Batinić, 1995).

As was mentioned in the work of Salvai and Batinic (1995), it is possible to have different variants of the hydrotechnical solutions of the pipe drain ending. One of possible schemes of the natural river engineering is presented in Figure 1. As far as the authors know, such solutions have not been previously reported. It is evident that the different natural conditions (pedological, hydrological, hydraulic, etc.) demand the different solutions, and in particular cases of heavy clayey soils and unfavourable technical and economic conditions, such a mode of drainage construction would be questionable. Therefore, all technical requirements and characteristics of such and similar solutions should be theoretically elaborated and experimentally verified in the future research.

Such solutions would diminish pollution of the watercourses by harmful matter originated from agriculture, and this is again implicitly related to the needs of the agricultural production, i.e. of irrigation.

4 Shortcomings of the natural river engineering solution

As the hydraulic engineer is primarily responsible for the improvement of natural watercourses for the benefit of navigation, the control of floods, and the provision of water power and water supply, he must also accept the responsibility for their stabilization. To be fulfilled, these requirements put before the design engineer primarily the "functionalistic" concept of the river engineering. It can be said that the main shortcoming of the natural river engineering solution is in the need for its "degradation" from the point of view of a purely economic-technological concept. More precisely, human needs and whims of nature have forced man to carry out stabilization and improvement of rivers in their function and safety. Therefore, the shortcomings of the natural river engineering are implicitly related to the human needs, i.e. only in the course of defining certain needs (on the entire watercourse or a part of it) one can define the shortcomings to be overcome, in the majority of cases by applying again the functionalistic concept of river engineering (Salvai, 1998).

5 Conclusions

The problem of environmental pollution caused by the agricultural production has not been adequately solved yet (Briggs and Courtney, 1985). The new approach employing the concept of "natural" river engineering, in contrast to the former "functionalistic" approach, should, if not remove, at least diminish the negative effects on the environment.

The projects of natural river engineering must rely upon practical application of modern advancements in science and technology. Having in mind that the processes taking place in watercourses have not been sufficiently understood yet, it is necessary to undertake multidisciplinary experimental research of natural river engineering on some characteristic locations. Such experimental projects should provide the basic information and practical technical solutions needed for the appropriate application of modern natural aproach to design and management of rivers and channels (Salvai, 1994). Besides, such studies should result in a number of simulation-estimation mathematical models for assessing the abiotic (transportation, thermal, chemical and other physical processes) and biotic (biological) processes, i.e. in complex ecological mathematical models allowing monitoring of the evolution of all the relevant processes taking place in the water stream. These models would be of great importance in designing, construction and exploitation of the water resources, and provide a fundamental technical and technological basis for ecological studies.

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Regional Hydrological Types - A Tool for Improved Runoff Forecasts

Günter Blöschl, Ralf Merz, Dieter Gutknecht, Martin Bachhiesl

Abstract: The objective of this paper was a regional analysis for identifying hydrologic situations and processes that give rise to changes in runoff in the main Austrian streams. The basic approach adopted consisted of a synoptic assessment of processes such as rain-on-snow, snow melt, frontal rainfall and dry spells, and a typology of regional hydrological situations based on a multiobjective iterative procedure. These analyses were assisted by an intuitive visualisation tool that includes still graphics and animations which provide both model developers and model users with information on the main changes in runoff, in snow conditions, and in rainfall on a synoptic chart. This typology and the visualisation tool allow a better interpretation and a more informed use of the runoff forecasts in the management of the hydropower systems.

Key words: visualisation, large scale processes, runoff dynamics, snow melt, rain-on snow

Regionale hydrologische Situationen als Grundlage für verbesserte Abflußvorhersagen

Zusammenfassung: Ziel dieser Arbeit war eine großräumige Analyse der Durchflußentwicklung in den großen Vorflutern Österreichs in Hinblick auf die regionale hydrologische Situation. Vorerst wurden typische hydrologische Situationen definiert wie etwa Regen-auf-Schnee, Schneeschmelze, synoptischer Niederschlag und Trockenwetter. In einem zweiten Schritt wurden diese Situationen für Einzeltage auf Basis einer iterativen Vorgangsweise bestimmt. Diese Untersuchungen wurden ergänzt durch ein Visualisierungstool bestehend aus synoptischen Graphiken und Computeranimationen, das Modellentwickler und Anwender in intuitiver Weise Informationen über Änderungen im Abfluß, Schneebedingungen und Regen zur Verfügung stellt. Die typischen Situationen und die Visualisierungen bilden eine wertvolle Hilfestellung bei der Interpretation und der Verwendung von Abflußvorhersagen, die für die Bewirtschaftung der Kraftwerksketten verwendet werden.

Schlüsselworte: Visualisierung, großräumige Prozesse, Abflußdynamik, Schneeschmelze, Regen auf Schnee

1 Introduction

The liberalisation of the electricity market has stimulated the development of improved methods for short term runoff forecasting at the main Austrian rivers. A dual approach was adopted consisting of a deterministic runoff routing model based on an hourly time step and a multiple regression model based on a daily time step (Drabek et al., 2000). There are a variety of hydrological processes that give rise to short term changes in runoff. These processes not only vary seasonally but also from year to year, and there are also major changes in the spatial patterns of these processes. As both types of runoff forecasting models implicitly make the assumption that the driving processes do not change significantly, a regional analysis was performed to compliment these two modelling approaches and to assist in parameter identification and choice of model structure.

The objectives of this paper was a regional analysis for identifying hydrologic situations and processes that give rise to changes in runoff in the main Austrian streams. The basis approach adopted consisted of (a) a synoptic assessment of processes such as rain-on-snow, snow melt, frontal rainfall, dry spells and (b) a typology of regional hydrological situations. Each type or situation usually consists of a spell of a few days.

2 Input Data

The input data used include air temperature, precipitation (liquid, solid), snow melt and snow water equivalent from regional snow simulations (Blöschl and Merz, 1999). All of these data represented average daily values for 19 regions in Austria and Southern Germany and covered the period 1990-1995. It is important to note that we did not use runoff data for *identifying* hydrological situations. However, we finally used runoff data as an independent *test* of situations identified by the procedure developed here.

3 Method

The method for identifying regional hydrological situations is based on a multiobjective optimisation routine using observed hydrometeorological data at numerous stations which can be telemetered. The method consists of an iterative procedure involving two main steps.

(1) Selecting regional hydrological situations deemed to be important for the study area and specifying criteria for each situation. Criteria are, for example, an increase in air temperature over 3 days less than a value K_1, or snow melt on a specific day less than a threshold value K_2. As a first guess, an *a priori* choice for these criteria and threshold values was made. The criteria were then evaluated by an objective function Z for each day and each situation,

$$Z_{ij} = 0 \qquad \text{for } X_{ij} \geq K_{ij}^{>} \qquad (1)$$

$$Z_{ij} = \frac{\left| X_{ij} - K_{ij}^{>} \right|}{\left| X_{ij} \right| + \left| K_{ij}^{>} \right| + 1} \qquad \text{for } X_{ij} < K_{ij}^{>}$$

where X_{ij} is the hydrologic variable i in region j, and $K_{ij}^{>}$ is the lower threshold of the criterion. Upper thresholds were evaluated analogously. The situation with the minimum value of

$$Z = \sum_i \sum_j Z_{ij} \qquad (2)$$

was assumed to be the representative situation for a particular day.

(2) Subjective assessment of situations. Next the regional hydrological situations were visualised along with the most important hydrological variables in the total catchment area of about 150000 km^2. This allowed a visual (subjective) examination of the situations by the analyst. If this visual examination revealed that the assessment by the algorithm was satisfactory, i.e. the algorithm did identify the situations properly, the criteria were accepted as the final criteria. If this was not the case, the situations and/or criteria were changed and step 1 was repeated.

4 Results

4.1 Typology of Regional Situations

The iterative procedure lead to the identification of seven regional hydrological situations. These are listed in Table 1 along with the number of days to which a particular situation was assigned. Table 1 indicates that runoff recession is the most frequent situation, and snow melt without rain is the second most frequent situation. Each type or situation usually consists of a spell of a few days.

Table 1 Regional Situation as identified by the proposed procedure for the Danube basin.

	Regional Situation	# of days (1990-95)
1	Snow melt without precipitation	497
2	Early winter thaws	56
3	Rain on snow events	167
4	Temperature drop	128
5	Synoptic and/or orographic precipitation	390
6	Runoff recession in winter	305
7	Runoff recession	648
	Total	2191

As an example, Fig. 1 shows the results of the typological classification for 1993 superimposed on the discharge hydrograph of the river Danube at Persenbeug (92452km^2). The colour symbols relate to the regional types. As can be seen from Fig 1, the particular flood event in late March was mainly caused by snow melt without precipitation (red asterisks) but there was also some rain involved (blue squares). In contrast, the shape of the hydrograph in late April and early May was controlled by snow melt alone. The runoff dynamics in mid summer were dominated by synoptic and/or orographic precipitation. In late December rain on snow (blue squares) as well as early winter thaws (green open squares) were important. The latter type of runoff tends to occur in response to rain falling on a shallow snow pack and a subsequent rise in temperature which leads to advective melt. The data analyses in this study suggest that these mechanisms occur very regularly every year in late December. Interestingly, it is not uncommon for local opinion to relate to this type of floods as "Christmas thaws". The lower panel in Fig. 1 depicts a quantity that is termed probability which has been defined as 1- Z in equation (2). A probability of unity means that most criteria are satisfied, implying that the correct situations has been identified with high probability. In contrast, a low probability means that the hydrological situation of a particular day is not very typical and does not exactly match any of the situations in Table 1.

4.2 Statistical Analyses

In a further step, a number of statistical analyses were performed in which runoff was stratified by the hydrological type. These analyses showed that the differences of runoff characteristics between the hydrological types are highly significant. For example, in multiple regressions, the stations explaining most of the variance differ vastly between situations. Another example is given in Fig. 2. Specifically, Fig. 2 shows the cross correlation functions of streamflow of two gauges at the Danube (Greifenstein and Jochenstein) which are about 200km apart. The maximum of the cross correlation functions represents the best correlation of the two gauges when allowing for some time shift, and the lag at which the maximum occurs is a measure of the travel times at the main river. As can be seen from the example in Fig. 2, the apparent travel times can change by more than a factor of two, depending on the particular type. For early winter thaws, the lag is very short (shorter than 5 hours) implying short apparent travel times. This is a result of lateral snow melt inflows from small tributaries within the particular reach which occur roughly simultaneously. These results imply that the dynamics of the runoff formation processes are fundamentally different in the different hydrological situations and hence it is important to take these into account for runoff forecasting.

4.3 Visualisation

As a final result we will illustrate, by example, the merits of the visualisation tool that has been developed and used in this study. The legend is depicted in Fig. 3 and a typical graphical display is shown in Fig. 4 which relates to Dec. 21, 1991. The graphics show, for the given day, the main changes in runoff, in snow conditions, and in rainfall on a synoptic chart for most of Austria. On Dec. 21, 1991, the regional hydrological situation was rain on snow. There was a snow pack in most regions (black asterisks) and heavy rain in Salzburg (blue open circles) which caused a significant increase in runoff (green arrows pointing upwards), particularly in Salzburg (centre of the figure). In contrast, snowfall prevailed south of the Alps (grey asterisks in Carinthia, bottom of the figure). The visualisation tool was developed for both still graphics and animations. In the animation mode plots as that in Fig. 4 are shown in sequence which then give an impression of the time development of the hydrological situations over a number of days. These graphics provide model developers and model users with information beyond the mere numerical figures of predicted runoff. The symbols are intuitive and readily allow an interpretation of which processes have likely given rise to changes in runoff.

5 Conclusions

The types identified in this study allow, at a glance, an assessment of the most important causes of runoff changes for the rivers under consideration, i.e. which particular hydrological and meteorological situations prevail. This is particularly appealing to model users who are interested in a concise statement of the main processes giving rise to observed and/or predicted runoff dynamics. While the typology of regional hydrological situations is also being used quantitatively for assisting in the selection and the refinement of various components of the runoff forecasting models, its main strength probably lies in the intuitive nature of how both the typology and the graphic visualisation tools can interface with the model user. They allow a better interpretation and a more informed use of the runoff forecasts in the management of the hydropower systems.

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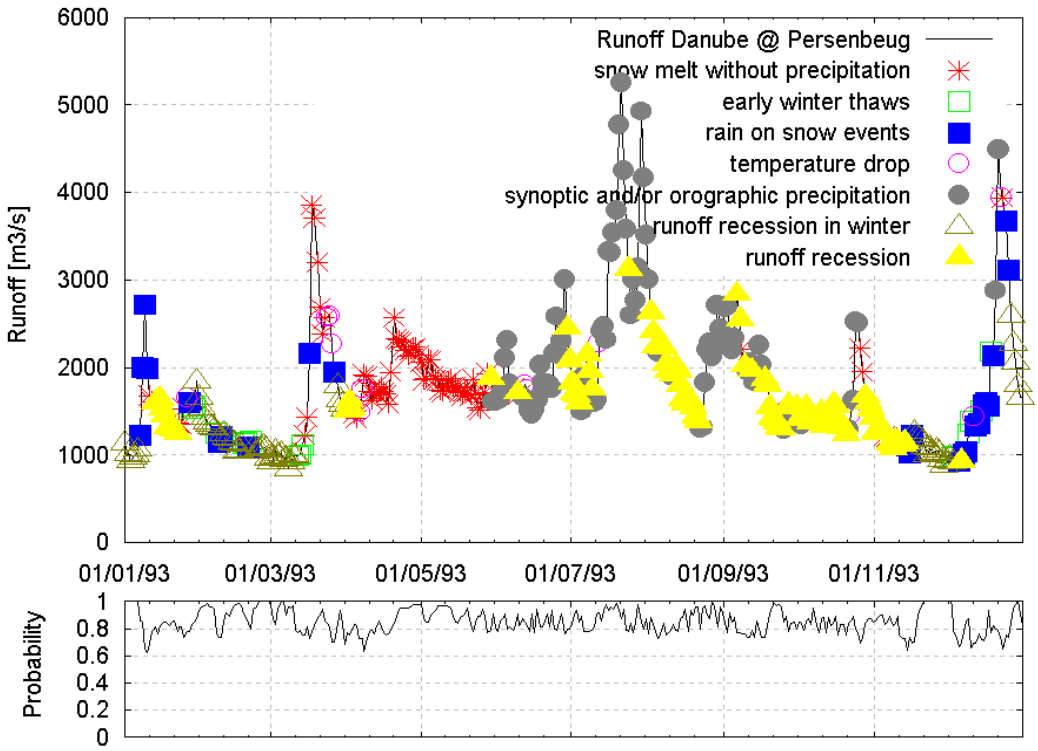

Fig. 1 Results of he typological classification for 1993 superimposed on the discharge hydrograph of the river Danube at Persenbeug.

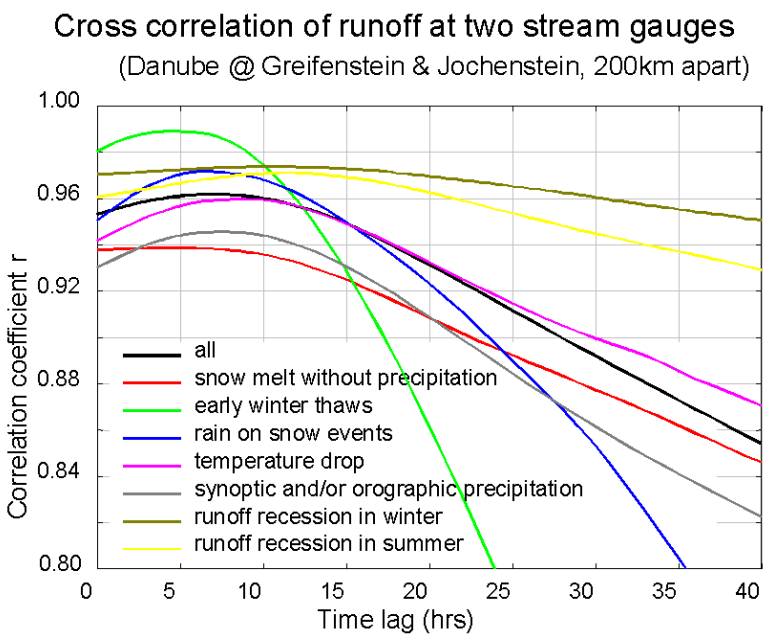

Fig. 2 Cross correlation functions of streamflow at two gauges at the Danube (Greifenstein and Jochenstein) stratified by the regional hydrological situation.

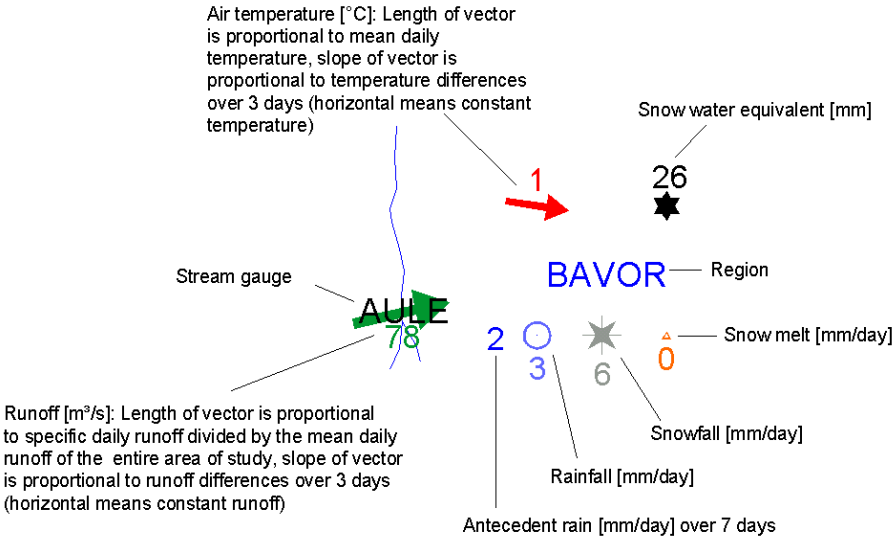

Fig. 3 Legend of the visualisation tool.

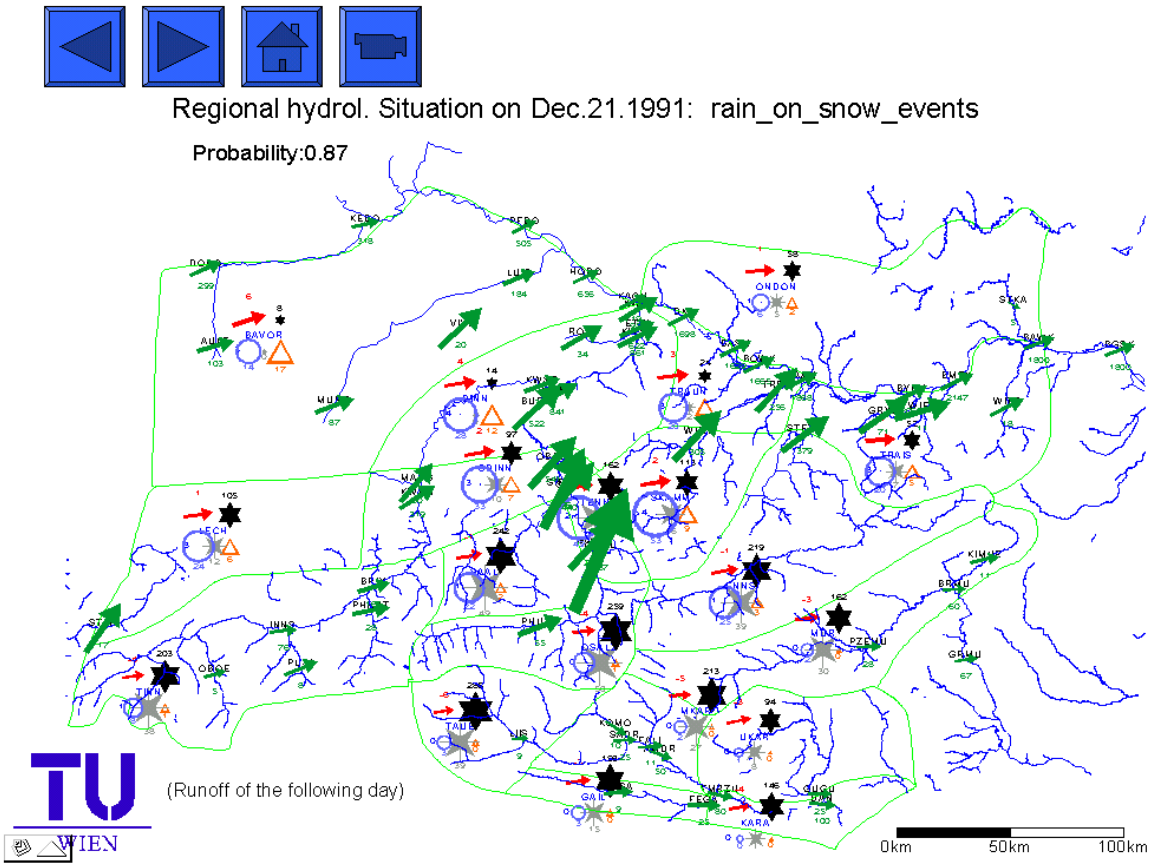

Fig. 4 Typical graphical display for the total catchment area covering most of Austria. The rightmost streamgauge is BGSK (Greifenstein, near Vienna), and one of the leftmost gauges on the plot is INNS (Innsbruck, Tyrol). Legend see Fig. 3.

Waters Resources and Water Demands in Romania

Elisabeta Cserwid, Andrea Cristina Serban

Abstract: In the first part of the work it is presented the quantitative and qualitative aspects of the water resources of Romania.
Further it is presented a description of the time variation of the waters resources from the following sources: inland rivers, Danube River and groundwater, for the main water users : water supply for population and industry, agriculture.
It is presented the causes of this variation in time of water demands determinate, mainly, by the transition economy.
In the final of the work it is presented a forecast of the water demands for the years 2020.
Key words: resources, demands, surface water, groundwater, quality, quantity, forecast.

Wasserhilquellen und wasserbedarf rumänien

Zusmmenfassung: Im ersten Teil dieser Arbeit die quantitativen und die qualitativen Gesichtspuncte über die Wasserhilfßquellen aus Rumanien dargestellt.
Weiter ist eine Darstellung der Zeitlichen variation von Wasserhilfßquelle den folgenden Quellen vorgestellt: innere flüße, Donau, Untergrundwässer; gleichfalls sind die Hauptbenutzer des Wassers dargestellt: Trinkwasser versorgungen für Bevölkerung, Wasserzuführungen für Industrie und Landwirtschaft.
Es werden die Ursachen der zeitlichen Variation der der Wasserbedürfrrisse vorgestelt, die hauptsächlich von der Transitionwirtschaft bestimmt werden.
Zum Arbeitschluß läßt sich eine kurze Prognose der Wasserbedürfrrisse für das Jahr 2020 dargestellt werden.
Schlüßelwörte: Hilfsquelle, Bedürfrrise, Quantität, Qualität, Oberflächewasser, Untergrundwasser.

Water resources of Romania

The rational management of the water resources of the country done in a unitary conception and with a large perspective is a major issue for the social and economic development of Romania, in order to satisfy the water requirements of the population, industry, agriculture, protection of waters against exhaustion, pollution and floods.

Romania has a relatively dense hydrographic network and most of it area (97,8%) is located in the Danube River Basin, except for the river basins situated in Dobrogea which are not Danube tributaries.
The water resources of Romania consist in the surface waters (the inner rivers, the natural lakes and reservoirs), the Danube River and the groundwater.

The water resources of our country , assessed on the basis of the mean runoff of the inner rivers and of the Danube River, depending of the physic-geographical characteristics of the river basins and also of the hydraulic structures , are presented as follows:

Water resources Table no. 1

Resources category	Theoretical resource billion m^3	Usable technical resource billion m^3
Inner rivers	40	25
Danube River	85*	30**
Groundwater	9	6
TOTAL	134	61

* represents ½ of the multiannual mean runoff of the Danube River.
** includes about 5 billion m^3 of resources in the natural hydrological regime.

The water resources of the Black Sea are not taken into account for the moment , due to the technical and economical difficulties of the desalinization of the sea water.

The main surface resource of Romania, consists in the 4,864 inner rivers of 78,905 km in length.
During a normal hydrological year the runoff volume is about 40 billion m^3 . Of the total surface runoff , 99.8% flows into Danube River and only 0.2% flows into Black Sea.

A basic characteristic of this water resource category is a **very large spatial variability:**

- half of the runoff volume come from the mountainous area which represent only 17% of the country surface;
- the variability of the specific mean discharge from less than 1 l/s and km^2 in the low areas of the Romanian Plain , most of Dobrogea, the Inferior Siret Plain, the South-Western side of the Timis and Arad Plain, up to 1.5 l/s and km^2 most of the Romanian Plain including the Oltenian Plain and the hill area of the Oltenia and Wallachia Plain, the Transylvanian Plateau, the Somes Plateau, most of Moldavia and in the plain area in the West of the country and up to 40 l/s and km^2 in the high areas of the Fagaras and Retezat Mountains.

Another characteristics is the **very pronounced time variability** with strong floods in spring – beginning of summer, followed by long droughts. On the average, the ratio between Q_{min}/Q_{max} = 1/200 and on certain streams can be 1/1,000 or even 1/ 2,000 .

The Danube River, the second large river in Europe, having 2,850 km in length, of which 1,075 km are situated on the Romanian territory (37,7%), has a 170 billion m^3 mean runoff at the border of the country. Its peripferical position and international character impose certain limitations regarding its water use and due to this, only half of the multiannual mean volume runoff on the Danube River in the Bazias section was considered as a resource.

The groundwater resources are located in the phreatic, mean and deep aquifers. The distribution of the runoff modulus on the large tectonic units in our country are presented as follows:

- 0.5 – 1 l/s and km^2 in northern and central Dobrogea;
- 0.5 – 2 l/s and km^2 in the Moldavian Plateau;
- 0.1 – 3 l/s and km^2 in the Transylvanian Depression and Panonian Depression, except for the Fagaras area, with values between 3 – 5 l/s and km^2 ;
- 0.1 – 5 l./s and km^2 in the Danubian and Dobrogea Platform, with large values in the piemountainous area or where gravel and blocks deposits develop;
- 15 – 20 l/s and km^2 in the quarts areas of the Jiu and Cerna River Basins.

Compared with the population of the country, specific usable resources, usable under natural regime, is about 2,680 m^3 /inhabitant and year, taking into account the Danube contribution and

theoretical specific resources of 1,700 m^3 /inhabitant and year respectively, taking into account only the inner rivers contribution (considering the peripheral position of the Danube), which places our country , from this point of view, in the category of countries with reduced water resources, below the European average which is 4,000 m^3 / inhabitant and year.

These resources can not be efficiently used without the achievement of complex hydraulic structures in the river basins, as the inner rivers are unevenly distributed in the territory and the Danube River is slightly used, due to its peripheral position at the southern limit of the country.

In this regard, in order to regulate the water discharges over 1,900 important reservoirs were made and they were equipped with the necessary devices corresponding the complex water uses, summing up a total volume of over 13 billion m^3 at the level of the year 1999.

Also, over 2,000 km channels and derivation galleries were made for transfer of the water resources from the exceeding basins into the deficitary ones or within the same river basin.

The basins having most of the hydraulic works are the following: the Prut River with about 300 reservoirs, the Siret River – about 230 reservoirs and Arges River – about 220 reservoirs.

The river basins having the most important live storage of the reservoirs are : Siret with 1,597 million m^3 and Olt with 797 million m^3 and the river basin with the largest volume designated for flood prevention and the attenuation of the floods waves is the Prut River Basin with 960 million m^3 .

The **"qualitative** " problems of the water resources are more and more combine with the **"quantitative**" ones in now days.

Due to the various pollutant contamination processes, waters become sometimes inappropriate for their use, so that the resource- demand ratio is given a more complex significance.

On the whole of the river basins 1,150 objectives were emphasized, that is: 677 industrial units, 143 agrozootechnical units and 326 localities which have an important impact on the water resources.

The lack or inappropriate operation or overflow of capacity of the WWTPs represent not only a pollution source of waters, but also a direct loss of some useful substances which are evacuated with the waste waters: 373,000 tones of suspended load , 129,000 tones of organic matter, 29,000 tones of oil greases, 2934 tones of metals (Pb, Cr, Cu, etc.), 14 tones of cyanides, substances which could be capitalized by adequate technologies at the level of year 1999.

Of the total length of the investigated rivers in 1999, of 21,900 km: 12957 km (59%) were included into the 1st quality category; 5703 km (26%) in the 2nd quality category; 1276 km (5,8%) in the 3rd quality category and 1998 km (9%) are outside the admitted limits. The most unfavorable situations occurred in the river basins : Prut – about 35% and Ialomita – about 29%.

As compared to the year 1989 an improvement of the inner waters quality was noticed, thus, the percentage of the river reaches with a good quality water (1st and 2nd category) increased from 60 % in 1989 to 85 % in 1999, (fig. no 1), as a result of the reduction of the industrial activities , of the retechnologization of the production processes and the application of the coercitive measures to the pollutant users conforming the Water Law of 1996.

The results of the carried out investigations on the main natural lakes and reservoirs lead to the conclusion that the quality of the important lakes, correspond to the limits of the 1st and 2nd categories, with a trophyc characteristic specific to the oligotrophyc and mezotrophyc types.

In the table no. 2 there are presented the principle characteristics, from the chemical point of view of the lakes of the river basin, and in the table no.3 , there are presented the characteristics of the lakes, taking into account the trophy level.

Table no. 2

River basin	Total lakes	QUALITY CATEGORIES							
		I		II		III		D	
		No.	%	No.	%	No.	%	No.	%
Tisa	1	1	100	-	-	-	-	-	-
Somes	4	4	100	-	-	-	-	-	-
Mures	6	6	100	-	-	-	-	-	-
Bega-Timis	4	4	100	-	-	-	-	-	-
Nera-Cerna	3	3	100	-	-	-	-	-	-
Jiu	2	2	100	-	-	-	-	-	-
Olt	11	7	63.6	3	27.3	1	9.1	-	-
Arges	12	10	83.3	2	16.7	-	-	-	-
Ialomita	6	3	50.0	3	50.0	-	-	-	-
Siret	18	13	72.2	3	16.7	-	-	2	11.1
Prut	9	2	22.2	2	22.2	5	55.6	-	-
Dunare	10	9	90.0	-	-	1	10.0	-	-
Litoral	6	-	-	-	-	6	100.0	-	-
TOTAL	**92**	**64**	**69.7**	**13**	**14.1**	**13**	**14.1**	**2**	**2.1**

Table no.3

River basin	Total lakes	TROPHY LEVEL					
		O		M		E	
		No.	%	No.	%	No.	%
Tisa	1	1	100.0	-	-	-	-
Somes	4	4	50.0	2	50.0	-	-
Mures	6	5	83.3	1	16.7	-	-
Bega-Timis	4	1	25.0	3	75.0	-	-
Nera – Cerna	3	1	33.3	2	66.7	-	-
Jiu	2	1	50.0	1	50.0	-	-
Olt	11	7	63.6	4	36.3	-	-
Arges	12	9	75.0	3	25.0	-	-
Ialomita	6	3	50.0	1	16.7	2	33.3
Siret	18	6	33.3	8	44.5	4	22.2
Prut	9	2	22.2	2	22.2	5	55.5
Dunare	10	2	20.0	1	10.0	7	70.0
Litoral	6	-	-	4	66.7	2	33.3
TOTAL	**92**	**40**	**43.5**	**32**	**34.7**	**20**	**21.7**

O –oligotrophyc ; M- mezotrophyc; E – eutrophyc level

As far as the groundwater are concerned , a tendency of decreasing of the water quality was noticed, as a result of both insufficient protection of the aquifer layers against the aggression of

the waste waters, especially in the industrial platform areas, and of the persistence of the effects caused by the sometimes inadequate application of the fertilizers and pesticides.

The areas with a high degree of pollution are situated in the river basins of Ialomita- the alluvial cone of Prahova-Teleajen; Arges – Dambovnic Valley; Sasar – Baia Mare area; Jiu – downstream area of Tg. Jiu; Barcau – downstream of Suplacul de Barcau.

Regarding the quality of the Danube River , the very large water discharges which flow into the river ensure a corresponding dilution of the waste waters, so that the water quality is between the limits of the 1st and the 2nd categories.
Quality concentration of the parameters for water, sediments, fishes and oysters increased in the period of the Kosovo war. Some of these parameters, specially heavy metals exceeded, in principle in April 1999, the standards limits and Romanian and international normative.

However, a systematic reduction of the quality of the Danube River waters was measured, due to the discharge of a larger and larger amount of waste waters in entire basin, which results in important effects on the aquatic flora and fauna in the Danube River and Danube Delta.

Water demands of Romania

The water demands increased from 1,4 billion m^3 in 1950 to over 20 billion m^3 in 1989, due to the population increase and industry and agricultural development. (fig. no. 2).

The main tendency registered after 1989 shows the decrease of fresh water requirements of the users up to more reduced values, representing almost 60% of the value of the water requirements mentioned in the permits acts for their normal operation conditions.

On categories of users, (fig. no. 3) in the period 1989-1999 the population used on the average between 10-17%, the industry 60-43% and the agriculture 24-45% of water quantity prelevated from sources, depending on the specific factors and climatic conditions. Among the causes that generated the serious decrease of the fresh water volumes prelevated from the sources, are to mention the following:

- the use of water for irrigation showed an accentuated decrease, being situated at about 30-35% as compared to 1989, due mainly to the difficulties met in ensuring the good operation of the irrigation systems and also to the effects of the application of the Law of the Land;

- the industrial production showed a significant decrease which determined a corresponding decrease of the water quantities, being of about 70-76% as compared to the ones prelevated in 1989;

In order to ensure the water requirements of the various user categories for the future, both from the quantitative and qualitative points of view, the following more important measures are necessary:

- the promotion and achievement of hydraulic works for new water sources in order to satisfy the requirements in the deficiency areas: Turda; Jiu Valley; Brasov; Baia-Mare; Campia Turzii; Medias; Bacau; Predeal; Azuga; etc.

- the promotion of investment programmes for the retechnologisation of the production processes, through the use of new clean, non pollutant technologies and the achievement of WWTPs , in view of eliminating the pollutants into the surface and groundwater;

- the reduction of the water loss in the distribution networks and in households which represent 30-40% of the treated waters;

- the improvement of the systems of economic mechanisms in the field of the water resources by updating the quantum of prices and penalties for the products and services of water management and the increase of fines to sanction the violations in the water field;

- the education regarding the interest in a clean water environment has to be continuous, begun in school, obviously at higher rates than it is done nowadays – it has to be continued in the working activities.

The preservation of the surrounding environment, in general, and of the water environment, in particular , has to be done by a rational understanding of the technological age, with a strict understanding observation of the biological requirements to the flora and fauna and not by stopping the socio-economical development.

Regarding the forecast of the water demands in Romania for the following 20 years, it is predicted, based on the studies elaborated of the economical departments, to be attained the water demands of the year 1989 – about. 20 billion m^3 in the year 2020.
In this period it is forecasted that the Romanian population to increase from 22,54 billion inhabitants in 1999 to 23,1 billion inhabitants in 2020.
Also, concerning the public water supply, this will increase in 2020, as: in country side from 20.03% in 1999 to 85%, and in urban localities from 87% to 99%.

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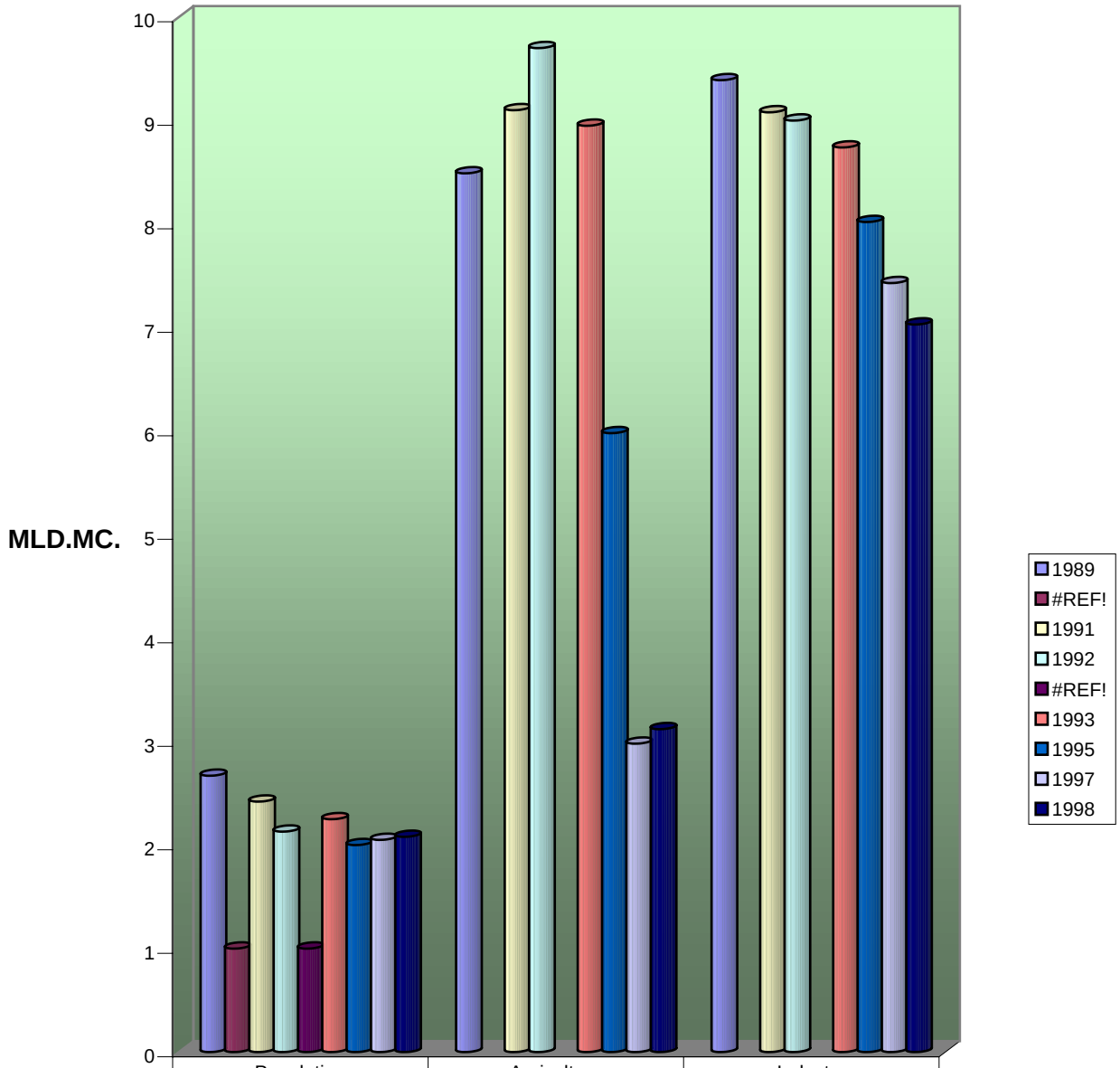
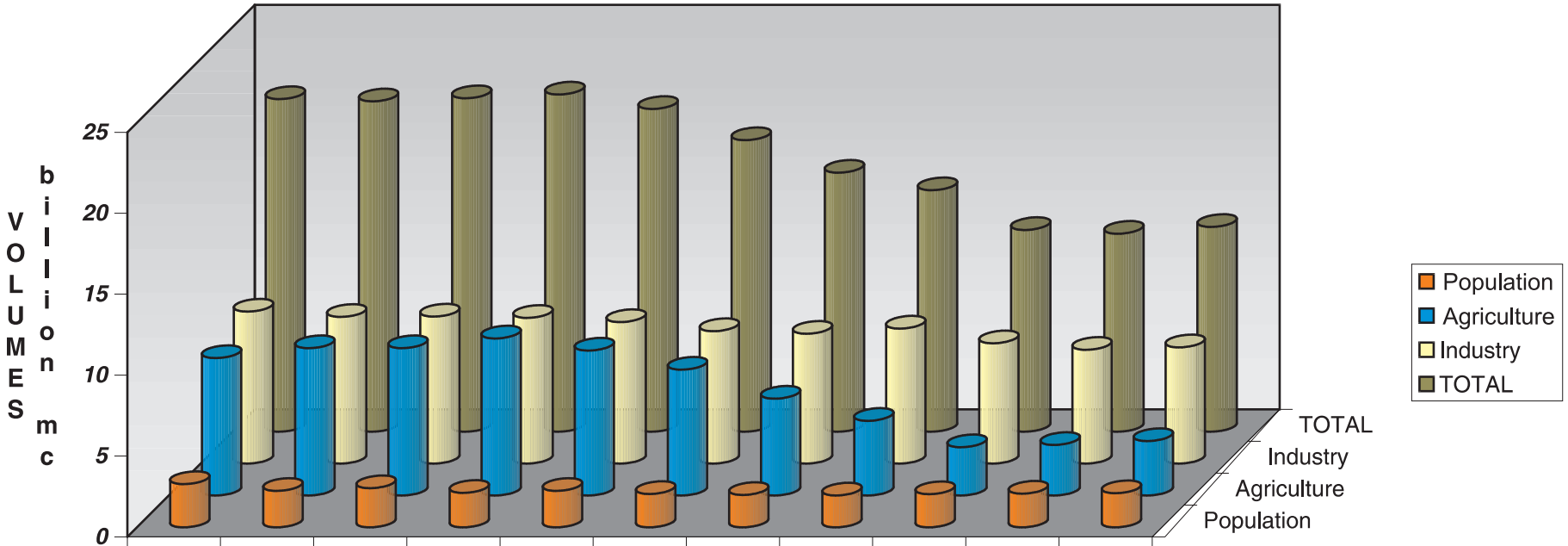
Fig.1 EVOLUTIA CERINTELOR DE APA IN ROMANIA



	Population	Agriculture	Industry
1989	2,67	8,49	9,39
#REF!	1		
1991	2,42	9,1	9,08
1992	2,13	9,7	9
#REF!	1		
1993	2,25	8,95	8,74
1995	2	5,98	8,02
1997	2,05	2,98	7,43
1998	2,08	3,12	7,03

ACTIVITATI

Fig. 2 Water demands in the period 1989-1999



	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Population	2,67	2,25	2,42	2,13	2,25	2,06	2	1,97	2,05	2,08	2,11
Agriculture	8,49	9,1	9,1	9,7	8,95	7,77	5,98	4,61	2,98	3,12	3,36
Industry	9,39	9,06	9,08	9	8,74	8,18	8,02	8,34	7,43	7,03	7,18
TOTAL	20,55	20,41	20,6	20,83	19,94	18,01	16	14,92	12,46	12,23	12,65

Managing Irrigation Projects By Using Extended GIS Model

Milan Čistý

Abstract: Integrated land use and water management play significant role in sustainable agriculture in the Slovak Republic. The most productive soils are located in regions with occasional water scarcity. Large scale irrigation projects are built in order to stabilize the farming industry and offset adverse effects and damage caused either by occasional shortage or an uneven distribution of precipitation.

In connection with the process of social and economic transition, which is under way in the region, irrigation projects need to meet other requirements, than those for which they have been designed. The paper presents application GIS and modern heuristic methods to evaluating rehabilitation needs of irrigation systems.

Key words: Irrigation, Rehabilitation, GIS, Genetic Algorithms

Verwaltung von Bewaesserungssystemen mit verwendung von GIS Modellen

Zusammenfassung: Die Integration der Bodennutzung und Wasserwirtschaft spielt eine bedeutende Rolle für das langfristige Überleben der Landwirtchaft in der Slowakischen Republik. Die produktivsten Böden befinden sich in Gebieten mit temporärem Wassermangel. Die Großflächenbewässerungssysteme sind gebaut worden, um die Landwirtschaft zu stabilisieren und die ungünstigen Einflüsse auszugleichen, die durch den Wassermangel oder ungeeignete Zeitverteilung der Niederschläge verursacht wurden.

Im Zusammenhang mit dem laufenden Prozess der sozialen und ökonomischen Transformation müssen die Bewässerungssysteme andere Anforderungen erfüllen, als die, für die sie ursprünglich geplant wurden. Der Beitrag präsentiert eine Applikation der GIS und moderner heuristischer Methoden für die Auswertung des Bedarfes für die Rekonstruktion der Bewässerungssysteme.

Schlüsselworte: Bewässerung, Rekonstruktion, GIS, Genetische Algorithmen

1 Preface

Transformation of the socio-economic system in Central and Eastern Europe, followed by the decline in the agricultural production and favourable hydrologic conditions, resulted in a negative impact on the exploitation of irrigation systems in the region. This situation lead to unfitness of irrigation equipment at times of dryiness (e.g. this spring). This fact will have negative impact to nation's agricultural output. Some of the larger sprinkler irrigation systems, which were built in the Slovak Republic starting from early fifties, are now approaching the end of their useful life. Some of them are out of operation, due to their wear-out, obsoleteness or more serious failures.

The need for irrigation in the individual regions of Slovakia is presumably determined by annual rainfall and its distribution throughout the year as well as by other climatic factors, as air temperature and saturation deficit are. Hence now, in the majority of irrigation networks, there are more consumers of irrigation water. As a result, there is higher demand for irrigation water during the peak period than is available in the system due to its limited capacity, i.e. both irrigation piping system and pump stations. That is why rehabilitation and modernisation of these systems has become a centre of primary interest for irrigators of today.

Geographic Information Systems (GIS) are introduced for use in irrigation industry in Slovakia (Jenčo, 1999). Recent advances (in both GIS technology and user implementation) treat the GIS as a true spatial modeller, in which the connectivity of the network, the hydraulic behaviour of components, and its relationship to consumers are paramount. Windows operating systems and inter-application communication encourage the use of GIS as an integrated component, rather

than an isolated tool. This paper is describing the possibilities for extending analytical tools of GIS by OLE Automation technology, so they could be used for designing of rehabilitation of the irrigation projects.

2 Methodology

Applications that support OLE Automation expose interface components known as ActiveX objects. To exemplify, one of them in GIS type of software is called the Drawing object. When a drawing is open, it is represented programmatically as an instance of the Drawing object, which provides a drawing with properties and methods that can be used to manipulate it. One of the Drawing properties is for instance FullName, the full path name of a drawing, and one of its methods is Save. Objects can contain other objects. Some types of contained objects are contained as individuals, and some as members of collections. The ActiveX objects of an application, their hierarchy of container relationships, and all the properties and methods that knit them together into a coherent programming interface are referred to collectively as the application's object model.

Used GIS package Autodesk WORLD includes integrated Microsoft Visual Basic for Applications scripting environment. By means of Visual Basic it is possible to manipulate with the GIS object model (programmatically manipulate with GIS data), add new features to program or attach and integrate thereto external programs. The software system presented here has attached the following analytical tools for network rehabilitation: linear programming model for optimization, simulation model of the network hydraulics, some specific analytical tools (longitudinal profiles, etc) and genetic algorithm model for rehabilitation optimization. The last one is now described in more detail.

3 Genetic Algorithm Model

The core of presented system is an ActiveX genetic algorithm component which is not specific to any particular domain. This component has been integrated with WORLD, a Geographical Information System (GIS) for Microsoft Windows 98 and NT. By means of the Visual Basic for Application also Epanet Toolkit (Rossman, 2000) for water systems network modeling was included.

Genetic algorithms are stochastic search methods that mimic the process of natural selection and mechanism of population genetics. Description of the GA can be found in Goldberg (1989). The following pseudo-code shows how a GA works:

```
BEGIN /* genetic algorithm*/
    Generate initial population;
    Compute fitness of each individual;
    WHILE NOT finished DO LOOP
            BEGIN
                    Select individuals from old generations for mating;
                    Create offspring by applying recombination and/or mutation
                    to the selected individuals ;
                    Compute fitness of the new individuals;
                    Kill old individuals to make room for new chromosomes and
                    insert offspring in the new generation;
                    IF Population has converged THEN finishes := TRUE ;
            END
END
```

In case of pipe network rehabilitation, the optimization problem lies in minimizing the cost of upgrading the network while preserving standard operational conditions. Rehabilitation options can include pipe removal and replacement (with pipes from any set of those with available diameters) or pipe duplication with pipes of any diameter. The chromosome can be either a binary or integer string of numbers (representing possible decisions), which thus defines the network design.

A model is first set up, incorporating all the options for individual network components. The GA then generates trial solutions, with each being evaluated by simulating its hydraulic performance on the simulation module. Any hydraulic infeasibility, such as failure to reach a specified minimum pressure at any demand point, is registered, and penalty cost calculated. Operational (e.g. power-consumption) costs can also be calculated at this point, if required. Penalty costs are then combined with anticipated capital and operational costs to obtain an overall measure of quality of the trial solution. The process will continue for many thousands of iterations (Fig. 1), and a population of good feasible solutions will evolve.

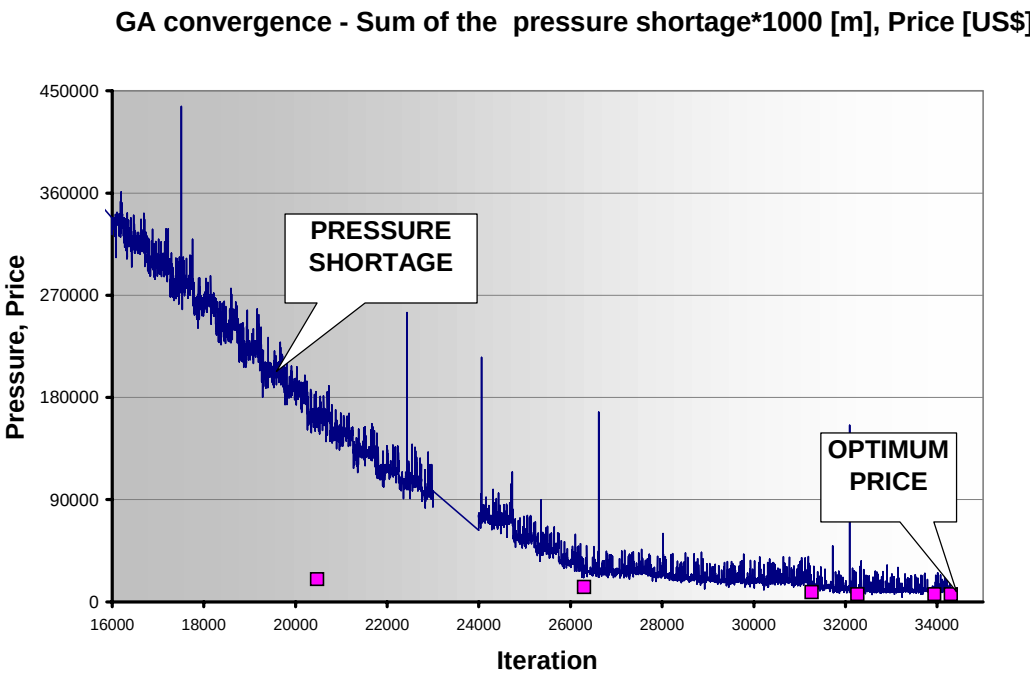


Fig.1 GA Convergence

4 Conclusions

Economic and hydraulic effectiveness of the rehabilitation of sprinkler irrigation systems is largely conditioned by the fact how effective was the rehabilitation of their pipe network. Due to complexity of networks and inability to cope well with discrete, non-linear combinatorial problem, such as pipe network optimization, the conventional optimization techniques are ill-suited for solving this task. The main practical advantages of using genetic algorithm approach are:

- Ease computing of complex networks (i.e., each part of the system that can be simulated could also be the subject of optimization).
- Relatively simple methodology (compared to conventional methods of mathematical programming).

Some technical demands on the proper water distribution network design are not included in the genetic algorithm methodology. It is for instance demand on continual decreasing of the

diameters sizes on path from source nodes (tanks, pump stations) to the end nodes of the network. This ought to be manually corrected by designer. There are also other such things and for all of them it is useful to review GA results in GIS environment. There is also large amount of graphical and database type of input data for GA computation – collecting and store them is also practical with GIS software. On the Fig.2 is displayed an example of such GIS analysis of the rehabilitation design. It is thematic map of the network. Thematic map is a graphic representation of attribute data related to specified spatial objects. In Autodesk World – used GIS software in this work - there are four basic types of thematic maps, which could be created. One of them is ranged map, which group the queried attribute data into ranges of values, so that World displays each queried spatial object (links or nodes of the irrigation network) differently depending on the value range associated with it. There are two themes displayed together on the Figure 2. On the first is database field with differences between original and designed diameters assigned to network links. Second theme is database field with difference between old pressures from original network and new pressure obtained by simulation computation of the rehabilitated network assigned to network nodes. Attribute values are represented by colours (see legend). On this thematic map one could to evaluate impact of diameter change in some part of the network to improvement of the pressures to desired level.

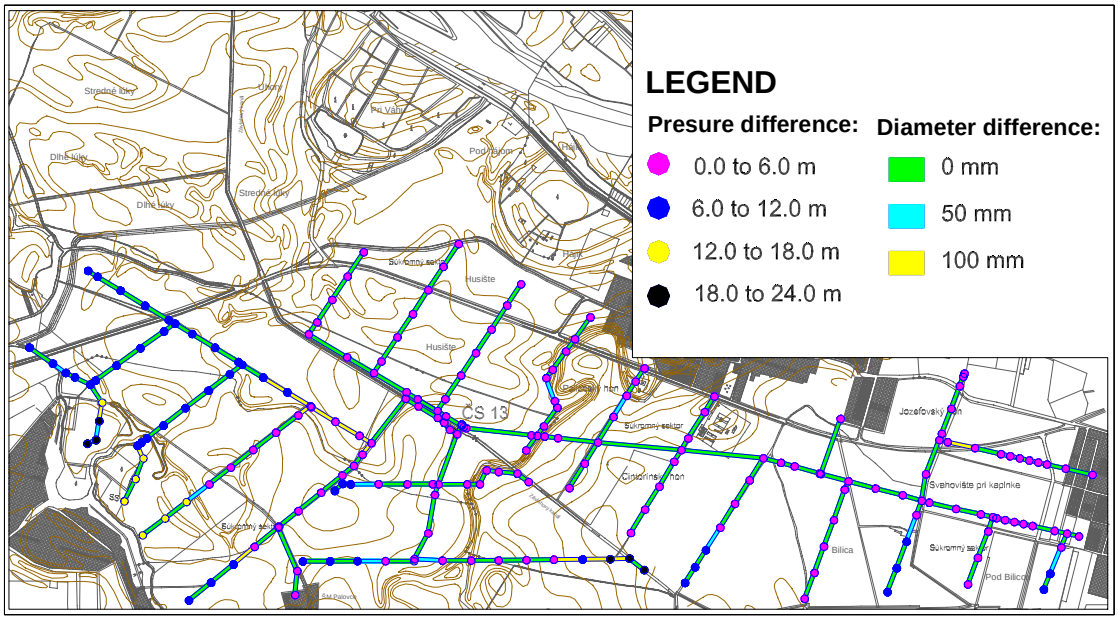


Fig.2 Irrigation network hydraulics analysis in GIS environment

Acknowledgment

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Comparison of Two Regional Approaches: the Danube Monograph (1986) and the FREND Report (1989)

Miklós Domokos

Abstract: The goals of international hydrological projects, including three major European projects: the Rhine Monograph (1977), the Danube Monograph (1986) and FREND (1989), are reviewed. The results of the latter two projects (database, data analysis) are evaluated in more detail. Based on a comparison of these two projects, the following conclusions are drawn: (a) The FREND region (2.5 million km^2) seems to be too large and geographically too heterogeneous as compared with the Danube Catchment (0.82 million km^2) which is a natural unit. Besides, the method of clustering gauging stations as adopted in FREND, has less to recommend it than grouping on a physical basis. (b) The database of the Danube Monograph is rather moderate in size, compared with that of FREND. (c) FREND offers a great number of hydrological relationships, which can be utilized to provide information on small ungauged basins. These relationships, however, do not appear to be more reliable than pre-existing similar relationships developed for those European countries with a well-established tradition in hydrology. (d) The Danube Monograph, on the other hand, offers relationships and hydrological longitudinal profiles for major rivers as well as isoline maps of water budget elements that could not have been compiled without international cooperation. (e) An additional feature of the Danube Monograph compared with FREND, is the series of long-term water balances of sub-catchments and partial national areas of the Catchment.

Key words: hydrological monograph, regionalization, database, water balance

Ein Vergleich von zwei regionalen Annäherungen: die Donaumonographie (1986) und der FREND-Bericht (1989)

Zusammenfassung: Es werden die Zielsetzungen von internationalen Projekten, darunter von drei größeren europäischen Projekten (Rheinmonographie 1977, Donaumonographie 1986 und FREND 1989) überblickt. Die Ergebnisse der beiden letzteren (Datenbasis, Datenanalyse) werden ausführlicher diskutiert. Aufgrund eines Vergleichs zwischen den beiden werden folgende Schlüsse gezogen: (a) Die FREND-Region (2,5 Mio km^2) scheint, mit dem Dunaueinzugsgebiet (0.82 Mio km^2) als einer natürlichen Eiheit verglichen, zu groß und geographisch zu heterogen zu sein. (b) Der Umfang der Datenbasis der Donaumonographie ist wesentlich bescheidener, als diejenige von FREND. (c) FREND stellt zahlreiche hydrologische Beziehungen zur Verfügung, welche die Abschätzung von Informationen über kleine unbeobachtete Einzugsgebiete ermöglichen. Diese Beziehungen scheinen jedoch keineswegs zuverlässiger zu sein, als diejenigen, die in den europäischen Ländern mit einer bestimmten hydrologischen Tradition bereits früher zur Verfügung standen. (d) Die Donaumonographie enthält andererseits Beziehungen und hydrologische Längsschnitte für die größeren Flüsse sowie Isolinienkarten der Wasserbilanz-Elemente, welche ohne eine internationale Zusammenarbeit nicht hätten erstellt werden können. (e) Eine zusätzliche Eigenschaft der Donaumonographie ist, im Gegensatz zu FREND, daß sie für die Teileinzugsgebiete und die nationalen Gebietsanteile im Donauraum auch eine Reihe langjähriger Wasserbilanzen enthält.

Schlüsselworte: hydrologische Monographie, Regionalisierung, Datenbasis, Wasserbilanz

The goals of international hydrological projects

The goals of international projects which involve the organizing and processing of hydrological data sets of large geographical regions not confined by national boundaries, can be mainly

summarized as follows: determination of relationships for filling data gaps and estimating missing data, adoption of uniform methods of data processing, comparison of the methods traditionally adopted in the countries concerned, transboundary characterization of hydrological regimes and regionalization of hydrological relationships, better understanding of hydrological behaviour.

History: Three major international hydrological projects

The western and middle part of Europe, covering about 5 million km^2, is heavily intersected by national boundaries. Cooperation between several countries to explore hydrological laws characterizing major geographical regions started relatively late in this area, only about 30 years ago. At the same time, various outstanding hydrologists (Kalinin, 1971; L'vovich, 1972; Sokolovsky, 1968) of the former Soviet Union (total area 22.4 million km^2, comprising 5.6 million km^2 of the European continent) had determined hydrological relationships of regions of similar or greater size, without being forced to transgress state boundaries or organize any international cooperation.

So far three important regional hydrological projects, based on international cooperation, have been carried out in the non-Soviet part of Europe:

(a) The hydrological monograph of the Rhine Basin, covering 0.16 million km^2, was finished in 1977 by the five countries concerned - Switzerland, France, Germany, Luxembourg and Netherlands (CIHBR, 1977). Since then, various thematic follow-up volumes of the Rhine Monograph have been published.

(b) The Danube basin, 0.82 million km^2 in area, was managed up until 1990 by eight riparian countries: Germany, Austria, Czechoslovakia, Hungary, Yugoslavia, Romania, Bulgaria and Soviet Union. As a result of the joint efforts of the hydrologists of these eight countries, partly inspired by the example of the Rhine Monograph, a three-volume hydrological monograph of the Danube basin was completed in 1986 (RZdD, 1986; Schiller, 1989). The Hydrological Yearbooks and other publications of the International Danube Commission (e.g. CD, 1966) can be considered as the antecedents of the Monograph and mainly contain information collected from the riparian countries regarding the navigability of the Danube. Since the publication of the Monograph in 1986, and still following the example of the Rhine Monograph, four thematic follow-up volumes of the Danube Monograph have been published (RZdD 1993a, RZdD 1993b, RZdD 1996, RCDC 1999) and a few more ones are now under preparation. In the meantime, the number of Danube Countries increased, as a consequence of political changes, to 13.

(c) The two-volume report of the international project FREND, investigating the hydrological regimes of an area covering about 2.5 million km^2 in northern and western Europe, was published in February 1989 (FREND, 1989). This was the result of the joint efforts of 13 countries (Austria, Belgium, Switzerland, Federal Republic of Germany, Denmark, Finland, France, Republic of Ireland, Luxembourg, Norway, Netherlands, Sweden, UK), prompted by, and carried out under, the framework of IHP/UNESCO, and based on important earlier results (NERC, 1975; Beran et al., 1985). Since the issue of the FREND report, the cooperation, supported by IHP/UNESCO, (under the acronym FRIEND), has been continued and even intensified, partly by substantially widening the scope of investigations and partly by expanding them to further regions: Middle and East Europe, Alpine and Mediterranean FRIEND-AMHY, etc. (Demuth, 1990). FRIEND reports are being issued every four years (FRIEND, 1993, FRIEND, 1997).

Hungary and the international hydrological projects

The whole national area of Hungary (0.09 million km^2) lies within the Danube Catchment. Due to her special geographical situation, the economic life of the country is heavily dependent on the success of measures for flood control and water resources. As a consequence, Hungary can rely on

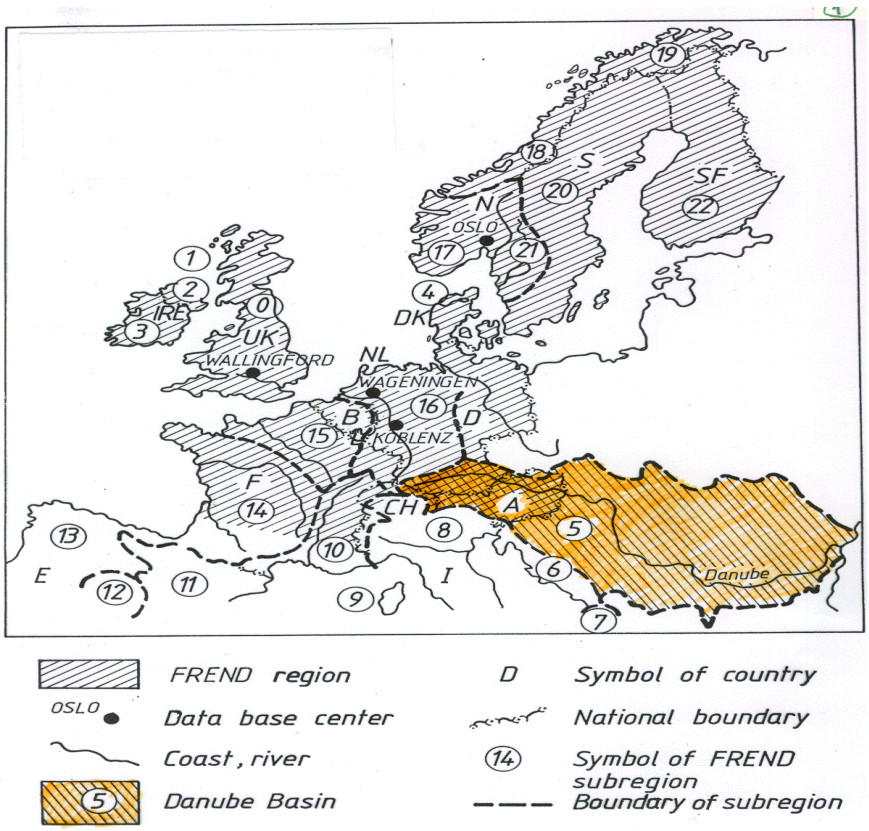

Fig. 1 The FREND region and the Danube Catchment

rich traditions and results in hydrology, having produced special hydrological methods, nomograms, etc. (Starosolszky, 1990).

Hungarian hydrologists have played an active role from as early as 1972 in developing the Danube Monograph. They also smoothed the way for cooperation among the Danube countries, with rather differing political establishments at that time. The synthesizing final chapter of the 1986 Danube Monograph, dealing with the water balance of the Danube Catchment, was prepared in Budapest (Domokos & Sass,1990). Three of the four follow-up volumes published before 2000, of the Danube Monograph were compiled in Budapest (RZdD 1993, RZdD 1996, RCDC 1999).

At the same time, the community of Hungarian hydrologists has paid great attention to the work of the FREND/FRIEND project, although Hungary has not played any active role in it so far. A very detailed review and evaluation of the FREND (1989) report, quoting as many as 18 of its figures was published in a Hungarian journal under the title "The hydrological project FREND of the west- and north-European countries, as the Hungarians see it" (Domokos, 1991). This paper, having reviewed in detail the results of the FREND 1989 report, makes a comparison between them and those of the Danube Monograph (RZdD, 1986). It also considers the expediency of continuing cooperation of the Danube Countries in the framework of FREND. However, it also looks at those results and experiences of FREND which could be adopted by the Danube Countries should the traditional framework of their cooperation be maintained in the future. Comments from this last paper are included in the following sections, whose main concern is a comparison of the basic philosophy of the two great regional projects, most explicitly expressed in their initial results: the Danube Monograph itself and the FREND report of 1989. Thus the following analysis will not be extended to the four follow-up volumes of the Danube Monograph and to the FRIEND reports of 1993 and 1997, since their philosophies did not change as compared with the initial works quoted.

The areas investigated by the two projects

By way of introduction, it seems to be worthwhile to point out the striking differences in the delineation of the areas investigated by the two projects (Fig. 1). The FREND area covering 2.5 million km^2, from the western coast of Ireland to the eastern boundary of Austria and from France up to Lapland, contains a number of great river basins and topographically and climatically different regions. The Danube project, on the other hand, focuses on the basin of a single river (the second largest in Europe) covering an area of 0.82 million km^2, which can more easily be considered a physio-geographical unit. When delineating the FREND region, political homogeneity obviously played a role, enabling more efficient utilization of research resources. On the other hand, when the Danube basin was identified as a project area, one of the focal viewpoints, besides physio-geographical unity, was the willingness to start scientific cooperation between the Danube Countries, having at that time different political systems and even now different financial and technical possibilities. The compilation of the Danube Monograph took 14 years, from its beginning in 1972 to its publication in 1986, while no more than 4 years was required for the 13 FREND-countries to compile their first report (FREND, 1989), including the processing of a considerably larger amount of observed data. This was mostly due to the political homogeneity and differing financial possibilities of the countries involved in the two projects.

As regards the main results of the two projects, both of them have two main components: the setting up of an international database and the determination of new hydrological relationships by analysing these data.

Databases

In the FREND database, the daily discharge data, basin characteristics and climatic information of more than 2100 catchments, from 13 countries each less than 500 km^2 in area, were stored. (In 1989, the average length of the discharge series was 17 years.) In the Danube project, no database of similar magnitude was created. Only the discharge series of 25 gauging stations on the Danube and 25 more stations on its main tributaries were archived with the average length of the series being about 40 years (1931-1970). Discharges of small streams were not collected at all. The values of the three main components of the water budget: precipitation, evapotranspiration and runoff, were taken from isoline maps previously compiled in the countries concerned. No numerical information about the physical characteristics of the sub-basins were collected; a verbal description of the physical features can be found in the text of the Monograph.

The results of data analysis

In the framework of the FREND project, a great number of regional hydrological relationships characterizing small catchments were derived by processing data en masse. Major results related to *floods* include: the clustering of the FREND stations into typical groups according to the main characteristics of flood regimes (Fig. 2), the elaboration of normalized flood duration curves (Fig. 3) and flood statistics for these clusters as well *as* the determination of empirical relationships for the estimation of the mean high flow Q_{max}, necessary for the practical application of these normalized curves. In the chapter dealing with regional *low flow* studies, the flow duration curves of drainage basins of different geological structure are typified, among others, along with their recession-duration curves. Empirical relationships between the mean annual characteristics of average runoff and its coefficient of variation were determined. The gauging stations of the FREND region are also classified according to their low flow regime. Next, the stations studied are listed into clusters on the basis of their low flow characteristics, and empirical relationships for each cluster and for the total FREND region (Fig. 4) are presented.

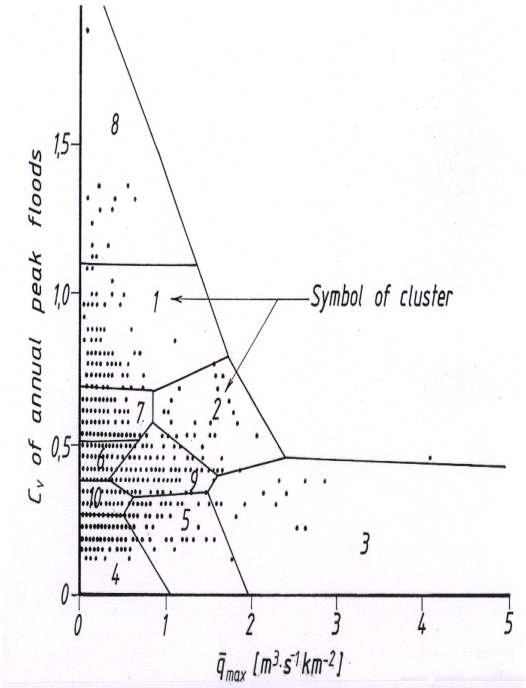

Fig. 2 The data space defined by specific mean flood yield q_{max} and its coefficient of variation C_v for 1597 series of annual instantaneous peak floods, with a partition into 10 station groups based on non-hierarchical cluster analysis (FREND, 1989).

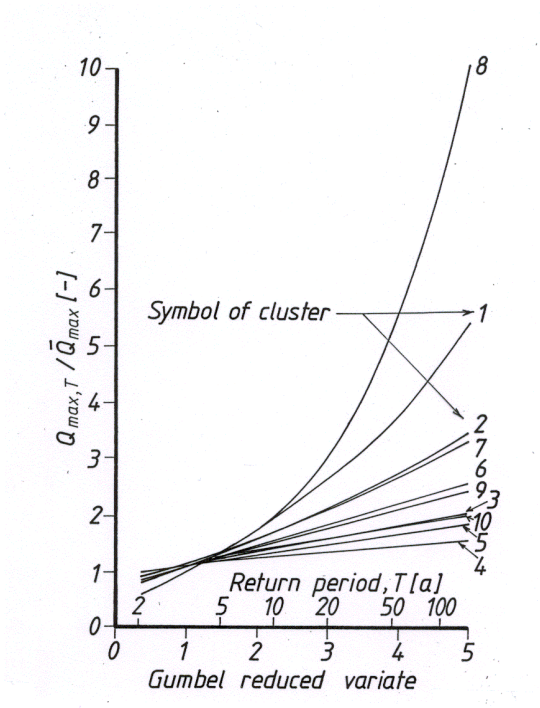

Fig. 3 Regional normalized flood frequency curves for 10 station groups identified by cluster analysis in Fig. 2 (FREND, 1989).

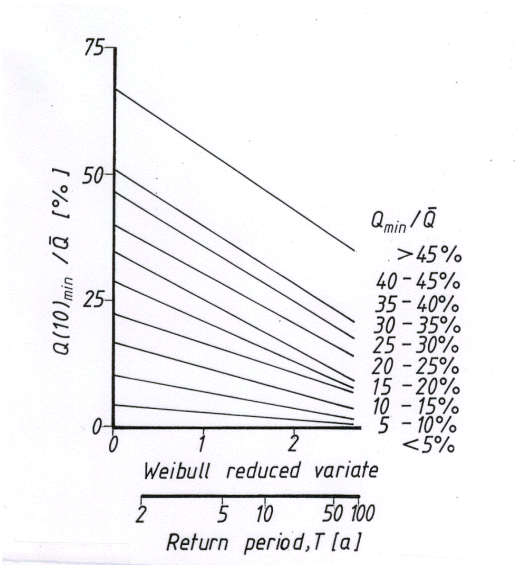

Fig. 4 Average duration curves of normalized daily discharges of 95% duration, $Q_{95\%}$, for the whole FREND region (FREND, 1989).

The database of the Danube Monograph contains, as mentioned above, only the discharge series of the Danube and its main tributaries, but no discharges and physical characteristics for smaller basins. As a consequence, the results of the Danube Monograph cannot include empirical relationships, like those of FREND (e.g. Figs 3 and 4), which can be utilized for the estimation of missing data in small ungauged catchments. However, a great number of hydrological relationships characterizing the flow regime of the major rivers in the Danube basin, like Figs. 5 and 6, were determined. Also a major addition of the Danube Monograph compared with FREND, is the construction of isoline maps showing the space distribution of multi-annual (1931-1970) average values of the three main elements of the water budget (precipitation, evapotranspiration and runoff, each in mm year^{-1}). These required international standardization of information and are also readily suited to filling gaps in data. The multi-annual hydrological balances for 47 sub-basins and 12 national partial areas

(the 8 Danube countries of that time plus 4 additional countries with minor areal shares in the Danube basin) were also compiled (Domokos & Sass, 1990) using these maps as a basis.

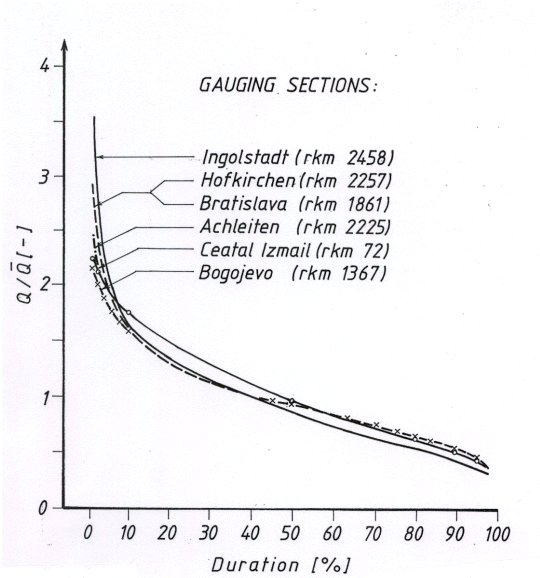

Fig. 5 Normalized flow duration curves for selected gauging stations of the Danube (RZdD, 1986).

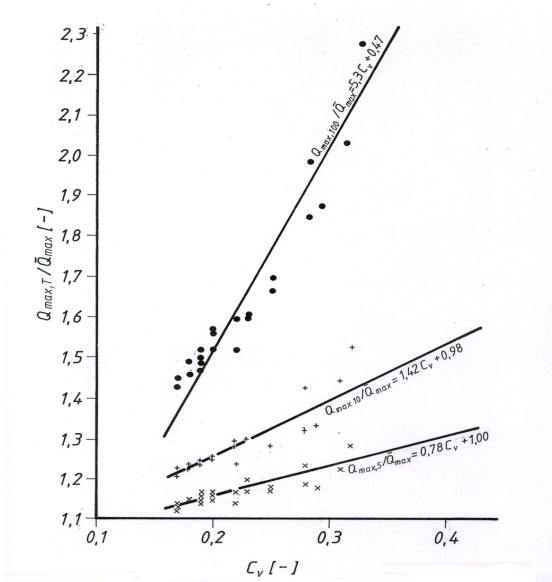

Fig. 6 Relationships between the normalized values of flood discharges $Q_{max,T}$ (for return periods of T years), and the coefficient of variation C_v on the basis of selected gauging stations of the River Danube (RZdD, 1986).

Conclusions

The following conclusions can be drawn in comparisons of the two important international hydrological projects, FREND and the Danube Monograph.

(a) The area investigated by FREND is considerably larger, and includes regions with very different characteristics, due to delineation on a political basis. In contrast, the Danube Basin is a natural hydrologic unit which however is large and sufficiently politically diverse to require international cooperation for its hydrological exploration.

(b) The FREND database includes far more information than that of the Danube Monograph. The latter ought to be substantially extended. Since the publication of the Monograph in 1986, the precipitation database containing the monthly values of 300 stations and the daily values of 30 stations (average length of the series is about 90 years) has already been created. This stock of precipitation data will be the basis for one of the follow-up volumes of the Monograph (dealing with precipitation trends within the Danube Catchment), presently still under compilation (Behr, 1992). Completion of the discharge database has also been started by collecting observed data from 1970, for the time being, from the 50 river gauging sections in the 1986 Monograph.

(c) A major result of the data analysis carried out under the FREND framework is the determination of a great number of empirical relationships, suited to estimating hydrological parameters for small ungauged catchments (e.g. Figs. 3 and 4). However, the experience of the author shows that in most European countries, with fairly dense and long term gauging networks, such empirical relationships had generally already existed (some Hungarian examples are: I.ászlóffy, 1954, Csermák, 1957, Kovács, (geogr.) 1983, Gilyén-Hofer & Domokos, 1985). They are being regularly updated and available in various national standards and handbooks. Such relationships, having been determined on a smaller-scale basis, taking into account non-quantifiable local experiences and being exposed to permanent checking by practical design applications, will necessarily be more reliable than the empirical relationships derived from processing pooled data of large regions. At best, the empirical relationships for small basins resulting from such ambitious international projects, may only be useful in providing international experience for local investigations, looking at the overall structure and tendency of relationships and the appropriate selection of their most relevant variables. But even so, a grouping of the gauging stations according to physio-geographical criteria would be more convincing than mathematical clustering (Fig. 2).

(d) As well as providing a detailed description in a uniform framework of the physio-geographical conditions of the Danube Catchment, the Danube Monograph results include a number of empirical relationships for major rivers, (like Figs 5 and 6), as well as various hydrological longitudinal profiles and the isoline maps of the main components of the water budget. All of them could be created only by international cooperation.

(e) The multi-annual average water balances compiled for the 47 sub-basins and 12 partial national areas of the Danube Basin (Domokos & Sass, 1990) further prove the consistency of the information included in the Monograph, i.e. their usefulness and reliability when adopted in future international water resources development plans of the Danube basin.

In summary, the writer suggests that hydrologists in Hungary and the other Danube Countries continue concentrating their efforts on the hydrological cooperation under way in the Danube basin, as a natural geographical unit.

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Information Bases for Master Water Planning in Croatia

Mira Filipovic, Dragutin Geres

Abstract: Along with the initiative for establishing the Water Management Master Plan in Croatia, a comprehensive work was started to design and develop an appropriate information support to that project. The goal is to provide a complete, efficient and dynamic computer-based information system to help explore the problem and define the plan. A wide range of data has to be processed to assess the status of water system, propose alternatives and evaluate them in accordance with objectives and constraints of the country. Also, a number of scientific and engineering disciplines have to contribute to understand the water matter and different natural and human impacts on it. The paper describes the proposed concept of the information system and initial status of it. Geo-relational approach, combined with some traditional file-based data models, has been implemented to store, manipulate, analyze and present data for planning purposes. Preparation of hydrographic layers (containing topology and description of significant water bodies) is just in progress, separately for four water basin districts in Croatia, the Sava river basin, the Drava and Danube river basin, the Istrian-Littoral basin and the Dalmatian basin. The background for identification and characterization of significant hydrographic components is digitized, 1:100,000-scale topographic map and digital terrain model of Croatia. Other relevant spatial data should be gathered from various sources and transformed to a consistent form. That can be the base for a regional approach and for an overall watershed modelling.

Key words: water master planning, data modelling, GIS

Informationsgrundlagen für die wasserwirtschaftliche Rahmenplanung in Kroatien

Zusammenfassung: Parallel zur Ausarbeitung des wasserwirtschaftlichen Rahmenplanes Kroatiens begann auch eine breitangelegte Erarbeitung des Entwicklungskonzeptes des entsprechenden Informationssystems, das der Unterstützung dieses Programmes dienen soll. Das Ziel der Arbeit ist, ein effektives, dynamisches System mit Hilfe der modernen Informationstechnologie aufzustellen. Um den Zustand der Gewässer zu beurteilen, Alternativen der Entwicklung vorzuschlagen, deren Bewertung durchzuführen und es im Einklang mit den gesellschaftlichen, ökologischen und anderen Zielen und Beschränkungen zu bringen, muss eine groβe Anzahl verschiedenartiger Daten verarbeitet werden. Dazu ist den naturwissenschaftlichen Disziplinen Beachtung zu schenken, sowie auch der Beeinflussung verschiedener Natur- und Gesellschaftsfaktoren, die zum Verständnis der Gewässerproblematik einen Beitrag leisten können. In diesem Artikel werden das Konzept des Informationssystems dargestellt sowie auch die Resultate, die man bisher erzielt hat. Für das Speichern, die Verarbeitung und Analyse und die Darstellung von Daten, die zur Planung erforderlich sind, wird ein georeferenziertes Modell mit den üblichen File-basierten Datenmodellen kombiniert. Hydrographische Layer (Topologie und Beschreibung signifikanter Wassersysteme) sind in Vorbereitung für 4 Einzugsgebiete in Kroatien: Einzugsgebiete der Save sowie der Flüsse Donau und Drau und der Bereich Istrien-Küstenland mit dem Bereich Dalmatien. Als Grundlage zur Definition und Charakterisierung der Gewässerläufe dient eine digitale Karte und ein Digitalmodell des Terrains im Maßstab 1:100.000. Andere wichtige Daten werden aus verschiedenen Quellen gesammelt und entsprechend transformiert. All das ergibt als Endziel eine Grundlage für die hydraulische Modellierung und die Erforschung der Wasserressourcen Kroatiens.

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1 Introduction

The initiative for establishment of the Water Management Master Plan was launched in the 1999, according to the provisions of the Croatian Water Act (1995.).

The Master Plan is stated as a long-term planning document defining the base of water management, water balance and improvement of the water system, in accordance with economic and social development of the country. In particular, it has to determine distribution, supply and properties of water, water requirements in all segments of life and the method of providing sufficient quantity of water, appropriate water protection from pollution and optimum solutions for watercourse regulation, for protection from floods and other adverse effects of water and for ensuring of suitable water regime. It must be based on scientific research, continuous observation of the situation and phenomena in connection with water and its use, respecting of specific water problems in each water basin and integrated environmental protection. So, there is a strong obligation to prepare the Water Management Master Plan within a Physical Plan, to approach to the planning in an integral manner and to co-ordinate it with the Land Use Plan and the Environmental Protection Plan (Geres and Berakovic, 1999). Also, there are some international conventions that have to be respected.

To define a feasible plan, a lot of recent changes, some of them very specific, have to be taken into account. As regards politics, Croatia has become an independent country, in economy many new subjects and relations have been established instead of those destroyed in the war and the transition. Regarding the society, a big devastation and depopulation of large parts of the country has taken place and regarding ecology environmental protection has got a first-rate importance. Under the new circumstances, all proposals have to be harmonized with the newly risen objectives and limitations.

“Hrvatske vode” (“Croatian Waters”) is the legal entity in charge of water management tasks in the Republic of Croatia. For water management purposes, the Croatian state territory is divided into water basins and catchment areas, respecting the fact that it is drained both to the Danube (34,400 km^2) and to the Adriatic Sea (22,100 km^2), trough a series of surface and subsurface flows. Inside these two drainage regions, there are four natural hydrographic entities, constituting four water basins, with their catchment areas comprising one or more catchments of minor watercourses for which integrated water management is provided, with respect to inter-conected problems and existing water system. These are (Fig. 1):

- the Sava river water basin including thirteen catchment areas,
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So far, consideration is given to the national Water Management Master Plan as a prime document. But regarding the data, their range and volume are adjusted to the more detailed purposes and their gathering is let down to the catchment level.

Fig. 1 Map of the water basins and catchment areas in Croatia

2 The Concept of the Information System for Water Master Planning

Powerful information technologies and tools of these days assigned to data modelling and mining, applications of computational simulation and optimisation methods, attractive presentations and similar, can offer a huge contribution at each of the planning phases and can improve to a large degree the quality of the final document. Along with the adequate information assistance, the final plan will be founded on the complete and credible facts and estimates and will have more chance to be properly synthesised, well documented and clearly presented. Also, accompanying information system allows the master plan to be easily reviewed and updated in the future. For all these reasons, a set of directives, regarding the role of informatics in the planning process, has been accepted.

- The Water Management Master Plan is defined as a composed product, combining final, hardcopy reports and maps and an accompanying dynamic information system, supposed to be continuously updated in time.
- The information system is mean to help the planning as well as an important part of the project. It is being designed and developed along with the master planning.
- The information system integrates data and information as well as suitable tools enabling uniform, harmonic and efficient elaboration of all parts of the project.
- The information system is common, official, obligate and accessible to all participants in charge of master planning and other water management tasks.
- The information system is resident at “Hrvatske vode”, putting together its own data and additional relevant data from inside sources and from abroad, to cover to a certain degree the upstream portions of river basins, because Croatia shares its main river basins with the neighbours.

- The central database consists of two major components,
  - integrated water resources register, defining topology and basic attributes of all water bodies in Croatia,
  - spatial data layers, defining natural conditions (climate, morphology, geology, soil, vegetation) and human environment (demography, economy, infrastructure, land use, protected areas) influencing the water system and its future prospects.
- The water body is defined as a discrete and significant element of water which is particularly characterized, including all waters from the water management map, e.g. fresh surface waters (streams, rivers, canals, lakes, reservoirs, wetlands), subsurface waters (springs, aquifers) and coastal waters. Each type of water body has its own characterization pattern and its own set of attributes.
- The integrated water resources register contains:
  - data on the territorial disposition of water bodies and their catchments,
  - basic physical characteristics of water bodies and their catchments,
  - basic morphological characteristics of water bodies and their catchments,
  - basic hydraulic characteristics of water bodies and their catchments,
  - basic hydrological (levels, discharges, volumes) and ecological (physical, chemical and biological) characteristics of waters, surface, subsurface and coastal, their size, variability and trends, estimated from the results of monitoring programmes,
  - basic data on the hydrotechnical development and human impacts on water such as water intakes for different purposes or water pollution from different sources,
  - derived, more meaningful information, get from the observed data by means of some regional analysis and other types of sophisticated water system investigations.
- The central database is designed as a part of the information system, based upon the ESRI's ARC/INFO and ArcView GIS.
- Due to its very nature, implemented geoinformation system is able to produce a lot of interesting parameters using its own technologies such as network analysis, spatial analysis, 3-D analysis, space modelling, watershed modelling.
- Basic hydrological and ecological indicators are estimated from detailed temporal databases, storing a selection of observed time-series, competent for water regime determination.
- The information system includes some additional user-friendly tools and procedures for data reviewing, exploring, processing and visualizing.

3 Development of the Information System

3.1 Origins of the Information System

Application of information technologies has a wide range and a long tradition at "Hrvatske vode". Available capacities are pretty satisfying regarding hardware, software and educated staff. But systematic data management has been slightly improved till now. So, the water system analyses are still dependent on a lot of distributed, redundant and non-consistent data, from a lot of scattered data sources. In such conditions, the main problem is not just the lack of data, but a dilemma which are the right ones, where they are, how to get them, how to transform them to the useful form. That is recognized as an aggravating and restricting factor for sustainable development, management and use of water resources, from the master planning level, through the design of some planned solutions to their implementation.

Water master planning in Croatia, as a comprehensive project, has initiated the idea of adequate integration of data upon the entire water system and its environs. Without a valid knowledge of

the actual state of the water resources system, the planning process and future decisions will be confusing (Grigg, 1996). The goal is to provide a complete, efficient and dynamic computer-based support (databases, models and communications) for planning purposes. A rough scheme of the whole proceeding is shown on Fig. 2, dividing entire information process into the preparation, design, processing and presentation phase.

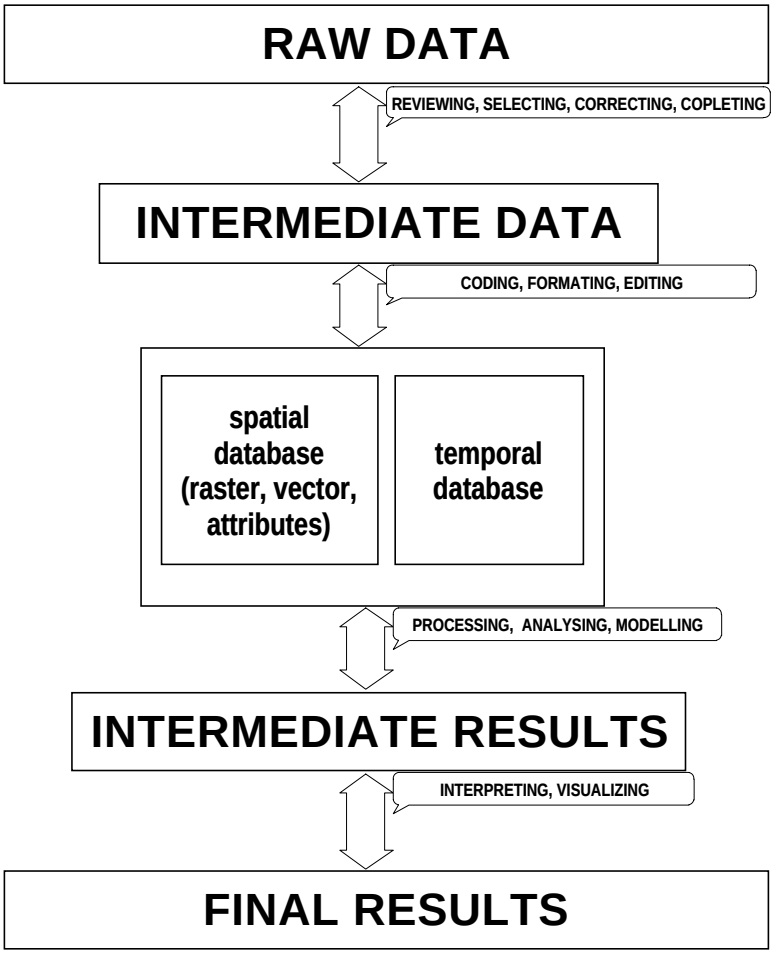

Fig. 2 Scheme of the information process for water master planning

So far, pre-processing is carried on, focusing attention to data as the prime and top priority subject. At disposal there are a number of single sources of raw data, more or less ordered and convenient for further elaboration, like

- conventional topographic maps at different scales,
- data files from run-in monitoring programmes such as meteorogical measurements (temperature, precipitation, evaporation, …), water quantity measurements (stages, velocities, …), water quality monitoring (physical, chemical, biological, …) and similar,
- results of additional field surveyings,
- some particular information systems on specific themes (hydrogeology, pedology),
- some information pilot-programs,
- inventories and inquiries of state administration,
- different existing paper documents, surveys, studies, assessments and plans.

Raw data are being reviewed and their relevant portions selected and remodelled. For all their diversity, interesting data can be divided into two rather distinct groups, those of spatial nature and those giving temporal insight into the problem. That is the reason for composite data model, combining two types of databases, spatial and temporal ones, relating each other through some common identifiers. Both have to be carefully designed and implemented to ensure consistency, accessibility, efficiency and safety of the whole project. Geo-relational approach (based on ESRI's ARC/INFO and ArcView GIS) is joined with some traditional file-based data models convenient for vast volumes of non-spatial data.

Current activities are focused to the central database development, starting from the very beginning. There are a few territorial frames accepted for modelling of spatial data:

- entire national territory (even a broader area) for describing the natural environment of the water system,
- administrative units (counties, communes, municipalities, …) for describing the socio-economic and ecological environment, e.g. human demands and human impacts on the water system,
- hydrographic units for water resources characterization and for water processes, water regime and water budget determination as the scientific basis for planning process.

For first, a general digitized 1:100,000-scale topographic map of Croatia has been obtained, as a background for farther activities. Mapped contents were taken from the official 1:25,000-scale paper map, updated to some extent, by means of satellite images, and converted into the digital form both, as a geocoded raster and as a set of vectorised thematic layers, containing administrative boundaries, settlements, traffic corridors, hydrography and hypsography (ready to generate 3D digital terrain model). Water themes have been put under an extra examination and completed to the up-to-date status.

3.2 Integrated Water Resources Register

Water themes are the most important components of the entire data model. Hydrographic segmentation of the water resources system into relevant water bodies is the first prerequisite to get the integrated water resources register. Water body is a definite portion of the water resources system, which has to be particularly registered and characterized. Such water body can be one single stream or more neighbouring minor streams or a part of a major stream or river, one or more neighbouring lakes, reservoirs or wetlands, an agricultural drainage network or a part of it, an urban drainage network or a part of it, a torrential network or a part of it, a transitional water or a stretch of coastal water, one or more neighbouring aquifers or a distinct part of an major aquifer, and so on. Establishing the water resources register means to identify and label each significant water body and to determine its characteristics.

A watershed oriented coding system has been developed and implemented, introducing a unique code for a watershed as an area, the associated water body, primarily as a line element (surfaces are also marked along some mid-line) and the downstream profile as a point element. The coding is rather specific, but follows some common experiences (Brilly, 1998). Individual catchments are numbered from the main to the subordinate entities and from those lying downstream toward those upstream. The flow direction for coastal water is equated with the sea-stream direction. Separation of individual catchment areas into sub-catchments is determined on the basis of the topography and hydrography, rarely (karst) some other criterion. Starting from the state as a whole, four large entities, corresponding to four water basins, are declared and labelled by one-digit codes: the Sava river basin (1), the Danube and Drava river basin (2), watersheds with direct outflow to the northern Adriatic (3) and watersheds with direct outflow to the southern Adriatic (4). At the second (and any higher) level, farther division and labelling take place, with even codes for main stream sections and associated intermediate catchments and odd codes for tributaries and tributary catchments.

Distance reference points are an additional labelling element for marking facilities or any extra locations comprised by the water body, such as water meter, sampling point, hydrotechnical structure, confluence and so on. Distance reference points originate from the detailed maps, where some mid-line is stated, continually along the flow, in the upstream direction. It is competent for the lenght of the water body. The width and depth are also measured relatively to the mid-line.

All three groups of spatial objects are vectorised and attributed (to a certain extent so far). Arc View and Arc View extensions have been implemented to create the topology for the water body, watershed and output profile and to calculate their topological attributes, like position, shape, size, altitude, slope. Many other attributes can also be determined by data overlapping and modelling, applying GIS technology. Defining of hydrological and ecological attributes is in progress, using time-series data from the monitoring programs. Water bodies, which have been extensively investigated in the past, may keep and probably would keep some of their well-known attributes.

4 Conclusion

Some initial achievements in development of the information system for water master planning are presented. That is an extensive, large-scale and long-term project, undertaken to provide a complete, efficient and dynamic computer-based support (databases, models and communications) for planning purposes. Applied geo-relational data model, joined with the traditional file-based approach, offers nice possibilities for successful data management. So far, attention is focused to the classification and integration of data upon the entire water resources system and its environs. The integrated water resources register is the most important component of the entire data model and its preparation is in progress, as the most extensive current task. Establishing the water resources register means to identify and label each significant water body of the water resources system and to determine its characteristics. In the next phase, more sophisticated methods (regional analyses, watershed modelling, simulation) will be implemented for farther attribution.

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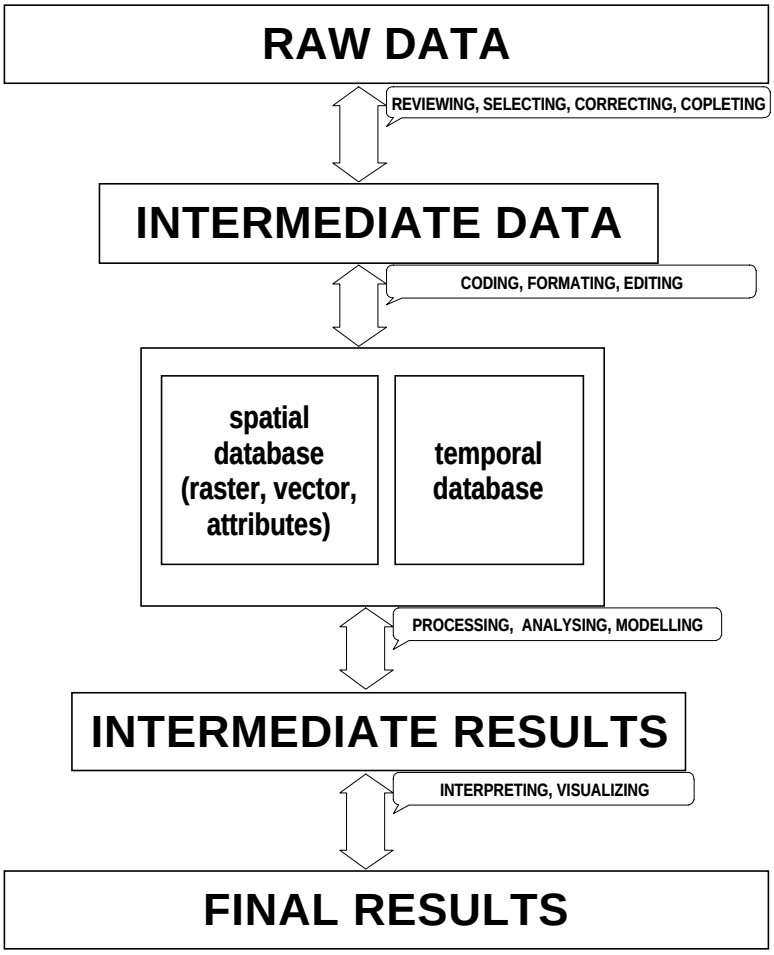

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So far, pre-processing is carried on, focusing attention to data as the prime and top priority subject. At disposal there are a number of single sources of raw data, more or less ordered and convenient for further elaboration, like

- conventional topographic maps at different scales,
- data files from run-in monitoring programmes such as meteorogical measurements (temperature, precipitation, evaporation, …), water quantity measurements (stages, velocities, …), water quality monitoring (physical, chemical, biological, …) and similar,
- results of additional field surveyings,
- some particular information systems on specific themes (hydrogeology, pedology),
- some information pilot-programs,
- inventories and inquiries of state administration,
- different existing paper documents, surveys, studies, assessments and plans.

Raw data are being reviewed and their relevant portions selected and remodelled. For all their diversity, interesting data can be divided into two rather distinct groups, those of spatial nature and those giving temporal insight into the problem. That is the reason for composite data model, combining two types of databases, spatial and temporal ones, relating each other through some common identifiers. Both have to be carefully designed and implemented to ensure consistency, accessibility, efficiency and safety of the whole project. Geo-relational approach (based on ESRI's ARC/INFO and ArcView GIS) is joined with some traditional file-based data models convenient for vast volumes of non-spatial data.

Current activities are focused to the central database development, starting from the very beginning. There are a few territorial frames accepted for modelling of spatial data:

- entire national territory (even a broader area) for describing the natural environment of the water system,
- administrative units (counties, communes, municipalities, …) for describing the socio-economic and ecological environment, e.g. human demands and human impacts on the water system,
- hydrographic units for water resources characterization and for water processes, water regime and water budget determination as the scientific basis for planning process.

For first, a general digitized 1:100,000-scale topographic map of Croatia has been obtained, as a background for farther activities. Mapped contents were taken from the official 1:25,000-scale paper map, updated to some extent, by means of satellite images, and converted into the digital form both, as a geocoded raster and as a set of vectorised thematic layers, containing administrative boundaries, settlements, traffic corridors, hydrography and hypsography (ready to generate 3D digital terrain model). Water themes have been put under an extra examination and completed to the up-to-date status.

3.2 Integrated Water Resources Register

Water themes are the most important components of the entire data model. Hydrographic segmentation of the water resources system into relevant water bodies is the first prerequisite to get the integrated water resources register. Water body is a definite portion of the water resources system, which has to be particularly registered and characterized. Such water body can be one single stream or more neighbouring minor streams or a part of a major stream or river, one or more neighbouring lakes, reservoirs or wetlands, an agricultural drainage network or a part of it, an urban drainage network or a part of it, a torrential network or a part of it, a transitional water or a stretch of coastal water, one or more neighbouring aquifers or a distinct part of an major aquifer, and so on. Establishing the water resources register means to identify and label each significant water body and to determine its characteristics.

A watershed oriented coding system has been developed and implemented, introducing a unique code for a watershed as an area, the associated water body, primarily as a line element (surfaces are also marked along some mid-line) and the downstream profile as a point element. The coding is rather specific, but follows some common experiences (Brilly, 1998). Individual catchments are numbered from the main to the subordinate entities and from those lying downstream toward those upstream. The flow direction for coastal water is equated with the sea-stream direction. Separation of individual catchment areas into sub-catchments is determined on the basis of the topography and hydrography, rarely (karst) some other criterion. Starting from the state as a whole, four large entities, corresponding to four water basins, are declared and labelled by one-digit codes: the Sava river basin (1), the Danube and Drava river basin (2), watersheds with direct outflow to the northern Adriatic (3) and watersheds with direct outflow to the southern Adriatic (4). At the second (and any higher) level, farther division and labelling take place, with even codes for main stream sections and associated intermediate catchments and odd codes for tributaries and tributary catchments.

