XVII. Konferenz der Donauländer über hydrologische Vorhersagen und hydrologisch-wasserwirtschaftliche Grundlagen

XVIIth Conference of the Danube Countries on Hydrological Forecasting and Hydrological Bases of Water Management

Budapest, 5–9 September, 1994

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the Hungarian Ministry for Transport, Communication and Water Management
the Hungarian Ministry for Environmental Protection and Regional Development
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the Water Resources Research Centre Plc. (VITUKI Plc.)
The Mayor of the Capital Budapest
the International Science Foundation
the UNESCO
the WMO
the Danube Programme Coordination Unit of CEC
the Hungarian Academy of Sciences

Budapest, 1994

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VORWORT / PREFACE

Die Reihe der Donaukonferenzen, dieses wichtige Forum des regionalen wissenschaftlichen Erfahrungsaustausches der Donauhydrologen, kann sich einer großen und ergebnisreichen Tradition rühmen. Die erste Vorhersagekonferenz fand 1961 in Budapest statt, wurde von den hervorragendsten Wissenschaftlern unserer Region (Dumitrescu, Kaczmarek, Kalinin, Lászlóffy, usf.) veranstaltet und überbrückte den die damaligen acht Donauländer in zwei Blöcke trennenden Eisernen Vorhang.

Seit 1961 wurden die Konferenzen abwechselnd in den acht daran interessierten Ländern veranstaltet. Sie haben wesentlich zum Austausch und zur Synthese des hydrologischen Wissens im Donauraum beigetragen.

Die XVI. Konferenz, mit welcher die zweite Runde abgeschlossen wurde, fand in Kelheim, Deutschland statt. Es nahmen daran etwa 200 Wissenschaftler aus den Donauländern teil. 80 von ihnen waren eingeladene Gäste der deutschen Regierung, da sie infolge der gegenwärtigen schwierigen wirtschaftlichen Lage der mittel-osteuropäischen Länder kaum imstande gewesen wären, an der Konferenz teilzunehmen und ihre Vorträge zu halten. Die XVI. Konferenz war die erste jener Serie, welche über das herkömmliche Thema der Vorhersage hinausgehend, sich als eine "Konferenz über hydrologische Vorhersagen und hydrologisch-wasserwirtschaftliche Grundlagen" definierte.

Die XVII. Konferenz wird vom Ungarischen IHP/OHP Nationalkomitee in Budapest vom 5-9 September 1994 veranstaltet. Mit ihr wird die dritte Runde unter der Donauländern begonnen, deren Anzahl inzwischen, infolge historischer Geschehnisse, nun schon 13

The series of Danube Conferences, as a major forum of regional scientific exchange of the Danube hydrologists, has by know a rich and successful tradition. The first Forecasting Conference took place in 1961 at Budapest, organized by the most outstanding scholars of our region (Dumitrescu, Kaczmarek, Kalinin, Lászlóffy, etc.) bridging the gap between the two blocks of the - at that time eight -Danube Countries separated by the Iron Curtain.

Since 1961, conferences were held biennially by turns in the eight countries involved, essentially contributing to the exchange and synthesis of hydrological knowledge in the Danube Basin.

The XVIIth Conference completing the second circle, was held in 1992 in Kelheim, Germany, and attended by about 200 scientists of the Danube Countries. 80 of them were invited guests of the Federal Goverment of Germany since otherwise - due to the actual economic situation in the Central-East European Countries - they would not have been able to attend the conference and deliver their lectures. The XVIth Conference was the first one of the series which, exceeding the traditional topic of forecasting, defined itself as a "Conference on Hydrological Forecasting and Hydrological Bases of Water Management".

The XVIIth Conference, will be organized by the Hungarian IHP/OHP National Committee and held in Budapest, on 5-9 September 1994, initiating the third circle of Conferences among the Danube Countries whose number has by now reached, due to beträgt. Das traditionelle Vorbereitungstreffen hat im Forschungszentrum für Wasserwirtschaft AG (VITUKI) am 19. und 20. Mai 1993 stattgefunden. Es nahmen daran die Vertreter der Länder Deutschland, Österreich, Slowakei, Ungarn, Kroatien und Rumänien sowie der UNESCO und der WMO teil. Die hauptsächlichen Ergebnisse des Vorbereitungstreffens waren erstens die Festlegung der fünf Konferenzthemen und zweitens der Beschluß, daß die Konferenzsprachen von nun an Deutsch und Englisch sein werden, anstatt Deutsch und Russisch wie bei den ersten 16 Konferenzen.

Die Informationsnote 1 (Anforderung von Beiträgen) für die XVII. Donauländerkonferenz wurde vom Veranstalter Ende September 1993 an die IHP Nationalkomitees sämtlicher europäischer Länder sowie der U.S.A. und Kanadas versandt. Als Beantwortung wurden bis zu den reichlich verlängerten entsprechenden Terminen etwa 250 ausgefüllte vorläufige Anmeldeformulare, 157 Kurzfassungen und schließlich 127 vollständige Konferenzbeiträge eingereicht. Als eine neue Maßnahme in der Geschichte der Donauländerkonferenzen wurde ein Wissenschaftlicher Beirat ins Leben gerufen, bestehend aus einem Sekretär, den Gutachtern der fünf Konferenzthemen (einberufen auf Grund von Nomienierungen aus den IHP Nationalkomitees der Donauländer), zwei Mitgutachtern (eingeladen durch die Gutachter) und dem Herausgeber des Sammelbandes der Konferenz.

Jeder Gutachter, eventuell unterstützt durch seinen Mitgutachter, hat die zu seinem jeweiligen Thema eingereichten Beiträge überprüft, entsprechende Empfehlungen für ihre Annahme, Zurückweisung (infolge inhaltlicher, formeller oder sprachlicher Probleme oder Irrelevanz für den Donauraum) oder Versetzung in ein anderes Konferenzthema gemacht. Es wurde

historical events, 13. Its traditional preparatory meeting took place on 19-20 May, 1993 in the Water Resources Research Centre Plc. (VITUKI) and was attended by representatives of the following Danube Countries: Germany, Austria, Slovakia, Hungary, Croatia and Romania as well as by those of UNESCO and WMO. The main issues of the preparatory meeting were the identification of the five Conference Themes and the decision that conference languages will be German and English, instead of German and Russian, as adapted during the first 16 Conferences.

The first circular (call for papers) of the XVIIth Danube Conference was sent at the end of September 1993 by the Hungarian National Committee for IHP/OHP to the IHP National Committes of all European Countries, the U.S.A. and Canada. As a response to it, about 250 filled-in preliminary registration forms, 157 abstracts and finally 127 full conference papers reached the Organizer by the generously prolongated respective deadlines. As a new institution in the history of the Danube Conferences, a Scientific Board was installed, consisting of a Secretary, the Conveners of the five Conference Themes (selected on the basis of nominations by the IHP National Committees), two Co-conveners invited by the latter and the Editor of the Conference Proceedings.

The Conveners, aided by their respective Co-conveners, reviewed the papers submitted for their respective themes, made recommendations about their being accepted, refused (because of content-related or linguistic causes or irrelevance for the Danube Basin) or transferred to another theme. They were also invited to prepare keynote papers for their respective themes. The following table is

No.	Land/Country		Kurz-fas-sun-gen Abst-racts	Konferenzbeiträge/Conference papers						
				einge-reicht sub-mitted	angenommen/accepted					
					ins-ge-samt total	für das Thema/for Theme				
						1	2	3	4	5
1	Donauländer/Danube Countries	Deutschland Germany	15	13	13	5	2	3	-	3
2		Österreich/Austria	7	6	6	1	-	1	3	1
3		Tschechien Czech Republic	4	4	4	-	1	2	1	-
4		Slowakei/Slovakia	6	6	6	1	2	-	1	2
5		Ungarn/Hungary	23	15	15	-	-	8	2	5
6		Slowenien/Slovenia	1	2	2	1	-	1	-	-
7		Kroatien/Croatia	11	9	9	1	2	4	-	2
8		Bosnien und Herzegovina Bosnia-Herzegovina	-	-	-	-	-	-	-	-
9		Jugoslawien Yugoslavia	20	18	18	5	5	-	1	7
10		Rumänien/Romania	13	12	11	-	4	5	1	1
11		Bulgarien/Bulgaria	11	10	8	1	2	1	1	3
12		Moldavien/Moldavia	-	-	-	-	-	-	-	-
13		Ukraine/Ukraine	22	17	14	-	3	3	1	7
14	Andere Länder Other Countries	Weißrußland Belorussia	2	-	-	-	-	-	-	-
15		Rußland/Russia	10	9	8	-	-	5	3	-
16		Usbekistan Uzbekhistan	8	4	1	-	-	1	-	-
17		Holland The Netherlands	2	1	1	-	1	-	-	-
18		U.S.A.	1	1	1	1	-	-	-	-
19		Kanada/Canada	1	-	-	-	-	-	-	
Insgesamt/Total			**157**	**127**	**117**	**16**	**22**	**34**	**14**	**31**

jedem Gutachter freigestellt, seinen Einführungsvortrag zu schreiben. Die Tabelle auf der vorigen Seite enthält eine Übersicht und die Aufschlüsselung nach Ländern der eingetroffenen Kurzfassungen und vollständigen Beiträge.

Das vorliegende Sammelwerk enthält in zwei Bänden vier Einführungsvorträge der Gutachter und die 117 akzeptierten Konferenzbeiträge die in camera-ready Form eingereicht wurden, wobei vom Herausgeber nachträglich höchstens geringere Änderungen formellen Charakters vorgenommen wurden.

Im Hindblick auf den Jubiläums-Charakter der XVII. Donauländerkonferenz, womit die dritte Konferenzrunde beginnt, war der Veranstalter bestrebt, hervorragende Festredner für die Eröffnungsfeier zu gewinnen. Die Festreden von Herrn Professor Kresser und Herrn Dr. Szesztay (beide waren unter den Gründervätern der Ersten Donauländerkonferenz in 1961), von Herrn Professor Hofius (der im Auftrag des Deutschen IHP/OHP Nationalkomitees die hydrologische Zusammenarbeit der Donauländer während der Periode 1987-1992 äußerst wirksam koordiniert hat), von Herrn Pfündl (der einen umfassenden Überblick über die neueste Entwicklung in den gemeinsamen Bestrebungen der Donauländer für die Koordinierung der Wasserwirtschaft und des Gewässerschutzes gewähren wird) sowie von Herrn Kraemer von der WMO, sind zusammen mit den bis Manuskriptsschluß angekommenen Grußreden, ebenfalls im vorliegenden Sammelband enthalten.

Um die erwünschte Teilnahme an der XVII. Donauländerkonferenz auch unter den gegenwärtigen schwierigen wirtschaftlichen Verhältnissen mancher mittel- und osteuropäischer Länder zu ermöglichen, hat der Veranstalter verschiedene ungarische und

a survey and a breakdown, according to the countries within and outside the Danube Basin, of the abstracts and full conference papers received.

The present two volumes of Conference Proceedings contain four keynote papers of the Conveners and 117 accepted conference papers as they were submitted by their authors, in camera-ready form, without adding other than minor formal adjustments.

In view of the jubilee character of the XVIIth Danube Conference, initiating the third circle, the Organizer strived to, and was happy to succeed in, inviting excellent speakers to the Opening Ceremony, including Professor Kresser and Dr. Szesztay - from among the Fathers of the First Danube Conference of 1961; Professor Hofius - who, on behalf of the German IHP/OHP National Committee, very efficiently coordinated the hydrological cooperation of the Danube Countries during the period 1987-1992; and Mr. Pfündl - offering a broad survey of recent developments in the joint efforts of the Danube Countries for co-ordinated water management and environmental control). The fifth festive speaker, Mr. Kraemer, gives a statement on behalf of WMO. These five festive speaches are also included in the present Proceedings along with the Greeting Addresses reaching the Editor before closing manuscript.

In order to enable a substantial attendance to the XVIIth Danube Conference even under the present difficult situation of some Central and East European Countries, the Organizer has approached various national and international institutions, as potential internationale Institutionen als potentielle Sponsoren angesprochen. Es wird hier den folgenden Institutionen, welche das Ansuchen positiv beantwortet und großzügige Unterstützungen geleistet haben, herzlichst gedankt: dem ungarischen Ministerium für Verkehr, Nachrichtenübermittlung und Wasserwirtschaft, dem ungarischen Ministerium für Umweltschutz und Regionale Entwicklung, der Ungarischen UNESCO-Kommission, dem Forschungszentrum für Wasserwirtschaft AG (VITUKI), dem Oberbürgermeister der Hauptstadt Budapest, der International Science Foundation, der UNESCO, der WMO, der Koordinierungseinheit Donauprogram der CEC und der Ungarischen Akademie der Wissenschaften.

Ein besonders herzlicher Dank geht auch an die Mitglieder des Lokalen Organisationsausschusses der Konferenz sowie ihren zahlreichen Helfern, deren selbstlose Arbeit bestimmt wesentlich zu den wissenschaftlichen Ergebnissen und der herkömmlich freundschaftlichen Atmosphäre der XVII. Donauländerkonferenz beigetragen hat.

Budapest, Mai 1994

sponsors of the Conference. The positive answers and substantial helps received from the Hungarian Ministry for Transport, Communication and Water Management, from the Hungarian Ministry for Environmental Protection and Regional Development, from the Hungarian UNESCO Commission, from the Water Resources Research Centre Plc. (VITUKI), from The Mayor of the Capital Budapest, the International Science Foundation, from the UNESCO, from the WMO, from the Danube Programme Coordination Unit of CEC and from the Hungarian Academy of Sciences are gratefully acknowledged.

Special thanks are also expressed to the members of the Local Organizing Committee of the Conference and their numerous helpers whose unselfish efforts may substantially have contributed to the scientific results and the traditionally amicable atmosphere of the XVIIth Conference of the Danube Countries.

Budapest, May 1994

M. Domokos

(M. Domokos)

Sekretär / Secretary
des UNGARISCHEN IHP/OHP NATIONALKOMITEES
of the HUNGARIAN IHP/OHP NATIONAL COMMITTE

G
GRUSSREDEN
GREETING ADDRESSES

"... an excellent forum for gathering better and more detailed knowledge on one of the most international rivers of the Earth ..."

Greeting address by

Dr. Gábor DEMSZKY
The Mayor of the Capital Budapest

Ladies and Gentlemen, dear Conference Participants:

It is my particular pleasure to greet you among the walls of Budapest. The Danube Countries have selected Budapest for the third time as the venue of their International Conference on Forecasting, Hydrology and Water Management.

The history and economic development of Budapest, situated almost at the middle point along the course of the great river, had been closely connected to the River Danube. The river offers natural resources and economic values of decisive importance for future development as well.

The two-leveled river embankments of Budapest, which were built in the 1870-ies, are of historic monument value and largely define both the development and the view of the city. They were built with the the following two main objectives:

- to provide flood defence and especially to prevent the occurrence of ice floods; and

- to facilitate river navigation and cargo shipping.

Indeed, the quays of more than 10 km total length had, in the last century, opened a wide gate for the shipping of all kind of products of the Danube Basin such as timber, agricultural and industrial products. The river-port function of Budapest had a significant role in turning the city into a major centre of the economic life of the broader region.

The downtown Danube reach between Margit Bridge and Szabadság Bridge, with the quays, bridges, buildings and with their natural environment has been declared by UNESCO a world heritage, but this area is by no means a kind of outdoor museum, set apart from the life of the city. Esşential urban traffic routes run, without level crossings, along both the Buda and Pest embankments, actually in the floodplain of the River Danube. Above a water stage of 6 meters the river gradually inundates these transportation corridors, like it happened in the spring of this year, too. This is one of the reasons why the operators of the public networks of the metropolis are extremely interested in the recent results research into water level forecasting. In the possession of more reliable forecasts the disturbance to urban traffic can be reduced, by reducing the period of traffic diversion from the quays, which creates from time-to-time an almost unbearable burden on the traffic of the city.

Among the operation and development tasks of municipal government, water supply and sewerage are two major ones with which the Conference is going to deal, too.

It is perhaps known to you also that the water supply of Budapest is based on bank-filtered drinking water resources and, to a smaller extent, also on surface water intake from the River Danube. As both sources are essentially those of the river, the papers of the conference dealing with water budgets, sediment transport, ice conditions, water quality and aquatic life are discussing important aspects from the point of view of these public supplies.

These subjects closely relate to the work of our water supply and sewerage experts, but they are also important for city planners, professionals of trade and commerce and also for those of tourism, who all attempt to develope and make use of other, environmental, landscape, ecological, etc. values of the River Danube.

Casting a view over the broader Danube Valley it is our particular pleasure to recognize that 13 riparian countries sent their professionals to the Conference in order to present the results of their research or practical works.