Distance reference points are an additional labelling element for marking facilities or any extra locations comprised by the water body, such as water meter, sampling point, hydrotechnical structure, confluence and so on. Distance reference points originate from the detailed maps, where some mid-line is stated, continually along the flow, in the upstream direction. It is competent for the lenght of the water body. The width and depth are also measured relatively to the mid-line.

All three groups of spatial objects are vectorised and attributed (to a certain extent so far). Arc View and Arc View extensions have been implemented to create the topology for the water body, watershed and output profile and to calculate their topological attributes, like position, shape, size, altitude, slope. Many other attributes can also be determined by data overlapping and modelling, applying GIS technology. Defining of hydrological and ecological attributes is in progress, using time-series data from the monitoring programs. Water bodies, which have been extensively investigated in the past, may keep and probably would keep some of their well-known attributes.

4 Conclusion

Some initial achievements in development of the information system for water master planning are presented. That is an extensive, large-scale and long-term project, undertaken to provide a complete, efficient and dynamic computer-based support (databases, models and communications) for planning purposes. Applied geo-relational data model, joined with the traditional file-based approach, offers nice possibilities for successful data management. So far, attention is focused to the classification and integration of data upon the entire water resources system and its environs. The integrated water resources register is the most important component of the entire data model and its preparation is in progress, as the most extensive current task. Establishing the water resources register means to identify and label each significant water body of the water resources system and to determine its characteristics. In the next phase, more sophisticated methods (regional analyses, watershed modelling, simulation) will be implemented for farther attribution.

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Variations in the Annual River Runoff of the Bulgarien Tributaries of the Danube

Marin Genev

Abstract: The time variations in the temperature, precipitation and runoff complexes for the total area of North Bulgaria are investigated. The analysis of the variations in the temperatures is performed on the basis of 71 measuring stations and for the precipitations - 134 stations. The variations in the river runoff are investigated through 72 hydrometric stations located in the different catchment basins.

In the chronological variations of the temperatures 6 secondary and 4 basic phases are observed, which form two cycles from 1892 to 1968 and from 1976 to 1995. In the variations of the precipitations have been determined 10 secondary and 6 basic phases also forming two cycles - from 1916 to 1944 and from 1945 to 1981. In the variations of the runoff 7 secondary and 4 basic phases are showed up which form one cycle - from 1945 to 1981. In the tendencies of the runoff a negative phase with a decrease in the wetness is established with a duration of 11 years (from 1985 to 1995) over the investigated area.

Key words: secondary phases, basic phase, cycle, tendencies of variations

Jahresabfluss - Schwankungen der bulgarischen Nebenflüsse der Donau

Zusammenfassung: Es wurden die zeit- und räumlichen Änderungen von Temperatur, Niederschlägen und Abflüssen in Nordbulgarien untersucht. Die Analyse der Temperaturschwankungen basiert auf 71 Stationen. Die Analyse der Schwankungen der Niederschläge wurde aus 134 Stationen abgeleitet. Die Abflußänderungen ergaben sich aus den Daten von 72 hydrometrischen Stationen der einzelnen Flusseinzugsgebiete.

Es wurden 6 sekundäre und 4 Hauptphasen in zwei Zyklen, 1892 bis 1968 und 1976 bis 1995, bezüglich der Temperaturschwankungen ermittelt. Die Niederschläge zeigen 10 sekundäre und 6 Hauptphasen, die ebenfalls zwei Zyklen, 1916 bis 1944 und 1945 bis 1981, bilden. 7 sekundäre und 4 Hauptphasen, ergeben einen Zyklus (1945 – 1981), in dem sich Abflußänderungen abzeichnen. Es wurde eine Phase mit einer Dauer von 11 Jahren (1985 – 1995) in dem untersuchten Gebiet festgestellt.

Schlüsselwörter: sekundäre Phase, Hauptphase, Zyklus, Veränderungstendenz.

1 Introduction

The investigation on the chronological annual changes of the river runoff allows us to determine periods with different duration and wetness. The change in the runoff is related to its genesis, which on the other hand is determined by climatic factors, and above all, by the precipitation. That is why, has been adopted the view that the runoff is a product of the climate. If we take into consideration the infrastructure of the catchment area, then the river runoff can be examined as a result of the action of the transforming basin system. The intensive use and management of waters requires in-depth knowledge of the water resources and their changes over time and space.

2 Short physiographical characteristic

North Bulgaria occupies the territory of one of the basic morphostructural regions of the country - the Danube hilly plain, the foothill of ”Stara Planina” and it’s mountain part. To the North, it borders on the Danube river. To the South, the border goes along the watershed, divide from the Timok river to the Petrohan pass, after which it goes south round the ridge of Vitosha and Rila mountains, and to the North (west of the Vitinia pass), it reaches the main watershed divide of Stara Planina. From there, the border goes eastwards along it up to the Vratnik pass. After that, it goes NorthEast-East side by side with the watershed of Kamchia river, and south of Suvorovo it goes to the North, along the watershed divide with the Black Sea’s rivers, and up to the border with Romania (Geography of Bulgaria, 1966).

3 Short climatic characteristic

According to the climatic division of Bulgaria into districts, North Bulgaria establishes itself as a temperate continental region. Its climate forms under the influence of the transformed oceanic air masses which push in predominantly from the West and the NorthWest (and rarely from the North and the North-East), of the continental air masses of temperate latitudes pushing in from the North-East (rarely from the North-West). Their influence also have the continental air masses that have been formed over the Balkan peninsula. There have also been observed both the intrusions of tropical air, whose frequency and intensity decrease as we move north ward, and of the arctic air masses during the cold half-year. The annual precipitation increases as we move up the mountain. The annual precipitation over the Danube river plain ranges in 500-600mm, and over the Fore Balkan and the valley fields between 600 and 800mm (The Bulgarian climate, 1991).

4 Runoff formation

The formation and the peculiarities of the runoff regime is under the direct influence of the climate of a given region. The climatic elements-precipitation, temperature, and vapour are among the most significant factors, not only in the genesis, but also in the change of the runoff over time (Genev, 1998, Gerasimov and al., 1999, Mandadjiev, 1989, Modev, 1995, Pryvalskiy, 1985). The precipitation is the active component exerting influence over the catchment basins. Having once fallen over a given area, the rainfall transforms under the influence of the nature-landscape, hydrographical, and anthropogenic complexes into runoff. ***Therefore, the precipitation are treated as a resulting effect of the influence (impact) of the meteorological complex over the basin transforming system.*** In its general form, the river runoff is a continuous event with respect to the time random process

$$Q(t) : t \in T \ , \tag{1}$$

which could be discretised over a different time interval. Then, assuming that $\alpha_i(t)$ are the elements of the meteorological complex ($i = 1, 2, \ldots\ldots, k$), the river runoff process is given by the equation

$$Q(t) = \Xi\left[\alpha_1(t), \alpha_2(t), \ldots\ldots, \alpha_k(t)\right] \ , \tag{2}$$

where Ξ represents the structure of the basin transforming system.

When the structure of the basin transforming system is in an equilibrium, i.e. in a permanent state, we assume that the runoff is undisturbed. In this case, to a certain input to the basin system corresponds a respective output. ***This state of the basin system, in which the natural***

regime of the runoff is expressed by the homogeneous time-series, is determined as undisturbed (natural) runoff.

5 Investigation of the fluctuations in the different complexes

When studing the hydrometeorological processes, it is possible to adopt various mathematical and statistical approaches, derived mainly from the theory of random variables, descriptive analysis, correlation analysis, spectral analysis, etc. (Alehin, 1975, Box and al., 1970, Jenkinsand al., 1972, Pentchev and al., 1990, Pery, 1992, Shelutko, 1983). In these cases, the processes describing the changes in the temperature, precipitation, and runoff complex are represented through their random numerical realisations – the time series. The investigations of their annual chronological changes can be divided into two basic approaches directed towards the detection of hidden cyclic recurrences and externally manifesting fluctuations. We use the methods of correlation and spectral analysis in order to find the first type of these fluctuations.

The investigation of the manifesting, external, cyclic changes is possible with the help of the filtered values of the series, and on the basis of calculations of the integral curves (Rojdestvenskiy and al., 1974). In Bulgaria in the analysis connected with the determination of manifesting periods, phases, etc. are used also integral curves (Genev, 1992, Genev and al., 1998, Koleva, 1991, Modev, 1995, Mandadjiev, 1989).

6 Results

The present investigations have been carried out on the basis of the archived information for the systematically conducted observations in the Supporting hydrometeorological network of the National Institute of Meteorology and Hydrology. The analysis of the temperature complex has been carried out on the basis of 72 stations, and for the precipitation complex - from 134 stations. For the runoff complex have been used the main hydrometric stations (basin integrators), located in the lower part of the catchment basins of the rivers Topolovetz, Voinishka, Archar, Lom, Tzibritza, Ogosta, Iskar, Vit, Osam, Rositza, Lefedja, Iantra and Rusenski Lom - right tributaries to river Danube. Due to the fact that the stations for the temperature and runoff complex have different observation periods, their respective series are extended and reduced to a common calendar period, beginning in 1892. The system measurements of water quantities at different hydrometric stations began in 1935, which determines the time period for their investigation as 1935-1997.

For North Bulgaria, which refers to the Danube catchment basin, the investigations of the temperature, precipitation and runoff complex are conducted on the basis of representative, or so - called ***generalized series***. The generalized series for the temperature and precipitation are obtained as a mean of the series reflecting the registered changes in the observed process at each separate station. For the river runoff, the generalized series are the total runoff, registered by the stations integrators, at all catchment basins occupying the given area.

In view of the comparison of the changes in the annual chronology of the series, the value of those are normalized, and represented as deviations from the mean

$$\Psi = (x_i - \bar{x}) / \sigma = (x_i / \sigma) - (1 / C_v) \ , \qquad (3)$$

where x_i is the next term of the series; $\bar{x}$ is the mean for the available time interval; σ - the mean quadratic deviation (standard); C_v - variation coefficient of the series.

The chronological development of the annual and filtered values of these series (representing the fluctuations of the different complexes) over time is given on **Fig.1**. From the figure we see the specificity in the annual changes of the temperature, precipitation, and runoff, which are

generated by the climatic conditions over that territory. We get a particularly clear idea about it from the curves of the filtered, by means of 10, annual values of these series.

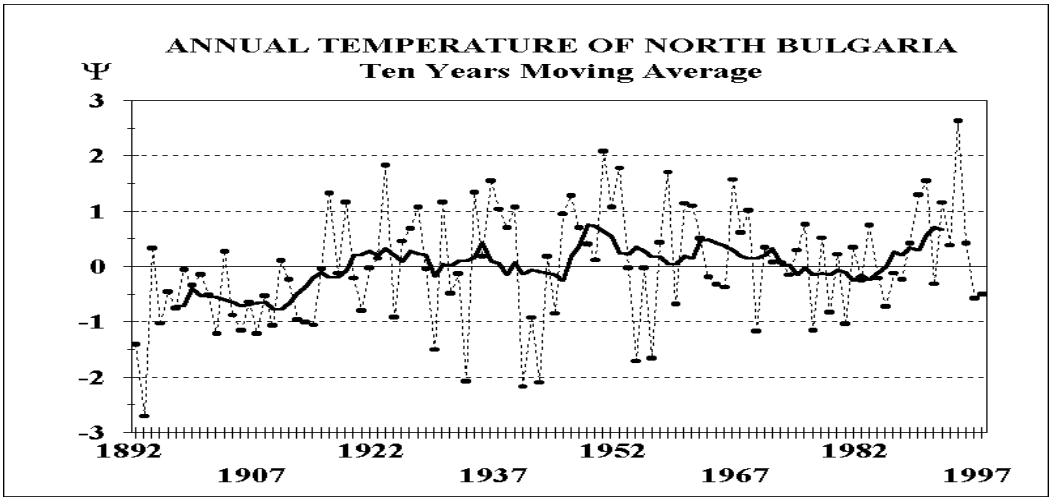
The correlation functions for the annual values of the temperature, precipitation and runoff, are calculated with the maximal deviation in time set to $\tau = 30$. The functions' confidence limits determine the following periods in the changes of the temperature as most significant - 2 years (and showing up periods of 8, 11, and 13 years), for the precipitation - only one manifesting period is determined - of 21 years, and significant for the runoff are periods with duration 1 and 2 years, and manifesting period is only one of 3 years. The average periods for these correlation functions are $t_R = 5.8$, $t_R = 4.1$, and $t_R = 5.8$ respectively (Gergov at al. 1996).

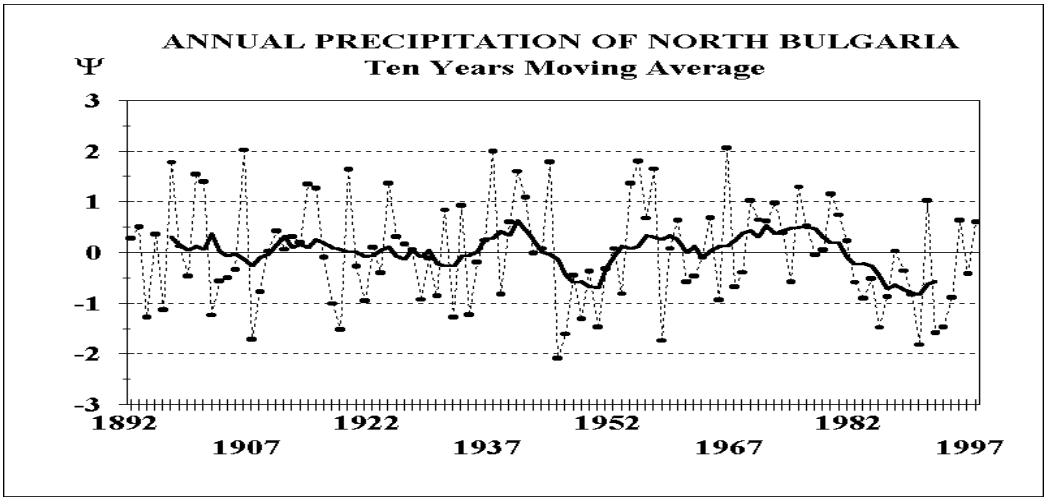
Using applied spectral analysis the hidden periodicities in the temperature, precipitation, and runoff complex are found. By means of them the basic periods with duration - 2.2, 6.9, 11.6 years have been established. For the precipitation these periods are - 2.2, 4.7, and 14.9 years. For the runoff, the established significant periods are: 14.8, 18.5, 24.7 years.

The changes in the annual series for the temperature, precipitation and runoff complex, investigated by means of integral curves, are shown on **Fig.2**. The analysis of the temperature curves show that a period consisting of a phase of decrease of 24 years (1892 - 1915) exists and a phase of smooth increase in the temperature of 53 years (1916 - 1968) do stand out. After that period the development of the process is mostly stable for 7 years (1969 - 1975), followed by a negative phase of 12 years (1976 - 1987), and another positive phase of 8 years (1988 - 1995). In the phase of the increase of the temperatures, whose duration is 53 years, consecutively are shown secondary positive and negative phases of 12 and 6 years (1916 - 1933), 6 and 5 years (1934 - 1944), and 8 and 4 years (1945 - 1956) respectively, and a positive secondary phase with duration 12 years (1957 - 1968). The series which build up the structures of the secondary phases are with duration ranging from 1 year to 2 ÷ 4 years.

In the changes of the precipitation a positive phase of 24 years (1892 - 1915) is observed, after which two periods with duration 29 years (1916 - 1944) and 37 years (1945 - 1981) are determined, and a phase of decrease in precipitation of 13 years (1982 - 1994). The initial phase of the increase in precipitation consists of the following secondary phases: negative of 5 years (1892 - 1896), positive of 5 years (1897 - 1901), negative of 7 years (1902 - 1908) and a positive of 7 years (1909 - 1915). In the evolution of the phase of negative decrease in precipitation of the first period the following secondary phases are shown: negative of 8 years (1916 - 1923), positive of 4 years (1924 - 1927) and a negative of 8 years (1928 - 1935). The positive phase of the second period are formed of a secondary positive phase of 4 years (1954 - 1957), secondary negative phase of 8 years (1958 - 1965) and secondary positive phase of 16 years (1966 - 1981). The structures of all secondary phases are built by the series with duration, ranging from 1 to 2 ÷ 4 years.

The analysis of the integral curve of the river runoff give reasons for finding one basic period (Fig.2). The evolution of the process begins with a feeble manifestation of a phase with positive wetness of 10 years (1935 - 1944), consisting of two secondary phases: of relatively stable





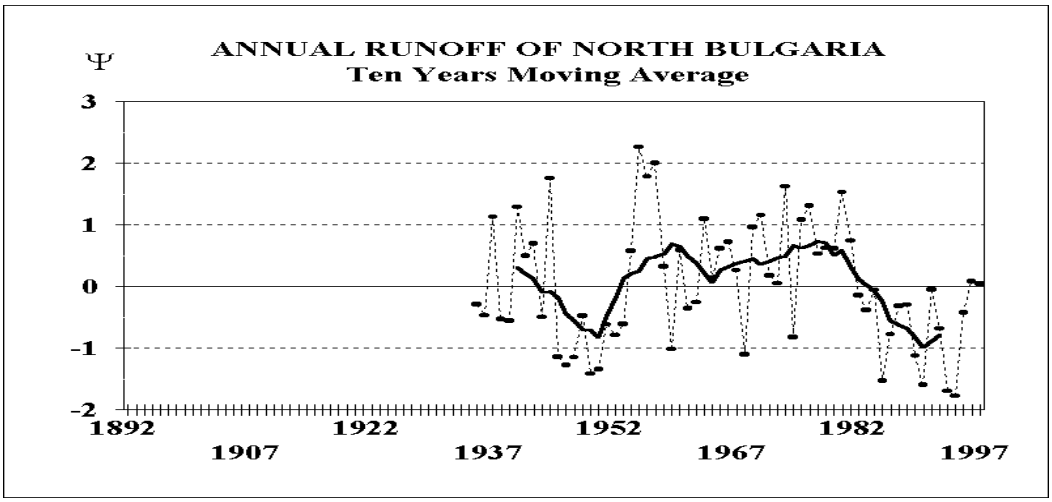
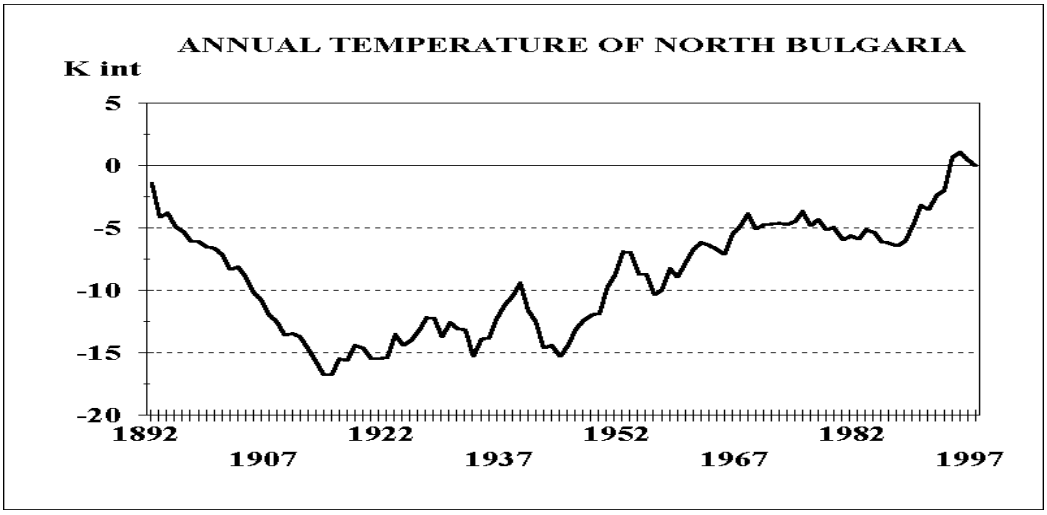
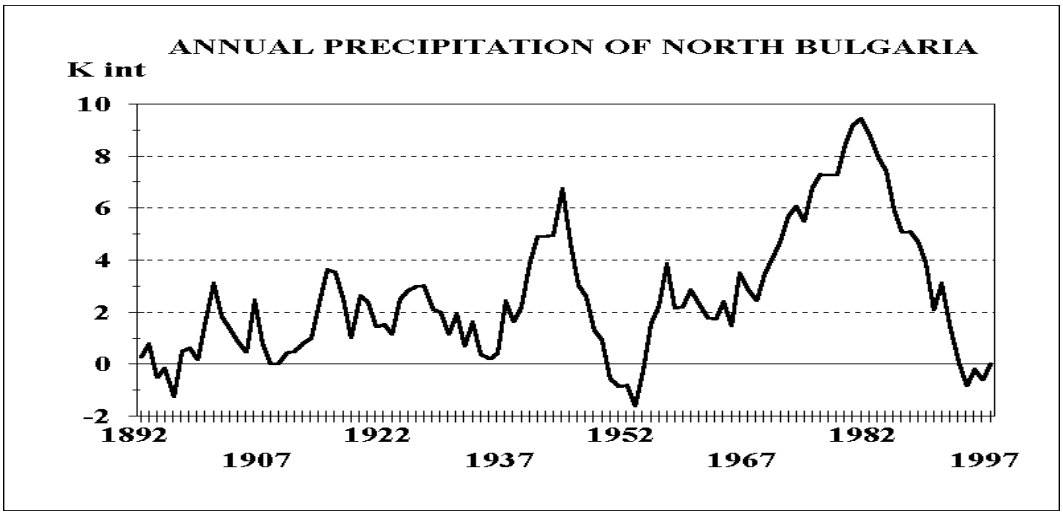


Fig. 1 Change of Annual and Filtered Values of the Temperature, Precipitation and Run off of North Bulgaria





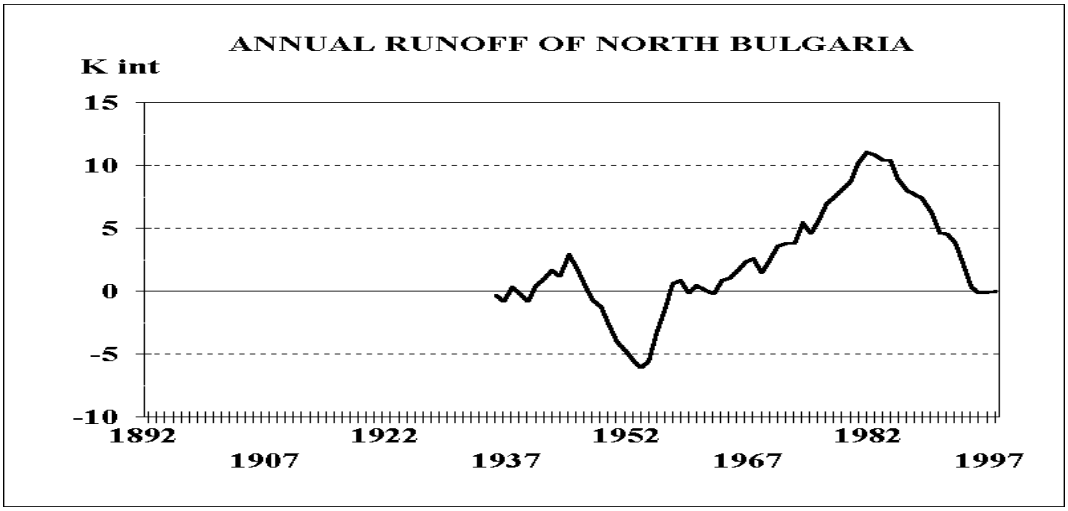


Fig. 2 Integral Curves of Annual Values of the Temperature, Precipitation and Run off of North Bulgaria

state of 5 years (1935 -1939), and of increase in wetness - of 5 years too (1940 - 1944). The basic period of 37 years (1945 - 1981) is formed by a manifested phases of decreased wetness - of 9 years (1945 - 1953) and of increased one of 28 years (1954 - 1981). After it a clear negative phase of 14 years (1982 - 1995) is manifested. The positive phase of 28 years is built by a secondary positive phase of 5 years (1954-1958), of relatively stable phase of 4 years (1959-1962), and by a series of consecutive secondary positive phases of 5 years (1963-1967), of 5 years (1969-1973), and of 7 years (1975-1981). The tendency in the development of the final three secondary phases is interrupted by one-year, negative series. The secondary phases are formed by series with different wetness, ranging from 1 to 5 years.

The tendencies in the annual chronology of temperature, precipitation, and runoff, have been determined on the basis of lineard trend analysis and have been calculated the following mean gradients:

$$\mathrm{Grad}_{T} \cong 0.00573 \text{ , } \mathrm{Grad}_{P} \cong -0.311 \text{ , and } \mathrm{Grad}_{Q} \cong -0.048 \text{ .} \qquad (4)$$

7. Conclusion

On the basis of the conducted investigations, it has been established the presence of manifesting periods and phases with different duration and tendencies in the changes of the chronological annual values of the temperature and precipitation for a period of 106 years as well as for the runoff for a period of 63 years.

In the chronological annual temperature changes (Fig.2), the following five secondary positive phases are observed (with respect to duration): 12 years (1916 - 1927), 6 years (1934 - 1939), 8 years (1945 - 1952), 12 years (1957 - 1968), and 8 years (1988 - 1995). In principle, the manifestation of the long-term positive phases are usually refered to droughts.

In the changes of the precipitation complex (Fig.2), an odd manifestation of three negative phases is established. The duration of the first is 20 years (1916 - 1935), the next is of 9 years (1945 - 1953), and the third one of 13 years (1982 - 1994). The duration of the second negative phase is related to the shortage of precipitation masses. By the Law of Similarity, this phase should have been over by 1990, or by 1991.

The chronological annual runoff changes, are also observed (Fig. 2) by the manifestation of negative phases with the same duration as in the case of precipitation. The duration of the first is 9 years (1945-1953), and that of the second - 14 years (1982-1995). It has been established that, from 1982 until 1984, the tendency of decrease in the wetness is not that clear, and it could be claimed that it preserves a stable state (1983 and 1984).

The deep decrease in wetness manifested itself only after that, and that was for a period of 11 years (1985-1995). The duration of the final one conditioned the decrease in the wetness of the investigated region with a 31%.The results obtained have a definite scientific and scientifically-applied aspect. They could be used for decision making in the management of the water resources in Bulgaria.

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Analysis of the Constant Volume Control System in an Irrigation Canal

Dragutin Gereš, Marija Šperac

Abstract: The system controlling the level and discharge of water in the irrigation canal has the function to regulate the irrigation water in order to achieve effective use for agricultural purposes. The task of the control system is allocation of the required water quantity to the specific user. The paper analyzes the remote control system with a constant volume of water. The Saint-Venant equations for flow in open canals are linearized by Taylor series. The result is a series of linear dynamic conditions for the open canal with several basins. In control, the principle of optimum control of delivery of irrigation water is applied, as well as the estimation theory. The algorhythm of water volume and level in the canal has been developed and tested, using linearized Saint-Venant equations. Algorthythm tests have given good results.

Key words: irrigation, level and discharge control, constant volume, Taylor series.

Analyse der Konstant-Volumen-Kontrolle im Bewässerungskanal

Zusammenfassung: Das System zur Kontrolle von Wasserstand und Durchfluss im Bewässerungskanal dient der Regelung der Bewässerung für landwirtschaftliche Zwecke. Die Aufgabe des Kontrollsystems ist, dem einzelnen Nutzer die geforderte Wassermenge zu liefern. Das Papier analysiert die Fernsteuerung über das konstante Wasservolumen. Die St. Venant'schen Gleichungen für Freispiegelabflluß sind linearisiert über Taylor-Reihen. Das Ergebnis sind lineare dynamische Bedingungen für offene Kanäle mit verschiedenen Becken. Zur Kontrolle wird die Bewässerungsdurchflusskontrolle und die Schätztheorie eingesetzt. Der Algorithmus über Wasservolumen und Wasserstand im Kanal wurde entwickelt und getestet unter Verwendung der linearisierten St. Venant'schen Gleichungen. Algorithmus-Tests haben zu guten Resultaten geführt.

Schlüsselwörter: Bewässerung, Wasserstand- und Durchflusskontrolle, konstantes Volumen, Taylor-Reihen.

1 Introduction

Insufficient performance of manually controlled largescale irrigation scheme stipulate the need for real-time monitoring and control of irrigation canal operations. The existing schedules do not allow the farmers to achieve the full potential of modern irrigation technology at the farm. Flexible delivery schedules would allow the needed flexibility to attain higher efficiencies. This schedule make the manual operation of irrigation canals difficult. To overcome this difficulties, attempts have been made to develop local and centralized control scheme and algorithms for demand delivery operations of irrigation canals. The control algorithms was based upon a trial and error procedure and using simulations of the unsteady open canal flow model.

Optimal control theory provides methodology to derive gate control algorithms for a centralized control system. This procedure take into consideration both initial interference and external interference, i.e. changes in lateral withdrawal rates [5]. The aim of this paper is to present a decentralized algorithm for demand delivery operation of irrigation canal in the presence of external interference, algorithm for operating a series of gates on a canal.

2 Open channel modelling

2.1. Open channel flow

The irrigation canal is provided with gate. Decision regarding gate openings in response to changes in water withdrawal rates into branch canals is required to maintain the depth of flow or the volume of water in pool at the target value. Very similar is the process control problem in which the state of the system is maintained close to the desired value by using real-time control. The Saint-Venant equation of open-chanel flow and continuity equation were linearized, to apply the linear control theory:

$$\frac{\partial Q}{\partial t} = -\left[\frac{\partial}{\partial x}\left(\frac{Q^2}{F}\right) + g \cdot F\left(\frac{\partial h}{\partial x} - I + S_f\right)\right] \tag{1}$$

$$\frac{\partial h}{\partial t} = -\frac{1}{B}\left(\frac{\partial Q}{\partial x} + q\right) \tag{2}$$

In eqs. (1) and (2), the spatial derivates were replaced by finite difference approximations, by dividing the pool into few reaches, or N number of nodes. The forward, the central and the backward-difference schemes were applied to the first, the intermediate and the last nodes of each pool. The turnouts can be located anywhere in the pool. To solve eqs. (1) and (2) boundary conditions at the gates were expressed in terms of the continuity and the gate discharge equations:

$$Q_{i-1,N} = Q_{i,1} = Q_{gi} \tag{3}$$

$$Q_{gi} = C_{di} \cdot b_i \cdot u_i \cdot \sqrt{2g\left(h_{i-1,N} - h_{i,1}\right)} \tag{4}$$

In the eq. (4), the change in bottom elevation of the canal across the gate was assumed negligible.

2.2. Lateral withdrawals

It is assumed that last node in each pool is to located immediately downstream of the lateral canals. Though the lateral withdrawal was concentrated at one point, it was assumed to be uniform by distributed between the modes, and was related to "q" in esq. (2):

$$q = q_{i,N} / s_d \tag{5}$$

where $s_d = \Delta x$ in the case of a backward difference scheme and $s_d = 2\Delta x$ in a central diference scheme. Similar relationships can be derived for situation where the laterals are located throughout the length of pool.

2.3. Linearized model

Upon initial steady state condition the linearized model was derived. Using the Taylor series expansion around the initial point, a set of linear equations was obtained. For a canal reach with P pools the discrete-time version of this equations is:

$$\mathbf{\Delta x}(k+1) = \mathbf{M_F} \cdot \mathbf{\Delta x}(k) + \mathbf{M_C} \cdot \mathbf{\Delta u}(k) + \mathbf{M_D} \cdot \mathbf{\Delta q}(k) \tag{6}$$

$$\mathbf{\Delta y}(k) = \mathbf{M_o} \cdot \mathbf{\Delta x}\,(k) \tag{7}$$

In equations (6) and (7), the variables **Δx**, **Δu** and **Δq** are defined as follows:

$$\mathbf{\Delta x} = (\Delta y_{1,1}, \Delta y_{1,2}, \Delta Q_{1,2}, \ldots \Delta y_{P,\,N-1}, \Delta Q_{P,N-1}, \Delta y_{P,N})' \tag{8}$$

$$\mathbf{\Delta u} = (\Delta u_1, \Delta u_2, \ldots, \Delta u_{P+1})' \tag{9}$$

$$\mathbf{\Delta q} = (\Delta q_{1,1}, \ldots, \Delta q_{1,N}, \ldots \Delta q_{P,\,n})' \tag{10}$$

2.4. Control algorithm

Equations (6) and (7) can be used to simulate the system dynamics as a function of time, given the initial conditions ($\mathbf{\Delta x}_{(0)}$), the external interferences acting on the system (**Δq**) and the gate opening (**Δu**). However, in canal operations the gate opening is the unknown. The selection of an appropriate gate opening becomes a trial and error procedure. It can be applied the concepts of control theory to eliminate trial and error procedure, and derive a direct solution for gate opening. To apply control theory, the matrices $\mathbf{M}_{\underline{F}}$, $\mathbf{M_c}$ and $\mathbf{M_o}$ must satisfy the stability, controlability and observability properties [3]. From optimal control theory was derived a proportional plus integral control in the following form:

$$\mathbf{\Delta u}\,(k) = -\,\mathbf{M_k} \cdot \mathbf{\Delta x}\,(k) \tag{11}$$

In a centralized control scheme, the control algorithm of each gate (eq. 11) needs real-time information from all the pools in the system. The decentralised control scheme, the control algorithm of each gate requires real-time information from only a few adjacent pools. The decentralized control algorithm needs information only from the three adjacent pools, one upstream and two downstream pools.

For the implementation of the control (esq. 11), measured values for all variables: depth and flow rate at all intermediate nodes of each pool, depth at the first and the last nodes of each pool, must be available, and for feedback link from only the adjacent pools (Figure 1).

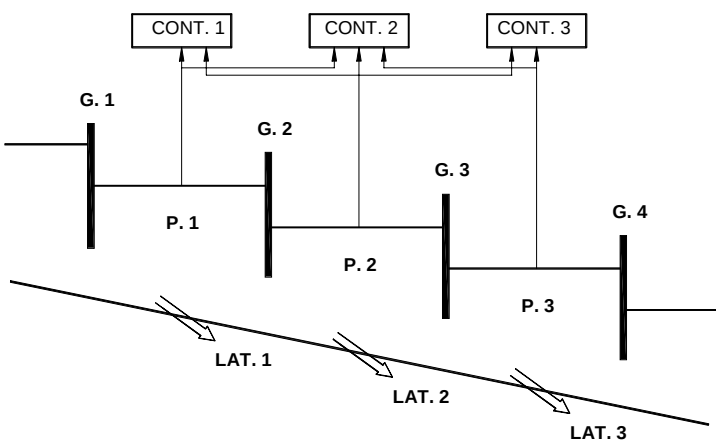

Fig. 1 Volume control scheme

It can be used an estimator to minimaze the number of measured state variables. The estimator is a mathematical model of the given system which predicts values for the state variables that are not measured, based upon measured values of a few state variables, upstream and downstream depth of flow in each pool. In [4] are presented a technique for designing an estimator for control system. The estimator equation is given:

$$\mathbf{\Delta x}\,(k+1) = \mathbf{M_F} \cdot \mathbf{\Delta x}\,(k) + \mathbf{M_C} \cdot \mathbf{\Delta u}\,(k) + \mathbf{M_L} \cdot \mathbf{\Delta y}\,(k) - \mathbf{M_0} \cdot \mathbf{\Delta x}\,(k) \qquad (12)$$

It is assumed that only the upstream and downstream depths of flow in each pool are measured. The dimension of the M_L matrix is equal to the number of state variables estimated, including the integral control variables, and the number of measured state variables.

3 Obtained results

An example problem was considered. The data presented in table 1 were used to derive the elements of M_F, M_C and M_D matrices, and the initial steady state gate opening for all the four gates. The discrete-time matrices were used in deriving the elements of the controller gain matrices M_K for a decentralized control scheme. In the evaluation, and approximate estimation of the variation in the volume of water stored in the pool was obtained by the expression:

$$\Delta V = F_s/2\,(0.50\Delta h_1 + \Delta h_2 + 0.50\Delta h_3) \qquad (14)$$

The values of F_S and the initial volumes of water stored in the pools are presented in table 2.

Table 1 Data for the simulation case

Description	Pool-gate 1	Pool-gate 2	Pool-gate 3	Pool-gate 4
POOL: length (m)	5,000	5,000	5,000	
bottom width (m)	12.25	12.25	12.25	
bottom slope	0.0001	0.0001	0.0001	
side slope	1.5	1.5	1.5	
init. lateral flow	9.0	6.0	5.0	
RATE (m^3/s)	4.0	3.5	2.6	
GATE: width (m)	18.3	18.3	18.3	18.3
discharge coef.	0.85	0.85	0.85	0.85
initial opening (m)	0.31	0.60	0.45	0.47
DISTURBANCES (m^3/s)	5.00	6.00	4.00	3.00

Upstream reservoir elevation (m): 91.50
Downstream reservoir elevation (m): 87.00
Upstream invert elevation (m): 83.50
Downstream invert elevation (m): 82.70

Table 2 Initial data in the pools

Pool N°	Top width average (m)	Length (m)	Surface area (sqm)	Volume (cum)
1	23.50	5,000	117,500	343,100
2	21.90	5,000	109,500	278,130
3	19.75	5,000	98,750	200,460

The results of the simulation are presented in Figure 2. The maximum volume variation occurred in pool 2, followed by a variation in pool 3. After an hour of introduction of the

interference, the variations in the volume of water stored in the pools bounced back to the initial volumes, and gradually become positive. The positive variations in the volume of water stored were smaller than the initial negative variations. This variations were considered to be acceptable.

The variations in gate opening in response to the simultaneous interferences were also simulated [1]. The maximum steady state variation in the opening was 0.31 m for gate 2 and 0.20 m for gate 4. The variation in the opening of all gates was in the range of 0.15 to 0.20 m. This variations were considered reasonable.

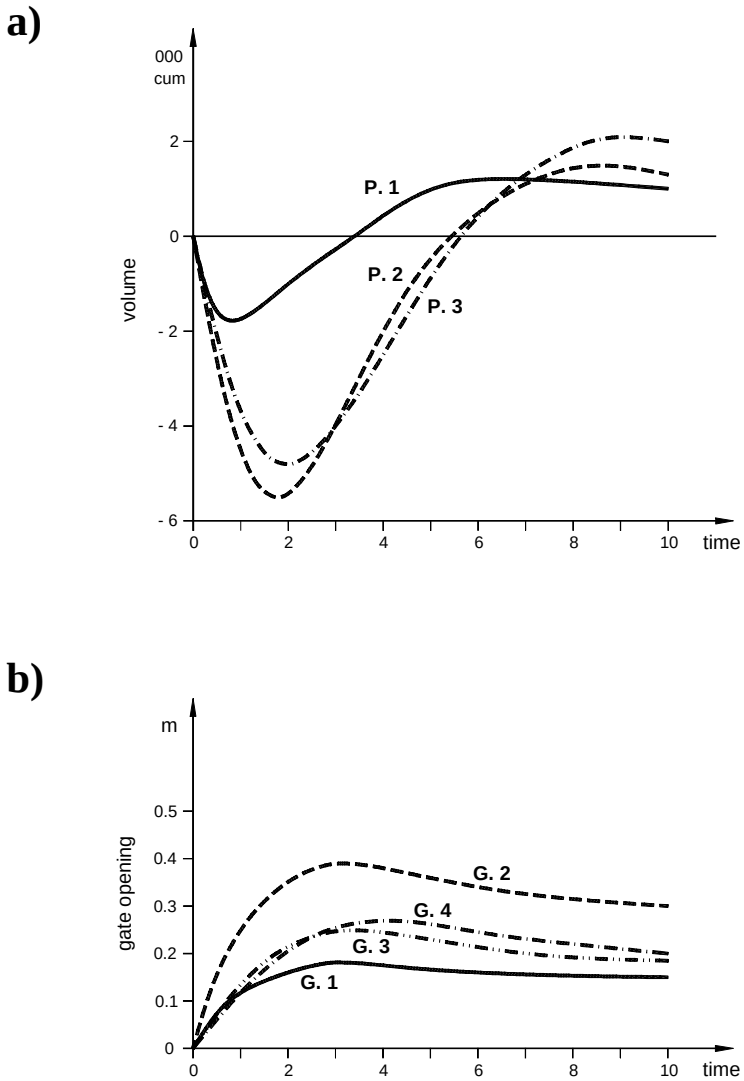

Fig. 2 Canal response in all pools: a) variations in volumes of stored water and b) variations in gate opening

It was assumed in the simulations that all the interferences were positive, i.e. increased flow rate into laterals and started at the some time. Under field conditions, all the interferences may not

be positive and start at the same time. The performance of the system of maintaining a constant volume in the pools would increase when the interferences acting on the system are temporally distributed. In adition, the performance of the system would be even better in case of spatially distributed negative interferences, i.e. either a decreased flow rate into a lateral or a distributed source of inflow into the canal, for example groundwater pumped into the canal.

Figure 3 present the results obtained using a estimator in the feedback loop. It is obvious that the gate openings calculated with the estimated values is close to the calculated gate openings with the measured values of the state variables within 1 hour of the simulation period. This is an acceptable performance.

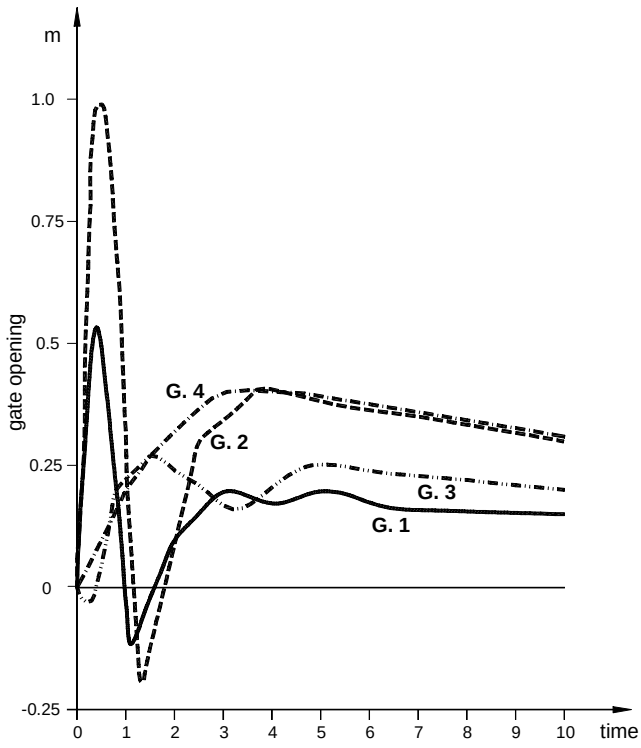

Fig. 3 Variations in gate opening

An ideal control algorithm is one that would yield a zero percent deviation in the volume of stored water in the presence of external interferences acting on the system. In order to minimize the deviations in the depths of flow, some variations in the volume of stored water must be accepted. In all the simulations the depth at the middle node of the pools remained more or less constant and the water surface elevation pivoted about that point, which is similar to the Bival control [2].

4 Conclusions

With Taylor series and using spatial discretization, a linear lumped parameter model of open-channel flow was obtained. The control problem was formulated as an optimal control problem. For the decentralized control algorithm the algorithm of each gate needs information only from three adjacent pools. A proportional integral control was used to handle both, the initial and the external interferences acting on the system. Local estimator was used to reconstruct most of the state variables of the system, given the measured values of the upstream and downstream depths in each pool. For testing the performance of the control algorithms, a canal reach with three pools was considered. The performance of the decentralised control scheme in sense of maintaining a constant-volume of water in the pools was found to be acceptable.

5 List of symbols

h	water depth in canal, (m)
Q	flow rate, (cum/s)
B	flow top width, (m)
F	cross-section area of flow, (sqm)
I	canal bed slope
S_f	friction slope: $Q/Q/K^2$
g	acceleration of gravity, (m/s^2)
q	lateral outflow (+) or inflow (-), in (cum/s/m)
K	hydraulic conveyance of the channel: FR^{β}/n
n	Manning friction coefficient
R	hydraulic radius, (m)
t	time, (s)
x	distance, (m)
C_{di}	gate discharge coefficient
b_i	gate width, (m)
u_i	opening of gate, (m)
$h_{i,1}$	flow depth at the first node in pool i, (m)
$h_{i-1,N}$	flow depth at node N in the pool i-1, (m)
P	number of pools
$Q_{i,1}$	flow rate at the upstream end of pool i, (cum/s)
$Q_{i-1,N}$	flow rate at the downstream end of pool i-1, (cum/s)
Q_{gi}	flow rate through upstream gate of pool i, (cum/s/m)
i	pool index (1to N)
j	node index (1 to N)
$q_{i,N}$	lateral with drawal rate at node N to pool i, (cum/s)
Δx (k)	(lx1) state vector (l= L)
Δu (k)	(mx1) control vector
M_F	(lxl) system feedback matrix (l= L)
M_C	($l$xm) control distribution matrix (l= L)
M_D	($l$xp) interference distribution matrix (l= L)
Δq (k)	(px1) external interference matrix (changes in water withdrawal rates)
Δy	(rx1) outputs vector (measured variables)
M_0	(rx$l$) output matrix (l= L)
M_K	controller gain matrix
M_L	estimator gain matrix
l	number of depedent variables in the system (l= L)
m	number of controls or gates
p	number of lateral canals on the supply canal in the reach

k	sampling instant
r	number of measered outputs
$\Delta Q_{i,j}$	variation in flow rate at node j of pool i, (cum/s)
$\Delta h_{i,j}$	variation in depth flow at node j of pool i, (n)
Δu_i	variation in upstream gate opening of pool i, (m)
Δu_{i+1}	variation in downstream gate opening of pool i, (m)
$\Delta q_{i,j}$	variation in water withdrawal rate at node j of pool i, (cum/s/m)
F_S	steady state water cross-section area, (sqm)
ΔV	variation in the volume of water stored in pool, (cum)
h_i	variation in the depth of flow at node i in pool, (m)

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Valuation Annual Peak Flow Discharge Regime for Cross-Section on the River Bodrog

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Abstract: This contribution presents estimated the annual peak flow regime for cross-section on the river Bodrog. In this profile river Bodrog leaves Slovak Republic. Bodrog is a part of the northern basin of river Dunaj. Its hydrologic regime is influenced by Hungarian waterworks Tiszalok and river Tisa as well as by waterworks working above this profile.

Evaluation is based on an analysis of peak discharges between 1951 -1997. The analysis of peak discharges shows that rate of the maximum annual peak flow discharge with exceedance probability 1% is in this profile 1469,742 $m^3.s^{-1}$. In 80-ties the time process of annual peak flow discharges slightly increased and then kept slowly decreasing till the latest years. According to this researches is presence of annual peak flow discharges during the year the highest in march and august. There wasn`t any maximum annual peak flow discharge measured in September.

Key words: annual peak flow discharge, average annual discharge.

Bewertung der jährlichen Hochwasser-Scheitelabflüsse im Fluss Bodrog

Zusammenfassung: Im vorliegenden Beitrag sind die größten jährlichen Scheitelabflüsse im Fluss Bodrog am Pegel Streda nad Bodrogom ausgewertet. Der Fluss Bodrog verlässt an diesem Punkt das Gebiet der Slowakei. Er ist Bestandteil des nördlichen Einzugsgebietes der Donau, welches sich in der Slowakei befindet. Sein hydrologisches Regime ist beeinflusst durch das ungarische Wasserwerk Tiszalok und den Fluss Theiß sowie durch wasserbauliche Maßnahmen oberstrom des Pegels am Fluss Bodrog selbst.
Die Bewertung gründet auf der Analyse der Scheitelabflüsse des Zeitabschnitts 1951 bis 1997. Aus der Analyse geht hervor, dass der maximale Abfluss bei 1% Überschreitungs-wahrscheinlichkeit am Pegel Streda einen Wert von 1469,742 $m^3.s^{-1}$ erreicht. Die maximalen jährlichen Scheitelabflüsse stiegen in den 80-iger Jahren zunächst leicht an, um danach bis heute allmählich wieder abzusinken. Das Auftreten der jährlichen Scheitelabflüsse ist im Jahresverlauf vor allem für die Monate März und August zu erwarten. Im September wurde kein einziger maximaler jährlicher Scheitelabfluss gemessen.

Schlűsselwőrter: Maximaler jährlicher Scheitelabfluss, durchschnittlicher Jahresabfluss

1 Introduction

The East Slovakian Lowland (VSN) is the down part of basins of rivers forming Bodrog , which leaves Slovak Republic in the profile Streda nad Bodrogom. It is the biggest stream in the East Slovakian Lowland draining 14,7% of the Slovakian territory. Its hydrologic regime is influenced by waterworks working above this profile as well as by Hungarian waterworks Tiszalok and river Tisa. The aim of presented article is to evaluate annual peak flow discharges of the Bodrog river at the Streda nad Bodrogom cross-section.

2 Brief characterisation of river Bodrog

Bodrog arises as a confluence of rivers Latorica and Ondava. 60% of its whole drainage basin area is situated in Slovakia and the rest 40% in Poland, Ukraine and Hungary, fig.1. The most of the area is taken by Nízke Beskydy and East Slovakian Lowland which form the character of basin and its hydrologic regime.

In the exploited profile Bodrog has drainage basin area of 11552 km2, the highest point of height 1230 m, the lowest point of height 94 m and the coefficient of basin shape of rate 0,28. The main streams gradually forming Bodrog in VSN are Ondava , Laborec, Uh and Latorica.

Bodrog arises as a confluence of rivers Ondava and Latorica. After 15 km leaves the Slovakian territory and after 65km flows into river Tisa.

3 Methods

The base of this analysis are the annual peak flow discharges of the Bodrog river at the Streda nad Bodrogom cross section of the period 1951 – 1997. Self analysis contains of supposed elaboration of presented discharges and evaluation of their time development. Supposed elaboration contains also calculation of main discharge characterisations and, to compare, annual mean discharges. Afterwards a theoretical line of exceeding annual peak flow discharges was calculated by method of moments.

While evaluating the time development the time process of annual peak flow discharges was graphically worked-out .

Evaluated is also the presence maximum annual peak flow discharges frequency during the year at water-gauging stations Streda nad Bodrogom.

4 Results

The main statistic characterisations of division of possibility and characterisations of variability of annual peak flow and mean discharges are presented in tab.1. Tab.1. shows that the biggest variability in absolute rate have the maximum annual discharges. Long term average annual discharge is 107,204 m3.s-1. Long term average peak flow discharge is 5,6-times higher than long term average annual discharge.

In the fig. 2 there is a line showing the curve of exceedance of the annual peak flow discharge. Picture 2 shows that the rate of annual peak flow discharge with exceedance probability 1 % in the profile Streda nad Bodrogom is 1469,742 m3.s-1. From the tab.1. and fig. 2. it is clear that the highest observed maximum annual peak flow discharge in years 1951 - 1997 in the profile was 1200m m3.s-1. This means that the probability of it's over-step is 4,0 %, which means it is a 25-year discharge.

Picture 3. shows the process of explored discharges and their multi-nominal trend. It is clear that in 80-ties it slightly increased and then kept slowly decreasing till the latest years. For deeper analysis we would need detailed study, mainly when talking about season discharges and the influence of waterworks.

In the picture 4. There is a presence of annual peak flow discharges frequency of river Bodrog during the year at water-gauging stations Streda nad Bodrogom (1951-1997). It shows that the most of peak discharges were in March (28,26%) and the least in August and September, when no maximum annual peak discharge was measured.

5 Conclusion

The presented article analysed the maximum annual peak flow discharges and partly average annual discharges at water-gauging station Streda nad Bodrogom in years 1951 - 1997. Discharges were analysed from temporal probable point of view. Results are presented graphically and in tabs.

Results of the calculations show that the rate of annual flow discharge with exceedance probability 1 % is 1469,742 m3.s-1. Long-term average annual discharge in this profile is 107,204 m3.s-1. Absolutely the highest observed maximum annual peak flow discharge in explored time was 1200 m3.s-1. Multi-nominal trend of annual peak flow discharges is in the last years decreasing.

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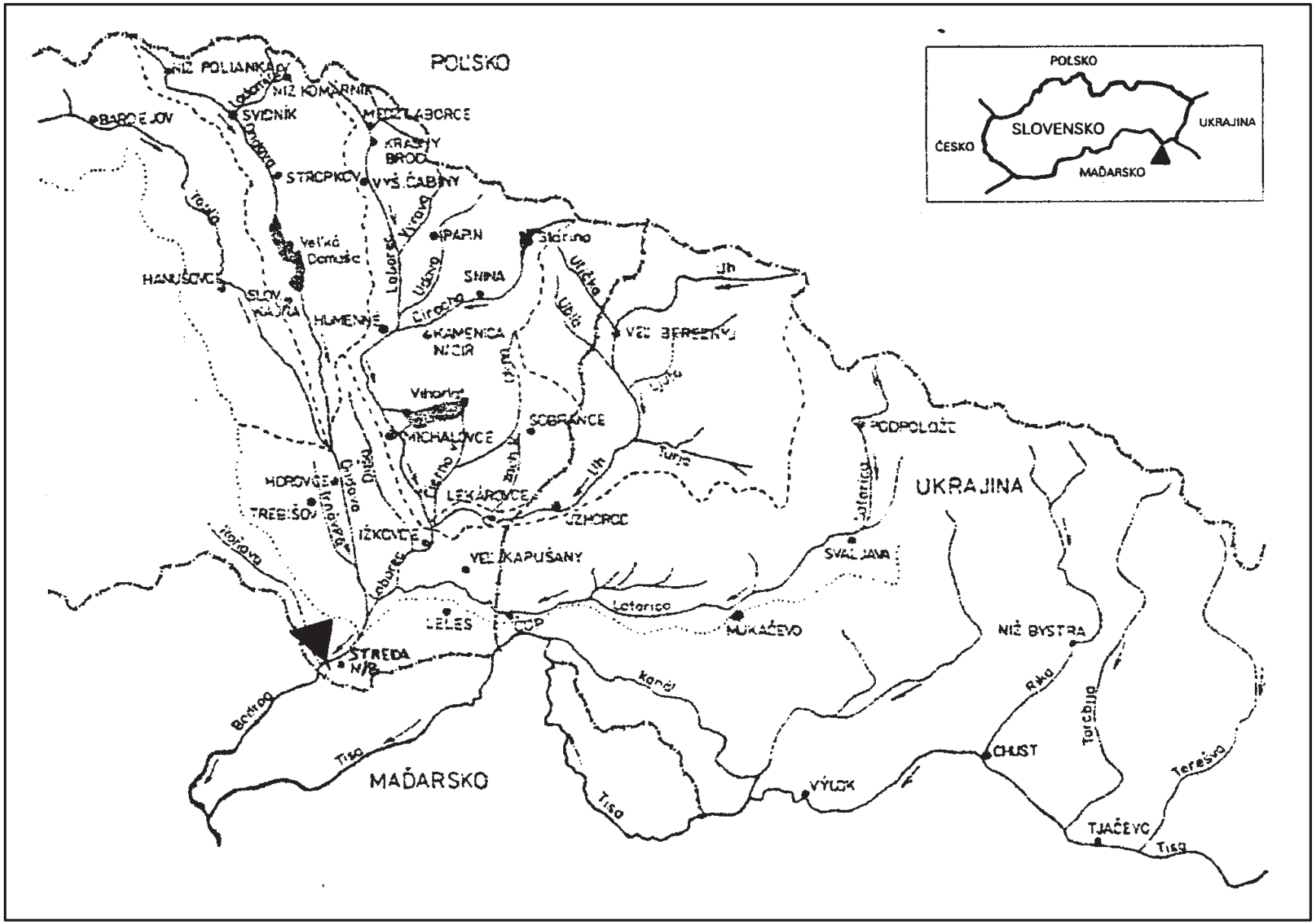

Fig. Location water-gauging stations Streda nad Bodrogom

Table 1 Statistical parameters series of annual peak flow and average annual discharges of Bodrog river.

Charakteristics	average annual discharges (1951-97)	annual peak flow discharges (1951-97)
Average value	107,204	597,128
Error average value	4,235	35,933
Medián	104,087	604,000
Standart deviation	28,721	246,347
Coefficient of variability	0,27	0,41
Kurtosiss	-0,716	-0,070
Skew	0,222	0,278
max-min	112,516	1083,000
Minimum	55,727	117,000
Maximum	168,243	1200,000

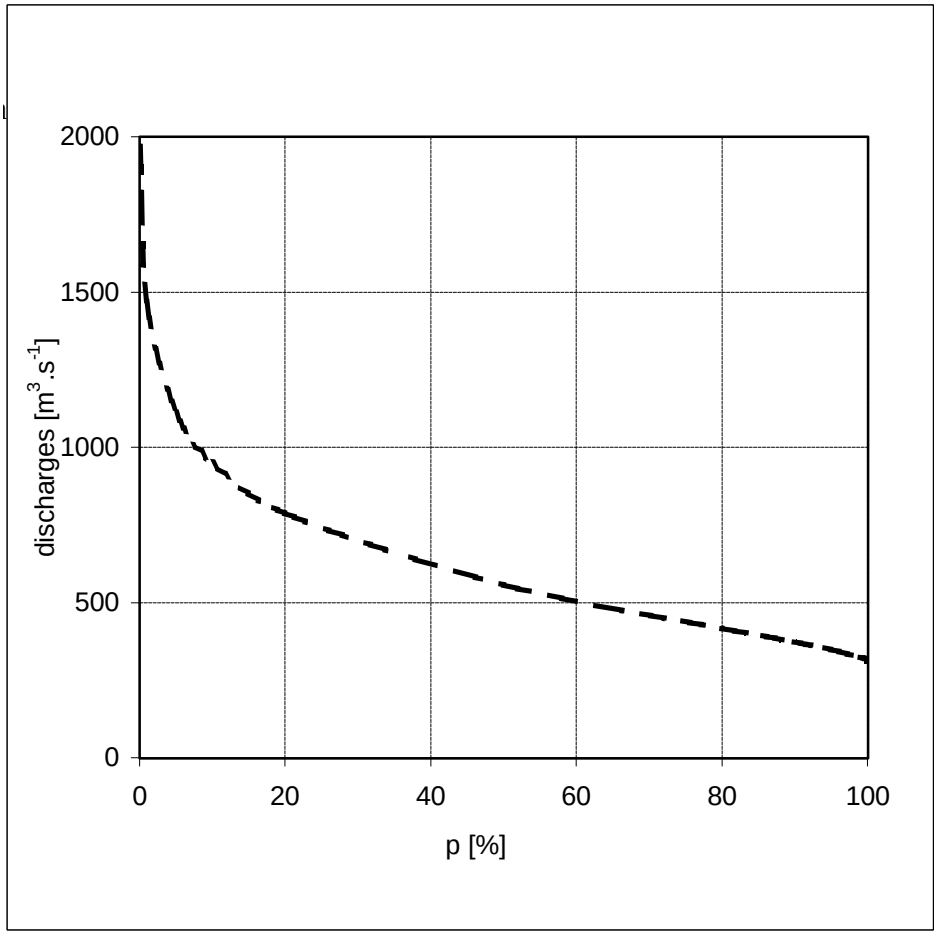

Fig. 2 Curve of exceedance of the annual peak flow discharges of the Bodrog river at the Streda nad Bodrogom cross-section of the period 1951 - 1997

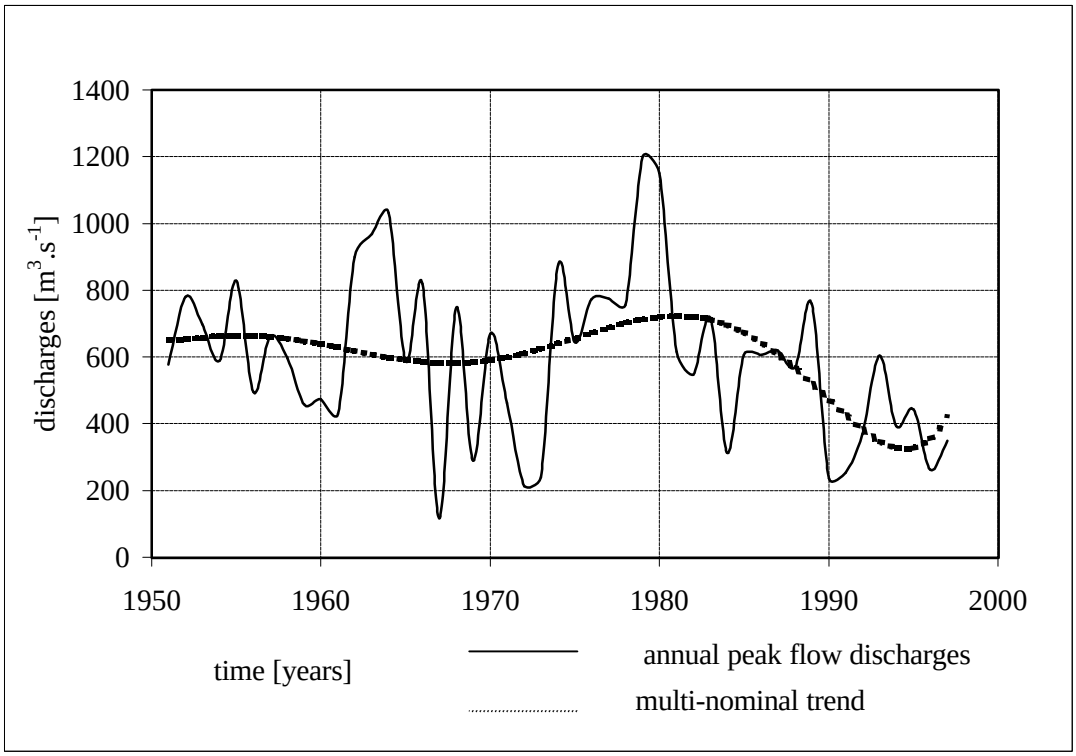

Fig. 3 Annual peak flow discharges of the Bodrog river at the Streda nad Bodrogom cross-section of the period 1951 - 1997

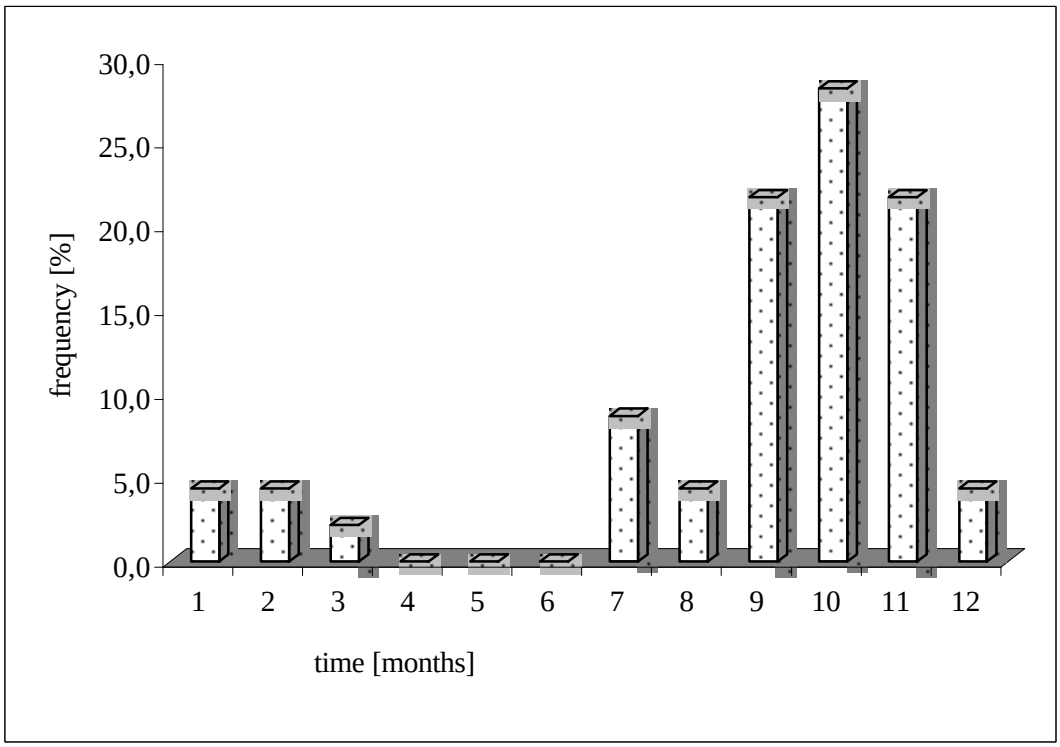

Fig. 4 Maximum annual peak flow frequency of river Bodrog during the year at water-gauging stations Streda nad Bodrogom (1951 - 1997).

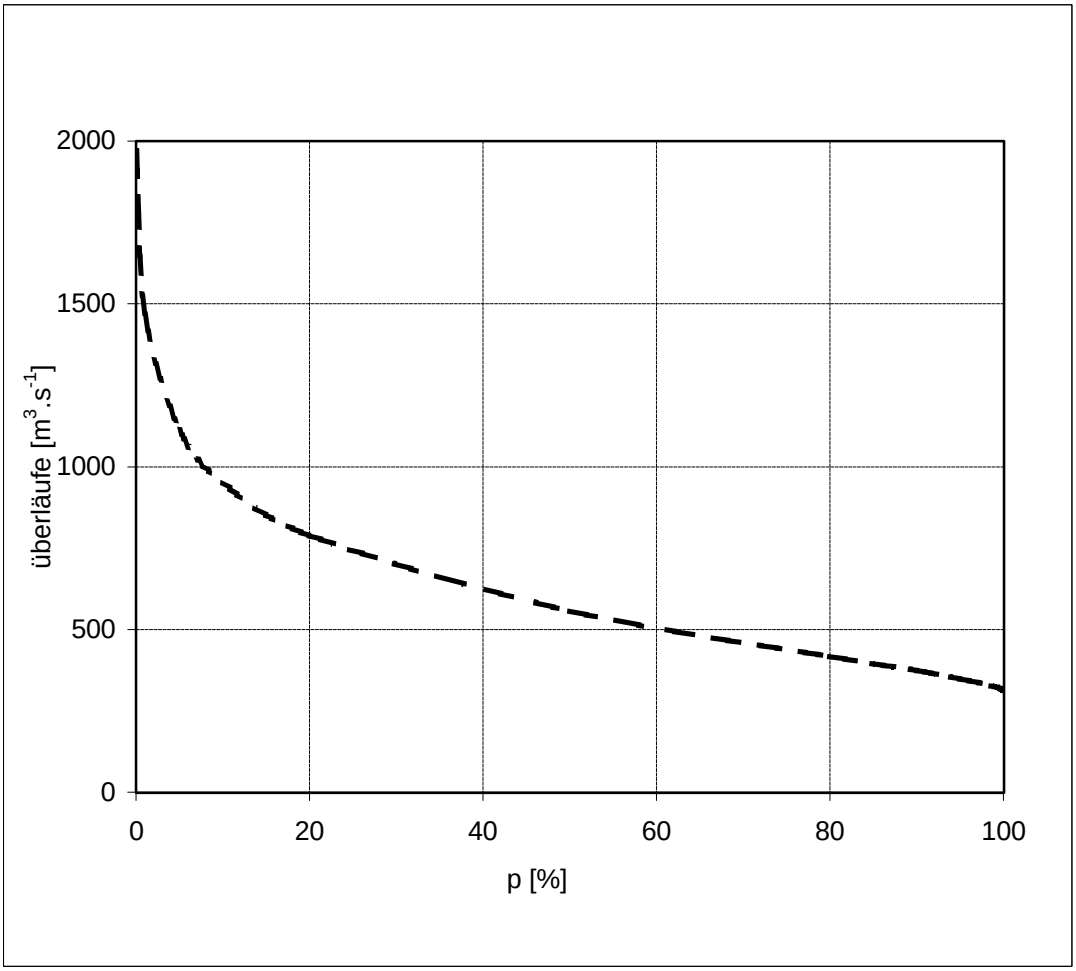

Abb. 2 Limit der Überschreitung der maximalen jährlichen Kulminationsüberläufe im Fluss Bodrog im Profil Streda nad Bodrogom

Methodical Approaches to Estimation the Danube Region's Water Resources (Ukraine and Moldova)

Evgeniy D. Gopchenko, Natalie S. Loboda

Abstract: The efficient approach for estimation of the Danube region water resources (Ukraine and Moldova) have been developed and numerically realized. The following tasks have been solved: estimation of annual flow of rivers under absence or deficiency of observation data on the flow by using the water-heat balance method; restoration and interpolation of annual flow on the basis of analysis of the annual precipitation and annual maximum possible evaporation; spatial-temporal generalizations of the annual natural flow parameters; definition of connection between the natural flow parameters and climatic ones and quantitative estimation of these parameters under new climatic conditions which are foretold in the climatic scenarios; stochastic simulation of natural annual flow rows and imitational stochastic simulation of life-conditioned flow rows based on watermanagement balance equations; development of regional model for annual flow parameters estimation under watermanagement reconstructions in watersheds and changed climatic conditions for rivers of the Danubisn region.
Key Words: annual natural flow, annual watermanagement flow, climatic factors of annual flow, water-heat balance, group estimations, empirical orthogonal functions analysis , modeling

Methodische Vorgehensweisen für eine Abschätzung der Wasserressourcen der Donau-Regionen Ukraine und Moldawien

Zusammenfassung: Es wurde eine wirksame Vorgehensweise zur Schätzung der Wasserressourcen der Donauregionen Ukraine und Moldawien entwickelt und rechnerisch verwirklicht. Die folgenden Aufgaben wurden gelöst: Die Abschätzung jährlicher Abflüsse bei fehlenden Beobachtungsdaten durch Anwendung der Wärmebilanz-Methode; Rekonstruktion und Interpolation jährlicher Abflüsse auf Grund von Analysen jährlicher Niederschläge und maximal möglicher Verdunstung; die raum- und zeitliche Verallgemeinerung jährlicher Abflussparameter; Definition der Verbindungen zwischen dem Abfluss und den klimatischen Parametern und die quantitative Abschätzung dieser Parameter unter geänderten Klimabedingungen, vorgegeben in Klimaszenarien; stochastische Simulation jährlicher Abflussreihen und natürliche Abflussreihensimulation auf Grund von Wasserbewirtschaftungs-Ausgleichs-Beziehungen; Entwicklung eines Regionalmodells zur jährlichen Abfluss-Parameter-Schätzung unter Wasserbewirtschaftungsbedingungen in den Einzugsgebieten und Klimaänderungen in der Donauregion.

Schlüsselwörter: jährlicher Abfluss, jährliche Abflussbewirtschaftung, klimatische Faktoren, Wasser-Wärme-Bilanz, Gruppenbewertungen, empirische orthogonale Funktionsanalyse

1 Determination of performances of a natural annual flow on meteorological data

1.1 Determination of statistical parameters of a natural annual flow by means of the water-heat balance equations

The basis of mathematical models of a flow in the conditions, infringed by economic activity, is made by a natural flow. On the greater part of the rivers of Danubian region data about a flow in a

natural condition is not present, therefore it is necessary to develop methods of its account on basis of meteorological information. For an evaluation natural (not infringed the economic activity) flow in conditions of defect of the hydrological observations data there have been proposed a method of water-heat balance, in which the meteorological data are used. One is used from updatings a method of hidrological- climatic calculations developed by V.S. Mezentsev [11]. The advantage of this method is the joint solving the equations of water and heat balances (for an earthly surface), which contain a common component - total evaporation E. These equations were jointly solved by means of the approximate functions for the quantitative characteristics of water and heat resources, and also physiographical conditions of formation of a total flow and evaporation. Heat resources or the maximum possible evaporation E_m is a layer of water (mm), which could evaporate provided that all positive components of heat balance of a surface are spent on this process. The equation of water and heat balance can be solved for estimation of a flow value. The flow calculated by the water-heat balance method, are called as climatic one and is designated as Y_C (mm). The initial data for calculations are as follows: the positive component of radiation balance, precipitation for various time intervals, temperatures and deficiencies of air humidity , water-physical characteristics of soil. The method used in paper have been developed in ref. [2,3]. The values of climatic flow depend on the climatic factors, which can be characterized by temperatures and precipitation. It's possible to consider the data of meteorological supervision till 80-th years to be not affected by anthropogenic influence; the climatic flow is calculated on the basis of materials for these years and identified as natural one. The comparison of norms for annual climatic flow with natural ones has shown satisfactory results [4,5]. The authors have developed a method of calculation of statistical parameters of natural annual flow using climatic flow data. This is highly important for southern regions of Ukraine, where practically no rivers left with a natural water regime. Climatic flow, while it reflects influences of large-scale processes, does not include effects of intra-catchment natural factors (azonal, intrazonal) that shape the annual flow. For the evaluation of small and medium river's resources, where influence of local factors is great, the special procedures has been developed to modify climatic flow into natural one. In particular, on the Danubian regional lakes catchments the small rivers flow is less then climatic one because of the surface retardation basin losses. As an index of these losses the average slope of catchment and median elevation of basin are used. Long-time average climatic annual flow Yc is defined by the dependence upon the coordinates of the catchment gravity centre. Factor of a variation Cv of annual flow of the rivers in the Danubian lakes region is the function of magnitude Yc :

$$C_V = \frac{5,6}{\overline{Y_C}^{0,62}} \qquad (1.1.1)$$

The coefficient of asymmetry is determined as $Cs = 1.7Cv$ .On the basis of climatic flow data with account of the transition coefficients from climatic flow norms to natural small catchments flow there have been received the main statistical characteristics of annual flow for weakly studied small rivers (the Dunabe lakes region) - (Table 1). .

Таble 1 Statistical characteristics of natural annual flow of some Danubian Lakes tributaries

Catchment	**F**	**Hcp**	**Yc**	**Yn**	**Cv**	**Cs**	***P*% duration annual flow value (mm)**			
	km^2	m	mm	mm			1	50	75	95
Sarata-Fillipenj	580	140	28	17.1	0.96	1.63	72.7	12.1	4.97	0.78

Kagul-Gavanosj	164	150	24	15.4	1.03	1.75	74.8	9.85	3.23	0.32
Jalpug-Komrat	428	160	25	17.0	0.97	1.65	73.1	12.5	4.59	0.72
Jalpug-Bolgrad	3230	130	24	13.9	1.10	1.87	67.6	8.25	2.68	0.23
Lunga-Taraclija	1050	150	21	13.4	1.12	1.90	24.8	7.64	2.06	0.18
B. Sal'cha-Chumaj	567	150	25	16.0	1.00	1.70	70.7	11.1	3.98	0.50

1.2 Analysis of regional annual flow and climatic characteristics with empirical orthogonal functions

The general idea of using the empirical ortogonal functions (EOF) is to make a linear transformation of the original data and produce a new ortogonal set of function [6,12]. EOF - analysis of annual precipitation, maximum possibility evaporation and runoff data showed that more then 80% of variation is already explained by the first three amplitude functions (components). The following interpretation of a physical sense of first components is given [10]. First of them is stipulated by the planetary scale processes which take influence on the climatic phone of precipitation , air temperatures, runoff. «Load» of this process on separate objects (weight coefficients of first amplitude functions) varies a little. The second component contains an information about synoptic scale processes. Per cold half-year (October - March) the warm and humid air masses move on quasimeridianal trajectories through territory of Ukraine. Per warm half-year (April - September) above territory of Ukraine anticyclonic weather predominates without precipitaton with a high temperature phone. Thus, the processes of synoptic scale ensure existence of two climatic factors, equal on effect, of shaping of an annual flow: annual precipitation and maximum possible evaporation. Weight factors (elements of the eigenvectors of matrixes of correlation or covariance) of the second amplitude function of precipitation and maximum possible evaporation change a sign in accordance with promoting west-to-east. It means that the oscillations of considered hydrometeorological magnitudes stipulated by the second on scale process, are in anti-phase. The position of the zeroth isoline is considered as the boundary of territories with synchronous oscillations of a flow. It has allowed to find difference between features of oscillations of an annual flow for the rivers of Danubian lakes region and inflows of Prut (Moldova) – [9]. The distribution of weight coefficients for third amplitude function of a annual flow field can be also considered as an outcome of interaction of the precipitation and maximum possible evaporation (fig.1), but already at a mesoscale level. There are the linear links between values of weight coefficients for the first three components of the maximum possible evaporation, precipitation and flow fields. For components of higher orders such links are absent. Numeral experiments have shown that the essential variations introduced to the separated flows raw make an exhibition at a level of fourth and fifth amplitude function. By means of the eigen vectors and components vector system it's possible the inverse transition from components to observed values excepting an influence of the poorly informative processes. The filtered values of initial variable $\tilde{x}_{ij}$ can be received from the following equations:

$$\tilde{x}_{ij} = \bar{x}_i + \sigma_i \sum_{k=1}^{p} u_{ki} z_{kj} \qquad (1.2.1)$$

$$\tilde{x}_{ij} = \bar{x}_i + \sum_{k=1}^{p} w_{ki} z_{kj} \ , \qquad (1.2.2)$$

where $\bar{x}_i, \sigma_i$ - average arithmetical values and average quadratic deviation of an initial number; - weight coefficients of amplitude functions, which are the elements of the eigen vectors of the covariance or correlation matrix (eigenvectors of a matrix of a covariance or correlation); z_{kj} - significance $k-th$ component in $j-th$ instant; $\bar{x}_i, \sigma_i, w_{ki}, u_{ki}$ are deterministic functions in space; they are dependent from coordinates at point (x,y); z_{kj} are set of functions common to all series. The features, established for southwest Ukraine, of oscillations of an annual flow, greatest possible evaporation and precipitation have allowed to make the following conclusions.

1. Fields of the main climatic factors and annual flow are formed under influence of common physical processes, which can be reflected by the first components of expansion of fields on natural orthogonal functions.
2. Under availibility of the lumpsum distortions of a natural course of an annual flow (break of a dam, clearing of a channel, the dumping in surface catchments of industrial - municipal waters), their influence can be excluded by executing a filtration of numbers of a flow on the basis of first three components (amplitude functions), which reflect a course of a flow in time stipulated only by the climatic factors.
3. On absence of observational data behind a flow (the situation, is characteristic for the small rivers of the Danubian lakes region) is possible the modelling for a point with coordinates (x, y) in accordance with (1.2.1) or (1.2.2), where the weight factors of expansion (expansion into EOF) fields of an annual flow are determined as the deterministic function in space depending on appropriate values of weight coefficients in a point of fields of the maximum possible evaporation and deposits. The data about $\bar{x}_i, \sigma_i$ can be received by results of application of the water-heat balance equation to calculations of a natural annual flow (see.part 1.2)

1.3 Group evaluations of statistical parameters of an annual flow

Even under availability of observational data some statistical parameters of an annual flow are determined with small reliability. To number of such parameters concern a coefficient of asymmetry Cs and coefficient of correlation *r(1)* between a flow of adjacent years. To enhance the reliability of the parameters assessment there is used the method of combining runoff data for the basins which are geographically close to each other [2,3]. The contribution of random Dr and geographical Dg components of spatial dispersion of the parameter under investigation are estimated. If the contribution of a geographical component into the net parameter dispersion doesn't exceed 50%, it is allowable to use its averaged value within the combined group in further calculations [2,3]. The quality criteration of such a generalization is a relative average quadratic error of the calculation of the averaged $\sqrt{Da}$ parameter and Dr value. The rise of geographical component of the dispersion as the number of the combined features increases brings to the enhachement of the influence of georaphical factors in the parameter spatial changeability. A compromise in the composition of features forming statistically uniform group is reached by $\sqrt{Da}$ minimum value. The analysis of the spatial changeability of relation Cs / Cv and parameter r(1) for annual flow series of Moldova basins disclosed that statistically valid relation of these ones with flow forming factor isn't found and a random component of the dispersion in both cases amounts to as much as 100% (Table.2). Factor of a variation of an annual flow also is subject to average (Table.2). There is a significant difference in values of a parameter r (1) for inflows of Prut,

located in limits of Moldova, r(1)= 0,45 and rivers of Black Sea lowland - r(1) = 0,01. The rivers of Moldova receive a more significant ground feed on a comparison with the rivers of Black Sea lowland. Just the availability of a significant share of a ground feed explains stability in space of factor of a variation Cv.

Table 2 Group estimations of statistical parameters of Prut annual flow (Moldova)

Parameter	Mean value of parameter	Average quadratic deviation $\sqrt{Da}$	Share casual component in a space variance of a parameter (%)
r(1)	0,45	0,0345	100
Cs/Cv	2,00	0,6675	100
Cv ($F > 100 sq.km$)	0,57	0,0239	100

1.4 Annual flow in conditions of global warming

From the eighties on the notion of anthropogenic influence includes effects of global warming that cause changes in climatic factors of water balance equations of watersheds and, as result, changes in flow characteristics. The method of water-heat balance was used for estimation of Ukrainian water resources under new circumstances [7]. Factors of water-heat balance for long-term period (precipitation and temperatures) were corrected according to data of alternative scripts of Second World Conference (Geneva,1990). It was found that water resources of Ukraine will either remain intact (script 2) or will diminish to 18-25% of present state (script 1 and 3). According to script 1 diminution of norms of annual precipitation in region of Moldova and Danubian lakes, will be equal on the average 7 %, and the maximum possible evaporation will increase on 9%. This circumstance will change a parity of resources of a moisture and heat (X / Em) in the party of a diminution. According to script 1, annual flow of water-scarce years in insufficiently moistured zone under global warming will diminish to 70%. That can result in the transition of a part of the rivers into the category of temporary watercourse.

1.5 Watersheds flow modelling under watermanagement reconstruction

In Southern Ukraine and Moldova, where for most part of territory available data on both natural and human-conditioned flow are insufficient and information on watermanagement is scarce such modelling is particularly important. Authors has developed methodic approaches for evaluation of annual flow in minor and medium rivers under anthropogenic influences [4,5,8]. The suggested mathematical model combines stochastic and deterministic approaches to annual flow calculations. It is based on watermanagement watershed balance equation that can be rendered thus:

$$W_{HC} = W_N - \Delta W_{OP} - \Delta W_{EV} + \Delta W_R, \qquad (1.5.1)$$

where $W_{CH,} W_N$ -are volumes of human-conditioned and natural flows respectively; ΔW_{IR} -is irreversible losses on irrigation; ΔW_{EV} - water losses in additional evaporation from the surfaces of

ponds and water reservoirs; ΔW_R - water removing to the surface water passage. Stochastic modelling of human-conditioned flow rows for each factor of anthropogenic influence is executed separately: a) when water is withdrawn for irrigation[3]

$$Y_{HC,P} = Y_{N,P} - \frac{M_{0,100-P}}{\eta} f_{IR} \; ; \qquad (1.5.2)$$

b) when there are artificial water reservoirs with seasonal flow regulation in the watershed and water losses are due to additional evaporation from water surface[2]:

$$Y_{HC,P} = Y_{N,P}(1 - f_{EV}) - (E_{WS} - X) f_{EV} \qquad (1.5.3)$$

$$Y_{HC,P} = Y_{N,P}(1 - \alpha_P f_{EV}) \;, \;\; \alpha_P = \varphi(Y_P) \qquad (1.5.4)$$

c) when there is regenerated flow

$$Y_{HC,P} = Y_{N,P} + \xi \frac{M_{0,100-P}}{\eta}(1-\eta) f_{IR} \,, \qquad (1.5.5)$$

where $Y_{HC,P}, Y_{N,P}$ are P% duration natural and human- conditioned flows (respectively with fixed statistic surety P) in millimeters of layer, f_{IR}, f_{EV} - sum square of irrigated fields and water surface of artificial reservoirs as a part of total watershed surface F; η - irrigation efficiency ; ξ - coefficient of regenerated flow of water lost in irrigational channels; $M_{0,100-P}$ is $(100-P)$% duration irrigation net norm; E_{WS} -free-water-surface evaporation; X - sum precipitation; α_P - numeric coefficient reflecting change in $(E_{WS} - X)$ as depending on P% duration annual flow value. Series of natural flow $Y_{N,P}$ are generated according to one of the simple Markov's chain modifications [1,13]. On an entrance in a model of a flow the statistical parameters obtained because of a method of water-heat balance, and also average group evaluations $r(1)$ and C_S / C_V are used. To estimate separate factor's influence on the flow method of statistical testing was used. In each testing non-random indexes on anthropogenic influence ($f_{IR}, f_{EV}, \eta, \xi$) were taken as constant to preserve stationarity of modelled series $Y_{HC,P}$. Parameters of human-conditioned flow (average long-term flow value, variation coefficient, asymmetricity coefficient - $\overline{Y}_{HC,} Cv, Cs$) in their turn were introduced as dependent upon level of economic cultivation of watersheds and humidification of the territory. Combined result of some anthropogenic influences was estimated using transition coefficients from parameters of natural flow to human-conditioned one:

$$k = \frac{A_f}{A_0} \,, \qquad (6)$$

where A_0 is value of some flow parameter in natural conditions; A_f is value of that parameter in human-conditioned flow under given indices of anthropogenic influence. The integrated effect of various watermanagement measures is taken into account by means of summation of correction factors. The suggested approach to estimation of water resources under anthropogenic influence was successfully used on small and medium rivers of Ukrainian south-western and southern regions where withdrawal of water for irrigation in upper parts of rivers is combined with regenerated flow from Danube-Dniester irrigation system channels to river firth and water reservoirs possesing no significant regulating ability are simply giant evaporating surfaces. On the small rivers running in Danubian lakes it has dominant significance the transportation of a flow of Danube on channels of Danubian irrigation system, which results in additional inflow into surface watercourse. Water

removing from large assigned squares compensates losses of a flow on additional evaporation from a water surface and irrigation at the expense of local water resources (Table. 3).

Table 3 Characteristics of annual flow of river Big Catlabuh - lake Catlabuh under different watermanagement conditions, obtained in modelling

State of object	Statistical parameters of annual flow			Relative square of artificial water reservoirs, %	Relative square of donor - irrigation land, %	P % duration annual flow value (mm)				
	Y,mm	Cv	Cs	f_B	f_{OP}	5	25	50	75	95
natural	9.2	1.41	2.40	0.0	0.0	35	13	4.6	0.5	0.0
artificial ponds	6.1	1.89	3.20	1.3	0.0	29	7.8	1.4	0.0	0.0
donor irrigation	11.0	1.24	2.40	0.0	4.5	39	15	6.1	1.6	0.0
Combined resalt	7.9	1.72	3.2	1.3	4.5	34	9.9	2.3	0.0	0.0

However growth of a long-term variability and asymmetries results in essential decrease of a flow of droughty years even provided that the average long-term significance of a flow is changed within the limits of an exactitude of its account.

1.6 Resume

The paths of a solution of a problem of an evaluation of water resources of the small and average rivers of Danube region (are stated within the limits of Ukraine and Moldova) in conditions of defect of data of hydrological observations. The developed techniques are illustrated by outcomes of accounts of performances for water resources on the separate rivers of region.

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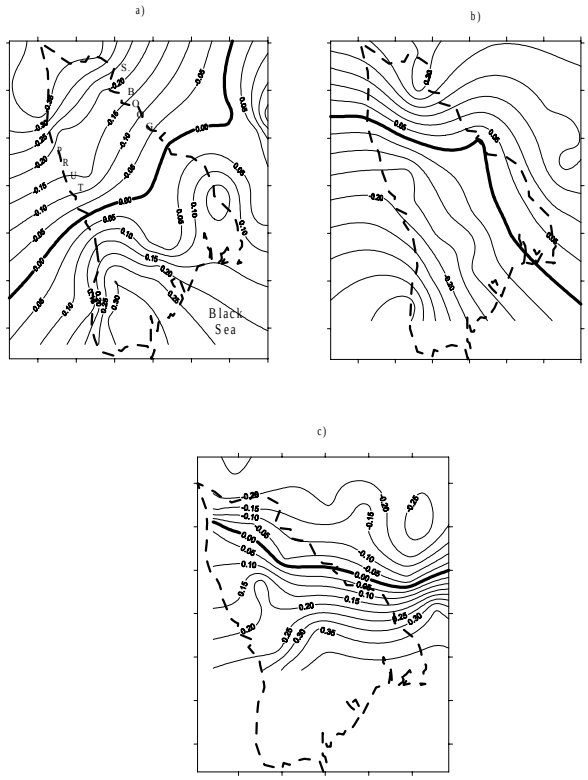


Fig.1 Third amplitude functions of
a) precipitation; b) maximum possible evaporation;
c) annual flow

Comparison of the Effect of the Expected Climate Change upon Water Reservoirs in Eastern Slovakia

Halmová Dana

Abstract: This paper presents an attempt to answer the question, as to what impact of the climate change upon multipurpose reservoirs (Vihorlat and Veľká Domaša) can be expected and how the reservoir inflow hence its capacity will be changed. That change was calculated by rainfall-runoff balance model WBMOD. The series of precipitation and temperature input data was used to express expected changes of the total runoff and needed reservoir capacity. Input data were modified in each month according to the respective climate scenario.

Key words: rainfall-runoff balance model, water reservoirs, and climate change.

Auswirkungen der erwarteten Klimaänderung auf die Wasserspeicher der Ostslowakei

Zusammenfassung: Dieser Beitrag erläutert, in welchem Umfang die Mehrzweckspeicher Vihorlat und Veľká Domaša durch Einflüsse der Klimaänderung betroffen sind und damit auch, wie deren Zuflüsse und Kapazitätsauslastung sich ändern werden. Diese Änderungen wurden mit Hilfe des Niederschlag-Abfluss-Wasserbilanzmodells WBMOD berechnet. Darin stellen die Reihen der mittleren Gebietsniederschläge und Temperaturen die Eingabedaten dar, woraus Speicherzufluss und Volumensummenkurve berechnet werden. Die Eingabedaten wurden nach dem entsprechenden klimatischen Szenario monatsweise modifiziert.

Schlüsselwörter : Niederschlag – Abfluss Bilanzmodell, Wasserspeicher, Klimaänderung

1 Introduction

Natural water resources become rare and we have to exploit them more effective than in the past [Lapin, M., 1997].

Growing qualitative and quantitative demands on water resources and limited possibilities of new resources (reservoirs) building contribute to development of optimisation methods of reservoirs and water-management systems in the last two decades. At the same time there is a requirement of more reliable hydrological background necessary for water reservoir design and management. It is necessary to determine specific conditions in which the reservoir will operate. Study of the impact of climate change upon the water reservoirs is topmost actual in coherence with water regime non-stationarity, caused by natural long-term oscillation of hydrological factors or development of human activities in last decades.

2 Climate change and scenarios

Under the notions climate changes, oscillation and variability of climate we understand in general only changes, which have natural origin and will occur independently of human activities. But on the other side under notion climate change we understand change caused by antrophogenically conditioned increase of greenhouse effect of the atmosphere. Today we are not able to exactly determine a difference between natural climate change and climate change caused by growing greenhouse effect of the atmosphere.

Climatic conditions of Slovakia are influenced by its geographical location in the centre of Europe, orography of Carpathian Mountains and Alps, and by west atmospheric air circulation. Higher precipitation and more substantial snowing at south and east Slovakia occur only in some years under southern and southwestern cyclone situations. Western and northwestern air circulation brings more rich precipitation mostly at mountain localities of western and northern Slovakia. There was observed significant increasing trend of the annual average air temperature (T) about 1°C and decreasing trend of annual atmospheric

precipitation (R) about 90mm (it is 17% from normal 1961-1990 period) at Hurbanovo station. Decreasing trend of atmospheric precipitation is fairly lower in the other parts of Slovakia and it isn't statistically significant in mountain parts of northern Slovakia.

Temperature and precipitation scenarios for Slovak territory result from the global circulation models (GCM). The *GFD, UKM, GISS* and *OSU* scenarios result from the older versions of GCMs and they are interpolated for the geographical position of the selected catchments. The *GFL, GIL, CCC and WPL* scenarios were developed more recently within the National Climate Programme of the Slovak Republic for the time horizon 2075.

Natural ecosystems, economic and social spheres in Slovakia are adapted to regime of climate variability. Eligible global warming of atmosphere can considerably change the mentioned characteristics, probably toward higher variability, which involves change of extreme conditions for natural ecosystems and for economic and social activities, too. [SHMI, NCP 1995], [Majerčáková, O. and Majerčák, J., 1994].

3 Climate change consequences on water resources and water management

3.1 Water resources and water management

One of the basic roles of the water management is to define a relationship between water demand and water resources availability (availability is a function of quality and quantity). Climate change can affect future water resources and water demands. The surface and ground water resources are supplemented explicitly by precipitation in Slovakia. The best indicator of water resources changes is the change of the average monthly and annual flows.

The changes of the water reservoir properties due to changes of the hydrological conditions can considerably influence the utilisation of recent reservoir capacity. The correct assessment of the water needs and utilisation has an important role for the future water reservoir exploitation and water management orientation.

Climate changes can oscillate in large-scale and their impact on water management can be considerably negative. This impact is a consequence of climate change assessment uncertainty. Now scientific research should be oriented on climate change specification for individual regions and draw conclusions for routine water management calculations.

3.2 Dams and water reservoirs

Dams and water reservoirs are built to covered water for several needs: irrigation, drinking water supply, low flow augmentation, hydropower generation, flood control etc., but dams are dangerous for the lower situated areas.

Actual water demands in Slovak Republic are supplied by some water reservoirs, which are able to transform the non-uniform discharges according to water management requirements.
The change of the relationship between reservoir storage magnitude, total augmentation and certainty invoked by the change of hydrological conditions, can influence the recent reservoir storage use markedly. Assessment of society water demand and reservoir use will play critical role in forthcoming future [Majerčáková, O., 1997]. Climate change relates to small water reservoirs, too. In the regions with small water reservoirs there is a tendency to recommend some conceptual adaptation arrangements for water management [Szolgay, J., and Parajka, J., 1997].

4 Selected catchments and method

WBMOD model (monthly water balance model or monthly precipitation runoff model) is useful for planning and controlling water resources systems and it is particularly suitable for water supply systems (drinking and industrial water, irrigation, low flow augmentation, hydropower generation, etc.). The monthly input data step of the model corresponds with the time step used in temperature and precipitation climate change scenarios. The climate change scenarios give us a distribution of temperatures and precipitation in monthly values during the hydrological year. The model was developed at V.U.B.–Vrije Universiteit Brussel-Hydrologie, basic equations and scheme of the model were described in several papers [Svoboda, A., 1996], [Halmová, D., 1997].

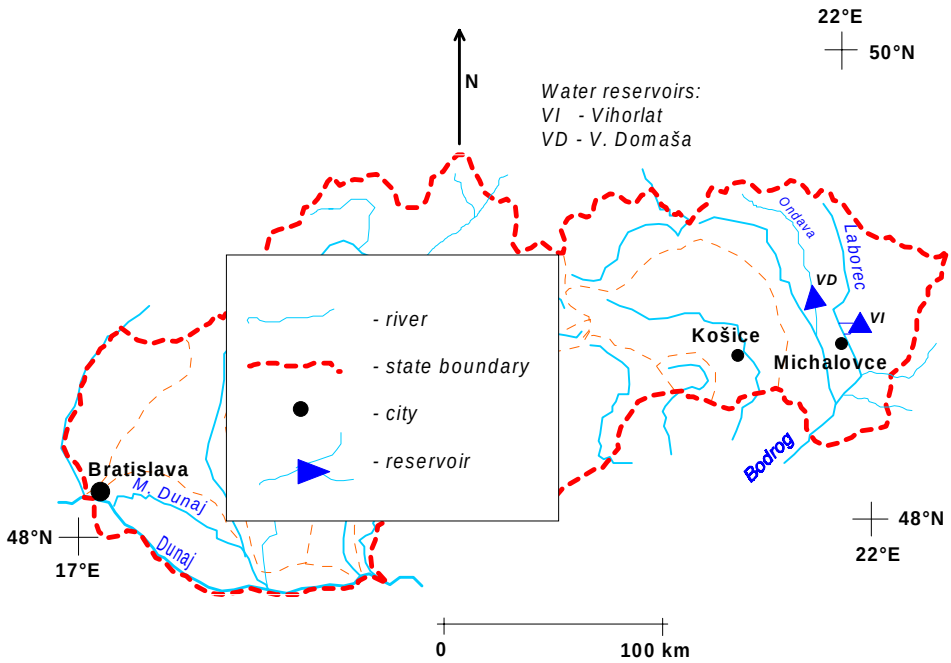


Fig. 1 Water reservoirs in eastern Slovakia

WBMOD model was calibrated for two catchments (*Fig.1*):
- Laborec-Humenné (VI), 27 years, 1971 - 1997, catchment area - 1266.8 km^2.
- Ondava-Stropkov (VD), 30years, 1966 - 1995, catchment area – 578.04 km^2.

Basic statistical characteristics of measured and modelled monthly average flow from both catchments are in *Table 1* (SUM [mm], MAX, MIN, and STDEV [mm/month]).

From hydrological point of view *river Laborec* is typical by floods, which occurrence during the year has random character and peak flows occur during spring months, usually.

Water reservoir Vihorlat was constructed as a part of water management system of East Slovakia Lowland and was put in operation in 1965 [Gomboš, M. and Friga, J., 1996].

Purpose of the project:
- reservoir has a positive influence on flood regime of the river Laborec and partly also on the whole region on the East Slovakia Lowland – it includes the protection of 8900 ha of agricultural land,
- irrigation of 54 000 ha agricultural land,
- project secures the required withdrawals of water for the thermal power plant Vojany,
- Increases the Laborec minimal discharges at profile Michalovce-Stráňany to Q_{min}=1,4 m^3·s^{-1}.

Water reservoir Veľká Domaša is the first step of the hydroelectric system on the river Ondava. Water management importance of this system consist in:
- project provides water supply for industry and irrigation, reduction of flood peaks, increase of low discharges, power production, creates conditions for recreation and water sports,
- water managers consider also the future fresh water supply [Abaffy, D. and Lukáč, M., 1991].

Table 1 Basic statistical characteristics of observed and modelled mean monthly discharge

Catchment	Ondava - Stropkov		Laborec - Humenné	
	Qobs	Qmod	Qobs	Qmod
SUMA[mm]	9702	9709	9011	9004
MIN [mm/month]	2.09	1.18	3	1
MAX [mm/month]	260	164	141	133
STDEV [mm/month]	28.74	22.89	24.42	18.85

Mean monthly precipitation and temperature from two catchments (Laborec-Humenné and Ondava-Stropkov), and mean monthly discharges from two profiles (Humenné and Stropkov) are the input data for WBMOD model. Course of the observed Qobs and modelled Qmod flow in profile Laborec-Humenné [mm/month] is on *Fig.2* and *Fig.3 a, b*. On *Fig.2* is the whole observed period (1971-1997). On *Fig.3 a, b* are Qobs a Qmod at selected time series.