The Conference provides an excellent forum for gathering better and more detailed knowledge on one of the most international rivers of the Earth, and for having discussions on, and making proposals for further research needed for the better protection and development of the great ecological and economic values of the River Danube.

I wish all of you dear Participants fruitful work and an enjoyable stay in our metropolitan city Budapest.

"...we are proud for our role played in the development of the Danube river or in the protection of the population and wealth against flooding."

Greeting address by

Professor Dr. Ödön STAROSOLSZKY
Director General of VITUKI Plc.

Distinguished Participants of the XVIIth Danube Conference:

On behalf of the host institute and its staff I have an extraordinary honour and particular pleasure to welcome you in the Water Resources Research Centre, the institute hosting the Conference and the Secretariat of the IHP/OHP National Committee of Hungary.

We are extremely glad since VITUKI's staff was active since these Conferences are regularly organized. We run the Secretariat since the launching of UNESCO's International Hydrological Decade, and the national reference centre of WMO's Hydrological Operational Multipurpose System.

The location of VITUKI is physically and spiritually bounded to the Danube. Our campus is accommodated in a former Danube bed which was filled partially by dredged material of the river, our campus border is the main levee of Budapest and the Ráckeve Danube arm. From the roof of our central building we can enjoy the beautiful view over the Danube. This physical neighbourhood is a representative factor for our institute.

The spiritual neighbourhood is supported by several hydrological, hydraulic or water-quality studies on, or related to, the Danube and her utilization. VITUKI's spiritual connections with the Danube were strengthened recently since VITUKI was appointed as national focal point for the Danube Environmental Programme of the European Community, World Bank and UNDP.

VITUKI has participating in several international studies and contributed to the Cousteou-team expedition over the Danube, the Environmental and Navigability Study of the Netherlands over the Danube, the UNDP/WHO water quality monitoring studies, and to the compilation of the hydrological yearbook of the Danube Commission.

It is almost 100 years now since it is the responsibility os VITUKI and its predecessors, respectively, to compile and disseminate daily reports and forecasts on the Danube water levels and discharges both along the Hungarian reach and thatextending from Regensburg to the Iron-Gate. This traditional activity was one major topics in the close cooperation within the biennial conferences devoted for a long period to the hydrological forecasting.

Danube water quality study over the joint Slovak-Hungarian reach is one of the biggest effort of our water quality laboratory made jointly with the relevant Slovak Institute, the VÚVH in Bratislava.

Danube water is flowing from our taps since bank-filtered wells supply partly the Budapest Water Works, therefore the detailed investigations of VITUKI on the bank-filtered water resources and their vulnerability are also regular topics of our research plans.

Our hydraulic laboratory was the site of several physical models related to barrages, water intakes and outlets, river training and flood control works along, or bridges over, the Danube. The hydraulic laboratory tests on the Paks Nuclear Power station and the regular field inspections over the greatest water intake of Hungary are also important features of the connection between the Danube and VITUKI.

This is the reason why we are proud of our role played in the development of the Danube river and in the protection of the population and wealth against flooding.

When we organize a technical-scientific meeting, as we do it relatively frequently, we like to introduce this large river to our guest and we put into the programme a visit or a boat excursion, like we do it at this conference by the courtesy of the Mayor of the City of Budapest, as you are certainly aware from the circular of the Conference. We like to introduce this river which is a connecting tie with several countries of Europe, upstream and downstream. Thus, we have close collaborations, particularly with the neighbouring countries, like Austria, Slovakia or Yugoslavia, including joint sampling or measuring programmes in order to generate data series acceptable for the border sections of the river. We feel that we can do more jointly than separately.

Therefore we wish to promote furthermore collaboration between institutes and researchers of the Danube Countries both in scientific programmes and in operational data acquisition. This forum, the XVIIth Danube Conference can be the site of the establishment of initiatives new or the reinforcement of existing collaborations. We are particularly glad to have this meeting with several representatives and excellent hydrologists from the Danube Countries, and also countries outside of the Danube catchment.

I hope that you will be satisfied by our efforts in the preparation and the implementation of the programme.

On behalf of the host institute I wish to all of the participants a successful conference and a memorable stay here in Budapest and Hungary.

Thank you for coming and visiting us!

F

FESTREDEN
FESTIVE ADDRESSES

XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
hydrologisch-wasserwirtschaftliche Grundlagen

XVIIth CONFERENCE OF THE DANUBE COUNTRIES
on Hydrological Forecasting and Hydrological Bases
of Water Management

Budapest, 5 - 9 September, 1994

BEITRAG/PAPER NO.: F.1.

GEDANKEN ZUR GRÜNDUNG DER ARBEITSGEMEINSCHAFT DER DONAULÄNDER FÜR HYDROLOGISCHE VORHERSAGEN IM APRIL 1961

von em.Prof.Dr.techn.Dr.h.c. W. Kresser, Wien

Kurzfassung

Der Verfasser ist - neben den weiland Professoren Kalinin, Lászlóffy, usw. - einer der Gründer der Konferenzen für hydrologische Vorhersagen der Donauländer, deren erste im April 1961 in Budapest getagt hat. Während der vergangenen 33 Jahre haben die im allgemeinen zweijährlich veranstalteten 16 Konferenzen in den bisherigen acht Donauländern in zwei Runden stattgefunden. Die 17. Konferenz, die neben der Vorhersage nunmehr auch allgemeinere Fragen der Hydrologie und der Wasserwirtschaft behandelt, wird bereits die dritte in der Gründerstadt Budapest sein. Mit ihr wird somit die dritte Runde in den inzwischen auf 13 angewachsenen Donaustaaten beginnen. Bei diesem festlichen Anlaß blickt Professor Kresser auf die Vorgeschichte der Gründung der Arbeitsgemeinschaft in einem weiter gespannten historischen Rahmen zurück, wobei er schwerpunktmäßig einige wichtigere Aspekte der Geschichte der globalen und der ungarischen Gewässerkunde hervorhebt sowie abschließend auf die Bedeutung und die Erfolge der bisherigen Konferenzen kurz eingeht.

Reflections on the foundation of the Working Pool of the Danube Countries for hydrological forecasting

Abstract The Author is - besides the late Professors Kalinin, Lászlóffy, etc. - one of the founders of the Conferences for Hydrological Forecasting of the Danube Countries, whose first meeting took place in April 1961 in Budapest. During the past 33 years the 16 Conferences, organized every second year alternatively in the so far eight Danube Countries, made two rounds. The 17th Conference, already dealing also with general topics of hydrology and water management, will be the third one taking place in the town of foundation, Budapest. With this Conference starts, the third round among the Danube Countries whose number has increased in the meantime to 13. At this festive occasion, Professor Kresser offers a review of the events preceding the foundation of the Working Pool for Hydrological Forecasting within a wider historical framework, focusing on selected aspects of the history of global and Hungarian hydrology and briefly underlining the importance and achievements of the Conference held so far.

GEDANKEN ZUR GRÜNDUNG DER ARBEITSGEMEINSCHAFT DER DONAU-LÄNDER FÜR HYDROLOGISCHE VORHERSAGEN IM APRIL 1961

von W. Kresser, Wien

Im Ablauf der Geschichte der Menschheit hat es immer wieder Zeitpunkte gegeben, die für die Entwicklung eines Volkes, der Technik oder einer bestimmten Wissenschaft eine Zäsur bedeuteten. So waren für die gesamte westliche Zivilisation entscheidend das Jahr 1453 mit der Eroberung Konstantinopels durch die Türken, 1492 mit der Entdeckung Amerikas, 1789 mit der französischen Revolution oder 1917 mit der Errichtung des Sowjetstaates mit allen sich daraus ergebenden Folgen, zu denen indirekt auch der Bau der Berliner Mauer im August 1961 zu rechnen ist.