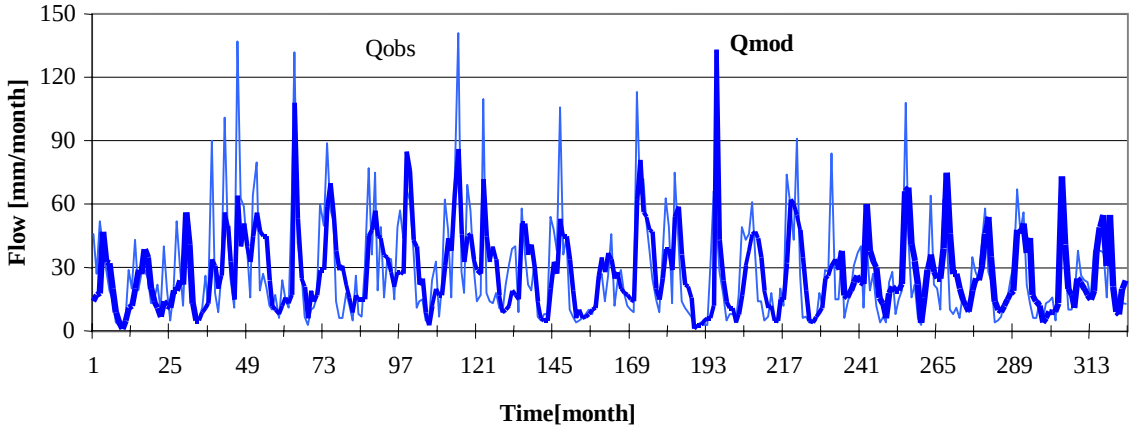
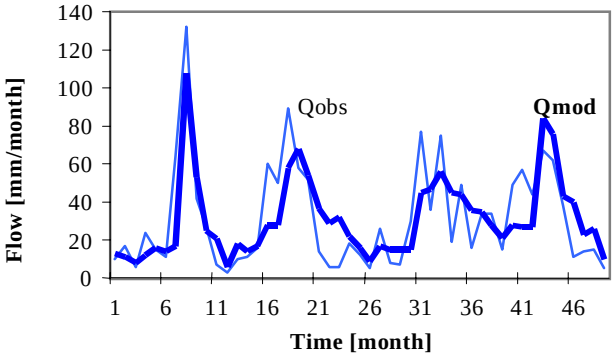
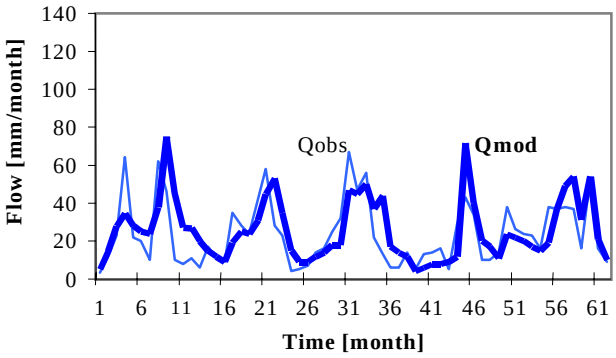


Fig.2 Course of the observed Qobs and modelled Qmod flows in profile Laborec-Humenné [mm/month]



a) IX.1975 – IX.1979



b) VIII.1992 – IX.1997

Fig.3 a, b Course of the observed Qobs and modelled Qmod flows in profile Laborec-Humenné in selected time-series [mm/month]

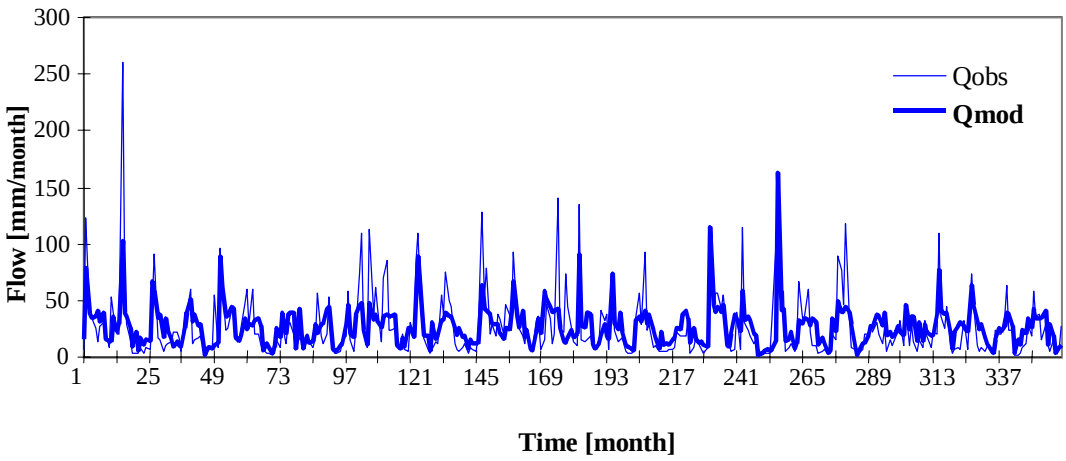


Fig. 4 Course of the observed and modelled flows in profile Ondava-Stropkov [mm/month]

a) VII.1966-X.1973 b) VIII.1989-XII.1995

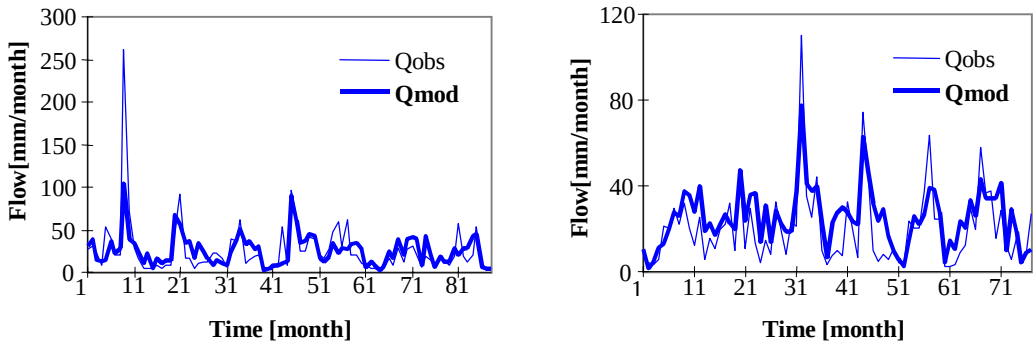


Fig. 5 a, b Course of the observed Qobs and modelled Qmod flows in profile Ondava-Stropkov in selected time-series [mm/month]

Course of the observed Qobs and modelled Qmod flows [mm/month] in profile Ondava-Stropkov is on *Figs. 4* and *5 a, b* (*Fig.4* – whole observed period 1966-1995, *Fig.5 a, b* - selected time-series).

Flow and reservoir storage changes were analysed by WBMOD model with respect to specific climate changes in atmosphere, *(Table 3 a, b)*. Temperature and precipitation scenarios for Slovak territory result from the global circulation model (GCM). The *GFD, UKM, GISS* and *OSU* scenarios result from the older versions of GCMs and they are interpolated for the geographical position of selected catchment. The *GFL, GIL, CCC and WPL* scenarios were developed more recently within the National Climate Programme of the Slovak Republic for the time horizon 2075 and northern part of Slovakia [1]. In *Table 2* there are listed the temperature and precipitation changes according to individual climate scenarios.

A subroutine calculating the necessary reservoir storage for a generated flow series (reservoir inflow) and a uniform reservoir output Qs was later supplemented to WBMOD model. In this paper, Qs is the average monthly flow of the whole-observed period.

Qmod are modelled monthly average flows [mm/month] and *Vmod* are the adequate reservoir storages [mil m^3]. *Vmax* is the reservoir storage necessary for uniform outflow Qs using discharges from whole observed period and *Qmax* is maximal uniform demand, which can be supplied at *Vmax* storage under the changed climate conditions (according to climate scenarios). %Qs is percentage of Qmax/Qs, which indicates the uniform demand decrease at climate change comparing to present situation.

Table 2 Temperature (T) [°C] and precipitation (P) [%] scenarios

SCENARIO		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
GFL	T	2.6	4.1	5.1	4.9	4.8	4.5	4.3	4.0	4.6	4.7	4.1	3.8
	P	0.95	1.44	1.08	1.13	1.07	0.99	0.84	1.19	1.36	1.45	1.44	1.01
GFD	T	5.7	6.8	6.7	5.1	2.6	4.1	5.8	6.4	5.4	3.5	2.3	7.1
	P	1.27	1.33	1.13	1.27	1.27	1.07	1.20	0.97	0.63	1.00	1.27	1.47
GIL	T	5.7	5.4	5.0	3.9	3.2	2.6	2.4	2.4	3.6	4.5	4.7	5.1
	P	1.16	1.31	1.27	1.34	1.18	1.07	1.08	1.06	0.84	1.25	1.31	1.04
UKM	T	6.6	10.2	11.7	12.0	7.7	4.7	5.9	10.1	7.0	6.1	9.7	9.3
	P	1.20	1.23	1.53	1.77	1.50	1.23	0.90	0.87	1.20	1.20	1.17	1.37
CCC	T	3.7	4.5	4.3	3.2	2.9	3.0	3.3	3.2	3.6	3.4	2.7	2.8
	P	1.32	1.17	1.01	1.10	0.94	0.99	0.88	0.87	0.87	1.18	1.27	1.35
GIS	T	4.9	6.7	3.3	5.1	3.1	2.2	2.7	2.3	4.8	2.7	5.3	5.4
	P	1.13	1.17	1.30	1.30	1.17	1.07	1.07	1.07	0.57	1.30	1.33	1.03
OSU	T	4.8	3.8	2.8	3.0	4.1	2.7	3.9	3.9	4.3	3.3	3.8	3.4
	P	1.10	0.97	1.33	0.97	1.33	0.93	0.87	1.13	0.73	0.90	1.07	1.20
WPL	T	4.3	5.3	4.7	4.0	2.8	1.9	2.8	3.4	2.4	1.3	1.0	2.1
	P	0.95	1.05	1.12	1.14	1.15	1.08	0.93	0.79	0.73	0.80	0.96	0.97

Table 3a Modelled annual uniform demands Qmod [mm/month], adequate accumulation storages Vmod [mil m^3], maximal possible uniform demands Qmax using Vmax storage, percentage Qmax/Qs, Laborec-Humenné catchment

SCENARIO	GFL	GFD	GIL	UKM	CCC	GIS	OSU	WPL
Qmod	22.219	22.434	22.963	217.532	21.986	22.241	20.759	20.726
Vmod	241.500	226.466	246.278	242.077	241.921	242.745	246.292	250.229
Qmax	22.300	22.618	23.062	17.728	22.213	22.427	20.857	20.728
Vmax	250.289	250.289	250.289	250.289	250.289	250.289	250.289	250.289
%Qs	80.1	81.3	82.9	63.7	79.8	80.6	75.0	74.5

Table 3b Modelled annual uniform demands Qmod [mm/month], adequate accumulation storages Vmod [mil m^3], maximal possible uniform demands Qmax using Vmax storage, percentage Qmax/Qs, Ondava-Stropkov catchment

SCENARIO	GFL	GFD	GIL	UKM	CCC	GIS	OSU	WPL
Qmod	25.14	24.46	24.36	24.17	24.07	24.04	22.64	21.71
Vmod	92.40	52.00	95.36	105.04	89.85	93.60	107.16	60.48
Qmax	24.97	24.51	24.29	23.37	24.01	23.92	22.53	21.76
Vmax	65.72	65.72	65.72	65.72	65.72	65.72	65.72	65.72
%Qs	92.6	91.0	90.1	86.7	89.1	88.7	83.6	80.7

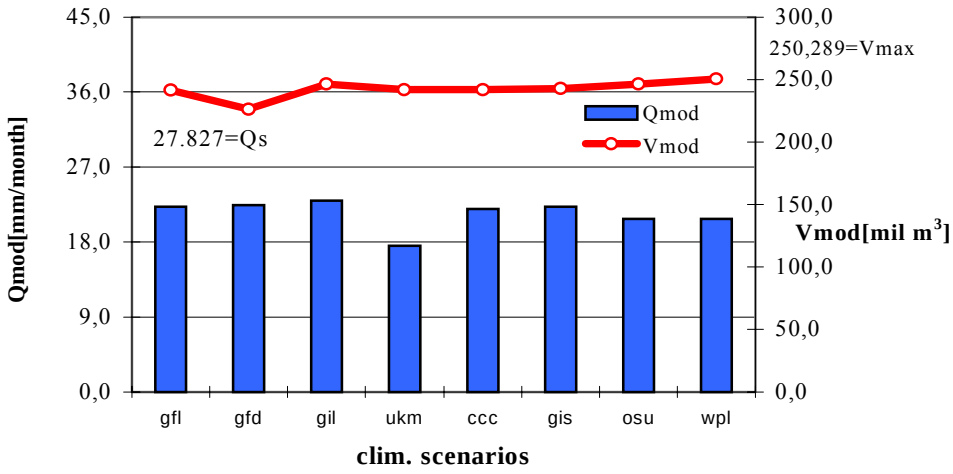


Fig.4a Mean modelled Qmod [mm/month] and the adequate accumulation storages Vmod [mil m^3] under the changed climate conditions (according to temperature and precipitation climate scenarios), Laborec-Humenné catchment.

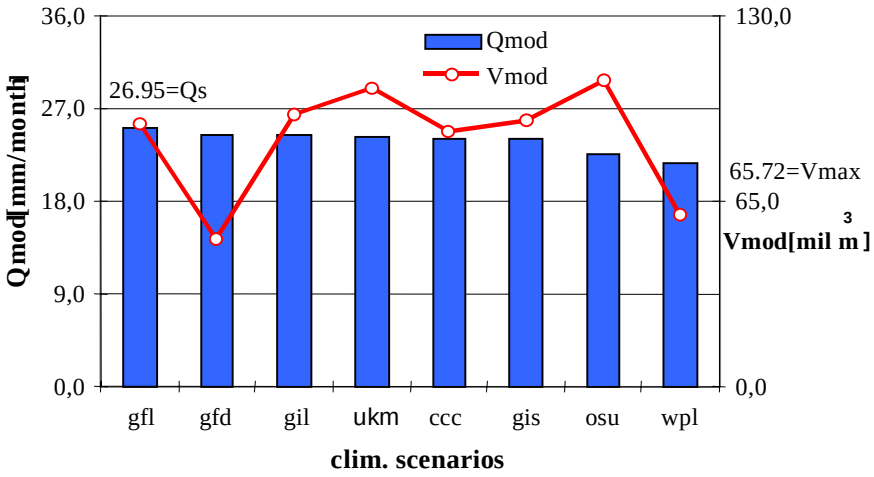


Fig.4b Mean modelled Qmod [mm/month] and the adequate accumulation storages Vmod [mil m^3] under the changed climate conditions (according to temperature and precipitation climate scenarios), Ondava-Stropkov catchment.

5 Results

Changed climate conditions in Laborec-Humenné and Ondava-Stropkov catchments considerably influence the supply of constant demand from the reservoir which was in this case equal to long-term mean of historical series, Qs=27.827 mm/month in Laborec-Ondava catchment and Qs=26.95 mm/month in Ondava-Stropkov catchment.

Using climate scenarios based on GCM models, the maximal uniform demand ranges from 63.7% to 82.3% of Qs in Laborec-Humenné catchment and from 80.7 to 92.6% of Qs in Ondava-Stropkov catchment.

Considering the large variance of the results, it is difficult to formulate unambiguous conclusion. This variance is caused by differences of individual climate scenarios in the main. Reliability increase of the climate change impact studies upon water management in general

and water resources certainty in particular, supposes rainfall-runoff model development and reduction of variance of climate elements, which influence catchment outflow in the main.

Continuation of the research is necessary with respect to the long-term character of the consecutive arrangements. Beginning of the adaptation measures timetable is not identical with the obvious beginning of potential climate changes. In most economy sectors adaptation measures should occur ahead of the climate change itself (as in water or forest management). Concerning this, the time for possible correction of climate change prediction, correction of possible implications assessment and time for re-evaluation of design adaptation measures shortens. Therefore information for decision sphere should be ready at earliest. Design of problem solution is closely connected with complex system of water use, which prediction is not simple in the market economy conditions [Hladný, J et.al. 1996].

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Hydrological Analysis of the November 1998 Flood on the Upper Tisza: Vision of the Development for the Forecasting System and Flood Defence

Hydrologische Untersuchung von Vorhesage des Hochwassers an der Oberen Theiβ im im November 1998: Entwicklungsvorstellungen zur Entwicklung des Hochwasserschutzsystems

Lajos Illés, Károly Konecsny

Extended abstract: During the 79-day period between August 20 and November 6, 1998, there were only 22 days without rainfall over the catchment above the Vásárosnamény river gauge on the Upstream Tisza. Special attention is called to the end of the rainy period, in that the rainfall depth on the Upstream Tisza catchment was 141.3 mm during the 12 days between October 26 and November 6. These rains have prevented desiccation of the soil, creating conditions conducive to the development of a major flood wave. Following the abundant antecedent rainfall, the rains in late October have triggered the first flood wave, the peak of which was recorded at 820 cm on the Vásárosnamény gauge in the evening of November 1 and was observed as far downstream as the Záhony and Dombrád gauges. The flood wave triggered by the heavy rains on November 4 and 5 has overtook the first one still in the bed of the Upstream Tisza and superimposed thereon has caused the second, the main flood wave. Most peak levels along the Tisza section in the Ukraine were in the vicinity of the highest on record. The tributaries entering a short distance upstream of the border have discharged unprecedented high flows. The flood waves on the tributaries have swept along the valleys causing tremendous devastation. In the Ukraine 236 communities were affected, 118 of which with 39 600 homes were inundated, 26 500 homes suffered damage and 1350 collapsed. The flood has destroyed 22 bridges, damaged 340 km of road and claimed human lives. Two levee failures on the Tisza reach upstream of the entrance of Batár-Canal on the national boundary had direct influence on the flood situation on the Hungarian river sections. These were estimated to have reduced the peak stage by at least 5-7, but not more by 15-30 cm. The peak flood discharge past the Tivadar gauge was 3570 m3/s, and thus 100 times the low-water flow. The tributaries Túr, Szamos and Kraszna discharged no major flows, so that owing to attenuation no record flood stages developed at, and downstream of, Záhony. Concentration and travel time of flood waves over the Upper Tisza is rather short. This underlines the importance of flood forecasting and warnings for flood defence operations. The experience of the floods of the last decade (December1993, December 1995,. November 1998) indicated further needs and also possibilities for the development of the flood forecasting system. Special emphasis should be made on the use of modern tools of informatics including telemetry, communication and computational techniques. Special interest is directed towards the utilisation of developing meteorological products. The improvement of meteorological forecasts should be utilised. Applied hydrological models should also be improved.

Analyse der räumlichen Variabilität von Starkniederschlägen in der Slowakei für die regionale Hochwasseranalyse

Silvia Kohnová , Dudley White, Ján Szolgay

Zusammenfassung: Im Rahmen von Bemühungen zur schrittweisen Einführung von neuen Methoden zur Bestimmung von Bemessungshochwässern in unbeobachteten kleinen Einzugsgebieten der Slowakei wurden in der vorliegenden Studie mit der Hilfe von der Clusteranalyse (K-means clustering), homogene Regionen für die regionale Hochwasseranalyse ermittelt. Im Vergleich zu vorherigen Arbeiten wurden als neue klimatische Charakteristiken die Intensitäten von Starkniederschlägen mit dem Wiederkehrintervall von 2, 50 und 100 Jahren und des absoluten beobachteten Maximums des 24-Stunden-Niederschlages für jedes Einzugsgebiet in die Analyse miteinbezogen. Mit Hilfe von geostatistischen Interpolationsmethoden wurden Isolienien und Rasterkarten der Niederschlagscharakteristika erstellt und für die Bestimmung von homogenen Regionen verwendet.

Schluesselworte: geostatistische Interpolationsmethoden, Starkniederschläge, homogene Gruppen, Clusteranalyse, Regionalisierung, Sommerhochwasser

Analysis of the Spatial Distribution of Extreme Daily Rainfall in Slovakia for Regional Flood Frequency Analysis

Abstrakt: In previous studies various regional methods for estimation of design discharges on small ungauged catchments in Slovakia were tested. In this paper pooling groups for regional flood frequency analysis were constructed using cluster analysis (K- mean clustering method). In comparison to the previous studies new climatic characteristics which describe the areal distribution the of extreme rainfall were included. Annual maximum daily precipitation series from the period 1901-1980 were used from 240 precipitation stations. The spatial distribution of the maximum daily precipitation amounts with the return period of 2, 50 and 100 years was analysed using geostatistical methods. Isoline and grid maps of these precipitation characteristics were constructed and were used as input for pooling catchments into homogenous groups for flood frequency analysis.

Keywords: geostatistical methods, extreme rainfall, homogenous regions, cluster analysis, regionalisation, rainfall floods

1 Einleitung

In den letzten Jahrzehnten beruhte die Bestimmung von Bemessungshochwassern in unbeobachteten Einzugsgebieten der Slowakei überwiegend auf der Verwendung der einfachen regionalen Formeln, die das 100-jährliche Hochwasser aus der Einzugsgebietsfläche in geographisch zusammenhängenden Regionen berechneten. Bemessungswerte mit kürzerer Wiederkehrperiode wurden dann mit Hilfe von Beiwerten aus den 100-jährigen Werten bestimmt, weiter wurden Korrekturbeiwerte in die Formeln eingeführt, die lokale Bedingungen im Einzugsgebiet berücksichtigen sollen. In mehreren vorherigen Studien wurde an Hand von Daten aus 260 kleinen und mittleren Einzugsgebieten aus der ganzen Slowakei gezeigt, dass mehrere ältere Formeln Umhüllungskurven der statistisch ermittelten 100-jährigen Bemessungswerte darstellen. In der Folge wurde die Entwicklung von regionalen Formeln, die auf neuen Prinzipien und Kennwerten basieren fuer notwendig gehalten. Als Ziel wurde gesetzt möglichst einfache Abflussformeln für den praktischen Gebrauch für kleine und mittlere Einzugsgebiete (cca 20 bis 200 km^2) abzuleiten ohne den Umhüllcharakter der bisherigen Formeln einhalten zu müssen. Da die Formeln

vorwiegend in unbeobachteten Einzugsgebieten Anwendung finden sollen, sollten dabei Daten auch aus digitalen Karten benutzt werden.

2 Vorherige Untersuchungen

Um die, durch die Entstehung von Hochwassern bedingte Heterogenität der Daten zu vermindern, wurde vorgeschlagen Hochwasser aus Regen und aus Schneeschmelze getrennt zu untersuchen. Ein Datensatz der jährlichen Sommerhochwasser und Winterhochwasser aus 247 Pegelstellen in der Slowakei wurde zusammengestellt. Die Fläche der untersuchten Einzugsgebiete lag zwischen 20 und 200 km^2, die kürzeste Datenreihe betrug 15 Jahre, die längste 61 Jahre. Es wurden insgesamt 14800 Datenjahre bearbeitet. Folgende 17 Gebietsparameter und klimatische Charakteristiken wurden aus einem digitalen Geländemodell und digitalen Karten mit Hilfe von GIS Verfahren bestimmt: die Fläche des Einzugsgebiets (F) [km^2], die Höhe des Pegels (NV) [mue B], der Formbeiwert des Einzugsgebietes (α), der Waldanteil (LES) [%], der langjährige mittlere Abfluss (ODT) [mm] aus der Periode 1930-1960, das mittlere Gefälle des Einzugsgebiets (SL) [%], die mittlere Einzugsgebietshöhe (HPR) [mue B], die mittlere Hangorientierung im Einzugsgebiet (ASP) [^{o}], die Höhe der Schneedecke mit dem Wiederkehrintervall von 50 Jahren (SN50) [cm], die Wasserkapazitaet der Schneedecke mit der Wiederkehrintervall von 10 Jahren (SVH10) [$kN.m^{-2}$], die mittlere Laenge des Hauptvorfluters (DL) [km], der Infiltationsindex der Bodentypen (IFI), die mittlere Neigung des Hauptvorfluters (IU) [%], die Konzentrationszeit (TC) in [h] berechnet nach den Formeln von Hradek (HRAD), Kirpich (KIRP), und Nash (NASH).

Im Rahmen von Bemühungen zu der schrittweisen Einführung von neuen Methoden zur Bestimmung von Bemessungshochwassern in unbeobachteten kleinen Einzugsgebieten der Slowakei wurden in früheren Untersuchungen verschiedene regionale Verfahren getestet. Zu beginn wurden verschiedene Teilgebiete und auch die ganze Slowakei auf Grund der Ähnlichkeit von oben angegebenen physiogeographischen und klimatischen Charakteristiken in geographisch homogene zusammenhängende Regionen geteilt. Dann wurden Einzugsgebiete mit Hilfe der Clusteranalyse (K-means clustering Methode (Hartigan, 1975), mit euklidischer Metrik und standardisierten Variablen) gemäß ihrer klimatischen Charakteristiken und Gebietskennwerten in Gruppen mit ähnlichen Eigenschaften aufgeteilt (siehe z. B. Szolgay, Kohnová (1999), Kohnová, Szolgay (1999a,b)). Die Ähnlichkeit der Einzugsgebiete wurde durch ihre Position in dem von den einbezogenen Variablen definierten n-dimensionalen Koordinatensystem und durch ihre Distanz zueinander bestimmt. Die Clustermethode wurde gewählt, weil sie ein objektiv begründetes und wiederholbares Verfahren zur Bildung von Raumtypen in Datenraum darstellt. Eine Diskussion hinsichtlich der Standardisierung und Anwendbarkeit von anderen Methoden sind z.B. in (Acreman, Sinclair, 1986; Burn, 1990; Gottschalk,1985; Mosley,1981, NERC, 1975), angeführt. In Gegensatz zur vorher benutzten Gliederung der Slowakei in geographisch zusammenhängende homogene Teilgebiete, resultiert aus der Clusteranalyse eine Gliederung in geographisch nicht kontinuierliche Gruppen von ähnlichen Einzugsgebieten.

In den ermittelten und als homogen angesehenen Regionen und Gruppen wurden mehrere gängige, und in der Literatur angeführte Formeltypen für die Berechnung von Bemessungswerten von Einzugsgebietskennwerten getestet. Verschiedene regionalen Regressionsformeln und Kombinationen von Eingangsvariablen wurden untersucht (siehe z.B. Stedinger, Vogel, Foufala-Georgiou, 1993; Pitlick, 1994; NRC,1988; Newson; 1978):

Multiplikative Formel:

$$Q = k.\ A^a.\ B^b.\ C^c.\ \ldots \qquad (1)$$

Additive Formel:

$$Q = k + a.A + b.B + c.C\ \ldots \qquad (2)$$

wo k, a, b, c sind die Regionalparameter, A, B, C ... und U, V, W… die Gebietskennwerte.

Da in den betreffenden Gebieten (wie aber auch anderen Fällen) keine hydrologisch eindeutig begründetet Wahl der Variablen für die regionale Regressionsformeln existierte, wurde die Abklärung der angewendeten Form des Zusammenhanges zwischen Gebietsparametern und der Charakteristika der Winterhochwasser im „Trial und Error“ Verfahren mit Mehrfachregression durchgeführt. Die Abgeleitete Beziehungen wurden für die Bemessung von hydrotechnischen Bauten als weniger geeignet eingestuft. Es ueberprueft ob man durch die Berücksichtigung von neuen Einflussfaktoren, wie die regionale Verteilung von Starkniederschlägen, bessere Resultate erzielen kann.

3 Geostatische Analyse von Starkniederschlagsdaten

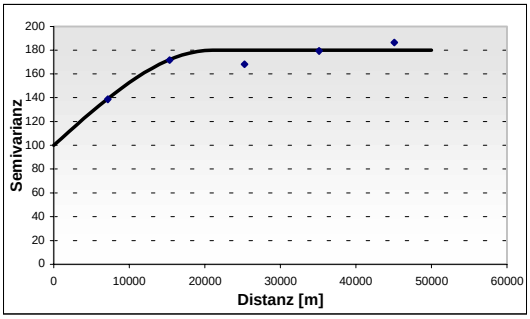
Für die Studie wurden die durch Šamaj, Valovič und Brázdil (1985) bestimmten Werte der jährlichen Maxima von 24-Stunden-Niederschlägen mit der Wiederholungszeitspanne von 2, 50 und 100 Jahren (NTn2, NTn50, NTn100) und des absoluten Niederschlagsmaximums für einen 24-Stunden-Niederschlag aus einem Zeitraum von der Periode 1901-1980 (ABSMAX) verwendet. Von den in der Slowakei beobachteten 450 Stationen zur Erfassung von Niederschlagsdaten wurden hier Daten aus 240 Stationen verwendet.

Das grundlegende Ziel der Analyse war die Ermittlung der räumlichen Variabilität der Starkniederschläge mit der Hilfe von geostatistischer Interpolationsmethoden, wie z.B. Kriging und Cokriging (Phillips et al., 1992). Es wurde hierfür eine räumliche Bestaendigkeit (Persistenz) der zu untersuchenden Größen angenommen. Mit der statistischen Beschreibung dieser räumlichen Persistenz wurde dann eine Schätzung deren Verteilung im Raum möglich. Folgende drei Schritte wurden aufgeführt:

1. Untersuchung der Covariation der Daten in Abhängigkeit von ihrer Entfernung zueinander
2. Anpassung theoretischer Modelle an diese Beziehungen
3. Benutzen dieser Modelle, um den Wert von Paaren benachbarter Punkte zu bestimmen und berechnen des interpolierten Wertes.

Im ersten Schritt wurde eine Reihe von experimentellen Semivariogrammen berechnet. Alle möglichen Paare von Datenpunkten wurden untersucht, die Paare waren in Distanz-Klassen eingeteilt und die Hälfte der Varianz von der Differenz der Werte (die Semivarianz) wurde graphisch gegen die Distanz aufgetragen. Daran anschließend wurden theoretische Kurven (Modell-Semivariogramm) in diese Punktreihen eingepaßt. Dies geschah entweder optisch, durch Regression mit den kleinsten Fehlerquadraten oder durch Optimierung des Modells durch “cross validation procedures”. Die visuelle Anpassung wurde vorgezogen, als Kontrolle jedoch mit einer mathematischen Anpassung verglichen (Phillips et al., 1992). Das Modellieren der raeumlichen Abhaengigkeiten wurde mit dem Programm GSTAT für multivariables, geostatistisches Modellieren, Vorhersage und Simulation von (Pebesma, 1997) durchgeführt. Abbildungen 1, 2, 3 und 4 stellen die Variogramm – Modelle dar.

Im Laufe der Untersuchungen wurden auch andere Interpolationsmethoden getestet, wie die Inverse-Distanz Methode oder Co-kriging. Die besten Ergebnisse bei der räumlichen Interpolation werden in diesem Fall mit dem einfachen Kriging erreicht. Das Visualisieren der Ergebnisse geschah in der Form von Isolinienkarten die weiter in Gridkarten transformiert wurden. In den Abbildungen 5 bis 7 sind die Isolienienkarten von den 24-Stunden-Niederschläge mit der Wiederholungszeitspanne von 2 und 100 Jahren und des absoluten Niederschlagsmaximums für einen 24-Stunden-Niederschlag aus einem Zeitraum von der Periode 1901-1980 für die ganze Slowakei dargestellt.



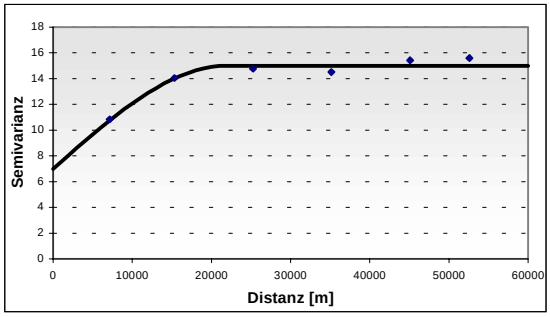
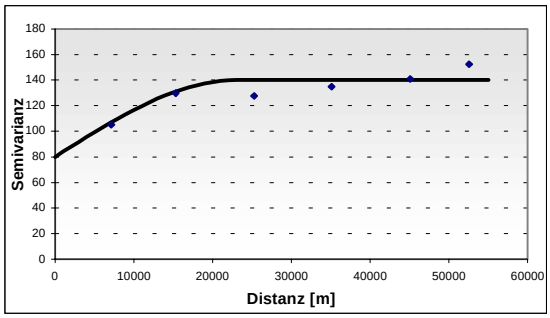


Abb. 1 Variogramm - Modell für NTn 100

Abb. 3 Variogramm - Modell für NTn 2



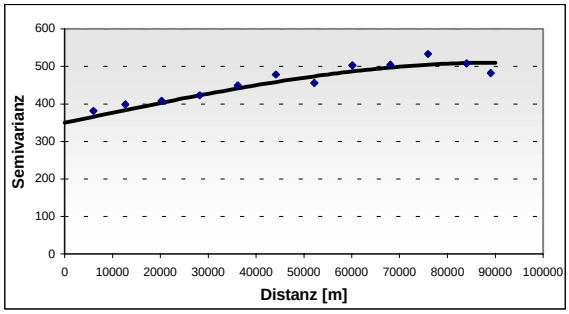


Abb. 2 Variogramm - Modell für NTn 50

Abb. 4 Variogramm - Modell für Absmax

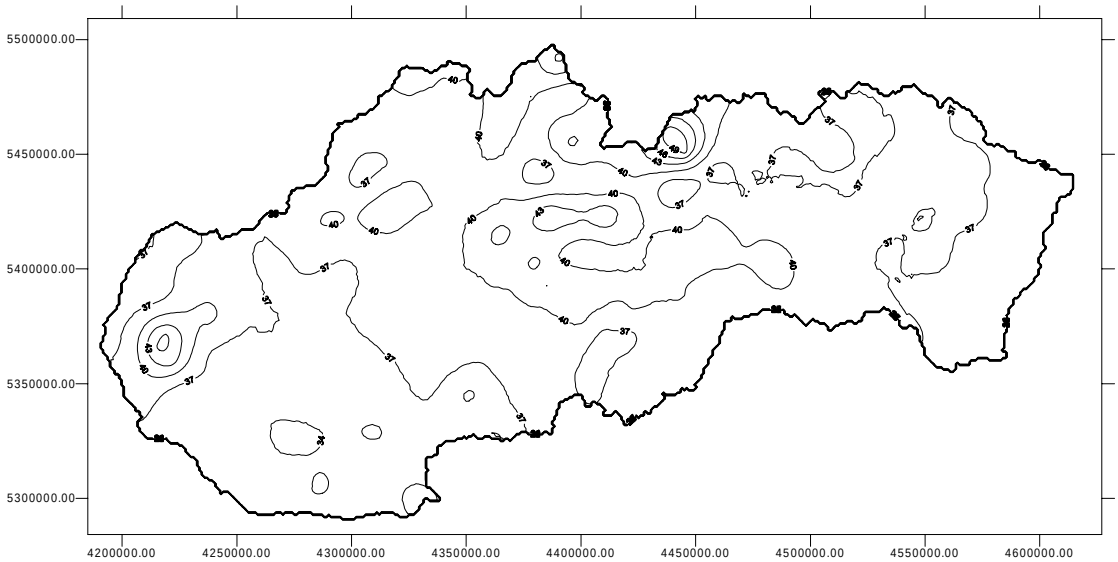


Abb. 5 Isolinienkarte der jährlichen Maxima der 24-Stunden-Niederschläge mit dem Wiederkehrsintervall von 2 Jahren in mm. (die X und Y Achse geben die geographischen Koordinaten in m an)

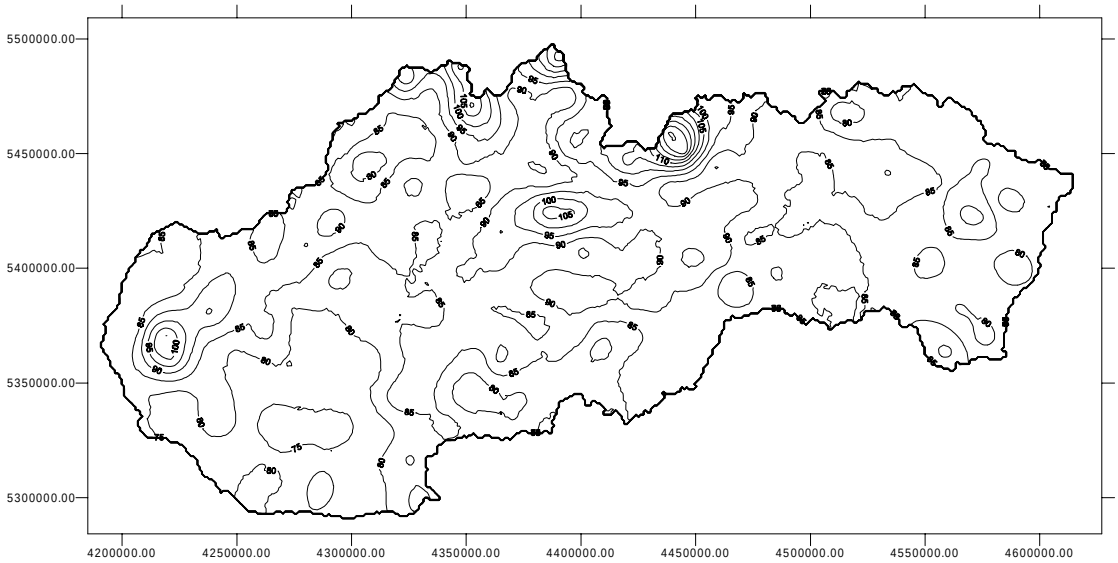


Abb. 6 Isolinienkarte der jährlichen Maxima der 24-Stunden-Niederschläge mit dem Wiederkehrsintervall von 100 Jahren in mm(die X und Y Achse geben die geographischen Koordinaten in m an)

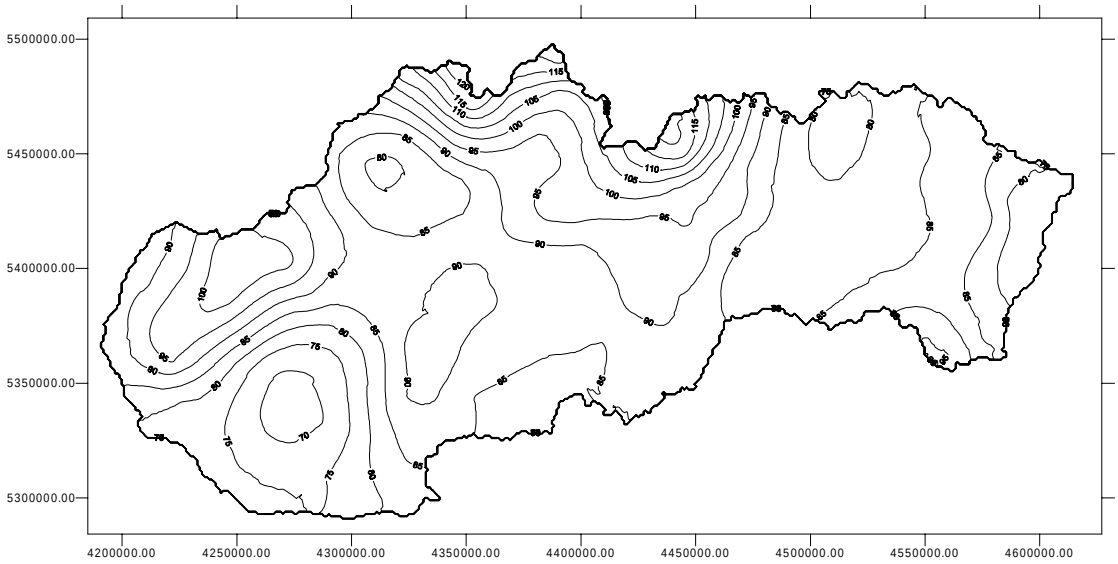


Abb. 7 Isolinienkarte der absoluten jährlichen Maxima der 24-Stunden-Niederschläge von der Periode 1901-1980 in mm. (die X und Y Achse geben die geographischen Koordinaten in m an)

Allgemein wurde eine Beziehung zwischen dem Niederschlag und der Meereshöhe erkennbar. Besonders ist dieser Zusammenhang in gebirgigen Regionen erkennbar und vor allem in der hohen Tatra (siehe Abb. 6 mit dem 24-h Niederschlagsereignis für das absolute Maximum in 80 Jahren). Die niedrigsten Werte lassen sich im Donaubecken ablesen. Die Werte für die Ostslowakei liegen über weite Gebiete auf einem sehr konstanten Niveau, die Niederschläge liegen in ihrer Höhe zwischen denen der gebirgigen Regionen und denen der Donauebene. Die Unterschiede zwischen den Starkniederschlägen für die 50-, bzw. 100-jährige Wiederholungszeitspanne sind gering. Die auffälligen Konzentrationen von Isolinien in der hohen Tatra im Norden der Slowakei sind auch durch die Station Lomnický Štít bedingt. Diese deckt bei den Interpolationen weite Bereiche ab. Zwar sind die in dieser

Station gemessenen Werte tatsächlich sehr hoch, aber sie sind nicht, wie in der Karte dargestellt, fuer das Umland repräsentativ.

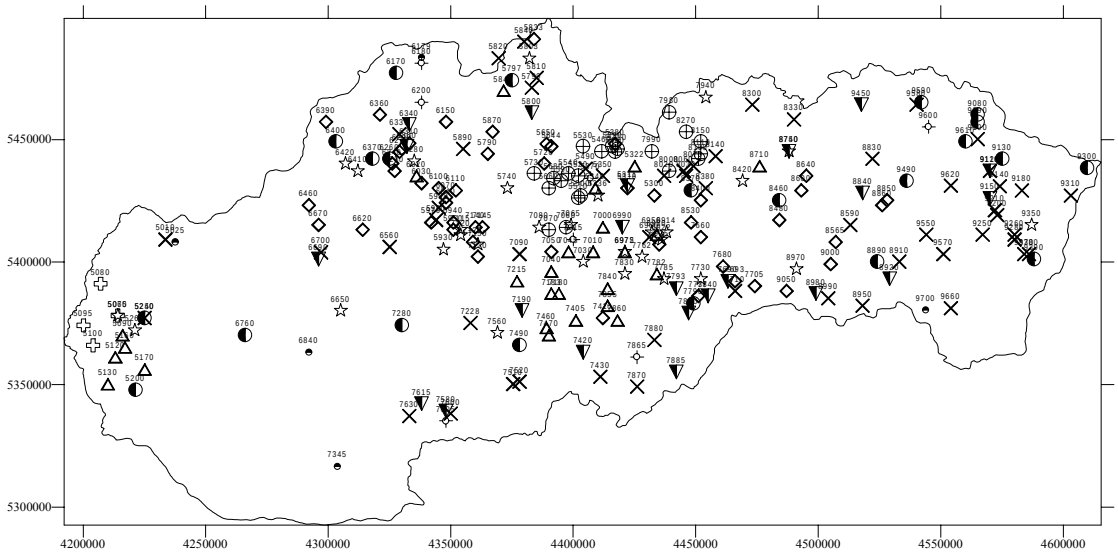
4 Gliederung der Einzugsgebiete in homogene Gruppen

Bei der folgenden Gliederung der untersuchten Einzugsgebiete der Slowakei in homogene Gruppen durch Clusteranalyse wurde wie folgt vorgegangen. Es wird oft empfohlen, dass man eine Vorstellung über die zu erwartenden Zahl der Gruppen hat, den die Anzahl der Cluster hängt auch von der praktischen Anwendbarkeit der Resultate ab. In jeder Gruppe wollten wir genug Einzugsgebiete für weitere Analysen bekommen. Deswegen wurde die Zahl der Cluster auf acht bis zehn beschränkt. Weiter wurde auch darauf geachtet, dass die Anzahl der Einzugsgebiete in den einzelnen Gruppen ungefähr gleich groß war. Als Eingangsvariablen wurden nur solche Kombinationen von Gebietsmittelwerten von Starkniederschlägen, Einzugsgebietskennwerten und anderen klimatischen Charakteristiken gewählt, die einen Korrelationswert zwischen diesen Parametern kleiner als 0.3 haben. Cluster Profile Plots wurden analysiert um solche Gruppen zu wählen die es ermöglichen die unbeobachtete Einzugsgebiete auf Grund der Werte der Eingangsvariablen in gut auseinanderhaltende Gruppen einteilen zu können.

Zum Vergleich wurden auch andere Methoden der Clusterisierung getestet, wie hierarchisches Clustering mit Ward-Distance, oder K-means Clustering Methode mit MW Metrik. Dabei wurde beobachtet, das die Aufteilung der Einzugsgebiete in Gruppen sehr ähnlich wurde. Im Allgemeinen hat die Analyse Einzugsgebietsgruppen geformt bei denen man größere Streung in den Werten der Einzugsbietscharakteristiken in der Gruppen nicht immer vermieden werden konnte.

Resultate, bei denen Gruppen geformt wurden, die es ermöglichten Einzugsgebiete auf Grund der Werte der Eingangsvariablen gut auseinanderzuhalten, wurden mit K-means Clustering mit Euklidischer Metrik erreicht. Aus den Versuchen (mehr als 70) mit verschiedenen Gebietskennwerten wurden folgende Parameterkombinationen für unsere Ziele als geeignet gefunden:

- α , TC NASH, IFI, NTn 100
- F, IFI, SL, α , NTn 100,
- F, IFI, α , NTn 100,
- SL, ASP, DL, ABMAX.



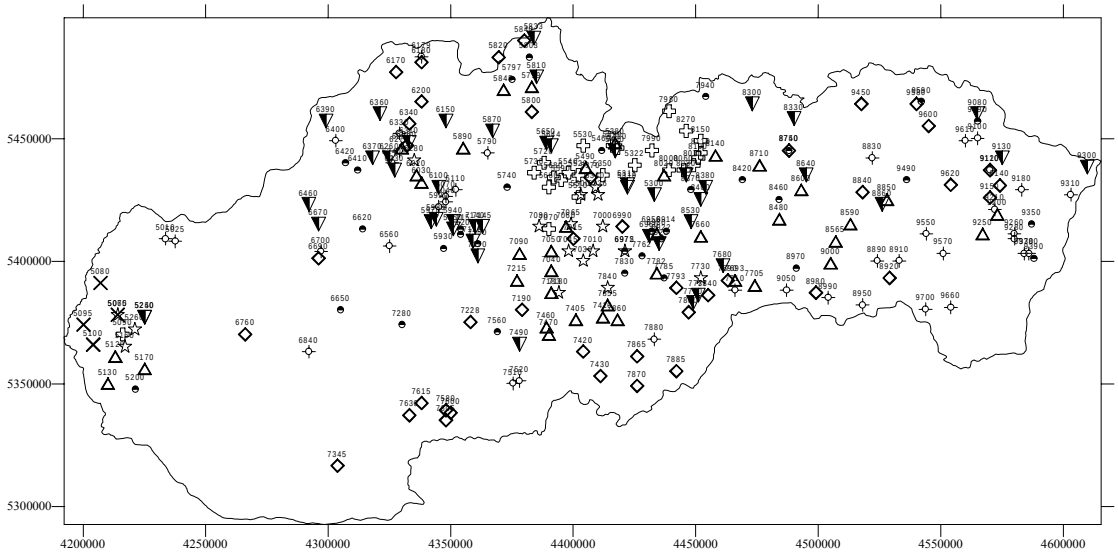


Abb. 8 Die Verteilung der untersuchten Einzugsgebiete der Slowakei in homogene Gruppen auf Grund der Ähnlichkeit von SL, ASP, DL, ABMAX.

Abb. 9 Die Verteilung der untersuchten Einzugsgebiete der Slowakei in homogene Gruppen auf Grund der Ähnlichkeit von α, TC NASH, IFI und NTn100.

5 Schlussfolgerungen

Die Einführung von Parametern der Starkniederschläge in die Gliederung der Einzugsgebiete in homogene Gruppen hat zur Verbesserung der Qualität der Gruppenbildung der Einzugsgebiete der Slowakei geführt. Im Vergleich zu vorherigen Arbeiten sind die Einzugsgebietsgruppen besser voneinander zu unterscheiden und oft haben verschiedene Kombinationen von Eingansgvariablen zu ähnlichen Einzugsgebietsgruppen geführt. Dadurch wird die Eindeutlichkeit der Klassifizierung erhöht.

Im weiteren wird die Anwendbarkeit der entstandenen Gruppen für die regionale Hochwasseranalyse untersucht werden. Es wird getestet, wie man mit den aus Gebietskennwerten geclusterten Einzugsgebieten zu regionalen Verteilungsfunktionen gelangen kann. Weiter werden Beziehungen zwischen Gebietskennwerten und Bemessungswerten gesucht.

6 Danksagung

Die presentierten Resultate wurden im Rahmen des Projektes 2/6008/99 entstanden. Die Authoren bedanken sich der Slowakischen Wischenschaflichen Grant Agentur fuer die Unterstuetzung des Projektes.

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Trends in vieljährigen Hochwasserabflussreihen im österreichischen Donaugebiet

Petra Lalk, Peter Lorenz, Franz Nobilis

Zusammenfassung: Nach einer Untersuchung der Hochwasserkollektive österreichischer Pegel für die Jahre 1952-1991 versucht die vorliegende Arbeit lange Zeitreihen, zum Teil ab 1821, für 18 Pegel im Hinblick auf Trend und Änderung im Median sowie der Hochwasser mit einer Wiederholungszeit von 1, 10 und 100 Jahren für Teilreihen mit 30 Jahren zu analysieren. Die Ergebnisse widerlegen nicht die Resultate der früheren Untersuchung. Es ergeben sich nämlich nur in einigen Fällen regional einheitliche Verhaltensweisen, aber keine landesweit einheitlichen Bilder.

Schlüsselworte: Hochwasserkollektive, Änderung charakteristischer Parameter, Trends

Trends in long-term flood series in the Austrian Danube Basin

Abstract: After an investigation of the flood series of Austrian gages for 1952-1991 the presented paper tries to analyse long series, partly starting from 1821, for 18 stations concerning trend and changes in the median, as well as for the maxima with a return period of 1, 10 and 100 years for series of 30 years. The results are not in contrary to the results of the primary investigation. Only in a few cases regional uniform behaviour occurs but not for the whole country.

Key words: Flood series, changes of characteristic parameters, trends

1 Einleitung

Für die Jahresreihe 1952-1991, unterteilt in Dekaden, wurden von maximal 441 mehr oder weniger unbeeinflussten Pegeln in Österreich die Jahreshochwasser und die Anzahl von Ereignissen über einem bestimmten Schwellenwert im Hinblick auf einen möglichen Trend untersucht (NOBILIS und LORENZ, 1997). Nur in der Dekade 1972-1981 bei der Anzahl der Ereignisse pro Jahr und in der Dekade 1982-1991 bei den Jahresmaxima zeigten sich geschlossene Gebiete von positivem (linearen) Trend, nur sehr lokal signifikant (5 %) positiv. Die Ausgangsbasis für diese Arbeit waren Untersuchungen über Hochwasser in Österreich hinsichtlich Fakten und Vermutungen (NOBILIS und LORENZ, 1996). Die vorliegende Untersuchung sollte an wesentlich längeren Reihen etwaige Trends bzw. Gebiete mit Trend bestätigen oder ablehnen.

2 Daten und Methodik

Das Hydrographische Zentralbüro hat in einer ersten Bearbeitung 18 Hochwasserkollektive an der Donau und deren Zubringer in Österreich zusammengestellt. Die längsten Reihen (Tab. 1) beginnen ab 1821 und wurden mit dem Phasenhäufigkeitstest von Wallis und Moore auf dem 5 %-Niveau als unabhängig beurteilt. In einer späteren Phase werden weitere Untersuchungen durchzuführen sein, um die Güte der Werte besser abzusichern. Von diesen Jahreshöchstwerten sind in der Tab. 1 Minima, Maxima, Mittelwert und Median angegeben sowie die Ergebnisse des Trendtests nach Cox und Stuart auf dem 5 %-Niveau. An die Kollektive wurde eine generalisierte Extremwertverteilung (GEV) angepasst. Um die signifikanten Trends zeitlich besser herauszuarbeiten, wurde der Test nach Sneyers (SNEYERS, 1963) für die längsten Reihen angewendet. Die Interpretation ist bei CEHAK (1973) hinsichtlich der Anwendung für Hochwasserkollektive nachzulesen.

3 Ergebnisse

3.1 Teilreihen

In Tab. 2 wurden Teilreihen mit 30 Jahren, beginnend mit 1841-1870 bis 1961-1990 ausgewiesen, wobei hinsichtlich Minimum und Maximum der Gesamtreihe ersichtlich ist, in welcher Teilreihe dieser Wert auftaucht. Hinsichtlich Mittelwert, Median und den charakteristischen Hochwasserwerten mit einer bestimmten Wiederholungszeit (HQ_1, HQ_{10} und HQ_{100}) wird angegeben, ob der jeweilige Parameter größer (+) oder kleiner (-) als jener der Gesamtreihe ist. Zudem ist ausgewiesen, ob in der Teilreihe ein Trend auf dem 5 %-Niveau vorhanden ist.

1841-1870: Die Parameter sind generell kleiner als jene in der Gesamtreihe, der Trend ist im Allgemeinen positiv.

1871-1900: Die Parameter bis zum HQ_1 sind bis auf Inn und Donau in Wien kleiner als jene der Gesamtreihe. Beim HQ_{10} liegen die Werte der Donau bei Stein und Wien höher als bei der Gesamtreihe, beim HQ_{100} ist dies generell der Fall. Der Trend ist am Inn in Tirol positiv, in Oberösterreich signifikant negativ. Die Donau selbst hat in Linz positiven, in Stein und Wien aber signifikant negativen Trend.

1901-1930: Ab dieser Reihe lassen sich schon eher Aussagen über Flussgebiete treffen. Beim Median haben Inn, Donau und Enns höhere, Traun und Mur niedrigere Werte als die Gesamtreihe. Beim HQ_1 trifft dies für Inn, Enns und Donau bzw. für die Drau zu. Beim HQ_{10} zeigen Donau und Mur kleinere Werte als die Gesamtreihe, beim HQ_{100} zeigen alle außer der oberen Traun kleinere Werte als die Gesamtreihe. Der Trend ist am Inn, der Drau, der Enns und der Donau außer bei Linz negativ, an der Mur sogar signifikant negativ.

1931-1960: Beim Median zeigt die Donau höhere Werte, die Mur niedrigere Werte als die Gesamtreihe. Beim HQ_1 haben Inn, Donau und Mur höhere Werte. Beim HQ_{10} zeigen Traun und Drau geringere Werte, während beim HQ_{100} Donau, Enns und Drau niedrigere Werte aufweisen. Der Trend ist hier bei Donau und Drau negativ, bei der Mur positiv.

1961-1990: Beim Median sind Inn, Donau und Mur höher als bei der Gesamtreihe, beim HQ_1 lediglich Donau und Traun. Beim HQ_{10} erweisen sich Donau und Mur höher als bei der Gesamtreihe, beim HQ_{100} sind Donau, Traun und Enns kleiner. Der Trend ist bei Inn, Donau und Traun negativ.

3.2 Gesamtreihen

Betrachtet man die jeweiligen Gesamtreihen, so zeigt der Cox-Stuart-Test auf dem 5 %-Niveau einen einheitlich signifikant positiven Trend an der Donau (Tab. 1 und Abb. 1) sowie einen negativen am Inn und einen positiven an der Traun und Drau.

Will man die Anzeichen hinsichtlich signifikantem positiven Trend etwas näher beleuchten, so kann man die Ergebnisse des Sneyers-Tests heranziehen. Für die Donau bei Linz ist ein signifikant positiver Trend schon ab der Wende vom 19. zum 20. Jahrhundert ersichtlich, in Linz und Wien erst ab 1955 bzw. 1940. An der Traun trifft dies für Steeg und Wels ab etwa 1975/80 zu.

Grundsätzlich sind auch Hinweise (CEHAK, 1973) zu beachten, dass die Jahre vor 1860 einem anderen Niederschlagsregime zugehören und eigentlich erst ab diesem Zeitpunkt gleich lange Serien für die Weiterberechnung zu verwenden wären. Auf etwaige anthropogene Einflüsse und deren Bewertung wurde bei dieser ersten Ausarbeitung verzichtet.

Tabelle 1 Kenndaten der verwendeten Hochwasserkollektive
TREND: Ergebnisse des Cox-Stuart-Tests (n = negativ, sn = signifikant negativ (5 %), p = positiv, sp = signifikant positiv (5 %))

NR	MESSSTELLE	GEWÄSSER	REIHE	MIN	MAX	MITTEL	MEDIAN	TREND
1	Stein-Krems	Donau	1828-1996	2985,0	10500,0	5254,0	4930,0	sp
2	Linz	Donau	1821-1996	1800,0	8800,0	3611,0	3355,0	sp
3	Wien-Nußdorf	Donau	1828-1996	3063,0	10496,0	5239,0	4993,0	sp
4	Rosegg im Rosental	Drau	1893-1966	120,0	2400,0	1057,0	997,5	p
5	Federaun	Gail	1890-1997	125,0	850,0	364,2	347,5	p
6	Schärding	Inn	1850-1997	1464,0	7000,0	2736,0	2484,0	sn
7	Steeg	Traun	1901-1997	116,0	610,0	212,4	196,0	p
8	Bad Ischl (Maxquelle)	Traun	1901-1997	119,0	930,0	223,3	194,0	p
9	Strobl (Bürglstein)	Ischl	1901-1997	14,6	56,8	27,1	26,1	p
10	Roitham	Traun	1919-1997	201,0	1200,0	386,8	355,0	p
11	Steyr (Ortskai)	Enns	1895-1997	640,0	3180,0	1314,0	1221,0	n
12	Wels-Lichtenegg	Traun	1895-1997	327,0	1660,0	648,2	588,0	p
13	Liezen	Pyhrnbach	1895-1997	180,0	564,0	313,4	307,0	p
14	Zeltweg	Mur	1920-1997	120,0	610,0	281,8	269,5	n
15	Leoben	Mur	1895-1997	165,0	1090,0	360,1	334,0	p
16	Bruck an der Mur Unter Mürz	Mur	1927-1997	220,0	1062,0	462,9	445,0	p
17	Frohnleiten	Mur	1895-1997	183,0	1360,0	504,9	491,0	p
18	Kirchbichl	Inn	1846-1997	649,0	2198,0	1184,0	1150,0	n

Abbildung 1 Kollektiv der Jahreshochwasser für den Pegel Stein-Krems/Donau

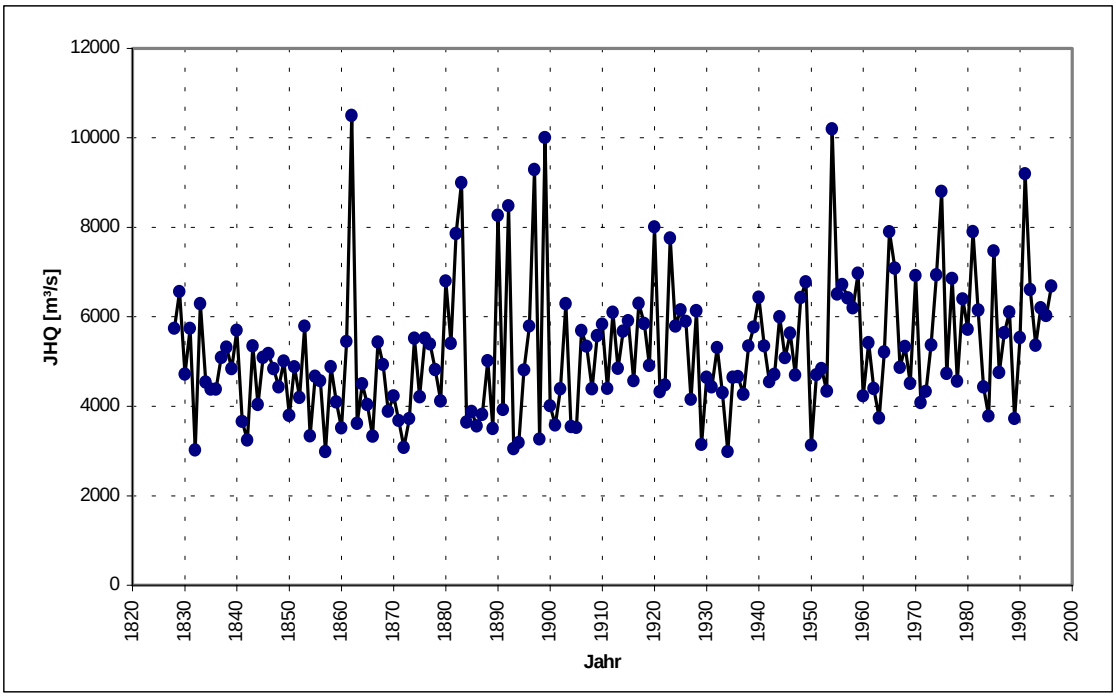

Abbildung 2 Kollektiv der Jahreshochwasser für den Pegel Linz/Donau

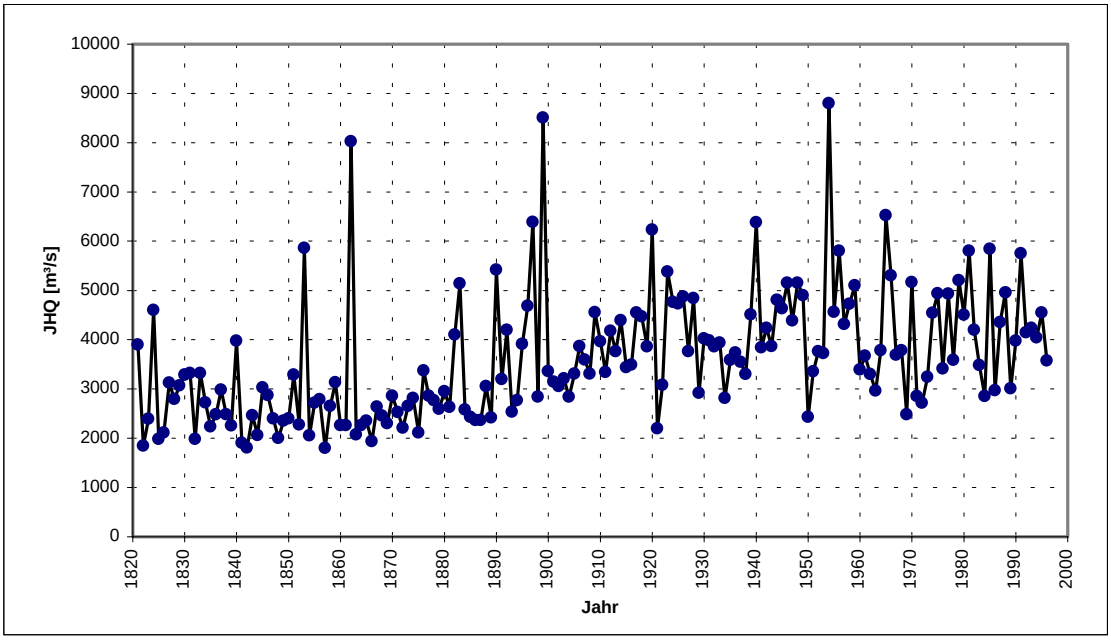

Abbildung 3 Kollektiv der Jahreshochwasser für den Pegel Wien-Nußdorf/Donau

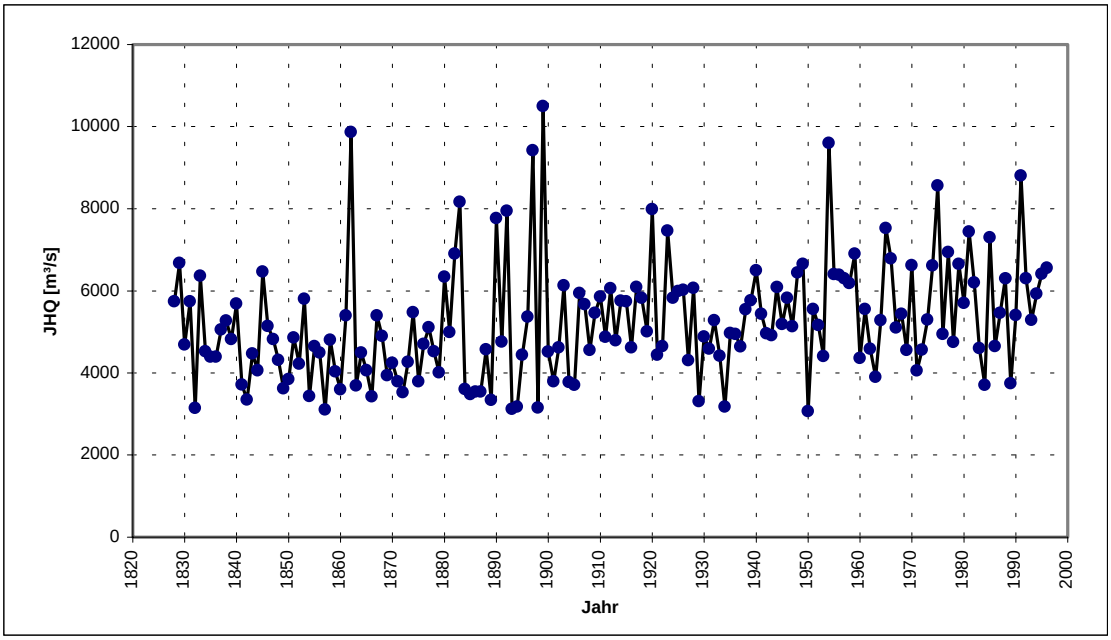

Tabelle 2 Ergebnisse für die Teilreihen bezogen auf die längste Reihe (n = negativ, sn = signifikant negativ (5 %), p = positiv, als Aussage für den Trendtest nach Cox-Stuart)

NR	MESSSTELLE	REIHE	MIN	MAX	MITTEL	MEDIAN	HQ1	HQ10	HQ100	TREND
1	Stein-Krems	1841-1870	+	o	-	-	-	-	-	p
		1871-1900	+	-	-	-	-	+	+	n
		1901-1930	+	-	-	+	+	-	-	n
		1931-1960	o	-	+	+	+	-	-	n
		1961-1990	+	-	+	+	+	+	-	n
2	Linz	1841-1870	o	-	-	-	-	-	-	p
		1871-1900	+	-	-	-	+	-	+	p
		1901-1930	+	-	+	+	+	-	-	p
		1931-1960	+	o	+	+	+	+	-	n
		1961-1990	+	-	+	+	+	+	-	n
3	Wien-Nußdorf	1841-1870	+	-	-	-	-	-	-	p
		1871-1900	+	o	-	-	-	+	+	n
		1901-1930	+	-	+	+	+	-	-	n
		1931-1960	o	-	+	+	+	-	-	n
		1961-1990	+	-	+	+	+	+	-	n
4	Rosegg im Rosental	1901-1930	o	-	+	+	-	+	-	n
		1931-1960	+	-	-	+	+	-	-	n
5	Federaun	1901-1930	o	-	-	-	-	-	-	n
		1931-1960	o	-	-	-	-	-	-	n
		1961-1990	+	o	+	+	+	+	-	p
6	Schärding	1871-1900	+	o	-	-	-	-	+	n
		1901-1930	+	-	+	+	+	+	-	n
		1931-1960	+	-	+	-	+	+	+	p
		1961-1990	+	-	+	+	+	-	-	n
7	Steeg	1901-1930	o	o	-	-	-	-	+	p
		1931-1960	+	-	-	-	+	-	-	p
		1961-1990	+	-	+	+	+	-	-	n
8	Bad Ischl (Maxquelle)	1901-1930	o	o	+	-	+	-	+	n
		1931-1960	o	-	-	-	-	-	-	n
		1961-1990	+	-	-	+	+	-	-	n
9	Strobl (Bürglstein)	1901-1930	o	o	-	-	-	+	+	sn
		1931-1960	+	-	+	+	+	-	+	n
		1961-1990	+	-	+	-	+	-	-	n
10	Roitham	1931-1960	o	-	-	-	-	-	+	n
		1961-1990	+	-	-	-	+	-	-	n
11	Steyr (Ortskai)	1901-1930	+	-	+	+	+	+	-	n
		1931-1960	+	-	-	+	+	-	-	n
		1961-1990	+	-	-	-	-	-	-	n
12	Wels-Lichtenegg	1901-1930	o	-	-	-	-	-	-	n
		1931-1960	+	-	-	-	+	-	-	n
		1961-1990	+	-	-	+	+	-	-	n
13	Liezen	1901-1930	+	o	+	-	+	-	-	n
		1931-1960	o	-	-	-	-	-	-	p
		1961-1990	o	-	+	+	+	-	-	p
14	Zeltweg	1931-1960	+	-	-	-	+	-	+	p
		1961-1990	o	o	+	+	-	+	+	p
15	Leoben	1901-1930	+	-	-	-	+	-	-	sn
		1931-1960	+	o	-	-	+	+	+	p
		1961-1990	o	-	+	+	-	+	+	n
16	Bruck an der Mur Unter Mürz	1931-1960	+	o	-	-	+	-	-	p
		1961-1990	o	-	+	+	+	+	-	n
17	Frohnleiten	1901-1930	o	-	-	-	-	-	-	sn
		1931-1960	+	o	+	+	+	+	+	n
		1961-1990	+	-	+	+	+	+	+	n
18	Kirchbichl	1871-1900	+	-	+	+	+	+	+	p
		1901-1930	+	-	-	+	+	-	-	n
		1931-1960	+	-	-	+	+	-	-	n
		1961-1990	o	o	-	-	-	+	+	n

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New Scenarios of Climate Change for Hydrological Applications in Slovakia

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Abstract: Hydrology is one of the greatest users of climatological data and products in Slovakia. It can use daily data from about 700 precipitation and 100 climatological stations in Slovakia. Data from about 60 climatological stations are to disposal in daily cycle and synoptic data are to disposal in one hour cycle or continuously. From the point of hydrological practice the very high daily precipitation totals and precipitation intensities are the most important there. Many climatological studies and climatic normals are frequently used in hydrologic projects. Climate change scenarios and impact studies can be applied as completely new tools in this field. Scenarios of change in hydrological cycle in Slovakia up to year 2100 are possible to be prepared using climate change studies. Examples of Canadian General Circulation Model (CCCMprep) generated series as scenarios of temperature, specific humidity and precipitation changes up to the year 2100 are presented. Besides no significant rise of monthly precipitation totals, the mean air temperature rise by 3 °C and specific air humidity rise by 25% is supposed according to modified CCCMprep outputs by the end of 21st century.

Key words: Scenarios of climate change, hydrological forecast, precipitation, climatological stations

Neue Szenarien für Klima-Änderungen hinsichtlich der hydrologischen Auswirkungen in der Slowakei

Zusammenfassung: Die Hydrologie ist der größte Nutzer klimatologischer Daten und Produkte in der Slowakei. Es sind die täglichen Werte von ungefähr 700 Niederschlags- und 100 klimatologischen Stationen nutzbar. Die Angaben von den ungefähr 60 klimatologischen Stationen fallen täglich und die synoptischen Angaben stündlich an oder stehen kontinuierlich zur Verfügung. Die maximalen täglichen Niederschlagshöhen und die Niederschlagsintensitäten sind für die Hydrologie von großem Interesse. Viele klimatologische Studien und die Klima-Normalen sind in vielen hydrologischen Projekten zu verwenden. Szenarien der Klimaänderungen und Fall-Studien können als völlig neue Mittel angewendet werden. Änderungsszenarien im hydrologischen Kreislauf der Slowakei können bis zum Jahr 2100 erarbeitet werden auf der Basis von Klimaänderungsstudien. Es werden Beispiele vorgestellt, in denen mit dem kanadischen CCCMprep-Modell generierte Zeitreihen der Temperatur, der spezifischen Feuchte und der Niederschläge bis zum Jahr 2100 berechnet werden. Nach den Ergebnissen könnten bis Ende des 21. Jahrhunderts unbedeutende Anstiege der monatlichen Niederschläge auftreten, während die Temperatur um 3°C und die spezifische Feuchtigkeit um 25 % zunehmen würden.

Schlüsselwörter: klimatologische Szenarien, hydrologische Vorhersage, Niederschläge, klimatologische Stationen.

Climatic data in Slovakia

Climate change scenarios and impact studies can be applied as completely new tools in hydrology and water economy. Climatic scenarios can be roughly divided into two groups: 1. Baseline scenarios, and, 2. Climate change scenarios for the next century. The baseline scenarios play very important role in downscaling the General Circulation Models (GCM) outputs for Slovakia, and in calibrating and testing the impact models (sensitivity). During the U.S. Country Studies Proj-

ect solving in Slovakia the 1951-1980 period was recommended for the baseline. Because of significant variability of precipitation data the 1901-1990 period (1951-1990 at least) would be more convenient as baseline. Baseline climatic series should be as reliable as possible (representative for all territory and elements, uninterrupted, homogeneous). New GCM outputs are computed as very detailed time series of several elements and their downscaling needs to use complicated statistical methods based on reliable baseline series. Scenarios of changes in hydrological cycle in Slovakia up to year 2100 are possible to be prepared using the newest climate change studies [U.S. Country Studies, 1994; IPCC, 1995; Marečková, et al., 1997; Lapin, et al., 1999a,b].

Hydrology and water economy belong among the greatest users of climatological data and products in Slovakia. The specialists in these branches can use daily data from about 700 precipitation stations and 100 climatological stations in Slovakia, stored in the Slovak Hydrometeorological Institute in monthly cycle. Precipitation (R) data (daily R totals, type of R, duration of R, new snow cover depth, snow cover depth, water equivalent of snow cover, occurrence and duration of some meteorological elements) are stored in the SHMI database from all stations since 1981. All measured/observed data at the precipitation stations are stored in the SHMI archives as basic documents (more than 200 stations since 1901, about 640 in 1931, about 760 in 1951 and about 690 in 1981). The pluviographs are installed at about 170 precipitation stations with continuous recording of precipitation in the nonfrosty period of year. The longest uninterrupted series of pluviograph data (80 years) are to disposal from the Hurbanovo station only. Most of pluviograph data series are not longer than 30 years, many of them have several interruptions, usually due to the technical/instrumental problems.

Nearly all data measured/observed at climatological stations (air temperature, humidity, sunshine duration, air pressure, wind, cloudiness, …) are stored in the SHMI database since 1961. In 1901 about 15 such station were in the operation, but uninterrupted series from only 3 of them are to disposal up to present. In 1931 about 20 stations were in operation and 12 uninterrupted series of them are to disposal up to present. Most of climatological and precipitation stations with longer period of measurement have changed their location/environment even several times. According to the homogeneity testing some series of data are not possible to be used without homogenisation. The Slovak Hydrometeorological Institute pays a great attention to prolongation of data series stored in the SHMI databases, since 1951 at least. Air temperature, precipitation, snow cover and sunshine duration observations are prepared primarily as computer data.

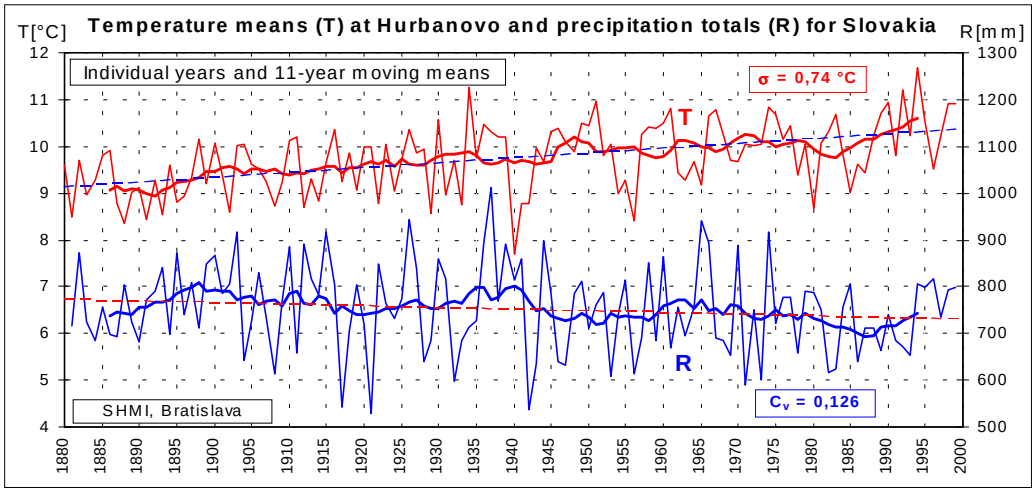

Fig. 1 Temporal course of annual air temperature means (T) at Hurbanovo and annual mean areal precipitation totals (R) for Slovakia (1881-1999; 11-year moving averages T and R - solid

line; linear trend - thin dashed line; σ - standard deviation; C_v - variance coefficient; $C_v = \sigma_R/R_p$; σ_R is σ for R and R_p is long/term average of R).

Monthly series of areal mean precipitation totals for Slovakia have been computed by the double weighted averages method using 203 stations since 1901 and more than 30 stations in 1881-1900 (Fig. 1). The same areal air temperature (T) series using 16 stations since 1951 and 3 stations since 1881 are under preparation. The most important Slovak station, the Hurbanovo observatory, has daily data series of the highest quality, some of them are nearly uninterrupted since 1872 (nearly complete daily series can be stored in computer form for temperature, precipitation, air pressure and air humidity; T series for Hurbanovo is shown in Fig. 1).

Data from about 60 climatological stations and 40 precipitation/snow stations in Slovakia are to disposal in daily cycle. Everyday maps and tables, prepared by the SHMI Climatological Department, can be offered to any user. Synoptic data are to disposal in hourly cycle or continuously from 25 Slovak stations in the SHMI Weather Forecast Centre (SHMI Telecommunication System).

Many climatological studies and climatic normals are frequently used in the hydrologic projects, research and operational practice. Monthly, seasonal and annual precipitation totals have been reconstructed for 203 stations in Slovakia since 1901, about 150 of them are considered as homogeneous according to the recent testing. As many as 607 precipitation stations are enough complete for the analysis of annual and monthly maximum in daily precipitation totals. The statistics of maximum daily totals were first time published in Contr. of SHMÚ, No. 24 (1985), this study was updated recently by Faško, et al. (1999). More profound elaboration of precipitation data has been carried out only for limited number of stations [Climate of Czechoslovakia, 1961 and 1969; Climate of Slovak Regions, 1966, 1968 and 1972; Contr. of SHMÚ, No. 33, 1991]. Even worse is the stage in pluviograph records elaboration in Slovakia, only 68 stations with the records exceeding 6 years were elaborated [Contr. of SHMÚ, No. 5, 1973].

Climatic Extremes

Review of climatic extremes and their possible statistical analysis based on historical meteorological observations in Slovakia have been published in several works [Climate of Czechoslovakia, 1961 and 1969; Contr. of SHMÚ, No. 24, 1984 and No. 5, 1973]. From the point of hydrological practice the very high daily precipitation totals and precipitation intensities are the most important there. Some of these are presented in the paper.

Slovakia does not belong among the countries with very high precipitation intensities up to present. The Table 1 shows the maxima of rain intensities in all Slovakia for the time intervals from 5 to 180 minutes. These measurements have been provided by unheated standard pluviographs. Pluviographs are installed at about 170 precipitation stations in Slovakia at present (about 80 in 1950). The Table 1 was elaborated in 1973 using 68 stations, but 9 of them had only 6-10 year records. Their operational period is only in the nonfrosty period of the year (usually from April 16 to October 15 in the lower localities).

Table 1 Maxima of precipitation totals [mm] in all Slovakia for the rain intervals - from 5 to 180 minutes (elaborated according to pluviograph records, mostly in 1931-1965)

Rain intervals [minutes]	5	10	15	20	**30**	40	50	**60**	90	120	180
Precipitation totals [mm]	26	40	48	55	**66**	74	80	**86**	97	105	117

Altogether 334 precipitation stations have sufficiently complete daily precipitation total measurements in the 1901-1999 period. This was enough for the analysis of the highest daily precipi-

tation totals. The Table 2 shows occurrence of daily precipitation totals higher than 150 mm at 334 stations in Slovakia in 1901-1999.

Table 2 The highest daily precipitation totals measured in Slovakia from 1901 to 1999 (334 stations have been analysed; lowland stations are signed as bold)

Station, altitude [m]	[mm]	Date	Station, altitude [m]	[mm]	Date
Salka, 111	**231.9**	**12.7. 57**	Velké Pole, 556	164.0	19.8. 66
Zverovka, 1027	220.0	16.7. 34	Oravská Lesná, 779	163.2	18.7. 70
Stará Bystrica, 484	193.0	17.6. 29	**Trnava, 146**	**162.8**	**3.6. 51**
Novot, 752	187.6	18.8. 70	**Limbach, 181**	**155.0**	**10.7. 99**
Ždiar, 910	180.5	16.7. 34	Zverovka, 1010	154.5	18.7. 71
Zboj, 354	176.1	21.3. 31	Bobrovec, 850	154.3	18.7. 70
Skal. Pleso, 1778	170.0	29.6. 58	Železnô, 1007	153.7	18.10. 61
Zbojnícka ch., 1958	169.0	29.6. 58	Ždiar, 910	152.3	30.6. 73
Zuberec, 764	168.5	16.7. 34			
Hrebienok, 1267	165.0	29.6. 58			

These 18 cases are not distributed equally in all Slovakia, relatively higher number was observed in the mountains, but the absolute maximum 231.9 mm occurred in the south Slovakian lowlands at Salka. Unequal distribution of very high daily precipitation totals was partly caused by unequal distribution of the stations being to disposal. The total number of daily precipitation totals higher than 100 mm at those 334 stations was 163 in the 1901-1999 period. Their distribution was much more equal in all Slovakia. It means, the probability of high daily precipitation totals occurrence has different patterns than the mean monthly totals. More profound analysis was possible to do for the period of 1981-1999. Altogether 700 stations have been analysed in this period and 53 cases of more than 100 mm of daily precipitation totals were found in Slovakia in this 19 year period. The maximum number of such cases was 12 in 1999, 9 in 1997 and 8 in 1994 (the highest number of such cases measured in one day in Slovakia up to present was 36 days on June 29th, 1958). Higher daily totals than 150 mm occurred at five stations in 1981-1999 (Cífer 162.8 mm in 1996, Limbach 155.0 mm in 1999, Jasná 154.0 mm in 1990, Luková 153.0 mm in 1990 and Grinava 151.5 mm in 1999), three of them lie in lowlands of south-western Slovakia.

Statistical and dynamic-climatological analysis showed that the heavy precipitation events depend mostly on specific cyclonic synoptic conditions with warm air flows from Mediterranean (sometimes these air masses approach to Slovakia from the north-east rounding the Carpathians range) and with high specific humidity in the lower part of troposphere lasting several days. Analysis of several such events since 1951 is briefly presented in the paper. More profound synoptic analysis will be made in separate contribution.

In 1949-1999 (51 years) at least 82 days with ≥100 mm of daily precipitation totals have been registered in Slovakia in the actual precipitation station network (1% of it in April and November, no such events were from December to March, maximum 38% days in July, 24% in August, 16% in June). According to Niedzwiedz synoptic classification (1981) 75% of high daily precipitation events occurred during cyclonic synoptic situations and 25% during anticyclonic situations. The most suitable conditions for high daily precipitation totals (30% of cyclonic situations) were during Bc (through of low pressure) and during Nc (22%, northern cyclonic situation). The mean annual number of days with ≥100 mm daily precipitation totals were 1.5 in Slovakia. The frequency distribution of such days was as follows: zero days in 9 years, 1 day in 20 years, 2 days in 9 years, 3 days in 9 years, 4 days in 2 years, 6 days in 2 years (1949 and 1997). On 8 days, during all 1949-1999 period, more than 5 stations with ≥100 mm of daily precipitation totals were registered. Most of them were during Nc (northern cyclonic synoptic situation), this is why one half of these events occurred in northern Slovakia (predominantly northward from the High Tatras and from the Western Tatras). It is curious that one such event occurred during anticyclo-

nic synoptic situation Ea. Relatively very frequently occurred such events in south-western Slovakia. Interesting two such events occurred in nearly identical area of the central Hron river basin on August 19, 1966 and on August 25, 1994. Both these events were characterised by stationary cold front in local cyclone. The thunderstorms occurred there during late afternoons and evenings.

Climate Change Scenarios for Slovakia

In 1994-1997 Slovakia participated in the U.S. Country Studies Program. Climate change scenarios were presented in the Slovak National Climate Program and Country Study publications. New generation of General circulation models (GCMs) has been issued since 1996. Outputs of the Canadian Climate Centre 1st generation atmosphere-ocean coupled model (CCCMprep) have been adopted for Slovakia (CO_2 rise by 1% per year, doubling of CO_2 in 1980-2050, negative aerosol forcing, model outputs for the 1901-2100 period). Temperature, precipitation, specific air humidity and solar radiation monthly data enable to calculate/generate time series of monthly means comparable to original measured ones (comparable averages, distribution, variability) for selected sites/grids in Slovakia. The regional modification of CCCMprep scenarios for the mean air temperature and precipitation changes in the 2010, 2030 and 2075 time frames are comparable with those prepared for the CCCM outputs in 1995. Precipitation scenarios have been constructed separately for the northern and southern Slovakia in 1995 and separately for each station in 1999 [Lapin, et al., 1995, 1999a, 1999b, Table 3 and 4]. The main problem at GCMs output downscaling is based on the necessity to remain physical plausibility and statistical structure of series (temporal and areal, cross-series relations) of all climatological elements in the future time periods comparable with the control period (1901-1990). This is possible to do by the dynamic-statistical methods only. Any statistical method or stochastic weather generator can hardly ensure that the scenarios of several elements will fulfil the physical theory in the area and time considered.

Table 3 Scenarios of mean monthly air temperature change for Slovakia

Frame	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
CCCM 1995 (compared to 1951-1980)												
2010	1.2	1.4	1.4	1.0	0.9	0.9	1.1	1.0	1.1	1.1	0.9	0.9
2030	2.0	2.4	2.3	1.7	1.5	1.6	1.8	1.7	1.9	1.8	1.4	1.5
2075	3.7	4.5	4.3	3.2	2.9	3.0	3.3	3.2	3.6	3.4	2.7	2.8
CCCMprep 1999 (compared to 1951-1980)												
2010	0.4	0.6	0.8	0.6	0.4	0.6	0.9	1.0	1.0	0.8	0.5	0.4
2030	0.8	1.1	1.4	1.0	0.8	1.1	1.4	1.5	1.5	1.2	0.7	0.6
2075	2.2	2.8	2.8	2.3	2.3	2.8	3.3	3.6	3.6	2.9	2.0	1.7

Table 4 Scenarios (quotients) of mean precipitation totals change for Hurbanovo

Frame	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
CCCM 1995 (compared to 1951-1980)												
2010	1.09	1.01	1.05	1.01	0.95	0.95	0.93	1.01	0.97	1.03	1.05	1.07
2030	1.15	1.01	1.08	1.02	0.92	0.91	0.89	1.02	0.95	1.06	1.08	1.12
2075	1.29	1.02	1.15	1.04	0.85	0.83	0.79	1.03	0.91	1.11	1.16	1.22
CCCMprep 1999 (compared to 1951-1980)												
2010	1.06	1.00	1.21	1.02	1.13	0.91	0.91	0.92	0.97	1.15	1.02	1.14
2030	1.09	1.03	1.25	1.07	1.17	0.92	0.92	0.94	0.98	1.17	1.06	1.17
2075	1.25	1.15	1.29	1.04	1.11	0.83	0.87	0.95	0.97	1.16	1.11	1.31

Simple dynamic and regression models have been designed for extreme precipitation scenarios preparing. The philosophy of models and the first results of scenarios are presented there only. Firstly the scenarios of possible change of specific humidity (**s**) have been designed. Based on the CCCMprep outputs downscaling, the **s** scenarios quotients are presented in Table 5 for 50-year time frames (2075 is for 2051-2100). In Slovakia the data of s at 850 hPa level are to disposal since 1951, so the time series of monthly s averages can be designed for the 1951-2100 period. Significant rise (6-11%) of s is supposed according to CCCMprep up to 2045, then even more intense continual rise of means and variability can be expected. Let us suppose that the internal **s** variability remains so as at present up to 2045, than the maxima of s at exceptional precipitation events will be greater by the same quotients as the long-term averages (Table 5).

Table 5 Scenarios (quotients) of specific humidity change at 850hPa level for Slovakia

Frame	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
CCCMprep 2000 (compared to 1951-1980)												
2010	1.04	1.06	1.07	1.04	1.03	1.06	1.08	1.07	1.06	1.08	1.09	1.07
2030	1.08	1.09	1.10	1.07	1.06	1.10	1.11	1.10	1.10	1.10	1.10	1.09
2075	1.21	1.21	1.18	1.14	1.16	1.22	1.25	1.25	1.25	1.24	1.23	1.22

Simple equation for precipitation totals calculation (upward movement, not taking into account turbulence and heat exchange) can be considered as follows [Zikmunda, 1966; Lapin, 1971]:

$$R = g^{-1} \int_{to}^{t} \int_{pc}^{0} \omega \frac{ds}{dp} .dp.dt ,$$

where $g \approx 10$ m.s^{-2}, $\omega = dp/dt = -\rho.g.v_z$ – generalized vertical velocity, v_z – upward vertical component of the velocity vector, s – specific humidity, p – air pressure, t – time, ρ - air density, p_c – condensation level. In case of s increase by 25% at the p_c level (≈850 hPa) it can be calculated from the above simple equation the increase of extreme precipitation total R at least by 25% as well. At higher s the upward v_z will increase in average, it depends on vertical temperature gradient. The increase of precipitation can be even about 50% in this case. More detail analysis of physical conditions at precipitation in the warmer and more humid atmosphere will be published in the separate paper.

Generated Series of Monthly Climatic Data

The generated series can be prepared by 3 basic methods: 1. Shift of measured data according to scenarios for time frames (Tables 3-5), 2. Using stochastic weather generator [Dubrovský, 1996], and 3. Modifying the time series of GCM outputs. Examples of CCCMprep based generated series as scenarios of temperature, solar radiation and precipitation changes up to the year 2100 are presented in Lapin, et al., 1999a, 1999b. Air temperature means increase relatively continuously in the 1991-2100 period (the examples of the modified series for Hurbanovo are shown in Figure 2). On the other hand, the precipitation changes are not so regular (small decrease or increase in some longer periods). Besides no significant rise of monthly precipitation totals, the mean air temperature will probably rise by 3 °C and specific air humidity by 25% according to modified CCCMprep outputs by the end of the 21st century. This will surely cause possibilities for much higher precipitation intensities and extreme daily/monthly totals than ever were measured in Slovakia in the 20th century. Designing generated series of precipitation faces serious problems in case of areal consideration. In spite of this that outputs in CCCMprep gridpoints correlate similarly than the data in correspondent precipitation stations, in case of downscaling the gridpoint's outputs to stations with distance lower than 100 km, the correlation is too high (1st modification, Table 6). No serious such problems are at air temperature, solar radiation and at some other monthly GCM outputs. In case of monthly precipitation series we compared all

monthly data with monthly series of areal precipitation totals for Slovakia in 1901-1990. Then we applied similar areal variability of monthly totals also for the 2001-2090 period (2nd modification, Table 6). This additional modification of CCCMprep outputs enables to prepare precipitation scenarios with suitable (nearly natural) areal variability for hydrological application and the areal mean precipitation totals in the river basins are physically plausible with the GCM outputs for all elements.

Table 6 Correlation of monthly precipitation series between stations Košice and Habura in Eastern Slovakia (distance 90 km), 0 - observed, 1, 2 - the 1st and 2nd modification.

Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1901-90(0)	0.36	0.35	0.69	0.64	0.62	0.51	0.58	0.57	0.59	0.80	0.68	0.38
2001-90(1)	0.98	0.98	0.99	0.99	0.99	0.99	1.00	1.00	1.00	0.99	0.98	0.99
2001-90(2)	0.51	0.45	0.56	0.61	0.61	0.61	0.66	0.62	0.66	0.74	0.68	0.47

Outputs of the other 1st generation coupled GCMs are under preparation for downscaling. This method is possible to apply for some of other climatic extremes scenarios design.

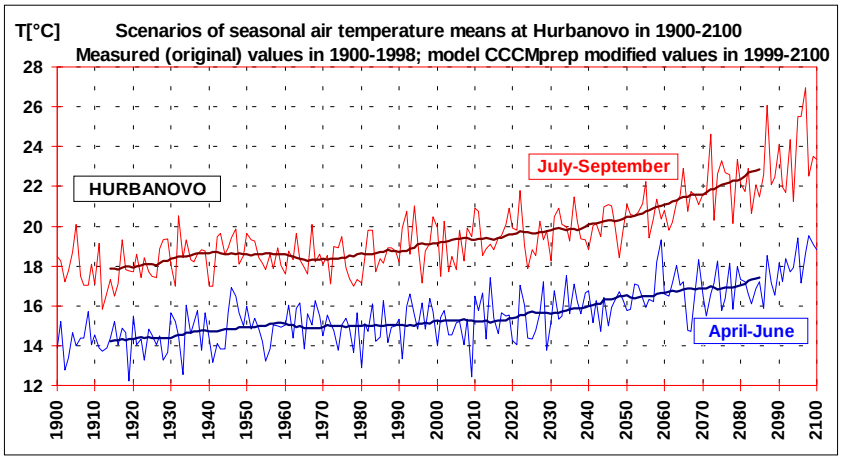

Fig. 2 Long-term course of measured (1900-1998) and modelled (1999-2100) seasonal air temperatures at Hurbanovo (115 m a.s.l., solid line - 30-year moving averages)

Conclusion

Only brief review of all problems connected with designing climatic scenarios for baseline period and for 21st century is presented in the paper. For more detailed information the contributions cited in references can be used. Our future plans are focused to prepare several alternative GCM scenarios of basic climatic elements (temperature, precipitation, humidity, solar radiation, snow cover, evapotranspiration, soil moisture) in the form of time series of monthly values for individual stations/grids in Slovakia. Besides those the scenarios of long term means change in the time frames 2010, 2030 and 2075 as well as scenarios of extreme values change for the 2001-2100 period will be designed.

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Methods for Extraction and Forecasting Long-Term

Climate Change Components

Vladimir A. Lobanov

Abstract: This paper deals with a development of the methods for empirical approach of climate change extraction. Time series can been obtained by two ways: by averaging in the particular stations (year, season, month) or determination of the spatial model parameters. In the second case, the spatial model have two coefficients *B1* and *B0*, which characterise an gradient and level of the field of hydro-meteorological characteristic, and the *Se*-parameter, which connected with intensity of macro-synoptic processes. The structure of the model can be used too for joint modelling of intra-annual and inter-annual fluctuations in the particular stations. For extraction of long-term climate change and climate variability components two new methods have been developed (smoothing of amplitudes of cycles and the truncation method) and applied together with consecutive averaging methods. Application is given for time series of monthly temperature and precipitation in the Danube river basin.

Key words: Climate change, time series modelling, extraction of large-scale components, intra and inter year fluctuations, extrapolation.

Methoden für die Bereitstellung und Prognose von Komponenten langzeitlicher Klimaänderungen

Zusammenfassung: Dieser Artikel befasst sich mit der Erarbeitung von Methoden für die empirische Ermittlung von klimatischen Änderungseffekten in vieljährigen Reihen. Dabei können die vieljährigen Reihen auf zweierlei Art erhalten werden: durch Mittelwertbildung an den konkreten Stationen oder mittels Bestimmung räumlicher Modellparameter. Im zweiten Fall gibt es die Koeffizienten *B1* und *B0*, die einen Gradienten und ein Niveau der hydro- oder meteorologischen Charakteristik und dessen Parameter charakterisieren, der mit der Intensität des makro-synoptischen Prozesses verbunden ist. Die Struktur des Modells kann auch für die gemeinsame Modellierung der Veränderlichkeit innerhalb von Jahren und zwischen verschiedenen Jahren an einzelnen Stationen verwendet werden. Für die Ermittlung von Klimaveränderungen und Klimavariationen wurden zwei neue Methoden entwickelt (Glättung der Amplituden von Perioden und die Stütz-Methode) zusammen mit der Methode der sequentiellen Mittelwertbildung. Die Anwendung wird für Zeitreihen monatlicher Lufttemperaturen und Niederschläge im Donaueinzugsgebiet gezeigt.

Schlüsselwörter: Klimaänderung, Zeitreihen-Modellierung, Bereitstellung großräumiger Komponenten, Fluktuationen innerhalb von Jahren und über mehrere Jahre, Extrapolation.

1 Background

A main problem of modern climatology is this: Can we detect a human induced influence from observed climatic fluctuations? It was a title of Chris Folland's keynote report on the First European Conference on Applied Climatology (Folland, 1996) and this problem stays today too. This is a fact that General Circulation Models (GCMs) are not perfect and give a wide range of the results in main meteorological characteristics for the same climate scenario and same regional areas (Henderson-Sellers & Pitman, 1995; Nichols et al, 1996). Major advances have been made in the recent time in the physical basis and spatial resolution of GCMs and «we are beginning to emerge from the era of «sensitivity studies» and approach the stage of true prediction» (Jones, 1999). The latest results obtained on the basis of General Circulation Models developed by the UK Hadley Centre (HadCM2 GCM) give the increasing of temperature and

precipitation for the Northern and Central Europe, flood risk is likely to increase on large rivers like the Rhine, Danube (Kwadijk, 1993). From other side, the Danube basin is located on the boundary between increasing of meteorological characteristics in the Northern Europe and their decreasing in the Southern Europe. Therefore the situation with GCMs modelling is widely uncertain for this area and need the empirical confirmation.

Of course we have to research natural fluctuations of meteorological characteristics on different time scales more detail and assess their regular properties in time and their possibilities for forecasting. It will be a valuable contribution both to our understanding of meteorological processes and improvement of any models. This aim is typical for the CLIVAR Programme (CLIVAR, 1995), which tackle questions of climate variability and predictability of the global climate on time-scales from months to a century, and our understanding of the interactions of natural variability and its modification by anthropogenic causes. Therefore the empirical approach stays as the general for analysis of trends and regular properties of characteristics of climate variability and climate change and adequate empirical-statistical methods should be developed for such analysis.

2 Methods

2.1. Generalization and modeling seasonal variability

Generalization of meteorological information within the intra-year period is the first step before the analysis of their long-term fluctuation connected with climate variability and climate change. There are two ways for such generalization: averaging (mean seasonal value, annual, etc.) and determination of parameters and coefficients of seasonal change (intra-annual function). In the first case an average (or sum) value of meteorological characteristics for month, season or year time interval can be obtained and used for further analysis of its long-term changes. For some meteorological characteristics, such as precipitation in cold region without seasonal change practically, this generalization is sufficiently and the temporal model of long-term fluctuation can be developed. For other characteristics, such as air temperature, it is necessary to take into account seasonal variation. Therefore the common model of climate variations has been developed for the description of fluctuations of meteorological characteristics on the intra-annual as well as inter-annual time-scales. This model has a linear structure. The basis of this model is the conception of division of complex composition process of meteorological fluctuations on two basic parts (sub-compositions) using for this aim the process of annual scale having practically the constant period of fluctuations:

$$Y_j = Y1_{ij} + Y2_{ij}, \qquad (1)$$

where $Y1_{ij}$ is a part of a composition containing a component on annual scale of fluctuations and more;

$Y2_{ij}$ is a part of a composition containing a component of time scales less than annual scale.

On the other hand, each part of a composition can be presented as:

$$Y1_{ij} = B1_j * Y_{mi} + B0_j, \qquad (2)$$

$$Y2_{ij} = E_{ij}, \qquad (3)$$

where

- Y_{mi} is average long-term function of intra-annual fluctuations of daily, ten-day, month and other period meteorological data during a year;
- $B1_j$ is a coefficient describing a difference between amplitude of intra-annual fluctuations function in the *j*-th year and amplitude of average long-term function and at $B1_j$=1 the amplitude of function of the particular year coincides with long-term amplitude;
- $B0_j$ is a coefficient describing a difference between the minimum level of intra-annual fluctuations function in the *j*-th year and a minimum average long-term intra-annual function, at $B0_j$ =0 the minimum level of the particular hydrograph coincides with average

long-term meaning;

- $E_{i\ j}$ are remainders from the relationship line between the particular and long-term conditions describing the components of composition process, which scale is less than annual process.

It is possible to describe the processes of temporary scales smaller than annual. The macro-synoptic and synoptic conditions of the particular year are characterized by one value such as S_{ej}. It is a standard deviation of the remainders E_{ij}. Synoptic fluctuations have period in 7-10 days, as usual and macro-synoptic - from one to several months. The parameter S_{ej} characterizes the variation of macro-synoptic processes if monthly data are used, and synoptic processes if daily data are applied for analysis.

Then the suggested common model of meteorological fluctuations will contain three parameters: $B1_j$, $B0_j$ and S_{ej} determined for each year on the equation of linear regression between the particular meteorological characteristics of the given year (as a rule, average for one month) and their appropriate average long-term value. On numerous empirical examples a validity of linear regression dependence has been proved (Lobanov, 1998).

Practically, the model (1) with presentation of its two parts as (2) and (3) is a linear regression between intra-year values of meteorological characteristic (temperature, precipitation, etc.) in the particular year (daily, monthly values) and the same averaged values for long-term period. The remainders from the relationship in each particular year characterise the macro-synoptic processes of this year. In the case when the remainders are small the macro-synoptic and synoptic processes in this year are not significant. It means that the conditions of this particular year (in the term of a concrete meteorological characteristic) are close to the mean historical climate conditions. The coefficients B1, B0 and Se in this relationship, which are obtained each year, have the following physical interpretation for each time series:

- *B1* characterises an amplitude of intra-annual function of the particular meteorological characteristic;
- *B0* is a minimum of this intra-annual function;
- *Se* is a standard deviation of macro-synoptic processes which characterises their intensity (the more standard deviation the more variation between synoptic processes, therefore their dynamic exchange is larger, too).

The relationship (1) with (2) and (3) can be expanded for a spatial case too, for example, for a description of the field of monthly temperature in homogeneous region. Homogeneous region means the same tendency of long-term climate change for each station. In the case of spatial modelling the relationships are built between the particular field of meteorological characteristic in each moment of time (for example, January 1999) and mean historical field for the same time interval or a moment. The coefficients of spatial model mean the following:

- *B1* characterises the change of gradient of spatial meteorological field in the particular moment of time to the same gradient for the historical period;
- *B0* characterises the change of level (minimum value) of meteorological field;
- *Se* characterises the spatial variation of macro-synoptic processes or homogeneity of the meteorological field.