1961 war auch das Jahr, das für die Hydrologie der Donauländer von besonderer Bedeutung werden sollte. Am 12. April 1961 umkreiste das sowjetische Raumschiff Wostok I die Erde, und mit dem russischen Major Gagarin betrat zum ersten Mal ein Mensch das Weltall. Zufällig wird a n d e m s e l b e n T a g hier in Budapest die Arbeitsgemeinschaft der Donauländer für hydrologische Vorhersagen gegründet, die heute bereits mit dem dritten Zyklus der alle zwei Jahre in jeweils einem anderen der Donauländer stattfindenden Konferenzen beginnt. So unterschiedlich diese beiden Ereignisse ihrem Gewicht nach zu bewerten sind, ist ihnen doch auch gleichzeitig Grundlegendes gemeinsam. Mit der sowjetischen Weltraummission hat der Mensch einen bis dahin verschlossenen Raum erobert und auch mit der Gründung der Arbeitsgemeinschaft für hydrologische Vorhersagen wurde Neuland betreten. Die Hydrologen der Donauländer wagten sich auf das schwierige Gebiet wissenschaftlich fundierter Vorhersagen, das bis dahin vorwiegend eine Domäne der Meteorologen gewesen war, und eröffneten sich damit ein Fachgebiet von großer Bedeutung für die Wasserwirtschaft und darüber hinaus für weite Bereiche der heutigen Wirtschaft.

Welche G r ü n d e waren es nun, die dazu führten, gerade h i e r i n B u d a p e s t die hydrologischen Vorhersagen als ein mehr oder weniger eigenständiges Forschungsgebiet der Hydrologie zu kreieren? Gewässerkundliche oder wasserwirtschaftliche Vorhersagen hat es zweifellos schon in der F r ü h z e i t der Menschheit gegeben, was am sinnfälligsten wohl für Ägypten zutrifft. Für dieses Land, dessen Existenzgrundlage das Wasser bildete, hing die notwendige Bewässerung eines ganzen Jahres entscheidend von der richtigen Voraussage des Einsetzens der Jahresflut des Nils ab. Das Erscheinen des Sirius am Abendhimmel galt als das astronomische Ereignis, das mit dem Beginn der jährlichen Überschwemmungen in Zusammenhang gebracht wurde. Ähnliche Relationen zwischen der Stellung der Gestirne und bestimmten hydrometeorologischen Geschehnissen und, darauf basierend, gewisse Vorhersagen auf Grund einer metaphysischen Betrachtungsweise der Natur wurden auch in Mesopotamien, in China und Indien sowie später im Bereich der mittelamerikanischen Hochkulturen erstellt.

Bei diesen ältesten Versuchen, durch eine bestimmte Vorhersage die Möglichkeit zu schaffen, das lebensnotwendige Wasser zu bewirtschaften oder mit dem Wasserüberfluß verbundene Gefahren abzuwenden, standen den frühen Entwicklungsstufen als Hilfsmittel somit hauptsächlich gewisse übersinnliche Vorstellungen und Kombinationen zur Verfügung. Erst mit der R e n a i s s a n c e trat der Mensch in ein neues Verhältnis zur Natur und ihren Erscheinungen. Das Streben der nächsten Jahrhunderte war daher mit steigendem Erfolg darauf gerichtet, die Zusammenhänge zwischen einzelnen Naturerscheinungen und konkreten, feststellbaren oder meßbaren Tatsachen zu ergründen, ihre Vielzahl und Vielfalt auf einheitliche Prinzipien zurückzuführen und womöglich mathematisch zu formulieren. Damit war der Weg der naturwissenschaftlichen Forschung bis in unsere Tage vorgezeichnet, ein Weg, der vor allem auch für das Gebiet der hydrologischen Vorhersagen gilt.

Es dauerte jedoch noch längere Zeit, bis es zu einem eigenständigen Fachbereich einer gewässerkundlichen Voraussage kommen konnte, denn zu seiner Etablierung fehlten noch einige wesentliche V o r a u s s e t z u n g e n. Eine davon war zweifellos der Mangel an ausreichenden Naturbeobachtungen, was allgemein auch für den Rückstand der gesamten Hydrologie galt. Als nachteilig erwies sich weiterhin die bis in die Mitte unseres Jahrhunderts herauf fehlende Kooperation mit den Nachbarwissenschaften der Gewässerkunde sowie die geringe Pflege der integrativen Disziplinen, wie der Physik und Mathematik. Erst nach der Behebung dieser Mängel und dem damit verbundenen tieferen Einblick in die naturwissenschaftlichen Zusammenhänge konnte mit der wissenschaftlichen Behandlung der vielen Probleme der hydrologischen Vorhersagen begonnen werden.

Im Jahre 1961 war es dann soweit, und wenn die Inauguration der Arbeitsgemeinschaft der Donauländer für hydrologische Vorhersagen hier in Budapest erfolgte, so lagen dafür h i s t o r i s c h e G r ü n d e vor. Für ein Land, dessen Gebiet zu einem erheblichen Teil unter dem Hochwassersaum der großen Flüsse, insbesondere der Donau und der Theiß liegt, bedeutete die Vorherbestimmung der Hochwasserstände von jeher eine Überlebensfrage. Unter dem Zwang der Erfordernisse der Wirtschaft und der Sicherheit der Bevölkerung wurden in

Ungarn daher bereits vor hundert Jahren mit den bescheidensten Hilfsmitteln und unbeschadet der damaligen Schwierigkeiten einer entsprechenden Nachrichtenübermittlung hydrologische Vorhersagen getroffen und damit eine Pionierarbeit geleistet, die nicht hoch genug eingeschätzt werden kann.

Das Hauptverdienst dafür, daß sich nach den Wasserstandsprognosen der französischen Hydrologen BELGRAND und MAZOYER für das Seinegebiet auch im Donauraum ein klassisches Zentrum gewässerkundlicher Forschung in bezug auf die hydrologische Vorhersage entwickeln konnte, gebührt ohne Zweifel dem bedeutenden ungarischen Hydrologen Joseph PÉCH. Im Jahre 1886 wurde PÉCH mit der Führung des eben gegründeten Ungarischen Hydrographischen Dienstes betraut. Schon vier Jahre später arbeitete er die ersten Wasserstandsprognosen für das von Preßburg bis zum Eisernen Tor reichende ungarische Donaugebiet und für neun Pegelstationen an der Theiß aus, wobei der Fehler in 72% der Fälle weniger als 10 cm betrug. Ab 1892 wurde dann der regelmäßige Vorhersagedienst eingeführt, und es kamen für alle bedeutenden Gewässer des Karpatenbeckens Tageskarten der Wasserstände heraus, die von der Post versandt wurden und einen großen Erfolg verzeichneten. Bereits ein Jahr später, als der Österreichische Hydrographische Dienst eben gegründet wurde und andere Länder noch lange auf eine ähnliche Institution warten mußten, gab PÉCH für 27 Pegel, wovon zwölf an der Donau lagen, schon sehr genaue ein- bis fünftägige Hochwasservorhersagen heraus. Ab 1898 folgten dann für 20 Donaupegel 24- und 48stündige Wasserstandsprognosen die eine erstaunliche Genauigkeit aufwiesen. PÉCH begnügte sich jedoch keineswegs mit der Einrichtung eines funktionierenden Vorhersagedienstes für ein ausgedehntes Gewässersystem, sondern arbeitete auch maßgebend an der methodischen Weiterentwicklung des von ihm in seiner Bedeutung erkannten neuen Teilgebietes der Hydrologie. Sein zweibändiges Werk darüber war die erste allgemeine, zusammenhängende Publikation auf dem Gebiet der gewässerkundlichen Vorhersage in den Donauländern und wurde auch in deutscher und französischer Sprache veröffentlicht.

Auch die später folgenden Hydrologen Ungarns pflegten bis in unsere Tage herauf die hohe Tradition, zu der sie sich allein schon durch das große Werk von PÉCH verpflichtet fühlten. So waren es denn auch die u n g a r i s c h e n Hydrologen, die sich nach dem Zweiten Weltkrieg, nach der Wiedererrichtung und Modernisierung des hydrographischen Nachrichtendienstes, dem Forschungszweig der hydrologischen Vorhersage zuwandten, neue Prognoseverfahren entwickelten und ihre praktische Anwendung und Zuverlässigkeit prüften.

Sie arbeiteten für sämtliche größeren Flüsse des Landes handliche graphische Verfahren oder geeignete mathematische Methoden, vorwiegend der mehrfachen Regression, aus.

Es war somit nur logisch, wenn im Jahre 1961 der wohl bedeutendste Hydrologe Ungarns der Nachkriegszeit, Woldemár LÁSZLÓFFY, die Gründung einer Arbeitsgemeinschaft für hydrologische Vorhersagen vorschlug, die sämtliche Donauländer einschließen sollte. LÁSZLÓFFY und der damalige Leiter der Forschungsanstalt für Wasserwirtschaft, Károly STELCZER, luden mich ein, gemeinsam mit ihnen das Gründungskomitee zu bilden, und so kam es dann im April 1961 zur Einrichtung eben dieser Arbeitsgemeinschaft, die somit auf 33 Jahre ihres Bestehens zurückblicken kann.