2.2. Modeling from inter annual to centennial climate variability

Since the generalized intra-annual values of meteorological characteristic have been obtained (annual, seasonal, $B1_j$, $B0_j$ and S_{ej} parameters of seasonal function, etc.), it is possible to develop the temporal model of their long-term fluctuations. As usual the long-term time series of meteorological characteristic are not homogeneous and consist of several homogeneous components connected with the processes of different time-scales: climate variability (inter annual – decadal scale) and climate change (with period of cycles about one century and more). The common equation of such non-homogeneous long-term process can be expressed:

$$Z_{com.} = \Sigma Z_{j\ cl.var} + Z_{cl.change.} \qquad (4)$$

$Z_{com.}$ is non-homogeneous long-term time series of generalised meteorological characteristic;
$\Sigma Z_{j\ cl.var}$ is a sum of homogeneous components connected with natural climate variability (periods of fluctuation less than century),
$Z_{cl.change}$ is a component connected with long-term climate change (anthropogenic and natural).

Of course climate change component in (4) is not homogeneous and consists of two parts: natural ($Z_{cl.nat}$) and anthropogenic ($Z_{cl.\ ant}$) changes:

$$Z_{cl.change} = Z_{cl.\ nat} + Z_{cl.\ ant} \qquad (5)$$

In the first approximation the analysis of climate change can be fulfilled on the basis of the complex process $Z_{cl.change}$. The separation of these two parts is possible by physical models or by a comparison of data in two different periods: today and before industrial time on the basis of the longest time series (more than 200-300 years).

The main problem is to develop the effective empirical-statistical methods for extraction of climate variability and long-term climate change components in (4). The existing decomposition methods, such as spectral and correlation analysis, moving average and smoothing need strong assumptions for analysed time series, for example: harmonic function of cycles, constant period and amplitudes of cycles and other that could not be suitable for real time series of meteorological characteristics. Therefore two new decomposition methods have been developed that have flexible conditions of application. First of them is truncation method is based on a choice of homogeneous points in time series. In according to this method by Lobanov (1995) any time series of meteorological characteristic can be presented as a sum or a superposition of homogeneous components of different time scales:

$$Y = Y_1 + Y_2 + \ldots + Y_m + const, \qquad (6)$$

where m is a common number of homogeneous processes on the given temporal interval.

The suggested method of decomposition is based on the selection of points that belong to the smallest time scale homogeneous process. These points are the minima of cycles and after their determination these points are connected by continuous lines and the homogeneous process of the smallest time scale is picked out (truncated) from the rest part of composition. On the second step this procedure is returned and the smallest scale process will be the next with middle scale and so on. The main equation is:

$$Z_j = [Z^*_{com.} - Z'_{com} f(Z_{min\ j})] \qquad (7)$$

- Z_j is a homogeneous j-th component,
- $Z^*_{com.}$ is a sum of all residual components (including j-th) without impact of man's activity,
- Z'_{com} is a sum of all residual components (without j-th) as a function of cycles' minima ($Z_{min\ j}$) without impact of man's activity,
- $Z_{cl.change.} = Z_M$ and M is a number of homogeneous components

There are only two main assumptions for this method:
- Periods of two processes of neighbouring scales differ:

$$T_1 < T_2 < \ldots < T_m \qquad (8)$$

- The fluctuations (cycles) are significant, if they are larger than the amplitude of errors $(A\varepsilon)$;

$$A_{YKj} > A\,\varepsilon \qquad (9)$$

The main idea of the truncation method is a possibility to find homogeneous points in the observed long-term time series. It is assumed that in the points of minima of fluctuations the process of the small scale (high frequency) is absent. Therefore these points of minima can be connected by linear or non-linear temporal interpolation and the obtained line characterises all other processes without the small scale one. The values of these other processes are obtained by subtracting the interpolation line from the observed data. After that the rest of time series is assumed as a new non-homogeneous process and the procedure of selection minima of cycles, interpolation and subtraction (truncating) return until the rest will contain one homogeneous

process in the form of one its cycle or its part present as a trend. Thus the procedure of this truncation allows to extract the homogeneous process of different scales step by step from the small to the large.

Unfortunately the number of minimum points are decreasing from the first truncation to other. In this case the processes of large time scale and climate change scale too are obtained with less reliability than the small scale processes. Therefore another method, smoothing the amplitudes of cycles, which were obtained by condition (9), has been developed for more reliable extraction of large scale climate components:

$$Y_j = f\,(A_{ji}/2) \qquad (10)$$

A_{ji} is amplitude of i-th cycle in the time series of sum of j homogeneous components.

The third method is a traditional method of determination of generalised parameters of time series (average values, standard deviation, etc.) in the consecutive samples for 10-15 year period. It is assumed that the climate variability under such averaging is smoothing and the parameters of samples characterise the climate change.

2.3. Choice the kind of the time series model

The kind of a model for each homogeneous component (time series) is obtained under the following conditions:

$$\begin{array}{ll} S(Ch) < Ey & \text{- deterministic (dynamic) model,} \\ Ey < S(Ch) < 100\% - Ey & \text{- dynamic-stochastic model,} \\ S(Ch) > 100\% - Ey & \text{- stochastic model,} \end{array} \qquad (11)$$

where:

- $S(Ch)$ is a standard deviation of the errors in the model: $Ch = f\,(t)$;
- t - time, Ch - informative characteristic, Ey - the error of the process (in %);

2.4. Extrapolation

In the case of dynamic-stochastic model the approach of extrapolation on the basis of auto regression equation can be used for meteorological values in every year or their characteristics of cycles:

$$Z_i = f\,(X_{i-1}, X_{i-2}, \ldots, X_{i-k}) \qquad (12)$$

where: k is the order of the memory of the process

The confidence intervals of forecast error are defined by intervals of coefficients' errors in (12). As a rule, this approach is suitable for climate change process extrapolation for the period to 10-15 years in the future, not longer.

3 Application

3.1. Data and calculation scheme

For extraction and analysis of long-term climate change components over the Danube River basin the longest time series of monthly air temperature and precipitation have been chosen with observation period more than 70-90 years. As a result 30 time series of precipitation and 31 time series of temperature have been used for the analysis.

The algorithm of the analysis includes the following main stages:

- generalisation of long-term time series of annual and seasonal temperature and precipitation in the particular stations;
- extraction of climate variability and climate change components by different statistical methods (truncation method – for climate variability components and smoothing of cycle amplitudes and consecutive averages in 10 years – for extraction of long-term climate change components);
- comparison of the results obtained by two methods (smoothing of cycle amplitudes and

consecutive averaging), their unification and determination of sign (direction) and gradient (per century) of climate change trends for each station;

- generalisation of the results over the Danube basin area and assessment of their homogeneity;
- simulation of the spatial models over the Danube River basin by (2), (3) for the monthly, seasonal and annual temporal interval;
- assessment of long-term climate changes in the coefficients and parameters of spatial models.

The following formula of generalisation of the results obtained by two (or more) methods have been applied:

$$a = \frac{\frac{1}{\sigma_1^2} a_1 + \frac{1}{\sigma_2^2} a_2 + \ldots}{\Sigma \left(\frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2} + \ldots \right)} \qquad (13)$$

where: a is a generalised parameter (for example, gradient of climate trend);

a_1, a_2, … are parameters obtained by different methods;

σ_1, σ_2, … are standard errors of obtained parameters a_1, a_2, ….

Apart from consecutive averages in 10 years the standard deviations for the same periods have been determined too, that characterise the stability of climate short-term variability.

3.2. Discussion of the results

Using the truncation method of decomposition two processes of climate variability of small scale (with average period of cycles is 3-4 years) and middle scale (period is 12-17 years) can be obtained correctly for time series of annual and seasonal generalisation.

By method of smoothing of cycle amplitudes the long-term climate components have been extracted and the main characteristics of these trend have been obtained such as: correlation coefficient of linear trend (*R*), gradient of the trend per 100 years (Ä) and contribution of the climate component in common variation of time series in % (as range *Ra* and variance *D*). The statistical significance of climate trends has been obtained too. In the case of consecutive sample method, the consecutive averages and standard deviations for each 10-year period have been calculated and correlation coefficient and century gradient have been obtained for the linear trends of averages and standard deviations. The generalisation of the results have been fulfilled by (13) for each station.

The spatial interpretation of climate trends for the Danube River basin is given in Fig.1 for annual and seasonal time series of temperature and precipitation. As it is seen from the pictures, the spatial distribution of temperature more homogeneous than the same distribution of precipitation. Annual temperature, as a rule, has positive climate trends for the most part of the area and stable conditions for south of the river basin. The negative tendencies in temperature take place in summer season only. The spatial distribution of precipitation trends is more complex. Positive trends in sums of annual precipitation are observed in the northern part of the basin. The negative trends are distributed in southern and eastern parts. The same picture is observed for summer season, but in winter the precipitation have a positive climate trends for the most part of the Danube region. Time series of standard deviations for consecutive 10-year periods more stable than for average. It means the processes of the scale of climate variability are stationary practically. The tendency of decreasing of standard deviation takes place for annual temperature that characterize more statistical significance of trends in average values.

The next step of analysis has been connected with development of spatial models. These models have been obtained for annual, seasonal period, for the particular months and for the whole river basin as well as for the separated its homogeneous parts connected with different climate trends:

the northern part, the southern and for eastern ones. After that the analysis of the parameters of spatial models (*B1*, *B0* and *Se*) has been fulfilled and the climate change trends extracted. As it has been established the coefficients of spatial models of precipitation are more stationary than the same parameters of temperature fields. Some positive climate trend is observed only in time series of *Se* and characterizes the increasing of intensity of macro-synoptic processes. Parameters of temperature field are not stationary and have significant climate trends. The example of these trends for *B1*,*B0* and *Se* is shown in the Fig.2. As it is seen from the Fig.2, the *B1*-coefficient has a negative trend connected with the decreasing of field gradient and as the result the field becomes more homogeneous. The *B0*-coefficient is increasing and reflects the increasing of air temperature. The intensity of synoptic processes is increasing too that connected with the increasing of extreme events.

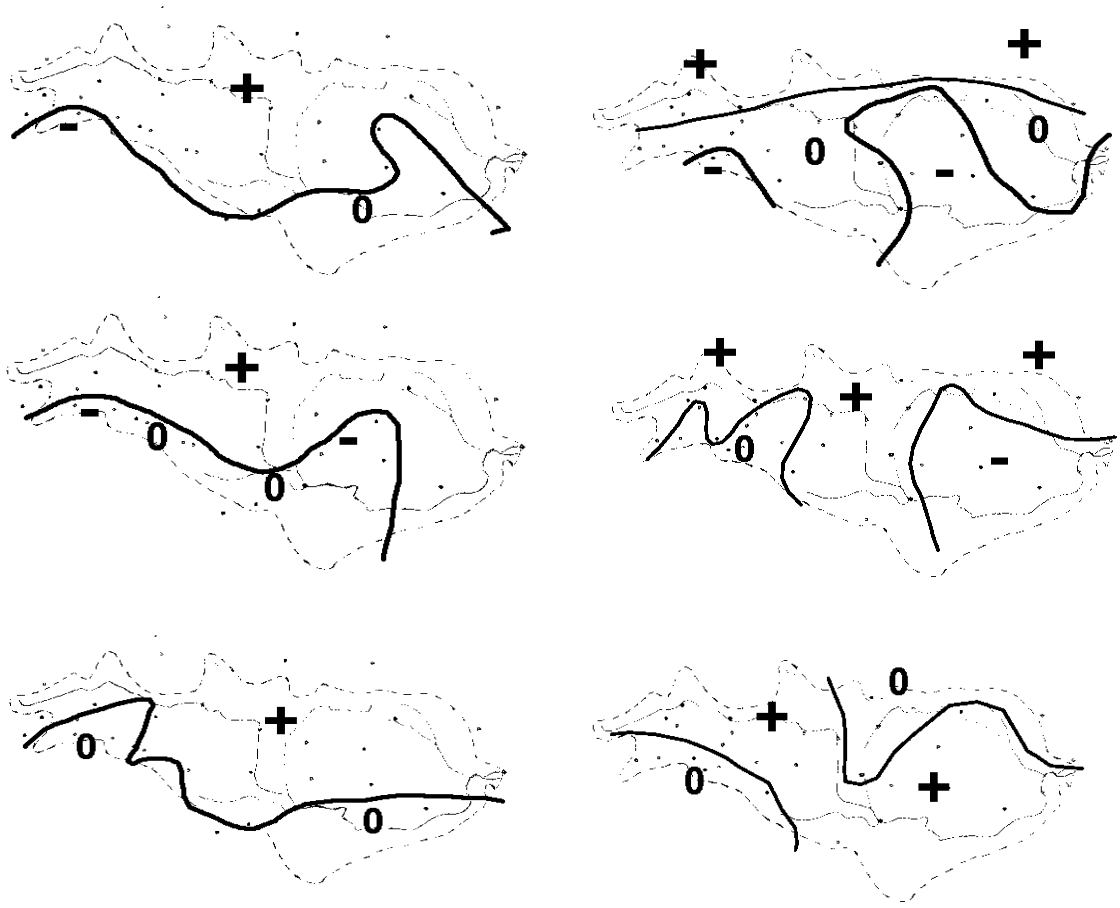

Fig. 1 Spatial generalization of long-term climate trend for the Danube River basin
1,2,3 – annual, summer and winter air temperature, 4,5,6 – sum of annual, summer and winter precipitation.

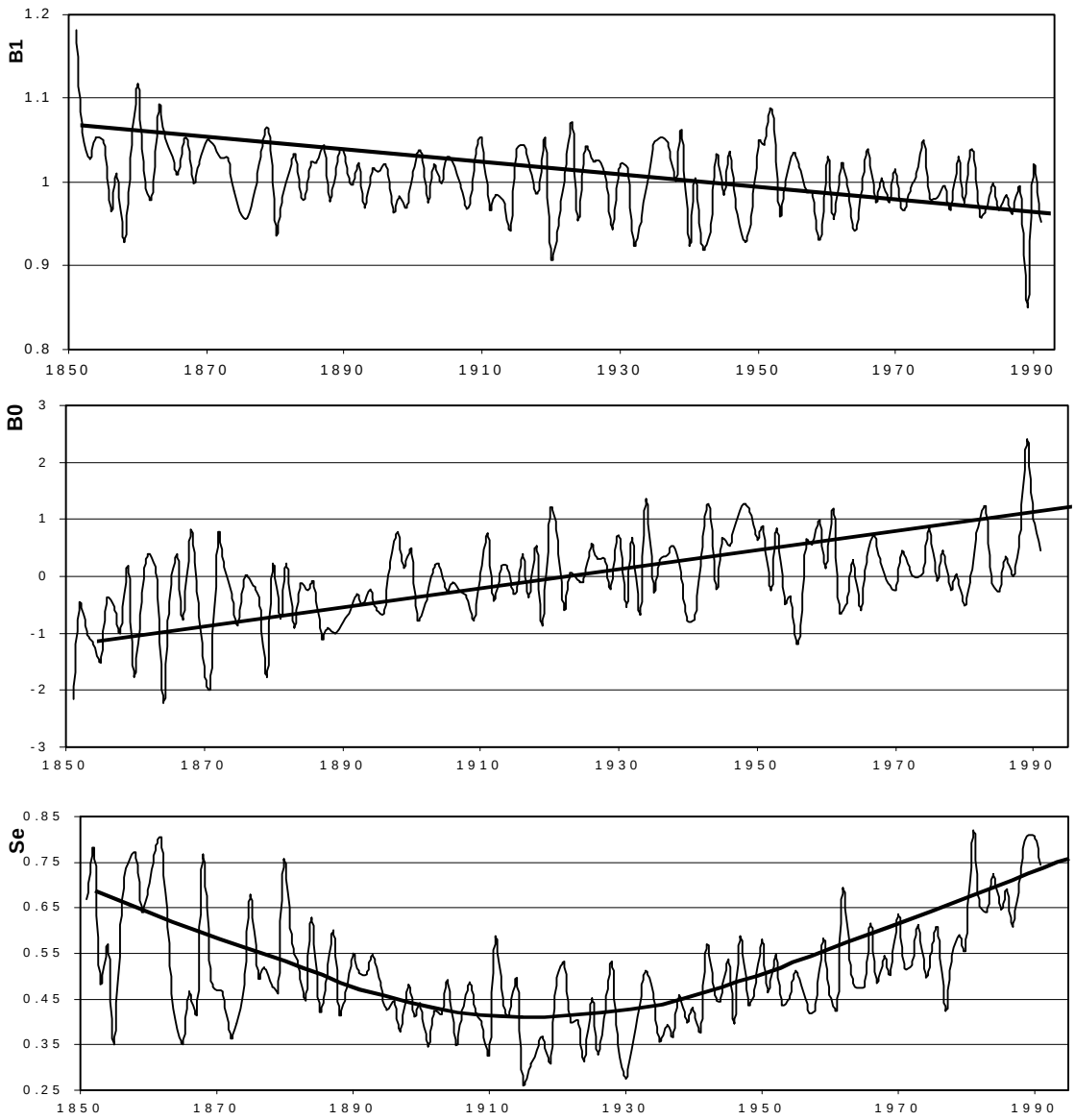

Fig 2 Long-term climate trends in time series of the parameters of spatial models for annual temperature in the Danube River basin.

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The Peculiarities of the Hydrological Computations of Extreme Hydrological Events under Changing Conditions

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Abstract: The peculiarities of hydrological computations of extreme hydrological events in changing conditions connect with the decision of the problems of non-homogeneity and non-stationarity. New methods have been developed for restoration long-term time series of hydrological characteristics, assessment of homogeneity of empirical distribution of extreme events, for extraction of man's impact component and restoration of «natural» time series of extremes, as well as for extraction of long-term climate change. New formula of empirical probability has been developed for extreme events which take place several times in an year or one time in several years. Joint criteria have been suggested for fitting of analytic function to empirical distribution, as well as empirical approach for assessment of quantile errors. Using of joint model of runoff fluctuation has been developed for computation of intra-annual runoff distribution. Example of application is given for the Danube river - site Bratislava.

Key words: Changing conditions, peculiarities of hydrological computations, extreme events, intra-annual distribution, common model of runoff fluctuations.

Besonderheiten von Berechnungen extremer hydrologischer Ereignisse unter wechselnden Bedingungen

Zusammenfassung: Die Besonderheiten von Berechnungen extremer hydrologischer Ereignisse unter wechselnden Bedingungen sind verbunden mit der Behandlung der Probleme, die sich aus Inhomogenitäten und Instationaritäten ergeben. Es sind neue Methoden entwickelt worden zur Rekonstruktion von Langzeitserien hydrologischer Charakteristika, zur Homogenisierung empirischer Verteilungen extremer Ereignisse, zur Isolierung menschlicher Einflusskomponenten und zur Rekonstruktion „natürlicher" Extremwert-Zeitreihen ebenso wie zur Darstellung langzeitlicher Klimaänderungen. Neue Beziehungen wurden entwickelt zur Darstellung empirischer Wahrscheinlichkeiten für extreme Ereignisse, die mehrfach im Jahr oder einmal in mehreren Jahren auftreten. Verbundkriterien wurden erarbeitet, die ebenso auf analytische Funktionen empirischer Verteilungen zutreffen wie auf die empirische Einschätzung von Fehlern. Der Einsatz von Verbundmodellen für Abfluss-Fluktuationen wurde entwickelt zur Berechnung der Jahresabflussverteilung. Ein Anwendungsbeispiel wird für den Donau-Bereich Bratislava vorgeführt.

Schlüsselworte: Wechselnde Bedingungen, Besonderheiten hydrologischer Berechnungen, extreme Ereignisse, Jahresverteilung, Abfluss-Fluktuaktionsmodell

1 Background

There are two main groups of factors impacted on extreme events and other hydrological characteristics in changing conditions: modern climate change and anthropogenic influence on watersheds and in river channels (different kinds of regulation by dams, water intake and outtake, etc.). The existing approach for the assessment of runoff frequency is based on the distribution functions theory and it suitable for homogeneous and stationary conditions (Kritsky & Menkel, 1981; Rozhdestvensky, 1990). The application of this approach in changing conditions is limited by two main reasons:

- non-homogeneity of flood time series connected with extraordinary outlying observations, different factors of anthropogenic influence and climatic processes of different time scales, including long-term modern climate change;

- non-stationarity of parameters of flood time series connected with non-stationarity of anthropogenic factors and climate change.

The third main peculiarity of extreme events, that is not taken into account usually, is their non-regularity of appearance, that varies from several flood events during a year (storm floods) to some events during century (as mud streams, drought, etc.). As a result, the new approach for estimation of frequency for extreme events in changing conditions need to develop.

2 Main stages of new approach

Algorithm of suggested approach includes the following main stages:

- assessment of extraordinary outlying observations by statistical criteria;
- assessment of man's activity influence and extraction of runoff components connected with anthropogenic impact and restoration of «natural» runoff time series for different input informational conditions;
- extraction of homogeneous different time scale components in «natural» conditions including long-term component of modern climate change;
- determination of time series models of stochastic or deterministic-stochastic kind for extracted runoff components connected with anthropogenic impact;
- determination of time series models for runoff component, connected with modern climate change and for «natural» runoff components;
- extrapolation of deterministic-stochastic models on the basis of auto-regression, scenarios and expert estimations for future period of water project operation;
- extrapolation of stochastic models by distribution function for future period;
- determination of common computed value in changing conditions as a sum of obtained quantile for «natural» conditions plus additions of extrapolated man's impact and climate change components.

3 Methods

3.1. Assessment of extraordinary outlying data

Time series of extreme hydrological events can include extraordinary values which are outlying data (extraordinary maximums and minimums) from the common empirical distribution. The statistical tests are used for assessment of statistical significance of such outlying data. The most popular are Dixon's and Smirnov-Grabbs criterions. Main peculiarities of these and many other criteria are normal distribution and random behavior of the sample which is used for the testing. From other side, the time series of extreme events have non-symmetric distribution and sometimes – a significant auto-correlation (low flow, as a rule). Therefore the classical tests Dixon's and Smirnov-Grabbs have been extended for the sample with auto-correlation and non-symmetric distribution by Monte-Carlo stochastic modeling. The results are given for example in works: Lobanov & Lobanova (1983), Lobanov (1984). Main conclusion is that the developed criterions are increasing the statistics of the tests for non-symmetric distributions and are decreasing them for auto-correlated samples. The particular relationships and recommendations are given.

3.2. Extraction of man's impact components

The main factor of man's influence on extreme events is seasonal re-distribution of runoff by reservoirs. In general, it leads to a reduction of maximum flood discharges and to an increase of low flow. Other man's influence factors, such as water intake and outtake, wood cutting, etc. are not significant for these hydrological characteristics as a rule. The common man's impact component (for case of dam regulation) could be obtained as a difference:

$$\Delta R = R_{real} - R_{nat}, \qquad (1)$$

where ΔR is the quantitative assessment of dam influence; R_{nat} is the runoff in dam site in natural conditions; R_{real} is the runoff in dam site in real conditions of operation.

For the synthesis of natural runoff in dam site several methods could be suggested:

- the method of inflow and water balance of reservoir:

$$R_{nat.} = R'_{nat.} - (P - E - \Delta R_1 - \Delta R_2 + \Delta R_3 \pm \ldots) \qquad (2)$$

where R'_{nat} is the natural runoff in the site of river falling into the reservoir, P is precipitation onto the surface of reservoir, E is evaporation from free water surface, ΔR_1, ΔR_2, ΔR_3 ,. . .- are runoff changes accordingly by the filtration to shores of the reservoir, by the filtration to the bottom of the reservoir, additional underground inflow to the reservoir and other factors;

- the relationships between the runoff in dam site during the natural period and its analogues to do temporary interpolation of these relationships during the hydropower station operation;
- the relationships between the runoff in dam site and in downstream sites, which are under the natural conditions, but only if link degree in the equations characterizes the natural runoff;
- the using of the runoff formation models computed for the natural period of runoff formation. These models can be used for the runoff synthesis during the hydropower station operation period under the condition, that the runoff factors fluctuation regime has been remained as a natural regime;
- difference methods, which determine the natural runoff through a difference between the upper stream site runoff and the dam site runoff in common during the natural period and the station operation period;
- the determination of reservoir influence (effect) using the analysis of common time-series characteristics (mean value, variance, etc.) during two periods, they are: periods before and after the hydropower station construction.

The using one or another of six suggested methods is determined by such parameters as the availability of necessary information or a necessary computation accuracy. Application of the suggested methods for extraction and analysis of flood components connected with large dam's regulation for Russian rivers is given in the work (Lobanova, 1999).

3.3. Extraction of climate change components

There are two ways for determination of modern climate change: use of climate scenarios (Jones, 1999) and extraction of long-term climate change component from observed time series with its future extrapolation in the nearest future (1-2 decades). The first way has a great uncertainty connected with different results obtained by different scenarios and is applied for average (annual, seasonal) meteorological characteristics at least. Therefore the empiric-statistic way has been used together with the scenario assessment. For extraction of long-term climate change components three groups of statistical methods have been used:

- consecutive averaging with periods 10-12 years, that is as a filter of high and middle frequencies of time scale of climate variability;
- different methods of smoothing (Lobanov & Lobanova, 1999);
- method of decomposition (Lobanov, 1995).

Two main characteristics of extracted climate change component are obtained: statistical significance (as contribution in the common time series variation) and direction of the tendency in the nearest period. The results obtained by different methods are compared and combined under the same conclusion about significance and direction of climate tendency. Extrapolation of climate component in the nearest period is based on the autoregression model.

3.4. Assessment of empirical frequency of non-regular extreme events

Well-known formula $i/(n+1)$ is suitable for regular random events, where i – rank, n – common number of events. Extreme events can be several times in a year and extremes of extremes – several times in century. For calculation of empirical probability (frequency) of distribution of such non-regular events a new formula has been developed:

$$P_i(X_i) = \frac{1}{n+1}[1 + \frac{n-1}{n-T_m}(n - \sum_{j=1}^{m-i+1} T_j)] \qquad (4)$$

when $X_1(T_1) > X_2(T_2) > \ldots > X_m(T_m)$ and where

- $T_1, T_2, \ldots$ is a duration of hydrological events or time intervals between them,
- m is a common number of random events in the time series,
- i is a rank number, n is a size of the sample.

3.5. Extrapolation of stochastic model

The first problem is connected with effective fitting of empirical distribution of floods to chosen analytic approximation (Pirson III, Kritsky-Menkel distribution and other). The most adequate criterion includes two kinds of errors: standard error of fitting for whole distribution ($\sigma\varepsilon$) and maximum error in the zone of small probabilities which is used for extrapolation ($max\ \varepsilon$). This way the suggested criterion will be:

$$\sigma\varepsilon + max\ \varepsilon = B\varepsilon \rightarrow \min \qquad (5)$$

The second problem connected with setting of designed probability. This probability or frequency is linked with the time interval, that includes the period of observation (T_{ob}) and period of future operation of water project (T_{op}). Therefore the designed frequency (P_d) has to include both of two these periods and the formula of the designed probability for will be as follows:

$$P_d = [1/(T_{ob} + T_{op})] * 100\% \qquad (6)$$

The last problem of extrapolation by stochastic model connected with determination of design discharge errors or random errors of quantiles. Today the theoretical approach is used but two other empirical methods could be suggested too:

- period of observation divides into two parts: hypothetic period of observation (T'_{ob}) and hypothetic period of operation (T'_{op}) and their ratio has to be equal to the ratio of the real observation and operation periods:

$$T'_{ob} / T'_{op} = T_{ob} / T_{op} \quad \text{and} \quad T'_{ob} + T'_{op} = T_{ob} \qquad (7)$$

- observation periods of the longest time series of floods over the world are divided into two parts: observation sample ($T'_{ob} = T_{ob}$) and operation sample ($T'_{op} = T_{op}$) for testing and estimation of quantile errors that are taken the same for the future too;

3.6. Calculation of design discharges in changing conditions

The designed discharge on the final stage is obtained as an algebraic sum of stochastic «natural» component and extrapolated components connected with factors of man's activity and modern climate change with the particular errors:

$$Y_p = [f(P_i(Y_{i\ nat.})) + \Delta Y_{i\ nat.}] + (Y_{cl.ant./T=f(P)} + \Delta Y_{cl.\ ant.}) + (Y_{ant./T=f(P)} + \Delta Y_{ant.}), \qquad (8)$$

where p is the designed probability; ΔY is an error of the designed value for homogeneous components.

3.7. Computation of intra-annual distribution on the basis of the common model of runoff fluctuations.

The application of the developed common model of runoff fluctuation (Lobanov, 2000, these Proceedings) can be also apply for computation of intra-annual runoff distribution, in which basis this kind of the equation is necessary:

$$Y_{P\,i} = B1_{P1}\, Y_{cp\,i} + B0_{P2} + E_{P3\,i}, \qquad (9)$$

where Y_{pi} is an ordinate of computed distribution of P(%) design probability for the i-th month;
$Y_{cp\,i}$ is an ordinate of average long-term intra-annual function for the i-th month,

E_{P3i} is the error of $P3$(%) design probability connected with the intensity of macro-synoptic processes for the i-th month,

$B1_{P1}$, $B0_{P2}$ are parameters of the intra-annual model (amplitude and level) of design probabilities;

P_1, P_2 , P_3 - design probabilities of homogeneous components formed the design probability P of the composition.

4 Application

4.1. Problem and data

The problem is to fulfil hydrological computations of maximum, minimum runoff and intra-annual distribution for the site Bratislava in the modern conditions of climate change and anthropogenic impact, which connected with dam's regulation on the Danube River in general. Time series of daily maximum and minimum discharges have been chosen for analysis of the extreme events as well as time series of annual and monthly runoff for analysis and computation of intra-annual distribution. Peculiarities of available information is that fact the time series of discharges for site Bratislava have period of observation from 1941 to 1980. Therefore the following strategy for runoff restoration has been used:

- restoration of discharges for the period 1921-1940 on the basis of relationships with water levels ($Q=f(H)$, where Q is discharge, H is a water level) for site Bratislava;
- restoration of discharges for the period 1981-1995 on the basis of relationships between discharges in site Bratislava (Slovakia) and site Nagymaros (Hungary) where data were available.

After that the follow stages of computations are realized:

- assessment of stationarity and homogeneity for restored time series of maximum, minimum, annual and monthly dischages;
- restoration of «natural» runoff (without anthropogenic impact) and determination of man's impact component connected with dam regulation if such influence is significant;
- extraction of long-term climate change component from time series of «natural» runoff if its contribution is statistically significant;
- development of the common model of runoff fluctuations and analysis of its coefficients ($B1$ and $B0$) and remainders (E_j) for each month in the time for assessment of stationarity and homogeneity;
- hydrological computations of the extreme runoff and intra-annual distribution in changing conditions for the site Bratislava.

4.2. Results and discussion

At the first the relationships between discharges (monthly, annual, maximum, minimum) and water levels have been development for each year of the observation period (1941-1980). These equations have the common structure: $Q=b_1H^2+b_0$ with correlation coefficients varied from R=0.982 to R=0.999. Analysis of stationarity of equation coefficients allowed to established that it is better to use for a restoration the averaged coefficients before 1960. The following equations have been obtained for restoration in 1981-1995 between runoff in Nagymaros and Bratislava:

$$Q_{IBr}=0.830Q_{INa}+59,53 \quad R=0.976, \qquad (10)$$
$$Q_{IIBr}=0.832Q_{IINa}+65,67 \quad R=0.972, \qquad (11)$$
$$Q_{IIIBr}=0.810Q_{IIINa}+102,01 \quad R=0.965, \qquad (12)$$
$$Q_{IVBr}=0.800Q_{IVNa}+148,54 \quad R=0.957, \qquad (13)$$
$$Q_{VBr}=0.914Q_{VNa}+21,93 \quad R=0.977, \qquad (14)$$
$$Q_{VIBr}=0.966Q_{VINa}-41,54 \quad R=0.983, \qquad (15)$$
$$Q_{VIIBr}=0.935Q_{VIINa}+41,91 \quad R=0.973, \qquad (16)$$
$$Q_{VIIIBr}=0.845Q_{VIIINa}+215,22 \quad R=0.968, \qquad (17)$$

$$Q_{IXBr}=0.840Q_{IXNa}+167,85 \quad R=0.970, \qquad (18)$$
$$Q_{XBr}=0.872Q_{XNa}+79,79 \quad R=0.960, \qquad (19)$$
$$Q_{XIBr}=0.819Q_{XINa}+119,22 \quad R=0.956, \qquad (20)$$
$$Q_{XIIBr}=0.794Q_{XIINa}+139,17 \quad R=0.959, \qquad (21)$$
$$Q_{AnBr}=0.820Q_{AnNa}+187,27 \quad R=0.969, \qquad (22)$$
$$Q_{MaxBr}=1.067Q_{MaxNa}+132,70 \quad R=0.924, \qquad (23)$$
$$Q_{MinBr}=0.711Q_{MinNa}+205,90 \quad R=0.900, \qquad (24)$$

where: Q_I , …Q_{XII}, Q_{An}, Q_{Max}, Q_{Min} are monthly, annual, maximum and minimum discharges, Q_{Br}, Q_{Na}, - discharges in sites Bratislava and Nagymaros

The historical time series have been restored for different characteristics (monthly, maximum and minimum runoff), the common model has been developed and its parameters (B1,B0, *Se*) have been calculated. Time series of maximum, minimum and annual runoff, as well as the parameters of the common model of fluctuations (intra and inter-annual) are shown in the Fig.1

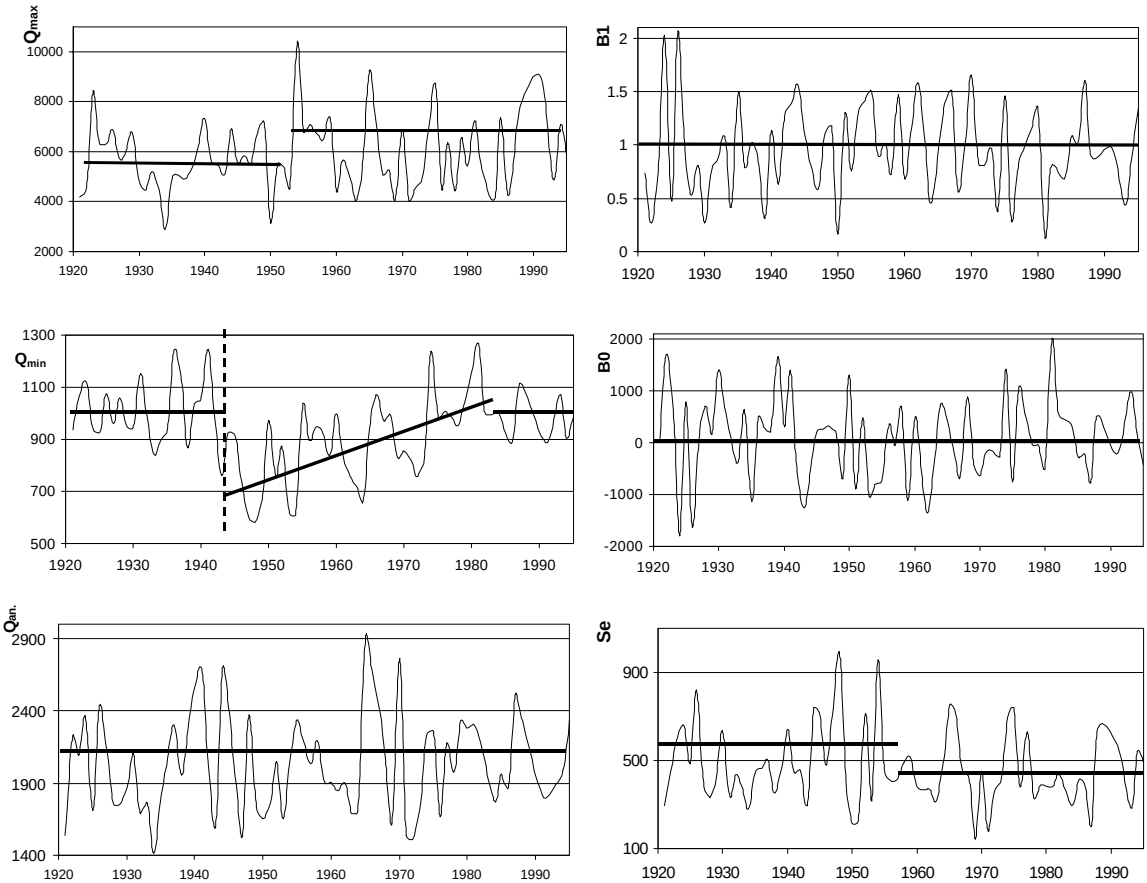

Fig. 1 Historical time series of the restored hydrological characteristics (maximum, minimum and annual runoff) and parameters of the common model of runoff fluctuations (*B1,B0, Se*) for the Danube River – site Bratislava.

As it is seen from the pictures, time series of maximum discharges has sharp decreasing in the beginning of 1960s and after that – stationary fluctuations. Therefore the first part of time series has been increased on the constant value. Minimum runoff has more complex kind of changes. Sharp falling takes place in the beginning of 1940s and from this date to the beginning of 1980s there is a positive trend. After that the fluctuations become stationary again on the same level as before 1940s. Therefore this positive trend has been eliminated and the whole stationary time series restored. The time series of annual runoff has stationary fluctuations that have been

obtained using the well-known statistical criterions (Student and Fisher tests). Time series of coefficients *B1* and *B0* are stationary too and have average values 1 and 0 accordingly. Some jump of decreasing takes place in the time series of standard deviation of remainders (errors) *Se*. Analysis of the time series of monthly discharges has shown their stability for all months practically excluding some trends in winter period and time series of monthly remainders (E_i) are stationary too for all months, although they have some non-homogeneous extremes obtained by statistical criterions.

The relationships between parameters of the common model are obtained by the following equations:

$$B1=-0.000502B0+0.000486Se+0.771 \quad R=0.956, \qquad (25)$$
(97.7%) (2.9%)

$$B1=-0.000514B0+1.000 \quad R=0.947, \qquad (26)$$

$$B0=-1744B1+1744 \quad R=0.947, \qquad (27)$$

$$Se=535.57B1+0.250B0-65.9 \quad R=0.524, \qquad (28)$$
(31.2%) (68.8%)

where (…) is contribution of the particular factor in the common variance of the equation.

Equations (25)-(28) show that the coefficients *B1* and *B0* connected by functional relationship (with R=0.95). It means that $P_1=P_2$ in (9) and the design probability could be given the same for the both coefficients. From other side, standard deviation of the remainders (*Se*) has very low positive relation (R=0.52) with two coefficients together and with each coefficient this relation will be less. Therefore it is possible to assume that errors will be a random value for the intra-annual function.

The main parameters of distribution functions for monthly (E_i) remainders and *B1*,*B0* and *Se* coefficients are given in the Table 1.

Table 1 Main parameters of distribution function (*Xm*- mean, *Cv*, *Cs*, *r(1)* – coefficients of variation, skewness and autocorrelation), maximum errors of the fitting of theoretical distribution to empirical one (e_{max}) and computed values for design probabilities *P*=1% and *P*=99%.

Month, parameter	*Xm*	*Cv*	*Cs/Cv*	*r(1)*	e_{max} (%)	*Qp* (*P*=1%)	*Qp* (*P*=99%)
1	0.64	0.05	0.0	-0.16	3	1200	-1140
2	0.52	0.06	0.0	-0.22	2	1320	-1260
3	0.30	0.06	0.0	0.06	4	1390	-1320
4	0.04	0.05	0.0	-0.03	4	1200	-1140
5	-0.12	0.04	0.0	-0.05	8	994	-945
6	-0.30	0.04	0.0	-0.15	4	950	-903
7	-0.12	0.06	0.0	0.11	6	1550	-1475
8	0.13	0.05	0.0	-0.09	1	1320	-1250
9	0.48	0.04	0.0	-0.08	1	945	-900
10	0.67	0.03	0.0	-0.03	1	818	-780
11	1.26	0.04	0.0	-0.03	2	886	-840
12	-3.5	0.04	0.0	-0.05	4	1050	-1050
B1	1.00	0.50	1.5	-0.13	43	2.407	0.165
B0	-1.7	0.09	0.0	-0.13	33	2250	-2145
Se	470.0	0.37	2.3	0.10	29	982	178

As it is seen from the table, the remainders have symmetric distributions in general. Some difference in averages connected with the non-homogeneous extreme values. This effect was eliminated by fitting of theoretical distributions.

Finally, the intra-annual distribution has been calculated by (9) for the average conditions (P=50%) and for design probabilities P=1% and P=99%. The values of errors (E_i) have been given for each month in 1% for maximum design hydrograph (P=1%) and 99% for minimum design intra-annual function (P=99%). The results are given in the Figure 2.

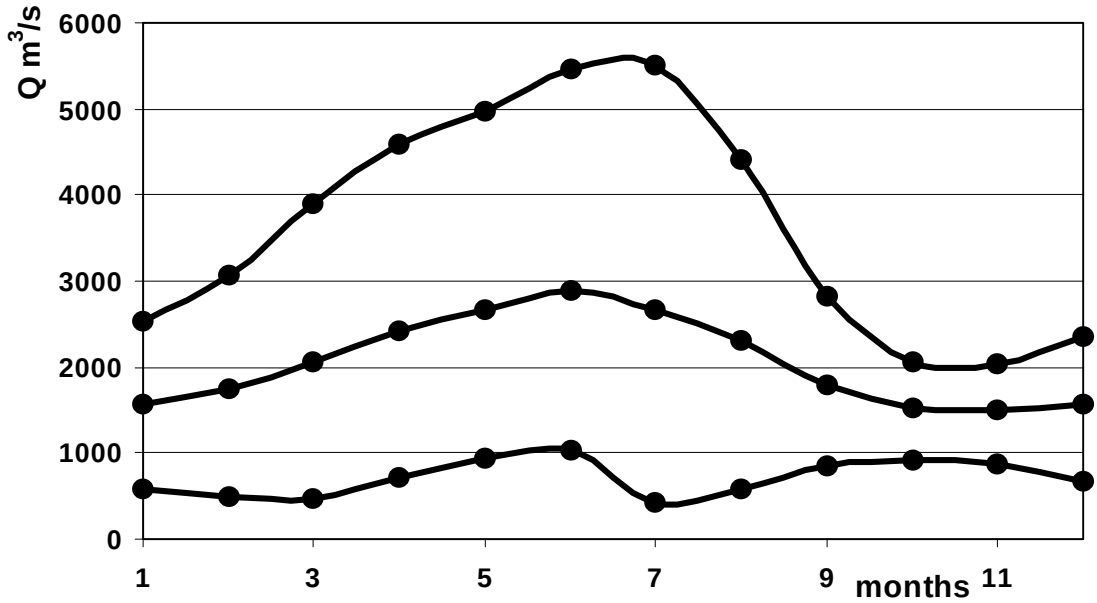

Fig. 2 Intra-annual distributions for the Danube River – site Bratislava obtained on the basis of the common model of fluctuations for design probabilities: P=1% ($P(E_j)$=1%), P=50% and P=99% ($P(E_j)$=99%).

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Ermittlung von Hochwasserabfluss-Wahrscheinlichkeiten für das Donau-Einzugsgebiet in Baden-Württemberg – Ergebnisse eines Regionalisierungsverfahrens

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Kurzfassung: Für die Fluss-Einzugsgebiete des Landes Baden-Württemberg wurde ein multivariates Verfahren zur Regionalisierung der mittleren Hochwasser-Abflüsse MHQ und der Hochwasserabfluss-Wahrscheinlichkeit HQ_T entwickelt. Dabei wurde das Ziel verfolgt, diese Abfluss-Kennwerte landesweit unter einheitlichen und vergleichbaren Bedingungen als Grundlage für wasserwirtschaftliche Aufgaben bereitzustellen. Das Modell basiert auf analytisch bestimmten Hochwasserabfluss-Wahrscheinlichkeiten von 335 Pegeln und ist sowohl für alle Pegel-Einzugsgebiete als auch für beliebige Einzugsgebiete ohne Messstellen anzuwenden. Das Modell berücksichtigt auch die Besonderheiten des in Baden-Württemberg liegenden oberen Donau-Einzugsgebietes ab den Quellflüssen bis Ulm.

Schlagworte: Oberes Donau-Einzugsgebiet, Regionalisierung, Hochwasserabfluss-Wahrscheinlichkeit

Probable Flood-Runoff for the Danube River Basin in Baden-Württemberg Calculated with a Regionalization Method

Abstract: A regionalization method has been developped, by using multivariate procedures, for calculating the flood runoff characteristics (mean annual runoff MHQ, probable flood-runoff HQ_T in river catchment basins in the Federal State of Baden-Württemberg. The aim of these investigations was to derive flood characteristics under homogeneous and comparable conditions and make them available for water projects. The model used is based on the analytically determined probable flood runoff at 335 gauging stations. It can be used in the catchment basins with discharge measurements as well as in any catchment basins without discharge measurements. Furthermore, the model takes account of the special features of the upper reaches of the Danube catchment basin between the headwaters and the city of Ulm.

Key words: Upper Danube River Basin, Regionalization, Probable Flood-Runoff

1 Einführung

Für die Planung und Beurteilung von wasserwirtschaftlichen und wasserbaulichen Maßnahmen wie

Beurteilung der Abflussleistung von Gewässern u. der Häufigkeit von Hochwasserabflüssen

Planung und Begründung von Hochwasserschutzmaßnahmen oder Gewässer-Renaturierungen

Abgrenzung und Ausweisung von Überschwemmungsgebieten sowie Abschätzung von Hochwasserschäden

sind definierte Kennwerte zum Hochwasserabfluss (mittlerer Hochwasserabfluss MHQ oder Hochwasserabflüsse bestimmter Jährlichkeit HQ_T) unerlässlich. Diese Kennwerte müssen nach einheitlichen Gesichtspunkten für Flussgebiete ermittelt werden und die entsprechenden Ergebnisse müssen regional vergleichbar sein.

Eine methodisch und landschaftsräumlich abgestimmte einheitliche Bearbeitung kann nur über Regionalisierungsmodelle erfolgen, in denen Landschaftsraum einschließlich der geologischen Verhältnisse, Landnutzung, Fluss- und Einzugsgebietsmorphographie und Gebietsniederschlag

als Einflussgrößen berücksichtigt werden. Die Neubearbeitung der Hochwasserabfluss-Regionalisierung umfasst alle Flussgebiete in Baden-Württemberg, einschließlich das der oberen Donau.

Die Regionalisierung der Hochwasserabfluss-Kennwerte wurde seit 1995 von der Landesanstalt für Umweltschutz Baden-Württemberg in enger Zusammenarbeit mit dem Institut für Wasserwirtschaft und Kulturtechnik der Universität Karlsruhe durchgeführt. Die Bearbeitung hat das Ziel verfolgt, für Baden-Württemberg landesweit die Abfluss-Kennwerte MHQ und HQ_T sowohl für die Einzugsgebiete der Pegel, als auch für Gebiete ohne Pegelbeobachtung für wasserwirtschaftliche Zwecke bereitzustellen. Diese Bearbeitung ersetzt die seit 1983 vorliegende Regionalisierung der Hochwasserabfluss-Wahrscheinlichkeiten im Donau-Einzugsgebiet.

Das in Baden-Württemberg liegende obere Donau-Einzugsgebiet ab den Quellflüssen Brigach und Breg bis Ulm hat eine Fläche von insgesamt 8.023 km^2 und ist aufgrund des geologischen Baues durch vielfältige Landschaftsräume (z. T. auch mit Karst-Erscheinungen) geprägt wie:

Grundgebirgslandschaft (Granit, Gneis) des Schwarzwaldes im Westen

Schichtenfolge des Buntsandsteins, des Muschelkalks und des Keupers im westlichen und nordwestlichen Bereich

Schichtenfolge des Schwarz- und Braunjuras im südwestlichen Einzugsgebietsbereich

Weißjura-Schichtenfolge im nördlichen und nordöstlichen Bereich des Einzugsgebiets, die im wesentlichen aus gebankten Kalken und Massenkalken bestehen; die Donau durchquert in einem Durchbruchstal diese Schichtenfolge, die durch mannigfaltige Karst-Erscheinungen geprägt ist

Molasse im südlichen und südöstlichen Bereich des Einzugsgebiets, die größtenteils mit eiszeitlichen Schotterfeldern und Moränen überdeckt ist.

2 Datengrundlage, Datenprüfung und Analyse der Hochwasserabfluss-Wahrscheinlichkeiten

Einbezogen und analysiert wurden sämtliche vorhandenen Hochwasserabfluss-Zeitreihen an aktuellen Pegeln sowie historische Zeitreihen an aufgehobenen Pegeln (insgesamt 400 Pegel im Bereich von Baden-Württemberg, davon 86 im Donau-Einzugsgebiet); siehe Abb. 1.

Grundlage für die Ermittlung der Hochwasserabfluss-Kennwerte sind die an den Pegeln ermittelten Zeitreihen der höchsten jährlichen Abflüsse HQ(J). Der Analyse der wahrscheinlichen Hochwasserabflüsse HQ_T gingen umfangreiche Konsistenz- und Homogenitätsprüfungen voraus. Insbesondere wurden die Abflusskurven überprüft und an 70 Pegeln (davon 15 im Donau-Einzugsgebiet) die jeweiligen Abflusskurven mit Hilfe hydraulischer Berechnungen verbessert. Die HQ(J)-Reihen wurden weitgehend auch von anthropogenen Einflüssen (z.B. Einfluss von Stauanlagen und Hochwasserrückhaltebecken) bereinigt. Abb. 2 zeigt beispielhaft die Reihe der höchsten jährlichen Abflüsse am Pegel Berg/Donau. Die Hochwasserabfluss-Zeitreihen der Pegel umfassen Beobachtungs-Zeitspannen zwischen 15 und 117 Jahren, die durchschnittliche Länge beträgt 45 Jahre. Die kürzeren HQ(J)-Reihen konnten im Rahmen der schrittweisen Bearbeitung des Regionalisierungs-Modells mit den längeren Reihen abgeglichen werden.

Nach der Konsistenz- und Homogenitätsprüfung der HQ(J)-Zeitreihen konnten für 335 Pegel (davon 69 im Donau-Einzugsgebiet) jeweils die mittleren Hochwasser-Abflüsse MHQ und über analytische Verteilungsfunktionen die wahrscheinlichen Hochwasser-Abflüsse HQ_T mit Jährlichkeiten T = 2, 5, 10, 20, 50, 100 (und 200) Jahre berechnet werden. Diese wurden in das Regionalisierungsverfahren als abhängige Variable einbezogen. Abb. 3 zeigt beispielhaft die analytisch ermittelte Wahrscheinlichkeitsverteilung am Pegel Berg/Donau.

3 Regionalisierungsmodell für die Hochwasserabfluss-Kennwerte

Das Regionalisierungsmodell für die o.a. Hochwasserabfluss-Kennwerte MHQ und HQ_T besteht aus multiplen linearen Regressionsansätzen (Tab. 1), wobei für jeden Hochwasserabfluss-Kennwert eine Regressionsgleichung gültig ist. Der mittlere jährliche Höchstabfluss MHQ und die jeweiligen Scheitelabflüsse HQ_T sind die abhängigen Variablen. Diese lassen sich aus den unabhängigen Variablen wie Einzugsgebietsfläche (A_{Eo}), Bebauungsanteil (S) und Waldanteil (W), gewogenes Gefälle (L_g), Fließlänge (L), Schwerpunkt-Lauflänge (L_C) [5], Landschaftsfaktor (LF) sowie Gebietsniederschlag (N_G) berechnen. Alle einbezogenen Gebietskenngrößen wurden digital über das Geographische Informationssystem Arc/Info bestimmt. Durch Hinzunahme von Landschaftsfaktoren, die als unabhängige Variable den Einfluss der geologisch-landschaftsräumlichen Struktur der jeweiligen Fluss-Einzugsgebiete berücksichtigen, konnte die Regionalisierung der Hochwasserabfluss-Kennwerte entscheidend verbessert werden. Diese Faktoren wurden zunächst empirisch geschätzt, dann aber mit Hilfe der digitalen geologisch-landschaftsräumlichen Strukturkarte landesweit regionalisiert und über Arc/Info für alle Fluss-Einzugsgebiete abgeleitet. Tab. 1 zeigt die multivariaten Regressionsgleichungen zur Berechnung der Hochwasserabfluss-Kennwerte MHQ und HQ_T (für T = 2, 5, 10, 20, 50, 100 Jahre). Tab. 2 gibt die entsprechenden Koeffizienten (Parameter) der jeweiligen Regressionsgleichungen an.

Der Vergleich zwischen den analytisch ermittelten und den regionalisierten Hochwasserabfluss-Kennwerten zeigt bei den 335 in die Modellrechnung einbezogenen Pegeln eine sehr gute Übereinstimmung. Bei den Hochwasserabfluss-Kennwerten HQ_T betragen die prozentualen Abweichungen (bezogenen auf die Abflüsse der Pegelstatistik) bei ca. 25 % der Pegel weniger als 2,5 %. Rund 35 % der Pegel zeigen Abweichungen unter 7,5 %, 20 % der Pegel unter 12,5% und nur 8 % der Pegel haben Abweichungen über 20 %. Größere Abweichungen treten bei solchen Pegeln auf, die entweder zu kurze Beobachtungsreihen haben oder die bei der Datenprüfung nicht bereinigt werden konnten oder die im Einzugsgebiet anthropogene Einflüsse aufweisen (Hochwasser-Rückhaltebecken, Flussbaumaßnahmen) oder die durch besondere geologische Verhältnisse (z.B. Karst-Quellen) gekennzeichnet sind. Landesweit konnten insgesamt die Zeitreihen von 65 Pegeln nicht in das Regionalisierungsmodell einbezogen werden. (Hier gelten dann jeweils die über die Regionalisierungsmodelle ermittelten oder die an den Pegeln statistsch ermittelten Hochwasserabfluss-Kennwerte).

Die regionalisierten Hochwasserabfluss-Kennwerte MHQ und HQ_T zeigen somit an Pegeln insgesamt sehr gute Übereinstimmung mit den analytisch ermittelten Kennwerten, so dass bis auf wenige Ausnahmen die regionalisierten Kennwerte landesweit in Baden-Württemberg gültig werden konnten. Zusätzlich lassen sich die Regressionsansätze auch auf unbeobachtete Fluss-Einzugsgebiete, insbesondere auch auf unbeobachtete Teileinzugsgebiete der hier behandelten oberen Donau, anwenden.

4 Ergebnisse des Regionalisierungsmodells und Anwendung auf das Donau-Einzugsgebiet

Abb. 3 zeigt beispielhaft den Vergleich zwischen der analytisch und der über das Regionalisierungsmodell ermittelten Hochwasserabfluss-Wahrscheinlichkeitsverteilung für den Pegel Berg/Donau. Die Ergebnisse der Hochwasserabfluss-Regionalisierung liegen für alle Pegel tabellarisch vor; als Beispiel siehe Tab. 3 mit ausgewählten Pegeln im oberen Donau-Einzugsgebiet. Landesweit konnten bisher 57 Hochwasserabfluss-Längsschnitte für Gewässer ausgearbeitet und veröffentlicht werden . Abb. 4 zeigt als Beispiel den Hochwasserabfluss-Längsschnitt der Breg und der Donau bis Ulm. Sieben Längsschnitte von Donau-Nebenflüssen

liegen bereits vor, acht weitere Längsschnitte sind in Bearbeitung. Die räumliche Verteilung z. B. der 100-jährlichen Hochwasserabfluss-Spenden (Hq_T) liegt ebenfalls als Karte vor (Abb. 5).

Alle Landschaftsräume konnten in dem oben beschriebenen Gesamtansatz der Regionalisierungsmodelle weitgehend berücksichtigt werden. Dies gilt auch für verkarstete Fluss-Einzugsgebiete, die zum Teil Versinkungen aufweisen, wie z. B. die obere Donau bei Immendingen und Fridingen, mit den am meisten betroffenen Donaupegeln Möhringen und Beuron. Karstquellen hingegen können nicht regionalisiert werden. Für Karstquellen gelten jeweils die angepassten Wahrscheinlichkeitsverteilungen, sofern Pegel mit längeren Zeitreihen des Abflusses verfügbar sind (z. B. am Pegel Blaubeuren/Blautopf, siehe Tab. 3). Abb. 5 zeigt die räumliche Verteilung der 100-jährlichen Hochwasserabfluss-Spenden für Baden-Württemberg und für das obere Donau-Einzugsgebiet, bezogen auf die Gewässerknoten des Gewässerkundlichen Flächenverzeichnisses von Baden-Württemberg.

Somit liegen mit der vorgestellten Bearbeitung auch für das obere Donau-Einzugsgebiet abgesicherte und räumlich abgestimmte Hochwasserabfluss-Kennwerte vor, die für die eingangs erwähnten wasserwirtschaftlichen, ggf. auch ökonomischen Zielsetzungen zur Verfügung gestellt werden. Ein aktuelles Beispiel ist die z. Zt. laufende Untersuchung „Risikoanalyse obere Donau“, in der die hier erarbeiteten Hochwasserabfluss-Wahrscheinlichkeiten Grundlage für die Berechnung von ein- und zweidimensionalen Wasserspiegellage-Berechnungen sind. Danach sollen Überflutungen bestimmter Jährlichkeit ausgewiesen und die potentiellen Hochwasserschäden in Abhängigkeit von zu planenden Hochwasser-Schutzbauten abgeschätzt werden.

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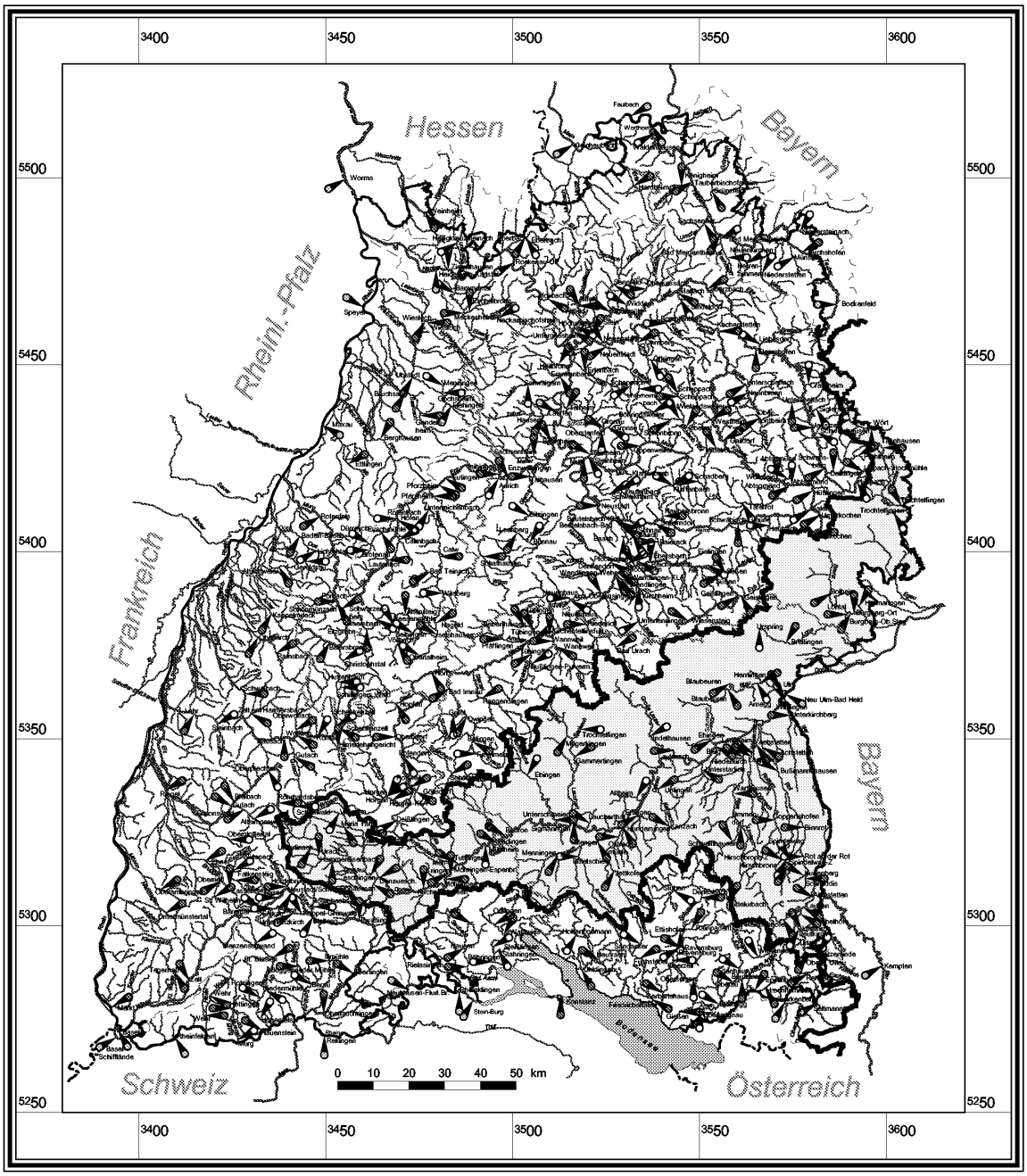
Donau - Einzugsgebiet, einbezogene Pegel



Pegel mit Abflußermittlung (Stand 12/1997)

- Basispegel
- Verdichtungspegel
- Aufgelassene Pegel
- Pegel Dritter

Flußeinzugsgebiete in B.-W.

- Donau
- Bodensee/Hochrhein
- Oberrhein
- Neckar
- Main

- Flußeinzugsgebiet
- Grenze Regierungsbezirk = Grenze Gewässerdirektion
- Landesgrenze
- Staatssgrenze
- Donau-EZG (BW)

Landesanstalt für Umweltschutz Baden-Württemberg

Quelle & Bearbeitung: LfU Baden-Württemberg, 1998. Herausgabe: LfU Baden-Württemberg, 1999. Vervielfältigung nur mit Genehmigung des Herausgebers

Abb.1 Einbezogene Pegel und Abgrenzung des oberen Donau-Einzugsgebiets

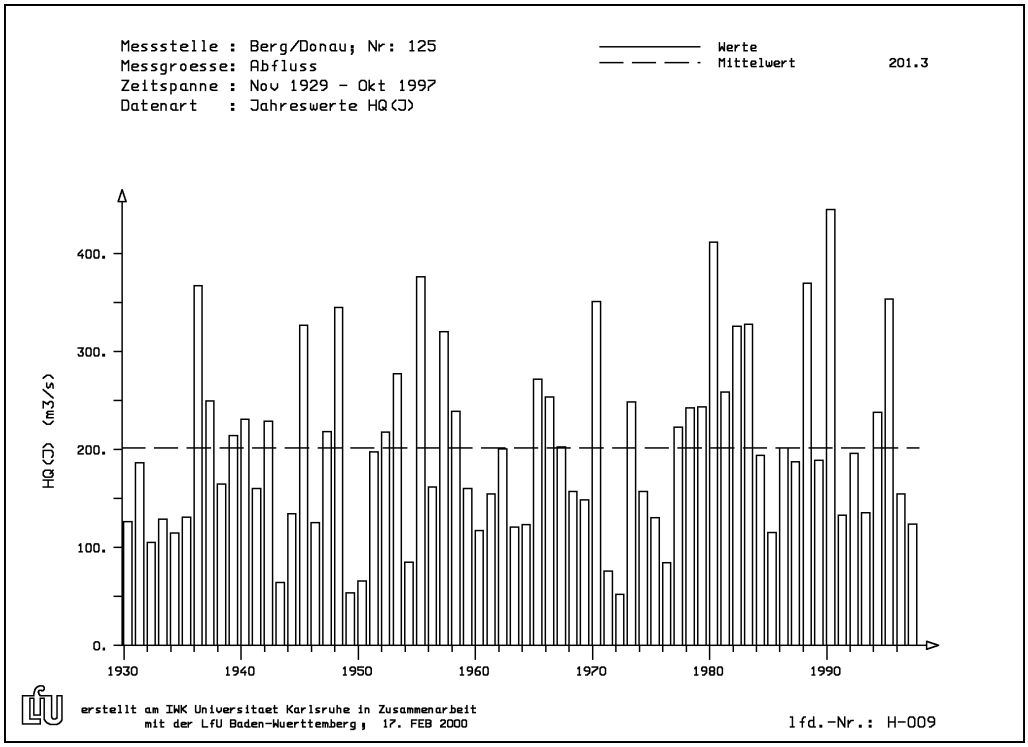


Abb. 2 Höchste jährliche Abflüsse HQ(J) am Pegel Berg/Donau (Zeitspanne 1930 – 1997).

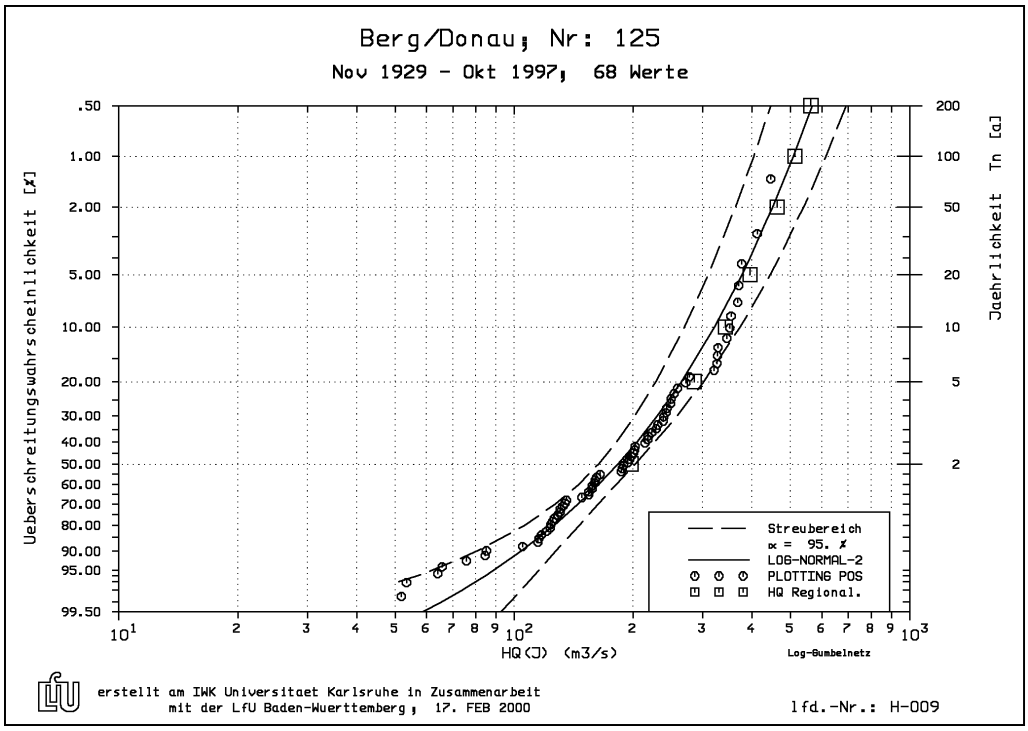


Abb. 3 Hochwasserabfluss-Wahrscheinlichkeit und Jährlichkeit am Pegel Berg/Donau (Zeitspanne 1930 – 1997). Vergleich der analytischen und der regionalisierten Verteilung.

Tab. 1 Multivariates Regressionsmodell für die regionalisierten Hochwasserabfluss-Kennwerte

$$\ln(Y) = C_0 + C_1 \cdot \ln(A_{Eo}) + C_2 \cdot \ln(S+1) + C_3 \cdot \ln(W+1) + C_4 \cdot \ln(I_g) + C_5 \cdot \ln(L) + C_6 \cdot \ln(L_C) + C_7 \cdot \ln(hN_G) + C_8 \cdot \ln(LF)$$

mit:

$Y = MHq$ zur Regionalisierung der MHQ-Werte

oder

$Y_T = \frac{Hq_T}{MHq}$ für: T = 2, ..., 200 a

zur Regionalisierung der HQ_T-Werte

Y, Y_T : abhängige Variable

MHq : Spende des mittleren jährlichen Höchstabflusses MHQ ($m^3/s,km^2$)

Hq_T : Spende des T-jährlichen Höchstabflusses HQ_T ($m^3/s,km^2$)

C_0 - C_8 : Koeffizienten

Gebietskenngrößen:

A_{Eo} Einzugsgebietsfläche in [km^2]

S Bebauungsanteil in [%]

W Waldanteil in [%]

I_g gewogenes Gefälle [-]

L Fließlänge bis Gewässerstelle in [km]

L_C Fließlänge ab Gebietsschwerpunkt in [km]

hN_G mittlerer Jahresniederschlag in [mm]

LF Landschaftsfaktor [-]

Der Hochwasserabfluss HQ_T ergibt sich aus:

$$HQ_T = Y_T \cdot MHq \cdot A_{Eo} = Y_T \cdot MHQ$$

Tab. 2 Koeffizienten (Parameter) der multiplen linearen Regressionsfunktionen

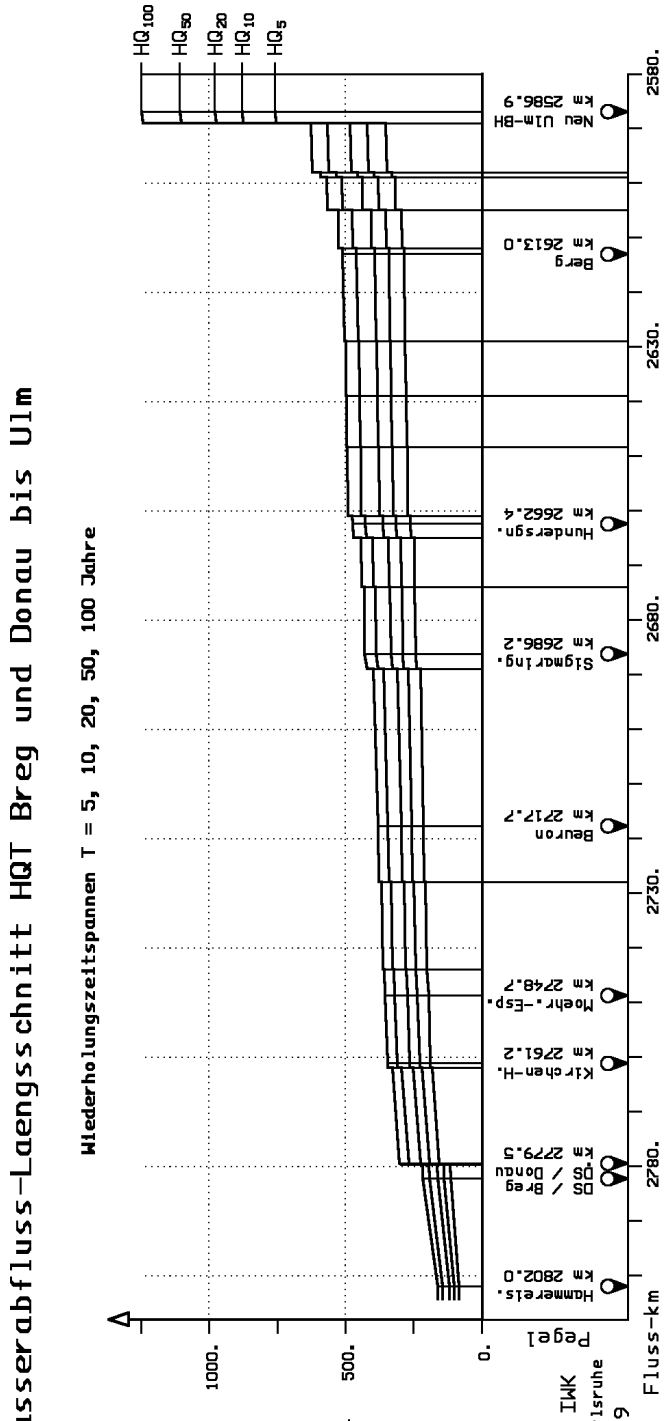
HQ-Kennwert	Koeffizienten zur Berücksichtigung der jeweiligen Gebietskenngrößen								
	C_0	C_1 (A_{Eo})	C_2 (S+1)	C_3 (W+1)	C_4 (I_g)	C_5 (L)	C_6 (L_C)	C_7 (hN_G)	C_8 (LF)
MHq	-17.0745	-0.3090	0.1105	-0.2044	-0.0710	0.2667	-0.1059	1.4799	1.5800
Hq_2	-1.3858	-0.0311	0.0055	-0.0713	-0.0517	0.0669	-0.0276	0.2361	-0.0307
Hq_5	1.1075	-0.0063	-0.0199	0.0037	0.0206	-0.0045	0.0200	-0.1243	0.0215
Hq_{10}	2.4326	0.0134	-0.0308	0.0410	0.0629	-0.0491	0.0405	-0.3138	0.0455
Hq_{20}	3.5938	0.0308	-0.0416	0.0661	0.1053	-0.0763	0.0490	-0.4773	0.0628
Hq_{50}	4.8795	0.0501	-0.0503	0.1017	0.1526	-0.1017	0.0530	-0.6618	0.0797
Hq_{100}	5.7391	0.0674	-0.0556	0.1221	0.1860	-0.1269	0.0564	-0.7824	0.0897
Hq_{200}	6.5645	0.0767	-0.0585	0.1456	0.2232	-0.1302	0.0551	-0.9011	0.0936

Die Bestimmtheitsmaße R^2 der linearen Regressionsfunktionen betragen jeweils $R^2 > 0{,}98$

Tab. 3 Regionalisierte Hochwasserabfluss-Kenngrößen für ausgewählte Pegel im Donau-Einzugsgebiet.

Hochwasser-Abflüsse [m³/s] ***Hochwasser-Abflussspenden [l/s*km²]***

lfd.Nr.	Peg.Nr.	STANDORT	Gewässer	A_{Eo}	Reihe	Anz.J.	MHQ *MHq*	HQ5 *Hq5*	HQ10 *Hq10*	HQ20 *Hq20*	HQ50 *Hq50*	HQ100 *Hq100*
1	105	Kirchen-Hausen	Donau	757.63	1922 - 1998	74	142.0 *187.5*	189.9 *250.6*	229.4 *302.8*	265.5 *350.5*	312.0 *411.8*	347.3 *458.4*
2	194	Möhringen-Espenbr.	Donau	861.55	1974 - 1995	24	146.6 *170.2*	196.7 *228.4*	237.6 *275.8*	274.6 *318.7*	322.1 *373.8*	357.7 *415.2*
4	168	Beuron	Donau	1 309.29	1926 - 1997	72	160.2 *122.3*	215.1 *164.2*	258.2 *197.2*	296.9 *226.8*	346.3 *264.5*	382.7 *292.3*
5	57119	Sigmaringen	Donau	1 673.05	1925 - 1995	62	182.6 *109.1*	244.5 *146.1*	291.9 *174.5*	335.1 *200.3*	390.7 *233.5*	431.3 *257.8*
6	120	Hundersingen	Donau	2 638.57	1930 - 1998	68	196.0 *74.3*	262.8 *99.6*	315.7 *119.7*	365.1 *138.4*	428.9 *162.5*	476.4 *180.6*
7	125	Berg	Donau	4 046.74	1930 - 1997	68	212.5 *52.5*	285.3 *70.5*	341.8 *84.5*	394.6 *97.5*	462.5 *114.3*	513.0 *126.8*
8	1139	Hammereisenbach	Breg	163.62	1926 - 1998	73	63.0 *384.7*	83.9 *513.0*	102.9 *628.6*	120.8 *738.4*	144.6 *884.0*	163.2 *997.5*
9	1181	Donaueschingen	Breg	289.87	1940 - 1997	31	86.0 *296.8*	115.7 *399.0*	140.6 *485.1*	163.8 *565.1*	194.1 *669.7*	217.0 *748.6*
10	140	Villingen	Brigach	100.29	1959 - 1995	37	37.7 *375.5*	49.8 *496.4*	60.4 *602.1*	70.4 *702.1*	83.9 *836.3*	94.3 *939.8*
11	1140	DS-Mühlenbrücke	Brigach	190.61	1930 - 1996	58	52.1 *273.3*	69.5 *364.4*	83.5 *438.1*	96.2 *504.7*	112.7 *591.2*	125.0 *655.8*
12	192	Tuttlingen	Elta	80.69	1957 - 1996	40	26.2 *324.8*	36.4 *451.5*	46.3 *573.8*	56.0 *694.5*	69.3 *858.5*	79.7 *987.4*
13	1156	Fridingen	Bära	134.96	1938 - 1996	59	18.5 *137.4*	25.7 *190.1*	32.7 *242.2*	39.7 *294.1*	49.3 *365.1*	56.9 *421.4*
14	1120	Unterschmeien	Schmiecha	150.63	1925 - 1997	73	9.7 *64.3*	13.1 *87.2*	16.2 *107.7*	19.2 *127.7*	23.3 *154.9*	26.5 *175.9*
15	1131	Laucherthal	Lauchert	451.67	1933 - 1996	64	14.0 *31.1*	19.1 *42.2*	23.4 *51.9*	27.7 *61.2*	33.3 *73.7*	37.6 *83.3*
16	1159	Mengen (Add.)	Ablach	441.72	1930 - 1996	66	29.6 *67.0*	40.6 *91.8*	50.4 *114.1*	60.1 *136.0*	72.9 *165.0*	83.0 *187.8*
17	1174	Jettkofen	Ostrach	100.14	1959 - 1995	36	6.5 *64.6*	8.6 *86.2*	10.2 *102.1*	11.7 *116.9*	13.6 *135.8*	15.0 *150.2*
18	47840	Unlingen	Kanzach	154.45	1931 - 1997	65	8.1 *52.3*	11.1 *71.9*	13.7 *89.0*	16.4 *106.0*	19.8 *128.4*	22.6 *146.3*
19	47834	Lauterach	Große Lauter	298.57	1930 - 1996	64	4.3 *14.4*	5.8 *19.4*	7.1 *23.7*	8.3 *27.8*	10.0 *33.4*	11.3 *37.7*
20	1160	Ehingen	Schmiech	193.19	1949 - 1996	48	5.2 *26.8*	7.1 *36.8*	8.8 *45.6*	10.5 *54.6*	12.9 *66.7*	14.7 *76.2*
21	1133	Schweinhausen	Riß	97.89	1980 - 1996	17	8.1 *82.4*	10.8 *110.2*	12.7 *129.8*	14.5 *148.0*	16.7 *171.0*	18.4 *188.3*
22	1144	Niederkirch	Riß	405.30	1931 - 1996	66	25.9 *63.9*	34.8 *85.8*	41.9 *103.5*	48.9 *120.6*	58.0 *143.0*	65.0 *160.3*
23	128	Achstetten	Westernach	236.79	1933 - 1992	60	18.3 *77.4*	25.0 *105.7*	30.5 *129.0*	35.9 *151.6*	42.8 *180.9*	48.2 *203.4*
24	1145	Laupheim	Rottum	135.22	1973 - 1996	24	13.0 *96.0*	17.7 *130.7*	21.3 *157.2*	24.7 *182.5*	29.1 *215.1*	32.4 *239.6*
25	177	Binnrot	Rot	130.18	1961 - 1996	36	16.9 *130.2*	23.3 *179.0*	28.9 *221.9*	34.3 *263.8*	41.5 *318.4*	47.0 *361.4*
26	129	Achstetten	Rot	263.79	1926 - 1996	71	28.6 *108.4*	39.5 *149.8*	48.4 *183.3*	56.6 *214.7*	67.2 *254.8*	75.1 *284.7*
27	144	Lauben	Aitrach	307.74	1939 - 1996	58	32.7 *106.1*	42.2 *137.3*	49.4 *160.5*	56.6 *183.8*	66.0 *214.5*	73.4 *238.4*
28	145	Blaubeuren	Blautopf	150.00	1952 - 1995	44	14.5 *96.7*	18.7 *124.7*	22.7 *151.3*	26.9 *179.3*	32.7 *218.0*	37.5 *250.0*
29	47766	Ulm (Add.)	Blau	479.01	1991 - 1995	5	16.9 *35.4*	23.2 *48.4*	29.0 *60.5*	34.7 *72.5*	42.4 *88.6*	48.6 *101.4*
30	1121	Hermaringen	Brenz	450.37	1923 - 1988	66	17.5 *38.9*	23.4 *52.0*	28.5 *63.3*	33.4 *74.2*	39.9 *88.7*	45.0 *99.8*
31	151	Burgberg-Oberer Steg	Hürbe	316.96	1974 - 1997	24	2.6 *8.1*	3.5 *11.0*	4.2 *13.3*	4.9 *15.6*	5.9 *18.5*	6.6 *20.8*
32	1137	Lontal	Lone	310.23	1978 - 1996	19	2.4 *7.6*	3.2 *10.3*	3.9 *12.4*	4.5 *14.5*	5.4 *17.3*	6.0 *19.4*
33	147	Trochtelfingen	Eger	124.96	1930 - 1997	68	26.4 *211.0*	36.4 *291.4*	45.0 *360.3*	53.2 *425.7*	63.8 *510.5*	72.0 *575.8*
34	153	Wört	Rotach	51.91	1961 - 1997	37	4.5 *87.1*	6.1 *118.3*	7.6 *147.1*	9.1 *175.1*	11.1 *213.7*	12.6 *243.6*



Fortsetzung Donau

Flusskilometer Station/ Nebenfluss	Einzugsgebiet A_{Eo} [km²]	HQT [m³/s]				
		HQ_{100}	HQ_{50}	HQ_{20}	HQ_{10}	HQ_5
Hammereis.	163.6	163	145	121	103	83.9
DS / Breg	289.9	217	194	164	141	116
DS / Donau	524.0	303	270	226	193	158
Altrach	660.6	329	296	254	220	183
Kirchen-H.	757.6	347	312	266	229	190
Moehr.-Esp.	861.5	358	322	275	238	197
Eltg	877.7	360	325	279	243	203
km 2748.7	959.0	365	329	281	244	203
Beara	1143.9	369	334	287	250	209
km 2728.0	1279.5	379	343	293	255	212
Beuron	1309.3	383	346	297	258	215
Schmiechq	1477.5	399	362	311	272	227
km 2689.0	1633.5	421	383	329	288	242
Sigmaring.	1673.0	431	391	335	292	245
Lauchert	1686.9	433	393	338	295	248
km 2674.0	2142.8	442	399	341	297	249
Ablach	2157.4	445	402	344	299	250
Ostrach	2842.8	494	444	378	327	273
Schwarzach	2950.5	495	446	379	328	274
km 2648.3	3100.3	497	448	382	331	277
Zwief.Bch	3286.5	498	450	385	334	280
km 2639.0	3540.8	500	451	385	334	280
Gr. Lautter	3572.8	500	452	387	337	283
km 2629.0	3873.1	504	455	390	339	284
Berg	4046.7	513	463	395	342	285
Schmiech	4275.0	529	476	407	352	294
Riss	4296.4	529	478	408	354	296
km 2605.0	4220.2	568	513	439	380	318
Westernach	4748.9	570	515	441	382	320
Rot	5301.1	624	563	480	416	349
Iller	5397.0	629	568	486	422	354
Neu Ulm-BH	7578.9	1250	1110	980	880	760

Abb. 4 Hochwasserabfluss-Längsschnitt HQ_T der Breg und der Donau bis Ulm

Regionalisierte 100-jährliche Hochwasserabfluss-Spenden (Hq100)
bezogen auf Gewässerknoten des Gewässerkundlichen Flächenverzeichnisses BW

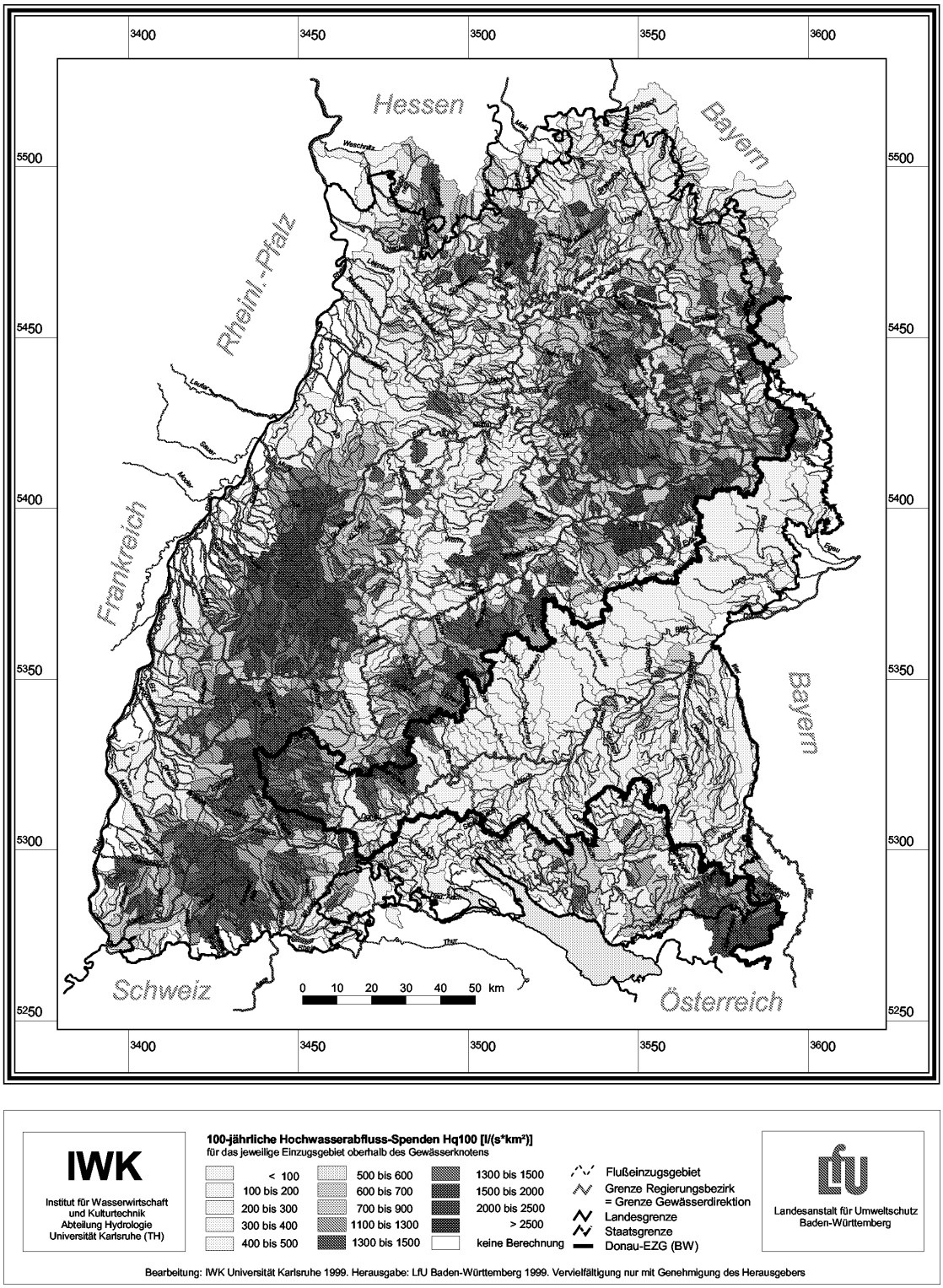


Abb. 5 Regionalisierte 100-jährliche Hochwasserabfluss-Spenden (Hq_{100}) bezogen auf Gewässerknoten des Gewässerkundlichen Flächenverzeichnisses Baden-Württemberg

Estimation of High Water Discharge on the Basis of Stochastic Water Level Analysis

Siniša Maričić, Josip Petraš, Vladimir Patrčević

Abstract: In the *Karašica* and *Vučica* basin (right side tributaries of the Drava River) at approximately 50 locations water level observations were done. At some 10 observation points measurements have been done for a period longer than 25 years. Until today no complete and scientific analysis of the performed measurements and collected data has been done. Because of the difficult current situation in the economy there is a possibility of stopping the measurements, so it is necessary to analyse and evaluate the obtained data which have a significant value and show the importance of observation continuation.

The intention of this paper is to help the decision-makers understand the importance of some measurements and take a right decision concerning the continuation of the measurements. It gives a hydrologic estimation of high water discharge, as an example for other similar research on the basis of collected data. A stochastic analysis of high water levels is done on the basis of the water level data collected on four small rivers with considerable torrential problems during a 35-year period. Independent water levels that exceed the selected threshold value are included into the analysis. The relation between water level and discharge is defined on the basis of channel geometry and hydraulic characteristics. In the end, high discharges are systematised according to the return periods of infrequent occurrence, which can find practical application in water management.

Key words: hydrological measurements, water level, stochastic analysis, high water, torrent

Durchflussschätzung mittels stochastischer Wasserstandsanalyse

Zusammenfassung: Im Einzugsgebiet der Flüsse Karašica und Vučica, den rechten Nebengewässern der Drau, wurden Wasserstände an fünfzig Pegeln beobachtet. An zehn Pegeln wird seit mehr als 25 Jahren gemessen. Bisher wurde keine vollständige wissenschaftliche Analyse der Messungen und der gesammelten Daten durchgeführt. Wegen der schwierigen Wirtschaftssituation besteht die Gefahr der Unterlassung weiterer Messungen. Es ist deshalb erforderlich, die vorhandenen Daten, die von Bedeutung sind auszuwerten, zu analysieren, und die Wichtigkeit der Fortsetzung der Beobachtungen zu zeigen.

Die Zielrichtung dieses Papiers ist es, die richtige Entscheidung bezüglich der Weiterführung dieser Messungen vorzubereiten.

Diese Arbeit sollte Überlegungen anregen über die Zweckmäßigkeit mancher Messungen sowie über die durch die ungeplanten Messunterbrechungen verursachten Schäden.

Es wird ein hydrologisches Verfahren zur Schätzung extremer Durchflüsse dargestellt, das als Beispiel für ähnliche Forschungen auf der Basis der gesammelten Daten dienen kann. Auf der Grundlage 35-jähriger Wasserstandsreihen von vier Wildbächen wurde eine stochastische Analyse der Hochwasserstände durchgeführt. Unabhängige Wasserstände, die einen ausgewählten Schwellenwert überschreiten, sind in die Analyse einbezogen. Die Beziehungen zwischen Wasserständen und Durchflüssen wurden entsprechend der Flussbettgeometrie und der hydraulischen Charakteristik definiert. Schließlich wurden die Hochwasserdurchflüsse nach der Wiederholungszeitspanne systematisiert, was eine praktische Anwendung in der Wasserwirtschaft finden kann.

Schlüsselwörter: hydrologische Forschung, Wasserstand, stochastische Analyse, Hochwasser, Wildbach

1 Introduction

The importance of relevant hydrologic measurement in a catchment area is indisputable. On one hand, in that way the input values for conceptual designing and dimensioning of hydrotechnical structures are obtained, and on the other the obtained data reveal what is happening in the catchment area. The water management practice is based on the so collected data. The more data of adequate quality are collected, the more valuable are the results of water management design solutions, which is directly related with the investment in the measurements. Concerning the measurements, there is a constant dilemma: when to invest, how much and in what, because on the one hand the funds are always limited, and on the other, there is a constant need for more and more data. If in this connection a wrong estimation is made concerning which data to collect or not to collect, the significance of the work done previously can be easily underestimated. Thus, it depends on the professional skill and work dedication of water management professionals to what extent the observation and measurement activities of a certain time period will be useful in the future. It implies that it is necessary to make constant analyses of previously done work, current and future needs, and available possibilities in order to plan and organise adequately the measurements in the period to come. However, illogical things also sometimes happen in practice. One example of such kind is given as a cause for reflection concerning the importance of some measurements and the damage caused by their unplanned ending.

2 Water Management Characteristics of the *Karašica* and *Vučica* Catchment Area

In the north-east of the Republic of Croatia, in region of Slavonia, between *Papuk* and *Krndija* mountains and the Drava River lies the catchment area of the small rivers *Karašica* and *Vučica* (Figure 1). It is mainly a low-lying region (3/4 of the area), although a part of it is high-lying (1/4 of the area). A number of natural watercourses collect the water from the high-lying area, and convey it through the low-lying area, where the slope is considerably lower, into the Drava River. Thus, there is traditionally developed agriculture in the plain, which is endangered by own water (ground and atmospheric), as well as by the mountain waters, and the waters from the Lower Drava.

In order to protect the area from floods and drain the excess water from the farmland, at the end of the last century organised was local water management. At first it was really struggle against adversities, however, later on it grew into an organised and planned activity.

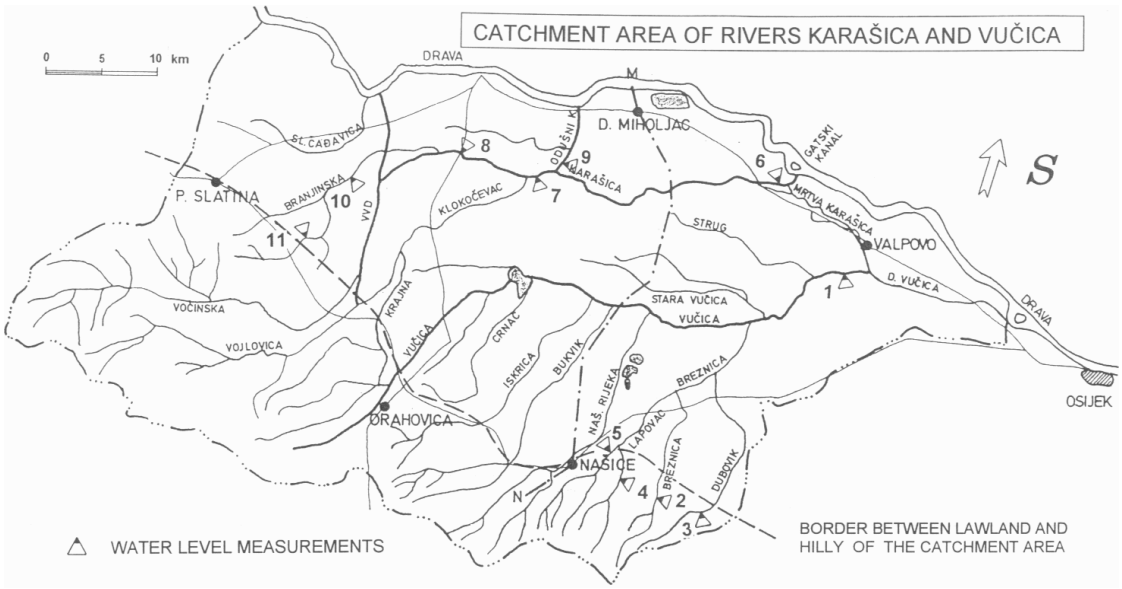


Fig. 1 Catchment area of Karašica and Vučica rivers and locations of active water level gauges

The basic drainage concept for the entire catchment area was already given in 1930 by Prof. Bella. It involves spatial and time separation of mountain waters from plain waters by means of the detention basins at suitable locations at the mountain foothills. The water wave from the hills would be stopped in the retentions which would reduce the maximum discharge in the recipients.
That basic concept was accepted and elaborated in later study documentation and in water management master plan. However, because of more and more expressed shortage of water for certain purposes in the area, and for the sake of better cost-effectiveness, emphasis is being placed on multipurpose structures. Thus, within the structures that ensure space for the acceptance and retention of water for the purpose of reducing the high water wave from the hills, water will be stored for the needs of fish-ponds, irrigation, supply of settlements, sports and recreation, etc.
In the study of Prof. Srebrenović from 1967, 17 multipurpose storage reservoirs of such kind are foreseen.

Drainage is done by four main recipients: through the channels of the small rivers *Karašica*, *Vučica* and *Slatinska Čađavica*, and through one canal (V-V-D). Along with a significant network of partly regulated watercourses and artificial canals, up to now only one storage reservoir - *Lapovac* has been built. Drainage is mainly done by gravity, and there are only two pump stations. In the highland zone the regulation works on the torrential parts of the watercourses are very scarce. For the most parts, the watercourses are completely unregulated, and thus it can be said that the highland part of the region is not protected from floods. The existing drainage system provides limited possibilities of water management by means of hydrotechnical structures. Due to the shortage of funds, the system completion and maintenance works have been completely neglected for a number of years (Morača, N., 1999).

In the process of design documentation elaboration, as the main problems occurs the shortage of discharge data due to the inadequate number of hydrometric locations on watercourses. The problems of such kind are often emphasised in professional papers, and proposals for possible activities are given (e.g. Đurković, Z., 1994).

3 Problems Related to Hydrologic Measurements

In the area recorded is the operation of 21 rain gauges (mainly daily data). The oldest staff gauges were installed at the beginning of the century (in 1908 – *Karašica*). For the sake of high-quality determination of water balance within individual watercourses, long-term measurements were introduced at particular watercourses. Thus from 1975 the water level started to be measured at some 50 sites. However, at the beginning of 1990 those measurements were reduced to only 11 sites – five in the *Vučica* catchment area, four in the *Karašica* catchment area, and two in the catchment area of V-V-D canal. The current measurement sites are marked in Figure 1. Out of 8 limnimeters in that area supervised by the State Meteorological Office, only two are functioning today, because some of them were damaged during the war, while at others observations were stopped.

Concerning the considered area, until now no professional analysis of the performed measurements and collected data has been done for the purpose of assessing the appropriateness and successfulness of the work done so far, and the needs and possibilities for the measurements in the future. Such considerations were certainly taken into account while making planned decisions in water management. However, due to difficult economic circumstances, some measurements were even suddenly stopped. All that had an impact on today's knowledge of the catchment area characteristics.

By placing staff gauges at numerous locations in the seventies, daily water level observations were started. It was also planned then to make for each location occasional measurements of flow velocity at the cross-section profile at the water gauge, and of water face slope. On the basis of these measurements, discharge and hydraulic (hydropower) losses would be estimated

and then a rating curve for the gauging site would be defined. That would enable more realistic water balancing per particular locations in the catchment area, and, for instance, more accurate planning of possible storage reservoirs. However, after the first year already, there was no money for flow velocity and slope measurements. At the major part of the locations rating curves were never defined. However, water level observations were done for several decades. Wouldn't it be better to make water level observations for fewer locations, and to define the rating curves for them? The situation is still unchanged today. There is a large amount of collected water level data, but the problem is how to use them. Thus, the attitude towards these measurements should be changed in the future. After the evaluation of the existing data, according to available possibilities, the most representative locations should be selected, and the results of measurements at these locations should be the values of daily discharges.

Examining the collected data on water levels it cannot be said with certainty when some very low value of the reading from a staff gauge means a completely dry river bed, and when it indicates a very low water level (especially when the „0" of the staff gauge is set at the channel bottom). Irregular and inadequate payment of the observers might be a cause of the inaccuracy of observations, because it is obvious that sometimes the reading values were roughly rounded (e.g. to 10 cm), and there were also short discontinuities in taking the readings. The existing recordings of cross-section profiles at water gauge locations mainly date from the seventies, and more recent ones are very scarce (only at some locations). The situations is the same concerning the data on hydraulic measurements of water velocity at the cross-section profile.

The possible use of the large amount of data on water levels collected over many years in water management practice, is illustrated on the example of the estimation of discharge for a certain return period on the basis of stochastic water level analysis.

4 High Water Stochastic Analysis

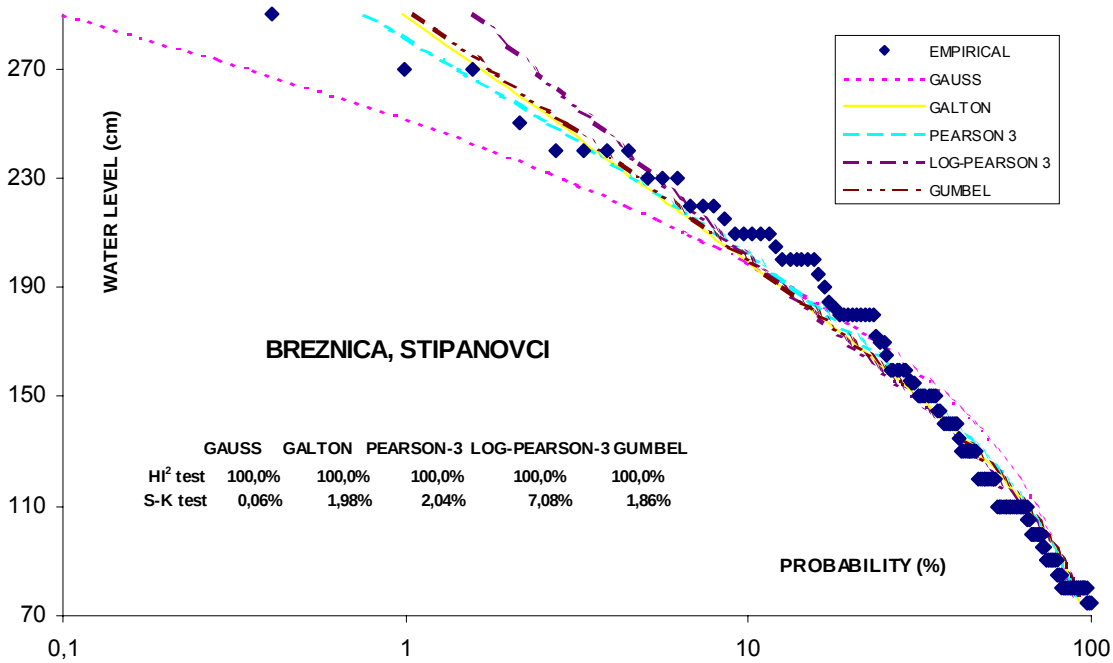
It is generally accepted that hydrologic data are being treated as statistic variables. According to the character of hydrologic data, statistic variables can be distinguished as discrete and continuous. Accepting the possibility of presenting hydrologic data by random variables, the concept of probability is introduced in hydrology. Thus hydrologic processes are considered as stochastic processes (Srebrenović, D., 1970, 1986; Brenier, I., 1970).

The water level at a certain location on the watercourse can be considered as a stochastic process random variable. The water level is a direct consequence of water quantity that flows in a watercourse, and of the channel geometry and roughness. Water quantity itself is the result of a stochastic process, and it depends first of all on the precipitation quantity and distribution, and on the conditions in the catchment area. Channel roughness can be also included among these conditions. Another interesting factor of watercourse oscillations due to some natural patterns is the change of watercourse geometry – meandering, and raising and lowering of the channel bottom as a cyclic process. Theoretically, by recording the channel geometry at one site, during a sufficiently long period of time, it is possible to form a set of all manifestation patterns. The channel geometry then at a certain instant of time also has a random character, and accepting also all other similar factors, it is right to study water level changes by stochastic analysis.

Because it was not possible to determine with sufficient reliability whether it is a question of low water or dry channel in some cases, it was decided to consider in the illustrative example upper extreme values – high water levels, i.e. high waters. The torrential watercourses of the catchment area highland part with water gauging locations at the border-line between highland and lowland areas were taken into consideration in the presented analysis. The following water levels are included: *Gornja Branjinska* at *Brezika*, *Breznica* at *Stipanovci*, *Podgorički Dubovik* at *Razbojišta*, and *Lipovac* at *Vukojevci*. They are marked with numbers 2, 3, 4 and 11 at Figure 1. The considered cross-section profiles are in the zone where the building of possible storage reservoirs is planned, and thus high water analysis is also interesting in terms of obtaining values for the estimation of evacuation facilities of dams. A large amount of data is available for

that purpose (daily water level observations taken over the period of last 24 - 35 years).

By simple statistic processing of the set of data on water level at a particular location it is possible to obtain frequency and duration curves for that phenomenon. It was done so. Then, for each location an adequate water level was selected as the threshold value so that the number of data which exceed that value (higher water levels) make some percentage of the total recorded data (see Table 1.). From the exceeding water level values selected were the water levels which as random variables have independent character. In the analysed case as independent high water levels (above the threshold value) considered are those water levels that did not result from a single precipitation occasion, i.e. they occurred at the intervals of at least 5–6 days. The selection of independent water levels was directly made by examining the available data. The number of independent exceeding water levels for each selected location is given in the enclosed table.



RET. PER.	1.001	1.010	1.020	1.042	1.053	1.111	1.250	2.000	5.000	10.000	20.000	25.000	50.000	100.00	1000.0
PROB. (%)	99.9	99.0	98.0	96.0	95.0	90.0	80.0	50.0	20.0	10.0	5.0	4.0	2.0	1.0	0.1
GAUSS	-21.33	17.18	30.92	46.20	51.54	69.86	92.06	134.40	176.80	199.00	217.40	222.70	238.00	251.70	290.20
GALTON	41.75	54.85	60.47	67.38	69.98	79.69	93.27	125.90	170.10	199.10	226.70	235.50	262.40	289.30	380.00
PEARS.-3	35.44	48.82	54.85	62.44	65.32	76.14	91.35	127.30	173.50	201.90	227.80	235.70	259.40	282.10	352.00
LOG.PEA-3	49.06	59.74	64.41	70.23	72.44	80.82	92.87	123.50	168.90	201.20	233.80	244.50	278.80	314.50	448.50
GUMBEL	35.75	51.69	58.11	65.78	68.61	78.95	93.04	126.20	170.70	200.30	228.60	237.50	265.20	292.70	383.40

Fig. 2 Example of obtained values of empirical and theoretical probabilities

In the case of extreme values, which are to be systematised according to the return period of infrequent occurrence, it is most important to select properly the function of probability distribution, because on the basis of empirical occurrences in a very short time a conclusion is made about phenomena of extremely low frequency. For the estimation of the distribution of data on high waters, for each location five theoretical functions were used: Gaussian, Galtonian, Pearson's, Log-Pearson's III and Gambel's. They are most frequently used in the Croatian hydrologic practice, and they are also used by the State Meteorological Office. The calculation results are illustrated by the presented example (Figure 2). Testing the adjustment of the theoretical function to the empirical data was also done in accordance with the practice done by the State Meteorological Office (Pearson's χ^2 and Smirnov-Kolmogorov test). Quality testing of the adjustment can be also done at graphic presentation of distributions. All the distributions

used prove acceptable for usage. For the considered locations, the best agreement with the empirical distribution is achieved by the Log-Pearson's III function. For further usage recommended are high water data systematised according to the return period based on that function.

5 Estimation of High Water Discharge

The problem of high water discharge estimation is based on the existing conditions and assumptions. For each of the considered locations determined were high water levels of particular return periods in the way described in the further text. There are recordings of the cross-section profiles at gauging locations which are not sufficient for making conclusions about morphological changes of the river bed. Longitudinal profiles were partly recorded on the spot, and partly taken from maps on a 1:5000 scale. Assuming that the cross-section profiles are representative enough, and that they have not been considerably changed in the course of time, and also that the averaged longitudinal slope of the bed is uniform at water gauging sites and is equal to hydraulic gradient, it is possible to estimate high water discharge.

For the needs of the calculation, for each cross-section profile at gauging locations determined was the dependence of wetted perimeter, **0** (m) and profile water area, **A** (m^2) on water depth (water level) in the watercourse. Hydraulic radius, **R** (m) is a ratio of pertaining water area, **A**, and wetted perimeter, **0**, for water level of a certain return period. The longitudinal slope of watercourse is denoted with „**I**". Using the Chezy formula, the velocity of high torrential water is calculated in the following way:

$$v = K \cdot C \cdot \sqrt{R \cdot I}\ , \qquad \text{(m/s)}, \qquad C = \frac{87 \cdot \sqrt{R}}{\sqrt{R} \cdot \gamma}\ ,$$

where: K – coefficient of torrential stream
C – Bazin's coefficient of flow velocity.

According to the instructions of Prof. Gavrilović for similar calculations, the values for **γ** and **K** are empirically recommended. The values for the channel roughness coefficients range from 1.75 to 1.30, and thus the value of 1.60 was accepted. The value of the coefficient of torrential stream usually ranges from 0.7 to 0.9, and the value of 0.9 was accepted. Finally, the discharge of high torrential water of a certain return period for the adopted watercourse cross-section and slope is:

$$Q_{HW}^{RP} = A \cdot v \qquad (m^3/s)\ .$$

The complete calculation for the considered locations is given in Table 1. However, having in mind the introduced assumptions, the obtained values should be critically considered.

In the end, an attempt is made to evaluate the results by making comparison with similar results obtained in previous studies. The most definite judgement can be, however, given by a direct comparison of the values obtained in the presented work with the discharge values calculated on the basis of precipitation already in 1967. Without getting into a deeper discussion how some values were obtained, and what are the reasons for differences, it should be pointed out that in the considered period (24-35 years) recorded were the water levels that considerably exceed the values given in the study from the 1970s when the data on water level measurement were not available.

6 Conclusion

Irregularities in the policy of carrying out hydraulic measurements cause damage to water management. The measurements have to be precisely planned, financed and performed. If due to some unfavourable circumstances a plan has to be modified, the modifications have to be professionally done. It is necessary to make periodical analyses of taken observations and collected data in order to point out further possibilities.

LOCATION WATER COURSE MEASUREMENT STATION SIMBOL AT THE FIGURE	PERIOD OF MEASUREMENTS / NUMBER OF YEARS	NUMBER OF DATA LIMITATION VALUE WATER LEVELS OVER LIMITATION VALUE HIGHWATER UNDEPENDENT HIGH WATER	RETURN PERIOD (YEARS)	RESULTS OF STOCHASTIC ANALYSIS OF WATER LEVELS, (cm)	ESTIMATION OF DISCHARGE							RESULTS GIVEN BY PROFESSOR SREBRENOVIĆ, (m^3/s)	THE HIGHEST MEASURED WATER LEVEL STOCHASTICAL DISCHARGE
					ASSUMPTIVE PARAMETERS	O (m)	A (m^2)	R (m)	c	v (m/s)	Q (m^3/s)		
1	2	3	4	5	6	7	8	9	10	11	12	13	14
GORNJA BRANJINSKA, BREZIK **11**	from 1963. until today without '73. '74., '91. / 33	11322 >100 cm 362 / 3.20 % 121 / 1.07 %	5	**182.00**	I = 0.006 γ = 1.6 K = 0.9	7.94	8.19	1.03	33.72	2.39	**19.59**	14.2	280 cm 43 m^3/s
			10	**210.90**		8.52	9.93	1.17	35.05	2.64	**26.20**	17.5	
			25	**249.60**		9.30	12.27	1.32	36.34	2.91	**35.72**	21.9	
			50	**279.90**		9.90	14.07	1.42	37.15	3.09	**43.44**	25.1	
			100	**311.70**		10.54	15.99	1.52	37.86	3.25	**51.96**	28.4	
			1000	**430.40**		12.82	22.83	1.78	39.57	3.68	**84.03**	39.3	
BREZNICA, STIPANOVCI, **2**	from 1963. until today without '91. / 33	12784 >70 cm 345 / 2.70 % 172 / 1.35 %	5	**168.90**	I = 0.00265 γ = 1.6 K = 0.9	10.35	10.20	0.99	33.31	1.53	**15.63**	14.5	290 cm 54 m3/s
			10	**201.20**		11.82	13.50	1.14	34.84	1.73	**23.29**	17.8	
			25	**244.50**		13.75	18.47	1.34	36.55	1.96	**36.25**	22.2	
			50	**178.70**		15.31	23.05	1.52	37.76	2.15	**49.48**	25.5	
			100	**314.50**		16.92	28.28	1.67	38.88	2.33	**65.86**	28.9	
			1000	**448.50**		22.91	52.29	2.28	42.25	2.96	**154.64**	39.9	
PODGORAČKI DUBOVIK, RAZBOJIŠTE, **3**	from 1974. until today without '91. / 24	8766 >30 cm 192 / 2.20 % 101 / 1.15 %	5	**76.44**	I = 0.003 γ = 1.6 K = 0.9	3.70	1.45	0.39	24.42	0.75	**1.09**	9.8	205 cm 12 m3/s
			10	**96.84**		4.45	2.15	0.48	26.35	0.90	**1.94**	12.1	
			25	**129.60**		5.60	3.60	0.64	29.04	1.15	**4.13**	15.1	
			50	**160.00**		6.60	5.10	0.77	30.84	1.34	**6.82**	17.4	
			100	**196.00**		7.95	7.40	0.93	32.72	1.56	**11.52**	19.7	
			1000	**373.90**		16.70	26.50	1.59	38.36	2.38	**63.06**	27.2	
LAPOVAC, VUKOJEVCI, **4**	from 1963. until today without '91. / 35	12541 >80 cm 310 / 2.50 % 149 / 1.19 %	5	**183.50**	I = 0.0028 γ = 1.6 K = 0.9	9.70	10.00	1.03	33.78	1.63	**16.33**	13.4	500 cm 150 m^3/s
			10	**230.80**		11.50	14.80	1.29	36.10	1.95	**28.86**	16.4	
			25	**304.70**		13.90	22.35	1.61	38.47	2.32	**51.92**	20.5	
			50	**371.20**		16.40	30.80	1.88	40.14	2.62	**80.68**	23.6	
			100	**449.00**		19.10	42.88	2.25	42.05	3.00	**128.73**	26.7	
			1000	**813.80**		30.35	116.60	3.84	47.90	4.47	**521.22**	36.9	

Table 1 Parameters of estimation of high water discharges on the basis of stochastic water level analysis for torrents in cetchment area of rivers Karašica and Vučica

In the *Karašica* and *Vučica* catchment area water level observations were done at a number of locations over many years. Although the observations at the majority of locations were stopped in 1990, the collected data can be used for obtaining some specific information about the catchment area. An example of that is the estimation of discharge of a certain return period on the basis of stochastic water level analysis. The carried out procedure points to the necessity of making new recordings of cross-sections, longitudinal slopes and hydraulic characteristics (velocity and roughness) at measurement locations in order to utilise in a more appropriate way the data collected over many years. The results of the estimation, discharges systematised by return periods, obtained on the basis of stochastic torrential water level analysis for four locations at the border-line between the highland and lowland parts of the catchment area, and existing recordings of the channel geometry partly deviate from the earlier defined values on the basis of parametric analysis of runoff. These deviations are greater for longer return periods. The obtained discharges are valuable information to engineers, for example, for designing of storage reservoirs planned in that area.
The interrupted measurements at the water gauging stations should be continued with occasional discharge measurements, with the aim of defining discharge curves. Automated measurement procedures should be gradually introduced.

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Rainfall Scenarios for the Upper Danube Catchment

János Mika and Gábor Bálint

Abstract: Method of instrumental variables is used to estimate linear regression coefficients between regional rainfall and hemispherical mean temperature for the 1974-1998 period, that exhibited a strong hemispherical warming trend (0.26 K / decade). Series of hemispherical mean temperature (Jones, 1994 and updated) is used for independent variable of the regression. For dependent variables observed precipitation data are used at 76 stations of the upper Danube sub-catchments situated in six countries (Austria, Czech Republic, Germany, Hungary, Slovak Republic and Romania). The sequence of consecutive years in the investigated 25 years is defined for instrumental variable, that fulfil the criteria for being instrumental variable: non-zero correlation to the independent variable (r=0.825), no correlation to its errors, and the same to residuals of the dependent variable. Outliers of local precipitation data are identified by cluster analysis. This method, based on inter-annual variability of precipitation, is also used to identify 9 regions in the upper-Danube region exhibiting fair in-cluster similarity of the regression coefficients, too. Results of the investigation suggest, that the reaction of the regional precipitation is not unequivocal even in its sign along the upper-Danube region. For an expected 0.5 K warming the local order of changes, in either direction, are mainly percents, or tens of percents of the total amount. In two other periods with monotonous global tendencies, it is also demonstrated that the regression between local precipitation and hemispherical temperature are not invariant to the selected period. This fact points at the difficulty to extrapolate any past statistical relation to the future.
Key words: precipitation - climate change - regression - cluster analysis.

Niederschlagscenarien für das Ober-Donau Einzugsgebiet

Zusammenfassung: Die Methode der instrumentalen Variablen ist verwendet um den linearen Koeffizient zwischen dem regionalen Regenfall und der hemisphärischen Mitteltemperatur in der Periode 1974-1998 zu schätzen, der einen startken Erwärmungstrend (0.26 K/Jahrzehnt) zeigt. Die Serie der hemisphärischen Mitteltemperatur (Jones 1994 und aktualisierte Angaben) ist für die unabhängigen Variablen der Regression verwendet. Für abhängige Variablen sind beobachtete Niederschlag-Angaben an 76 Stationen des Ober-Donau Sub-Einzugsgebiet in sechs Ländern (Deutschland, Österreich, Rumänien, Slowak Republik, Tschech Republik und Ungarn) verwendet. Die Zahlenreihe der konsekutiven Jahren ist in den geprüften 25 Jahren für instrumentalen Variablen definiert, die dem Kriterium der instrumentalen Variablen entsprechen: non-zero Korrelation zu der unabhängigen Variable (r=0.825), keine Korrelation zu ihren Fehlern und dieselbe zum Residuum der abhängigen Variablen. Die Outlier der lokalen Niederschlag-Angaben sind durch Cluster-Analyse identifiziert. Diese auf inter-jähriche Niederschlag-Varietät basierte Methode ist auch verwendet um 9 Regionen in der Ober-Donau Region zu identifizieren, die klare in-cluster Ähnlichkeit der Regression-Koeffizienten zeigen. Die Erfolge der Prüfung versinnlichen, daß die Reaktion des regionalen Niederschlages dem Ober-Donau Becken entlang nicht einmal in Vorzeichen eindeutig ist. Für eine erwartete 0.5 K Erwärmung ist der Veränderungsorder in jeder Direktion hauptsächlich Prozent oder zehne von Prozenten des gesamten Betrages. In zwei anderen Perioden mit monotonen globalen Tendenzen ist es auch demonstriert, daß die Regression zwischen dem lokalen Niederschlag und der hemisphärischen Temperatur nicht unvariant zu der gewählten Period ist. Diese Tatsache zeigt wie schwierig es ist irgendwelche statistische Relation der Vergangenheit zu der Zukunft zu extrapolieren.

Schlüsselworte: Niederschlag - Klimaänderungen - Regression - cluster-Analyse.

1 Introduction

Water resources of Hungary are dominated by transit flow coming from the neighbouring mountainous regions (95-97 per cent of total flow). The region is very sensitive to floods of the 46 large and medium size of streams arriving to the territory. This corresponds also to long-term changes considered to be, at least partly, related to global climate changes. Hydrological scenarios, therefore, can not be complete without estimation of regional climate changes in the distant up-stream regions of the Upper Danube watershed.

At present no broadly acknowledged approach to downscale the global (hemispherical) changes exist. Besides the more complicated methods of downscaling based on diurnal circulation patterns (e.g. Bardossy and Plate, 1992, Bartholy et al., 1995), more simple regression estimations between local and hemispherical variables were also recommended (Mika, 1998). This latter method, however, requires time series of 100 years, or so. For large watershed regions, especially with mountainous influence such long series exist just in a minority of stations. Hence, a new approach to scenario construction is introduced and illustrated in the present study.

2 Method of instrumental variables

One of the possible way to estimate regression coefficient b of the linear stochastic connection, $Y = Y_0 + bX$, is the so called method of instrumental variables, first applied by Groisman, Vinnikov and their co-authors (abstracted by Vinnikov, 1986) in climatology. This method (Fomby, et al., 1984, White, 1984, Körösi et al., 1990) is suggested when we expect correlation between observed values of the independent variable and residuals of the dependent one. In this case the traditional estimates of b may be inconsistent.

The criteria for an instrumental variable are:

- surely non-zero correlation with observed values of the independent variable,
- no correlation with the errors of the independent variable,
- no correlation with the residuals of the regression in the dependent variable.

In case of an instrumental variable ,Z, the linear regression coefficient of the connection should be estimated as the proportion of appropriate covariances:

$$b = \frac{\mathrm{cov}\,(Y,Z)}{\mathrm{cov}\,(X,Z)} .$$

For independent variables, X, we selected series of hemispherical mean temperature (Jones, 1994 and updated). In our approach, the instrumental variable is the sequence of years from the 25 years long warming-up period sufficiently covered by precipitation data in the region of interest. The period, itself, was selected by searching highly significant non-zero correlation with the sequence of time in the hemispherical mean temperature series. Regression and correlation estimates of the basic 1974-1998 period and also of two other ones, selected for comparison (see Section 5), are presented in Table 1.

The applied method allows an undistorted point-wise estimation of the regression coefficient. However, it is rather difficult to establish significance criteria for these point-wise estimations, which is a disadvantage, compared to classical regression estimations requiring longer time series. (In this paper, we did not try to estimate these confidence limits.)

The need for most complex approach to the regression estimation was already demonstrated by Mika (1994) on a shorter, 15 years period, as the proportion of significant regression coefficients were rather low in the selected countries of Central Europe. The same was experienced for the present data set, too. From among the 76 regression coefficients between

annual precipitation totals and the hemispherical mean temperature we found only 19 ones (25 %) to be significant at the 95 % level in the 1974-1998 period.

Table 1 Hemispherical temperature tendencies and their estimated correlation in the basic, 1974-1998 period and in two others found for comparison.

Period	dT/dt (K/10 years) regression coefficient	r (T,t) correlation coefficient
Basic period: 1974-1998 (warming-up)	+0.261 ± 0.004	+0.825
Control (Hungary only): 1916-40 (warming-up)	+0.189 ± 0.003	+0.796
Control (Hungary only): 1957-76 (cooling-down)	-0.161 ± 0.004	-0.715

The new approach, developed due to the lack of very long series, is a combination of that applied by Vinnikov and his co-workers (overview by Vinnikov, 1986) and that suggested by van Loon (1976). The former is the application of instrumental variables in estimating regression coefficients of linear connections between hemispheric and regional variables. The latter analyses the geographical distributions of local trends in appropriate 30 years' periods from the past series when the global variables exhibit definite trends.

3 The regional precipitation database

3.1 The Selected region and stations

The local database for further analysis consists of monthly precipitation values from hydrological and meteorological stations, participating in the international data exchange for the basic period, 1974-1998, with complete, or nearly complete in the Upper Danube Watershed. Missing data were substituted by considering spatial correlation. The area covers corresponding parts of six countries, i.e. Germany, Austria, the Czech Republic, Slovak Republic, Hungary and Romania.

3.2 Regionalisation by cluster-analysis

Cluster analysis was employed for indication of outliers (data errors) and also for grouping of the inter-annual variability of precipitation into regions, that were further used for interpretation of regression estimations. More specifically, hierarchical joining based on Euclidean distance (i.e. between precipitation values) was used. The amalgamation was performed by Ward's method (Ward, 1963), which uses an analysis of variance approach to evaluate the distances between clusters. We used the STATISTICA™ for Windows (5.0) software for these computations.

The winter and summer half-year's results (7 and 9 sub-regions, respectively) were further specified into 11 sub-regions by keeping the most frequent semi-annual combinations separated. These sub-regions are fairly regularly situated in the map of the region, with exclusion of two pairs of regions (C+D and B+E) members of which are sporadically mixed in the vertically uneven parts of the West-Alpine and East-Carpathian regions. These two regions are unified in the followings.

4 Results

Computation of regression coefficients is performed in 12, 6, 4, 3 (2 versions), 2 and one monthly resolution. More exactly, the expected changes of precipitation assuming 0,5 K

hemispherical warming were computed and related to the 25 years' averages of the same resolution. So, relative changes of precipitation, expressed in percentages are computed to ensure spatial and temporal comparisons.

The nine regions, obtained by cluster analysis of inter-annual variability of the precipitation series, exhibit similar signs of regression, i.e. at the decade time scales, too. Proportion of non-identical signs is far less than without the preliminary clustering . signs (background curves).

With some rare exclusions, the background variable (i.e. the random selection or regression sign without preliminary clustering) is equal to the proportion of positive regression coefficients. These exclusions, where negative coefficients are indicated (i.e. the positive ones are in majority) are: autumn (September-November), bi-monthly averages, March-April and September-October, single months, April, September and November.

Briefly assessing the spatial distribution of decreasing and increasing connections of precipitation to warming global tendencies, one can establish a generally non-linear dependence on the longitude (distance from the Atlantic ocean). Effect of elevation above the sea level and also of the direction of the hill-slopes towards the main circulation trajectories needs further statistical elaboration. The 9 regions, likely after some further amalgamation of the clusters, may be an appropriate basis for such an analysis in the future. In the narrow geographical belt no definite dependence on the latitudes can be established.

Besides the 6 and 4 monthly changes, major numbers of the annual and seasonal changes are given, below, in Table 2. The seasons are not simply periods of conventional averaging, but they are also optimal in the sense that the proportion between monthly positive and negative regression coefficients among the 76 stations is the most similar within these periods, more similar than either in the other 3-monthly groupings, or in the 6, 4 or 2-monthly ones. As Table 2 indicates, these seasonal changes are also different in the various sub-regions and, also, between the seasons, as well.

Table 2 Relative changes of annual and seasonal precipitation totals assuming 0.5 K hemispheric warming: sub-region averages, minimum and maximum coefficients (% of the 25 years average)

	Stations		Annual total	Winter	Spring	Summer	Autumn
Reg.	Linz	Average	**+16**	**-14**	**+33**	**+18**	**+23**
A	Brno	Min/max	+ 5 +34	-35 +19	+13 +59	- 2 +47	- 1 +58
Reg.	Zalau	Average	**-27**	**-26**	**-24**	**-35**	**-16**
B+E	Odorhei	Min/max	-50 - 1	-68 - 1	-40 - 4	-56 -14	-45 +26
Reg.	Klippeneck	Average	**-12**	**-27**	**-10**	**- 6**	**- 6**
C+D	Augsburg	Min/max	-21 + 5	-48 - 8	-23 +15	-23 + 6	-26 +28
Reg.	Kecskemét	Average	**- 6**	**- 4**	**-11**	**-18**	**+15**
F	Arad	Min/max	-12 + 3	-19 + 8	-36 + 9	-44 + 3	- 7 +33
Reg.	Bratislava	Average	**- 1**	**-28**	**+ 9**	**-10**	**+22**
G	Siófok	Min/max	-20 +13	-51 -16	- 8 +29	-39 +29	- 4 +42
Reg.	Holesov	Average	**- 1**	**-41**	**+16**	**+ 2**	**+ 7**
H	Chopok	Min/max	- 8 + 6	-57 -27	+6 +22	-11 +25	-9 +17
Reg.	Lienz	Average	**+10**	**-14**	**- 4**	**+ 8**	**+37**
I	Bruck.. Mur	Min/max	-10 +34	-51 + 8	-60 +32	- 8 +30	+23 +64
Reg.	Regensburg	Average	**- 2**	**-19**	**- 1**	**+ 3**	**+ 4**
J	Innsbruck	Min/max	-10 + 5	-29 - 3	-21 +13	-13 +23	- 6 +24
Reg.	Debrecen	Average	**-19**	**-30**	**- 8**	**-35**	**- 0**
K	Baia Mare	Min/max	-40 - 8	-71 - 5	-24 + 9	-73 -14	-20 +23

5 Discussion

From hydrological point of view, the correlation of local precipitation to the hemispheric mean temperature, experienced in the investigated 25 year's period together with earlier experience gained in the region (Bálint et. al, 1995 and 1996); Hlavčova et al. (1999) indicate, that...

1. Expected changes over the Upper and Central Danube catchments can be significantly different;

2. A slight tendency to decrease is observed moving eastwards and also from higher elevations to lower ones;

3. Cold season decrease of precipitation might be compensated by temperature rise and consequently with shifting of spring thaw to earlier periods;

4. Great cautiousness has to be applied at deriving conclusions regarding extreme values especially flood events. Also as discussed below, it is rather problematic to extrapolate these regression coefficients into the future.

Changes of local precipitation corresponding to the 0.5 K hemispherical warming are of mostly similar sign, but rather variable in their absolute (percentage) value. One of the reason for this is the probably wide (and un-quantified in the present study) confidence interval remained after the relatively short period of regression estimation, 25 years.

Another reason might be if regional anomalies are governed by more hemispherical parameters and these "hidden" variables dominate upon the hemispheric mean temperature. One of these parameters is likely the continent-ocean contrast (Mika, 1998), this variable, however, does not exhibit monotonous trends in the 1974-1998 period.

An even more questionable moment of the applied methodology is that, since we do not know the physical background of the correlation between local precipitation and global (hemispherical) temperature, we can not be sure that in another warming period the connection, i.e. the estimated regression coefficient, remain the same as in the 1974-1998 period. Since the authors have longer series only for Hungary, Table 3 demonstrates point-wise regression estimations for two control periods previously specified in Table 1. As indicated in Table 3, regression coefficients are very rarely of the same sign in the two half-years (positive coefficient in the 1957-1976 period means decreasing precipitation).

Table 3 Precipitation changes for 0.5 K warming estimated from different periods (mm/half-year)

Stations	Winter half-year (October-March)			Summer half-year (April-Sept.)		
	Basic period (1974-98)	Warming control (1916-40)	Cooling control (1957-76)	Basic period (1974-98)	Warming control (1916-40)	Cooling control (1957-76)
Mosonmagy.	*- 41*	+ 19	+ 13	+ 81	+ 94	+ 65
Sopron	+ 14	*- 5*	+100	+113	+ 11	+147
Szombathely	- 27	+ 52	+ 11	+ 39	+ 75	+ 82
Pécs	- 5	+ 52	+ 44	+ 29	+ 8	*-162*
Budapest	- 80	+ 30	+ 30	*- 8*	+141	*- 72*
Miskolc	- 77	+ 32	+ 8	*- 19*	+126	*- 91*
Nyíregyháza	*- 15*	*- 14*	+102	+ 5	+118	*- 54*
Debrecen	*- 48*	*- 60*	+ 78	*- 77*	+ 75	*-242*
Kecskemét	+ 2	+ 20	+ 71	*- 36*	+ 68	*-246*
Szeged	+ 15	+ 45	+ 92	*- 43*	+ 94	*-230*

Physics of precipitation is rather complicated, here we mention just two possible effects that could cause differences of the coefficients: global warming or cooling could modify the circulation patterns, whereas concentrations of sulphate (and other water-soluble) aerosols, as condensation nuclei, could, even locally, modify vertical distribution of water content in the cloud systems. These two factors were differently related to global temperature trends in the above mentioned periods. Quantification of their role in precipitation changes requires further investigation, including mezo-scale dynamical modelling.

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Regional co-operation of the Danube Countries in hydrology in the frame of the IHP UNESCO (information of the co-ordinating country)

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Abstract: A paper is giving an overview about the present state of the art in the regional international co-operation in frame of the so-called IHP UNESCO "Danube Working Group" (DWG). This is a group of institutions, organisations and experts delegated for the mutual research activities by National Committees of IHP UNESCO in Danubian Countries. Co-ordination is circulating down the river, now in the second do-loop, for the period of 1999 – 2002, the Slovak Republic is in charge for the co-ordination duties.

The main aim of the present period is to assess the new, second, improved and enlarged edition of the Hydrological Balance of the Danube River. A set of partial problems has already been solved and this paper is giving a brief description of open problems in our co-operation for the nearest period.

Keywords: Hydrological balance, Danube region, IHP UNESCO, international regional co-operation, large international rivers, water management

Die regionale Zusammenarbeit der Donauländer in Hydrologie in Rahmen des IHP der UNESCO (Information des Koordinationslandes)

Zusammenfassung: Das Referat gibt einen Überblick über die heutige Situation in der regionalen internationalen Zusammenarbeit im Rahmen der so genannten „Donauarbeitsgruppe". Es repräsentiert eine Gruppe von Instituten, Organisationen und Experten, die von NK IHP UNESCO der Donauländer für diese Forschungszusammenarbeit delegiert geworden sind. Die Koordinazionspflicht ändert sich im Zyklus entlang der Donau und jetzt, in die zweite Runde, ist die Slowakische Republik für diese Aufgabe, für den Zeitraum 1999 – 2002, verantwortlich.

Das Hauptziel für diese Periode ist die Vorbereitung der neuen, zweiten, erweiterten und verbesserten Ausgabe der Hydrologische Monographie der Donau. Eine Reihe von Teilproblemen ist schön gelöst und diesen Beitrag gibt die kurze Beschreibung noch geöffneten Kooperationsfragen in dem nächstliegenden Zeitraum.

Schlüsselworte: Hydrologische Bilanz, Donauregion, IHP UNESCO, internationale regionale Zusammenarbeit, große internationale Flüsse, Wasserwirtschaft.

Introduction.

Surface of the Danube River catchment in hydrological sense represents totally 817 000 km^2 and it is today created from areal contributions of 18 countries. Part of them are so called direct riparian countries (D, A, SK, H, HR, YU, RO, BG, UA, Moldavia) and the rest (Italy, Switzerland, Czech Republic, Slovenia, Poland, Bosnia and Herzegovina, Macedonia and Albania) represents countries,

that do not have direct approach to the Danubian riverside. Water, as the main condition of life at all, is now within the IHP UNESCO Programme studied preferably from the point of view of water quantity, both as far as flood and drought are concerned. So called IHP UNESCO "Danube Working Group" (further DWG) is a group of institutions, organisations and experts delegated for the mutual research activities by the National Committees of IHP UNESCO in the Danubian Countries. Co-ordination is circulating down the river, now in the second do-loop, for the period of 1999 – 2002, the Slovak Republic is in charge for the co-ordination duties.

The economic-and political "diversity", but also variety of scientific interests in the Danube river basin, created conditions for many organisations that would like to contribute to the common scientific knowledge base and to participate on the common economical activities and profit, too.

Problems related to water itself are in the main interest of many organisations, some of them have to be unconditionally mentioned.

On the first place there is **The Danube Commission**, that is (at present) dealing with the navigation and closely related topics. Navigation is highly dependent on the water level in the Danube River and ~~the~~ joint interests with the IHP UNESCO Programme are evident. Anyway also here the IHP DWG has a possibility to improve common communication and exchange of information and data.

From the point of view of nowadays-environmental importance the first is the **International Commission for the Protection of the Danube River** (further "ICPDR"), that starts a real life after being officially created and after creating the joint Permanent Secretariat in Vienna within the UNO International Center. The ***"Danube River Protection Convention"*** defines in the Article 1 the ***"Danubian States"*** as states sharing at least 2,000 km^2 of the hydrological catchment area. It is evident, that this definition does not cover all ~~the~~ Danubian countries in the total Danube Catchment area in hydrological sense.

Similar commissions are already working in Europe, the "International Commission for the Protection of the Rhine River" seems to be in Europe the best organised one and conceptually dealing on a long-term basis both with the water quality and water quantity. Something like the "Action Plan on Flood Defence" (http://www.iksr.org/icpr/11uk.htm) is in the Danube river basin missing not only at the international level agreed by the EU, but in some countries the improved national flood protection plans are under development only now. Also the economic situation in the Rhine river basin and in the Danube river basin seems to be different.

While speaking about the latest period after 1989 and the international support for the Danubian countries in the restructuring period, an inventorying the "young socialist heritage" in the environment, performed with the PHARE support under the title the "Environmental Programme for the Danube River Basin" played unsubstitutable role. Also the TACIS programme, which is oriented on the new independent states (NIS) that emerged mainly from the previous parts of the USSR, is significantly contributing to the improvement of the environmental and water management situation in the Danube region, too.

There are, of course, further organisations within the UN structure as WMO, WHO, UNDP, UNEP (incl. GEF http://www.gefweb.org/INDEX.HTM) and others, which are dealing seriously with problems, related to water. Each such organisation has its own area of interest and from the point of view of water quantity and "engineering" water a complex solution is difficult to be found.

More and more the influence of non-governmental organisations (NGO's) is taken into account in the decision process. Here from the point of view of water itself the International Association for Danube Research (IAD), oriented on limnology, water protection and water management, has an interesting position. Significant role is played here also by organisations, that have larger geographical extend than the Danube basin only. Here has to be mentioned the WWF-World Wide Fund http://www.panda.org/ and Greenpeace http://www.greenpeace.org/, both organisations enter

the water management area, but sometimes, according to my feeling, not informed enough. An interesting list of NGO's can be seen at http://www.unep.org/unep/gef/ngo.htm. Additionally to the mentioned list it is necessary to name REC Budapest, IAP2, IWRA and IAHS (see also [12 – 14]).

In a multinational, politically and economically not easy situation of the Danube Region the role of the IHP Danube Working Group is (among others) the scientific support of the knowledge base for all the – to the water quantity and engineering water problems related – economic activities.

About our IHP UNESCO Danube Working Group.

The regional co-operation in hydrology started officially by the suggestion issued by the Yugoslav National Committee for the International Hydrological Decade (IHD) in 1970/71 to elaborate a comprehensive hydrological monograph of the Danube drainage basin.

Simultaneously also the work of the Working Group for Scientific Hydrology at the Danube Commission had started. Work was finalised after 15 years, maps were published in Hungary, working version of full text in German was published in Munich [1], in Russian in St. Petersburg, and the "representative" publication in 4 languages in Bratislava in 1988 [2].

The aim of the publication was to give a general view of basic information useful also for navigation, flood control, water supply, waterpower utilisation, water pollution control, and other water resources development activities.

Scientific aspects of obtained results and summary of remaining water balance assessment problems were discussed by Domokos [3].

The common interest and also the practical requirements created a base for continuation of the co-operation. The "umbrella" of the International Hydrological Programme (IHP) UNESCO was in this time probably the only possibility of co-operation at the so-called governmental level in the politically divided Europe. UNESCO is the organisation within the UN system and it was taken as the top official international joint scientific base for showing the good will in the co-operation of scientists from the two political systems. Thanks to this the „Danube Working Group" (further „DWG") was created and the first regular „Working Group Meeting" (further „WGM") in Budapest (1987) opened the second phase of co-operation.

The tasks of the third phase are practically finished. It was decided to work on specific scientific topics dealing with the hydrology in the Danube catchment area and since that time six follow-up volumes were published [4 – 9].

The fourth phase of the co-operation started in 1999 under the co-ordination of the Slovak National Committee for IHP UNESCO, all the practical work related to these duties is to be done by the Water Research Institute Bratislava.

The most actual topic in the processing today is the second, updated and enlarged edition of the Danube Monograph. Mapping the balance elements has to be based on the data sets from the period of 1951 - 1980 with the hydrometeorological conditions, that (lets hope) before 1980 are not significantly influenced by the climate change. The aim of the mutual work is to create a new base for evaluation of water balance, available water in the watershed. Expected results should create a starting point for future mutual evaluation of possible climate change warming in the Danube Region, due to which some reservoirs in the down part of the river can't for a longer time reach the operational standard water level.

The present socio-economic situation within the Danube region creates probably more complicated conditions for real co-operation than in past, due to the countries in economic restructuring stage problems. There exists a good will, presented in signed "Principles of mutual co-operation" but there is a serious lack of financial sources for research work and contribution to the mutual projects.

According to the principles of co-operation, mutual work is organised at the project level. Each project, agreed as a project of the common interest, is based on the contribution (data, country report, schemes and graphs) from each participating country, work done within the countries is (*has to be*) paid from the budget of a participating country.

The international co-operation is negotiated, checked, verified and finalised on the representatives and delegated experts meetings (WGM), usually at least once a year.

From the year 1987, when the new co-operation started in Budapest, the ordinary WGMs were organised in Vienna (1988 and partially in 1994 and 1995, shared with Slovakia), Sofia (1989 and 1998), Kiev (1990), Straubing (1991), Kelheim (1992), Tulcea (1993), Malé Vozokany (partially in 1994, shared with Austria), Eckartsau (partially in 1995, shared with Slovakia), Smolenice (partially in 1995, shared with Austria), Lednice (1996), Budapest (1987, 1998), Bratislava (1999) and finally Postojna (2000). Summarising, Austria and Slovakia were involved three times, Germany, Hungary and Bulgaria twice, and Czech Republic, Romania, Slovenia and Ukraine organised one WGM.

The present stage has been since 1989 significantly marked, as like as also the other areas of scientific research in the CEE region, by a serious lack of available financial sources and mutual work became here more and more slow~~ly~~ and more and more difficult.

The seriously positive support for our common activities has been since that time organised by the National Committee for IHP UNESCO / OHP WMO in Germany and by the Austrian Committee for IHP UNESCO. They have used practically on the voluntary level to cover nearly full cost of the Danube Working Group Meetings for limited amount of participants from former socialist countries. In the latest time a new patron of science, “Maecenas”, enters the scene - it is the UVO - ROSTE (UNESCO Venice Office for Science and Technology for Europe) in Venice. This office has an ability and we are with gratitude using these possibilities to support finalisation of the common research projects and support for our publication. The practical output from this support is printing of our follow-up volumes [6, 8, 9]. I am sure, that also this Conference here is a proper place, where I can on behalf of all the IHP Danube Region representatives and experts express our thanks for this kind assistance.

The present tasks and problems.

It is expected, that six further reports summarising the common projects will be ready for publication very soon:

- Long-term fluctuations of precipitation in the Danube basin (project 3),
- Inventory of main hydrotechnical structures in the Danube River basin (project 5.1),
- Update of the water (runoff) regime analysis (project 5.2),
- Regionalisation of the annual maximum runoff in the Danube river basin (project 7),
- Hydrological bibliography related to the Danube basin (project 8.1), which to the time of the XXth Danube Conference should be available via the main page of the Bundesanstalt für Gewässerkunde Koblenz – Berlin: http://www.bafg.de/welcome.htm
- Basin coding and numbering for the Danube basin (project 8.2)

It has already been mentioned above that the most important and most complicated task within our IHP-Danubian Working Group activity is the assembling of the new hydrological balance for the whole Danube catchment area (project 5.3), which will use also results obtained by projects 3 and 5.2. We are still in the phase of finalising of the data collection. From the scientific point of view the present situation is supported by the recommendation of WMO at the top level, that

meteorological and hydrological data for the mutual work at the international level have to be prepared free of charge. Nevertheless part of data banks in the environmental area seems to be privatised and data collection phase became complicated just due to the need to key-in data sets, that already somewhere exist~~s~~ in computerised data banks, from printed yearbooks again. Further there is also a significant difference in task processing.

Within the first edition each country prepared maps of precipitation, runoff and actual evapotranspiration within their country contribution. The role of co-ordinator in a mapping part of the Monograph was just to collect all input maps, to bind isolines in the states boundary areas and solve some problems related to mapping theory itself. Now the co-ordinator has to process everything just on the base of obtained point observations of main hydrometeorological stations. Any sub-regionalisation for quasihomogeneous areas (where e.g. evapotranspiration – elevation relation seems to be "uniform"), requested from participating countries is still missing. More details are presented at the poster, text and graphs of which are not included into this CD proceedings.

Last but not least and not only for assembling the water balance elements maps there is a set of topics, which should be solved using the up-to-date methods and which represent a general problem.

This shared need can be formulated as the commonly agreed base map for presentation of results in a (digital) map structure, it means in the geographical information system (GIS) technology. Such project could under certain conditions represent a general interest not only within the IHP-DWG.

The present situation is, that according to the flood study just few centimetres can decide, where the first water is going to flow over the flood dikes, but till now in the Danube River basin we have been using different co-ordinating systems and different see level base. This is in detail the "hot potato" problem especially on cross-border areas. It means, that on different river sides of the same river can be the official sea elevation of the same top of dike different in maps of both on the boundary lying states. Prediction of flood risk and mapping of risky inundation regions belongs today to the most urgent needs formulated not only by the local authorities, but also from the level of the public safety system.

In the macroscale we do not have hydrologically rectified digital elevation model of the Danube region, that can be used with the feeling that we know, what we are using. For hydrological modelling of spatial distribution of temperature, potential evapotranspiration and areal precipitation the USGS HYDRO1K DEM is probably good enough. But when we are looking for details, also here it is possible to find some discrepancies (digital version of this map in *.tif or *.jpg format is available on request from the co-ordinating country). There exists ~~an~~ information at the level of the information noise that an excellent map is in hands of NATO. We could only hope that sometimes a simplified version of this map would be available for the public sector and hydrological and hydraulic modelling at the basin level.

Water divides have been till now prepared and given for disposal by Germany, the Czech Republic, Albania and partially by Slovakia.

The future orientation of our co-operation

In the nearest future it seems to be reasonable first to finalise ongoing projects.

For further co-operation it is necessary to strongly keep rules given in Principles of co-operation, where paragraph 4 is describing the elaboration of the implementation approach. In Principles of co-operation it is not explicitly stated who has to bear cost of work, that has to be done.

Similarly to the paragraph 8 it can be implicitly supposed, that this is also a duty of particular participating country for each project, where this country promised its participation. This is at present time also a kind of the boundary condition for new project proposals approving.

There exist some new project proposals, which were not generally agreed within the Danube region. To this set of open questions it seems to be necessary to order such proposals as

- The idea to enlarge the project on Climate Change in the Danube Delta to the whole Danube River basin.
- Austria has prepared the proposal to deal with the "Seasonal Water Balance of the Danube River Basin"
- Hungary is preparing a proposal of the project: Stability of the runoff regime in the Danube Catchment.
- Slovenia proposed to discuss part of the VI phase of IHP - project HELP (Hydrology for Environment, Life and Policy) in time of the XXth Danube Conference (this one) meeting.
- Ukraine proposed to launch a project "The flood regime of rivers in the Danube river basin"
- There is continuing growing - but not generally accepted - support to the idea to launch within the Danube river basin the FRIEND DANUBE PROJECT. This was recommended by the central IHP UNESCO office in Paris and by a supporting E-mail distributed by Austria.

In the broader sense we have a chance to create contacts with official structures, where the most effective, according to our feeling, will be the ICPDR. Practically all our topics are included in the Convention, the possible difficulties could be in the shared responsibility for water and water management in CEE countries and from that resulting different interest of particular decision sphere in setting up priorities in the internationally supported projects. Here it seems to be useful to continue with approaching this formal governmental level top management in the Danube River Basin.

The most optional (till now not successfully realised) case seems to be some type of cost sharing with the international structure also of other origin. Here we recommend to continue ~~with~~ preparing projects proposals in frame of the European Union 5th Framework programme in RTD and creating contacts with different global and European organisations also in the NGO area (e.g. GPW).

Last but not least we have to mention the UNESCO recommendation, that is not only explicitly stated in the VI-Phase IHP proposals, but also formulated by the 2nd World Water Forum, where UNESCO and WMO http://www.worldwaterforum.org/ played a significant role in the Forum organisation and realisation. The http://www.worldwaterforum.org/Ministerial/declaration.html parallel World Ministerial Conference agreed a declaration as a recommendation for the beginning of the 21st Century. It looks like that also in the Danube River Basin we will face a significant river scarcity, what was presented there also by Kindler and Szomlyódy [14].

Conclusions

The Danube River basin is a nice large natural area worth to be dealt with from many points of view. The Conference here creates an opportunity to gain more information, more contacts and discuss chances to have better co-ordination and higher complexity of tasks, which all of us are dealing with.

From the point of view of hydrology and/or water quantity and engineering water, the scientific tasks and solved problems have also reached the level of needed international co-operation. Maybe

in a near future we also (like it is already in the Rhine River basin) will feel a need of the international level of flood protection programme and mutual water management.

With respect to the economic situation in the Danube River basin it seems to be very useful to create more close contacts (http://www.cordis.lu/eesd/calls/calls.htm) for the 5th framework programme of the EU. Due to the present organization of the EU's project administration, the participation of Austria and/or Germany seems to be very important. When we are speaking about the whole area, the umbrella for the fully mutual project is here to be discussed, as well. Today they are here in the area four groups of states: EU member states, non-member states of the EU (e.g. Switzerland also), associated countries and non-associated countries, the latest are included (among other) into the TACIS program. A significant number of the Danube countries are now associated with the EU and are waiting for the admission to the common European authority structures. It would be highly welcomed to have a chance to simplify the process of the EU's RTD Danubian projects preparation and acceptation. The environmental water component is the challenge to work in very close co-operation and help to contribute to the sustainability of the common world and life in a changing climate.

Let's keep in mind The Hague' Meeting slogan: "Water is everybody's business"!

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b) Teil 2 Tabellen - Таблицы

c) Teil 3 Karten - Карты

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Long-Term Runoff Analysis of Slovak Rivers

Pavla Pekárová, Ján Pekár

Abstract: In the paper two statistical methods of long-term runoff prediction are presented: classical time series analysis and stochastic Box-Jenkins models. To the analysis 98-yearly data series (1901-1998) of four rivers (the Danube at Bratislava, the Váh at Trnovec, the Morava at Moravský Ján, and the Bodrog at Streda n. Bodrogom) were used. All, the stationarity, homogeneity, trend, and periodicity of monthly and annual discharge series were studied. In every considered river the significant 3.7-years period was found. This period is manifested by substantial changes in runoff regime on a seven-year basis (seven dry years followed by seven wet ones). The wet periods were: 1912–1916; 1926–1927; 1939–1943; 1966–1970; 1978–1982, as well as the years 1996-1998. Using spectral analysis, periods of 2.4-; 4.2-; 5-; 7-; 14-; 21 and 28- years were identified. To illustrate the results of the modelling, the seasonal integrated mixed model ARIMA (P,D,Q) $x(p,d,q)_L$ was applied.

Key words: hydrology, statistic, long-term forecasting of discharge

Langfristige Analyse der Abflüsse slowakischer Flüsse

Zusammenfassung: In dem Artikel werden zwei statistische Methoden der langfristigen Vorhersage des Abflusses präsentiert: Die klassische Analyse der Zeitreihen und das stochastische Box-Jenkins Modell. Die 98-jährigen Zeitreihen (1901-1998) von vier Flüssen (Donau in Bratislava, Váh in Trnovec, Morava in Moravský Ján und Bodrog in Streda n. Bodrogom) wurden analysiert. Die Stationarität und die Homogenität, der Verlauf der Trendgeraden und die Periodizität der monatlichen und jährlichen Abflüsse wurden betrachtet: In allen Fällen wurden 3,7-jährige Perioden gefunden. Eine solche Periode deutet den Wechsel des Abflussregimes auf der 7-jährigen Basis an (sieben trockene Jahren folgen sieben nassen Jahren). Die nassen Perioden waren: 1912–1916; 1926–1927; 1939–1943; 1966–1970; 1978–1982. Mittels einer spektralen Analyse wurden diese Perioden (2.4-; 4.2-; 5-; 7-; 14-; 21- und 28- Jahre) identifiziert. Im Beitrag werden die Ergebnisse des saisonmässigen gemischten ARIMA (P,D,Q) $x(p,d,q)_L$ Modells präsentiert.

Schlüsselwörter: Hydrologie, Statistik, langfristige Vorhersage der Abflüsse

1 Introduction

While studying the impact of climatic changes on the hydrological regime in the basin, the forecast or at least an estimate of runoff for some future decades (e.g. for water works operating time) seems to be the main problem. A significant runoff decrease was recorded in Slovak rivers during 1980-1995 (Majerčáková and Šedík, 1994). Nowadays, hydrologists are interested above all in looking for solutions to this problem. They ask whether the runoff decrease is caused by climate change or if it follows from natural runoff oscillation.

In the 60's, several Czechoslovak hydrologists analysed the development of climatic and hydrological phenomena, e.g. Křivský (1957), Bratránek (1964), Švec (1962), Balek (1968). More recently runoff variation has been studies by Klige at al., (1989), Bradley (1994), Brázdil (1994), Lapin at al., (1994), Bucha and Charvátová (1996), Hladný (1997), Kuznetsova et al., (1997), Miklánek (1997), Lukjanetz and Sosedko (1998). On the basis of their results we can assume that a natural 220 year climate oscillation occurs and is strengthened by some long- and short-periodic cycles (e.g. about 28, 14, 7, and 3.6 year cycles).

This paper deals with a statistical analysis of cyclicity and trends in discharge time series of some selected rivers and with a stochastic forecast of their flows for the next years.

2 Methods

During the 1990´s rapid progress in long-term time series modelling has been symptomatic. The progress was enabled due to the development of several stochastic models of the hydrological time series that use random sampling method (the Monte Carlo method), classical time series analysis, or Box-Jenkins methodology.

2.1 Methods of classical time series analysis

Spectral analysis enables deeper study of the inner structure of stochastic processes. The considered time series $\{x_i\}_{i=1}^{n}$ is assumed to be a sum of sine and cosine curves with different amplitudes and frequencies. Using special statistical tools (e.g. periodogram, spectral density), significant frequencies λj that cause the main variance of the series can be determined. By this method information on how the time series oscillates in time is gained. Periods of T (T=2π/λj) for which x(t) ≈ x(t+T) are found. To predict the discharge a stochastic process model of the following form is used:

$$E(x_t) = A_0 + \sum_{j=1}^{m}\left(A_j \cos\lambda_j t + B_j \sin\lambda_j t\right). \qquad (1)$$

Here, the parameter A_0 was estimated by the arithmetic average of the series $\bar{x}$. Next, the empirical series $\{x_i\}$ is centred to the series $\{x_i'\}$, xi´ = x_i - $\bar{x}$, with zero mean. The parameters A_j, B_j, j = 1,2, … m, were estimated by the following formulae:

$$A_j = \frac{2}{n}\sum_{t=1}^{n} x_t.\cos(\lambda_j.t), \qquad B_j = \frac{2}{n}\sum_{t=1}^{n} x_t.\sin(\lambda_j.t). \qquad (2)$$

A simple stochastic process prediction was obtained by the formula

$$x_{n+z} = \bar{x} + \sum_{k=1}^{m}\left(A_k.\cos\lambda_k(n+z) + B_k.\sin\lambda_k(n+z)\right). \qquad (3)$$

Interpreting this prediction it is necessary to realise that it only predicts the mean of the process while the real process is influenced by random errors.

2.2 The Box-Jenkins methodology

The Box - Jenkins models (AR, MA, ARMA, PARIMA) represent reasonable tools to describe the periodic time series with essential stochastic behaviour. They are highly flexible and can stochastically model both, the seasonality and trends, performing better than classical time series analysis. The basic component of these models is an independently and normally distributed random variable Et. The general form of the PARIMA(p,d,q) x(P,D,Q)L model takes the form:

φ (B) φ(BL)∇d ∇DL Yt = Θ(B)Θ(BL)Et, (4)

where: Et - independently and normally distributed random variable
with zero mean □=0 and variance σE2,
Θ - the regular MA operator of order q;
φ - the regular AR operator of order p;
φ - the regular PAR operator of order P;
Θ - the regular PMA operator of order Q;
∇d - the backwards difference operator;
∇DL - the periodical backwards difference operator;
B - the reversion shift operator defined as BYt = Yt-1.

The PARIMA model identification

To identify this model, it is necessary to analyse the particular components of the time series as follows:

1. Identification of the trend (differentiating of order d) and the periodicity (periodical differentiating of order D).
2. Selection of model type (AR, MA, ARMA) and model order determination.
3. Estimation of model parameters.
4. Model verification.

3 Results of statistical analysis of the discharge series

Yearly discharge time series (1901–1998) of five rivers were analysed. Basic hydrological characteristics of considered rivers are given in Table 1.

Table 1 Basic hydrological characteristics

River	Station	Area [km^2]	Q_a (1901-1998) [m^{3}s^{-1}]	q_a [l.s^{-1}km^3]	c_s	c_v
Danube	Bratislava	131 329	2022	15.4	0.29	0.16
Morava	Moravský Ján	24 129	110	4.6	0.80	0.34
Bodrog	Streda n.Bodrogom	11 474	114	9.9	0.41	0.29
Váh	Šaľa	11 217	151	13.4	0.15	0.21

On Figure 1, the two-fold moving averages (7-years and then 5-years) of yearly discharges at four selected stations (and of Labe River at Dečín) are shown.

From Figure 1, a 14- year cycle consisting of about seven dry and about seven wet years is clearly visible. To determine the linear trend that is not influenced by the periodicity of the series, it is necessary to determine the trend corresponding to the period of a closed cycle starting and ending at maximum (or minimum). It is necessary to determine the hydrological characteristics (e.g. mean, trend, and variation) for a closed cycle (e.g. 1903–1931 or 1932–1959 or 1960–1987). In Table 2 the basic hydrological characteristics of these periods are given. The runoff decrease during the century follows from the values in this Table.

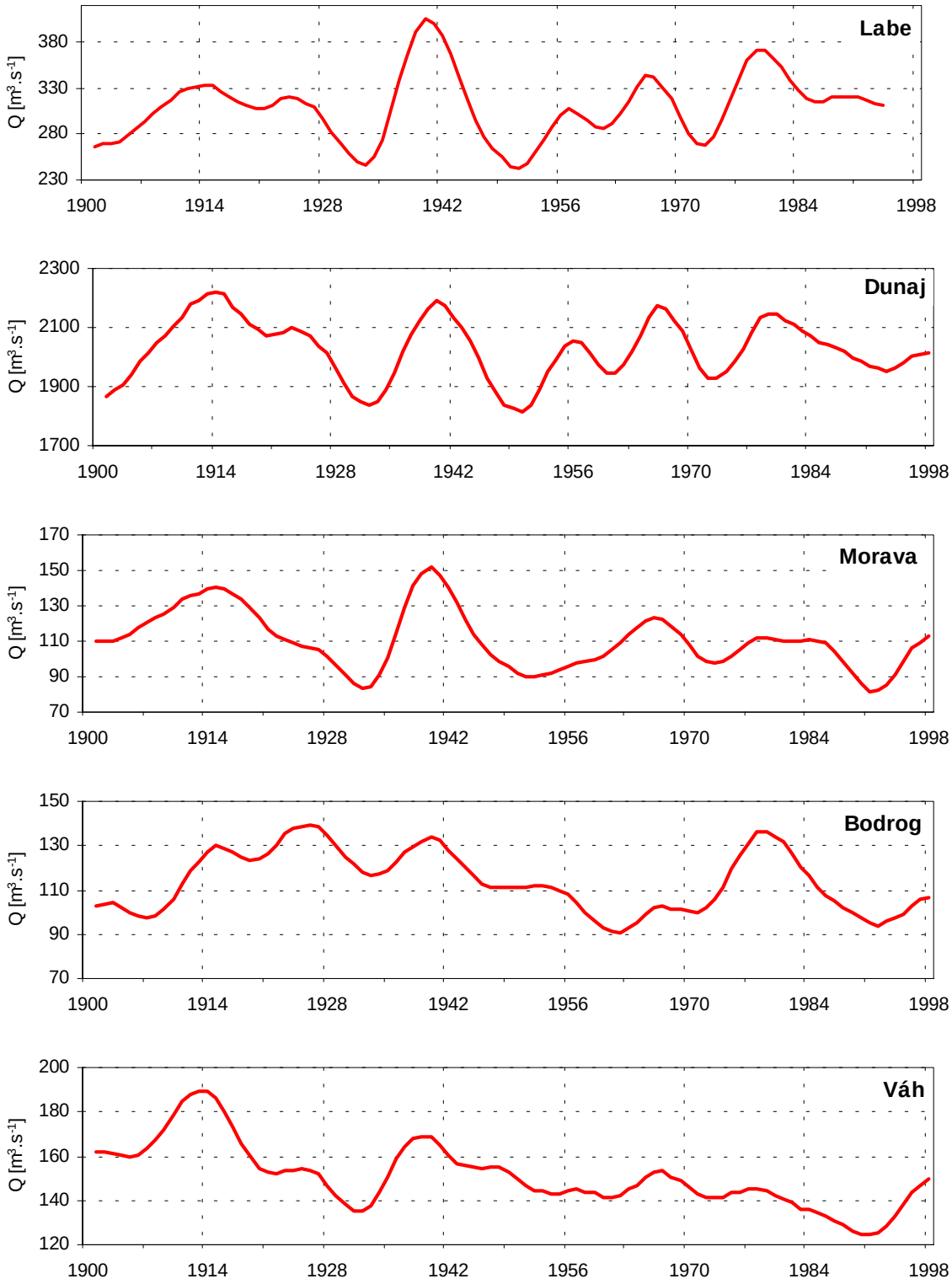


Fig. 1 Series of two-fold moving averages (7-years and then 5-years) of yearly discharges at four stations (and of Labe River at Dečín).

Table 2 Basic hydrological characteristics of Danube, Morava, Bodrog and Váh river, periods 1903–1931, 1932–1959, 1960–1987, and 1988–1998

River	Period	Q_a [m^3s^{-1}]	q_a [$l.s^{-1}km^3$]	c_s	c_v
Danube	1904-1931	2082	15.9	0.03	0.16
	1932-1959	1986	15.1	0.01	0.17
	1960-1987	2048	15.6	0.48	0.17
	1988-1998	1950	14.8	0.36	0.13
Morava	1904-1931	121	5.0	0.78	0.30
	1932-1959	106	4.4	1.11	0.41
	1960-1987	112	4.6	0.59	0.29
	1988-1998	90	3.7	0.73	0.35
Bodrog	1904-1931	121	10.5	0.25	0.31
	1932-1959	116	10.1	0.20	0.27
	1960-1987	110	9.6	0.46	0.29
	1988-1998	100	8.7	0.68	0.20
Váh	1904-1931	162	14.5	-0.40	0.19
	1932-1959	151	13.4	0.22	0.24
	1960-1987	143	12.8	0.26	0.18
	1988-1998	132	11.7	-0.95	0.17

Significant periods were searched by the periodogram method. In Figure 2, the annual discharge periodograms of the considered rivers are given. At all cross-sections, spectral analysis gives a significant 3,7 ±0,1-year period. The following periods were found as well: 2.4-; 4.2-; 5-; 7-; 14-; 21 and 28- year. This result corresponds to that of other authors such as Lukjanetz and Sosedko (1998) or Takáč (1989). On Figure 3. the empirical cumulative frequency curves of annual discharges are shown.

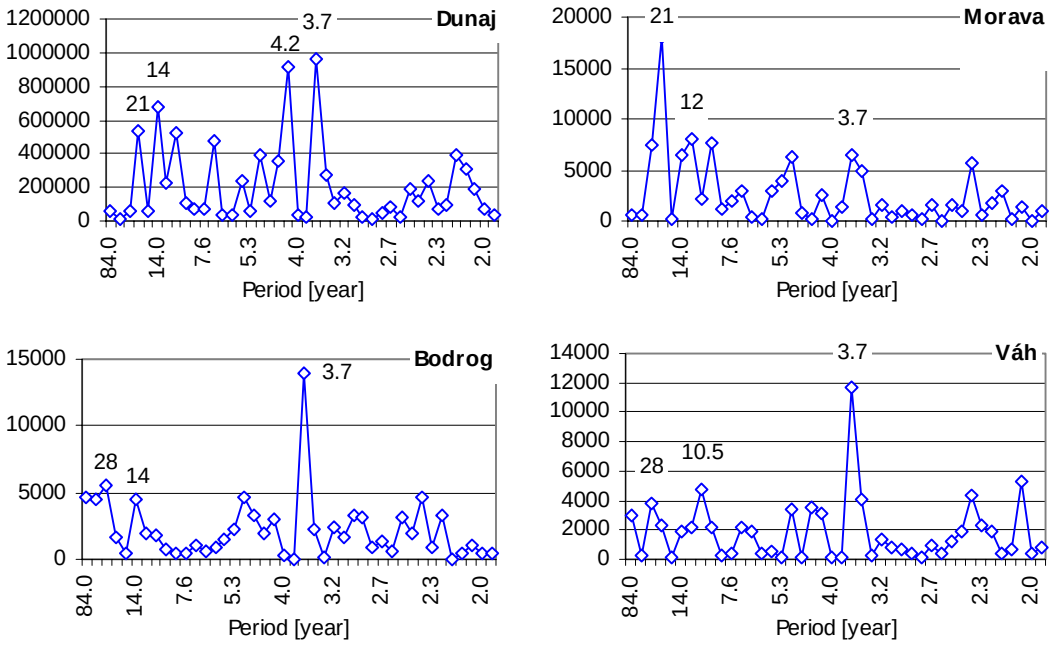
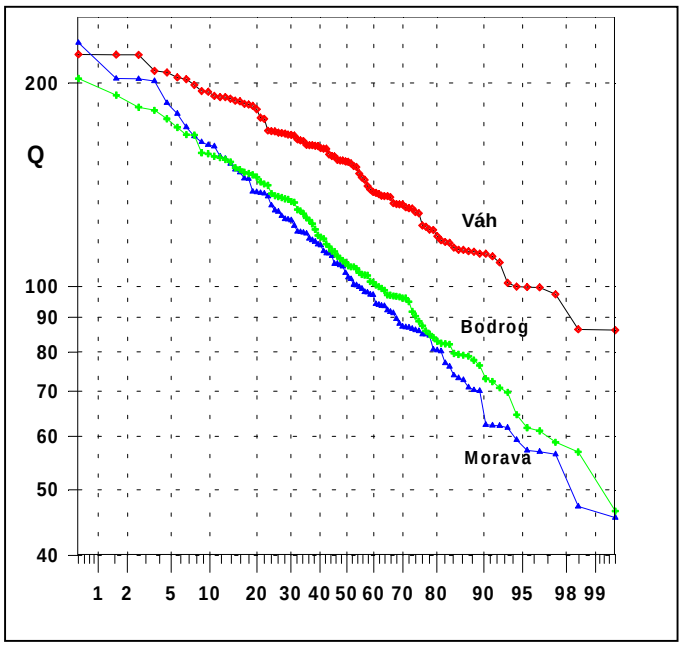


Fig. 2 Annual discharge periodograms of the Danube, Morava, Bodrog, and Váh River.



Minimum and maximum annual discharges observed during the period 1901-1998 were:

		Qa [m^3s^{-1}]	Year
Dunaj	min	1420	1934
	max	2856	1965
Morava	min	45	1933
	max	228	1941
Bodrog	min	47	1961
	max	203	1926
Váh	min	86	1921
	max	220	1937

Fig. 3 The empirical cumulative frequency curve of annual discharge.

4 Results of modelling

Formulae (3) and (4) can be used to make a long-term prediction of the mean values of annual discharge, precipitation, and temperature time series. On the basis of equations (1)-(3), a computer program for estimation of both parameters A_k and B_k and prediction of annual values of the considered time series was developed. For long-term prediction the following 84-years discharge (Q) time series were used:

1. Danube River at Bratislava (1914–1997);
2. Morava River at Moravský Ján (1914–1997);
3. Bodrog River at Streda n. Bodrogom (1914–1997);
1. Váh River at Šaľa (1914–1997).

In Figure 4, the measured annual time series and predicted discharge of two rivers for the next 20–years are presented. In Table 3 the average values of these time series for the period 1998–2017 are given. It seems that the future period 1998–2017 should be colder and wetter than the previous period 1980–1995.

Table 3 Prediction of mean values of time series for the next twenty years according to Box–Jenkins model ARIMA

Period	Danube Q [$m^3.s^{-1}$]	Morava Q [$m^3.s^{-1}$]	Bodrog Q [$m^3.s^{-1}$]	Váh Q [$m^3.s^{-1}$]
1999-2018	**1996.47**	**113.745**	**128.82**	**150.26**
1999–2003	2130.45	158.792	128.78	171.23
2004–2008	2119.71	108.97	128.28	149.17
2009–2013	1941.46	106.94	137.93	147.73
2014-2018	1794.25	80.27	120.29	132.92

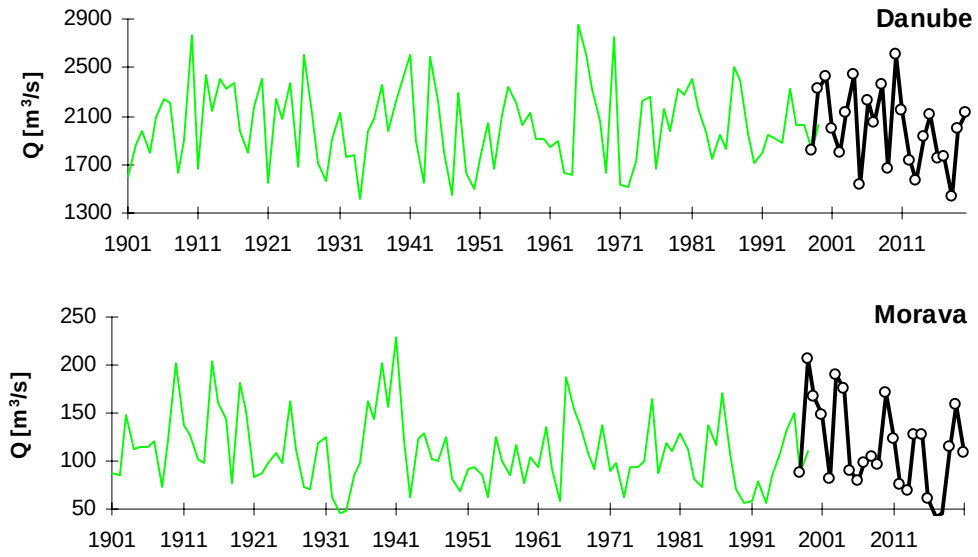


Fig. 4 Series of annual discharge for Danube and Morava rivers (line) and predicted values (bold line with points) according to ARIMA model.

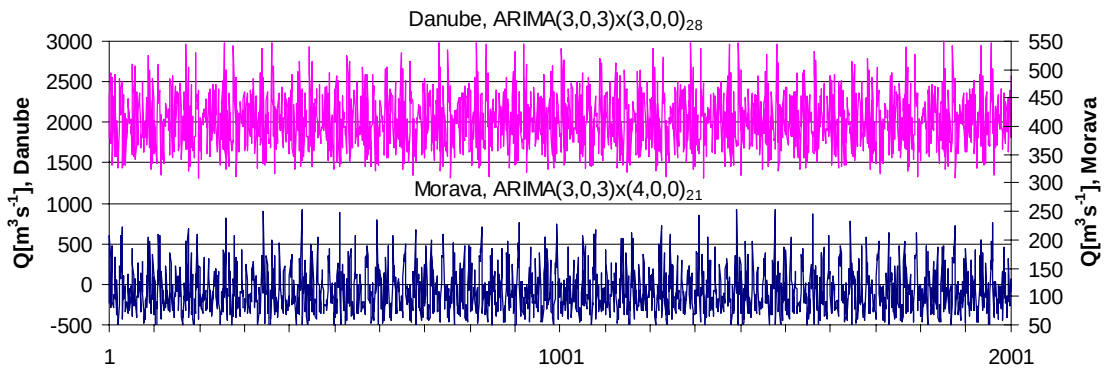


Fig. 5 Two thousand series of annual discharge for Danube and Morava rivers simulated by ARIMA model.

5 Conclusion

From analysis of the cyclicity and trend of the discharge time series the following conclusions can be drown:
At almost all Slovak stations, the discharge time series recorded during the years 1960-1995 show a decreasing trend. A significant decrease of the runoff occurred in the period 1978-1993. It was mainly caused by a natural 27-29 years discharge oscillation cycle. The discharge also decreases due to the anthropogenic influences (e.g. landscape exploitation changes, deforestation, irrigation, etc.).
Model (4) predicts a moderate increase of annual discharge for the next five years.

Acknowledgement

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New Assessment of the Water Balance in the Danube River Basin – Remarks to Methodology

Neue Wasserbilanzschätzung im den Donaueinzugsgebiet - methodologische Bemerkungen

Petrovič Pavel

Extended abstract: Evaluation of the water balance elements in the Danube river basin is a task, which started within the ongoing activities of the Regional co-operation in the Danube river basin in the IHP UNESCO frame as task 5.3 in year 1995. The aim of the study is to prepare the second enlarged and improved edition of the study that was first published in 1988. The initial state was co-ordinated by the Austrian party and the preliminary methodology was prepared in 1997.

In 1998 and 1999 the main aim was oriented on the data collection. The bad lack with the illness of the former task co-ordinator Dr. Behr caused serious difficulties in reassembling of the data collected before the end of 1998. Some data were reconstructed in Vienna and some sets of data are to be supplied by the participating Danube countries again. The present inventory of the available data can be seen at the poster.

The methodology of processing assume usage of the GIS environment for not only final presentation of study results but also as a tool for evaluation of selected balance river basins, their main characteristics and for the regional analysis of main elements of water balance evaluation.

Assembling of temperature data is nearly finished. Processing of the temperature field for the reference elevation in the Danube river basin and for the “real” terrain configuration is presented on maps at the poster. The basic approach is the recalculation of measured values in given terrain elevation to the reference level, consecutive spatial analysis using ArcView (version 3.2) with its extensions and finally recalculation of the value to the terrain pixels or elevation layers using map algebra.

Further analysis of input meteorological elements (at least the air humidity) for evapotranspiration estimation had to be postponed due to the delay in data assembling from participating countries.

Evaluation of runoff based on the runoff data in selected river profiles is in progress. The delineation of basins boundary (water dividing lines) and areas to the relevant gauging profiles has already had to be prepared by the participating countries.

Water balance in reference profiles will be estimated first using the “WatBal family” model with lumped parameters and in the second step tuned for spatial elements distribution with respect to reach as close as possible runoff in closing profile.

It is expected that the final map will be produced in the scale of 1:1M. As a base for mapping the data obtained from the participating countries (stressing the Digital Terrain Model), the state boundaries and main river net can be used in proposed scale from ESRI sources, attached as data to the ArcView (v. 3.2) package distribution.

The work plane at present seems to have all the study ready in the year 2002.

Methodology for Assessment of the Effects of a Multipurpose Reservoir on the Reduction of Floods

Stevan Prohaska, Dejan Divac, Predrag Srna

Abstract: The paper presents a methodology for assessment of the effects multipurpose reservoir on reduction of the floods. The methodology is based on the fact that exists the asynchronous of coincidence of the maximum river flow and the maximum reservoir stages. With regard to that the methodology for calculation the within-the year coincidence of the considered events has been evaluated. The paper is illustrated by a real example of assessment of effects of resercoir :Kljuc" on reduction of floods on Sumanka river in Yugoslavia.

Key words: Multipurpose reservoir, flood reduction, within-the-year coincidence, flood routing

Methode zur Abschätzung der Effekte von Mehrzweck-Stauseen auf die Minderung von Hochwasserwellen

Zusammenfassung: In diesem Beitrag wird eine Methode zur Abschätzung der Effekte von Mehrzweck-Staussen auf die Minderung von Hochwasserwellen dargestellt. Die Methode basiert auf der Tatsache, dass die maximalen Hochwasser-Abflüsse mit den maximalen Stausee-Wasserständen zeitlich nicht zusammentreffen. Darauf bezugnehmend ist eine Methode für die Ermittlung der jährlichen Koinzidenz von genannten Ereignissen entwickelt worden. Der Beitrag ist mit einem Beispiel zur Einschätzung der Effekte des "Kljuc"-Stausees auf die Hochwasser des Flusses Sumanka in Jugoslawien ergänzt.

Schlüsselworte: Mehrzweck-Stausee, Hochwasser-Verminderung, jährliche Koinzidenz, Hochwasserwellen-Transformation

1 Preliminaries

Every constructed water storage, in addition to its primary role, may retain a part of the flood wave during the time periods when it is not completely full. In that way it transforms the hydrograph shape decreasing its flood peak value downstream from the dam. The degree of the flood wave transformation, besides other factors, depends on the within-the-year coincidence of flood flows and the reservoir water level, since there is a possibility that two events do not occur at the same time.

This paper describes procedure for an assessment of the within-the-year coincidence of flood events and high water level in the reservoir. In addition it gives an estimation of the reservoir effects on the flood reduction. The boundary conditions pertaining the reservoir stage should be defined taking into consideration the degree of the within-the-year coincidence.

2 Definition of probability of the random variables

Assessment of probability that the considered events will occur simultaneously represents the prime objective. In this particular case, the following random variables are analyzed:

- The maximum water level in the reservoir within a considered time intervals;
- The maximum river discharge during the same period.

In order to create conditions to easily follow the described procedure, a calculation of the probability is outlined for the random variable X. The basic data for this calculation are seasonal and monthly values of the maximum river flows. The seasons can be chosen to represent three

month periods. In the particular case the seasons are defined as winter (January to March), spring (April to June), summer (July to September), and fall (October to December). The sample values are obtained by selecting the maximum discharge within each considered time interval. In a similar manner, the maximum annual values are selected to form the sample. The size of all samples equals the number of years for which the data were available. The formed samples are then used to calculate statistical parameters and to fit theoretical distribution functions to the observed data (most often Pearson III or Log-Pearson III). The final outcome of this calculation produces discharge values associated with the probability of excedance as follows:

- The annual maximum discharge - $X(p)$
- The seasonal maximum discharges - $X_i(p)$, for i=1,2,3 and 4;
- The monthly maximum discharges - $X_j(p)$, for j=1,2,...,12.

Where p stands for the probability that the considered random variable, X, will exceed the flood peak discharge.

The procedure for calculation of the probability of the random variable X inside the year consists in the following: for selected characteristic values of the probability, p, from the fitted probability curve, the values of the maximum annual values X(p) are determined. Using the theoretical distribution functions for the seasonal series, the probability of the maximum annual discharge of the random variable X is defined for each season Pi(X(p)). It is reasonable to assume that the sum of the probabilities associated with the seasonal floods should be equal to the probability of the maximum annual discharge, i.e.:

$$\sum_{i=1}^{4} P_i\left(X(p)\right) = P\left(X(p)\right) \quad (1)$$

However, due to the presence of the correlation between the maximum seasonal values of the random variable and because of short time series, this equality almost never is satisfied. Assuming that there exist the proportionality between the considered probabilities, a correction should be made to fulfill condition required by Eq. (1).

The next step represents calculation of the percentage of the probability distribution of the maximum monthly discharges inside each season. A similar condition should be satisfied as follows:

$$\sum_{j=1}^{i} P_j\left(X(p)\right) = P_i\left(X(p)\right) \quad (2)$$

where:

j = 1, 2, 3	for i = 1	(winter)
j = 4, 5, 6	for i = 2	(spring)
j = 7, 8, 9	for i = 3	(summer)
j = 10, 11, 12,	for i = 4	(fall)

The probabilities of the maximum monthly discharges of the random variable X should be done for the previously stated reasons and according to the same principles applied to correct the probabilities of the maximum seasonal values in order to satisfy the annual maximum discharge.

In that manner it is obtained that the sum of the maximum monthly floods is equal to the probability of the annual flood event, which follows from the relation:

$$\sum_{j=1}^{i} P_j(X(p)) = P(X(p)) \tag{3}$$

The obtained monthly values $P_j(X(p))$ corresponding to the probability of the maximum annual floods X(p) are plotted in a coordinate system, where the ordinate stands for the return period of the maximum annual flood, the abscise represents the time (month j = 1,2,...,12), while the third parameter is the probability of occurrence of the event.

Values of the probability of the annual flood plotted for each particular month (at coordinates representing month and the return period) can easily be interpolated. The iso-lines constructed in such a way represent the probability of the annual flood discharge X(p) pertaining the return period of floods in the particular months.

3 Assessment of within-the-year coincidence of two random variables

A procedure required to determine within-the-year coincidence of two variables, let say X and Y consists of calculation of probabilities that maximums of both considered variables will occur simultaneously. More precisely, it is firstly needed to determine the probabilities $P_j(X(p))$ and $P_j(Y(p))$.

The coincidence actually represents the probability of the intersection of two events, which is given as the probability defined by:

$$P_j(X(p) \cap Y(p)) \tag{4}$$

When the random variables X and Y are independent, the probability of their coincidence is defined as a product of probabilities of one-dimensional variables:

$$P_j(X(p) \cap Y(p)) = P_j(X(p)) \cdot P_j(Y(p)) \tag{5}$$

However, if the events are highly correlated, the probability of their coincidence can be approximately defined from the probability of the union of the considered events as follows:

$$P_j(X(p) \cap Y(p)) = (P_j(X(p)) \cup P_j(Y(p)))/2 \tag{6}$$

Broadly speaking, when defining the within-the-year coincidence, there must be satisfied the condition that the sum of the monthly coincidence equals the probability of coincidence of two events representing the annual values. i.e.:

$$\sum_{j}^{12} P_j(X(p) \cap Y(p)) = P(X(p) \cap Y(p)) \tag{7}$$

The obtained probabilities of the coincidence of monthly events $P_j(X(p) \cap Y(p))$ should also be plotted in the coordinate system, where the ordinate is the return period of the within-the-year coincidence, the abscise represents month j = 1, 2, ..., 12, while the third parameter is the probability.

4 The results of analyses

The reservoir "Kljuc" was constructed with prime objective to provide the water supply of the town of Lebane in the south of Serbia. The secondary effects in attenuation of flood wave are felt during time periods when the reservoir is not full. The previously described model is applied to evaluate these effects.

For an assessment of the within-the-year coincidence of flood flows and high water level in the reservoir, there only were available series of mean monthly discharge, Q_j, and mean monthly water level elevation, W_j. For that reason it had to be assumed that occurrence of the maximum discharge coincides with the average monthly flows, and that the same assumption holds for the reservoir water level.

In accordance with the descried methodology, there had first to be calculated the probabilities, $P_j(Q(p))$, of the [umanka river maximum annual discharge, as well as the probabilities, $P_j(W(p))$, of the maximum annual water level in the "Kljuc" reservoir. The results of calculation are plotted in Figure 1. Generally speaking, the results show an evident coincidence between the river flood flows and high water level in the reservoir during the year. It also can be concluded that lacks of coincidence characterize the fall - winter season, when the river flood flows precede the high water level in the storage. That conclusion does not hold for the spring - summer season, when the reservoir retains the flood flows for purpose of water supply.

Evaluation of the coincidence of flood flows and high water level in the "Kljuc" reservoir performed according to the procedure described in section 3 were depicted in Figure 2. From these results it can be concluded that the very large floods (corresponding to the return period 1000 to 10000 years) and high reservoir levels coincide in February and March. Smaller coincidence is likely to happen in April and May. The floods with hundred years return period coincide with the full reservoir in March and February, while floods of shorter return period - 10 years are likely to occur in March.

Analyses of effects of the "Kljuc" storage upon flood wave attenuation was performed for the following three initial conditions defined by the values of the reservoir level:

- At the spillway crest altitude 492.00 m.a.s.l.
- At the water level is at 491.00 m.a.s.l.
- At the water level mean altitude $\overline{Z}(p)$ = 487.24 m.a.s.l.

The calculations were done for the floods of the probabilities: 0.01, 0.1, 1, 5 and 10 %. The results of analyses are illustrated only for the hundred-year flood and the initial reservoir stage at 492.00 m.a.s.l. Figure 3 shows the input flood hydrograph - Q_{in}, the spillway discharge - Q_{prel} , and the reservoir level -Z. In addition, Figure 4 compares the probability lines of the maximum annual floods downstream from the dam under natural condition, and the peak discharge of the attenuated flood wave simulated for the above stated initial reservoir levels

The numerical presentation of the reservoir "Kljuc" effects upon transformation of the Sumanka river flood wave can be seen in Table 1. From these results it can be concluded that flood wave would be greatly attenuated. Namely, the simulated spillway outflow equaling the natural hundred-year peak discharge receives the return period of 670 years under condition that the flood wave arrives when the reservoir level is at the spillway crest - 492,00 m.a.s.l. If the reservoir stage happens to be at 491 m.a.s.l., the flood peak reduction would further increase. In comparison with the previous case, the simulated maximum overflow equal to the natural hundred-year flood peak would be associated with the return period of 1100 instead of 670 years. Moreover, due to the lack of coincidence of the flood events and high reservoir levels, the situation is significantly improving. Namely, under the assumption that the natural inflow and the expected water consumption would create the initial reservoir stage at 487.24 m.a.s.l., the return period of a hundred year simulated flood would increase to 25000 years.

Naturally, to achieve these effects, there should be a reliable system for flood forecasting.

Table 1 Change of the return period and the flood peak discharge of the Sumanka river downstream from the dam caused by operation of the "Kljuc" reservoir

p (%)	Return period (years)				Maximum peak discharge		
	Q_{in}	The initial reservoir stage - KGV (m.a.s.l.)			The initial reservoir stage - KGV (m.a.s.l.)		
	m^3/s	492.00	491.00	487.24	492.00	491.00	487.24
0,1	270				162.1	140.4	61.2
1	146	670	1100	25000	84.8	65.6	6.5
5	85.1	100	200	2500	49.5	33.3	0
10	62.9	33	60	1000	36.4	22.1	0

The results in table 1 it can also be seen that the "Kljuc" reservoir can play an important role in flood protection of the downstream area, for it would significantly reduce peak values of the considered flood waves. The hundred-year flood peak (146 m^3/s) would fall down to 84.8 m^3/s for the initial reservoir stage 492.00 m.a.s.l, to 65.6 m^3/s for the initial reservoir level 491.00 m.a.s.l., and reduces to only 6.5 m^3/s for 487.24 m.a.s.l.

5 Conclusion

The proposed methodology for assessment of multipurpose reservoirs on peak discharge reduction takes into account the coincidence of the flood wave and reservoir stage. This methodology indicates that effects of the "Kljuc" reservoir upon flood wave transformation are very significant, and that the flood risk downstream from the dam are greatly decreased.

The results obtained for the "Kljuc" reservoir on the Sumanka river make the authors of this paper believe that the described methodology should be widely used to evaluate potentials of multipurpose reservoirs related to flood control practice.

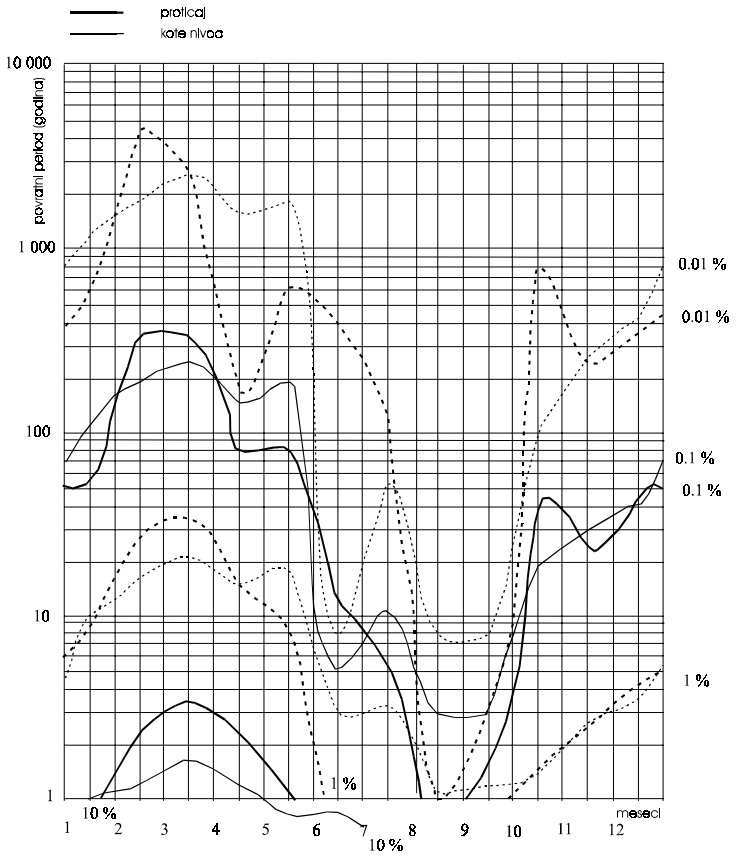

Fig. 1 Probability of the maximum flood discharge and the maximum water stage in the reservoir "Kljuc"

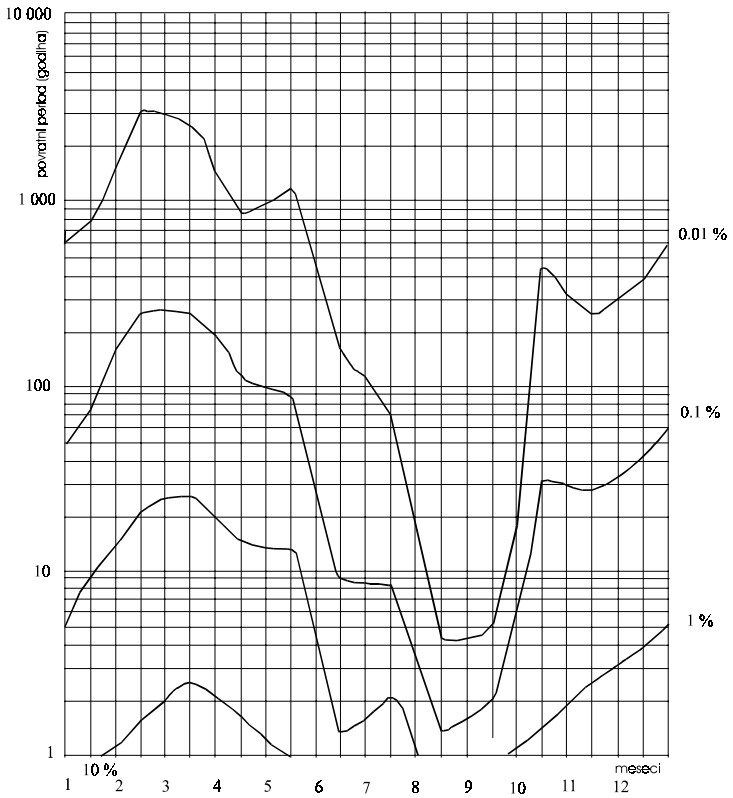

Fig. 2 Coincidence of the maximum annual discharge and the "Kljuc" reservoir stage

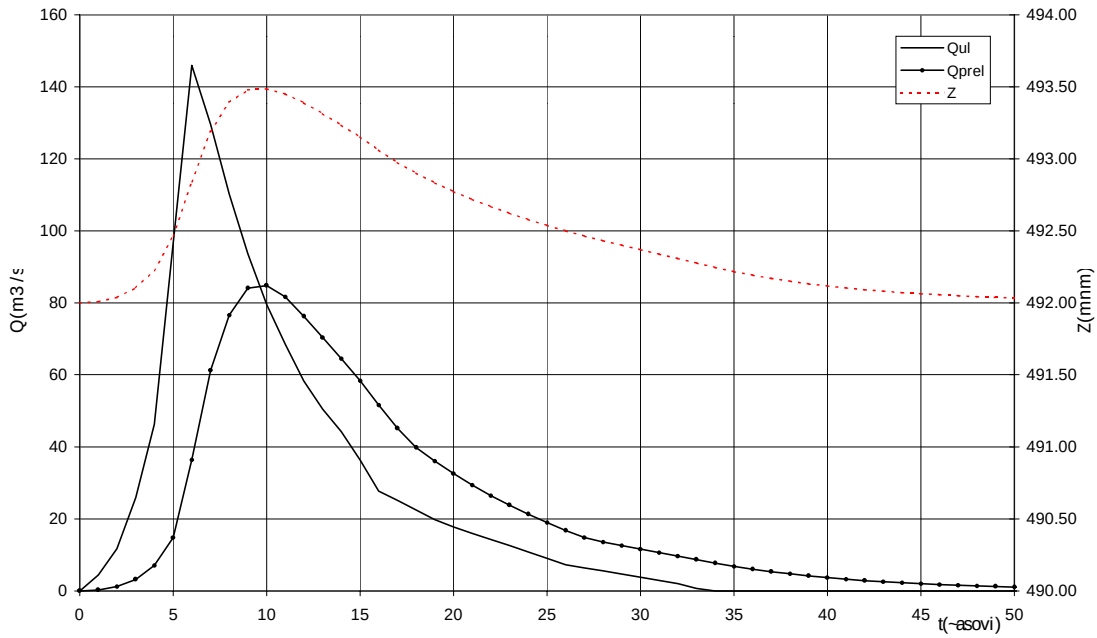

Fig 3 Flood routing of the 100-years wave through the reservoir “Kljuc”

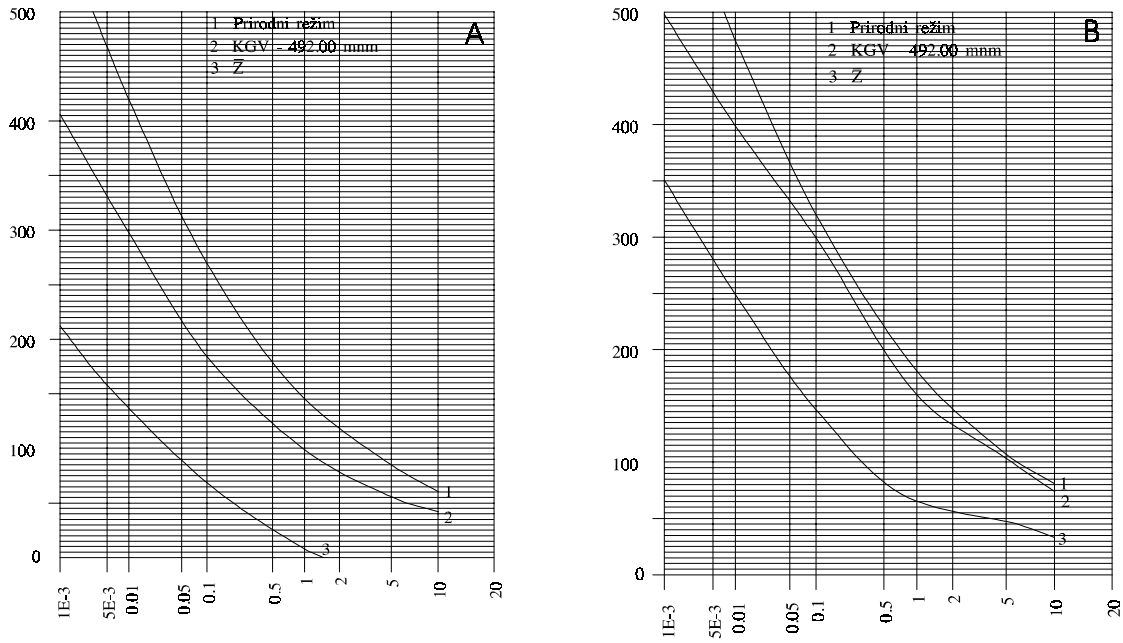

Fig. 4 Probabilities of the maximum anual discharges of Sumanka river in different countries

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Ein Hochwassermanagementsystem zur koordinierten Steuerung der österreichischen Donaustaustufen

Thomas Rauschenbach, Hans-Joachim Hoffmeyer-Zlotnik,

Jürgen Wernstedt, Heinz Allmer

Zusammenfassung: In diesem Beitrag wird ein Verfahren zur modellbasierten optimalen koordinierten Steuerung von Staustufenkaskaden vorgestellt. Ziel ist die Echtzeit-Lösung der mehrkriteriellen Optimierungsaufgabe zur Verbesserung des Hochwasserschutzes, der energieoptimalen Überführung von der Normalwassersituation zur Hochwassersituation und umgekehrt, sowie zur Gewährleistung der Schiffahrt. Voraussetzung dafür ist eine Hochwasservorhersage. Da diese nur für einen relativ kurzen Zeithorizont genaue Ergebnisse liefert, wird die Optimierung repetierend durchgeführt. Damit wird die Steuertrajektorie an veränderte Situationen angepaßt. Die Anwendung wird am Beispiel der österreichischen Donaustaustufen Abwinden-Wallsee-Ybbs-Melk gezeigt.

Schlüsselwörter: Koordinierte Steuerung, optimale Steuerung, Staustufenkaskaden, Hochwasserschutz, mehrkriterielle Optimierung, Simulation

Flood Management System for Coordinated Control of River Power Plants at the Austrian Danube

Abstract: A method for model-based optimal coordinated control of cascades of river power plants is presented in this contribution. Aim is the real-time solution of the multiple criteria optimization problem for improvement of flood control, energy optimal change from normal water situation to highwater situation and reverse as well as guarantee of navigation. Condition for it is a flood forecast. Because forecast only supplies precise results for a short time horizon, the optimization is repeated after an improved forecast. In this way, control trajectory is adapted to the changed situation. Application is shown at the casacade of Austrian Danube reservoirs Abwinden-Wallsee-Ybbs-Melk.

Keywords: coordinated control, optimal control, reservoir cascades, flood control, multiple criteria optimization, simulation

1 Einleitung

Die bisherigen Steuerkonzepte werden dem mehrkriteriellen Problem der Prozeßführung von Staustufenkaskaden nicht gerecht. Es wurde daher ein Konzept der vorhersagegestützten, optimierten koordinierten Steuerung erstellt [RAUSCHENBACH 1996/1]. Besonderes Augenmerk wurde dabei gerichtet auf:

- die energieoptimale Überführung von der Niederwassersteuerung zur Hochwassersteuerung,
- die maximal mögliche Reduzierung der Durchflußspitze des Hochwasserereignisses,
- die Gewährleistung der Bedingungen für die Schiffahrt und die Einhaltung von Grenzwerten, z.B. für die Änderungsgeschwindigkeit des Pegelstandes.

Das Gesamtgütekriterium für die Optimierung setzt sich somit aus mehreren Teilkriterien zusammen, wobei die Wichtungsfaktoren für diese Teilkriterien stark situationsabhängig sind. In diesem Beitrag wird ein Fuzzy-System zur automatischen Bestimmung der Wichtungsfaktoren in Abhängigkeit von der Prozeßsituation vorgestellt. Damit wird ein Verfahren zur repetierenden, mehrkriteriellen Echtzeit-Optimierung für die Steuertrajetorien der Staustufenkaskade aufgebaut. Die Leistungsfähigkeit des Konzeptes wird am Beispiel der

koordinierten Steuerung der Staustufenkaskade Abwinden-Wallsee-Ybbs-Melk an der österreichischen Donau gezeigt.

2 Verfahren der mehrkriteriellen, fuzzy-unterstützten repetierenden Optimierung (MEFURO) zur Staustufensteuerung

2.1 Prinzipielle Struktur des Verfahrens

Wie bereits beschrieben, führt die Ermittlung von optimalen Steuertrajektorien für Staustufenkaskaden zu einem mehrkriteriellen dynamischen Optimierungsproblem. Eine Lösungsmöglichkeit dafür ist die Abbildung des Problems auf ein skalares Gesamtgütefunktional [PAPAGEORGIOU 1980]. Dieses setzt sich aus der Summe der gewichteten Teilgütekriterien zusammen. Die Wichtungsfaktoren ändern sich in Abhängigkeit von der Zeit und/oder der Situation. Eine manuelle Vorgabe dieser Wichtungsfaktoren ist bei automatisch arbeitenden System aus zeitlichen Gründen nur in seltenen Fällen möglich. Außerdem wird bei dieser Vorgehensweise die Güte der Steuerung von der Kompetenz des jeweiligen Operateurs abhängig.

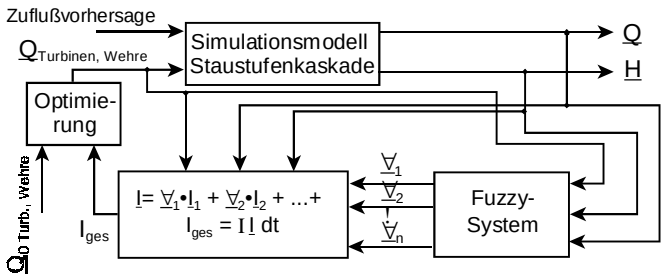


Abbildung 1 Struktur des MEFURO-Konzeptes

Aus diesen Gründen wurde es erforderlich ein System zu entwickeln, welches eine autonome Bestimmung der Wichtungsfaktoren in Abhängigkeit der Prozeßsituation erlaubt. Damit ist gleichzeitig die Voraussetzung für eine repetierende Optimierung zur Bestimmung von Steuertrajektorien geschaffen worden. Eine zum Zeitpunkt k ermittelte Steuertrajektorie kann zum Beispiel zum Zeitpunkt k+1 auf Grund einer Situationsänderung, wie z.B. eine aktualisierte Zuflußvorhersage, ungültig geworden sein und muß daher durch einen erneuten Optimierungslauf mit veränderten Wichtungsfaktoren der Teilgütekriterien aktualisiert werden. Mit dem MEFURO-Konzept wurde für diese Problemstellung eine neuartige Lösung entwickelt [RAUSCHENBACH 1998/1]. Erstmals wird ein Fuzzy-System zur Bestimmung der Wichtungsfaktoren für die Teilgütekriterien eines Gesamtgütefunktionals eingesetzt. In Abb. 1 ist der prinzipielle Aufbau des MEFURO-Konzeptes dargestellt.

Für die Ermittlung der Steuertrajektorie mit dem MEFURO-Konzept muß ein Modell der Staustufenkaskade vorhanden sein. Ausgehend von einer Stellgrößenmatrix $\underline{Q}_{\text{Turbine, Wehre}}$ und der Zuflußvorhersage werden mit dem Simulationsmodell die für die Steuerung relevanten Durchflüsse $\underline{Q}$ und Pegelstände $\underline{H}$ innerhalb der Kaskade bestimmt. Im Fuzzy-System werden entsprechend der Anforderungen die Wichtungsfaktoren $\forall_i$ für jedes Teilkriterium bestimmt und als Vektor mit je einem Wert pro Zeitpunkt an das Modul zur Berechnung des Gesamtgütefunktionals übergeben. Hier wird für jeden Zeitpunkt die gewichtete Summe der Teilkriterien gebildet und durch Integration über den betrachteten Zeitraum ein skalarer Gütewert gebildet. Dieser wird einem Optimierungsalgorithmus übergeben und die beschriebene Vorgehensweise so oft wiederholt bis ein Abbruchkriterium erreicht wird und damit die optimale Steuertrajektorie gefunden ist. Durch Aktualisierung der Zuflußvorhersagen kann sich die Situation verändern. Dadurch wird es erforderlich, die Berechnung der Steuertrajektorie repetierend durchzuführen. Ausgehend von der aktuellen Situation ist damit eine Anpassung der Steuertrajektorie möglich.

2.2 Gütekriterium

Das mehrkriterielle Gütekriterium für die Führung von Staustufenkaskaden kann entsprechend den genannten Forderungen wie in Gl.(1) formuliert werden. Es gilt:

$$I(t) = \alpha_1(t) \cdot I_1(t) + \alpha_2(t) \cdot I_2(t) + \alpha_3(t) \cdot I_3(t) + \alpha_4(t) \cdot I_4(t) \qquad (1)$$

unter Einhaltung der Beschränkungen G_1 und G_2. In Tabelle 1 werden die Teilkriterien und die Beschränkung erläutert [ALLMER 1998].