Während auf der Gründungskonferenz und auch noch auf der 2.Tagung in Graz im Rahmen eines mehr oder weniger geschlossenen Kreises von in der Hydrologie Tätigen grundsätzliche Fragen der Prognose, insbesondere die notwendigen Definitionen, die Möglichkeiten und Grenzen einer Vorhersage sowie die Methoden und ihre Genauigkeit behandelt wurden, ergab sich später eine zunehmende Ausweitung der zu behandelnden Themen. Die 3.Konferenz fand dann in Bukarest statt, wobei sich der Teilnehmerkreis von da an laufend vergrößerte, was aber nicht immer mit einer Erhöhung der qualitativen Effizienz verbunden war. Es folgten die Konferenzen in Bratislava, Beograd, Kiew, Sofia und Regensburg, bis dann im Jahre 1977 die IX. Konferenz an ihren Gründungsort Budapest zurückkehrte und damit die zweite Runde der alle zwei Jahre stattfindenden Tagungen einleitete.

Läßt man die bisherigen sechzehn Konferenzen Revue passieren, so erhebt sich die Frage, ob der seinerzeitige, die ersten Tagungen prägende Optimiusmus berechtigt war, oder ob die ursprünglichen Erwartungen zu hoch lagen. Reicht die damalige Konzeption im wesentlichen auch heute noch aus, oder verlangen darüber hinaus neue Probleme eine Behandlung, um den heutigen Erfordernissen einer umfassenden Wasserwirtschaft zu entsprechen? Das sind nur einige Fragen, die sich anläßlich einer Jubiläumstagung aufdrängen und deren Beantwortung selbstverständlich nur eine subjektive sein kann.

Zieht man die Erfolge auf dem Sektor der hydrologischen Vorhersagen in den letzten Jahren in Betracht, so läßt sich trotz gelegentlicher Rückschläge feststellen, daß sich der Gedankenentwurf des Jahres 1961 bewährt hat und das Forschungsgebiet der hydrologischen Prognose einen hohen Stand wissenschaftlicher Erkenntnis erreicht hat. Besonders augenfällig ist dabei die erfolgte A u s w e i t u n g d e r A r b e i t s t h e m e n , so daß jetzt nicht nur das zur Grunderzeit angesprochene Gebiet der hydrologischen Vorhersagen, sondern auch die hydrologisch-wasserwirtschaftlichen Grundlagen behandelt werden sollen. Damit stellt sich dem forschenden Hydrologen eine Fülle neuer Aufgaben, und die Wandlung der Problematik und der Methoden zwingt ihn, im Suchen nach neuen Erkenntnissen immer weiter in die komplexen Zusammenhänge des hydrologischen Geschehens einzudringen. Dabei rücken in zunehmendem Maße Problemkreise in den Vordergrund, die an den G r e n z e n z u a n d e r e n W i s s e n s c h a f t e n liegen. Es gilt also die Barrieren zu einigen Nachbargebieten zu überwinden und die bestehenden Kontakte noch mehr zu pflegen. Somit wird es auch bei den hydrologischen und wasserwirtschaftlichen Vorhersagen zunehmend zur Anwendung der in anderen Disziplinen bewährten Methoden und Denkweisen kommen. Bei allen euphorischen Zukunftsplänen sollte man jedoch bedenken, daß, ungeachtet aller wissenschaftlichen Fortschritte, das sinnhafte Begreifen der naturhaften Zusammenhänge in der Hydrologie stets im Vordergrund stehen muß. Das eigentliche Experimentierfeld gerade in der hydrologischen Vorhersage ist bei aller Achtung vor den geistigen Leistungen weder der Schreibtisch noch das Laboratorium, sondern einzig und allein d i e N a t u r i n a l l i h r e r V i e l f a l t.

XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
hydrologisch-wasserwirtschaftliche Grundlagen

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COHERENCE AND DIVERSITY IN THE DANUBE BASIN

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Abstract

The role of water as impact transmitting media and coherence creating force in nature and society was an important recognition and far sighted vision of Professor Dr.Woldemár Lászlóffy, who was the principal initiator of the regular conferences on Danube hydrology and from whom I have learned theory and practice of hydrology for more than two decades.In nature the integrating role of water is a reflection of the holistic character of planetary evolution and manifests itself in the harmonization of local diversity with macrosacle coherence through an intricate and very finely tuned interaction between the processes of water balance dynamics and landscape ecology. The atomistic principles and fragmented approaches underlying the market induced tendencies of the technological and industrial developments of the last few centuries sharply conflict with nature's holistic functioning, as well as with the deeply holistic structure and capabilities of the human brain and mind itself-leaving and nourishing hope that the cultural and ecological dimensions will soon find their proper place in a world order of lasting peace and real prosperity. This holistic principles seem to be reflected also in the history of the long-lasting co-operative initiatives and efforts preparing the ground for the regular conferences and bringing surprisingly full and quick success even under the difficult conditions of the late fifties and early sixties when the iron curtain system crossing the Danube Basin was still in full force.

Kohärenz und Diversität im Donaueinzugsgebiet

Kurzfassung

Die in der Natur und der Gesellschaft als wirkungsübertragendes und kohärenzschaffendes Mittel gespielte Rolle des Wassers war eines der wichtigen Erkenntnisse und weitsichtigen Visionen von Professor Dr.Woldemár Lászlóffy, dem hauptsächlichen Veranlasser der regelmäßigen Konferenzen über die Donauhydro-

logie, von dem ich die Theorie und Praxis der Hydrologie während mehr als zwei Jahrzehnte erlernt habe. Die integrierende Rolle des Wassers ist in der Natur eine Wiederspiegelung des holistischen Charakters der planetaren Evolution. Diese Rolle kommt darin zum Ausdruck, daß sie die lokale Diversität mit der großmaßstäblichen Kohärenz - über komplizierte und äußerst fein abgestimmte Wechselwirkungen zwischen den Prozessen der Wasserbilanz-Dynamik und der Landschaftsökologie - in Einklang bringt. Die den vom Markt geprägten Tendenzen der in den letzten Jahrhunderten stattgefundenen technologischen und industriellen Entwicklungen zugrunde liegenden atomistischen Prinzipien und fragmentarischen Annäherungen geraten in einen scharfen Konflikt sowohl mit der holistischen Funktion der Natur als auch mit den tiefwurzelnd holistischen Struktur und Fähigkeiten des menschlichen Gehirns und des menschlichen Geistes selbst. Dies alles läßt uns speist unsere Hoffnung darauf, daß die kulturellen und ökologischen Dimensionen bald ihren geeigneten Platz in einer Weltordnung des andauernden Friedens und einer wahrhaftigen Prosperität finden werden. Diese holistischen Prinzipien scheinen sich auch in der Geschichte von langdauernden Anregungen zur Zusammenarbeit und Anstrengungen widerzuspiegeln, welche den Grund für regelmäßige Konferenzen ebnen,wobei sie überraschend vollständige und rasche Erfolge zeitigen, sogar unter den schwierigen Verhältnissen der späten fünfziger und der frühen sechziger Jahre, als das das Donaubecken überquerende System des Eisernen Vorhangs noch in voller Kraft war.

1. Introduction

Every drop of water flowing in the drainage basin and the river system of the Danube - being in unceasing motion and accompanied on their journey by a great variety of biogeochemical constituents - serves as impact transmitting and integrating media among the basin's various landscapes and ecosystems ranging from the magnificient mountain peaks of the Alps and Carpaths through large alluvial flatlands till the grandious and fertile delta at the Black Sea. Similarly, the region's hydrologists - and today this term includes all those concerned with the aquisition and application of knowledge on the role of water in nature and in society - could and should serve as initiators and promoters of understanding and co-operation for the common good of all the people sharing the blessings and hazards of the world's most international river, the Danube.

The role of water as coherence creating media of nature and society, and the high relevance of this role within the conditions of the Danube Basin was a deep conviction of Professor Woldemár Lászlóffy who has planted the seed ideas of the Danube Hydrology Conferences and from whom I have learned hydrology for more than two decades. In sections 2 and 3 of this homage and tribute paying writing I am trying to outline, very tentatively and briefly, the integrating and impact transmitting role of water in large fluvial basins and how this role conflicts with the atomistic principles underlying the market shaped industrialization of the last few centuries and decades of human evolution.In section 4 an attempt is made to revive events and pieces of personal memory on how Prof.Lászlóffy's seed ideas cristalized into success with devoted and most competent support of two other "founding fathers" of the Conferences, Professor Dr.Werner Kresser and Professor Dr.Genadij Pavlovich Kalinin.