Tabelle 1 Teilgütekriterien und Beschränkungen für die Optimierung der Steuertrajektorien von Staustufenkaskaden

Kriterium	**Bedeutung**
$I_1(t) = q_{ab\,KW\,max}$	Der maximale Durchfluß, der an den Unterlieger abgegeben wird, soll minimiert werden.
$I_2(t) = \left(\frac{dq_{ab\,KW}(t)}{dt}\right)^2$	Es wird ein konstanter Abfluß im Bereich der Durchflußspitze erzwungen.
$I_3(t) = \int (h_{Oberwasser}(t) - h_{Stauziel})dt$	Am Ende eines Hochwasserereignisses muß die Staustufe das Stauziel (Sollwert) wieder erreichen.
$I_4(t) = -\int P(t)dt$	Die erzeugte elektrische Energie wird maximiert.
$G_1 = (h_{Wendepegel}(t) - h_{Wendepegel\,max}) \leq 0$	Beschränkung, daß der Wendepegel einen Maximalwert nicht überschreiten darf.
$G_2 = \left(\frac{dh_{OWP}(t)}{dt} - v_{OWP,\,Grenz}\right) \leq 0$	Beschränkung, daß die Änderungsgeschwindigkeit des Oberwasserpegels einen Maximalwert nicht überschreiten darf.

2.3 Fuzzy-System zur Bestimmung der Wichtungsfaktoren der Teilgütekriterien

Für jeden Abtastpunkt k ist es möglich den zugehörigen Wert der einzelnen Wichtungsfaktoren $\forall_1(k)$, $\forall_2(k)$, $\forall_3(k)$ und $\forall_4(k)$ zu bestimmen. Voraussetzung dafür ist das Vorliegen des aktuellen Zuflusses q(k) zur Staustufe, das vom aktuellen Zeitpunkt k aus gesehen zu erwartende Durchflußmaximum $q_{max}(k)$ und der prognostizierte Anstieg)q(k). Bei Untersuchungen zur Optimierung hat sich gezeigt, daß die energieoptimale Umsteuerung am besten berücksichtigt wird, wenn man den Wichtungsfaktor $\forall_4$ für das Teilkriterium I_4 konstant hält. Dadurch wird eine energieoptimale Steuerung in allen Durchflußbereichen erreicht. Im Bereich der Durchflußspitze, wo es auf maximalen Hochwasserschutz ankommt, wirkt dieses Teilkriterium automatisch nicht mehr, da die erzeugte elektrische

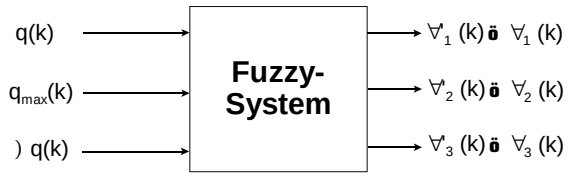


Abbildung 2 Fuzzy-System zur Ermittlung der Wichtungsfaktoren

Leistung durch Unterschreitung der minimalen Fallhöhe zu null wird. Der Faktor $\forall_4$ wird zu 0,1 festgelegt. Das Fuzzy-System besitzt deshalb nur die drei Ausgänge $\forall_1$ bis $\forall_3$. Zunächst sind die Faktoren $\forall'_1(k)$, $\forall'_2(k)$ und $\forall'_3(k)$ die Ausgangswerte. Zur Anwendung als Wichtungsfaktoren im Gütekriterium I(t) ist es sinnvoll diese Faktoren zu normieren, so daß ihre Summe zu jedem Zeitpunkt den Wert eins ergibt. Die Zugehörigkeitsfunktionen für die Eingangsgrößen wurden trapezförmig festgelegt und für die Ausgänge wurden Singletons mit den Attributen NIEDRIG, MITTEL und HOCH verwendet [KOCH 1996]. Abb. 3 zeigt die Zugehörigkeitsfunktionen für den Durchflußgradienten)q.

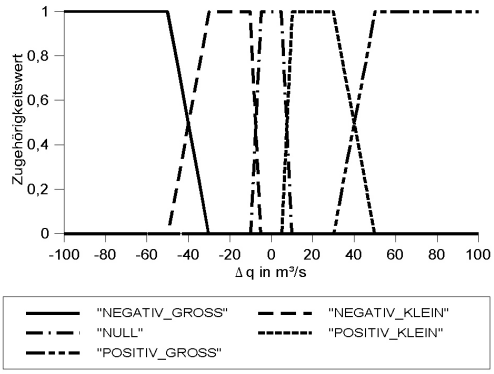


Abbildung 3 Zugehörigkeitsfunktionen für den Gradienten)q

Bei der Erstellung des Regelwerkes müssen alle für die Wahl der Wichtungsfaktoren relevanten Situationen berücksichtigt werden. Dies sind:

Situation 1: Normalsituation,

Situation 2: Überführung von Normal- in Hochwassersituation,

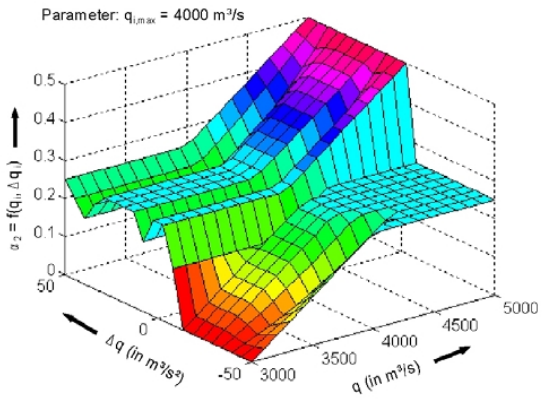
Situation 3: Hochwassersituation,

Situation 4: Überführung von Hochwasser- in Normalwassersituation.

Für jede dieser Situationen wurde eine Regelmenge erstellt [RAUSCHENBACH 1998/2]. Beispielhaft werden in Tabelle 2 die Regeln für Situation 1 (Normalsituation) gezeigt. Für diese Situation spielt der vorhergesagte Gradient des Durchflusses keine Rolle und wird deshalb auch im Regelwerk nicht benutzt. Ist der Durchfluß "NIEDRIG" und auch der vorhergesagte Maximalwert "NIEDRIG", dann wird $\forall_3$ auf "HOCH" gesetzt. Während $\forall_2$ und $\forall_1$ "NIEDRIG" zugewiesen bekommen. Es wird das Kriterium für die Einhaltung des Stauzieles am Oberwasserpegel am höchsten gewichtet, während die beiden Kriterien für den Hochwasserschutz keine Bedeutung erlangen.

Tabelle 2 Regelwerk für Normalsituation

R1: if (q(k) =NIEDRIG) and (q_{max}(k) =NIEDRIG) then α_3 (k):=HOCH
R2: if (q(k) =NIEDRIG) and (q_{max}(k) =NIEDRIG) then α_2 (k):=NIEDRIG
R3: if (q(k) =NIEDRIG) and (q_{max}(k) =NIEDRIG) then α_1 (k):=NIEDRIG



In Abb. 15 ist zur besseren Veranschaulichung der Verlauf des Wichtungsfaktors $\forall_2$ in Abhängigkeit vom Durchfluß q und dem Gradienten der Durchflußentwicklung)q aufgetragen. Der vorhergesagte Maximaldurchfluß q_{max} wurde als Parameter verwendet und beträgt hier 4000 m³/s.

Abbildung 4 Wichtungsfaktor $\forall_2$ als Funktion von q und)q (Parameter q_{max})

2.4 Optimierungsverfahren

Vom verwendeten Optimierungsverfahren hängt entscheidend die Geschwindigkeit und die Genauigkeit der gefundenen Lösungen ab, d. h. ob globale oder lokale Extrempunkte im Gütefunktional gefunden werden. Für mehrdimensionale Probleme mit Gütefunktionalen, die mehrere lokale Extremwerte aufweisen, sind zum Beispiel evolutionäre Optimierungsstrategien gut geeignet [PAPAGEORGIOU 1991]. Die Wahrscheinlichkeit das globale Extremum zu finden, ist sehr hoch. Nachteilig sind die hohen Rechenzeiten, die einen Einsatz für die repetierende Optimierung an Staustufenkaskaden nicht erlauben.

Ein bewährtes Verfahren zur Lösung mehrdimensionaler Probleme ist das Simplex-Verfahren. Einen wesentlichen Nachteil weist jedoch das Verfahren auf. Es ist nicht für die Einbeziehung von Beschränkungen geeignet. Daher müssen die notwendigen Beschränkungen für die Staustufenoptimierung in das Gütekriterium mit einbezogen werden. Dazu wird beim Überschreiten einer Beschränkung das Quadrat der Differenz zum Grenzwert auf den Gütewert aufaddiert. Man kann dies als eine Art “weiche” Beschränkung auffassen. Je stärker der Grenzwert überschritten wird, um so schlechter wird das Gütemaß.

2.5 Simulationsmodell

Die Simulation des Verhaltens einer Staustufe setzt deren analytische Beschreibung voraus. Für eine Steuerung ist es ausreichend, das Verhalten an den Pegeln hinsichtlich des Durchflusses und des Wasserstandes zu kennen. Der Entwurf und die Realisierung von Regelungskonzepten zur Beeinflussung einer Staustufe bzw. der koordinierten Steuerung von Staustufenkaskaden erfolgte bisher auf der Basis von regelungstechnischen Modellen oder Black-Box-Modellen. Sie sind nicht in der Lage das nichtlineare instationäre Verhalten mit ausreichender Genauigkeit zu beschreiben. Modelle auf Basis der Saint-Venant-Gleichungen, die den Flußlauf in zahlreiche Modellabschnitte unterteilen, können die Anforderungen besser erfüllen. Sie sind aber durch die umfangreichen Berechnungen zur Lösung des Differentialgleichungssystems nicht in der Lage, die für eine on-line Optimierung geforderte Simulationszeit zu garantieren. Am Beispiel der Simulation des ca. 250 km langen Neckars mit dem Programmpaket CARIMA der Universität Karlsruhe soll das belegt werden. Damit dauert die Simulation des Fließverhaltens über einen Zeitraum von 20 Stunden (mit einer Abtastzeit von 30 s entspricht dies 2400 Simulationsschritten) auf einer Workstation (HP-9000 712/80) ca. 9 Minuten. Für

eine Optimierung muß diese Simulation mehrere tausend Mal aufgerufen werden. Bei 5000 Aufrufen entspricht dies einer Simulationszeit von über 31 Tagen. Gleichzeitig ist es jedoch mit diesen Modellen schwierig, Retentionsräume oder das Rückstauverhalten bei Einmündung von Nebenflüssen zu modellieren. Aus diesen Gründen wird in diesem Kapitel eine Synthese beider Modellansätze, die HR- Modelle (hydrodynamisch-regelungstechnische Modelle) vorgestellt, welche die gestellten Anforderungen hinsichtlich Genauigkeit und schneller Simulation erfüllt [RAUSCHENBACH 1996/2].

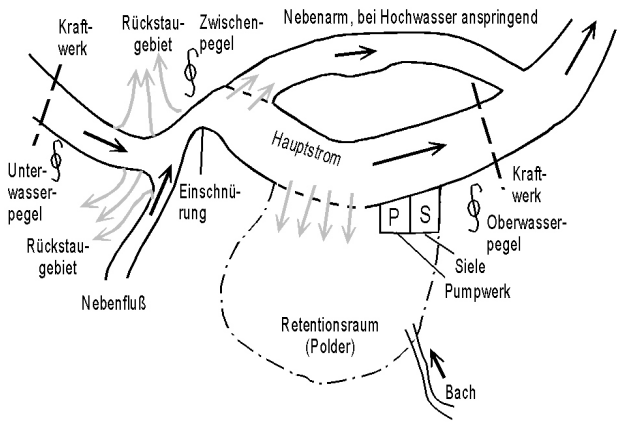


Abbildung 5 Bei Staustufenmodellen zu beachtende Effekte

In Abb. 5 wird ein möglicher Flußlauf zwischen zwei Kraftwerksanlagen gezeigt, der die wichtigsten, bei der Modellierung zu beachtende Effekte enthält. Die Simulationsmodelle wurden für MATLAB/SIMULINK® entwickelt und in der Bibliothek "RIVER-MOD" hinterlegt. Folgende Modelle stehen zur Verfügung:

- Durchflußmodell, auch für instationäres Verhalten geeignet,
- Wasserstandsmodell,
- Ausuferungsmodell,
- Modell für Retentionsräume unter Einbeziehung von Pumpwerken und Sielen und
- ein Rückstaumodell.

Die genannten Modelle basieren auf den Saint-Venant-Gleichungen zur eindimensionalen Beschreibung des insationären Fließens in Gerinnen. Sie stellen ein System von zwei Differentialgleichungen, der Kontinuitätsgleichung und der Bewegungsgleichung, dar. Zur Lösung werden diese nach Raum und Zeit diskretisiert und somit in ein nichtlineares Differenzengleichungssystem 1. Ordnung umgewandelt. Für die Bestimmung der Parameter wird die Methode der kleinsten Fehlerquadrate eingesetzt. Bei der räumlichen Diskretisierung erfolgt der Übergang von infinitesimalen kleinen Wegabschnitten zu endlichen Wegabschnitten, hier die Entfernung zwischen den vorhandenen Pegeln. Die erreichten Simulationsgenauigkeiten zeigen, daß diese Herangehensweise zulässig ist.

Mit dieser Methode erhält man beispielsweise für die Beschreibung der Durchflußgangline den in Gl. (2) angegebenen Zusammenhang. Es gilt:

$$\begin{aligned} q(m_{ab},k) &= a \cdot q(m_{ab},k-1) + b \cdot q(m_{zu},k-k_1) + \\ &+ c \cdot \left[h(m_{ab},k-1) - h(m_{zu},k-1) - h(m_{ab},k-2) + h(m_{zu},k-2) \right] \end{aligned} \tag{2}$$

mit m_{zu} - Argument für örtlichen Beginn des betrachteten Flußabschnittes,
m_{ab} - Argument für örtliches Ende des betrachteten Flußabschnittes.

q - Durchfluß,
h - Wasserstand,
k - Zeitpunkt,

Die Parameter a, b und c werden anhand von Originaldurchflußdaten mit der Methode der kleinsten Fehlerquadrate geschätzt.

Für vier Stausufen an der österreichischen Donau (Gesamtlänge des simulierten Flußabschnittes ca. 120 km) liegt die Simulationszeit für ein Hochwasserereignis mit 100 Std. Dauer (mit einer

Abtastzeit von 3 min entspricht dies 2000 Simulationsschritten) bei ca. 10 Sekunden (mit Prozessor Pentium II, 400 MHz Taktfrequenz). Damit wurden wesentliche Voraussetzungen zur modellgestützten echtzeitfähigen Prozeßführung erstmals geschaffen.

3 Koordinierte Steuerung der Staustufen Abwinden-Wallsee-Ybbs-Melk

3.1 Struktur

Die koordinierte Steuerung soll am Beispiel der Staustufenkaskade Abwinden-Wallsee-Ybbs-Melk dargestellt werden. Die Entwicklung der koordinierten Steuerung beruht auf der Theorie der hierarchischen Steuerung komplexer Prozesse. Den prinzipiellen Aufbau zeigt Abb .6.

Jede Staustufe besitzt wie bisher ihre eigenen unterlagerten Steuerungen/ Regelungen, die im Fall des Nieder- und Mittelwassers die Einhaltung der Wehrbetriebsordnung gewährleisten. Hierbei wirkt der Koordinator nicht auf die Staustufenregelung ein. Dies entspricht dem bisherigen Betriebsregime.

Der Koordinator wird nur aktiviert, wenn eine Hochwassersituation vorhergesagt wird oder Sondersituationen eintreten. In diesem Fall berechnet der Koordinator nach dem bereits beschriebenen MEFURO-Konzept anhand der Vorhersagedaten die optimalen Steuertrajektorien für die vier Staustufen. Repetierend nach jeder Zuflußvorhersage wird die Optimierung wiederholt und die Steuertrajektorien an die neue Situation angepaßt [RAUSCHENBACH 1997].

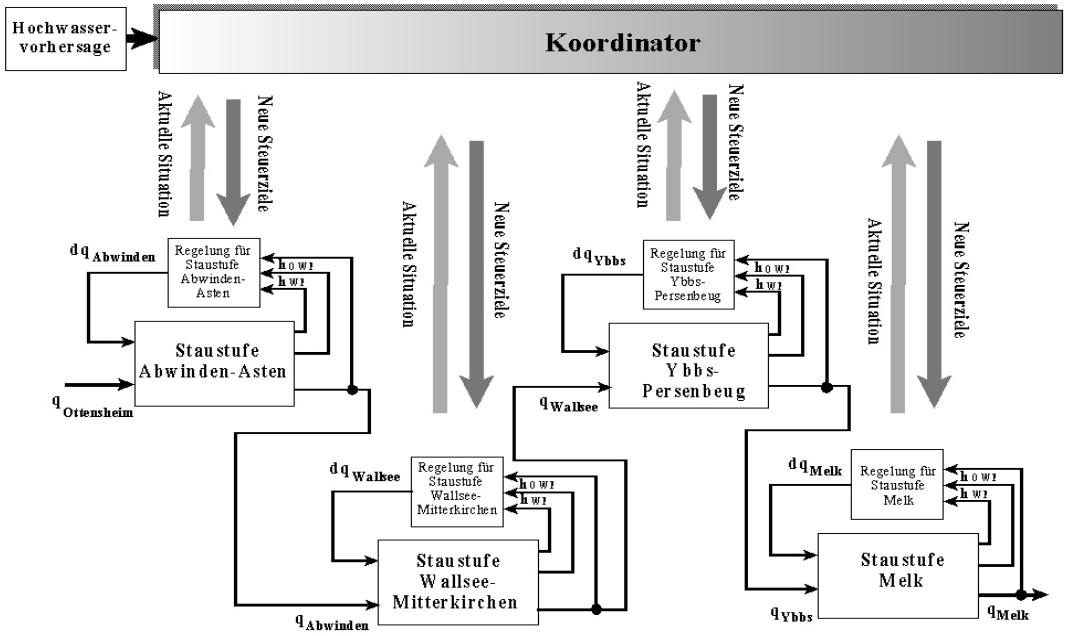


Abbildung 6 Prinzipieller Aufbau der Koordination

3.2 Ergebnisse

Die koordinierte Steuerung wurde für Hochwasser unterschiedlicher Scheitelhöhen simulativ erprobt, um die Wirksamkeit in verschiedenen Durchflußbereichen beurteilen zu können. Deutlich ist an den Ergebnissen zu erkennen, daß mit zunehmendem Durchfluß die Möglichkeit den Spitzendurchfluß zu verringern sinkt. Während bei einem Ereignis mit einem Spitzendurchfluß von ca. 4.000 m^3/s die Reduzierung ca. 900 m^3/s beträgt, ergeben sich bei 8.000 m^3/s 1600 m^3/s, wobei eine Reduzierung von über 1000 m^3/s durch die Polder hervorgerufen wird. Die Dauer des Hochwassers wurde hierbei gleich gewählt, da die Effektivität der koordinierten Steuerung vom Volumen des Hochwasserereignisses wesentlich abhängt. Abb. 7 zeigt die Durchflußganglinien der koordinierten Steuerung für die gesamte Staustufenkasakade.

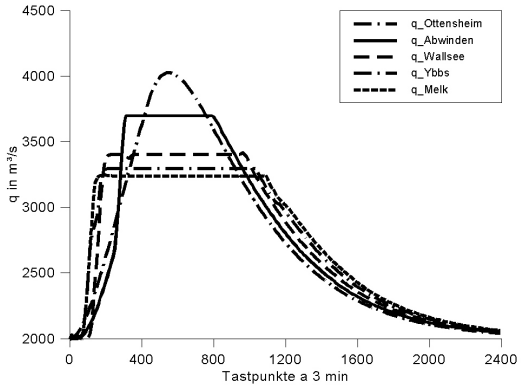


Abbildung 7 Durchflußganglinien bei koordinierter Steuerung

Sehr gut ist die erzielte Reduzierung des maximalen Durchflusses der Hochwasserwelle (Dämpfung) durch die koordinierte Steuerung von vier Staustufen zu sehen. Gleichzeitig konnte bei den Untersuchungen nachgewiesen werden, daß sich durch die situationsabhängige dynamische Gestaltung der Wichtungsfaktoren der Teilkriterien im Gesamtgütefunktional eine wesentliche Verbesserung der Energiebilanz gegenüber der gültigen Wehrbetriebsordnung erzielen läßt. Bei einen Hochwasserereignis mit einem Spitzendurchfluß von 6000 m^3/s wurden bei koordinierter Steuerung 660 MWh mehr als bei der Steuerung nach Wehrbetriebsordnung erzielt.

4 Zusammenfassung und Ausblick

Als Ergebnis der durchgeführten Untersuchungen kann festgestellt werden, daß es in jedem Durchflußbereich möglich ist, durch die koordinierte Steuerung nach dem MEFURO-Konzept eine Verringerung der Durchflußspitze gegenüber der bisherigen Vorgehensweise zu erreichen. Es ist jedoch zu beachten, daß mit zunehmendem Spitzendurchfluß der erreichte Effekt kleiner wird, da das freie Stauvolumen innerhalb der Stauhaltungen geringer wird. Damit werden die Grenzen der koordinierten Steuerung deutlich. In Fällen von extremen Hochwasserereignissen kann durch die koordinierte Steuerung keine Verbesserung des Hochwasserschutzes erreicht werden. Betrachtet man daneben das Potential der vorhandenen Retentionsräume, ist folgendes festzustellen. Eine koordinierte Steuerung kann den Hochwasserschutz durch bereits vorhandene Polder sinnvoll ergänzen, diese aber niemals ersetzen.

Zur Zeit werden an der österreichischen Donau die Voraussetzungen geschaffen, daß alle neun vorhandenen Staustufen zentral von einer Leitstelle aus gesteuert werden können. Dazu ist eine umfangreiche Erneuerung der Prozeßleittechnik notwendig, die bis zum Jahr 2005 abgeschlossen werden soll. Dabei wird die hier vorgestellte Lösung zur koordinierten Steuerung von Staustufen im Leitsystem mit umgesetzt. Dafür ist es notwendig, die Simulationsmodelle für die verbleibenden fünf Staustufen zu erstellen und diese in das Konzept der koordinierten Steuerung mit einzubeziehen.

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Aktualisierung der Werte von n-jährlicher Hochwasserabflüsse im Flußgebiet der oberen March

Tomáš Řehánek

Zusammenfassung: Der Beitrag konzentriert sich auf die Aktualisierung der n-jährlichen Hochwasserabflüsse an ausgewählten Pegelstationen im Flussgebiet der oberen March. Der Aufsatz beschreibt die früher angewandten Methoden der Festlegung der Q_n Werte und stellt die durch diese Methoden erzielten Ergebnisse denen der aktuell angewandten Verfahren gegenüber. Es werden die regionalen Verhältnisse in den einzelnen Gewässern des Flußgebietes der oberen March mit den Abflussspenden einer hundertjährigen Reihe, die für ein Gewässer des Flussgebietes gegeben ist, verglichen.

Der Beitrag bewertet sowohl erreichte Ergebnisse als auch Beschlüsse, die sich aus diesen herleiten, für die wasserwirtschaftliche Öffentlichkeit. Das Papier gibt der Meinung Ausdruck, dass n-jährliche Hochwasserabflüsse auch in Zukunft mit hoher Zuverlässigkeit zu ermitteln sind. Dieser Text unterstreicht nachdrücklich das Bedürfnis nach zuverlässigen Festlegungen hydrologischer Aussagen mit dem Ziel, erforderliche Korrekturen zu minimieren.

Schlüsselwörter: Flußgebiet der oberen March, höchster jährlicher Hochwasserabfluß, n-jährlicher Hochwasserabfluß

Improvement of N-Year Flood Discharge in the Upper Morava River Basin

Abstract: Paper is focused on improved elaboration of N-year flood discharge in selected water measuring stations in the Upper Morava River basin. Article summarizes used methods of Q_N values determination and reached results are compared with methods used. Paper compares mutual regional relations of the individual water streams of the River system in the Upper Morava River basin with shown dependencies of specific one hundred years runoff in the River basin area.

Text evaluates both reached results and arrived conclusions for the public in the field of water management. Paper expresses the opinion that values of N-year flood discharge will have to be improved in the future as well. Article emphasizes the need of the hydrologic data determination of the very best quality focused on necessary corrections minimization.

Key words: Upper Morava River basin, maximum discharge, N-year flood discharge

1 Einleitung

Zu den hydrologischen Hauptangaben, die das Tschechische Hydrometeorologische Institut (CHMU) der wasserwirtschaftlichen Öffentlichkeit mitteilt, gehören unter anderem N-jährigen Hochwasserdurchflüsse (Q_N). Diese werden für die Profile der Pegelstationen vom Gesichtspunkt aus der Überschreitung der höchsten jährlichen Hochwasserdurchflüsse (Q_{max}) festgelegt, nach der Norm CSN 75 1400 - Hydrologische Angaben des Oberflächenwassers. Das Ergebnis sind abgeleitete Werte Q_N, die durchschnittlich einmal pro N Jahre erreicht oder überschritten werden können. Mit N versteht man ausgewählte Zeitperioden der Wiederholung der höchsten Scheiteldurchflüsse (Q_{kulm}), die 1, 2, 5, 10, 20 und 100 Jahren gleich sind.

Der Beitrag liegt neue Verarbeitung des Hochwassers bei den ausgewählten Pegelstationen des Flußgebietes der oberen March vor (s. das Bild 1).

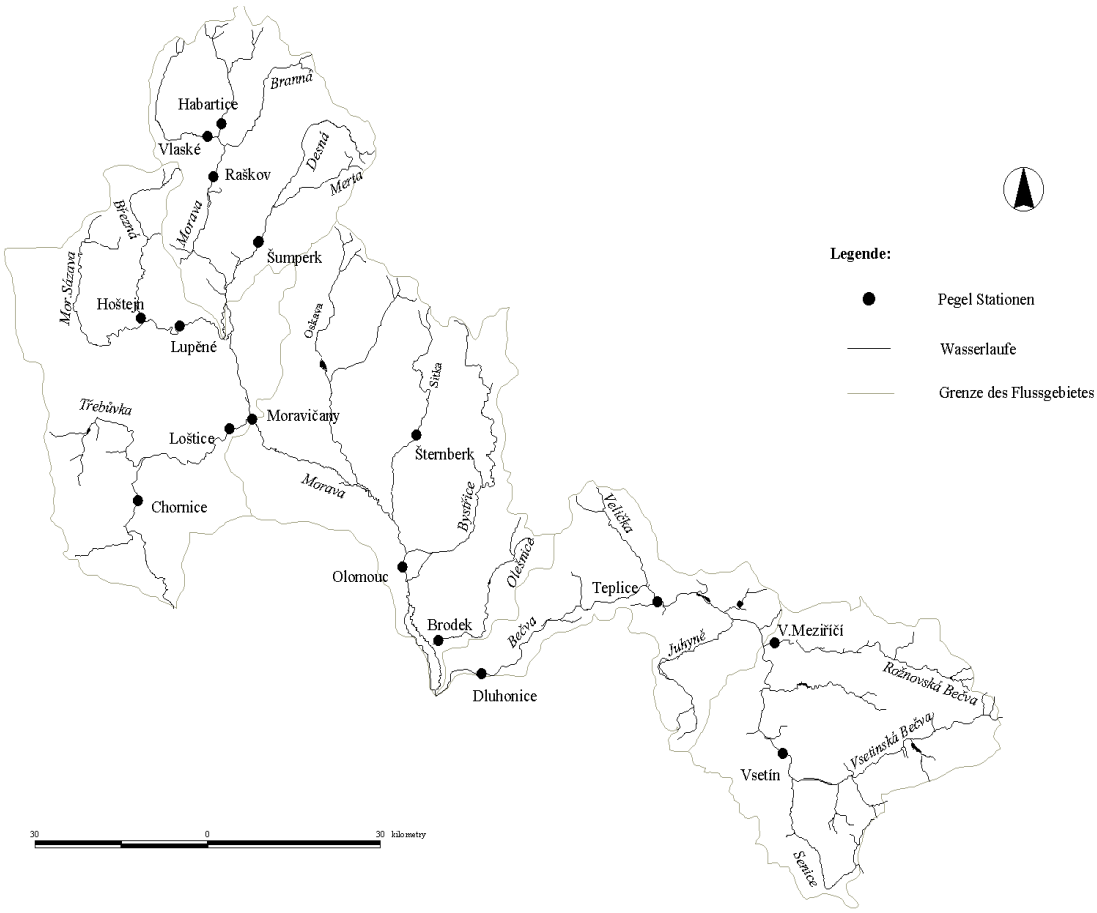

Bild 1 Die auswählenen Pegelstationen im Flußgebiet der oberen March

2 Flußgebiet der oberen March

Vom hydrologischen Standpunkt aus, das Flußgebiet der oberen March verwaltet die Zweigstelle des CHMU in Ostrava. Dieses Flußgebiet stellt einen sehr vielfältigen Gebietskomplex von einer gestreckten Form dar, liegend am westlichen und südlichen Rand Nordmährens. Das Schlußprofil ist der Zusammenfluß der Flusses Morava und Becva bei Tovacov, das die Fläche von fast 5 196 km^2 schließt. Das Flußgebiet erreicht die höchste Seehöhe auf dem Berg Altfater (1491 m); die niedrigste Seehöhe erreicht es im Bereich des Zusammenflusses (197 m). Das Flußgebiet gehört zu zweiten verschiedenen Naturkomplexen, und zwar das Flußgebiet des oberen Laufes der March gehört zum Tschechischen Massiv (das Grobe Jesenik-Gebirge und das Niedrige Jesenik-Gebirge, die Obermährische Talsenkung), das Flußgebiet des Flusses Becva gehört zum Karpatenteil des Gebietes - Mährisch-schlesische Beskyden und Hostiner-Wsetiner Bergland. Physisch-geographische Verhältnisse dieser Gebietskomplexe bestimmen zusammen mit der Menge und Intensität der Niederschläge das Vorkommen der höchsten Scheiteldurchflüsse und ihrer zeitliche und räumliche Verteilung.

Bei den Wasserströmen im Flußgebiet der oberen March sind in der Vergangenheit hydrologische Verhältnisse bei 159 Pegelstationen in einer unterschiedlich langen Überwachungszeitperiode gemessen und ausgewertet worden (auch unterbrochene Überwachungen). 47 Stationen messen hydrologische Verhältnisse auf diesem Gebiet in der Gegenwart; davon 16 Stationen während der längsten Zeitperiode (s. die Tabelle 1).

Tabelle 1 Die Überwachungszeitperiode des Q_{max}s in den auswählenen Pegelstationen

R. N.	Pegelstation	Wasserlauf	Fläche des Flußgebietes (km^2)	Mittlerer Durchfluß ($m^3.s^{-1}$)	Überwachungszeitperiode des Q_{max}s
1	Vlaské	Morava	41.44	1.963	1914-1998
2	Habartice	Krupá	66.45	2.181	1914-1998
3	Raškov	Morava	90.28	6.267	1895-1998
4	Šumperk	Desná	109.49	4.081	1895-1998
5	Hoštejn	Březná	109.84	1.768	1914-1998
6	Lupěné	M. Sázava	130.16	4.350	1895-1998
7	Moravičany	Morava	159.26	17.817	1896-1998
8	Chornice	Jevíčka	231.70	0.204	1910-1998
10	Loštice	Třebůvka	241.16	2.662	1882-1998
11	Šternberk	Sitka	253.07	0.593	1926-1998
12	Olomouc	Morava	444.45	27.186	1883-1998
13	Brodek	Olešnice	505.78	0.580	1918-1998
14	Vsetín	V. Bečva	573.40	6.566	1893-1998
15	V. Meziříčí	R. Bečva	1558.82	3.499	1897-1998
16	Teplice	Bečva	1598.79	15.338	1888-1998
17	Dluhonice	Bečva	3322.07	17.335	1896-1998

3 Aktualisierung der Werte von N-jährigen Hochwasserdurchflüsse

Der Hauptimpuls für die Überarbeitung der Werte von N-jährigen Hochwasserdurchflüsse, die bis 1985 galten, ist die außerordentliche Hochwassersituation im Juli 1997 gewesen. Diese Situation hat einige Ungenauigkeiten in der früheren Festlegung der Zeitperioden der Wiederholung des Hochwassers bei den Pegelstationen und ihren schlechten Anschluß an das Flußsystem der Wasserströme aufgedeckt.

3.1 Kurze Beschreibung der Verarbeitung

Die Eintrittsdaten für eine neue Festlegung sind die wirklich ausgewerteten, bzw. nach den überlieferten Aufzeichnungen von Limnigrammen und Schlüsselkurven, abgeleiteten Q_{max} gewesen. Für den Fluß Becva in Dluhonice sind diese auf dem Bild 2 eingezeichnet. Eine wesentliche Schwankung in der Größe der erreichten Werte ist für die Wasserströme auf dem Beskyden-Gebiet und im Vorbeskyden-Gebirge typisch; und umgekehrt, im westlichen Teil des Flußgebietes schwanken die Werte viel weniger und in meisten Fällen scheint das Jahr 1997, wahnsinnig extrem zu sein.

Zum Ausgleich der klassifizierten Reihen Q_{max} ist die logarithmisch-normale theoretische Kurve der Überschreitung (LN) oder ihre spezielle Modifikation angewandt worden, nach der Auswahl der Kurvenasymmetrie und der Berechnung des Durchschnittes von Logarithmen, genannt nach ihrem Autor als Prochazkas Verteilung (P). Dabei sind im Falle LN die Varianten mit zweien Parametern (LN II) - Durchschnitt Q_{max} und mit ihrem Variantenkoeffizient (C_v) ausgearbeitet worden, und auch mit dreien Parametern (LN III), wo wir noch dazu mit dem Koeffizient der Asymmetrie (C_s) rechnen. Für die günstigste Kurve wird eine solche theoretische Kurve gehalten, die die Reihe der Werte Q_{max} am besten durchliegt. Den Durchschnitt der höchsten Hochwasserdurchflüsse, aus einer genug langen Zeitperiode zusammengefaßt, kann man für einen konstanten und glaubwürdigen Durchschnitt halten; weitere zwei Parameter sind oft zum Erreichen eines besseren Anliegens zur empirischen Kurve zu abzuweichen. Dazu kann man die Methode der Quantile [4] verwenden, wann wir die Berechnung der Parameter der theoretischen Kurve so wählen, daß diese durch ausgewählte empirische Punkte durchgeht - in der Regel Q_1 und Q_{100}, manchmal auch Q_{1000}.

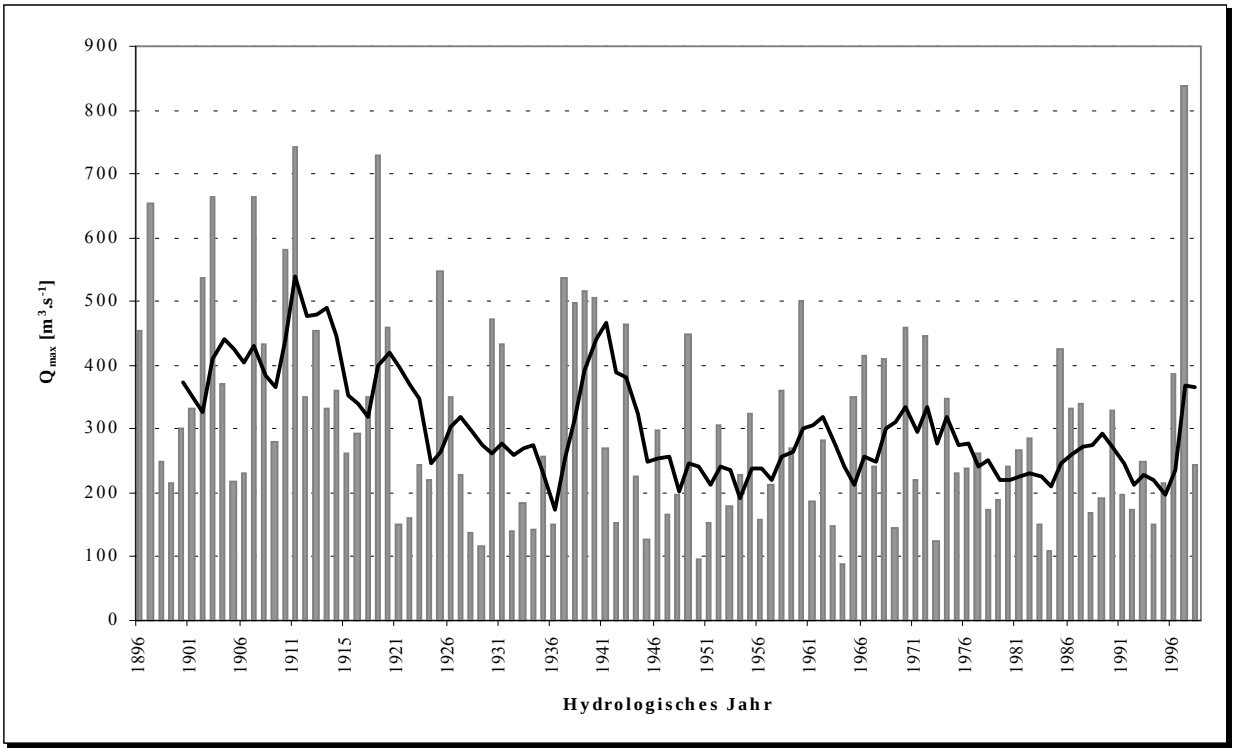

Bild 2 Die höchsten jährlichen Hochwasserdurchflüsse des Flusses Becva in Dluhonice (mit 5-jährigen glatten Durchschnitten)

Die angeführten theoretischen Kurven sind für den Fluß March in Vlaske mit der früher angewandten Kurve LN II (1985), mit der resultierenden Kurve (LN III mit der Modifizierung der Abweichung) und mit den Werten Q_{max} auf dem Bild 3 eingezeichnet.

Neue Werte Q_N sind im Flußgebiet der oberen March unter der Anwendung von LN III verarbeitet worden, und zwar entweder mit den Korrekturen für die Abweichung oder ohne sie. Das Ergebnis sind die Änderungen des theoretischen Hochwassers mit dem Ziel, die Zeitperiode der Wiederholung Q_{max} aus dem Jahre 1997 realer zu bewerten.

3.2 Vergleich der neuen und älteren Q_N

N-jährigen Hochwasserdurchflüsse gehören zu den hydrologischen Angaben, deren Gültigkeit zeitlich begrenzt ist, was besonders durch die Länge der verarbeiteten Zeitreihen Q_{max} gegeben wird. Auf dem Interessengebiet sind diese insgesamt vier mal (s. das Bild 4) zusammengestellt worden. Die älteste Verarbeitung war nur für ausgewählte Stationen, die länger hydrologische Verhältnisse überwachen; diese Verarbeitung ist erst in 1954 verlaufen. Danach folgte die erste Ableitung des Hochwassers für sämtliche damals messende Profile, was Ende der 60. Jahre geschehen ist. Die gewonnenen Angaben sind in der hydrologischen Praxis fast seit 20 Jahren lang angewandt worden; es fehlte aber eine mehr komplexe Verarbeitung von Q_N im Rahmen der anderen Profile des Flußsystems der Wasserströme. Aus diesem Grunde hat man angefangen, die Werte des Hochwassers weiter abzuleiten. Es entstand der sog. Kataster des Wasserreichtums. Vergleichen wir die Werte Q_{100}, stellen wir fest, daß es im Vergleich mit der vorherigen Verarbeitung zu wesentlichen Änderungen gekommen ist, was besonders eine längere Zeitperiode der Auswertung von Q_{max} und einheitliche PC-Verarbeitung unter der Anwendung der Verteilung LN II widerspiegelt.

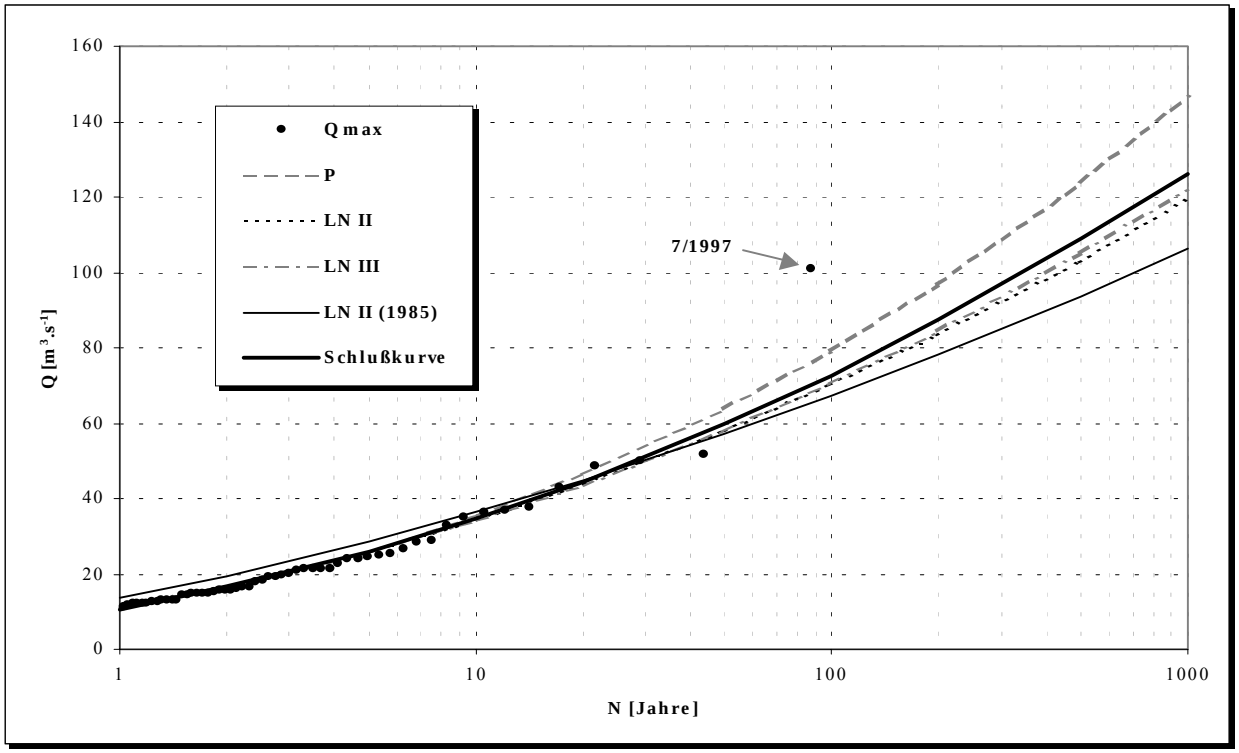

Bild 3 Die Zeitperioden der Wiederholung der höchsten jährlichen Hochwasserdurchflüsse des Flusses March in Vlaske

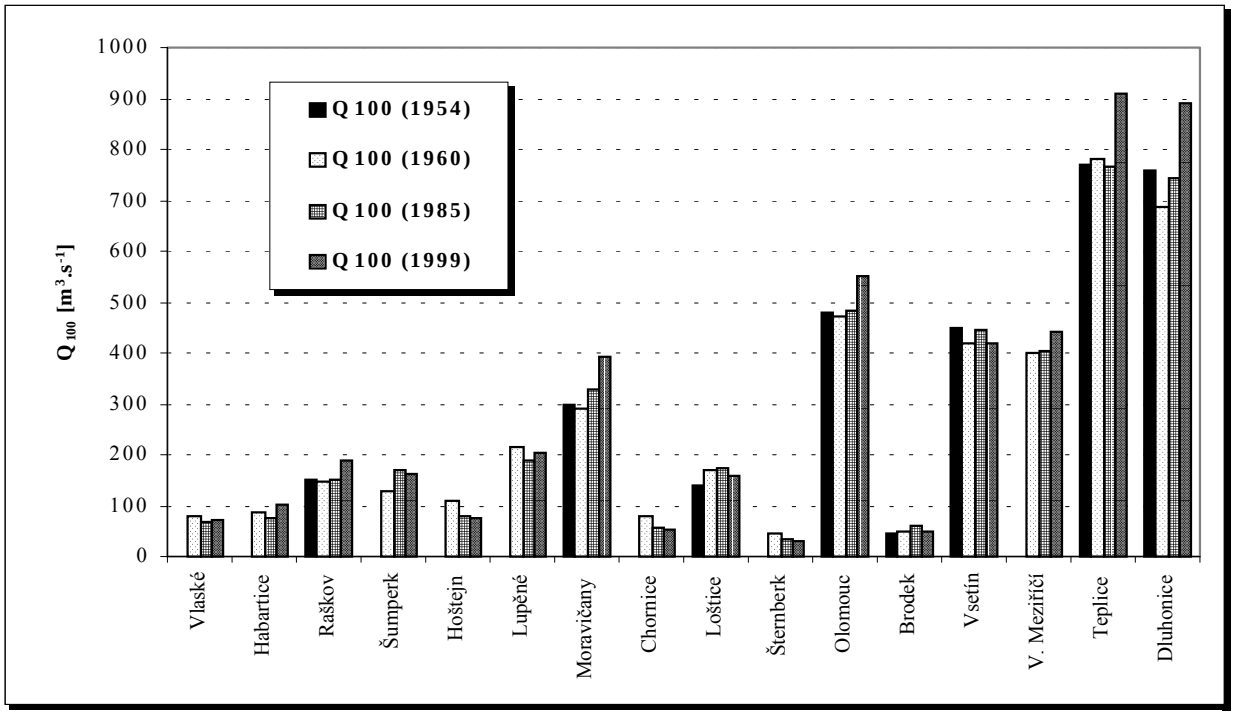

Bild 4 Vergleich der neuen und älteren Q_{100} in den auswählenen Pegelstationen

Die letzte Aktualisierung wurde bisher in 1999 durchgeführt. Die Werte des Hochwassers in eigener Strömung des March Flusses und auf dem Becva Fluß sind nach einer ausführlicheren Beurteilung erhöht worden. Sonstige Änderungen widerspiegeln die Bestrebungen, die theoretische Kurve mit empirischen Werten Q_{max} am glaubwürdigsten durchzulegen.

3.3 Regionale Abhängigkeiten des Vorkommens von q_{100}

Zur Festlegung der Werte Q_{100} zu einem beliebigen Profil verwendet man außer einer Reihe der theoretischen Formeln auch die Abhängigkeit der Abflusspenden (q_{100}) auf der Fläche des Flußgebietes (s. das Bild 5). Sie widerspiegelt regionale Besonderheiten einzelner Wasserströme gemäß den überwiegenden Naturbedingungen. Die höchsten Werte erreicht q_{100} auf dem Becva Flußgebiet, dann folgen die Zuflüsse der March aus dem Groben Jesenik-Gebirge, der eigene Fluß Morava und die Zuflüsse aus dem westlichsten Teil des Flußgebietes und aus dem Niedrigen Jesenik-Gebirge. Zu den ausgewählten Wassermeßprofilen sind wahrscheinlich die Hüllkurven q_{100} ergänzt worden, die eine Zone vermarken, in der wir nach der neuen Verarbeitung Abflusspenden Q_{100} finden können. Diese Zone erstreckt sich in einem Bereich von 4 bis 0,38 $m^3.s^{-1}.km^{-2}$ auf der Fläche des Flußgebietes von 50 km^2 und mit der wachsenden Fläche verengt sie sich bis zu einem Bereich von 0,7 - 0,17 $m^3.s^{-1}.km^{-2}$ auf der Fläche von rund 2 000 km^2.

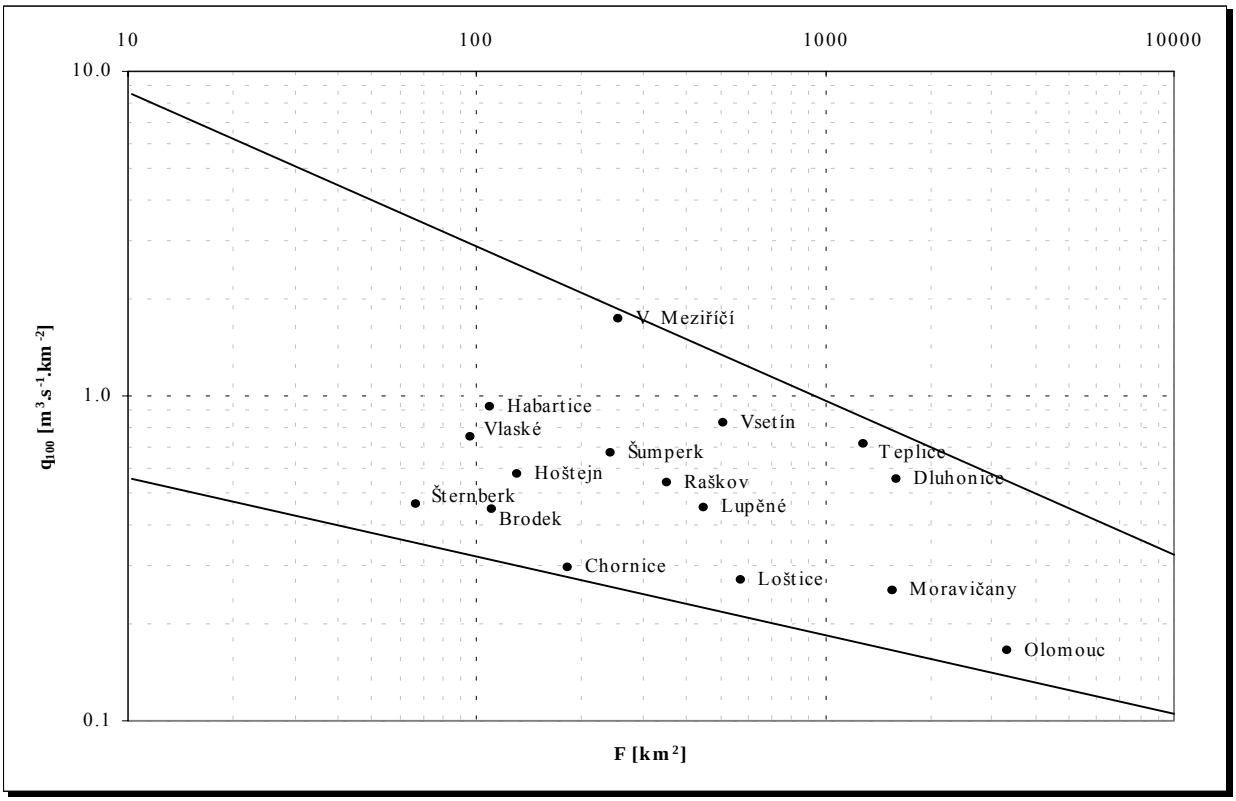

Bild 5 Die Abflusspenden des auswählenen Profiles

4 Abschluß

In 1999 ist bei der Zweigstelle von CHMU in Ostrava eine neue Verarbeitung der N-jährigen Hochwasserdurchflüsse im Flußgebiet der oberen March verlaufen. Das Ziel war, vor allem reale Zeitperioden der Wiederholung der höchsten Scheiteldurchflüsse aus dem Jahre 1997 festzustellen und die Werte nach den verlängten Zeitreihen der höchsten jährlichen Hochwasserdurchflüsse bei den Pegelstationen und anderen Profilen des Flußnetzes der Wasserströme zu ändern. Für den Ausgleich

der Durchflußreihen hat man eine logaritmisch-normale 3-Parameterkurve der Überschreitung angewandt, und zwar entweder mit einer Korrekturmöglichkeit der Änderung oder ohne sie.

Aus der Verarbeitung ergaben sich diese Erkenntnisse:

- Aufgrund der LN III Anwendung war es möglich, die nicht realen Zeitperioden der Wiederholung Q_{kulm} des Hochwassers in 1997 zu ändern.
- Aufgrund des Vergleiches mit den früher festgelegten Q_N Werten ist es festgelegt worden, daß diese Werte in beiden Richtungen in einem ähnlichen Umfang auch in der Vergangenheit geändert wurden.
- Für ausgewählte Pegelstationen sind die Hüllkurven q_{100} festgelegt worden.

Über die resultierenden Werte Q_N sind entsprechende wasserwirtschaftliche Organisationen informiert worden; und diese werden auch bei der Verarbeitung der hydrologischen Fachbegutachtungen angewandt.

Die Überarbeitung des Hochwassers kann man in der Zukunft auch nicht ausschließen. Die Hauptbestrebung ist, theoretische Werte sehr genau so festzulegen, daß es zu keinen grundlegenden Änderungen der gewährten hydrologischen Angaben kommt.

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Analysis of the Periodicity Discharge of Large Rivers in Voivodina

Atila Salvai, Pavel Benka, Radovan Savic

Abstract: The phenomenon of dry and wet years have always had a significant role and they have been of great interest in many fields of human activity. It can be said that the influence of dry as well as wet periods is not only of great but even of crucial importance for almost all economic branches. Today, when material goods have attained the high level of their value, it is very important to investigate and predict certain regularities of dry and wet years, as well as their cycles.

In this paper, the importance of preliminary hydrologic analyses in of raw data Yugoslavia, which, apart from the estimation of the basic statistic parameters, verification of consistency, representativity, homogeneity, and independence, include the investigation of time series periodicity, has been discussed.

Besides, an example of the periodicity discharge analysis of the major Yugoslav rivers, using the integral curves of modal deviation from the mean value and periodograms, has been performed. The application of the mentioned methods, has been carried out by using personal computer.

Key words: stochastic processes, periodogram, raw data treatment, mean annual discharges.

Die Analyse periodischer Abflüsse in großen Flüssen der Voivodina

Zusammenfassung: Das Phänomen trockener und nasser Jahre war immer von großer Bedeutung und von Interesse für viele menschliche Aktivitäten. Es kann festgestellt werden, dass der Einfluss trockener wie nasser Perioden nicht nur von großer sondern von entscheidender Bedeutung ist für nahezu die gesamte Wirtschaft. Bei den heute üblichen hohen Wertschöpfungen ist es sehr wichtig, bestimmte Gesetzmäßigkeiten für trockene und nasse Jahre zu erforschen und vorauszusagen.

In diesem Artikel wird die Bedeutung der grundlegenden hydrologischen Analysen der Rohdaten diskutiert, die neben der Schätzung der grundlegenden statistischen Parameter, der Überprüfung der Übereinstimmung der Repräsentanz sowie der Homogenität und Unabhängigkeit, die Untersuchung der Zeitperiodizität umfassen.

Außerdem ist ein Beispiel für die Analyse der Periodizität der Durchflüsse der großen jugoslawischen Gewässer beschrieben, unter Verwendung von Integralkurven der modalen Abweichungen vom Mittelwert und von Periodogrammen. Die erwähnten Methoden sind auf PC's programmiert.

Schlüsselwörter: stochastische Prozesse, Periodogramm, Mittlere jährliche Abflüsse, Behandlung der Rohdaten.

1 Introduction

Chronological changes of hydrologic quantities can indicate the occurrence of certain periodicity, not only within one year but also in the long-term intervals. The aim of this investigation was to study the possible periodic nature of mean annual discharges of the main Voivodina rivers.

The necessity of analyzing periodicity of time series has been pointed out in the modern hydrologic literature worldwide. Although some Yugoslav authors (Yevyevich, 1972; Prohaska, 1984; Zelenhasic et al., 1994; Salvai et al., 1994a; Savic and Salvai 1997b) have emphasized the importance of these analyses for a correct appreciation and description of hydrologic processes, studies of the potential periodicity has not yet become a constitutive and compulsory part of preliminary hydrologic analyses of raw data in treating the stochastic series.

Starting from the fact that valuable analyses of periodicity lacking, as well as being aware of the negative experience in treating the hydrologic cycles (mainly due to extensive computation), the researchers of the Institute for Water Resources Management, Novi Sad, in the frame of the research project "Management Utilization and Protection of Water in Voivodina", have developed several programming packages to calculate periodicity of the hydrologic and meteorological series using the methods of integral function of modular deviations and periodograms.

2 Study of the periodicity of mean annual discharges

Variations in the river discharge on a certain location is, among the others, observed as the occurrence of a potential periodicity of the hydrologic series of mean annual discharges. Thus for example, the mean annual discharge on a location in an observation period of many years, may have a cyclic character. Full cycles, if they appear, have their low- and high-water period (groups of years).

An in-depth analysis of this problem requires the application of several methods for studying the potential periodicity of hydrometeorological series, usually by applying correlation and spectral analyses, integral curve of modular deviations, method of floating mean method, etc. In this work we study the occurrence of periodicity using the methods of integral curve of modular deviations from the mean value and spectral analysis.

2.1 Integral curve of modular deviations indicate the chronological appearance of the low-water and high-water groups of years. For its construction it is necessary to carry out the time summation of modular coefficients deviations of the series of annual discharges from their mean long-term value.

In dealing with the regional analyses, in order to diminish the effect of general variability of the mean annual discharge on particular rivers or water gauging stations, the integral curve of modular deviations is described by the following formula:

$$\varphi(t) = \sum_{i=1}^{m} \frac{|K_i - 1|}{C_v} \quad ,$$

where: $K_i = Q_i / \overline{Q}$ is the function of modular coefficients; Q_i is the mean annual discharge of the given series i=1,2, ..., m; $\overline{Q}$ is the long-term average value of mean annual discharges, and C_v is the coefficient of variation.

When the problem of water state of a certain water stream is concerned, the high-water period is considered a series of years in succession for which the ordinates of the integral curve $\varphi(t)$ are positive. The period in the course of which the curve $\varphi(t)$ has a negative value corresponds to the low-water period, provided it is important for the total water inflow. The time interval containing one high-water and one low-water period is called the hydrologic cycle.

The definitions of the high-water and low-water cycles are different when total integral water inflow is not important. In that case, the high-water period is determined by a series of consecutive years in which the curve $\varphi(t)$ shows an increase, while in the low-water period it shows a decrease.

The groups of high-water and low-water years observed on the integral curves are often unevenly distributed in the time interval considered, they are characterized by different duration and water abundance. For a more reliable analysis of the periodicity of mean annual discharge values on a given location it is necessary to consider at least two to three full cycles. This analysis is also used to determine the representative series of years, making the basis for

estimating the mean long-term discharges.

2.2 Method of spectral analysis, line spectrum, or periodogram can be successfully applied to estimate the harmonics parameters of the periodic components. Thus, according to Yevyevich (1972), in the case of the series

$$x_t = D_t + C\varepsilon_t \quad ,$$

where: x_t is the instantaneous value of x in the moment t, D_t is the periodic component (or the periodicity exists only in the mean value), C is a constant, and ε_t is the stochastic stationary component, then the discrete series can be written in the form

$$x_{p,\tau} = \mu_\tau + \sigma_x \varepsilon_{p,\tau} \quad ,$$

in which $\tau = 1,2,...,\varpi$, where ϖ is the fundamental period of the series expressed by an integer, $p = 1,2,...,n$, where n is the number of periods ϖ in the finite series (when ϖ is one year, n is the number of years, $N = n\varpi$ is the length of the sample series), μ_τ is the periodic component in the mean, σ_x is the standard deviation of $x_{p,\tau}$ for which is assumed to be a constant, and $\varepsilon_{p,\tau}$ is the stochastic component. The periodic component $D_t = \mu_\tau$ is then described mathematically as

$$\mu_\tau = \mu_x + \sum_{j=1}^{m}\left(A_j \cos 2\pi f_j \tau + B_j \sin 2\pi f_j \tau\right) \quad ,$$

in which μ_x is the mean value of the series, A_j and B_j are the Fourier coefficients, and m is the number of significant harmonics. The parameters A_j and B_j, j=1,2,...,m, are estimated from

$$A_j = \frac{2}{n\omega}\sum_{p=1}^{n}\sum_{\tau=1}^{\omega}\left(x_{p,\tau} - \mu_x\right)\cos\frac{2\pi j\tau}{\omega} \quad ,$$

and

$$B_j = \frac{2}{n\omega}\sum_{p=1}^{n}\sum_{\tau=1}^{\omega}\left(x_{p,\tau} - \mu_x\right)\sin\frac{2\pi j\tau}{\omega} \quad ,$$

where $f_j = j/\omega$, which is the classical procedure for estimating the Fourier coefficients A_j and B_j by which the amplitudes C_j (as the parameters of different harmonics) are determined from the ratio

$$C_j^2 = A_j^2 + B_j^2 \quad .$$

Graphical representation of the values $C_j^2/2$, half of the amplitude squares, or sometimes the values C_j, C_j^2 or $\sum C_j^2/2$ as a function of f_j is called the linear or discrete spectrum, or periodogram.

It is necessary to notice that with the majority of time series of the mean annual values of hydrologic variables regular periodic variations are not observed. On the other hand, for the series of mean monthly data it is easy to notice the influence of the season in the form of a periodic component of the given hydrologic time series. Besides, the time series of the annual means may point out to the irregular cycles, but the nature of their periodicity is questionable.

3 Calculation results and periodicity characteristics

The analysis was carried out for the Danube, Tisa, and Sava at the gauging stations Bezdan, Senta, and Sremska Mitrovica, respectively for the period 1931-1998. To define the chronology of the occurrences of high- and low-water years and determine the representative periods, it was necessary to work out the integral functions of modular deviations of the average annual

discharges from the mean value. Besides, to define correctly the internal structure of the given hydrologic series, i.e. to find out the periodicity parameters, the periodograms of mean annual discharges have been constructed (Fig. 1). In constructing such periodograms for the fundamental series period the adopted values were 2, 4, 6,….60 years. This procedure ensured a successful determination of higher-order harmonics and identification of various sorts of periodicity.

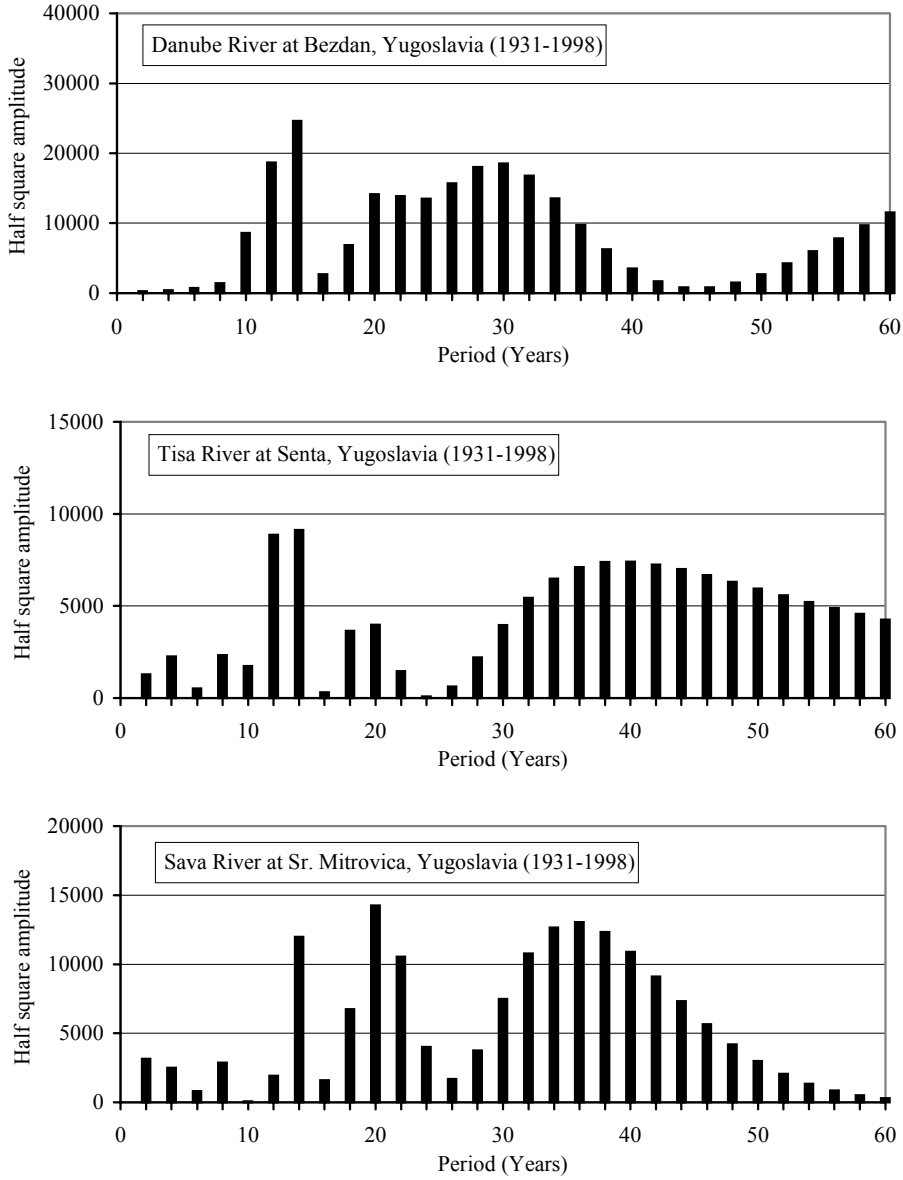

Fig. 1 Periodogram of mean annual discharges of large rivers in Voivodina.

The presented periodogram indicates the possibility of the presence of several significant harmonics, i.e. cycles, of which it is possible to single out:

- for the Danube – Bezdan, periods of 14 and 30 years;
- for the Tisa – Senta, periods of 14 and 38 years;
- for the Sava – Sr. Mitrovica, periods of 14, 20, and 36 years.

These conclusions have also been confirmed by the analysis of the integral function of modular deviation from the mean value. On the basis of the presented results it is possible to conclude that the mean annual river discharges are of a cyclic nature, with more or less pronounced

periods. This indicates that in the statistical analysis of the mentioned series the representative period has to be determined separately for each of the series. This could be expected in view of the fact that the effects of the different watersheds characteristics and, consequently, of the very regime of mean annual discharges, are of essential importance for the occurrence of low- and high-water cycles.

In a previous paper (Salvai et al, 1994) it was stated: "One can derive another hypothetical conclusion: if the integral function of modular deviations is extrapolated, then in the next period starting from the year 1994, it could be expected the occurrence of higher mean annual discharges of the analyzed rivers with the duration of 4 to 7 years". This prediction has appeared true for the 1994-2000 period. Consequently, on the basis of the analyses, some of which are given in the present work, in the subsequent period starting from the year 2000, it is possible to expect smaller mean annual discharges and a mild shortage of precipitation in the catchment area in the course of 4 to 7 years. Of course, this should be understood only conditionally, as this is merely a prediction based on the periodicity established for a series of annual discharges.

4 Conclusions

On the basis of the results obtained for the analyzed rivers, i.e. for the corresponding gauging stations, it is possible to identify certain significant cycles, as well as those that are less pronounced.

On condition that there are no changes in the climate, the analyst may dare to give even a crude prediction of the values of mean annual discharge in the forthcoming years.

In the future research, it would be inadmissible to disregard periodicity in treatment of raw data, as the availability of personal computers has removed the obstacle that hindered their wider application in the past.

Although the authors have not considered the error estimation, i.e. the accuracy of determining the parameters of hydrologic series in dependence of the adopted representative period, it is unquestionable that the enhancement of the accuracy of assessing the statistics of hydrologic series by defining the representative period for the sample size, the obtained values give a more realistic picture of the hydrologic circumstances and can yield more valuable conclusions and predictions. Besides, to estimate the significance of periodicity it is necessary to carry out statistical testing. This should be subject of the future research in this domain.

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Flood Control and Water Streams Regulation in Voivodina

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Abstract: Historical development of flood control and regulation of water streams are considered as a set of constructions, activities and measures yielding a decrease of unfavourable effects (damages) caused by floods, as well as a planned water resources management, and environmental protection. Useful experience, gained both in the country and abroad, indicate that because of the stochastic nature of flood discharge and the possibility of failure of the protection objects, an absolute flood control is not practically possible, so that the goal is to rationally diminish flood damages. It is pointed out that the system of flood control, together with the improvement of natural streams and canals network, represent for Voivodina the infrastructure of the "first-rate importance", whose normal functioning influences the development of practically all the economic and other activities. The direct and most frequent causes of flood in Voivodina have been the extremely high waters of the large and medium rivers, causing overbank flooding at some sites and, less frequently, the overflow of the dike crest, ice accumulation, as well as some other causes. To advance further the functioning of the flood control system, some additional measures of the investment and noninvestment character have been proposed on the basis of techno-economical and ecological analyses. Also, a proposition was made related to the realization of specific research projects, studies and surveys, as well as the completion of the technical and legislative documentation, all with the aim of enhancing the efficiency and economy of the system for flood control and streams regulation. At that, some specificities of Voivodina have to be taken into account, and especially the unfinished reconstruction and inadequate maintenance of the existing control systems.

Key words: flood, flood control, high waters, flood damages, flood mitigation.

Hochwasserschutzmaßnahmen und Abflussberechnung in der Voivodina

Zusammenfassung: Die historische Entwicklung der Hochwasserschutzmaßnahmen und der Abflussregelung werden als Paket aus Bauwerken, Aktivitäten und Maßnahmen betrachtet, mit dem Ziel der Minderung nachteiliger Effekte (Schäden) aus Hochwassern sowie als planvolles Verwalten der Wasserressourcen und Umweltschutz. Hilfreiche Erfahrungen, gewonnen im eigenen Land und anderswo zeigen, dass wegen der stochastischen Natur der Hochwasserabflüsse und wegen der Möglichkeit des Versagens der Schutzanlagen ein absoluter Hochwasserschutz praktisch nicht möglich ist. Daher muss das Ziel sein, Flutschäden vernünftig zu begrenzen. Es wird ausgeführt, dass das System der Hochwasserschutzmaßnahmen zusammen mit dem Ausbau der natürlichen Gewässer und des Kanalnetzes für die Voivodina eine Infrastruktur von höchster Bedeutung darstellt, deren reibungsloses Funktionieren die Entwicklung aller ökonomischen und sonstigen Aktivitäten beeinflusst. Die unmittelbaren und häufigsten Ursachen für Hochwasser in der Voivodina sind die extrem hohen Fluten der großen und mittleren Flüsse gewesen. Diese haben in einigen Bereichen ausufernde Überflutungen und gelegentlich Deichüberströmungen, Eisversetzungen und andere Schwierigkeiten verursacht. Um das Funktionieren der Hochwasserschutzmaßnahmen zu unterstützen wurden ergänzende Maßnahmen (kostenträchtige und ideelle) vorgeschlagen auf der Basis technisch-wirtschaftlicher und ökologischer Analysen. Darüber hinaus wurden Vorschläge unterbreitet zur Durchführung besonderer Untersuchungsprojekte, Studien und Übersichten wie der Vervollständigung technischer und gesetzgeberischer Dokumentationen. Alle Vorschläge verfolgen das Ziel, die Effizienz und Wirtschaftlichkeit des Hochwasserschutzsystems und der Abflussregelungen zu verbessern. Dabei müssen einige Besonderheiten der Voivodina in Betracht gezogen werden, besonders der unfertige Ausbau und die unzulängliche Wartung der vorhandenen Steuersysteme.

Schlüsselwörter: Überschwemmung, Hochwasserschutzmaßnahmen, Hochwasser, Flutschäden, Hochwasserminderung

1 Introduction

As is the case with many engineering undertakings, in the domain of water streams regulation, the decisions about acceptance of the majority of projects have been mainly made on the basis of the results of techno-economical analyses in which the parameters of technical reliability, functionality and economy of the proposed solution are of the crucial importance. However, the awareness of the increasing risk to the environment in general suggests that all the engineering projects, including the projects of river improvement for the control of floods, have also to take into account the parameters concerning environmental protection and its advancement (Official Gazette of the Republic of Serbia, 1991; Salvai, 1998). In fact, the word is about bringing into concordance the modern ecological and traditional techno-economical concepts in taking the engineering decisions. In other words, it is a rational compromise between human activities and nature itself, which should ensure a sustainable development of the society with an appropriate protection and advancement of the environment. The problem thus formulated is of general significance, and its solution is sought in terms of the new scientific-technological discipline called "engineering ecology" (Mazur, 1989; Arskii, 1992; Salvai, 1994).

Previous activities on flood control and improvement of watercourses in Voivodina have primarily ensured the basic conditions for physical existence of the major part of population, and then also for general economic and cultural development of the region. In relation to this, the flood protection structures, together with the network imrovement of watercourses (natural and artificial), represent for Voivodina the infrastructure systems of crucial importance, whose proper functioning influences almost all economic and other activities. However, the word is not only about the protective function of the system but also of ensuring the conditions for the development of some new activities, as well as of the enhancement of the utilization value of the land, water, and other resources in Voivodina (Institute for Water Resources "J. Cerni", 1995). It should be especially pointed out that, without flood control objects and water resources management in Voivodina, there would be no possibilities for intensive agricultural production on the reclamation systems based on modern methods of irrigation and drainage.

In view of the above it is obvious that for an effective flood protection it is necessary to analyze both the natural and anthropogenic factors which can yield an increased flood risk. This assumes the continuous co-operation with all the neighbouring countries, systematic measurements, monitoring and research of water streams regime on our territory, as well as the joint studies of different undertakings on the catchment areas and along the parts of water streams on our territory and the territories of the neighbouring countries (Hungary, Romania, Bulgaria, Croatia, etc.).

2 Assessment of the present state of flood control and water streams imrovement in Voivodina

The numerousness of the water streams in Voivodina and their diversity in respect of the hydrological, hydraulic, morphological characteristics, etc., as well as in respect of the purpose and utilization mode, have necessitated construction of the different structures, and undertaking various measures on the existing flood control and regulation systems. However, a crucial role in flood control and water streams imrovement have undoubtedly played the so-called passive measures, i.e. protection dikes and classical protection structures in the river bed, whereas the so-called active measures (effects of accumulations and retention) are of the secondary importance. An exception makes the main canal network of the Danube-Tisa-Danube (DTD) Hydrosystem, which in certain circumstances can also play an important active role in flood control.

The Voivodina region has been from ancient times endangered by flood because of the plain character of the terrain, as well as because of a developed network of water streams, with the diversity in their size and hydrological-hydraulic regimes (Fig. 1).

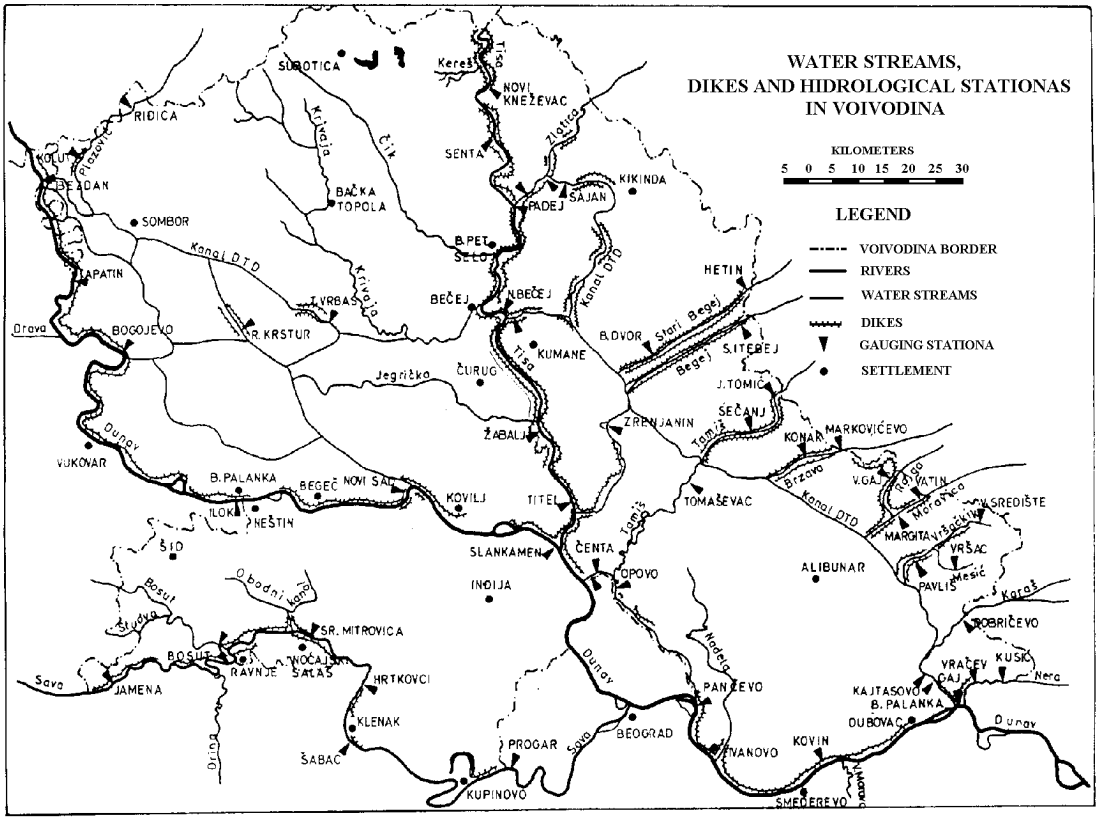

Fig. 1 Water streams, dikes and hydrological stations in Voivodina.

In Voivodina, about 60% of total territory (about 12,900 km^2) is potentially endangered by flood discharge frequency 1/100 per year. On the endangered surfaces there are about 80% of the most fertile agricultural soil, 260 settlements with 1.2 million of inhabitants, about 4,000 km of traffic routes, and a number of capital objects of national economy. The endangered areas are protected by a system of dikes of a total length of 1,400 km, with the accompanying objects and 14 smaller reservoirs. An active role in flood control has also the network imrovement of streams and canals of the DTD Hydrosystem. Out of the numerous flood occurrences which caused great direct and indirect damages in Voivodina, the most harmful were those of the rivers Danube (1965), the Tisa (1970) and the Sava (1974). The greatest damages were caused to agriculture (above 40%), and total damages in some communes exceeded 10% of the gross national product for the previous year.

The dikes along the Danube and Tisa have been reconstructed after the floods of the year 1965 and 1970, respectively, as well as in the frame of coastal belt protection from the backwater of the Hydropower Dam "Djerdap I". Reconstruction of the dikes has been completed on the 90% of their total length for one-hundred year high water and protective height of 1.0-1.7 m. The reconstructed dikes are presently in a satisfactory state. However, it should be noticed that there plans on reconstructing their remaining parts and sanitation of the weak points on about 30 locations in the zones of the objects constructed along the main protection line. In the future period, some new calculations and analyses should be carried out in order to quantify the need for constructing additional dikes along the Djerdap accumulation because of the additional back water due to sediment deposition.

The protective line of dikes along the Sava river is very heterogeneous in respect of the degree of its completeness, water bed discharge capacity, type of dikes and banks, time and technology of the dike construction, so that the flood control degree for the pertaining area is not

satisfactory. For this reason, it is necessary to carry out first completion of the construction, and then re-examination of the entire protection system. At that, it is also necessary to take into consideration all the possible variations of the hydrological-hydraulic regime of the high Sava waters under the influence of retentions and accumulations existing outside our country.

As for the smaller plain water streams, with the exception of the Karas river, they have been encompassed by the projects of dike construction, as well as by the projects of partial reconstruction of the dikes along the Stari Begej and Plazovic and some other small water streams. However, the realization of these projects will be probably slowed down because of the shortage of financial resources.

When the Voivodina torrents are concerned, the state of flood control is inappropriate and uneven. Although there are protecting structures on some of such streams, flood damages are evident, especially if the stream is flowing through the settlements (Bozinovic et al., 1995).

In order to increase the reliability of flood control systems in Voivodina it would be necessary, in addition to other works, to design and construct the border-line dikes, with the aim of preventing the uncontrolled breach of water from the neighbouring countries to the Voivodina territory during high water occurrence. A considerable attention should also be paid to the protection from ice-caused floods, i.e. to the prevention of formation of ice barriers. However, the ice protection service is not organized and equipped at a satisfactory level. It would be necessary to complete the icebreaker fleet along the Danube, Tisa and Sava rivers, as well as to establish and equip mobile teams to fight ice formation on smaller water streams.

On the whole, the state of flood control system in the region of Voivodina cannot be considered as fully satisfactory, so that it would be necessary to continue the action on realization of the works mentioned above. It would be highly desirable to do prompt sanitation of the weak points along the main protection lines, as well as to pay more attention to the systematic auscultation and maintenance of all the control system objects.

The works on regulation of the water stream beds in Voivodina have been very extensive and diverse in the previous period (Bozinovic et al., 1995). The most comprehensive works have been carried on the Danube with the aim of providing waterway traffic and protecting the river banks from deformation. In the period since the end of the 19th century to the present, the following works have been carried out on the Danube: 155.9 km of revetments; 27.8 km of groynes; 6.7 km of bariers; 1.1 km of bed fixation by sills ; 21.9 km stone deposition; 15 km cutoff meanders and other structures. The extent of regulation works has been directly influenced by the more stringent requirements for increasing the depth and other characteristics of the waterway. In 1965, in accordance with the recommendations of the Danube Commission, an investment programme was elaborated concerning regulation of the Yugoslav part of the Danube for the river traffic, requiring the minimal waterway depth of 2.5 m (the former minimal depth was 1.8 m and then 2.0 m), minimal width of 180 m, and minimal radius of the waterway bending of 1000 m. Up to now, more than 60% of the works have been carried out in accordance with this programme (Institute for Water Resources "J. Cerni", 1995), allowing thus a satisfactory state of the waterway traffic on the section Hungarian-Yugoslav border to Belgrade.

After the construction of the hydroelectric power station "Djerdap I", there has been no need any more for regulation works on the Danube downstream of Belgrade, because of the favourable effect of the back water on the Danube navigation characteristics. However, very extensive works had to be carried out on rising and reconstruction of the embnkments and revetments along the accumulation, with the aim of protecting the coastal belt from the increased water level and erosion action of the waves. Also, the works have been carried out on reconstructing of the quays in the settlements, water tapping objects, and on some other coastal structures.

On the river Tisa, significant regulation works were carried out still in the end of the 19th century. To the end of 1875, the length of the river bed of Tisa was shortened from 1419 to 962

km, which was due to the realization of 110 cutoffs (13 cutoffs on the Voivodina territory), with simultaneous constructing of a number of regulation objects. In the period of constructing the dam on the Tisa at Novi Becej it was necessary to reconstruct 8.5 km of revetments, to build the quay walls in the urban zones of Novi Becej, Knezevac and Senta (including the bed fixation by sills), and cutoff meander near the village of Sanad.

Regulation works on the Sava river can be dated back to the ancient times, especially those near the town of Sremska Mitrovica and in the zone of the Drina mouth. However, these works have been of fragmentary character, most often carried out for the purpose of navigation and strengthening the river banks in the settlements and coastal industrial zones.

In comparison with those carried out on the Danube, Tisa, and Sava, the regulation works that have been performed on the smaller water streams have been significantly less extensive in their scope. However, these works have allowed the majority of these water streams be successfully incorporated in the basic canal network of the DTD Hydrosystem, ensuring thus water regime management in the largest part of Backa and Banat. It should be especially pointed out that very favourable results have been obtained in protection of canal banks of the DTD Hydrosystem from erosion using biological means (Acimovic, 1994) and new synthetic materials (Bozinovic, 1984). In the Srem region, the situation in respect of regulation and control of water regime of smaller water streams is more unfavourable, but on the basis of the realization of the water supply project, a significant improvement in this region is to be expected.

Small longitudinal slopes of the majority of the natural water streams and canals in the plain region, as well as the periodic action of back waters, bring about a decrease in the transportation capacity for sediment and formation of deposit layers in the stream bed. As was already mentioned, this problem will be more acute in the near future, especially in the Djerdap accumulation, although some unfavourable consequences have also been evident on a large scale with some other water streams. For example, it was found that, to the year 1987, in the basic canal network of the DTD Hydrosystem there had been about 12 million m^3 of deposit, which had significantly diminished water conducting capacity of the canals, and there had been the instances when the deposit formed had greatly hindered operation of water gates, water locks, and other water management objects. Besides, the unfavourable characteristics of these deposits can cause substantial problems in the functioning of the drainage and irrigation systems (Savic, 1993).

3 Conclusions

The works and structures involved in flood control and regulation of the natural water streams and canals represent the infrastructure systems of primary importance, crucially influencing the overall economic and social activities in the Voivodina region. Thanks to the structures of flood control and water streams regulation, the whole Voivodina region has become a complex water management and land reclamation system. If it is taken into account that Voivodina represents the most developed region and the granary of Yugoslavia, then it can be concluded that a normal functioning of this system is of vital interest not only to Voivodina but to the country as a whole. Related to this, the auscultation and normal maintenance of the protection objects have to be considered as a permanent obligation of the whole community.

The nature of occurrence of floods, as well as the experience that has been gained in many countries of the world indicate that an absolute flood control cannot be achieved, but the application of a range of mutually compatible measures of the investment and noninvestment character can only yield rational diminishing of flood risks and damages. The largest part of Voivodina will be further protected by dikes (passive measures), with a reasonable utilization of the existing accumulations, retentions, and canal network of the DTD Hydrosystem (active measures). The measures of noninvestment character as a supplement to the investment ones, represent a set of administrative, legislative, and institutional measures aiming at the preventive

reduction of flood damages. The key elements of these measures are: specific landscape planning and land reclamation on the flood-endangered territories; regulations related to the mode of utilization of land, objects and other resources on the endangered areas; specific technical regulations in the domain of construction, utilization and maintenance of flood control objects on the flood-endangered areas; specific regulations concerning insurance of the property on the endangered areas. These measures are to be consequently applied in the forthcoming period.

Further advancements in the domain of designing, constructing, and utilizing of the system for flood control and regulation of water streams should be based on modern achievements of science and technology. All this assumes modernization of the equipment for field and laboratory research, application of modern methods for simulation, prediction and control of the processes important for all the activities in the field of flood control and water streams regulation. Besides, it is necessary to strengthen the co-operation with the neighbouring countries and promote joint synchronized actions on flood control and water streams regulation.

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Using Weather Data Generators for an Evaluation of the Effect of Climate Changes upon the Hydrological Regime at a Catchment Scale

Catalin Simota, Ciprian Corbus, Marinela Simota

Abstract: Weather data generators were developed for generating temperature and rainfall input data for a deterministic hydrological model (HIDROZ) predicting water balance elements on a catchment in order to predict climate change induced effects on water balance elements for a case study catchment (river Prahova, Poiana Tapului hydrological station).

Key words: Weather data generators, Climate Change, Hydrological simulation models.

Die Verwendung des Wetterdatengenerators für die Ermittlung von Effekten der Klimaänderung auf das hydrologische Regime im Einzugsgebietsmaßstab

Zusammenfassung: Wetterdatengeneratoren wurden entwickelt zur Erzeugung der Inputdaten Temperatur und Niederschläge für ein deterministisches hydrologisches Modell (HIDROZ). Damit soll die Prognose von Wasserbilanzelementen für ein Einzugsgebiet erzeugt werden, zwecks Vorhersage der durch Klimaänderungen verursachten Effekte in einem Pilotgebiet (Fluß Prahova, Poiana Tapului).

Schlüsselwörter: Wetterdatengeneratoren, Klimaänderung, hydrologische Simulations-Modelle.

1 Introduction

Climate changes predictions due to increasing concentration of carbon dioxide-like gases in the atmosphere from human activities need to be transferred in predictions of the changes in the main natural systems. One of the most sensitive natural systems to climate changes is the water body. The aim of the paper is to evaluate the effects of climate changes on the water resources using a deterministic hydrological model (HIDROZ) linked with a weather data generator deriving daily weather input data from monthly averages predicted by General Circulation Models. Generating rainfall data is crucial for running deterministic hydrological model. Therefore, new algorithms for generating rainfall data were developed in order to improve the performance of previous generators (Richardson, 1985; Danuso and della Mea, 1994) by including the generation of monthly averages in a multiple year series and of daily events corresponding to this sample of monthly data. The estimation of the snowmelt processes and evapotranspiration are depending on accurate predictions of maximum air temperature. A simple temperature data generator based on fractal properties of the daily instrumental temperature data was developed including the same characteristics (monthly and daily generation) as the rainfall generator.

2 Method

2.1 Weather data generators

An integrated spreadsheet (WTHGEN) application generating daily values for air temperature (mean, low or maximum) and rainfall using statistical parameters derived from long time series of instrumental data was developed. WTHGEN has incorporated algorithms deriving the statistical parameters for each model, and analysing the statistics of the output data.

WTHGEN could be used to generate weather data for climate change scenarios using the monthly outputs from General Circulation Models (GCM). The statistical parameters of the weather data generators are modified for generating daily data corresponding to climate change scenarios considering the following assumptions: the monthly average of precipitation or temperature are changed according with GCM-predictions, and the coefficient of variation of data is the same as for the actual climate

2.1.1 Rainfall generators

Rainfall is generated by sampling from Γ distributions. Three different rainfall generators were included in the software. The generators use various ways of grouping data and calculating parameters for Γ distributions for the sampling procedure. The generators were coded M1, M2 and M3.

- **M1** generates daily values of the rainfall sampling from Γ distributions corresponding to each Julian day. The parameters for Γ distributions are estimated for each Julian day analysing the rainfall events for that day occurred in a long time series. The statistical parameters needed for each Julian day are: average rainfall [P], maximum rainfall [Pmax], variance of the rainfall events over all the years with instrumental data [V], and the probability of the rain in the given Julian day. Therefore, using the input instrumental daily values of rainfall for a long time series 365 values of the above mentioned statistical parameters are calculated.

The dry/wet character of the day is determined in M1 comparing an uniform distributed random number {RND} with the probability of a rain day corresponding to the given Julian day. If {RND} is greater then this probability the day will be wet; otherwise it will be dry.

For each day sampling is from a Γ distribution with parameters:

$$a_\Gamma = [P(day)]^2 / [V(day)] \quad \text{or } a_\Gamma = [P_{CC}(day)]^2 / [V_{CC}(day)]$$

$$b_\Gamma = [P(day)] / [V(day)] \quad \text{or } b_\Gamma = [P_{CC}(day)] / [V_{CC}(day)]$$

for the actual climate, and climate change scenario, respectively.

- **M2** generates daily values of the rainfall sampling from Γ distributions corresponding to each month. The parameters for Γ distributions are estimated for each month analysing the rainfall events for the days corresponding to the given month occurred in a long time series.

The statistical parameters needed for each month are: average rainfall [P], variance [V] considering all the rainfall events in the given month in all years, standard deviation [σ] corresponding to the many-year series of monthly averages of rainfall events, the probability of a dry day following a dry day [ρ_{dd}] , and the probability of a wet day following a wet day [ρ_{ww}]. For computing P and V parameters only the days with rain are considered.

The rainfall generation procedure has four steps:

(i) estimation of the monthly average of rainfall for each year in the series of years to be generated by sampling from a normal distribution with mean P(month) or P_{CC}(month) and standard deviation σ(month) or σ_{CC}(month) ;

(ii) using uniform distributed random numbers and the values of ρ_{dd} and ρ_{ww} to fix the wet/dry character of the days in the given month, for each year in the series;

(iii) sampling for each year and month a large set of values from a Γ distribution having the parameters:

$$a_\Gamma = [P(month)]^2 / [V(month)] \quad \text{or } a_\Gamma = [P_{CC}(month)]^2 / [V_{CC}(month)]$$

$$b_\Gamma = [P(month)] / [V(month)] \quad \text{or } b_\Gamma = [P_{CC}(month)] / [V_{CC}(month)]$$

(iv) moving on the sampled set of values in order to find the sub-set having the average closest to the average sampled at the first step of the algorithm and the variance in a defined range around V or V_{CC} (default value for this range is 0.1*V, 0.1*V_{CC} respectively).

- **M3** generates daily values of the rainfall sampling from Γ distributions corresponding to each month. The parameters for Γ distributions are estimated for each month analysing the rainfall events for the days corresponding to the given month occurred in a long time series.

The statistical parameters derived for each month are: average rainfall [P], standard deviation [σ] corresponding to the many-year series of monthly averages of rainfall events, average of the series of each year standard deviations of daily rainfall from the monthly average rainfall [σ_{intra}], standard deviation [$\sigma_{\sigma\text{-intra}}$] of the series of each year standard deviations of daily rainfall from the monthly average rainfall, the probability of a dry day following a dry day [ρ_{dd}] , and the probability of a wet day following a wet day [ρ_{ww}].

The rainfall generation procedure has five steps:

(i) estimation of the monthly average of rainfall for each year in the series of years to be generated [Prec(month, year), or $Prec_{CC}$(month, year) for climate change scenario] by sampling from a normal distribution with mean P(month) and standard deviation σ(month). For climate change scenario the parameters of normal distribution are P_{CC}(month) and σ_{CC}(month), respectively);

(ii) estimation of the monthly variance of rainfall events in the series of years to be generated [Σ(year, month), Σ_{CC}(year, month) for climate change scenario] by sampling from a normal distribution with the mean σ_{intra}(month) and the standard deviation $\sigma_{\sigma\text{-intra}}$(month). For climate change scenario the parameters of normal distribution are $\sigma_{intra\ CC}$ (month) and $\sigma_{\sigma\text{-intra}\ CC}$(month);

(iii) using uniform distributed random numbers and the values of ρ_{dd} and ρ_{ww} to fix the wet/dry character of the days in the given month, for each year in the series;

(iv) sampling for each year and month a large set of values from a Γ distribution having the parameters:

a_Γ = [Prec(month, year)]^2 / [Σ(month, year)] or a_Γ = [$Prec_{CC}$(month, year)]^2 / [Σ_{CC}(month, year)]

b_Γ = [Prec(month, year)] / [Σ(month, year)] or b_Γ = [$Prec_{CC}$(month, year)] / [Σ_{CC}(month, year)]

(v) moving on the sampled set of values in order to find the sub-set having the average closest to the Prec(month, year) or $Prec_{CC}$(month, year) and the variance in a defined range around Σ(month, year) or Σ_{CC}(month, year).

2.1.2 Air temperature generator

Temperature is generated by superposition of a general trend of temperature across the year and a fractal noise stochastic process. The generator uses the same fractal dimension for all the months in the year. Generally, this fractal dimension is in the range 1.18-1.22.

The statistical parameters needed for each month in order to generate daily temperature values are: monthly average temperature [T]; standard deviation [σ] of the many-year series of monthly averages of temperature; average of the many-year series of standard deviations [σ_{intrs}] of daily temperatures from the corresponding monthly average.

The generation process for daily temperatures has the following steps:

(i) stochastic generation of series of 365 fractal random numbers having the standard deviation 1 and 0 mean;

(ii) inflating the numbers in order to reach the standard deviation of temperatures corresponding to the given month (σ_{intra});

(iii) sampling from the 12 normal distributions with mean T(month) and standard deviation σ(month) of sets of average monthly temperature;

(iv) changing the fractal random numbers with the trend of temperature as resulted from sampling procedure from the previous step.

2.2 HIDROZ model

HIDROZ is a computer model developed for the simulation of the main hydrological processes on the catchment scale: snow melting, rainfall interception, storage in micro-depresions, evapotranspiration, infiltration, runoff, subsurface flow, percolation, base flow (Serban et al. 1990). HIDROZ splits the catchment in sub-catchments in accordance with the integrated flow network. For each sub-catchment:

- the degree-day method is used for estimating the water from the snowcover (Chow, 1971);
- the average water inflow is computed by weighting the instrumental values of rainfall and water melting from the snowcover recorded in the network of rain-gauge and meteorological stations (Serban et al. 1989);
- the net rainfall (runoff) is estimated extracting from the average water inflow the values of infiltration and evapotranspiration using a reservoir-type algorithm (Serban et al. 1989);
- use of the convolution integral having the instantaneous unit hydrograph as the transfer function, for the hydrological system integration of the net rainfall on the slopes and on the first order hydrographic network providing the hydrograph for each sub-catchment (Serban, 1984).

The mathematical relationships included in HIDROZ are not included in the full extent the physical laws describing the main hydrological processes due to the limitation of the available instrumental data. Therefore, HIDROZ includes simplifications of the physical laws (infiltration, percolation), empirical (evapotranspiration) or euristic relationships (interception, water storage in micro-depresions, runoff, subsurface and base flow).

3 Results

The catchment of river Prahova at the hydrological station Poiana Tapului was selected as case study (catchment area : 204 km^2, average altitude: 1362 m) having long time and good quality instrumental weather data.. Precipitation were recorded on 3 rain-gauge stations (Piatra Arsa, Azuga and Busteni), 3 meteorological stations (Predeal, Virful Omul and Babele) and 1 hydrometric station (Poiana Tapului).

The average rainfall on the catchment was calculated for each day by arithmetic mean of the values recorded on the 7 sites with instrumental records.

The maximum daily temperatures were calculated adding 2^0 to the recorded values at Predeal meteorological station due to the difference in altitude between the meteorological station (1000 m) and the average altitude of the catchment (1362 m).

The scenario for climate change considering the doubling of CO_2 concentration was derived from CCCM Global Circulation Model (Boer et al., 1991). Table 1 shows the monthly averages of temperature and rainfall changes for the case study area.

Table 1 Monthly averages of temperature and rainfall according with CCCM Global Circulation Model (Prahova river catchment)

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
δT (°C)	4.0	3.7	4.3	3.2	3.4	4.3	5.5	5.0	4.2	3.4	3.4	3.1	3.96
δP	1.09	0.88	1.03	0.94	0.98	0.81	1.17	0.99	0.80	1.24	1.11	1.14	1.50

The three methods used for rainfall generation were tested using the statistical parameters derived analysing the instrumental datasets of average precipitation on the catchment for the period 1971-1988. Figures 1-3 show some standard statistical parameters comparing the instrumental and generated rainfall data series for the M1, M2 and M3 generators. The data

were analysed considering monthly cumulated values and daily values of rainfall events. The best fit between instrumental and generated rainfall data (monthly and daily) were for the M3 generator. Data generated with M3 generator will be used in the next of the paper.

Figure 4 shows the fit between instrumental and generated data for maximum temperatures.

Figures 1-4 show the average and standard deviations for the rainfall and temperature series corresponding to climate change scenario derived from using weather data generators, too.

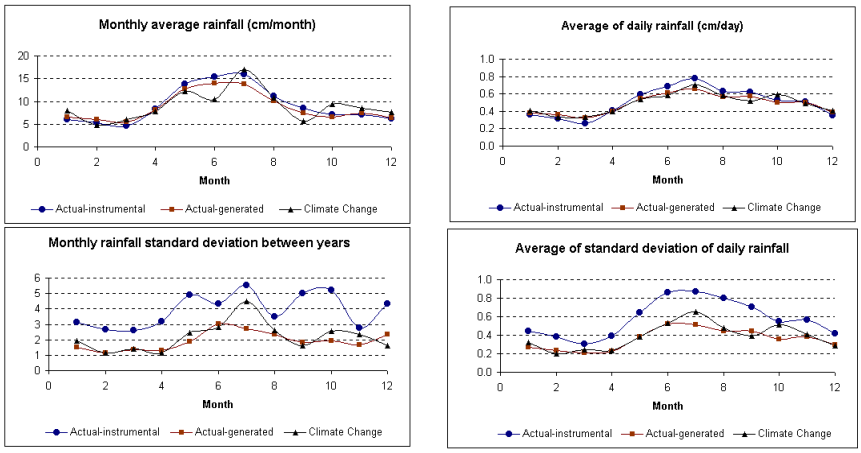


Fig.1 Standard statistical parameters for monthly and daily rainfall for actual (instrumental and generated) and climate change scenario (Prahova river, Poiana Tapului hydrological station, 1971-1988). M1 rainfall generator.

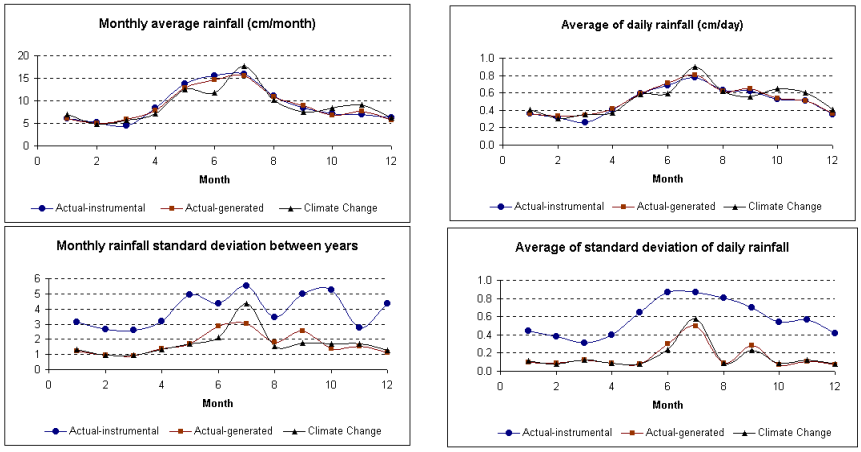


Fig. 2 Standard statistical parameters for monthly and daily rainfall for actual (instrumental and generated) and climate change scenario (Prahova river, Poiana Tapului hydrological station, 1971-1988). M2 rainfall generator.

The hydrological model HIDROZ was calibrated for the Poiana Tapului catchment by simulating the daily river flow for the period 1971-1980. Most of the model parameters have a precise physical meaning. Therefore, their values were derived from hydro-meteorological data. The other parameters, also having a definite physical meaning have a pronounced spatial variability on the catchment area. Their average values on the catchment were derived using optimisation techniques having as criteria of convergence minimisation of standard deviation between measured and simulated unit hydrograph. The optimum values of these parameters were: cumulated water in interception reservoir = 6.8 mm; maximum soil infiltration rate = 30 mm h^{-1}; minimum soil infiltration rate = 2.5 mm h^{-1}; subsurface flow coefficient = 0.002; water storage in micro-depresions = 2 mm; threshold for subsurface flow = 33 mm; water storage in

vadose zone = 100 mm; base-flow parameter = 0.04; delay time between weight centre of the rainfall hietograhm and the weight centre of the runoff hydrograph = 20 h; recession coefficient of the hydrograph = 0.25.

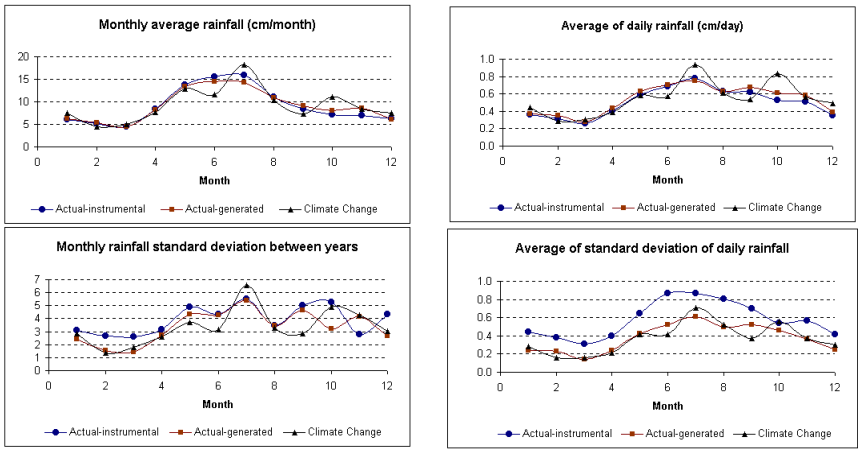


Fig. 3 Standard statistical parameters for monthly and daily rainfall for actual (instrumental and generated) and climate change scenario (Prahova river, Poiana Tapului hydrological station, 1971-1988). M3 rainfall generator.

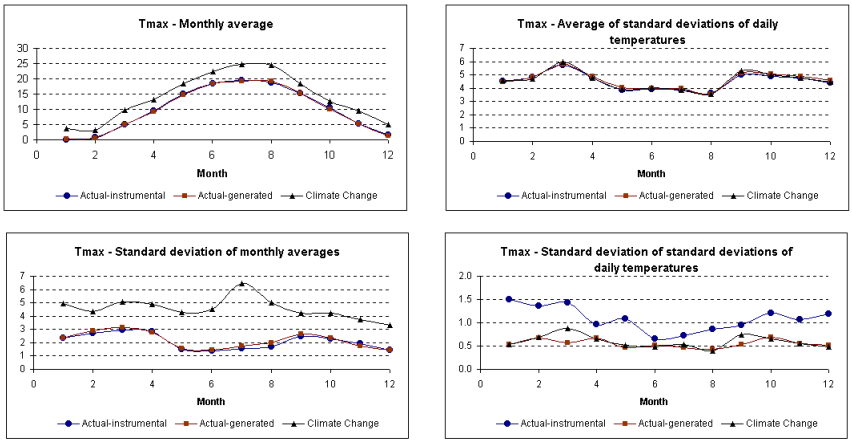
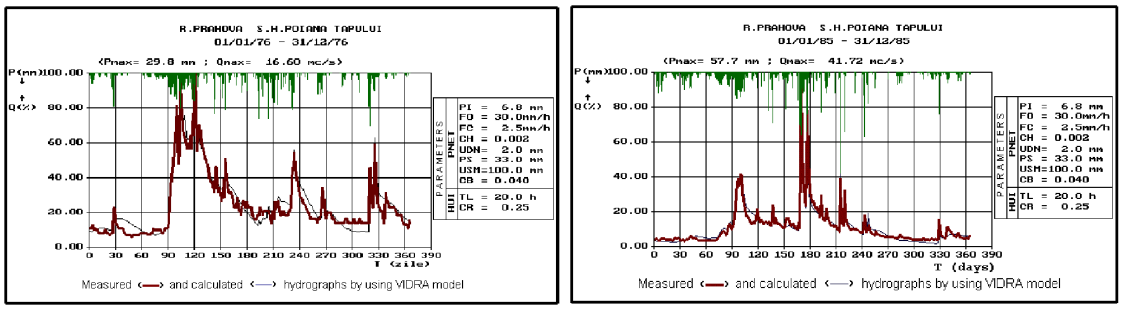


Fig. 4 Standard statistical parameters for monthly and daily maximum temperatures for actual (instrumental and generated) and climate change scenario (Prahova river, Poiana Tapului hydrological station, 1971-1988).

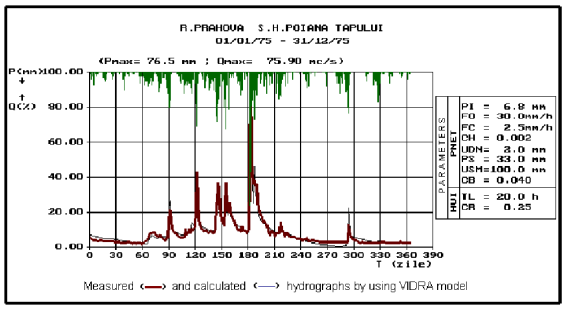
Figure 5 shows the comparison between recorded and simulated values for low (year 1976), average (year 1985) and maximum (year 1975) flow. The errors induced by the simulation model are low compared with the errors from meteorological and hydrological instrumental data, and from averaging meteorological data on the catchment scale.

The results of simulations for actual and climate change scenario show the following changes in the main water balance elements on the case study catchment:

- for climate change scenario, the average annual precipitation decreases with 1.5 %;
- in autumn-winter season the precipitation increases with up 29 % in november;
- annual actual evapotranspiration increases in climate change scenario with 56.6 mm due to the rise of annual average air temperature with 3.9 ^{o}C;
- in may-july (monthes with maximum development of the crop cover) were estimated the highest increases of actual monthly evapotranspiration (with up to 30-35 mm month^{-1});



(a) **(b)**



(c)

Fig. 5 Comparison between measured and HIDROZ simulated low (a), average (b) and maximum (c) flow (Poiana Tapului hydrological station, 1976, 1985, 1975)

- the soil water content in vadose zone decreases in climate change scenario with an average of 12 % due to decreasing rainfall and increasing actual evapotranspiration. During the year this variable show an increase during the winter (up to 26.5 %) and a sharply decrease in summer (down to 34 %);
- the soil water content in saturated zone is decreasing in climate change scenario in average with 24.3%. During the year this parameter shows an increase (up to 63.7 %) in december-march and a decrease (down to 53.7 %) in the rest of year;
- the average flow decreases with 30.9 %;
- the variation of flow during the year shows an increase up to 61.1% in november-march and a decrease down to 58.1 % in the rest of the year;
- the low flowduring the summer months is reducing notably in climate change scenario (down to 97.5 % in august);
- floods due to snowmelting will be in climate change scenario earlier in the year and higher. The floods from snowmelt processes will be time separated from rainfall floods.

4 Conclusions

The integrated system of weather data generators, simulation model for hydrological processes and Global Circulation Model output is an usefull tool investigating the effects of climate changes on water resources.

For the case study area (Prahova river, Poiana Tapului hydrological station) the main changes in hydrological cycle due to climate changes are:

- reducing the depth and duration of snow cover due to the increase of temperature in the winter months. Therefore, the risk of pollution due to contaminant substances from the snowcover is decreasing;
- the average water flow will decrease with 30 % mainly due to decreasing the precipitation;

- the snowmelt floods will be earlier in the year;
- the spring mixt floods (rainfall and snowmelt) will reduce due to the time lag between snowmelting and rainfalls;
- decreasing the soil water content induces the decrease of low flow (in summer and autumn months). Therefore, the risk of pollution increases and drinkable water supply could be restricted.

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Gesetzliche Überschwemmungsgebiete zur Hochwasservorsorge

Detlef Sönnichsen, Thomas Rieck

Zusammenfassung: Die Lenkung menschlichen Handelns in Überschwemmungsgebieten (ÜG) ist eine bezahlbare Hochwasservorsorge. Sie ist Aufgabe der staatlichen Verwaltung. Es bedarf Kartenwerke mit einer klaren Darstellung der gefährdeten Flächen, der Angabe der zu erwartenden Wasserspiegelhöhen und gesetzlicher Regelungen, die einfache, nachvollziehbare und langfristig durchsetzbare Anordnungen enthalten. ÜG-Gebiete sind durch die zuständigen Wasserbehörden zu pflegen und zu überwachen.
Aus wasserwirtschaftlicher Sicht gilt folgendes Handlungsgebot:

1. Information und Beratung der Betroffenen (Schutz durch Eigenvorsorge).
2. Freihalten leistungsfähiger Fließquerschnitte in besiedelten Gebieten (Schutz durch Wasserspiegelsenkung).
3. Schutz der Retentionsräume zur Dämpfung und Verzögerung der Hochwasserabflüsse in unbesiedelten Gebieten (Schutz durch Retention).

Schlüsselworte: Hochwasserschutz, staatliche Lenkung

Statutory Flood Plains for Flood Prevention

Abstract: The regulation of human intervention in flood plains is a payable way of flood prevention. It is the duty of the statutory administration to do this. This requires good maps with clear representation of the endangered areas, declaration of the expected waterlevel hights and statutory regulations that consist of simple, understandable and in the long term acceptable regulations. The flood plains need to be controlled and taken care of by the competent authority.
From the view of the water recources management following actions are required:

1. Infomation and advice to the persons concerned(protection through selfprecaution)
2. Keeping clear an efficient flow cross-section in populated areas (protection through lowering water level)
3. Protection of retention areas to absorb and delay the flood water flow in unpopulated areas (protection through retention).

Key words: Flood control, statutory survey

1 Hochwasservorsorge

Außerordentliche Hochwasser sind Naturereignisse mit seltenen Wiederkehrintervallen. Sie werden für den Menschen zur Katastrophe, weil sie sich in seinen Lebensraum ausdehnen.

Abb. 1 Lügde HW1946, Emmer A_{Eo} 400 km²

Auch heute noch gehen extreme Hochfluten über das Vorstellungsvermögen der meisten Menschen hinaus. Dieser Mangel führte und führt zu falscher Siedlungspolitik und Sorglosigkeit, die häufig auch eine Vernachlässigung der Unterhaltung der Gewässer und der Bauwerke zur Folge hat.

Erst nach Ablauf von Hochwasserkatastrophen werden besondere Anstrengungen unternommen, mit dem Ziel besserer Vorhersage und Vorsorge.
Zur Vorsorge zählen:

- Technischer Hochwasserschutz wie: Gewässerausbau, Deichbau, Hochwasserrückhaltung (Maßnahmenvorsorge)
- Dezentraler Hochwasserschutz
- Ausweisung der Überschwemmungsgebiete, (Flächenvorsorge)

Für diese Aufgaben zuständig ist der Staat. Er muss

- die Hochwassergefahren erkennen,
- die Vorsorgemaßnahmen ergreifen und
- ihre Wirksamkeit auf Dauer sicherstellen.

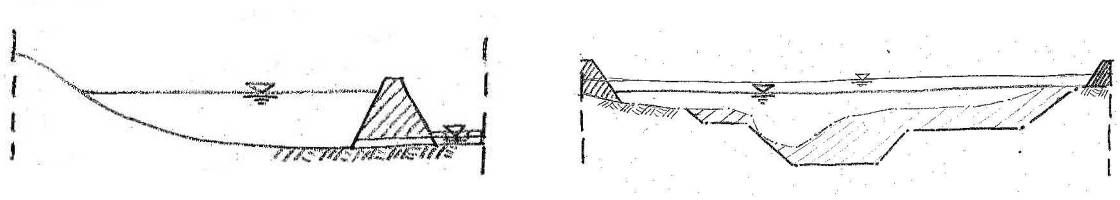


Abb. 2 Technische Maßnahmen a) Volumenbewirtschaftung b) Linienschutz

Verbessern und Vorsorgen durch technische Maßnahmen werden weiterhin notwendig sein. Genauso wichtig sind aber Ordnungsmaßnahmen, die einen weitsichtigen zukunftsorientierten Hochwasserschutz verfolgen. Ordnungsziel muss sein, menschliches Handeln am Gewässer und in den ÜG zugunsten eines schadlosen Hochwasserabflusses zu regeln.

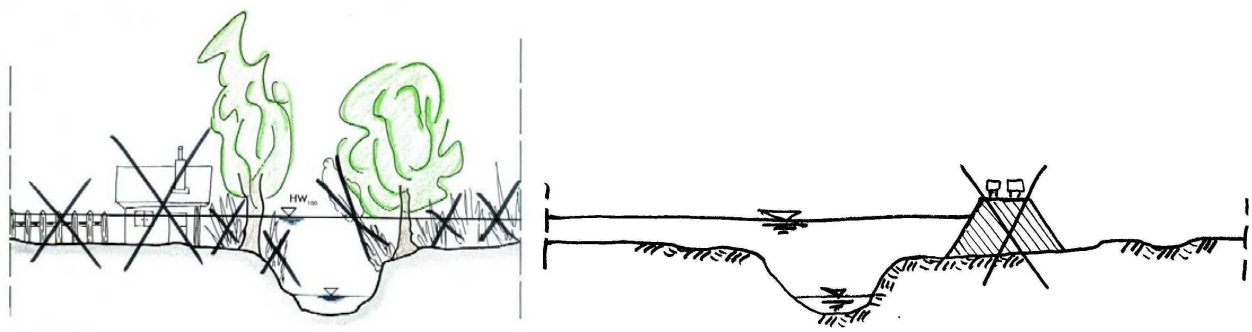


Abb. 3 a) Profilpflege in besiedelten Gebieten, b) Verlust Retentionsraum

Grundlage für Ordnungsmaßnahmen, die kurzfristig und mit verhältnismäßig geringem finanziellem und verfahrensrechtlichem Aufwand ergriffen werden können, ist die Festsetzung gesetzlicher Überschwemmungsgebiete. Als Warnhinweis für Betroffene, als Planungsgrundlage für die Städte, als Lenkungsinstrument der Wasserbehörden. Dazu sind drei Bausteine erforderlich:

1. Karten der Überschwemmungsgebiete
2. Gesetzliche Regelungen
3. Überwachung

Sie sind Grundlage, im öffentlichen Interesse so zu handeln, dass die Abflussverhältnisse nicht verschlechtert und Schäden an vorhandenen und geplanten Anlagen verringert oder vermieden werden.

2 Preussische Pionierleistung

Bereits Anfang dieses Jahrhunderts belegte die preussische Wasserwirtschaftsverwaltung die Überschwemmungsflächen der Gewässer mit gesetzlichen Beschränkungen. Auf der Grundlage des

Hochwasserschutzgesetzes von 1905 wurden im Staatsgebiet innerhalb von 10 Jahren flächendeckend Verzeichnisse der hochwassergefährlichen Gewässer aufgestellt und Karten im Maßstab 1 : 25.000 mit deren Überschwemmungsgebieten angefertigt. Auslöser und Grundlage für die umfangreichen Arbeiten waren die Hochwasserkatastrophen von 1841, 1890 und 1909.

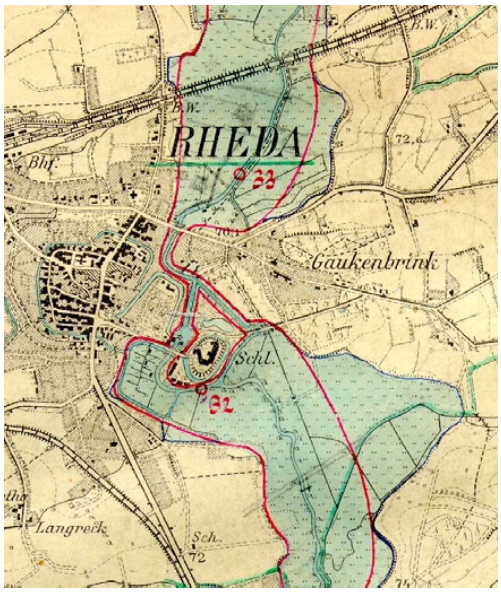


Abb. 4 Überschwemmungsgebiet von 1911, Massstab 1 : 25 000, Ems A_{Eo} 360 km²

Die Karten waren sorgfältig erarbeitet und wurden durch textliche Festsetzungen ergänzt. Sie enthielten sehr detaillierte Vorschriften, z.B. über die Art der Zäune an den Gewässern. Durch farbliche Kennung wurde in Stau- und Abflussgebiete unterschieden. Bis zur 6. Novellierung des bundesdeutschen Wasserhaushaltsgesetzes –WHG- 1996 übernahmen die Gesetze die preußische Vorschrift über gesetzliche Überschwemmungsgebiete fast unverändert. Allerdings wurde die Gültigkeit nur auf die Abflussgebiete (innerhalb der roten Grenzen) beschränkt. Das hatte zur Folge, dass ohne besondere Vorschriften in den Staugebieten gebaut werden durfte – mit negativen Auswirkungen.

3 Aktuelle Situation

3.1 Jüngere Ereignisse

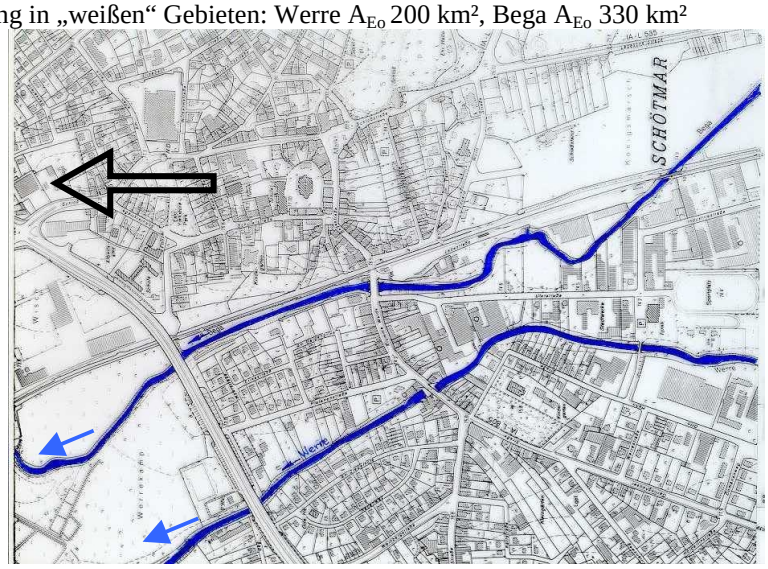
Katastrophenhochwasser in der jüngeren Geschichte haben durch Medienberichte die Bevölkerung beeinflusst und politische Folgen gehabt. Aktionspläne wurden und werden erarbeitet. Vorsorgemaßnahmen durch technische Anlagen und ein gezieltes Flächenmanagement sollen folgen.
Durch die Novellierung des § 32 WHG hat die Politik die Überschwemmungsgebiete in der Bundesrepublik neu bewertet. Aus dem Dornröschenschlaf wechselten sie in das Rampenlicht des Tagesgeschäftes. Der fast 90 Jahre alte preußische Text wurde stark verändert und mit ökologischen Ansprüchen angereichert. Jede Inanspruchnahme ist heute an das öffentliche Wohl geknüpft und muss strikt ausgeglichen werden. Hochwasser-Aktionspläne wurden und werden erarbeitet. Vorsorgemaßnahmen durch technische Anlagen und ein gezieltes Flächenmangement sollen folgen.
Es ist eine Situation entstanden, die folgendermaßen charakterisiert werden kann:

- Der Einfluß der Überschwemmungsgebiete auf die Dämpfung von Hochwasserabflüssen wird oft überschätzt.
- Die negative Wirkung der Inanspruchnahme kleiner Stauflächen wird ebenfalls oft überschätzt.
- Jegliche Inanspruchnahme wird hysterisch abgewiesen
- Unklare Rechtsverhältnisse und fehlende Vorgaben verzögern ein zügiges Erarbeiten der Karten und Verordnungen.

3.2 Alte Karten, „weiße“ Gebiete

Bis auf Ausnahmen galten die preußischen Karten Jahrzehnte unverändert, teilweise gelten sie heute noch. Es ist schwer nachzuprüfen, wie positiv ihre Wirkung war. Allerdings gibt ein Blick auf Gewässer ohne gesetzliche ÜG einen Eindruck, wie regelloses Bauen gerade in der stürmischen Entwicklung der Nachkriegszeit zu einem beträchtlichen Schadenspotential führen konnte.

Abb. 5 Entwicklung in „weißen“ Gebieten: Werre A_{Eo} 200 km², Bega A_{Eo} 330 km²



In den vergangenen 80 Jahren hat sich viel getan. Die alten ÜG-Karten sind zu aktualisieren und in „weißen“ Gebieten neu aufzustellen. Heute sind flächendeckend kleinmaßstäbliche Grundkartenwerke der Landesvermessung mit Höheninformation vorhanden und mit modernen Berechnungsmethoden lassen sich Bemessungsabflüsse und Wasserspiegellagen ermitteln. Eine gute Grundlage für eine Neubearbeitung.

4 Erarbeitung von Überschwemmungsgebietskarten

4.1 Arbeitsziel

Weil die Überschwemmungsgebietskarten und ihre Verordnungen vor allem für außerordentlich seltene Hochwasser Vorsorge tragen, müssen sie folgenden Ansprüchen genügen:

- Sie müssen eindeutig und verständlich sein.
- Sie müssen die gefährdeten Flächen ausweisen und die auf NN bezogenen WSP enthalten.
- Die Verordnungen sollten sich auf wenige, nachvollziehbare und überprüfbare Tatbestände beschränken, die auf Dauer verfolgt werden können.

Um im Entscheidungen im Gebäudemaßstab fällen zu können, sollte der Maßstab 1 : 5.000 nicht überschritten werden.
Man muss nicht für die Ewigkeit arbeiten. Die Erfahrung lehrt, dass Unterlagen nach 20 oder 30 Jahren ihre Glaubwürdigkeit verlieren, wenn sie nicht auf dem laufenden gehalten werden. Lieber zügig mit einfacheren Mitteln abarbeiten, als im Detail verhungern.
Um Akzeptanz und Respekt zu erreichen, sind die Bedürfnisse der Betroffenen (Kommunen, Landwirtschaft, Industrie) zu berücksichtigen. Es ist der Mensch, der vor dem Hochwasser gewarnt und geschützt werden soll und nicht das Hochwasser vor dem Menschen.
Die Sozialgebundenheit des Eigentums bedingt, dass Beschränkungen entschädigungslos hingenommen werden müssen.

4.2 Grundlagen

Der Bearbeiter benötigt Karten im Maßstab 1 : 5.000 mit Höheninformationen in Form von Isolinien oder als digitale Geländemodelle.
Der Wasserspiegellängsschnitt wird auf der Grundlage historischer Wasserstandsbeobachtungen oder mit Hilfe mathematischer Modellberechnungen erzeugt. Grosse, schiffbare Wasserläufe werden in der Regel intensiv beobachtet und es gibt längendeckend aufgenommene Hochwassermarken historischer Ereignisse. Es gilt diese in den Archiven und der Örtlichkeit aufzufinden.
Bei den übrigen Gewässern sind Hochwasserabflussspenden zu ermitteln und in Wasserspiegel umzusetzen. Hinter dieser lapidaren Feststellung kann ein enormer Aufwand stecken: Modellierung des Einzugsgebietes für die Nachbildung des N-A-Prozesses, Modellierung des Gewässers für die Umsetzung der Abflüsse in Wasserspiegel. Im einfachen Fall kann auf eine Pegelstatistik und Beobachtung historischer Hochwasser zur Ermittlung der Bemessungsabflüsse zurückgriffen werden.
Für die Berechnung der Wasserspiegel ist auf jeden Fall ein Hydraulikmodell aufzubauen. Eingangsgrößen sind

- Talquerprofile,
- Bauwerksgeometrien,
- Rauheiten,
- Anfangsbedingungen,
- Abflüsse.

Ist der Aufwand nicht sofort auf ganzer Länge zu leisten, besteht die Möglichkeit sich inselartig auf die Ortsdurchgänge mit ausreichend langen Anschlussstrecken zu beschränken.
Die Berechnung mit eindimensional rechnenden Modellen ist i. d. R. ausreichend. Für die Güte der Ergebnisse sind die Rauheiten des Gewässerbettes, der Linienführung und des Bewuchses von Bedeutung. Ergebnisse sollten durch Messungen bei Hochwasser überprüft werden.

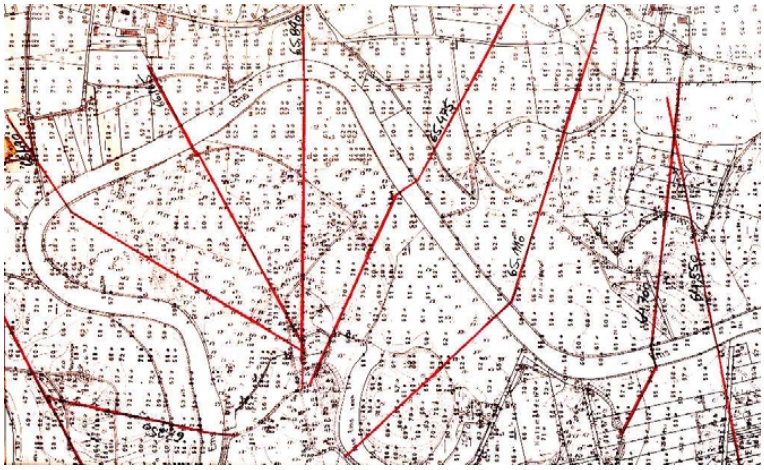


Abb. 1 1D-Modell-Anpassung durch abgewinkelte Profile, Ems A_{Eo} 4800 km²,

Dadurch, dass natürliche Entwicklungen wie Auflandungen und Bewuchs die Talverhältnisse ständig ändern und wegen der Toleranz der Bemessungsabflüsse sollte übertriebener Aufwand vermieden werden.
Jegliche Modellanwendung erfordert ausgiebige Erfahrung und Zugang zu möglichst vielen Kontrolldaten.

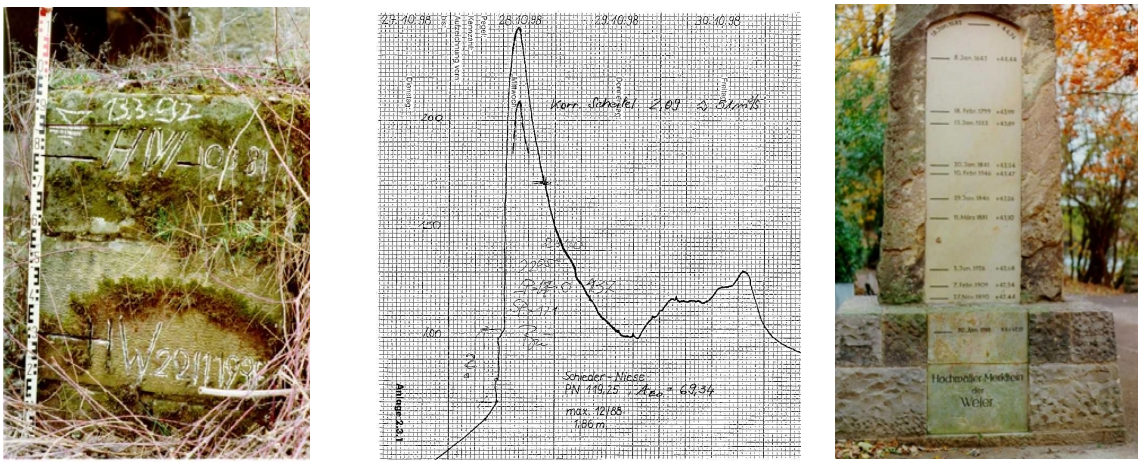


Abb. 2 a) Eigene Erhebungen, b) Pegelaufzeichnungen, c) Historische Marken

4.3 Bearbeitung

Der durch die Höheninformation abgebildete Talraum ist mit dem Wasserspiegellängsschnitt zu verschneiden. Das kann von Hand erfolgen oder durch Anwendung eines Geografischen Informationsystemes (GIS). Diese Computer gestützte Anwendung ist auf jeden Fall von Hand nachzuarbeiten.

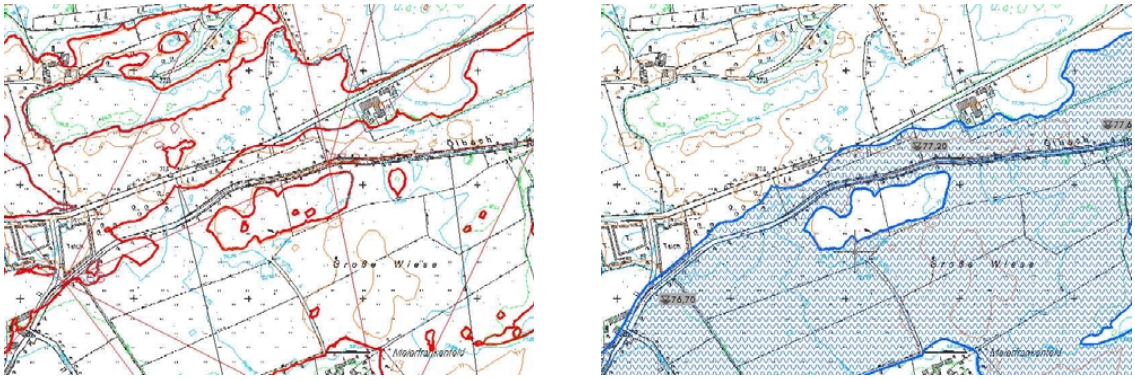


Abb. 1 a) Auto-Benetzungslinien b) manuelle Nachbearbeitung; ÜG Ölbach A_{Eo} = 80 km²

Danach erfolgt die Abgrenzung und Darstellung des gesetzlichen ÜG‘s durch Schraffieren des natürlichen ÜG‘s. Geschlossene Baugebiete werden herausgenommen und überschwemmungsgefährdete Flächen durch beschriftete Linienzüge gekennzeichnet.

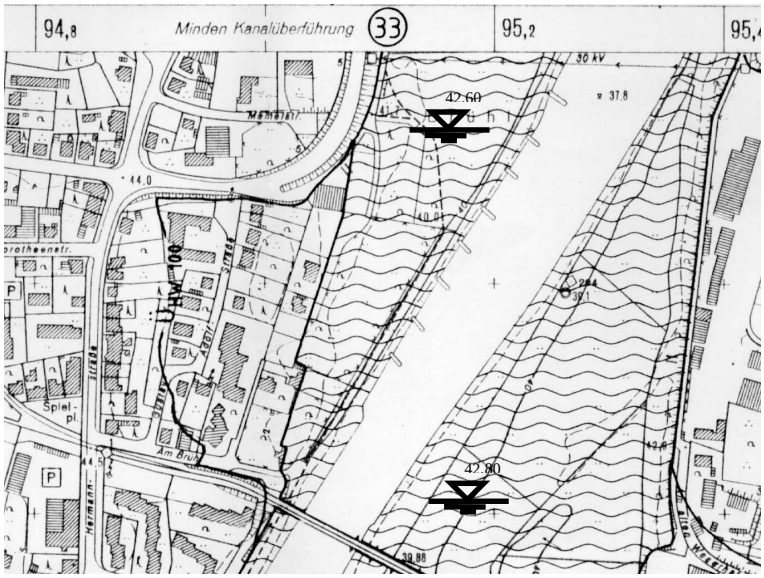


Abb. 2 Geschlossenes Baugebiet, Weser A_{Eo} 19 300 km²

An hochliegenden Ufern, die vom Bemessungsereignis nicht überschwemmt werden, sollte ein Schutzstreifen je nach Gewässergröße zwischen 10m und 50m vorgesehen werden. Er dient als Puffer bei eigendynamischen Verlagerungen des Gewässers oder läßt Raum für potentielle Ausbaumaßnahmen.

5 Pflege der Überschwemmungsgebiete

5.1 Gesetzliche Regelungen

In der Bundesrepublik Deutschland verpflichtet der § 32 Wasserhaushaltsgesetz -WHG- die Bundesländer zur Festsetzung von Überschwemmungsgebieten und legt in Grundzügen den Umgang damit fest. In ihren jeweiligen Landeswassergesetzen erlassen die Bundesländer verbindliche Anordnungen. Sie legen fest, welche Maßnahmen genehmigungspflichtig sind und bestimmen die Zuständigkeit.
Der Festsetzungsakt erfolgt durch eine Verordnung. Sie enthält die notwendigen Kartenwerke, Erläuterungen und Vorschriften. Durchweg gilt eine Genehmigungspflicht für das Herstellen von Anlagen, das Erhöhen oder Vertiefen der Erdoberfläche, das Lagern von Stoffen und das Pflanzen von Bäumen und Gehölzen.
Um Nachteile auszugleichen können die Genehmigungen mit Bedingungen oder Auflagen verbunden werden. Befreiungen von der Genehmigungspflicht sind möglich. Maßnahmen zum Beispiel, die eine kurze Bauzeit haben oder, wie z. B. Versorgungsleitungen, die nach Beendigung keine Veränderung der Oberflächengestalt zur Folge haben, können von der Genehmigungspflicht ausgenommen werden.

5.2 Berücksichtigung des Naturraumes

Je nach topografischen Verhältnissen haben die Gewässer stark unterschiedliche Hochwasserverhalten. Reissende Flüsse des Mittelgebirges haben eine andere Schadwirkung als großflächig ausufernde Gewässer in Flachlandregionen. Während im schmalen Tal des Mittelgebirgsflusses jede nachteilige Veränderung zu vermeiden ist, können die Restriktionen in Gebieten mit weitflächigen Überflutungen den Nutzungen angepaßt werden.

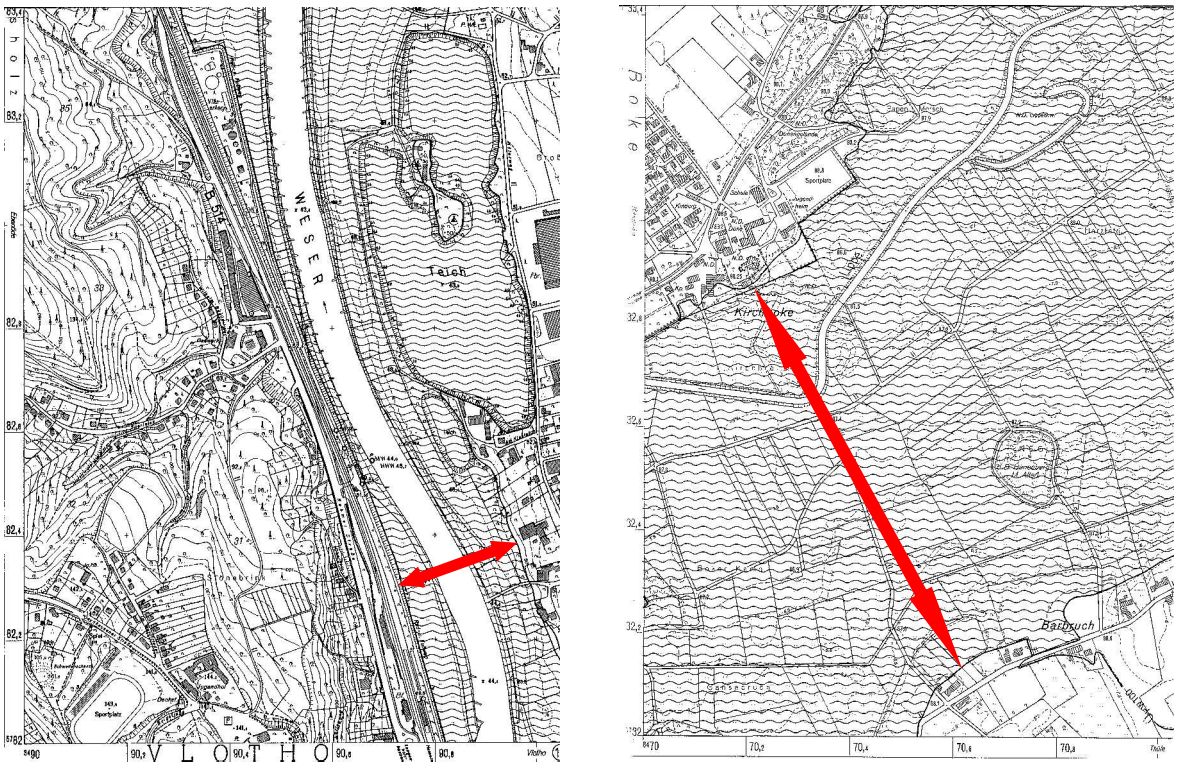


Abb. 1 Überschwemmungsgebiete a) Weser A_{Eo} 18.400 km², b) Lippe A_{Eo} 1.200 km²

5.3 Aktualisierung

Wie für andere Kartenwerke üblich sollte auch das Kartenwerk der ÜG aktualisiert werden. Das gilt für Änderungen durch Baumaßnahmen und für Änderungen der Überschwemmungsflächen durch neuere Grundlagen oder durch Maßnahmen.

5.4 Erfahrungen

Die Autoren haben in einem Zeitraum von 8 Jahren das Erarbeiten und die Nutzung von Überschwemmungsgebieten an 670 km Gewässerlänge betreut. Es handelte sich dabei um Gewässer in unterschiedlichen geografischen und politischen Regionen. Die Erfahrungen zeigen, dass die preußische Idee, Überschwemmungsgebiete darzustellen und ihre Nutzung zu organisieren, weitsichtig war und gut ist.

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Identification of Meteorological Causes of Flood Events in the Raab/Rába Basin

Jiři Stehlik, András Bárdossy, Gábor Bálint

Abstract: The linkage between flood occurrence and daily atmospheric circulation patterns (CPs) in the Raab/Rába catchment is investigated. The CPs have been obtained using automated fuzzy rule based optimization procedure which takes large scale daily 500 hPa geopotential heights and local precipitation into account. These daily CPs were subsequently linked with daily discharges in order to define flood producing CPs or their sequences. The most advantageous feature of the method is that it enables to prolong the lead-time of flood forecasting and warnings.

Key words: flood occurrence, atmospheric circulation patterns, fuzzy rule based optimization

Identification of Meteorological Causes of Flood Events in the Raab/Rába Basin

Zusammenfassung: Der Zusammenhang zwischen Hochwasserereignissen und der großräumigen atmosphärischen Zirkulation (Großwetterlagen) wurde untersucht. Die Großwetterlagen wurden mittels einer automatischen, optimierten und auf den fuzzy Regeln basierten Methode definiert, die die großräumigen 500 hPa Geopotentialhöhen und Niederschlagszeitreihen als Daten benutzt. Diese Großwetterlagen wurden mit den Raab-Tagesabflüssen gekoppelt um die zu den Hochwasserereignissen führenden Großwetterlagen oder der en Sequenzen zu identifizieren. Der Hauptvorteil dieser Methode ist die Verlängerung des Zeitraumes für die Hochwasservorhersage.

Schlüsselworte: Hochwasserereigniss, Großwetterlagen, Optimisierung, fuzzy Regeln

1 Introduction

The aim of this paper is to present results of hydrometeorological investigation in the Raab/Rába basin. The upstream third of the 10,113 km^2 total area of the drainage basin, which produces most of the runoff, belongs to Austria; the lower mostly flat and undulating part is situated in Hungary. The investigated Árpás cross-section drains 6610 km^2. The research was focused on explaining flood events by means of large-scale (continental) atmospheric conditions. The daily discharges and daily circulation patterns (CPs) are linked in order to select CPs responsible for floods. The probabilistic linkage is evaluated by means of two performance indices, relating flood occurrence, observed CP occurrence before floods and purely random count of CPs. CPs which lead to flood events have been identified for each season separately.

A close relationship appears to exist between atmospheric circulation and climatic variables, and hence hydrologic ones. Bürger (1958) studied the relationship between atmospheric CPs and mean, maximum and minimum daily temperatures, precipitation amounts and cloudiness using time series from 1890 to 1950 measured at four cities (Berlin, Bremen, Karlsruhe and Munich). He found a good correspondence between climatic variables and atmospheric circulation. In related research, Lamb (1977) stated that even highly varying precipitation is strongly linked to atmospheric circulation.

In contrary to climatic variables the flood occurrence is dependent also on basin characteristics (e.g. physical and geographical conditions). Because the transformation of precipitation into discharge in the basin system requires certain time, a lag time or delay time may be present

between a flood-producing rainfall occurrence and the flood occurrence itself. This lag time is one of the classical hydrological problems. The presented research contributes to this problem by considering flood-producing CPs instead of rainfalls."

Following Peterson et al. (1987), Enzel et al. (1990, 1991), Ely et al. (1991) and Duckstein et al. (1993) the CPs are directly linked with flood events.

In CPs classification techniques the two main groups of methods can be distinguished, namely subjective and objective classifications. In subjective classifications the knowledge and experience of meteorologist is fully used. A major disadvantage is that the results cannot be reproduced and that these methods can be applied for a certain geographical regions only. Second type of methods is objective techniques. They are based on automated algorithms, and allow fast classification, which is necessary especially for climate change scenarios.

The classification method used in this paper is optimized fuzzy rules based classification (Bárdossy et al., 2000). It is automated, objective and takes precipitation series from a set of stations in the selected area into account. The classification explains in part the variability of precipitation specifically for each location. It means that the CPs can be used to explain dependence between large-scale atmospheric circulation and precipitation.

2 Methods used

2.1 Circulation pattern classification

The classification method used is the fuzzy-rule based classification (Bárdossy et al., 2000). It is based on the concept of fuzzy sets (Zadeh, 1965) which enables to deal with imprecise statements.

The CPs are based on geopotential heights observed over a large area. The data used are the NMC grid data in different windows over Europe in the grid resolution 5° x 5°. The procedure for fuzzy rule based classification is described in Bárdossy et al. (1995). Every CP is described with a fuzzy rule represented by a vector $v(k) = (v(1)^{(k)}, \ldots, v(n)^{(k)})$ where n is the number of grid points for which the air pressure data are available. The $v_i^{(k)}$-s are the indices of the membership function corresponding to the selected locations. Five possible classes of membership functions v (defined as triangular fuzzy numbers) of rule premises appear to be adequate according to the normalized pressure values. They represent high and low anomalies and indifferent locations.

For the data classification the membership grades of the normal height anomalies were computed. These membership values are combined to calculate the degree of fulfillment of the rule. The rule for which the degree of fulfillment is maximal is selected as CP for a classified day.

2.1.1 Optimization criteria

There were two objectives introduced to measure the performance of the classification with regard to precipitation. The task of the optimization based on precipitation observations is to achieve such set of CPs, which explain the variability of precipitation behavior as much as possible. It means to identify both very wet and very dry conditions. The first objective deals with the probability of precipitation on a given day. Considering the threshold ϑ for daily precipitation amount enables the general definition of the first objective:

$$O_1(\vartheta) = \sum_{i=1}^{S} \sqrt{\frac{1}{T} \sum_{t=1}^{T} \left(p(CP(t))_i - \overline{p}_i \right)^2} \qquad (1)$$

Here S is number of stations with precipitation observation, T is number of days, $p(CP(t))_i$ is the probability of a day with precipitation exceeding the threshold ϑ with the given CP on

station i, $\overline{p}_i$ is the probability of a day with precipitation exceeding the threshold ϑ without classification.

For the precipitation amounts the following objective function is defined:

$$O_2 = \sum_{i=1}^{S} \frac{1}{T} \sum_{t=1}^{T} \left| ln\left(\frac{z(CP(t))_i}{\overline{z}_i} \right) \right| \tag{2}$$

Here $z(CP(t))_i$ is the mean precipitation amount on a day with the given CP on station i and $\overline{z}_i$ is the mean daily precipitation without classification at the same station. The higher are the values of $O_1(\vartheta)$and O_2 the better is the optimization. It is possible to optimize more objective functions at the same time.

The goal of the optimization procedure is to find out such fuzzy rules for which the optimization criterion is maximal. For maximizing the objective functions a Simulated Annealing algorithm was used.

2.1.2 Validation of CP classifications

Any classification that defines probability $p(CP(t))$ and mean $z(CP(t))$ of precipitation on a selected station for a single day t referring to the classification of the same day can be measured by the indices I1 and I2 identical with the objective functions O_1 and O_2.

The higher the indices the more variability b can be explained from the CPs. To allow a seasonal difference of behavior for the classes (e.g. dry in summer and wet in winter) the indices are usually calculated for all seasons separately. Defining threshold values for precipitation guarantee that the optimized classification is good especially for extreme rainfall events.

2.2 Linking CPs with flood events

According to (Duckstein et al., 1993) two performance indices were defined in order to identify flood-producing CPs. The first measure of contribution of a pattern of type j to the occurrence of floods is the relative number of days with pattern j in the N=N* days preceding the flood. This number is compared with the flood-unconditioned frequency of occurrence of pattern j during the season considered; ID_1 is defined as

$$ID_1(j) = \frac{n_1(j)}{n_2(j)} \tag{3}$$

where $n_1(j)$ is the relative number of days with pattern j in N* days before the flood, and $n_2(j)$ is the relative number of days with pattern j in the season. If $ID_1(j)$ is smaller than unity, then pattern j does not contribute much to floods; the more it is above unity, the more pattern j is likely to cause floods. On the other hand, a value of $ID_1(j)$ near unity means that the correlation of $ID_1(j)$ and flood occurrence is not evident.

The second criterion $ID_2(j)$ measures the conditional probability of finding at least k days out of N* with pattern j over the calibration period, given that a flood occurred on day zero:

$ID_2(j)$ = pr(CP = j for $\geq k$ days, $0 \leq k \leq N^*$)

This conditional probability is compared with the binomial probability of at least k days out of N* of pattern j using historical frequencies of occurrence.

$$B(N,p,k) = \sum_{i=k}^{N} \binom{N}{i} p^i (1-p)^{N-i} \tag{4}$$

where p is overall frequency of occurrence of CP estimated from the record.

3 Results and discussion

3.1 Selecting CPs classification

The daily 500 hPa elevation data were selected for classifying CPs. Based on previous experience the number of CPs was set to 12. It was decided to use the time interval 1980 – 1989 as a calibration period. Daily precipitation amounts from 9 stations positioned in the Central Danube basin were considered (TABLE 1 or FIGURE 1). Two runs for different pressure windows were done (35N - 65N, 15W - 40E and 20N - 65N, 20W - 50E). These windows are shown in FIGURE 2. Both classifications were validated in 1990 – 1994.

In TABLE 2 validation results for both windows are presented. The average annual values of indices I1 and I2 for all 9 stations show that the smaller pressure window yields better results than the larger one. Therefore it was decided to use the CPs classified by means of this window (FIGURE 2).

Precipitation station Bad Gleichenberg is one from the stations used for CPs classification. Because this station is at the same time situated in the Raab basin, it was selected for presentation of CPs characteristics (TABLE 3). From the table for example follows that CP 1 dominates in each season. Considering the yearly averages, the most wet CP is CP 5.

3.2 Linking CPs and floods

The daily discharge data of the river Raab from the gauging station Árpás have been linked with the CPs series. With respect to the data available the period 1958 – 1990 was selected. As a threshold for the flood event the discharge exceeded with the probability equal or less than 5% has been determined. Altogether 128 flood events have been obtained from which 33 are in winter, 36 in spring, 34 in summer and 25 in fall.

According to equation (3) the index $ID_1(j)$ was computed for every CP j and time window from $N^* = 1$ to $N^* = 10$ days before flood. The optimum delay before flood for each CP is considered as a maximum value of $ID_1(j)$. FIGURE 3 shows the dependence between $ID_1(j)$ and size of time window N^* for each season. Always three lines are presented for the most floods contributing CPs (i.e. CPs with highest $ID_1(j)$).

In each season the CP 5 provokes a very quick response yielding therefore an optimum delay of 1 day. Note that for fall the $ID_1(5)$ is almost 7. It means that 1 day before an autumn flood CP 5 occurs seven times more frequently then on other autumn days. After the first day there is a rapid decrease of $ID_1(5)$ in each season. So the CP 5 provokes the last flood-producing impulse after the basin is saturated from precipitation resulting from another CP types. The best results for autumn were expected, because in winter the precipitation is often in form of snow, in spring the flood producing mechanism is especially snowmelt and in summer convective rainfalls account for some flood events.

In FIGURE 4 the distributions of mean (1970-1979) normalized 500 hPa pressure anomalies for CP 5 are presented. The map shows that the Danube basin is positioned under the pronounced negative pressure anomaly with the center over Adriatic. For comparison the pressure anomalies for CP 1, which almost does not contribute to floods, is also shown. High pressure anomaly with the center over Poland is typical for this CP. Anticyclonic character of weather causes low precipitation probabilities and low wet-day amounts in each season (TABLE 3). So from the maps of pressure anomalies follows that the classification produces physically realistic CPs.

TABLE 3 shows that the average yearly frequency of CP 5 is 2.5 % (for the time period 1958-1990 the number is similar: 3.1%. Precipitation probability varies from season to season having the maximum in fall (66.7 %) and the minimum in winter (14.3 %). The case of mean wet-day amount is similar.

For the time delay being more then 2-4 days (the number of days depends on season) the most flood-contributing CP changes from CP 5 to another CPs, which responses are more slower-acting. The maxima of $ID_1(j)$ are not so distinct as in case of CP 5, however the optimum delay can be identified. The values are listed in TABLE 4.

The relative frequencies $n_1(j)$ from the flood producing CPs are combined into an overall figure of merit *FM*. Flood producing CPs are defined as CPs yielding in average $ID_1(j) > 1.5$ for the time window of 5 days. Based on this criterion the CPs presented in TABLE 5 were selected. From FIGURE 5 follows that the optimum delay for spring, fall and summer is 2 days, for spring only 1 day. Low values of explained n_1 for spring are caused by the fact that only 3 CPs were selected for determining *FM* whereas in other seasons 4 CPs were selected.

In TABLE 5 the seasonal and flood conditioned frequencies of CPs are shown. The best results were achieved for fall when 26.24% (7.53% + 2.4% + 4.26% + 12.05%) of the CPs appear to produce 72% (14% + 12% + 8% + 38%) of floods. It is caused also by the very low relative frequency of CP 1: $ID_1(1)$ for autumn is 0.28 only whereas for other seasons this index is at least two times higher.

TABLE 6 shows the conditional probabilities $ID_2(j)$ for observed and binomial frequencies. Based on the results of optimum delay estimation, the delay of 2 days for each from 3 seasons was taken into account. Spring is missing because the optimum delay is 1 day only. Comparing the columns 1 and 3, one can see that the observed occurrence probabilities are distinctly greater for every CPs in all 3 seasons. Because of the effect of natural CPs clustering, the results for 2 occurrences are even better then for >= 1 occurrence (exception is only CP 5 in autumn).

4 Conclusions

The following concluding points may be made:

1. The linkage between flood occurrence and daily atmospheric CPs in the Raab/Rába basin was investigated.
2. The CPs have been defined using automated fuzzy rule based optimization procedure which takes large scale (European) daily pressure fields and local precipitation into account. 12 CPs were defined which explain the variability of daily precipitation in 9 stations in the Upper and Central Danube basin.
3. These daily CPs were linked with daily discharges in order to define CPs causing flood events.
4. Comparison of probability of occurrence for each CP before flood with an overall frequency of CP enables identification of flood producing CPs.
5. Optimum time delay before flood has been defined for flood producing CPs and for figure of merit of these patterns. This delay is 2 days for summer, fall and winter and 1 day for spring. The best results have been achieved in fall.
6. The conditional probability of at least k CPs of type j in N days before the flood has confirmed the identification of flood producing CPs.
7. The future research should focus on analysing more basins that will enable to explain the role of physical and geographical conditions with respect to the flood occurrence. Also the sequence of CPs before flood should be investigated and the flood volume should be taken into account as a criterion of flood definition.

Acknowledgements

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TABLES

Table 1 Precipitation stations used for CPs classification

Station	Altitude, m
Kremsmünster	383
Linz/Horsching	298
Wien/Hohe Warte	203
Brno/Tuřany	241
Bad Gleichenberg	303
Hurbanovo	115
Bratislava/Ivanka	133
Banská Bystrica	335
Sliač	316

Table 2 Validation of CPs classifications

	smaller window	larger window
I1	0.182	0.166
I3	0.670	0.667

Table 4 Optimum delay window N^* in days

	spring	summer	fall	winter
CP 4	-	-	4	1
CP 5	1	1	1	1
CP 7	-	3	-	-
CP 8	4	-	2	-
CP 9	-	-	-	2
CP 11	-	2	-	-
CP 12	1	-	-	

Table 5 Seasonal CPs frequencies (*SF*), flood-conditioned CPs frequencies (*FF*) and their ratios ($ID_1(j)$) for optimum time delays and flood producing CPs

	SF	*FF*	$ID_1(j)$		*SF*	*FF*	$ID_1(j)$
winter (2 days)				**spring (1 day)**			
CP 3	4.97	9.09	1.83	CP 5	2.87	10.81	3.77
CP 4	11.32	21.21	1.87	CP 8	11.10	21.62	1.95
CP 5	2.96	10.61	3.59	CP 12	4.68	10.81	2.31
CP 9	2.35	6.06	2.58				
Summer (2 days)				**fall (2 days)**			
CP 5	4.55	9.09	2.00	CP 4	7.53	14.0	1.86
CP 7	5.01	7.58	1.51	CP 5	2.40	12.0	5.00
CP 8	11.17	19.7	1.76	CP 7	4.26	8.0	1.88
CP 11	5.14	12.12	2.36	CP 8	12.05	38.0	3.15

Table 3 CP characteristics, Kremsmünster. Averaged over the validation period 1990-94.

	CP occurrence frequency [%]					Precipitation probability [%]					Mean wet-day amount [mm]				
CP	Spring	Sum-mer	Fall	Winter	Year	Spring	Sum-mer	Fall	Winter	Year	Spring	Sum-mer	Fall	Winter	Year
1	45.2	42.3	34.5	56.2	44.6	32.9	21.4	22.1	23.6	25.0	0.9	0.8	0.8	0.6	0.8
2	2.6	2.4	4.3	3.2	3.1	83.3	54.6	73.7	92.9	76.1	4.1	6.9	2.8	2.9	4.2
3	4.6	7.1	7.6	2.7	5.5	52.4	53.1	67.7	83.3	64.1	2.2	4.9	5.5	3.3	3.9
4	9.4	7.5	9.4	10.8	9.3	55.8	70.6	73.8	81.3	70.4	3.3	4.0	4.7	4.7	4.2
5	2.4	3.5	2.7	1.6	2.5	81.8	81.3	83.3	85.7	83.0	10.3	6.2	4.1	3.5	6.0
6	7.9	7.9	4.3	7.0	6.8	61.1	41.7	63.2	83.9	62.5	4.2	2.2	4.4	4.4	3.8
7	4.2	2.9	4.7	2.3	3.5	68.4	61.5	76.2	60.0	66.5	5.4	5.2	4.1	1.7	4.1
8	9.2	10.4	11.0	5.8	9.1	57.1	87.2	63.3	57.7	66.3	2.8	5.5	3.1	2.7	3.5
9	3.5	4.0	4.0	1.1	3.2	68.8	66.7	55.6	40.0	57.7	4.9	3.6	3.5	5.2	4.3
10	2.4	5.7	3.1	4.9	4.1	36.4	34.6	42.9	50.0	41.0	2.5	3.2	0.8	0.9	1.8
11	3.9	3.3	7.9	3.2	4.6	38.9	60.0	25.7	14.3	34.7	2.1	3.4	0.8	0.1	1.6
12	2.8	1.8	6.1	1.1	2.9	38.5	25.0	51.9	60.0	43.8	2.2	4.0	3.3	1.4	2.7

Table 6 Conditional probabilities $ID_2(j)$ for flood producing CPs and delay time 2 days

	observed		**binomial**			**observed**		**binomial**	
	>=1 occurrence	**>=2 occurrence**	**>=1 occurrence**	**>=2 occurrence**		**>=1 occurrence**	**>=2 occurrence**	**>=1 occurrence**	**>=2 occurrence**
winter					**summer**				
CP 3	12.1	6.1	9.7	0.2	CP 5	12.1	6.1	8.9	0.2
CP 4	27.3	15.2	21.4	1.3	CP 7	12.1	3.0	9.8	0.3
CP 5	12.1	9.1	5.8	0.1	CP 8	33.3	6.1	21.1	1.2
CP 9	9.1	3.0	4.6	0.1	CP 11	18.2	6.1	10.0	0.3
fall									
CP 4	20.0	8.0	14.5	0.6					
CP 5	24.0	0.0	4.7	0.1					
CP 7	12.0	4.0	8.3	0.2					
CP 8	52.0	24.0	22.7	1.5					

FIGURES

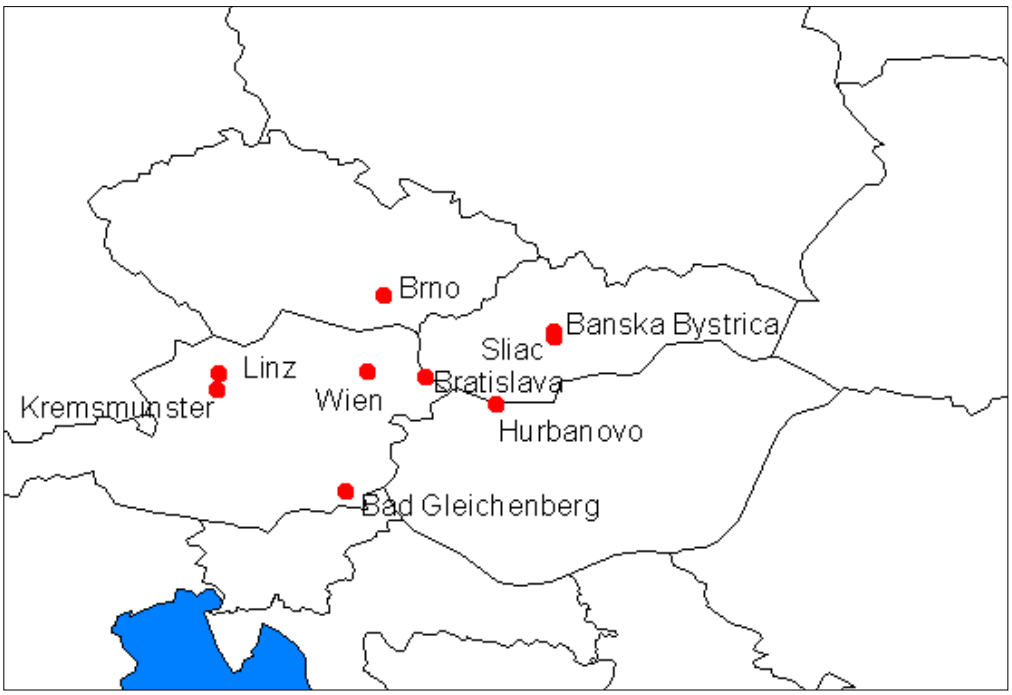

Figure 1: Precipitation stations used for CPs optimization.

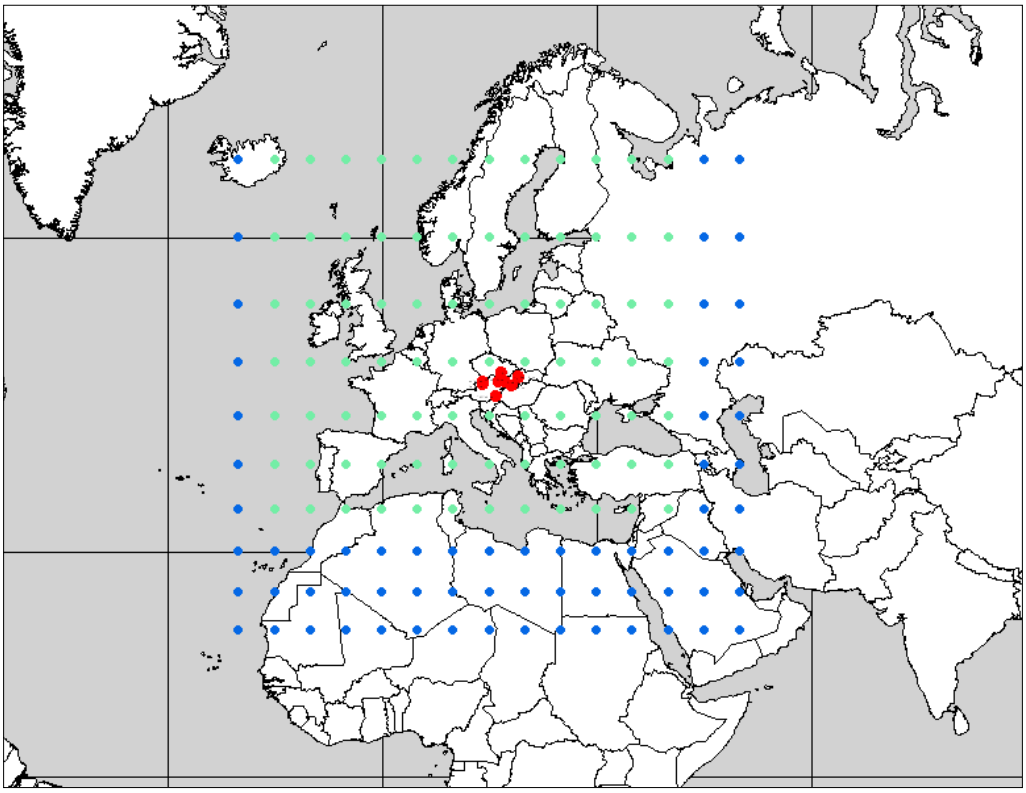

Figure 2 Two pressure windows used for CPs optimizations.

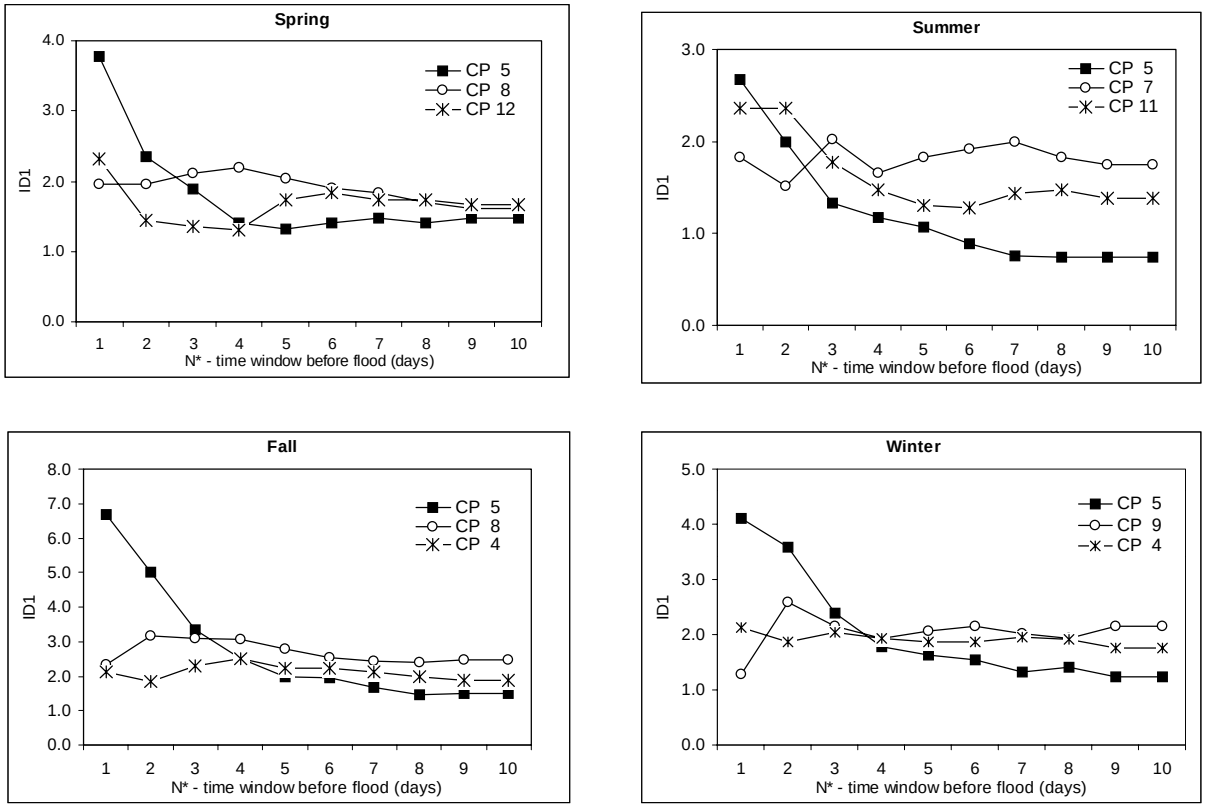

Figure 3 Dependence of index $ID_1(j)$ on time delay before flood for three flood producing CPs in each season

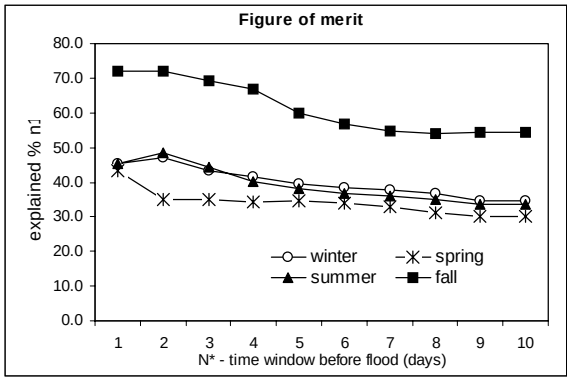

Figure 5 Dependence of index figure of merit *FM* on time delay before flood for each season.

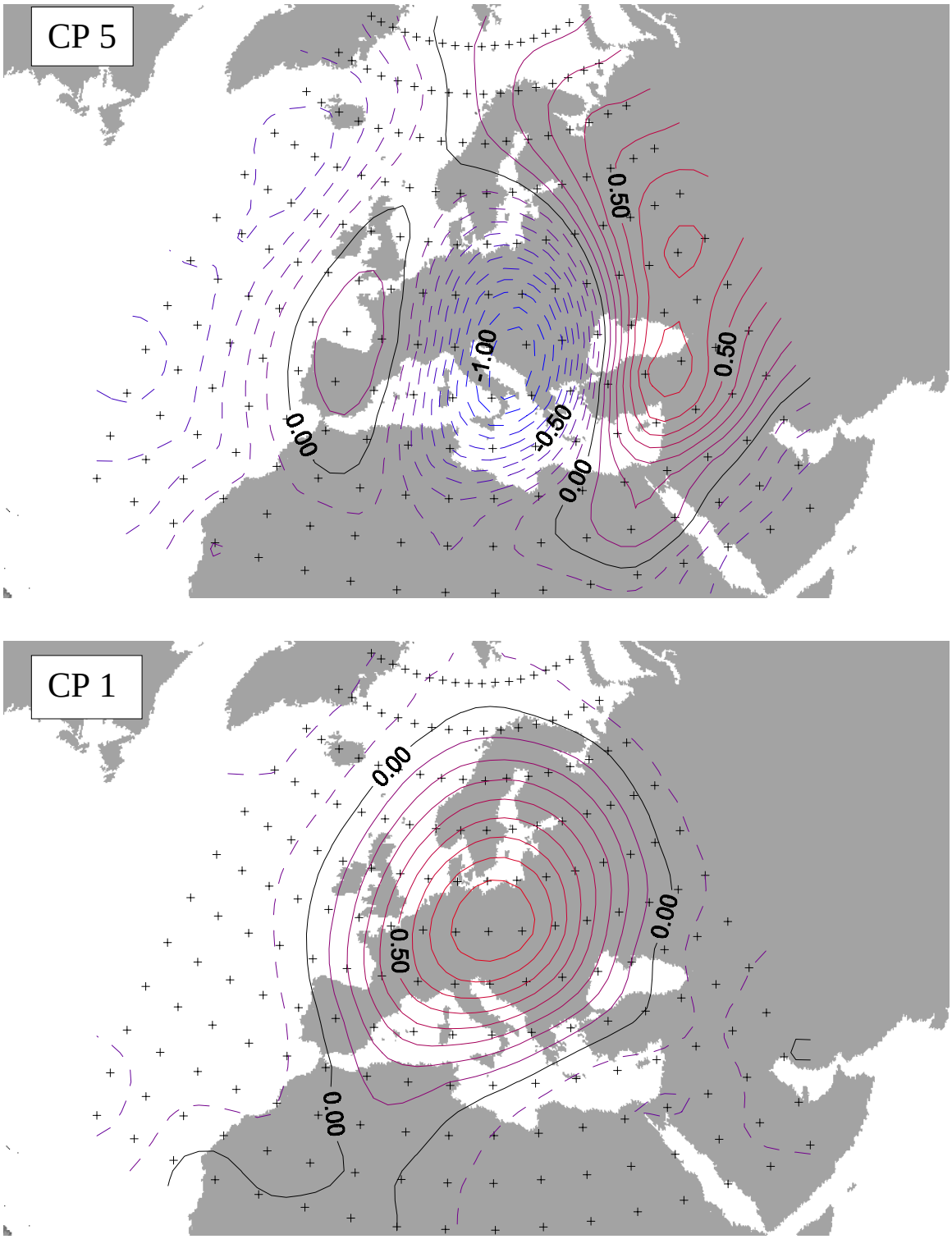

Figure 4 Mean normalized distributions of 500 hPa pressure anomalies averaged over 1970-79 for flood producing CP 5 (above) and CP 1 (bottom) which does not contribute to floods [CPs optimized in 1980-89 with 500 hPa data and 9 stations in Danube basin].

Using the probability weighted moments method for the flood regionalization in Albania

Mirela Sula

Abstract: The major problem encountered in the Albanian river basins is the scarcity of streamflow data. Therefore under the circumstances of the lack of sufficient hydrological data, the regionalisation technique is a useful method to provide estimates of the flood characteristics for ungaged or poorly gauged catchments. The probability weighted moments methods (PWM) was found to describe better the frequency distribution of the annual peak flood than the method of moments (MM), where both of them are applied for the Gumbel distribution. Therefore the non-dimensional regional growth curves were derived by method of PWM for Gumbel distribution. In order to obtain the at-site quantiles at ungaged catchments, multiplying by the mean annual flood computed from the predictive regression equation can rescale the regional growth curves for annual maximum peak flood. The mean annual flood predictive regression equation is produced based on the physiographic (area, basin mean elevation, etc) and climatologically basin characteristics (precipitation etc).

Key words: probability weighted moments, annual peak flood, frequency distribution, and quantiles.

Das Benutzen der Methode des Wahrscheinlichkeit gewichteten Momentes für die Flut Regionalization in Albanien

Zusammenfassung: Der Mangel der Abflußdaten ist ein bedeutenden Problem, das in den albanischen Abflußgebieten begegnet wird. Unter diesen Umständen, stellt die Regionalizationstechnik eine nützliche Methode dar, um die hydrologische Eigenschaften der Fluten in den Gebieten ohne oder mit begrenzte Beobachtungsstellen. Die Methode des Wahrscheinlichkeit gewichteten Momentes (WGM) beschreibt die Verteilung des jährlichen Maximalabflußes besser als die klasische Momentenmethode (MM). Die beiden werden die Gumbel Verteilung anwenden. Deshalb, die nicht dimensionale Wachstumkurven von der WGM Methode hergeleitet wurden. Um die Quantilen der Maximalabfluß in den ohne Beobachtungen Gebieten zu erhalten, wurden die regionale Wachstumkurven des Maximalabflußes mit langjährigen Mittelwert des Maximalabflußes multipliziert. Die multiple Regressionsgleichung, basiert auf physiographischen (Gebiet, mittleres Hocheben, usw.) und auf klimatologischen Eigenschaften des Abflußgebietes, ist produziert.

Schlüßelwort: Wahrscheinlichkeit gewichtetes Moment, jahrliche Maximalflut, Heufigkeitsverteilung, Quantil.

1 Introduction

One of the continuing problems that we face most often is the estimation of the relationship between extreme flow events and the associated recurrence interval (the so-called Q – T relationship). In the past, procedure followed was to check and to compare the suitability of the several candidate distribution based on at-site data. In order to reduce the uncertainty of the estimated parameters of the chosen theoretical distribution, i.e., to improve at – site estimates based on limited data and to estimate the t- year flood, $Q_{T,}$ for ungaged sites, a regional estimation technique is needed. Regionalisation can be effective in substituting an increased spatial characterisation of the data for un insufficient temporal characterization. The emphasis in this paper is on the methodology, which combines a regional growth curve (a curve showing the

variation with return period of the ratio between the T – year flood and the annual mean flood) with the estimation of the mean annual flood from catchments characteristic.

2 Comparison of the probability weighted moments method with the method of moments for the Gumbel distribution

The results of the previous studies carried out in Albania have shown that distribution that fit the best the annual peak flood was the Gumbel distribution. The estimation of the parameters for this distribution has been done based on the traditional method of moments. The method of Moments (MM), which is widely used in hydrology, is subject to some bias and is relatively inefficient. Morerover, the parameter estimators are subject to algebraic boundedness. The method of maximum likehood (ML) has also been used in hydrology in Albania. Although this method is known to provide asymptotically minimum variance estimators, it is used to lesser extent, partly because its application does not lend itself to easily manipulated algebraic expressions. For the Pearson III distribution, the parameters cannot be estimated by this method when the skewness coefficient is equal to or greater than 2 and the estimates of the parameters do not always converge.
In this paper a new method so called, the probability weighted moments method, is applied on the estimation of the parameters of the Gumbel distribution for the annual peak flood for 29 profiles within the Albania basin, containing 906 station years of record. The distribution of the profiles all over the Albania territory is given in Fig 1.

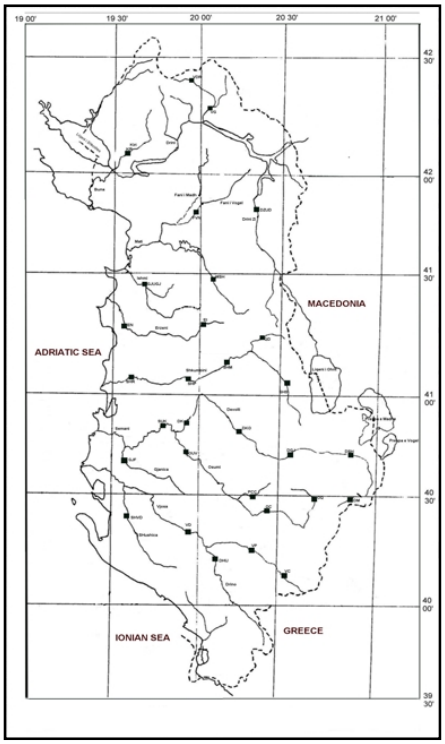

Fig. 1 Distribution of the runoff profiles over the Albanian territory
Greenwood at al (1979) introduced for the first time the probability weighted moments (PWM) method. They pointed out that for the specific distribution, the relations between PWM and the parameters are of a simpler analytical structure than those between the conventional moments and parameters.

This method is compared with the traditional methods of moments. Two types of goodness-of-fit indices were applied in the present paper in comparing the different methods for the Gumbel distribution:

1. Kolmogorov – Smirnov (KS)
2. The mean absolute deviation index (DAM)

$$\left|\hat{d}\right| = \frac{1}{N}\sum_{i=1}^{N}\left|d_i\right|$$

where: the quantity di = (Qi – Qic)/Qm and Qi – is the observed discharge, Qic – is the calculated one and Qm is the mean of the sample.

The results obtained from those indices are tabulated in Table 1. For each profiles the two methods were ranked according to their index value from smallest to largest as such rank (1) is given to the larger index value and rank (2) to the least index value, therefore the rank 2 in the Table 1 is pointed for the method that gives the best results according to the corresponding indices.

Table 1 Comparison of two methods (PWM, MM) for Gumbel distribution

Profiles	EV1 (MM)				EV1 (PWM)			
	KS		DAM		KS		DAM	
	Values	Rank	Values	Rank	Values	Rank	Values	Rank
DZUD	0.160	1	0.090	1	0.153	2	0.085	2
VG	0.218	2	0.274	1	0.237	1	0.250	2
KR	0.096	2	0.055	1	0.098	1	0.054	2
MSH	0.130	1	0.064	1	0.111	2	0.060	2
FVN	0.099	1	0.036	1	0.097	2	0.035	2
GJUGJ	0.110	2	0.081	1	0.112	1	0.067	2
EI	0.111	1	0.048	1	0.105	2	0.044	2
EN	0.125	1	0.082	1	0.113	2	0.080	2
SHM	0.081	1	0.060	1	0.071	2	0.055	2
SHP	0.093	1	0.060	1	0.089	2	0.057	2
QD	0.206	1	0.216	1	0.197	2	0.186	2
SHR	0.123	1	0.069	1	0.088	2	0.056	2
SHS	0.160	2	0.125	1	0.161	1	0.113	2
DGJ	0.083	1	0.033	2	0.077	2	0.034	1
DKO	0.139	1	0.079	2	0.137	2	0.080	1
DK	0.115	1	0.051	2	0.109	2	0.051	1
DM	0.158	1	0.062	1	0.151	2	0.063	2
DT	0.110	1	0.046	1	0.106	2	0.045	2
GJF	0.173	1	0.239	1	0.153	2	0.205	2
OC	0.090	1	0.048	2	0.078	2	0.049	1
OQ	0.128	1	0.047	1	0.122	2	0.046	2
OUV	0.087	1	0.046	2	0.083	2	0.046	1
PCC	0.142	2	0.086	1	0.146	1	0.083	2
SUK	0.121	2	0.050	2	0.126	1	0.053	1
VC	0.095	1	0.040	2	0.091	2	0.040	1
VD	0.095	1	0.063	1	0.077	2	0.058	2
DHU	0.122	1	0.069	1	0.088	2	0.045	2
VP	0.103	1	0.032	2	0.098	2	0.033	1
SHVD	0.149	1	0.120	1	0.145	2	0.118	2

The results of Table 1 shows that for 23 profiles out of 29 and 21 out of 29 according to respective indices (KS index and DAM index) the PWM method provides a better representation of the recorded data than the other method (MM).

Finally it can be concluded that regardless of the type of the goodness-fit-index the PWM method estimators of quantiles for the Gumbel distribution based on the at-site data, where found to be superior with respect to the traditional method of moments (MM).

3 Estimates of the regional growth curve

A growth curve shows essentially the variation with return period of the ratio between the T-year flood and the mean annual flood. The derivation of the regional growth curve relies on the assumption that there exists a hydrologically – homogeneous region within which the annual maximum discharge series at all stations are identically distributed when divided by their respective means. Based on this assumption data from more than one station can be combined to yield more reliable parameter estimates. Dimensionless quantile estimates can then be calculated for all basins in the region, which is particularly useful for sites which are ungaged or which have inadequate data. These estimates can be rescaled at the site of interest by multiplying by a mean annual flood, determined either from a record of discharge data or from the physical characteristics of the basin (see Hosking at al., 1985).

In this paper only the results of one region (region 2) are shown although Albania is divided into five hydrological homogenous regions using the graphical approach presented by Andrews (1972)**.** A cluster of the similar catchments appeared as a band of closed spaced curves (see Fig. 2).

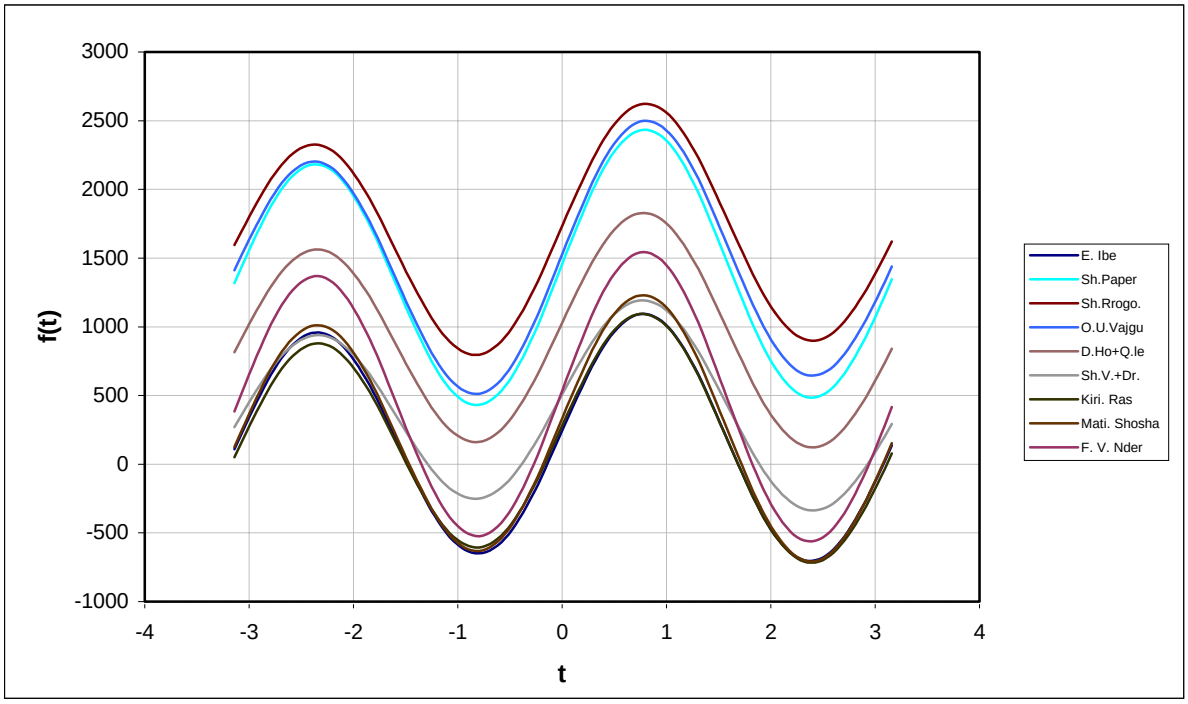

Fig.2 Andrews' curves for the profiles of the zone 2.

Any catchments that fall outside the identified band may be assumed to belong to a different group. Traditionally, the regionalization groupings encompassed geographically contiguous areas. However, subregions defined on the basis of similarity of hydrological characteristics may not have geographical significance. With the classification techniques such as Andrews curve, it was not necessary for catchments within a grouping to be geographically contiguous.

In order to provide estimates of flood characteristics for ungaged catchments in Albania, two type of regional equations were developed:

1. A relationship between the mean annual flood and the basin characteristics. The latter are found to be significantly related to the mean annual flood and easily extracted from published maps. The multiply regression equation for region 2 is:

   $$Q = 1.23 * 10^{-6} * A^{0.861} * P^{1.333} * I^{2.278} \quad \textbf{(1)}$$

   Where: Q – longterm mean annual flood; A – area (km^2); P – the longterm mean of the annual maximum of 24 hours precipitation (mm); I – the slope of the hill (‰).

2. A relationship showing the variation with return periods of the ratio between the T-year flood and the mean annual flood (non-dimensionless regional growth curve). The REGPWM program was used to derive parameters of the regional growth curves. The regional quantile Q_T of the region 2 for different return periods T can be estimated as follows :

   $$Q_T = 0.797 + 0.352 [-\ln (-\ln (1-1/T))] \quad \textbf{(2)}$$

Finally we can conclude that for ungaged catchments as the best distribution can be considered the regional growth curve of that zone where the ungaged catchment belongs. In order to obtain the at- site - quantiles at ungaged catchments the regional growth curve can be rescaled by multiplying by the mean annual flood, computed from the predictive regression equations.

4 Verification of the model

Equation 1 and 2 for the region 2 were verified selecting two profiles, Fani i Madh Bukmire (FMB) and Rrapuni Togez (RT), whose data were not used for predicting the above mentioned equations. Some hydrological, meteorological and morphometric characteristics for these two profiles are given in the Table 2.

Table 2 Hydrological, meteorological and morphometric characteristics of the verified profiles

Profiles	Abrev.	Q (m^3/s)	A (km^2)	P (mm)	I (‰)
Fani Madh- Bukmire	FMB	344	428	91	36
Rrapuni –Togez	RT	294	424	95	34

Q (m^3/s) –the longterm mean annual flood; A (km^2) catchment area; P (mm) –the long-term mean of the annual maximum of the 24 hours precipitation; I (‰)- the slope of the hill

The Andrews curves for those two profiles shown the same pattern as the profiles of the region 2, therefore it can be assumed that they belong to the region 2 (see Fig. 3).

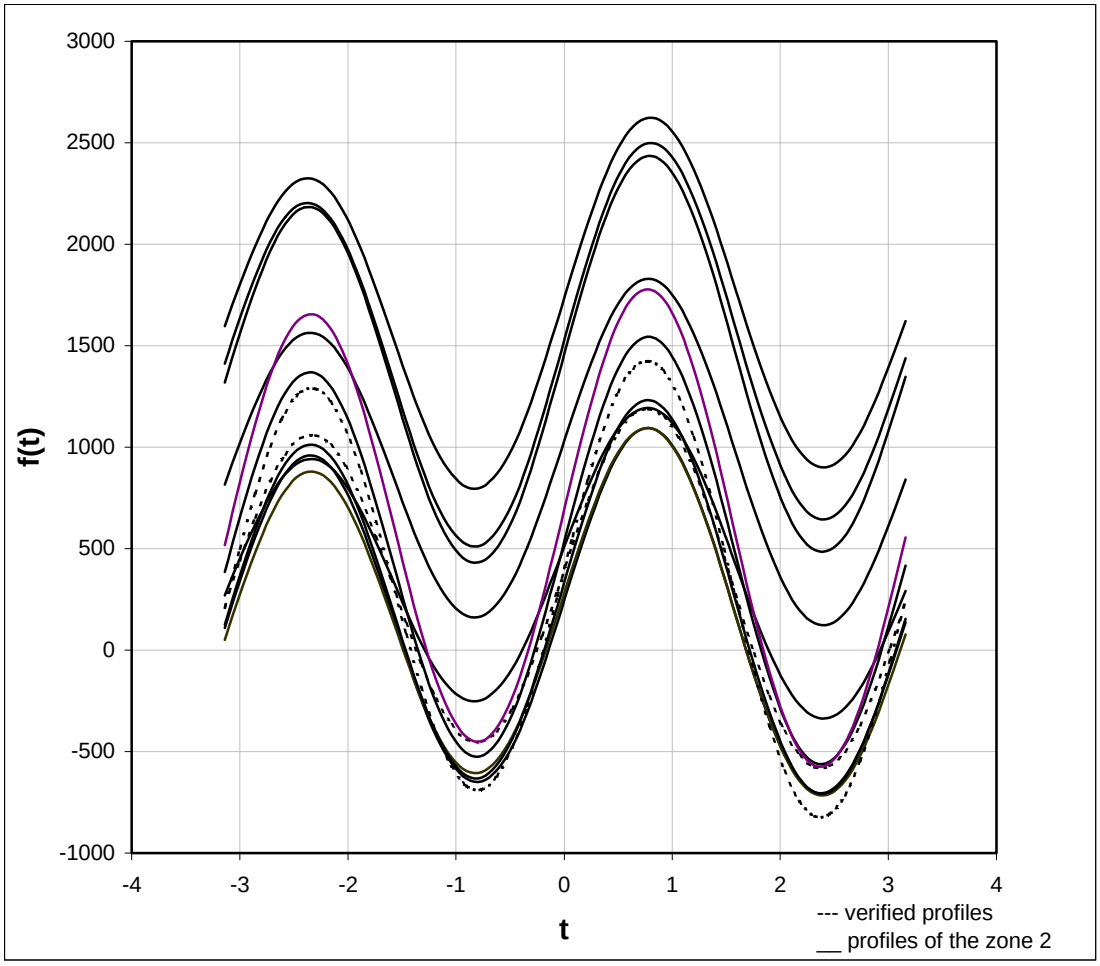

Fig. 3 Andrews curves of the region 2 and verified profiles

They have a long time hydrological series, thus the respective mean and quantiles of flood are calculated based on their series. Then those results are compared with the results derived from equation 1 and 2. Table 3 brings the summary of the calculations.

Table 3 Comparison of the factice and calculated quantile

V	Mean			Return Periods (T)								
				10			50			100		
	F	LL	G%	F	LL	G%	F	LL	G%	F	LL	G%
FMB	344	325	5.5	519	516	0.58	705	705	0	780	785	0.64
RT	294	300	-2.0	491	477	2.85	697	651	6.6	765	725	5.2

Prof. – profiles ; mean –longterm mean of the annual maximum discharge; F – factice quantile calculated from the hydrological series; Ll –calculated quantile according to the equations; Res –the difference between factice and calculated quantile; G% - error in calculation

The results of Table 3 shown that the maximum error is 6.6%, which is acceptable in the hydrological calculation.

5 Conclusions

Gumbel distribution, whose estimating parameters were derived by the probability-weighted moments, was the most appropriate distribution for the annual maximum discharge. Therefore , the regional growth curve was derived by this distribution.

The verification of the model has shown good agreement between calculated and factice quantiles. It might be concluded that for the ungaged sites, the mean annual flood be computed from the predictive regression equation and this be used to multiply the appropriate ordinate on the region curve in order to obtained the at – site quantiles.

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Hypothetical Catastrophic Flood in the Ipeľ (Ipoly) River on its Slovak – Hungarian Border Reach

Aleš Svoboda, Daniela Kyselová

Abstract : Ipeľ (Hungarian name Ipoly) river catchment is located in the southern part of central Slovakia and through its left hand tributaries also in northern Hungary. Up to its cross section Ipolytölgyes (20 km up from its mouth into Danube) its catchment area is 5010 km^2, about quarter of which lies in Hungary. Hydrological regime of Ipeľ is characterized by a high range of extremes. Also its flood regime is quite variable because of high variability of its climatic and physiographic conditions influencing formation of the flood events. Recently (June – July 1999) catastrophic floods occurred on tributaries from both sides of the central catchment part. They originated from the heavy rainfall and were rather flashy, however, frequent historical records document also "winter" floods originating by combination of an intensive snowmelt with heavy rain. In this paper we present a synthesis of an extreme flood caused by high rainfall covering almost the whole catchment area. Such rains, advancing from southwest across the Great Danubian Plain are slowed down by the first Carpathian mountain ranges and through a continuous influx of the moist air masses they can cause heavy rainfall covering unusually vast territory. Similar catastrophic extensive rainfall scenario has been recently experienced in 1997 in the Czech Republic over catchments of the Morava and the Odra rivers with catchments even several times larger than the one of the Ipeľ. The tool for analysis of the indicated problem is a hydrological model containing components for rainfall – runoff modeling from the catchment area, as well as components for routing the flood hydrograph through the river channel. Our results indicate that rainfall amounting to appr. 150 millimeters in two days and covering almost all the Ipeľ catchment, can cause a devastating flood with peak close to 1000 m^3s^{-1} on its lower reach. This represents almost doubled value of the so far evaluated 100- year flood peak.

Key words : Rainfall – runoff catchment modelling, Floods, Flood catastrophes, Ipeľ – Ipoly River (southern Slovakia, northern Hungary) flood regime

Eine hypothetische Hochwasserkatastrofe des Flusses Ipeľ (Ipoly) in der Flussstrecke zwischen Slowakei und Ungarn

Zusammenfassung : Einzugsgebiet des Flusses Ipeľ liegt in den südlichen Teil der Slowakei und durch die linken Zuflüsse im nördlichen Teil Ungarns. Die Gebietsfläche ist 5010 km^2, ein Viertel davon liegt in Ungarn. Hydrologisches Regime von Ipeľ ist charakteristisch mit grossem Umfang von Extremen. Auch sein Hochwasserregime ist höchst variabel wegen den klimatischen und physiographischen Bedingungen des Einzugsgebietes. Die extremen Hochwasserereignisse in den letzten Jahren (im Juni – Juli 1999 zuletzt) waren beschränkt auf die kleinere Zuflüsse in den zentralen Teil des Einzugsgebietes.. Doch die historische Beobachtungen zeigen auch auf mehrere winterliche Hochwässer die durch eine Tauflut kombiniert mit heftigen Regengussen hervorgeruft waren. In diesem Beitrag ist ein Hochwasserereigniss presentiert das durch ein starkes Regen über den ganzen Ipeľeinzugsgebiet verursacht werden konnte. Regenfälle von solchen Ausmasses entstehen während den starken zyklonalischen Strömung von Südwesten über die Grosse Ungarische Ebene, die sich an den ersten Karpatenkämmen verlangsamt und bei den ständigen Zustrom von feuchten Luftmassen Regenfälle mit äussersten flächlichen Ausmass verursachen kann. Ähnliche Katastrofenregen ereigneten sich im Jahre 1997 in Tschechien im Einzugsgebieten von Morava und Odra, in viel grösseren Einzugsgebieten als dem von Ipeľ. Die erwähnte Analyse haben wir mit Hilfe von einem hydrologischen Modell durchgeführt, das

Komponenten erhält, die Regen-Abfluss Prozess von dem Einzugsgebiet wie auch die Flutwellenbewegung in Flussstrecken simulieren. Unsere Resultate zeigen, dass ein Regen von der Stärke etwas um 150 mm in zwei Tagen, der fast die ganze Einzugsgebietsfläche beeinflusst, kann ein zerstörendes Hochwasser herforrufen mit dem Scheiteldurchfluss nähernd zu 1000 m^3s^{-1} in der unteren Ipeľstrecke. Das bedeutet fast die Zweifache des heute geltenden Werte des 100 – jährigen Durchflusses.

Schlüsselworte : Hochwässer, Hochwasserkatastrofen, Niederschlag – Abfluss Modellierung, Ipeľ - Ipoly (Südslowakei, nörd. Ungarn) Hochwasserregime

1 Introduction

Frequency of the observed severe floods seems to have increased during the recent years in the Danube catchments (and not only there). The heaviest in areal extent were those in 1997 which hit the eastern part of the Czech Republic, the catchments of rivers Morava and Odra (CHMI, 1997) Devastating floods occurred in the following period of years (1998 – 1999) in Slovakia and Hungary, however, they were rather flashy with very high rainfall intensity but with a fairly limited areal extent. Whatever devastating, these flash floods will always pose problems in their forecasting and preparedness of the potentially vulnerable sites. It is because under particular meteosynoptical conditions they can occur over any of our countless small catchments. They are all “potentially vulnerable”. With their limited areal extent the relevant damages, whatever painful, cannot be compared with those caused by large rivers whose catchments would be hit by rainfall of the extent close to that of Bohemia in 1997. It seems therefore reasonable to review a possible flood runoff scenario of our large rivers, particularly of those flowing through densely populated valleys, with developed industry and agriculture around. It was exactly an uncontrolled boom in construction of housing quarters, industrial plants, infrastructure of all kind within the range of possible flooding, which suffered the most losses to property and life in the 1997 floods.

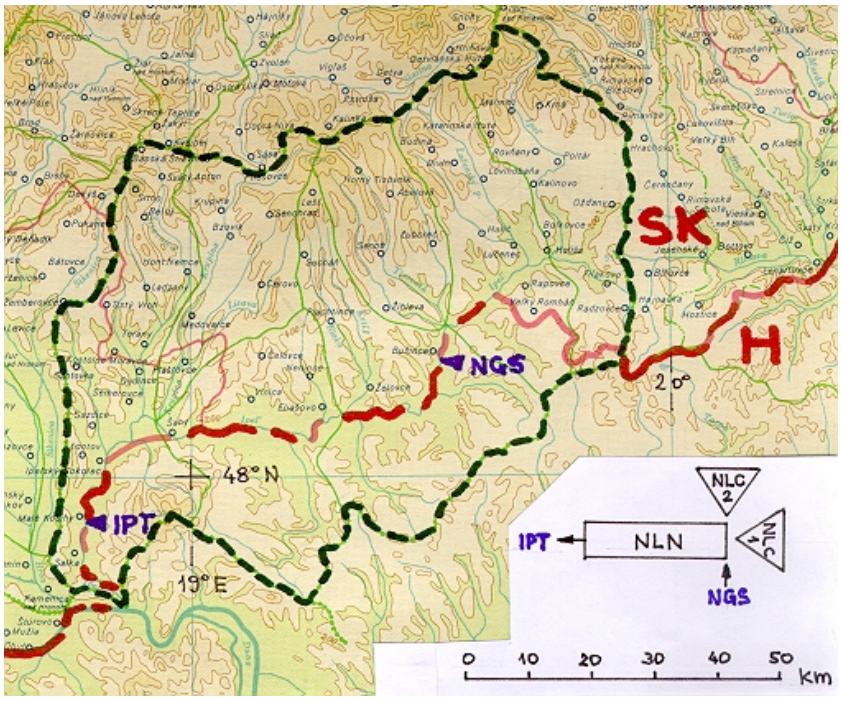

Fig. 1 Map of the Ipeľ catchment and the model scheme

In this paper we concentrated on the Ipeľ (Ipoly) catchment, because in cooperation of the Slovak Hydrometeorological Institute (SHMU), VIZIG Budapest, and Institute oh Hydrology, Slovak Academy of Sciences (UH SAV), a hydrological model of this catchment has been developed and calibrated, allowing also a hypothetical simulation of extreme floods. Model development documented a serious lack of reliable information on rainfall over the catchment (neither real – time, nor historical) which is crucial for a fairly reliable runoff forecasts. Because this deficit is not expected to be removed in a near future, we feel a need at least to indicate what is physically feasible to happen in this catchment under extremely unfavourable meteosynoptic conditions.

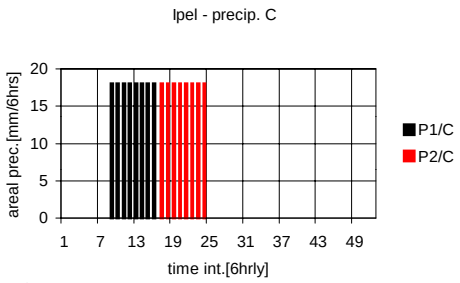

Fig. 2a

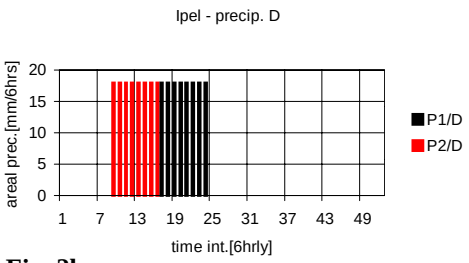

Fig. 2b

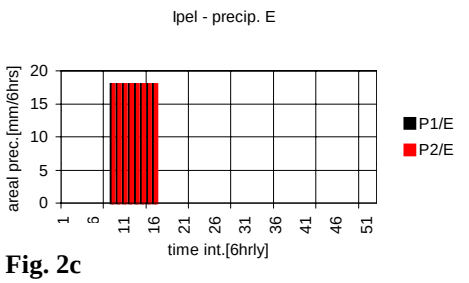

Fig. 2c

Ipeľ catchment, up to Ipolytölgyes (IPT) some 20 km upstream from its mouth to Danube, has a catchment area of 5010 km^2. In Fig.1 is a map of the catchment together with the model scheme showing also locations of the main rainfall and river gauges. The upper catchment part (P1, - 1850 km^2) up to Nógrádszakál (NGS) is simulated by the rainfall – runoff model component NLC1, the subcatchment (P2, - 3160 km^2) between NGS and IPT is simulated by another component NLC2. Model output from P1 is superimposed with the model output from P2, and routed by the river component NLN up to the catchment outlet point at IPT. There is no space here for detailed description of the individual model components, they were described by their author earlier (Svoboda, 1993a, 1993b).

2 Catastrophic rainfall scenarios

It was assumed that uniform rainfall covering the whole catchment area will amount close to 150 mm within two days, which makes for 6 – hourly simulation time interval 18 mm in each step. With certain simplification, similar scenario occured also over the mentioned part of the Czech Republic during the decisive flood phase in July 1997. Rainfall of that intensity has been observed also in several parts of the Ipeľ catchment during some historical floods, however, not that uniform and not of that large areal extent.

Further on, we examined also the influence of the relative temporal occurrence of the rainfall spells over the both catchment parts, P1 and P2. Except for a simultaneous occurence (scenario E), we assumed a rainfall over the upper catchment part P1 preceding that of P2 by 48 hours (scenario C), and lagging the P1 rainfall behind P2 by 48 hours (scenario D). In each of these two groups we also used three alternatives (C1, C2, C3, D1, D2, D3) with smaller time shifts by 12, 24, and 36 hours, respectively. Graphical interpretation of the C, D, and E scenarios is shown by hyetographs in Fig.2a, 2b, and 2c.