2. Water balance and landscape ecology

Water is an element of integration and interaction. The fluvial basin wherein water performs its present day actions is itself the river's own creation as having responded to forces of geology and climate during the preceeding thousand and million years (boxes A and B in Figure 1). From point of view of hydrology and water balance dynamics the fluvial basin is a self contained and integer unit of nature with its own set of structural and functional parameters, such as the humidity/ aridity coefficients; percentages and types of vegetation cover; infiltration and exfiltration coefficients; river network densities and the interconnected layers of groundwater aquifers, and many others as sampled further tentatively in box C of Figure 1.

From point of view of life forms and landscape ecology the same piece of land consists of hundreds and thousands of mosaics that are selfcontained and autonomous units with regard to their biological and physiological functions; They are, however, closely interlinked and interdependent along the pathways of the hydrological processes in terms of the flow of water, energy, nutrients and many other important biogeochemicals. These mosaics can be loosely classified into (1) terrestrial, (2) aquatic and (3) littoral ecosystems the proportion and territorial pattern of which is one of the major aggregate feature of the fluvial basin as the homeland of landscape ecology (box D in Figure 1).

The interrelatedness of the processes of the water balance and the landscape ecology is very close and crucial, indeed, in both directions: Any climate or geology generated change in the water balance or the flow pattern of the fluvial basin leads slowly but surely to very finely tuned responses within the mosaics of landscape ecology; Similarly,any change in structures or evolutionary processes within the terrestrial, aquatic and littoral ecosystems (which can be caused under natural conditions by aging, disease, forest fire, climate change, tectonics, and many other internal or external factors) leads slowly but surely to very precisely corresponding changes in the flow pattern and the water balance of the fluvial basin - as indicated by the feedback arrows among the various boxes of Figure 1.

The features of coherence and diversity characterizing the

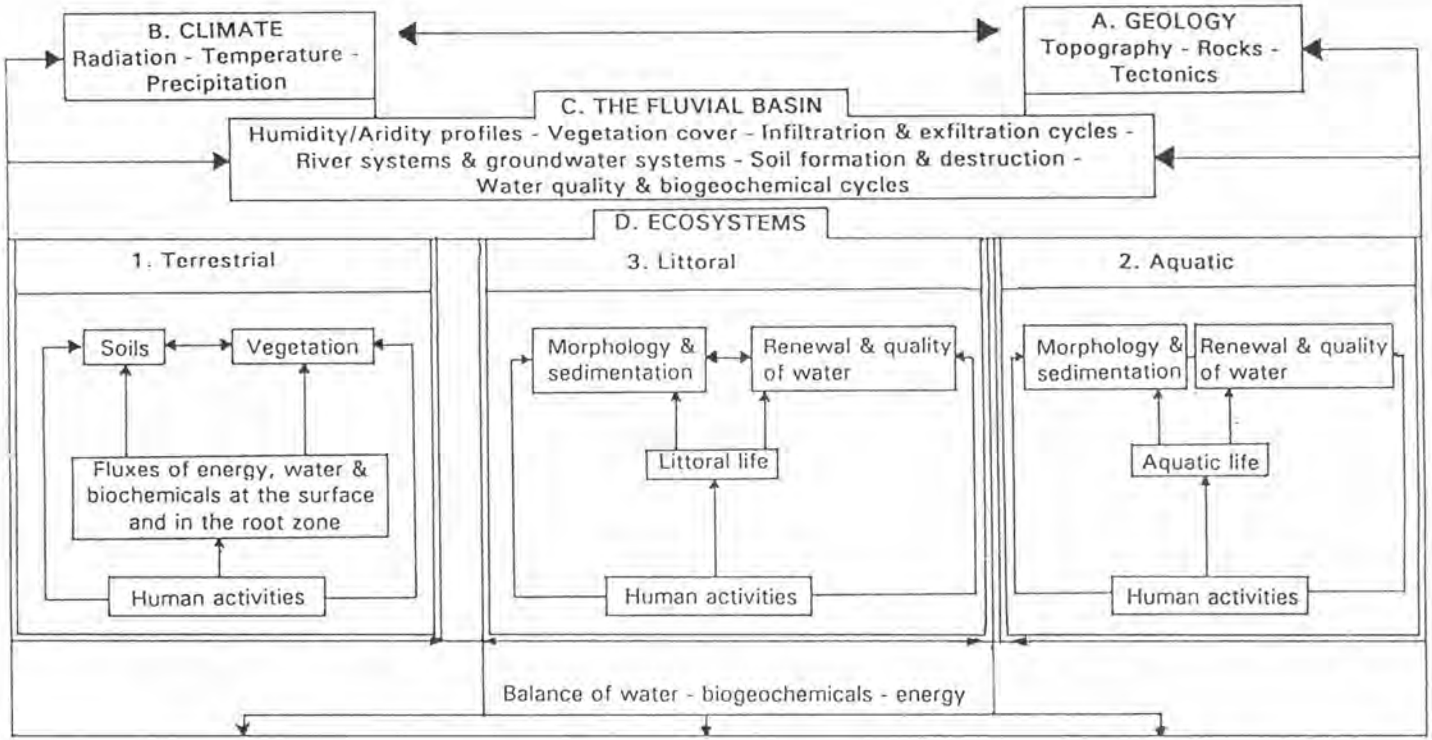

Fig. 1. Major physical and ecological factors and processes in the formation and evolution of the fluvial basins (*Orlóci & Szesztay* 1993)

alluvial basin as home of the interacting processes of water balance dynamics and landscape ecology are visualized and quantified on Figure 2. This scheme summarizes average and extreme values of the partition of precipitation water during its journey through the unsaturated zone and the various layers of groundwater aquifers leading to its recycling in the form of evapotranspiration and runoff.The values written near the arrows of this manybranched partition process relate to the Hungarian portion of the Carpathian Basin's Great Plains (the largest alluvial basin of Europe with its almost hundred thousand sq.km aggregate extension) and its 57 subbasins (varying in size from a few tens to a few thousands sq.km). The single standing values (560 mm for precipitation; 106 mm for infiltration reaching the first groundwater layer, etc.) describe the average water balance conditions for the 43 thousand sq.km Hungarian portion as a whole, whereas the corresponding two values in bracket (500 and 600 mm for precipitation; 5 and 190 mm for infiltration to the first groundwater layer; etc.) indicate the respective minimum and maximum of the 57 subbasins.Even this highly simplified representation of water balance dynamics clearly demonstrates that territorial variability is relatively small within processes dominated by climate (precipitation and evapotranspiration), but diversity among the sub-basins in terms of variability and skewnew of the statistical distributions increases rapidly when factors of landscape ecology (soils, vegetation, topography, depth of the subsequent groundwater layers, etc.) come in play and reach dominant role. This is examplified by the balance components within and below the unsaturated zone, such as the values of infiltration reaching the first groundwater layer (with a range between 5 and 190 mm for a mean of 106 mm) or the downwards and upwards fluxes of water between the subsequent groundwater layers (ranging for the 57 sub-basins from 0 to 180 mm with a mean of 20 mm and 0 to 40 mm with a mean of 5 mm, respectively).

As far as concepts and methologies of experimental assessments and research are concerned the finely tuned harmonization of macroscale coherence and local diversity of water balance dynamics and landscape ecology, outlined on Figure 1 and examplified on Figure 2, can conveniently be approached by procedures of multivariate statistical analysis such as factor analysis, cluster analysis, discrimination analysis) as it was recently well demonstrated in the 4/1991 issue of the Journal "Hidrológiai Közlöny" by Gál and O.Kovács within the context of the chemical composition of groundwaters participating in various branches of the infiltration/exfiltration cycles of the Pannonian basin.

Fig. 2. Comparison of selected characteristic features of natural evolution (N) and the market-induced industrial technologies and organizations (M)

A. General features		
	N	M
General hierarchical structure and the worldview reflected in it	Holistic and highly non-linar	Atomistic and linear
Geographical distribution over the continents and the planet	Even and site specific (decentralized)	Highly uneven and centralized
Driving motivations and evolutionary trends	Increasing diversity and stability	Market mechanism and principles of comparative economic advantages
Typical time period of reaching significantly new state of the system	Millenia and longer	Years and shorter
Energy basis	Renewable only	Mostly non-renewable
B. Specific features of landscape ecology and water balance dynamics		
Plant cover types	Diversity in plant communities	Monocultures in isolation
Typical period of plant successions	Multi-annual and longer	Annual growing season or shorter
Relation to soil conditions, moisture availability and microtopography	Finely tuned local adaptations	Little or no regard, large monolithic units
Relation to climate	Adaptation through plant successions	Trying to minimize impacts through irrigation, plant breeding, etc.
Relation to wetlands, river flooding and groundwater	Adaptation through plant selection	Minimization of impacts through drainage, flood control, etc.
Energy basis	Sunshine and its converted forms	Mostly fossil fuels in nitrogen fertilizers, machine cultivation, etc.

3. Coherence and diversity of nature versus fragmentation and monocultures of the industrialized societies

In a historical perspective the ecologically controled coherence and diversity of water balance dynamics, alongside with the formation and continuous reformation of the fluvial basins is the result of the interplay of climate and geology at various time scales. The planetary machine of wheather and climate driven by transformations of the solar energy is in vigorous activity virtually at all possible time scales: Minutes and hours in the case of radiation cycles controled by Earth's rotation, some 20 to 100 thousand years in case of the cycles in the parameters defining the Earth's orbit around the Sun, and billions of years in the case of the slow but unceasing trend in the intensification of solar radiation, which is almost exactly compensated by the decreasing trend of atmospheric absorption and the greenhouse effect. Impacts of geology follow loose cycles of a few hundred million years of internal heat storage and mountain formation accompanied by continental drift. This basic cycle is supplemented by occasional upheavals of earthquages and vulcanic eruptions, as well as by a gradual and slow decreasing trend in the intensity of radioactive heating within the Earth's interior. Within planetary evolution as a whole climate and geology closely interact and control each other at sensitive points: Carbondioxid, one of the most important output of vulcanic eruptions and rock formation is the crucial atmospheric constituent controlling climate through the greenhouse effect. At the same time the formation of climate controled sedimentary rocks is frequently a decisive factor in designating critical places and periods of vulcanizm and plate tectonics. In this way large scale coherence and local diversity are characteristic features of natural evolution, indeed, within all its segments and at all scales of time space.

Human activities entered planetary evolution (as well as the mosaics of landscape ecology and water balance dynamics of box D in Figure 1) some ten thousand years ago with the invention and wide spread application of crop production technologies. Human inpacts became dominant, however, only very recently when industrialization spurred by objectives of economic power and supported by technology centric science, reached full hegemony and global coverage. As examplified in the Table the principles of fragmented analysis and stereotyped monocultural solutions guiding market oriented industrial organizations and technologies are radically different from strategies and solutions of natural evolution and ecology. The ultimate source of these radical differences lies in the system forming and functioning principles of the two domains. Nature forms her systems on a holistic basis and operates them in the direction to increase stability,resilience and energy efficiency for the system as a whole by applying highly structured non-linear regulatory mechanizms to this effect. Systems of the market driven modern industrialized world economy are designed one by one "atomistically" with the overriding single ultimate objective to increase capital accumulation and fiscal efficiency through linearly formulated functional concepts and with the general consequences of decreasing social and ecological diversity, stability and resiliense paralleled by rapidly increasing demands for external energies and support services (see e.g.the well documented analysis of Daly and Cobb in "For the Common Good", Beacon Press, 1989). As water deeply penetrates both, nature and society hydrology and water management are becoming crucial fields of research and action in redirecting global development to properly include the cultural and ecological dimensions and to bring lasting peace and real prosperity for the human race.

4. Origins of the Danube Conferences

In search for answer why the principal features of natural evolution and the market-induced industrial growth are so radically different,it is interesting and surprising to note that the human mind and brain which has created the rapid industrialization, is in itself the latest product of the planetary evolution and in latent potentialities it is the most perfect holistic system capable to harmonize immensly diverse structures and functions into admirable coherence and integrity. In the light of this recognition the scientific--technical - industrial revolutions of the last few centuries can be regarded as the enlightment and bloom of the human brain's left side only (which is mainly responsible for sequential and linear thinking of analytical nature); It seems, therefore, that a second period of enlightment bringing into balance and bloom also the human brain's right side potentials (with major functions for coherent and holistic pattern recognition, as well as for integrative and intuitive appreciation and judgement of aesthetic and ethical nature) is still to come. In fact, there are numerous signs within both, the various walks of practical life, as well as the realms of scientific thoughts that this second age of human enlightment is already dawning in spite of and among the many serious social, ecological and political conflicts of our troubled times. It is in this spirit that I am greatly honoured and priviledged to be here today to testify for the great human and professional personality of the late Professor Dr.Woldemár Lászlóffy who radiated holistic thinking and strengthened coherence through his words and actions,and who was the initiator and principal founding father of the biannual Danube Hydrology Conferences, the first of which was held 33 years ago.

Dr.Lászlóffy recognized the need for this type of conferences at the very beginning of his career, at the late twenties and early thirties, when he was occasionally involved in the hydrological background studies of important practical issues of flood control and river hydraulics emerging during the sessions of the International Danube Commission (IDC) of that time. He felt extremely frustrated - as he told me some 25 years later - seeing the wide gap between theoretical capabilities and practical expectations as e.g. in the case of the 1926 high floods of Danube when the impact of the new flood control dikes on the flood flows of the Danube and the Drava Rivers had to be investigated and quantified under the pressures of time and formalities of the meetings of the interested IDC countries. Although these pressures triggered sometimes peak achievements - as in the case of the solution of the above mentioned impact assessment by the excellent hydraulic engineer of that time J.Benedek the basic principles of which might be seen a forerunners of the subsequent flood routing and cascade-model approaches - Dr.Lászlóffy has clearly recognized how more easily and efficiently the theoretical foundations and practical applications of such issues could be discussed and solved if the same experts could meet and develope personal aquaintance and professional understanding within the framework and atmosphere of regular scientific conferences held sequentially in the Danubian countries.

The approaching second world war made, however, formal initiatives impossible. Prof. Lászlóffy unceasingly and systematically continued to work towards this objective by personal research on the hydrology of the Danube Basin; by extensive personal correspondence with hydrologists of other Danubian countries; by establishing a rich and well classified Hydraulic Engineering Library (mostly by sacrificing his evening hours and weekends, and acquiring the majority of the publications in exchange for the quarterly journal "Vizügyi Közlemények" which he has edited for more than two decades); as well as by spreading the concepts of integrated river basin development in scientific conferences and in private conversations.

As soon as the post-war conditions did allow, i.e. around the mid and late fifties when the Water Resources Research Insitute VITUKI was consolidated and the newly constituted Danube Commission started to play its role as a potential link between the Eastern and Western part of Europe, Prof.Lászlóffy resumed inquiries about outlooks of initiatives for the regular conferences. The fact that these tentative and entirely informal inquiries brought rapid success and the first conference could be held already in 1961 was due primarily to the full hearted and highly competent support of the regions two other distinguished personalities and hydrologists, Professor Dr.Werner Kresser and Professor Dr.Genadij Pavlovich Kalinin. It turned soon out that these three leading hydrologist of integrated vision and foresight were already pursuing the same common objectives for quiet some time. Although each of them had to act according to his own conditions these seemingly independent thoughts and actions met together into a well balanced strategy of quick and full success.

Prof.Kresser as Director of the Central Hydrological Office of Austria, then subsequently Professor and Rector of the Vienna Technical University not only symbolized in his friendly and always ready to help personality his country's historical role as a link between West and East; he also importanly and most competently contributed to its practical realization. Prof.Lászlóffy and Prof.Kresser developed and maintained in these years full and firm alliance and have realized a great many of their common co-operative endeavours through rare but always contented personal meetings and conversations (permeated by deep sympathy and high respect towards each other, as well as by full competence and far sighted vision in water sciences - as I had the inspiring opportunity to witness this at a few occassions) and through frequent correspondence as well as through an excellent mediator, Civ.Eng. Ernst Glasel Austria's long standing delegate at hydrology--related meetings of the Danube Commission, subsequently Director of the Hydrological Office in Vienna and always a dedicated supporter of international co-operation in hydrology.