3 Results and discussion

Results of the model runs with rainfall input described in previous part are summarized in Fig.3 (hydrographs of scenarios C, D, E), Fig.4 (scenarios C1, C2, C3), and Fig.5 (scenarios D1, D2, D3). In Fig.6 is shown the simulation of historical flood of June 1995 (event Q6), clearly indicating deficiency in the information on areal distribution and amount of raifall in the upper catchment part at the later phase of flood. Simulated peak values of all the catastrophic scenarios are shown in Tab.1 for two characteristic sites on the river : Nógrádszakál (NGS) in the catchment central part, and Ipolytölgyes (IPT) – the catchment outlet point. There are also indicated the presently valid peak flow values with 100 years return period (Q100). Because of brevity, results for Nógrádszakál are not presented in figures.

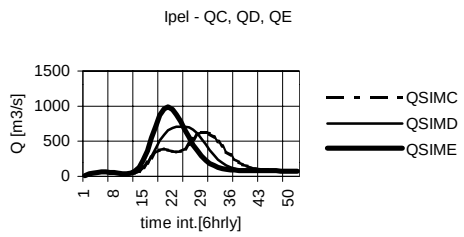

Fig. 3

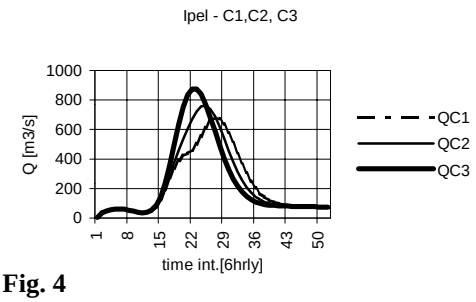

Fig. 4

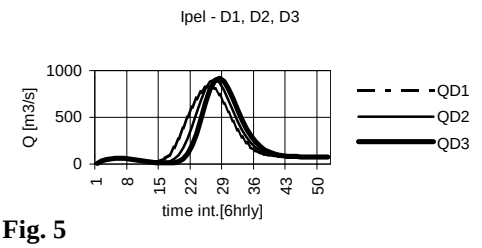

Fig. 5

No doubt, each flood in its formation is an event of a unique character. It is due to a large variety of possible occurence of meteosynoptical conditions, initial conditions of the catchment, its physiography, and other factors. However, in case of extreme floods, decissive is the rainfall amount falling on a catchment surface saturated with water from previous rains, together with the areal distribution of rains. Such conditions, in spite of necessary schematization, are contained in the used input scenarios. Several conclusions can be drawn from the described numerical experiment.

In all scenarios, with exception of C, the simulated peaks at IPT exceeded the Q100 with different magnitudes. In scenario C, this lower extremality is apparently due to high lag of the upper catchment flood contribution combined with its attenuation in the long river channel between NGS and IPT. For the Ipeľ central section (NGS), all simulated peaks exceeded the Q100 to much higher extent than those at Ipolytölgyes. It is partly due to the catchment physiography (mainly slope and shape) which, for smaller catchments, is always more favourable to extreme flood formation, partly to the model setup determining the outflow hydrographs superposition from both catchment parts (upper P1 and lower P2). Keeping in mind the catchment shape in its lower part, slope, and density of the numerous smaller tributaries, and also the experience gained from the described model numerical experiments, the highest peaks we expect to occur not far below the Nógrádszakál gauge. This conclusion pertains particularly to flood catastrophe caused by rains according to scenario E – simultaneous rainfall over the both catchment parts.

Tab. 1 Peak flows in m3/s at Nógrádszakál (NGS) and Ipolytölgyes (IPT) for all scenarios

Profile	Q100	C	D	E	C1	C2	C3	D1	D2	D3
NGS	460	729	660	729	729	729	729	660	660	660
IPT	650	630	713	989	678	768	876	831	905	919

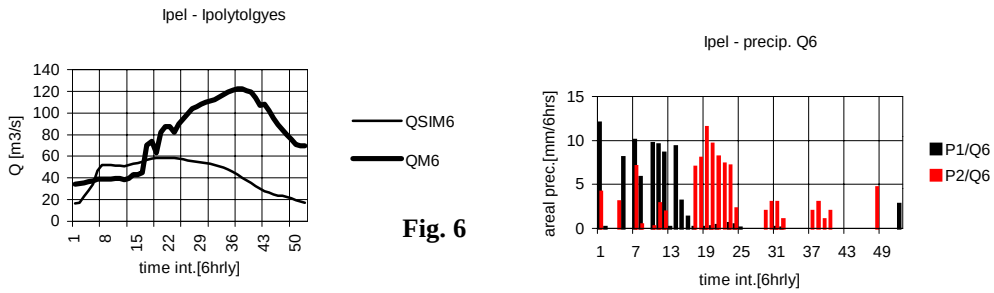

Fig. 6

One would assume that the most dangerous flood situation would be caused by rains progressing from the northeast in the direction of the main river valley, as simulated by the scenario C (Fig. 2a). However at this scenario the peak at Ipolytölgyes was by more than 300 m^3s^{-1} lower than that resulting from the scenario E (Fig. 2c). Unfortunately, the most rain bearing depressions are arriving to the Ipeľ catchment from the south – southwest, sometimes with combination of the moist air influx from west – northwest. It should be therefore expected that the extreme floods of Ipeľ would also occur under such meteorological conditions.

However, the described numerical experiment presents only a part of the information which could be achieved with the calibrated Ipeľ rainfall – runoff model. Rainfall scenarios with different rainfall intensities over different catchment parts on one side, and with variable rainfall intensity in time on the other, could also be examined. This would further elucidate the most dangerous flood formation conditions and eventually would lead to better preparedness for flood relief activities at he early stage of the coming flood. Model runs with such combinations of rainfall scenarios have not been performed so far, because the presented model development and calibration was completed just recently and because of a great extent of activities connected with the data preparation and processing. In further model development for operational forecasting purposes, and its calibration and updating, it is also assumed to arrive at further results based on additional catastrophic rainfall scenario flood simulations.

Closer look at the figures in Tab. 1 reveals that flood with peak close to 1000 m^3s^{-1} on the lower Ipeľ could hardly pass through a channel contained with today existing protection bunds (levees). Apparently several breaches (some of them may be intentional) would be the result on the both sides of the river with extensive flooding of the adjacent valley in such case. Does this information bring something relevant to the flood protection of the Ipeľ catchment ? It does not predict such catastrophic event, nor gives it its return period. It merely states that a realistic rainfall event is physically possible, and what are its hydrological consequences. Rainfall of such magnitude and areal extent did not occur during our historical period only over the Morava and Odra catchments, similar event was observed also in July 1954 over the left Danube tributaries in Bavaria and Austria (Kresser, 1957), when catchments of rivers Inn, Isar, and Iller in the extent of over 10000 km^2 received rainfall close to 200 mm within three days. Interesting observation is mentioned in the CHMI report (CHMI, 1997) related to the extent of flooding in the valley of Morava river. Its line almost coincides with the line of extent of the fluvial soils, which leads to the conclusion that floods of comparable magnitude were not extremely rare in the more distant past from which we are lacking hydrometeorological records.

Floods in recent years drew the attention of publics and also politicians to the flood problems, particularly to prevention of flood damages. Human effort and funds are being invested in improvement of existing and development of new flood forecasting and warning systems.

These “products”, unfortunately, cannot be purchased on a turnkey basis, like a new house or car. Their “running in” is practically a continuous process requiring a lot of training in a variety of procedures, maintenance activities, permanent and dedicated staff with sufficient experience. All this, together with sofisticated software ready to be used and perform perfectly, often after long years without a significant flood event. Like a lifeboat, such systems may be used to its full purpose only few times (some of them never) in its existence, but needs to be maintained and checked by a competent crew before each and every new cruise.

Structural measures for flood fighting, not to speak about flood eliminating, of catastrophic floods hardly exist. There are neither flood storages available for retention of the necessary amount of flood waters, nor can the bunds be constructed to such levels to contain the catastrophic floods in the river bed. People must be aware of the threat of possible flooding, informed about its extreme extent, and about the activities they are supposed to perform in case of the extreme flood warning. If the competent authorities will manage to keep their regional community prepared and to issue such warnings well in time, the effort and funds invested into the flood forecasting and warning systems will not be wasted.

Results of the numerical experiment described above should help to indicate a situation with which the population and administration of the lower Ipeľ Ipoly region in Slovakia and Hungary would be confronted in case of a possible flood catastrophe.

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Record River Floods and Inundation by Undrained Runoff in The Tisza Catchment in Hungary 1998-1999

Lajos Szlávik, Gábor Bálint

Abstract: Under the particular geographic conditions of Hungary, important and steadily growing interests have been attached to flood control for centuries. The fundamental cause of the grave flood hazard is that the overwhelmingly plain country is situated in the deepest part of the Carpathian Basin. The system of 4000 km long 3-8 m high flood protection embankments and floodwalls has been created starting the mid-19th century and nowadays 97 % of the flood plain is protected. Rainfall, snowmelt induced and mixed floods all are frequent. Most of the rivers inherit the possibility for the formation of ice jams and related flooding. Catastrophic floods appeared on River Tisza in 1888, 1932, 1940-41, 1970, 1985, 1998 and 1999. 1998. The last two events proved to produce extreme flood crests on the Upper Tisza and on the Middle Tisza - downstream of the Bodrog mouth consecutively.

Key words: flood hazard, flood embankments, catastrophic floods

Die bedeutendsten Hochwässer und Schuβpolderwasser-Überflutungen im ungarischen Einzugsgebiet der Theiβ zwischen 1998 und 1999

Zusammenfassung: Unter Ungarns besonderen geographischen Bedingungen wurde dem Hochwasserschutz während der Jahrhungerte eine groβe und ständig zunehmende Aufmerkasamkeit gewidmet. Die grunglegende Ursache der strarken Gefährdung durch Hochwässer ist die Tatschache, daβ das überwiegend flache Landesgeiet sich im mittelren , tiefsten Teil des Karpatenbeckens befindet. Das aus den insgesamt 4000 km langen, 3-8 m hohen Hochwasserschutzdeichen und –schutzmauern bestehende Systems wurde ab Mitte des XIX. Jh. Ausgebaut, so daβ heutzutage bereits 97% des früheren Überflutungsgebietes vor Hochwassern geschützt ist. Vom Regen, von der Schneeschmelze ausgelöste wie auch gemichte Hochwässer kommen oft vor. Die meitesen Flüsse neigen noch immer dazu, Eisprofen zu bilden, welche Eishochwässer zu Folge haben. Am Fluβ Theiβ gab es katastrophale Hochwässer in den Jahren 1888, 1932, 1940-41, 1970, 1985, 1998 und 1999.

Schlüsselworte: Hochwassersutz, Hochwasserschutzdeichen, katastrophale Hochwässer

1 The flood hazard situation in Hungary

Under the particular physico-geographic conditions of Hungary, important and steadily growing interests have been attached to flood control for centuries. The fundamental cause of the grave flood hazard is that the overwhelmingly plain country is situated in the deepest part of the Carpathian Basin, where the flood waves rushing down from the surrounding Carpathian and Alpine headwater catchments are slowed down, overtake and coincide with each other resulting often in high river stages of extended duration. Owing to the climate and the physico-geographic situation floods are liable to occur virtually on any Hungarian river in any season of the year.

Flood plains make up 22,8 % (21,248 km^2) of the total 93,000 km^2 large area of the country. 2,5 million people of around 700 communities in the protected flood plains are exposed to flood hazard. These plains comprise 1,8 million hectares or one-third of the arable lands in the country, over 2,000 industrial plants, 32 % of the railway lines and 15 % of the road network. Some 25 % of the gross domestic product is generated in this area.

2 Floods in the Tisza Catchment

2.1. Physical-geographical and hydrological specifics of the Tisza Catchment

River Tisza is the largest tributary to the Danube as regards stream length (977 km) and catchment size alike. She collects the runoff from the eastern part of the Carpathian Basin. The approximately oval catchment has an area of 157 200 km^2 and represents 20% of the Danube Basin. The East-West and North South diameters are 520 and 460 km, respectively. The highest peak rises to 2506 m above mean sea level and the mean annual flow at the mouth to the Danube has been estimated at 830 m^3/s.

The catchment areas upstream of the entrance to, and outflow from Hungary are 9707 and 139 078 km^2. Of the 129 371 km^2 large Hungarian part 86% are drained by the major tributaries (the rivers Túr/Tur, Szamos/Somes, Kraszna/Crasna, Bodrog, Sajó/Slana, Hernád/Hornad, Zagyva-Tarna, Körös/Cris, Maros/Mures), which save the Zagyva-Tarna originate beyond Hungarian territory and discharge the floods from their mountain headwaters to the recipient Tisza. Practically the entire Hungarian part of the catchment (46 200 km^2) consists of flat lowlands. Floods develop almost exclusively in the neighbouring countries, Hungary having thus virtually no influence on the implementation of constructional flood control measures like retention reservoirs.

The annual mean precipitation over the Tisza catchment is between 500 and 1600 mm, the seasonal distribution of which is governed by the general pattern of the moderate climatic zone in the northern hemisphere. The annual runoff ranges from 1000 mm (30-32 l/s km^2) in the mountain parts to 10-15 mm (0.5 l/s km^2) in the semiarid lowlands.

The peak flood flow of 4000 m^3/s in the Tisza at her entrance to Hungary, the peak discharges from the tributaries exceeding 1000- 1500 m^3/s.

The flashy hydrological regime of the Upstream-Tisza and her tributaries is illustrated by the fact that the floods triggered by torrential rains over the mountain headwaters take only 21-30 hours to appear at the Hungarian border. The duration of these floods is limited to a few days, increasing in length to several weeks over the middle and downstream sections.

In comparison with European rivers of similar size, water levels fluctuate over a rather wide range in the Tisza catchment, thus from about 5 m on the Upstream Tisza to 13 m over the lowland sections. Similarly wide ranges (3-10 m) are typical on most of the tributaries, those on the rivers Körös and Szamos being widest with 10.3 and 10 m, respectively. The ratio of low and high flows is also high, thus 1:300 on the Upstream-Tisza and 1:40 farther downstream.

According to the flow regime, the Hungarian Tisza section can be divided into the upstream and middle sections. Three major floods may occur normally on the Upstream Tisza: the spring and May floods drain the snowmelt runoff, whilst the autumn flood is caused by storms. However, downstream of the Szamos mouth the first two are liable to overtake each other and to coincide with the flood waves discharged by the two large Tisza tributaries, the Körös and the Maros rivers. Such situations give rise to high water levels of long duration over the Middle-Tisza. Of the major Tisza floods recorded over the past 100 years those of 1879 and 1919 occurred in spring, the one in 1888 was triggered by winter rains, that in 1895 by snowmelt. The flood wave arriving on the River Maros has caused especially high water levels on the middle and lower Tisza reaches in 1932. Simultaneous extreme floods on the Tisza and all her tributaries have caused record stages along the river. The ice-run flood of 1985 on the Upstream Tisza was unprecedented in its category. In November 1998 and in March, 1999 two flood waves of extreme hydrologic parameters followed each other virtually without a low-water period. The Tisza tributaries show similar flow regimes.

From the flood statistics of the various rivers and regions it is concluded that the recurrence period of minor and medium floods is 2-3 years, that of major floods 5-6 years, while that of unusually high floods 10-12 years in Hungary. The duration of major floods is 5-10 days on the

Hungarian upstream river sections and may be as long as 50-120 days along the flat middle and lower sections. Durations of similar length are rare on other European rivers.

Torrential regimes are typical on the headwater reaches of the tributaries, the floods triggered by rapid snowmelt or a violent storm arriving within 1-2 days at the entrance to Hungary and raising the water level by several metres within a very brief period of time (in some cases within a few hours). In this respect the hazard is an especially grave one on the Upstream Tisza and her tributaries, further on the Körös rivers, where the water level may rise by 8 to 10 metres at the national boundary 28-36 hours after a storm event.

2.2. Geographical situation and population of the Tisza Catchment

Five countries share Tisza catchment: the Ukraine (8.1 %), Rumania (46.2 %), Slovakia (9.7 %), Hungary (29.4 %), and Yugoslavia (6.5 %). Co-operation between these countries in the field of water management is regulated by bi-lateral transboundary agreements.

There is no major city in the catchment, of the 15 million total population 2.5-3.0 million living in 25-30 towns of 60 to 400 000 inhabitants, the rest in small towns and villages. The major towns have been the natural regional centuries for centuries.

2.3. Flood control development in The Tisza Catchment

Two centuries of planned water management have transformed the Tisza catchment to its present shape. Following sporadic, isolated river training attempts, the ambitious, integrated reclamation project launched in 1846 has provided flood control to 20 000 km^2 in the catchment (30% of the lowlands), which were formerly inundated permanently, or periodically for the greater part of the year. Steady efforts over 150 years have resulted in 4500 km long flood levees affording flood safety to 27 000 km^2 of arable land. Hungary's present share of this development comprises 2900 km of levee and 18 000 km^2 of reclaimed land. To appreciate the magnitude of this project it should be noted that it is the largest of its kind in Europe. In the Po Valley in Italy 2400m km of levees protect an are of 12 000 km^2, while in the Netherlands the reclaimed area is 15 000 km^2 (*Fig. 1*.).

Flood exposure in the Hungarian part of the Tisza catchment is illustrated by the fact that of the 21 151 km^2 flood plains 74%, or 23% of Hungarian territory are situated there. These plains are protected by 2900 km of mainline levees, or 70% of the total in the country.

The defences built to control floods since the middle of the 19th century consist of the embankments referred to as the main-line levees of 4003 km total length (3973 km earth embankment, 30 km flood wall) along the rivers. The total volume of the embankments is approximately 120 million m3. These have been completed virtually along all flood plain sections considered valuable enough to deserve protection, so that further efforts must be concentrated on raising their standard of safety.

The flood waves rushing down the mountain catchments enter the lowlands before the national boundary. Along the streams forming, or crossing the boundary river- and levee sections of common interest have been designated with the neighbouring country. The total length of levees covered by international agreements amounts to 1055 km, or one-fourth of the defences.

The standard against which the defences are assessed is the design flood, which these are required to withstand. The magnitude thereof is decided upon to comply with the safety required at the actual level of socio-economic development and with due regard to the economic strength of the country (or the interested beneficiaries). The likelihood of disastrous situations differing from the reasonably anticipated conditions is too small to serve as design criteria. Such situations must be controlled by appropriate emergency measures to avert, or minimise losses. Under the provisions currently in force in Hungary, the defences must be dimensioned to withstand safely the ”one in hundred years” (”one in thousand” along major towns) ice-free flood, at a safety freeboard of 1.0-1.5 m. Considerations of safety, traffic and transportation on

the crest in emergency situations, further of maintenance with mechanical conditions are involved in deciding on the minimal cross sectional dimensions. The resulting embankments rise locally more than 5-8 m above the surrounding terrain. Embankments of 2421 km length (60.5% of the total) comply with the dimensional specification. The rest of the levees (1582 km) offers safety against floods of 60-80 recurrence period, though at considerable emergency efforts. It should be noted at the same time, that even the improved, strengthened levee sections include local weak spots with properties poorer than those of the connecting parts, which fail to meet the safety criteria. As a result of regular levee surveillance several hundred shorter-longer sections are known, where the level of safety is dangerously low (e.g. crossing of ancient meanders, streams, cracked embankments). The total length of these sections is approximately 560 km.

There are 1800 structures (sluices, culverts), which cross the levees. Some of these were built 80-100 years ago and are in a very poor state of repair. These, but also the other crossing structures represent potential safety risks and are monitored with special care.

Though split up by national boundaries, the Tisza catchment consists of an integrated network of stream, where land use and other changes in the headwater parts affect flood conditions in the Hungarian section. Construction of flood embankments during the past two decades beyond Hungary has raised flood levels in the Tisza and her tributaries. The Körös rivers offer the most striking example thereof, where the flood peaks rose by 111-172 cm during the last 30 years.

2.4. Historical review of flood control and flood fighting in Hungary

No river comparable in flatness of slope and rampant meandering to the unregulated Tisza exist in Europe and a very few flood control systems of similar complexity were built worldwide. The first comprehensive flood plain reclamation programmes were started in the early 1800s only. Embankments, ring dykes designed to provide local flood safety alone were built earlier. The active stage in the history of relations between Man and rivers was introduced in Hungary – among the first worldwide – by the Act of 1840 on the training of the Danube and other rivers, which was followed in 1844 by the Act known as the „Tisza Law". Construction work was started in 1846 and continued for over 50 years. Flood control development was practically completed by the end of the 19th century, though actually some work is still outstanding. The areas inundated per decade have shrunk in size to a fraction of the former and Tisza floods have caused since no major devastation, demonstrating the significant benefits of the vast river regulation and reclamation project.

The abnormal floods and the losses caused thereby over the 150 years long history of flood control in Hungary have always revived interest in flood defence, raising to high standards the professional level of emergency control. From the long list of flood events two must be mentioned because of the devastation caused: The 1838 ice-jam flood on the Danube, which has divested Pest town and the 1879 Tisza flood, which has destroyed Szeged town to an extent prompting the capitals in Europe to contribute to her reconstruction. The list includes further major floods, like the 1947 flood on the Upstream Tisza, the 1954 summer flood on the Danube, the 1956 ice-jam flood on the Danube, the 1970 record flood on the Tisza, the 1974, 1980, 1981 and 1995 floods in the Körös Valley, and the last ones in 1998 and 1999 on the Tisza. The Tisza and her tributaries responded to the cutting of meanders and reducing the width of the flood plains by considerably higher flood levels, the fast sizing process continuing to these days (Fig. 2). Induced by the combined effect of changes in parameters of flood routing, occurrence of hydrometeorological extremes and/or coinciding runoff from sub-catchments not experienced thus far, though conceivable, further of human interference in the mountain and lowland catchments, flood levels are liable to rise further on some other Hungarian rivers as well.

2.4. Institutional background, the emergency organisation

Control in flood emergency situations is assigned by law to the state. Within the central government it is the Minister of Transport, Communication and Water Affairs, who is responsible for the water management functions, thus also flood management. The national professional agency subordinated to the minister to perform the operative functions of water management is the National Water Authority (NWA), handling emergency situations through its 12 Regional Water Authorities (RWA) organised by catchments principle. The Central Water Emergency Organisation is presently responsible for performing the special tasks of emergence control all over the country, like operating the emergency squad, the icebreaker fleet, blasting ice jams, etc. The National Hydrological Forecasting Service, a unit of VITUKI Plc, performs collection and dissemination of hydrologic data, issues flood forecasts.

The water agency is required to provide guidance for the engineering measures of emergency control, for which the manpower and technical equipment are secured by the municipalities, the civil defence and the army. In major flood fighting operations (for instance the recent 1998 November and 1999 spring floods) 5000 employees of the water service and 10-15 thousand other emergency workforce were mobilised.

Particular conditions of the flood defences in Hungary call often for the application of special emergency measures, materials and equipment to cope with major floods. Construction work on the embankments was started in the 19th century, using earth materials available at the nearest borrow sites. Construction technology and the quality of work varied from section to section. Repeated strengthening resulted in the typical ”onion” structure of the embankments (Fig. 4). The organic, alkaline and disperse soils placed present still serious problems in assessing the stability of the levees.

The Flood Management Information System (FMIS) created by integrating into a network the roughly 400 workstations at the centres of the 17 institutions involved in handling flood emergency operations on national and local levels, has been operating on a routine basis since 1994.

2.5. Major floods in the Tisza Basin

Each major flood has revived the demand and arguments for flood control development. This was the case also in the past century, when the floods of 1916, 1830 and 1845 have provided the final impetus triggering the comprehensive reclamation project in the Tisza Valley, while the floods of 1855, 1867-68, 1879, 1881 and 1888, each of disastrous proportions, have redirected public attention to the importance of continuing and improving the defences.

In the present century such periods of intensive development were prompted in response to the major floods in the Tisza valley: 1919, 1925, 1932, 1939, 1940-41, 1947-48, and 1970.

The Tisza and her tributaries responded to the cutting of meanders and reducing the width of the flood plains by considerably higher flood levels, the fast sizing process continuing to these days (Fig. 2). Induced by the combined effect of changes in parameters of flood routing, occurrence of hydrometeorologic extremes and/or coinciding runoff from sub-catchments not experienced thus far, though conceivable, further of human interference in the mountain and lowland catchments, flood levels are liable to rise further on some other Hungarian rivers as well.

Recent events have again focused public attention on flood safety in the country. A major flood has travelled down the Körös rivers in winter 1995-96. The most recent floods occurred in November 1998 on the Upper-Tisza and Bodrog rivers with disastrous consequences in the part of the catchment beyond the national boundary, followed immediately by another season of extreme historical floods on the Bodrog and the Middle Tisza in March-April 1999, requiring great efforts and considerable flood defence expenditure.

Although several floods on the streams in Hungary rose to record stages, the defences along them have withstood these flood waves without failure virtually since 1980. The last flood to claim lives was the ice-jam flood in winter 1955-56 on the Danube. And this not attributable to

luck, to any fortunate situation, but rather to carefully planned, methodical development and organising efforts.

3 The extraordinary Tisza floods in November, 1998 and in spring, 1999

3.1. Hydrology of the flood wave in November, 1998

During the 79-day period between August 20 and November 6, 1998, there were only 22 days without rainfall over the catchment above the Vásárosnamény river gauge on the Upstream Tisza. The average rainfall depth over the catchment was 63.7 mm from August 20 to the end of the month, 129.5 mm in September, 155.8 mm in October and 68.9 mm during the first six days of November, amounting to a total of 417.9 mm. Special attention is called to the end of the rainy period, in that the rainfall depth on the Upstream Tisza catchment was 141.3 mm during the 12 days between October 26 and November 6. These rains have prevented desiccation of the soil, creating conditions conducive to the development of a major flood wave. However, rainfall depth over the catchment is only one of the factors triggering and affecting the magnitude of a flood wave, the others including the form (liquid, or snow) and intensity of precipitation, its spatial pattern, further the direction and speed of travel of the storm front.

Following the abundant antecedent rainfall, the rains in late October have triggered the first flood wave, the peak of which was recorded at 820 cm on the Vásárosnamény gauge in the evening of November 1 and was observed as far downstream as the Záhony and Dombrád gauges.

The flood wave triggered by the heavy rains on November 4 and 5 has overtook the first one still in the bed of the Upstream Tisza and superimposed thereon has caused the second, the main flood wave. Most peak levels along the Tisza section in the Ukraine were in the vicinity of the highest on record. The tributary Rika entering at Khust and the Borzhava, a short distance upstream of the border, have discharged unprecedented high flows. The flood waves on the tributaries have swept along the valleys causing tremendous devastation. In the Ukraine 236 communities were affected, 118 of which with 39 600 homes were inundated, 26 500 homes suffered damage and 1350 collapsed. The flood has destroyed 22 bridges, damaged 340 km of road and claimed human lives.

On the Tiszabecs gauge at the border to the Ukraine the flood peak of 680 cm exceeded the highest on record (Hmax) by 28 cm, while 38 km farther downstream at Tivadar the 944 cm peak exceeded the former record by 99 cm. On the Vásárosnamény gauge the 14 hours long 946 cm peak stage recorded on November 7 at 6.00 hours was also above the 912 cm mark recorded in 1970.

Two levee failures on the Tisza reach upstream of the entrance of Batár-Canal on the national boundary had direct influence on the flood situation on the Hungarian river sections. These were estimated to have reduced the peak stage by at least 5-7, but not more by 15-30 cm. The peak flood discharge past the Tivadar gauge was 3570 m3/s, and thus 100 times the low-water flow.

The tributaries Túr, Szamos and Kraszna discharged no major flows, so that owing to attenuation no record flood stages developed at, and downstream of, Záhony.

On the other hand, a severe flood situation emerged at the confluence of the rivers Tisza and Bodrog. The Uzh and the Latorica were the only Bodrog tributaries which carried record flood flows and inundation in the Ukraine have retained part thereof, so that the peak at the entrance from Slovakia (Streda nad Bodrogom) has remained 67 cm below the highest so far. Nevertheless, owing to the combined effect of Tisza backwater and the flood wave on the Bodrog, the November peak at Sárospatak was but 4 cm lower than the historical record in 1979.

The 872 cm peak of the main flood wave at Tokaj was 8 cm lower than the HHW in 1979 and lasted on November 11 from 6 p.m. to midnight Between Tokaj and Szolnok the duration of the

flood peak was unprecedented 10 days and caused at Szolnok a peak lower by 12 cm only than the Hmax of 1970. Downstream of Szolnok the November flood peak travelled down at relatively fast rate with stages well below the highest levels on record.

3.2. Floods on the Tisza and Bodrog rivers in March-April, 1999

In 1999, following a dry January, the largest mass of snow of the recent decades has accumulated in the second half of February in both the mountain and the lowland parts of the catchment Over the Tisza catchment upstream of Szolnok and Szeged the water mass stored in the snow cover was 6.8 and 11.0 km^3, respectively, on February 18. In terms of rainfall depth this corresponded to over 90 mm for the average of the catchment, with 150-240 mm at elevations higher than 500 m and 60-80 mm in the lowlands. Owing to the abundant rainfalls in the antecedent year, further to soil frost in December and January, the danger of floods was imminent. In late February and early March mild spring weather induced rapid snowmelt first in the lowland areas, which extended gradually to the higher elevations in the catchment. The consequences were inundations by untrained runoff in the lowlands and growing runoff generating flood waves in the mountain parts.

In early March - hardly four months later - and extraordinary flood wave developed and travelled down the Bodrog and the middle reaches of the Tisza, although the rainfall accompanying the temperature rise was insignificant in all catchment parts.

The flood on the Bodrog was abnormal as regards both water levees and duration. Over the widely extending, southward sloping hills of medium height in the Bodrog catchment a water mass of 1.74 km^3 has accumulated. Rising temperatures and sunshine has induced rapid snowmelt in the entire catchment. This is the reason why the flood runoff surpassed here substantially that observed in the catchment of the other tributaries. On the Sárospatak gauge the flood level surpassed the peak recorded 111 years ago in 1888. This abnormal flood wave developed without any major rain accompanying snowmelt in the catchment, where a rainfall of 26 mm only was registered between March 1 and 11. The rate of rise was also an extraordinary one, in that the water level rose 60-70 cm daily for several days. The duration of the flood was unprecedented.

The peak stage on the Tokaj river gauge was 894 cm (14 cm above the HHW - highest high water - on record) on March 14-15. Over the Tisza section downstream of Tokaj the water level rose at a rate never experienced earlier. The flood waves surpassed in steepness, height, and duration the 1970 flood referred to as historic, so they were truly extraordinary. From Tokaj down to Csongrád the peak flood level has surpassed the highest thus far on record at every gauging station for an unprecedented period of time.

The flood wave was successfully confined between the flood levees, so that the river has not invaded any of her flood plains.

The costs of the emergency operations during the 1998 November flood on the Upstream Tisza amounted to 2.8 million Euros to save national assets worth more than 500 million Euros. Fighting the 1999 Spring flood in the Tisza Valley to ensure the safety of 6500 million Euros worth of national asset involved an expenditure of 14 million Euros.

Unexpected events, anomalous features of the Tisza floods in November, 1998 and March-April, 1999 have alerted us to the urgency of analysing comprehensively the flood hydrology of the river. Never since the middle of the last century, the decades following immediately the reclamation project, the construction of the flood defences in the Tisza Valley have the peak stages been "rewritten" to this extent. Studies and research projects have been launched to determine the extent of changes, to identify the impacts and importance of the factors involved, further to reappraise flood travel conditions on the Upstream Tisza, the Bodrog, the Middle Tisza and the Körös rivers.

These studies have included a detailed hydrological review of the 1998 and 1999 floods and the statistical evaluation thereof. The conceivable flood situations at the confluence of the river Tisza and her tributaries (the Szamos, Bodrog, Körös and Maros rivers) are being studied in models. The changes and developments in the upstream countries are being identified and assessed for their potential impacts (for instance higher flood peaks) on flood safety in downstream Hungary. The capacity of the main channel and the flood bed of the river Tisza in conveying flood flows is being re-estimated, with special regard to the consequences of changes in land use. The experiences gained during the recent two record floods have demonstrated convincingly that the flood bed must be returned to the river, conditions enabling it to carry a major part of the flood flow must be created there in harmony with the requirements of ecology and nature conservation. These considerations must have priority over land uses, otherwise we must be prepared to face even graver extreme flood situations under more adverse hydrometeorological conditions, the occurrence of which cannot be excluded.

3.3. Emergency measures

Highest (Level III) flood warnings were maintained simultaneously over 1520 km length of defences during the passage of the 1998 November flood wave. Emergency operations involved the mobilisation of a large workforce, heavy equipment and engineering measures. Along the Upstream Tisza the objective was to prevent overtopping by stages rising above the levee crest. On the section between Tiszabecs and Vásárosnamény the total length of the levees on both sides is 79 km. Overtopping posed a risk along 9 km, while along further 35 km length the peak stage remained 0-50 cm below the crest. Owing to the adverse weather and difficult local transportation, manual labour became necessary to build crest dikes of sandbags. In several places buttress ribs were built to increase the stability of the airside slope of the embankment. Along the middle and lower reaches long flood exposure caused seepage across and under the embankment, where sublevee basins were built to control a number of boils.

The 1999 February-April flood required simultaneous emergency measures over 2700 kms of levee, virtually the total length of defences in the Tisza Valley. These protect an area of 15 640 km^2 size in which 435 communities and over 1 million people were directly exposed. The gravest situation developed along the River Bodrog and the middle reach of the Tisza, where 16 kms of temporary defences and 17 kms of crest dike had to be built using over 1.5 million sand begs.

At the peak of the emergency operations during the 1998 November and the 1999 spring flood alike - over 10 000 people worked on averting a flood disaster. The emergency measures proved successful, the levees withstood the extraordinary flood exposure without failure.

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Calculation the Working of a One- Well Group Near the River Drava in Osijek

Marija Šperac, Dragutin Gereš

Abstract : The watersupply of city Osijek is based on the subsurface water, which is pumped from eighteen wells. The wells are located near the river Drava. This paper will present the calculation of depression in piezometer on the flow field. The basic rules for the solution of the problem are : the group of wells is substituted with one fictitions well with equivalent hydraulic effect, located in the center of wells group. The quantity of water from substitution well is a summ of flow of wells group.

The next step needed to solve the problem is : the substitution well presents a real well, and we introduce one new fictitions well from the other side of the equipotential line (the river Drava) at the equal distance. The direction of flow in the fictitions well is oposite to the real well. The depression in piezometer in flow field presents the result of superposition deppresions (positive and negative values) which form real and fictitions well.

In this paper will be presented comparasion calculated values and measured values.

Key words : the group of wells, the river, the subsrface water, the depression, calculated values, measured values.

Arbeitsberechnung der Brunnengruppe neben dem Fluss Drau in der Umgebung der Stadt Osijek

Zusammenfassung: Die Wasserversorgung der Stadt Osijek basiert auf den Fördermengen von achtzehn Brunnen, die in der Nähe der Drau liegen.
In dieser Arbeit wird die Berechnung der Absenkung dargestellt, begründet auf Piezometer, die im Absenkungsbereich der Brunnen installiert sind.
Die Grundsätze zur Lösung der Arbeitsberechnungen sind:

- die Brunnengruppe wird durch einen fiktiven Brunnen mit äquivalentem hydraulischem Effekt ersetzt;
- die Förderung des Ersatzbrunnens stellt die Durchflusssumme der Brunnengruppe dar.

Die Problemlösung ist:

- der Ersatzbrunnen wird als realer Brunnen angenommen,
- es wird ein neuer fiktiver Brunnen jenseits der Äquipotential-Linie (der Drau), in gleicher Entfernung von ihr, definiert.

Das Durchflussvorzeichen des fiktiven Brunnens ist dem des realen Brunnens entgegengesetzt. Die Absenkung im Strömungsfeld stellt das Ergebnis der Superposition von Depressionen (Summe der positiven und negativen Werte) dar, die sich für die realen und den fiktiven Brunnen ergeben.
Schließlich werden Berechnungs- und Meßwerte verglichen.

Schlüsselworte: Brunnengruppe, Fluss, Grundwasser, Absenkung, Depression, Wertberechnung, Messwerte

1 Introduction

This study deals with the problem of groundwater dynamism. The need for water supply in the city of Osijek leads to the exploitation of 18 wells with an amount of 600 l/s of water to be dipped. The analysed area refers to the right bank of the river Drava covering around 400 km^2. The Osijek part of the Drava basin is the lowest part of that

territory. It is an extremely low area where the wide river valleys of Drava and Dunav merge.

In low parts of the Drava basin thre are thick quart layers as the final step in sedimentation in the Drava geotectonic depression. On the surface only the youngest halocene and upper pleistocene sediments can be found, such as fluvial, swampy and Aeolian facies. The quart groundwater supply system is conducted by infiltrating precipitation from surface streams. The surface streams are usually filtered when the water level is high.

Surveys of the level of subterranean sinking conducted while evaluating the model of ground water streams at the sight Vinogradi showed 10-20 % of average annual precipitation inspite of the quite unfavourable sasonal precipitation distribution. The renewal of groundwater in deeper layers is conducted by filtering through semi-permeable layers of clay and dust from a water-carrying layer with higher piesometric level towards the one with the lower piesometric level.

In the area of this well a substantial number of layers with groundwater made of small and middle grained sand has been registered.

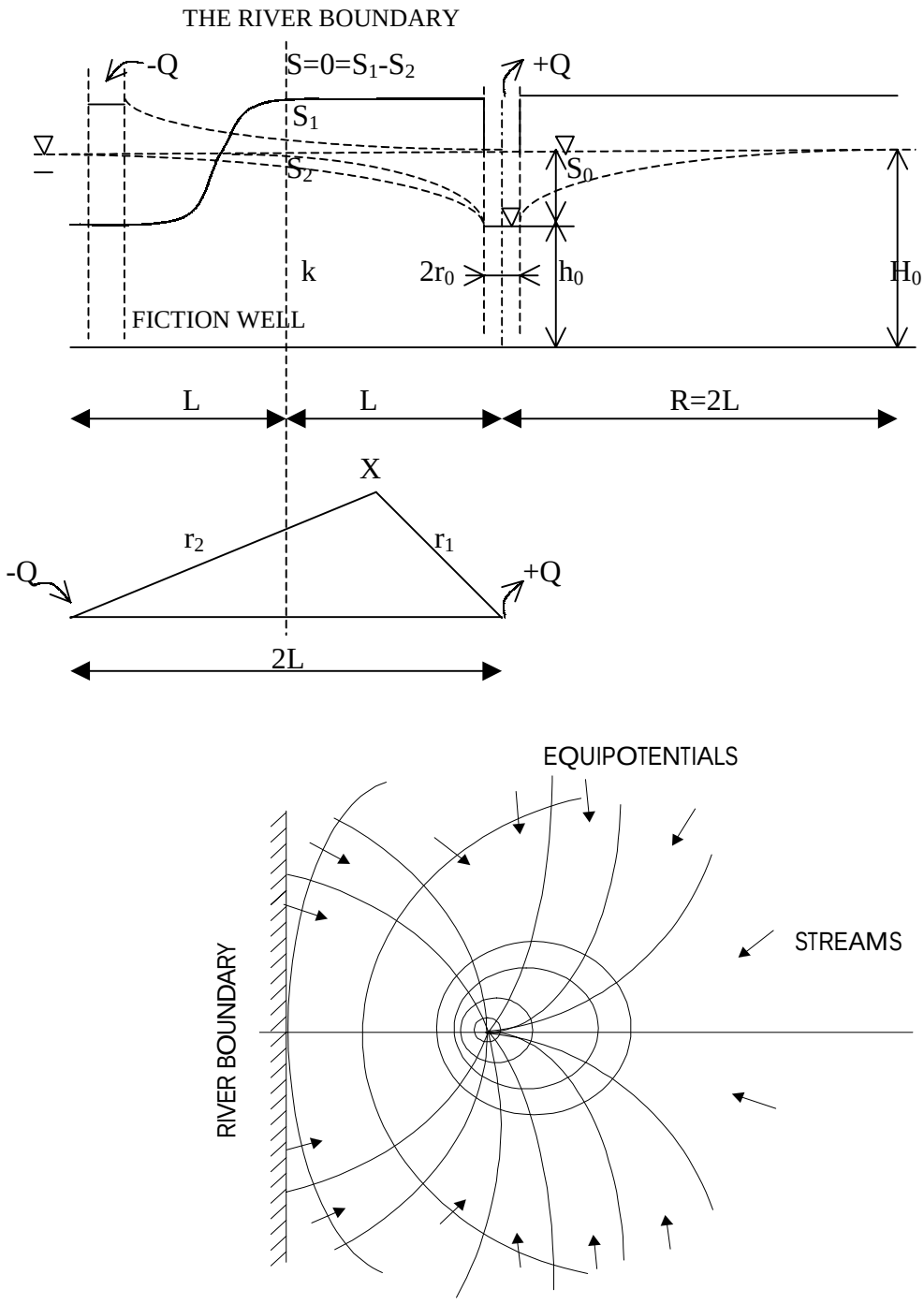
In the long-term process of the exploration of groundwater we have to use the maximum well capacity while at the same time maintaining favourable conditions for the renewal of groundwater supplies. The first shallowest layer (up to 30m deep) is not suitable for this kind of use in a big well site because of high drainage in case of intensive exploitation. In this case, it becomes a source layer through which the renewal of groundwater will be made using not only natural precipitation supply and induced watering from the Drava waterchannel, but also stored water as a reserve in case of drought. At the sam time a very important role of this layer is self-purification of groundwater from the possible surface pollution. At the Vinogradi site water is dipped at the depth of 40 to 176m When analysing works at this site apart from the geological structure limits also regional, local and hydraulic limitations have to be considered. Regional hydraulic limitations are multiple. They imply interference with the neighbouring wells and condition of ground water supplies. The problem of limitations has been solved by grouping the wells which also reduced the internal interference of the well. Local hydraulic limitations refer to hydraulic conditions in the immediate area of the well. Basic features of water-carrying layers are heterogenity and semi-permeability.

2 The working of one wells group

Dipping water from two or more wells which interfere with each other is known as ‘steam accordance’ or the working of a wells group. In case of wells with free water face the lowering of piesometric surface is not linear and depends on the amount of water flowing through it. If we introduce the term ‘lowering’ of Girinski potential $\Delta\Phi$ (in a certain point related to the starting Φ_0) we can say that this relation is linear. With problems of linear dependence we apply the superposition principle which in the example of a well says: the lowering of the water level i.e. Girinski potential in a certain point in the well area caused by the simultaneous process of dipping of more wells will be equal to the sum of each separate lowering in each of the well.

Since wells in Vinogradi site are located in the immediate neighbourhood of the Drava River we cannot apply the term well in an unlimited area. A well by the stream is fed from the stream The lowering of the water level by the straem equals zero.

Fig. 1 The well by stream (half-plane)

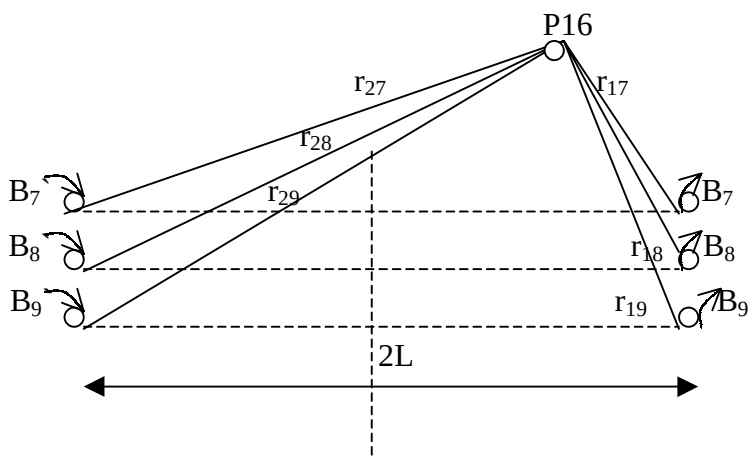


The activity of a well by the stream can be drawn from the superposition of the positive and the negative well. We can imagine a well into which water pours. In this way instead of one well by the stream there are two wells in an unlimited area. From one of these two wells water is dipped and is ppoured into the second (imaginary) one. The combination of two wells (one positive and the other negative) in an unlimited are, provides a solution for working of one well in a semi-flat surface. The negative well has too be imagined symetrically to the positive one in relation to the water stream.

For the calculation of the group of 18 wells that are located in Vinogradi, a grooup of three wells has been chosen (B1, B8, B9) and piesometer P16 which is located within a radius of influence of these wells. This group of wells has the longest range of depression measurements.

The input data in the calculation is:
$Q_{B7}=Q_{B8}=Q_{B9}=0.034$ m3/s
$L_{B7}=L_{B8}=L_{B9}=11.5$ km - distance of wells from the river
$H_{B7}=H_{B8}=H_{B9}=90$m
$L_{P16}=10{,}00$km – distance of piezometer from the river
$2r_0=0.8 \Rightarrow r_0=0.4$m
k=0.00018m/s

Fig. 2 Scheme of wells position



Result:
Besides three existing wells from which water is dipped we can imagine three other wells into which it pours. Radius of influence for the wells by the stream R=2L. Since this is a case of three wells with the same hydraulic features and at the same distance from the stream, we have enough information to calculate a depression in one well.

$$Q \ln \frac{R}{r_1} = \pi k (H_0^2 - h_1^2)$$

$$\frac{Q}{2\pi}\ln\frac{R}{r_1}k\left(\frac{H_0^2}{2}-\frac{h_1^2}{2}\right)=\Delta\Phi_1$$

$$\Phi=\frac{kH_0^2}{2} \quad \rightarrow \text{POTENCIJAL GIRINSKOG}$$

$$Q\ln\frac{R}{r_1}=2\pi\left(\frac{kH_0^2}{2}-\frac{kh_1^2}{2}\right)=2\pi\left(\Phi_0-\Phi_1\right)$$

$$\frac{Q}{2\pi}\ln\frac{R}{r_1}=\Phi_0-\Phi_1=\Delta\Phi_1$$

R = 2L

$r_1 = r_0$

$$\frac{Q}{2\pi}\ln\frac{2L}{r_2}=\frac{k}{2}\left(H_0^2-h_0^2\right)$$

$$H_0^2-h_0^2=\frac{Q}{k\pi}\ln\frac{2L}{r_0}\Rightarrow h_0=\sqrt{H_0^2-\frac{Q}{k\pi}\ln\frac{2L}{r_0}}$$

$$h_0=\sqrt{90^2-\frac{0.034}{0.00018\pi}\ln\frac{23000}{0.4}}=86{,}26m$$

<u>The well lowering</u> $S_{B7}=S_{B8}=S_{B9}$

$S_B=H_0-h_0=90{,}00-86{,}26=$<u>3,74m</u>

The stream lowering ($r_2=r_1=L$):

$$\Delta\Phi_X+\frac{Q}{2\pi}\left(\ln\frac{R}{r_1}-\ln\frac{R}{r_1}\right)=0$$

<u>The piesometer lowering P16:</u>

For the effect of one well on the other linearisation has to be made using the Girinski potential.

$$\Delta\Phi_P=\Delta\Phi_{B7}+\Delta\Phi_{B8}+\Delta\Phi_{B9}=$$

$$\frac{kH_0^2}{2}-\frac{kh_P^2}{2}=\frac{Q_{B7}}{2\pi}\ln\frac{R}{r_{17}}+\frac{Q_{B8}}{2\pi}\ln\frac{R}{r_{18}}+\frac{Q_{B9}}{2\pi}\ln\frac{R}{r_{19}}$$

The depth of water in piesometer

$$h_P=\sqrt{H_0^2-\left[\frac{Q}{2\pi}\left(\ln\frac{R}{r_{17}}+\ln\frac{R}{r_{18}}+\ln\frac{R}{r_{19}}\right)\right]}$$

$S_P = H_0 - h_P$ <u>= 1.21 m</u>

3 Measurements of the depression (m) on wells B7, B8 and B9 in the period 1965-1975.

Well B7

mjes	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	GOD
SRE	2.86	2.06	1.74	1.68	1.68	1.96	2.20	2.69	3.2	3.56	3.43	3.11	2.40
MAX	4.63	4.48	4.46	3.59	3.59	3.67	3.60	4.33	4.86	5.03	4.86	5.13	4.25
MIN	0.38	0.37	0.63	0.63	0.83	1.10	0.77	1.25	1.44	1.72	1.19	0.86	1.57

Well B8

mjes	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	GOD
SRE	2.52	2.07	1.54	1.48	1.42	1.61	1.88	2.51	2.81	3.08	2.97	2.70	2.22
MAX	4.44	4.44	4.33	3.78	3.37	3.66	4.04	4.30	4.46	4.5	4.62	4.59	4.00
MIN	0.63	0.32	0.38	0.50	0.86	1.07	0.73	1.10	1.28	1.01	1.10	0.72	1.30

Well B9

SRE	1.53	1.24	0.92	0.83	0.86	1.09	1.30	1.71	1.86	2.01	1.76	1.61	1.40
MAX	3.32	3.22	3.31	2.90	2.20	2.33	2.90	3.10	2.85	3.20	3.20	3.52	2.39
MIN	0.27	0.12	0.12	0.17	0.20	0.52	0.36	0.40	0.64	0.75	0.47	0.36	0.86

Piesometer P16

mjes	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	GOD
SRE	0.77	0.62	0.74	0.75	0.86	0.87	0.79	1.07	1.4	1.49	1.20	0.94	0.96
MAX	0.87	0.78	0.82	1.10	1.03	1.12	1.07	1.40	2.12	2.42	2.25	1.54	1.29
MIN	0.60	0.52	0.70	0.50	0.62	0.68	0.46	0.66	0.85	0.54	0.57	0.50	0.71

4 Conclusion

Osijek water-supply system is based in Vinogradi wells. This site consists of 18 wells with a total capacity of 600 l/s, i.e. the average pproductivity is 34 l/s for each of the wells. Wells are supplied by water from the river Drava and precipitation. Since wells have been grouped to avoid interference among wells in one group and amoung neighbouring groups of wells, a representative group of 3 wells has been chosen. These wells are located 11.5 km from the mainstreamand piesometer is in the area of wells interference.

The input calculated data are average measurements of hydraulic features of the whole Vinogradi wells group. Measurements of depressions in wells and piesometer are the result of calculations and correspond to the actual measurments on the site. These figures show that the lowering of groundwater (depression) in wells and piesometer varies depending on the seasons, which implies that if the level in Drava is higher and there is more precipitation the refilling of wells happens faster and vice versa.

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Indicators of Sustainable Land Management

Lidija Tadić

Abstract: Last few years great efforts have been made on identification and definition of sustainable land management. Because the sustainability can not be measured directly, it is necessary to define indicators of sustainable land management relevant to the certain area and compare them to the specific standards. The concept of sustainability includes the limits of resource availability, environmental impacts, economic viability and social acceptability.
This paper is going to present some of the indicators applied on one smaller catchment area of Karašica and Vučica rivers (2400 km^2) in the river Danube basin. It describes a methodology of achieving a certain level of sustainability. This catchment is very interesting from the land management point of view. The main human activity is intensive agriculture that is potentially source of water and soil pollution. Density of population is high and great amount of water is used for water supply. There are many opposite interests , which have to be incorporated in the sustainable land management.

Key words: sustainable land management, indicators, water quality and quantity

Indikatoren des nachhaltigen Einzugsgebietsmanagements

Zusammenfassung: Die Wissenschaft bemüht sich in den letzten Jahren sehr, den Begriff des nachhaltigen Einzugsgebietsmanagements zu identifizieren und zu definieren. Da die Nachhaltigkeit nicht direkt meßbar ist, ist es notwendig, die Indikatoren zu definieren, die für ein bestimmtes Gebiet relevant sind. Erst danach kann man sie quantifizieren und mit den spezifischen Standards vergleichen. Das Nachhaltigkeitskonzept schließt die Begrenzung der Naturressourcen, den Umweltschutz, die Wirtschaftskriterien sowie die soziale Akzeptanz ein.
In diesem Artikel werden einige Indikatoren präsentiert, die in dem kleinen Einzugsgebiet (ca. .2400 km²) der Flüsse Karašica und Vučica im Donau-Einzugsgebiet benutzt wurden. Es wird die Methodologie zur Aufrechterhaltung eines bestimmten Grades der Nachhaltigkeit dargestellt. Das hier behandelte Einzugsgebiet ist sehr interessant hinsichtlich des Gebietsmanagements. Der wesentliche anthropogene Eingriff besteht in intensiver Landwirtschaft, die ein großer potentieller Verschmutzer der Wasserresourcen ist. Die höheren Bereiche des Einzugsgebietes wurden aufgeforstet. Die große Bevölkerungsdichte in diesem Gebiet erfordert eine große Wassermenge für die Wasserversorgung. Die sehr unterschiedlichen Interessen der Wassernutzer müssen mit der geregelten Bewirtschaftung befriedigt werden.

Schlüsselwörter: Nachhaltiges Einzugsgebietsmanagement, Indikatoren, Wasserqualität und -menge

1 Introduction

In the beginning, it is necessary to describe concept of sustainability and sustainable land management to make following text clear and understandable. There are many more or less clear definitions, but they all include multifunctional and in some way contradiction targets:

- Satisfaction of human needs
- Preservation of environment for the future generation
- Conservation of natural resources.

Considering the concept of sustainability, we usually talk about area of the river basin, region or national territory, but several issues of global significance which impact on sustainable land management can not be neglected. Some of them are: finite supply of land suitable for agricultural production, impacts of rapidly rising population, impacts of land and soil degradation and impacts of changing land use on the global environment and genetic diversity. These impacts have, more or less, significant presence on the national and regional levels.

Talking about sustainable land management, it presents the usage of land to meet changing human needs and ensuring the long term social, economical and ecological functions of land.

Sustainable land management combines technologies, policies and activities aimed at integrating social and economical principles with environmental concerns to simultaneously maintain or enhance production, reduce the level of production risk, protect the potential of natural resources and prevent soil and water degradation, be economically viable and be socially acceptable (Smyth and Dumanski, 1993).

Sustainable land management is the key to harmonizing the environmental and ecological concerns of society with the economic realities of producing food and fiber for expanding world population (Dumanski, 1993).

These definitions has to be taken more like a basic principles or pillars in developing the research model, because the project of achieving the sustainability has to be developed for each area and its specific conditions, geographical, natural, economical and social.

The research model must include main goals, a conception framework, and a set of procedures and indicators (criteria) for diagnosis.

It is obviously complex work that needs a multidisciplinary approach. Promotion of sustainable land management requires comprehensive research to identify present situation including meteorological and hydrological analysis, soil survey, topographical survey, etc. and define adequate programs necessary for implementation of sustainable land management. Research must reflect the basic pillars of sustainable land management, including indigenous knowledge, on-farm experimentation and long-term research. Research is required in order to provide better and more quantified definitions of sustainability. This should include: exactly what is to be sustained; at what level and for how long; what resources will be required; and what degree inputs will be required to achieve certain level of sustainability.

One of the questions that have to be asked is related to the scales or levels. Agricultural policies and programs such as soil conservation programs and fertilizer subsidies are formulated at the national level. Besides, rural development projects operate mostly at the district level.

It is important to define time frame, too. While the collection of baseline data requires surveys of limited duration, the monitoring of soil quality or the extent of soil erosion requires continuous observations, analysis and data processing. The ecological and socioeconomic sustainability of new management technologies can be proven only after period of at least ten years.

Next very important requirement is adequate technology of food production tailored for local application and local environmental and economical conditions. Sustainability of present technology must be examined and options developed for improved systems.

The field of training, also should not be neglected. Universities and other educational institutions are orientated to producing specialists. Much more efforts have to be done on developing integrated approaches and teamwork to achieve the objectives of sustainable land management.

2 Land quality indicators

The sustainability can not be measured directly, because it is consisted of many different parameters. Some of them hardly can be expressed in numerical values. Quantitative indicators are preferred to be simple, clear, accurate and valid. Sometimes, it is necessary to use qualitative indicators that are more difficult to present and therefore may appear less accurate than quantitative data. So, it is necessary to define indicators of sustainable land management relevant to the certain area. In other words, assessment of sustainable land management requires appropriate measurable evaluation instruments, such as land quality indicators.

Land quality is a condition or state of the land relative to the human requirements, including agricultural production, forestry, conservation and land management. Comparing to the soil quality, land quality has much wider meaning, including climate, land use, human interventions on the landscape, etc.

Land quality program has been developed by Word Bank in association with Food and Agriculture Organisation (FAO), Consultative Group of International Agricultural Research (CGIAR), United Nations Developing Program (UNDP) and United Nations Environment Program (UNEP) in the beginning of nineties.

The program of land quality indicators, or sustainability indicators, has very wide range of indicators depending on climate zone in the first place. Developing of the basic set of indicators to the subgroups depends on specific conditions present on the observed area (catchment). Besides, it is necessary to have a good background in the field of standards, regulations (law) and policy.

Table 1 Sustainability indicators for temperate climate zone.

BASIC SUSTAINABILITY INDICATORS		
1.	Agronomic/agricultural	-crop yield (trend and variability) -nutrient balance -match use to land capability -measures of diversification (type/change) -maintenance of soil cover
2.	Ecological	-impacts/rate of change of natural stresses -soil quality/quantity (change) -water quality/quantity (change) -wildlife habitat (type/quality)
3.	Economic	-net farm profitability (trend) -market returns compared to the subsidies -use of external inputs (trends)
4.	Social	-adoption of conservation tillage (rate) -participation of conservation programs -environmental policies/regulations (number) -acceptance of sustainable land management standards (rural/urban) -opinion polls

These basic sustainable indicators can be further developed to the more specific parameters, depending on conditions present at the certain area. It will be shown on the example of one project which is still in development.

3 Application of Sustainable Indicators

The procedure of achieving the set of indicators relevant for the sustainable land management is going to be present on one smaller catchment area in the Drava river basin. It is a catchment of two rivers, Karašica and Vučica, which is very interesting from the water management point of view (Fig. 1).

The majority of the area is under intensive agriculture what have significant influence on water and soil quality. Agricultural fields have very developed surface and subsurface drainage, including flood protection.

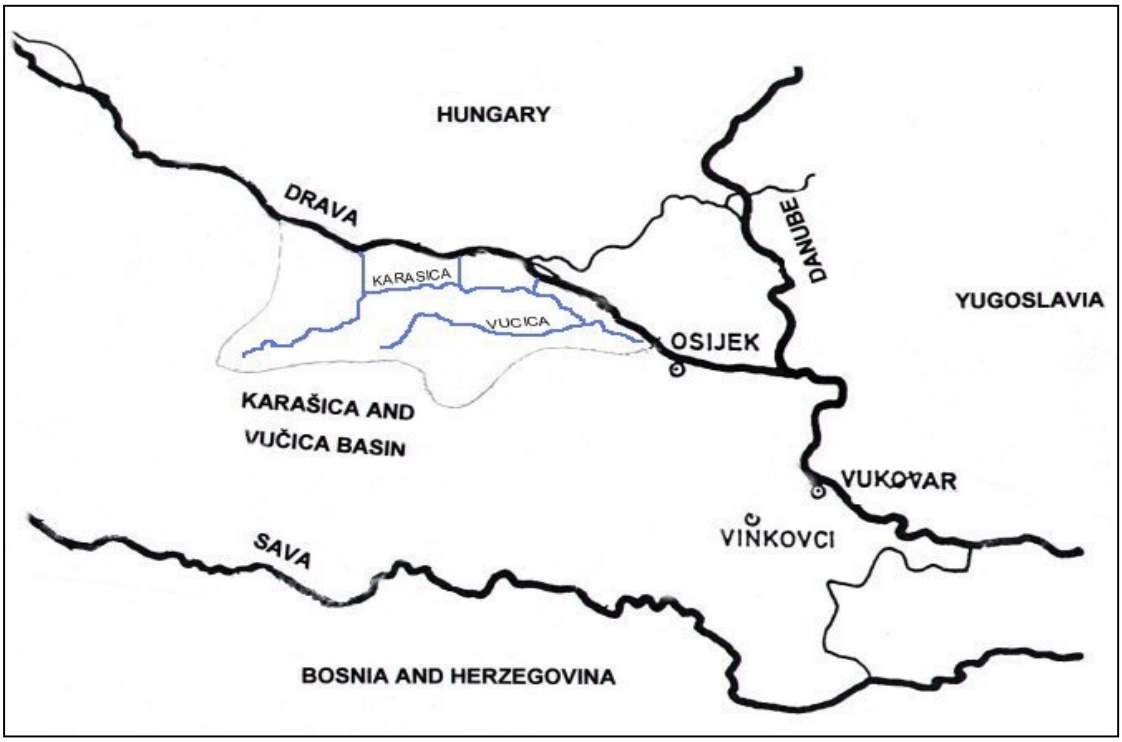

Fig.1 Scheme of position of Karašica and Vučica catchment area in the northern part of Croatia

3.1. Agronomic/agricultural Indicators

The main crops are wheat and maize, produced without irrigation, what implies a great variability in production depending on annual precipitation. Besides these two crops, many other crops are in production, what is the measure of diversification. Last few years agronomists have started several observations of nutrient balance and land capability for agricultural usage. Maintenance of soil cover is very interesting issue, especially its impact on surface runoff.

In general, agronomic indicators are well investigated, and there are sufficient data for analysis.

3.2. Ecological Indicators

In this group of indicators main attention is paid to water quality and quantity. Analysis of water quantity includes groundwater balance, balance of surface water, identification of great water users (industry, agriculture). Water quality analysis includes classification of open watercourses according to their quality and vulnerability and identification of water quality status (concentration of heavy metals, conventional pollutants and pesticides). Water and soil pollution, due to agriculture is under investigation last, about eight years. Results shows that water and soil quality is still satisfactory, but rising trend of pollutant concentration is present.

Problem of soil quantity is related to the erosion and matching the use of land to its capability. Erosion problem is not very expressed, because the majority of hilly part of the catchment is under forests and orchards.

Analysis of natural stresses includes floods and droughts. Development of flood protection systems has started one hundred years ago, but drought problem is much more recent. The both problems need very comprehensive hydrological study. They are closely connected with human impact on natural hydrological regime. Drainage, dam construction and irrigation have a strong influence on natural water regime.

Protection of wildlife habitat in this case can be applied on big fishpond which also have a function of wetland during high water level in surrounding area.

Ecological indicators are mostly related to the state and protection of surface and subsurface water. It is logical, because water problem will be the most important in the future. Water consumption is increasing due to the developing of human standards and population (social indicators) and economic development (industry and irrigation).

3.3. Economic Indicators

The basic economic indicators is net profit (trend) and cost benefit ratio. Besides, subsidies and market returns are also in this group of indicators.

3.4. Social Indicators

Social indicators are related to the increasing of population and its migration. It implies changes in land use. It can be said that lost of arable land happens every day. One of the important social indicators is development of protective regulations and laws. In Croatia, a great improvement has been made in the field of regulation during last decade. It is important to stress an importance of mutual co-ordination and exchange of experiences on national and international levels. A good example is co-operation of Danube countries. It is also one of the social indicators – education and exchange of experiences.

4 Conclusion

From the previous analysis it is obvious that all indicator are related one to another. They can not be observed separately.

Concept of sustainability shows that problems have to solved step by step, considering opposite interests. There is no finite solution, it changes during time because we can not predict all possible circumstances in the future. At this point of development of sustainability it can not be said is it a right way or not, but previous strategies did not show positive results. During the process of implementation the concept of sustainability will probably survive a certain modifications according to the obtained results.

Croatian project of developing sustainability indicators is still in the beginning and this article is preliminary note

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Education of Hydrology Personnel - Needs and Possibilities

Dušan Trninić, Karmen Cerar, Ljudevit Tropan, Nataša Benić, Janja Milković

Abstract: Insufficiency has been noticed of qualified personnel for routine jobs in hydrology, primarily observations (meteorological measurements).
The 50-year experience in the field in Croatia points to different new causes both objective (insufficient resources for payment of observers) and subjective (loss of self-esteem) behind decrease in interest in these jobs.
Regardless of development of new technical means and technologies applicable to the hydrological observations, engagement of trained personnel remains necessary.
Different possibilities of targeted training are proposed and discussion on this issue encouraged, particularly regarding the countries in transition.

Key words: education, meteorology, hydrology, water resources management

Bedürfnisse und Möglichkeiten für die Ausbildung hydrologischen Personals

Zusammenfassung: In Kroatien ist ein Fehlbestand an qualifiziertem Personal für Routineaufgaben in der Hydrologie feststellbar, vor allem im Bereich der Beobachtungen (meteorologische Messungen). Die 50-jährigen Erfahrungen Kroatiens weisen auf verschiedene neue Gründe hin, sowohl objektive (unzureichende Mittel für die Beobachterentlohnung) wie subjektive Gründe (Einbußen hinsichtlich der Achtung des Berufsstandes), die für den Interessenverlust gegenüber diesen Jobs verantwortlich sind. Unabhängig von der Entwicklung neuer technischer Mittel und Möglichkeiten im Bereich hydrologischer Beobachtungen bleibt die Ausbildung und die Einsatzbereitschaft entsprechenden Personals erforderlich. – Es werden unterschiedliche Möglichkeiten der zielgerichteten Ausbildung vorgeschlagen und es wird zu Diskussionen ermutigt, insbesondere in den Ländern, die sich in der Umgestaltung befinden.

Schlüsselwörter: Ausbildung, Meteorologie, Hydrologie, Wasserwirtschaftsverwaltung

1 Introduction

Meteorological and Hydrological Service (MHS) and water resources management sector of the Republic of Croatia have always paid special attention to education of human resources in hydrology. The political changes of 1991 and subsequent war have caused some problems in personnel training, which particularly related to the secondary education level. Before dissolution of the former Yugoslavia, the secondary education was organized at the Hydrometeorological School in Belgrade. It was a school with long tradition, good curriculum and quality teaching staff, and the students educated there covered the needs of all the former republics (now independent states). Since its independence, Croatia has been striving to organize specialized secondary education at the High Forestry and Woodworking School in Karlovac. The water resources management sector has organized training personnel for water watchmen.

2 Education and Additional Training of the Croatian Meteorological and Hydrological Service Personnel

According to its initial concept and the chart given in fig. 1, the Meteorological and Hydrological Service of the Republic of Croatia has been conceived to conduct the following activities:

(a) Organization, operation and maintenance of networks of surface and upper air stations;

(b) Collecting, control, processing and storage of meteorological and hydrological data;
(c) Setting up, operation and maintenance of adequate telecommunication system for acquisition and dissemination of data and information;
(d) Processing of meteorological and hydrological information and consultancy, including forecasts, different statistical overviews and other types of information;
(e) Advancement of meteorology and hydrology based on scientific and professional research;
(f) Application of scientific achievements and new technologies in meteorology and hydrology;
(g) Advancement of meteorology and hydrology through collaboration with the World Meteorological Organization (WMO) and other organizations in Croatia and worldwide.

The activities and tasks of the MHS are various and numerous. To conduct and fulfill them, a wide range of specialized and educated personnel is requested. To perform these activities properly and exchange information and data with the similar services worldwide, the human resources need to be educated uniformly and respecting the recommendations of the WMO.

As written in the Convention by which WMO has been established (paragraph 2f), one of the essential tasks of the WMO is encouragement, assistance and coordination of education and additional training of meteorological and hydrological personnel. The Third Congress of WMO 1959 has recommended that particular attention should be paid to personnel education. In 1961, the Executive Council entrusted a group of experts to prepare programs for different countries and regions (Milković, 1999) (Figure 1).

Generalized classification of personnel requested by MHS based on any chosen criteria is a delicate job because of the differences in educational systems of the WMO member countries. These systems differ from the primary school to the university, from duration of education in different schools to the school curriculum.

2.1 MHS Personnel Profiles According to the WMO Classification

The following classification of personnel has been adopted based on the WMO classification (WMO No. 258, 1984)

Class IV (primary education)

Primary education (9 to 11 years) is requested for the personnel from this Class. Additional training of minimum 6 months and supervised practice of minimum 4 months are also requested.

Class III (secondary education)

Secondary education and additional training in natural sciences, meteorology and hydrology. Minimum 12 year education before additional training of minimum 10 months and supervised practice of minimum 4 months.

Class II (associate degree)

Two-year college or secondary school education and sufficient knowledge of mathematics, physics, computers and additional training in meteorology and hydrology within adequate curriculum. The additional training should be university or other adequate educational institution having Class I instructors. The additional training of minimum two years and supervised practice of minimum 6 months.

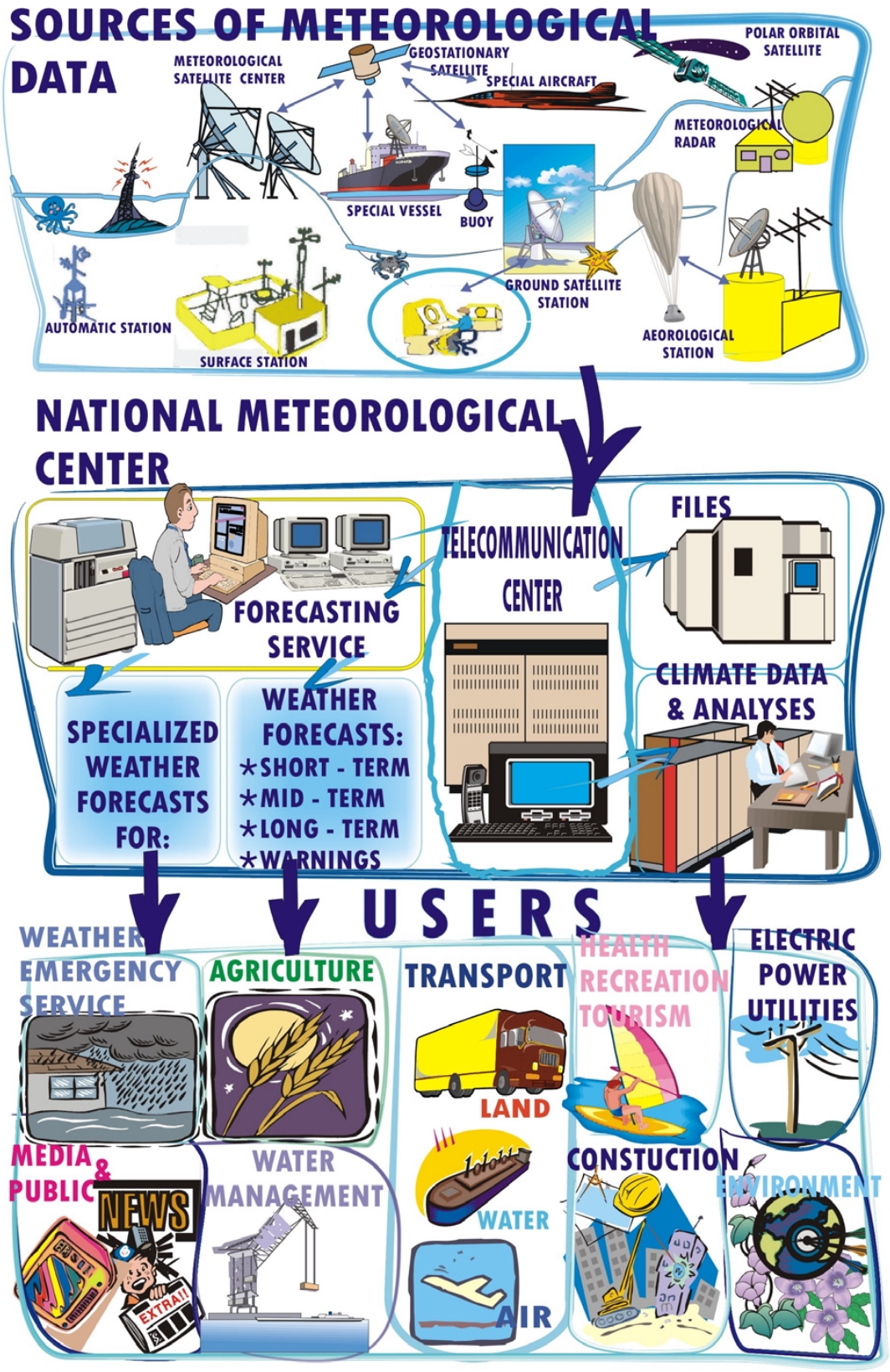

Fig. 1 National meteorological and hydrological service

Class I (university degree)

Adequate university degrees. The personnel from this group is educated in different fields of technical and natural, economic and social sciences. This group encompasses different specializations which need to be preceded with practical work in the service of minimum 6 months. The personnel from this group ought to continue with education through post-graduate and doctoral studies. Additional training should be part of official policy of the service, but it may also be the result of personal study.

2.2 MHS Personnel Breakdown

It would be utterly unacceptable to put the modern technology, particularly the one used in operational meteorology and hydrology, before the men to whom it serves. Therefore, any reasonable development policy includes the care of personnel as a flywheel of such development (Meteorological and Hydrological Service, 1998).

When the hydrometeorological service was established in 1947, it recruited the staff of about 50 persons. These were predominantly secondary school graduates who completed additional training courses. The university graduates could be counted on one hand. Naturally, the number of personnel increased with time and the personnel breakdown for June 1997 is given in the Table 1.

Table 1 MHS personnel breakdown, June 1997

Qualification	Total	Percentage
Unskilled	9	2
Semi-skilled and primary education	23	5
Skilled	38	9
Secondary education	217	51
High-skilled	12	3
Associate degree	31	7
University degree	68	16
Masters	19	5
Doctors	5	2
Employees, total	**422**	**100**

Source: Meteorological and Hydrological Service, 1998

The Table 1 indicates predominance of secondary school graduates (51%), followed by university graduates (22%), out of which 7% masters and doctors of sciences. The question is, whether the Government of the Republic of Croatia, which is financing the majority of activities conducted by the service, is satisfied with quantity and qualifications of the personnel? It is not an easy question, and there is room for comparison with other countries. For example, number of employees in hydrometeorological services of smaller countries (e.g. Albania) is smaller than in the Croatian service. In some countries of Central Europe (Hungary, Czech Republic) the number corresponds with the Croatian data. In countries larger than Croatia, such as Germany, Great Britain, Japan or the United States of America, the human resources range from several thousand (Great Britain about 2000) to tens of thousands (Japan about 20,000). It is impossible to forecast labor trends in the future, but it will certainly be necessary to consider their qualification for efficient state-of-the art operation. In addition to professional skills, the hydrometeorological activity as an international and technically

sophisticated discipline demands continuous additional training of the personnel. Such education should particularly focus on implementation of new technologies and command of foreign languages (English in particular) which opens the door to efficient communication with the rest of the world.

2.3 Proposals for Resolving Issues Related to Education and Additional Training of the Croatian Personnel in Meteorology and Hydrology

The conducted analyses of institutional education and additional training of the personnel requested by the service and water resources management sector, and comparison with the proposed classification and curriculum ensuing from the WMO recommendation show that Croatia has adequately resolved only undergraduate, graduate and postgraduate (mastership and doctorship) university studies. The major problems are those related to the secondary education, which means the most numerous group of personnel. This problem will be best resolved by specialized education in training schools with adequate curriculum. In Croatia, we are striving to resolve this problem at the Forestry and Woodworking School in Karlovac which offered its syllabus for regular four-year education.

3 Water Watchmen

The water resources management sector has specific problems with education and additional training of its personnel. The most interesting issue is that of water watchmen, which will be described in more detail. This is not meant that other employees should be neglected, but the limited space makes us focus on the water watchmen.

The **Rules on Water Watching Standards** (Official Gazette 46/98) specify the requests to be met by a person carrying out the job of a water watchman. Through regular education such person gets the qualification (minimum grade IV - 12 years of education - secondary school or grade III - 8 years of education - primary school, and minimum two years of work experience in water resources management sector), and through their work they gain the experience and seniority. When they pass a special exam they are given the State Water Management Directorate Certificate for water watching. The examination focuses on two basic topics:

1. Knowledge of the basic regulations in the field of water resources management necessary to perform the water watching activities,
2. Keeping of water watching documentation.

The exam is conceived so that the water watchman gets the basics in hydrology and hydrometry (hydrological cycle and water level and flow rate measurement) related to the flood and ice control. The exam papers also include the basics in chemistry and biology for water contamination detection and water sampling. Further, they cover the basics in civil engineering, mechanical engineering and electrical engineering necessary for detection of damage in hydraulic structures, equipment and facilities, control of their maintenance and handling of weirs, plugs, pumping stations, communication system and other equipment.

The water watchman must be familiar with the procedures and methods applied to flood and ice control, keep the logbooks and warehouse records, keep permanent records on water levels and water control equipment, prepare reports, fill out and submit data on sampling and file the charges against the offenders under the stipulations of applicable regulations.

The water watchman is authorized to conduct direct supervision of condition of water and hydraulic structures for preventing, determining and removing of water contamination and damage on hydraulic structures, and for identification of persons in order to file the charges against the offenders.

All the activities are supervised by engineers of different specializations working for the water management sector.

4 Conclusion

This paper is intended to encourage a discussion on a very important issue. Our experience has been presented same as the problems we have been facing since the independence of our state and its status of a country in transition. It would be interesting to hear the experience of developed countries and their recommendations on methods of education and additional training.

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Das Programm „Klimaveränderung und Konsequenzen für die Wasserwirtschaft“ ein Kooperationsvorhaben für das Gebiet von Baden-Württemberg und Bayern

Hans Weber

Zusammenfassung: Nach dem derzeitigen Erkenntnisstand der Klimaforschung wird sich die mittlere globale Temperatur bis Ende des Jahrhunderts signifikant erhöhen. Verläßliche Aussagen zu den Auswirkungen dieser Klimaveränderung auf das deutsche Donaugebiet, also auf den Wasserhaushalt im regionalen Maßstab, liegen bislang nicht vor. Im Kooperationsvorhaben „Klimaveränderung und Konsequenzen für die Wasserwirtschaft (KLIWA)“, das die Länder Baden-Württemberg und Bayern gemeinsam mit dem Deutschen Wetterdienst durchführen, wird versucht, die möglichen Folgen der erwarteten globalen Temperaturerhöhung auf den Wasserhaushalt der regionalen Flußgebiete abzuschätzen. Das dafür festgelegte Vorgehenskonzept zu dieser komplexen Problemstellung wird vorgestellt.

Schlüsselworte: Klimaveränderung, Niederschlagsanalyse, Abflußzeitreihen, Wasserhauhaltsmodellierung

The Program “Climate Change and Consequences for the Water Management” – a Joint Project for the Region of Baden-Württemberg and Bavaria

Abstract: According to the actual findings of climate research, the average global temperature will raise significantly till the end of this century. Presently there is no reliable statement regarding this impact to the German Danube catchment area, as well as to the water balance in a regional scale. The joint project “Climate change and consequences for water management (KLIWA)”, realized by the countries Baden-Württemberg and Bayern together with Deutscher Wetterdienst tries to anticipate the consequences of the expected global temperature raise for the water balance of the regional river areas. We introduce the appropriate procedure regarding this comprehensive problem.

Keywords: Climate change, precipitation analysis, long-time series of the run-off, water balance modelling

1 Einführung

Nach dem derzeitigen Erkenntnisstand der Klimaforschung ist davon auszugehen, daß sich die mittlere globale Temperatur in den kommenden Jahrzehnten signifikant erhöhen wird. Für diese Entwicklung sind neben natürlichen Klimaschwankungen auch anthropogene Ereignisse ausschlaggebend. Die durch den „Treibhauseffekt“ verursachte mittlere Temperaturerhöhung wird bis Ende des Jahrhunderts auf etwa 1,5 bis 3 K geschätzt. Diese Klimaveränderung wird mit erheblichen Auswirkungen auf den Wasserhaushalt verbunden sein. Im Zusammenhang mit dieser Feststellung stellt sich die Frage, ob und in welchem Umfang sich die hydrologischen Verhältnisse im regionalen Maßstab verändern werden.

In Süddeutschland sind seit Mitte der 80er Jahre eine Reihe größerer, mit hohen Schäden verbundene Hochwässer aufgetreten. Im öffentlichen Meinungsbild zu den Ursachen dieser Katastrophen wird immer wieder die Vorstellung geäußert, daß sie bereits eine Folge des sich abzeichnenden Klimawandels sein könnten und daß künftig verstärkt mit extremen Ereignissen im Hochwasserbereich, aber auch im Niedrigwasserbereich zu rechnen sein wird. Bei einer Verallgemeinerung dieser Problemstellung auf die Koppelung von Klima und Wasserwirtschaft

stellt sich die Frage nach dem Zusammenhang der Klima- und Wasserhaushaltselemente hinsichtlich ihres Langzeitverhaltens.
Die bisherigen Aussagen über Klimaveränderungen beziehen sich auf den globalen Bereich bzw. auf großräumige Gebiete. Verläßliche Aussagen zu den Auswirkungen auf den Wasserhaushalt im regionalen Bereich liegen derzeit nicht vor. Die Fragestellung bedeutet aber für die Wasserwirtschaftsverwaltungen eine große Herausforderung: Wenn es möglich ist, den Umfang der Auswirkungen zu quantifizieren, können angepaßte wasserwirtschaftliche Maßnahmen in die Wege geleitet werden. Zur Behandlung dieser Aufgabenstellung haben die Wasserwirtschaftsverwaltungen der Länder Baden-Württemberg (BW) und Bayern (BY) im Dezember 1998 zusammen mit dem Deutschen Wetterdienst eine langfristige gebiets- und fachübergreifende Zusammenarbeit vereinbart. Im Rahmen des Kooperationsvorhabens „Klimaveränderung und Konsequenzen für die Wasserwirtschaft (KLIWA)“ wird das Gebiet der beiden Länder, also auch das deutsche Donaugebiet in seinen Teilgebieten, aber auch als Gesamtgebiet mit einer Fläche von 56.000 km^2 hinsichtlich der Auswirkungen von Klimaveränderungen untersucht.

2 Das Kooperationsvorhaben KLIWA

Im Rahmen des Kooperationsvorhaben „KLIWA“ sollen die künftigen Veränderungen des Wasserhaushalts in den Flußgebieten von Baden-Württemberg und Bayern als Folge der zu erwartenden Klimaveränderung abgeschätzt werden. Soweit erforderlich sollen daraus im Sinne des Vorsorgeprinzips so frühzeitig wie möglich Hinweise für ein angepaßtes wasserwirtschaftliches Handeln abgeleitet werden. Zum Gewinnen der notwendigen Erkenntnisse ist ein Vorgehenskonzept vereinbart, das eine Reihe von Einzelprojekten zur Untersuchung des überaus komplexen Zusammenhangs zwischen Klima und Wasserhaushalt zur Durchführung vorsieht. Die derzeit geplanten bzw. in Bearbeitung befindlichen Einzelprojekte sind vier Bereichen zugeordnet. Diese vier Bereiche betreffen:

- die Ermittlung bisheriger Veränderungen des Klimas und des Wasserhaushalts (Bereich A)
- die Abschätzung der Auswirkungen möglicher Klimaveränderungen auf den Wasserhaushalt (Bereich B)
- das Betreiben eines Integrierten Meßnetzes mit der Ausrichtung, künftige Veränderungen des Klimas und des Wasserhaushalts erfassen zu können (Bereich C) sowie
- die Öffentlichkeitsarbeit (Bereich Ö) zur Informationsbereitstellung über KLIWA.

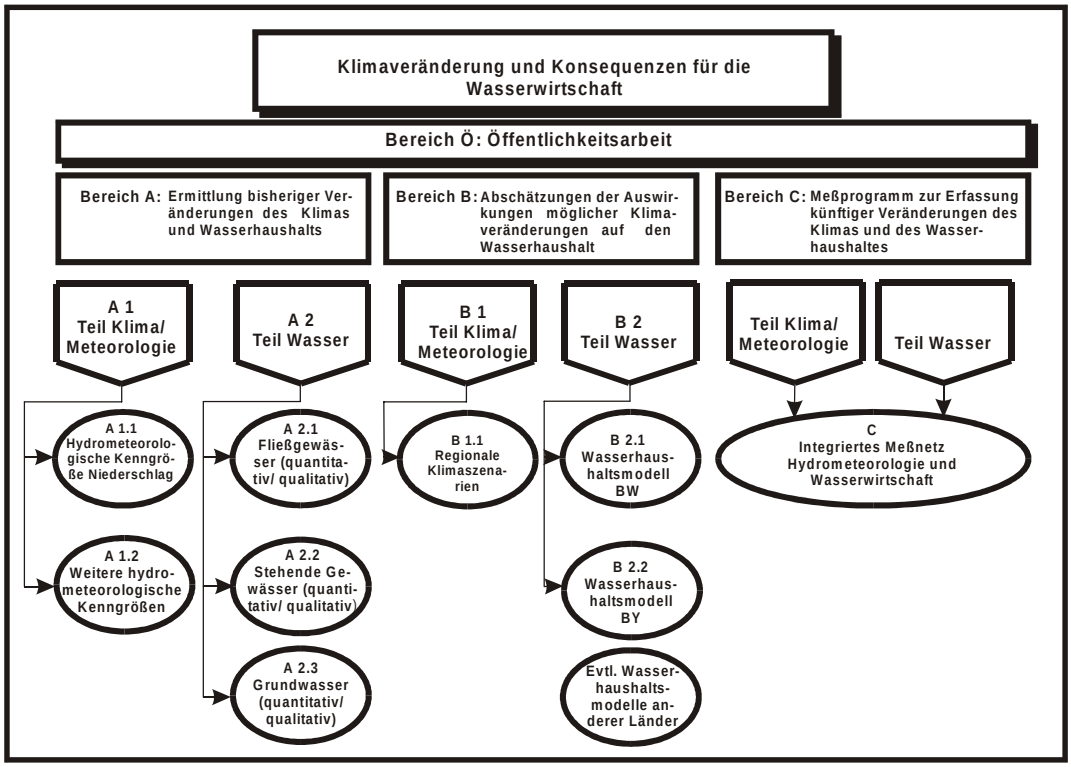

Abb. 1 Darstellung der Struktur des Untersuchungsprogramms KLIWA

Der bisherige Projektrahmen ist schematisch in Abbildung 1 dargestellt. Jedem Projektbereich ist eine Reihe von Einzelprojekten zugeordnet, mit denen den verschiedenen Fragestellungen nachgegangen wird. Die vereinbarte Kooperation ist auf lange Sicht, mindestens aber auf 5 Jahre angelegt. Durch die Bündelung des Fachwissens werden Synergieeffekte erwartet, die die Behandlung der komplexen Untersuchungsproblematik erleichtern sollen. Die Einzelprojekte werden teilweise durch die Kooperationspartner, zum Teil aber auch durch beauftragte Universitätsinstitute behandelt. Die wesentlichen Programmbereiche sind in den nachfolgenden Kapiteln näher ausgeführt.

3 Die Ermittlung bisheriger Veränderungen durch die Analyse langer Zeitreihen

Zur Abschätzung möglicher künftiger Veränderungen des Klimas und des Wasserhaushalts haben fundierte Kenntnisse über zurückliegende Veränderungen eine grundlegende Bedeutung. Zur Ermittlung der bisherigen Veränderungen ist es erforderlich, die über einen längeren Zeitraum gewonnenen und dokumentierten Beobachtungsdaten mittels mathematisch-statistischer Verfahren hinsichtlich Variabilität und Trend zu analysieren. Damit können Erkenntnisse gewonnen werden über die räumliche und zeitliche Variabilität der Meßgrößen und daraus über die natürlichen Schwankungen und eventuelle systematische Veränderungen. Bei dieser retrospektiven Betrachtung ist es erforderlich, die Zeitreihen der hydrometeorologischen und hydrologischen Kenngrößen wegen ihrer Wechselwirkungen in einer Gesamtschau zu untersuchen und zu bewerten. Dafür ist bereits eine Reihe von Einzelprojekten vorgesehen; ein Teil davon ist schon in Arbeit.

Bezüglich der hydrometeorologischen Kenngrößen sind auf der Basis der vorliegenden Meßreihen derzeit insbesondere folgende Ermittlungen und Untersuchungen vorgesehen:

- Berechnung des langjährigen Gebietsniederschlags über die Bereitstellung von langen Reihen interpolierter Gitterpunktwerte (Raster ca. 7 x 7 km) des Niederschlags in Tageswerten
- Untersuchung des Langzeitverhaltens der Gebietswertreihen des Niederschlags
- Trenduntersuchungen von extremen Niederschlagsereignissen einschließlich Andauer von Naß- und Trockenperioden
- Analyse des Langzeitverhaltens der Schneedeckenparameter
- Flächendeckende Analyse des langfristigen Verhaltens der potentiellen Verdunstungshöhe als Grundlage für Wasserhaushaltsbilanzierungen.

Im Rahmen der Analyse der hydrologischen Meßreihen werden vorerst die folgenden Projekte bezüglich des Abflußverhaltens der wesentlichen Fließgewässer bearbeitet:

- Untersuchung des Langzeitverhaltens der Niedrigwasserabflüsse, der mittleren Abflüsse und der Hochwasserabflüsse.
  Die Analysen beziehen sich auf die bedeutsamen Pegel mit langen Meßreihen. Für das Gebiet von Baden-Württemberg und Bayern sind dafür rd. 180 Pegel ausgewählt worden. Zur Anwendung kommen einige der herkömmlichen statistischen Verfahren, auf die sich die Kooperationspartner geeinigt haben.
- Erhebungen über große historische Hochwasserabflüsse
  Ziel ist es, die Zeitreihen der Hochwasserabflüsse um historische Ereignisse zu ergänzen sowie die Entstehung extremer Hochwasser zu analysieren.
- Ermittlung zeitlicher Veränderungen in langen Abflußzeitreihen
  Das Langzeitverhalten von Abflußzeitreihen soll hier mit dem Verfahren der Spektralanalyse und neuen Methoden der Fraktaltheorie analysiert werden, um zu einem besseren Verständnis der Variabilität in den Zeitreihen zu kommen. Mit den vorgesehenen Methoden werden dabei neue Wege beschritten.

Mit den vorstehend skizzierten Untersuchungen sollen die natürliche Variabilität der Meßgrößen sowie etwaige Signale oder Trends als Folge klimatischer Änderungen festgestellt werden.

Dabei besteht allerdings auch die Schwierigkeit, die Ursache eines Trends als Wirkung klimatischer Veränderungen eindeutig zu belegen. Unabhängig davon lassen sich konkrete Anhaltswerte für die Spannweite der natürlichen Variabilität und damit realistische Eingangsgrößen für Simulationsrechnungen mit Wasserhaushaltsmodellen ableiten.

4 Die Abschätzung möglicher Klimaveränderungen auf den Wasserhaushalt

In Zusammenhang mit den zu erwartenden Klimaveränderungen stellt sich die Frage, welche Auswirkungen auf den Wasserhaushalt sich ergeben können. Die Abschätzung künftiger Veränderungen soll mit Hilfe von Simulationsrechnungen unter Verwendung geeigneter Wasserhaushaltsmodelle durchgeführt werden. Mit physikalisch basierten Wasserhaushaltsmodellen, die den Zusammenhang zwischen den hydrometeorologischen Größen und dem hydrologischen Output für das jeweilige Untersuchungsgebiet abbilden, werden die Auswirkungen von Klimaszenarien ermittelt. Die Klimaszenarien sollen dazu aus der Analyse der langen Zeitreihen abgeleitet werden. Sobald regionale Klimamodelle einen ausreichenden Entwicklungsstand aufweisen, können auch sie zur Ermittlung von sachgerechten Klimaszenarien herangezogen werden.

Wasserhaushaltsmodelle ermöglichen quantitative Aussagen zu den Abflüssen im Niedrig-, Mittel- und Hochwasserbereich, zur Grundwasserneubildung und auch zur Verdunstung. Neben Szenarienberechnungen zum Wasserhaushalt und Wasserdargebot können die Modelle auch als

Prognoseinstrumente eingesetzt werden. Damit sollen die Veränderungen des Wasserhaushalts infolge von Klimaschwankungen und auch von möglichen Klimaveränderungen nachgebildet werden. Eine besondere Bedeutung kommt dabei neben den Zeitdaten auch den Raumdaten als Modelleingangsgrößen zu. Zur Verifizierung sind die Modelle auf Tageswertbasis auszutesten und die Auswirkung von Systemänderungen abzuschätzen.

Im Rahmen von KLIWA setzt Baden-Württemberg das Modell LARSIM ein, während Bayern das Modell ASGi, an dessen Entwicklung mitgewirkt wurde, bevorzugt. Die beiden Modelle, mit unterschiedlichen Schwerpunkten entwickelt, weisen in Teilbereichen identische Module aus. Die in jedem der beiden Modelle integrierten Prozeßbeschreibungen machen es möglich, die Auswirkungen veränderter meteorologischer Randbedingungen eines Untersuchungsgebiets flächendetailliert quantitativ hinsichtlich der Wasserhaushaltsgrößen abzuschätzen. In einer vergleichenden Anwendung sollen beide Wasserhaushaltsmodelle auch für ein gemeinsames Untersuchungsgebiet eingesetzt und danach ggf. über eine gemeinsame Modellweiterentwicklung im Hinblick auf die zu behandelnden Fragestellungen entschieden werden.

Im Wasserhaushaltsmodell LARSIM (Abkürzung von „Large Area Runoff Simulation Modell“), werden im wesentlichen die hydrologischen Teilprozesse Interzeption, Evapotranspiration, Schneeakkumulation und -schmelze sowie Bodenwasserspeicherung jeweils getrennt für die Landnutzungsklassen der Teileinzugsgebiete, weiterhin lateraler Wassertransport in der Fläche sowie Translation und Retention deterministisch beschrieben. Für das Neckargebiet mit einem Einzugsgebiet von rd. 13.500 km^2 ist das LARSIM-Modell bereits erstellt. Für die Flächeneinteilung ist ein Raster von 1 x 1 km Seitenlänge gewählt. Mit dem Modell sind bislang gute Ergebnisse erzielt worden, so daß nun auch eine Weiterentwicklung für den operationellen Betrieb erstellt werden soll.

Auch ASGi, das als Niederschlags-Abfluß-Modell für „Kontinuierlichen Abfluß- und Stofftransport, Integrierte Modellierung unter Nutzung von Geoinformationssystemen“ steht, entspricht dem Konzept der flächendetaillierten Prozeßmodellierung. Die räumliche Unterteilung wird durch ein regelmäßiges Raster realisiert, die Rastergröße liegt in Abhängigkeit von der Größe des Untersuchungsgebiets im Bereich von 200 bis 1000 Meter. Das Modell ist für Flußgebiete mit Größen ab 1 km^2 bis zu mehreren 1000 km^2 einsetzbar, um die Wasser- und Stoffströme zu erfassen. Kennzeichnend ist weiterhin der streng modulare Aufbau. Zur Verdeutlichung ist die Modellstruktur des Wasserflußmodells in der Abbildung 2 dargestellt.

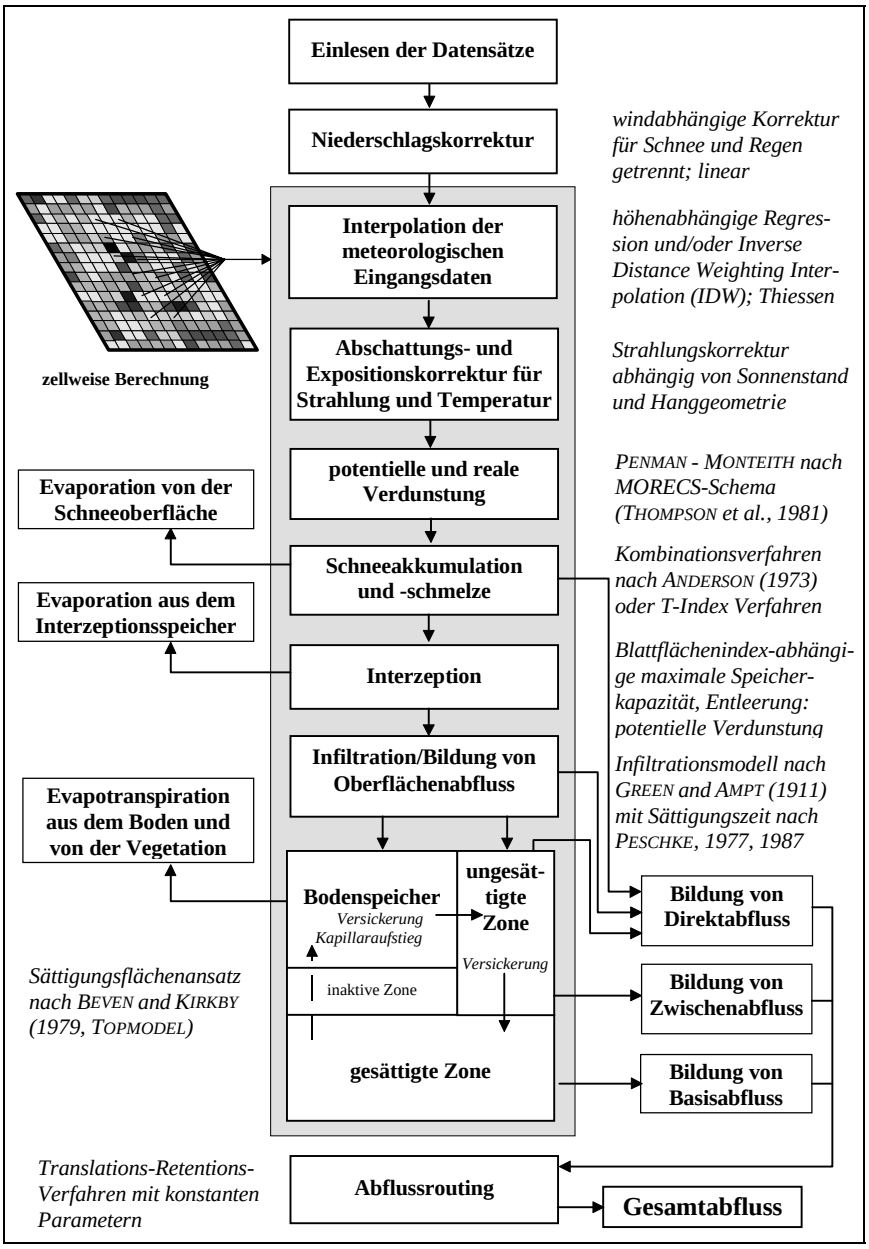

Abb. 2 Darstellung der Modellstruktur von ASGi (nach Schulla, 1996)

5 Die weiteren Projektbereiche des Untersuchungsprogramms

Ergänzend zu den angesprochenen Untersuchungen ist die Festlegung eines Integrierten Meßnetzes und dessen Betrieb vorgesehen. Das Meßnetz soll für die Teileinzugsgebiete der Donau sowie von Main, Neckar und Rhein in Baden-Württemberg und Bayern repräsentative Meßstellen, d. h. Niederschlagsstationen, Pegel, Grundwasser- und Beschaffenheitsmeßstellen, umfassen. Ein wesentliches Kriterium für die Meßstellenauswahl ist das Vorhandensein langer, zuverlässiger Datenreihen; so sind für Baden-Württemberg und Bayern über 60 bzw. 120 Pegel dafür bereits ausgewählt. Die KLIWA-Meßstellen sind vorgesehen für ein längerfristiges Monitoring der hydrometeorologischen und hydrologischen Kenngrößen.

Der Projektbereich Öffentlichkeitsarbeit legt Aktivitäten zur Unterrichtung der Fachwelt, aber auch der interessierten Bürger über das Kooperationsvorhaben fest. So soll alles Wissenswerte über „KLIWA“ im Internet auf eigener Homepage (www. KLIWA.de) dargestellt werden. Die Arbeitsergebnisse sollen in einer eigenen Publikationsreihe erscheinen. Auch sind spezielle Fachveranstaltungen und Informationsgespräche mit den Fachleuten geplant, die sich mit dem Fragenkomplex „Klima und Wasserhaushalt“ beschäftigen. Am 29. und 30.11.2000 wird ein Symposium zu KLIWA in Karlsruhe durchgeführt, um die bis dahin vorliegenden Ergebnisse zu präsentieren und mit anderen Fachleuten zu diskutieren.

6 Ausblick

In der gesellschaftlichen Diskussion über die möglichen Folgen von Klimaveränderungen wird heute oft eine Gefährdungszunahme infolge von Hochwasserverschärfungen gesehen. Der sachgerechten Behandlung dieses Problemkreises, aber auch anderer Fragestellungen kommt eine hohe Priorität zu. Daher nimmt das Vorhaben KLIWA bei allen Kooperationspartnern einen hohen Stellenwert ein. Die Projektarbeiten, die Anfang des Jahres 1999 begonnen haben, stehen bei dem langfristig angelegten Vorhaben eigentlich erst am Anfang. Das gilt für die bisherigen Einzelprojekte, aber auch neue Projektbereiche wie „Sozioökonomische Folgewirkungen“ und „Auswirkungen auf die Gewässerbeschaffenheit“, die im Laufe der nächsten Zeit den Projektrahmen erweitern werden. Dadurch soll der komplexen und breitgefächerten Aufgabenstellung möglichst umfassend Rechnung getragen werden.

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