The aquaintance and the subsequent fruitful co-operation with Prof.Kalinin came about through rather unexpected and irregular ways - as it frequently happens in the history and evolution of the holistic and non-linear systems. Late summer in 1959 Prof.Lászlóffy was requested to prepare himself for a three weeks study tour in the Soviet Union in order to bring home first hand information and utilizible experiences, and I was privileged to accompany him as interpreter (and to see again the country where I have spent already 26 months some ten years earlier as a prisoner of war). The study tour took place in November via Moscow-Leningrad-Walday-Moscow-Kiew. One of its highlights was shortly after our arrival to Moscow when we met Prof.Kalinin whose pioneering research on river forecasting and global hydrology was known to us from his outstanding publications. He received us late afternoon of a snowy day at his surprisingly small desk in a medium size room shared by four or five other members of his research team. When, after having listen for about half an hour his modest and concise words on latest research projects of his team, Prof. Lászlóffy started to speak about the ideas and informal initiatives on the regular Danube Conferences he responded with glowing face and enthusiastic words giving at once his personal consent and willingness to participate and to be one of the key speakers of the envisaged first conference. After this good start Prof. Lászlóffy raised the issue of the eventual Danube conferences also during the brief receptions at the directors of the visited institutions and by the end of the three week study tour he succeeded to obtain not only preliminary agreement but also active interest towards the proposed conferences particularly in their potential role as supplementary tools supporting the objectives and the activities of the Danube Commission.

Having found general agreement on the basic idea and preliminary green lights on its realization Prof. Lászlóffy initiated informal and semi-formal consultations in Budapest, Vienna and Bucarest about constitutional and procedural issues of the envisaged conference. Based on Proposal from Dr.Sorin Dumitrescu, that time Director of the Hydrological and Hydraulic Engineering Research Institute in Bucarest, it was unanimously accepted that no central administration or secretariat will be established for this purpose. The conferences will be organized by the Danubian countries sequentially on a voluntary basis and that the host institute will convene for each conference an international preparatory committee meeting, consisting from representatives of the participating central institutes of the Danubian countries, to decide upon the agenda and other major details of the forthcoming conference. In retrospect of three decades this loose and decentralized approach performed perfectly.

It was also general agreement at the preparatory consultations that the conferences should concentrate on questions of hydrological forecasting for which the practical need and utility was most obvious in terms of navigation and flood loss prevention. There was, however, also general consent on Prof.Lászlóffy's repeated notion that at a later stage,when the regular conferences will solidify and when the emerging new demands and conditions will make it reasonable and feasible, the conferences could gradually broaden their scope and objectives to include also other aspects of hydrology as a basis for water resources management, as well as for environmental management and land use planning. It is most gratifying to see that this hope and foresight of the "founding fathers" is now becoming a fact of this 17th Conference and a promise for the future perspectives.

XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
hydrologisch-wasserwirtschaftliche Grundlagen

XVIIth CONFERENCE OF THE DANUBE COUNTRIES
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Hydrologische Zusammenarbeit der Donauländer auf Expertenebene

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Kurzfassung: Der Beitrag befaßt sich mit der hydrologischen Zusammenarbeit der Donauländer im Rahmen des Internationalen Hydrologischen Programmes der UNESCO in der Zeit von 1987 bis 1992.

Hydrological Cooperation of the Danube Countries on Expert Level

Summary: This contribution describes the hydrological cooperation of the Danube countries in the framework of UNESCO's International Hydrological Programme between 1987 and 1992.

Die Zusammenarbeit der Donauanliegerstaaten im Rahmen der Hydrologie-Programme der UNESCO - 1965-1974 Internationales Hydrologisches Dezennium (IHD) und seit 1975 Internationales Hydrologisches Programm (IHP) - hat nun eine fast 30jährige Tradition. Diese Zusammenarbeit läßt sich unterteilen in: 1. die seit 1961 (also bereits vor Beginn der IHD) alle zwei Jahre ausgetragenen Konferenzen über hydrologische Vorhersagen und 2. die seit 1970 laufende Zusammenarbeit von Experten der Donauländer.

Auch die Zusammenarbeit der Experten besteht aus zwei Phasen: In der ersten Phase, 1970 im Rahmen des Internationalen Hydrologischen Dezenniums begonnen und ab 1975 im Rahmen des Internationalen Hydrologischen Programms fortgeführt, wurde die Hydrologische Monographie, Die Donau und ihr Einzugsgebiet, erarbeitet.

Die Zusammenarbeit gestaltete sich aufgrund der politischen Lage in Wirklichkeit etwas komplizierter als hier dargestellt werden kann, da lediglich vier Donauländer ihren Beitrag zur Monographie im Rahmen des IHD/IHP erstellt haben. Hierüber wird in einem anderen Beitrag zu dieser Konferenz ausführlicher Stellung genommen.

Mein Beitrag und Vortrag beschränkt sich auf die 2. Phase der Zusammenarbeit der Donauländer auf Expertenebene, d.h. auf die Zeit nach Fertigstellung der Monographie.

Als 1986 die deutschsprachige Version der Donaumonographie erschienen war, herrschte für kurze Zeit Unklarheit darüber, ob und wie die Zusammenarbeit der Donauanliegerstaaten fortgesetzt werden sollte. Unter der Schirmherrschaft der UNESCO hatte sich die Zusammenarbeit außerordentlich gut gestaltet. Alle beteiligten Institutionen, aber vor allem die mitwirkenden Experten, fühlten sich im Schutze dieser Weltorganisation geborgen.

1986 bestand der politische Gegensatz zwischen Ost und West in Europa noch in vollem Maße. So ist es verständlich, daß allseits der Wunsch geäußert wurde, die Arbeiten fortzusetzen und dies im Rahmen des Internationalen Hydrologischen Programms der UNESCO .

Die Initiative für eine Fortsetzung der Arbeiten ging von einer Gesprächsrunde über die hydrologische Monographie der Donau aus, die am 17. und 18. September 1986 in Belgrad stattgefunden hatte. Dort wurde die Empfehlung ausgesprochen, die Arbeit fortzusetzen. Ungarn übernahm die Ausarbeitung von Vorschlägen für eine weitere Zusammenarbeit. Die Vorschläge sollten mögliche Themen, aber auch formale Angelegenheiten, wie Durchführung und Koordinierung der Arbeiten sowie einen Zeitplan, beinhalten. Ungarn hat diese Aufgabe in hervorragender Weise erfüllt. Die erste Sitzung der Vertreter der IHP-Nationalkomitees der Donauländer in der zweiten Phase der hydrologischen Zusammenarbeit fand in Budapest vom 13. - 17. April 1987 statt. Die Einladung hierzu ging zurück auf die bereits erwähnte Gesprächsrunde in Belgrad, aber auch auf einen Beschluß der 12. Sitzung der IHP-Nationalkomitees der europäischen sozialistischen Länder, ausgetragen vom 15. - 20. September 1986 in Smolenice, CSSR. Bei dieser Sitzung sind außerordentlich wichtige Beschlüsse gefaßt worden, die die Arbeit der hydrologischen Experten aus dem Donauraum in den nachfolgenden Jahren stark geprägt haben und Hauptgegenstand der bis 1993 abgehaltenen, insgesamt acht Sitzungen der Vertreter der IHP-Nationalkomitees waren:

Arbeit und Beschlüsse der 1. Sitzung in Budapest beinhalten einen formellen und einen fachspezifischen Teil.

Der formelle Teil ist für eine Zusammenarbeit mit Beteiligung mehrerer Länder unerläßlich. Wenn diese Länder zwei unterschiedlichen politischen Grundsystemen angehören, wie es 1987 im damalig politisch strukturierten Donauraum noch der Fall war, dann gewinnt dieser formelle Aspekt eine noch herausragendere Bedeutung.

Die Teilnehmer der 1. Arbeitssitzung erarbeiteten auf der Grundlage eines ungarischen Vorschlages einen Entwurf über

<u>*Grundsätze*</u>

der regionalen Zusammenarbeit der Donauländer im Rahmen des Internationalen Hydrologischen Programms (IHP) der UNESCO auf dem Gebiet der Hydrologie

1

Die nationalen IHP-Komitees der acht Donauländer (D, A, CS, H, YU, RO, BG, SU) kommen überein, nach Fertigstellung des ersten Bandes auch weiterhin über hydrologische Probleme zusammenzuarbeiten. Die Zusammenarbeit erfolgt im Rahmen des Internationalen Hydrologischen Programms der UNESCO, insbesondere im Projekt 1.1 der 3. Phase und Projekt II.6 der 4. Phase.

2

Ziel der Zusammenarbeit ist es, durch gemeinsame Anstrengungen einen Beitrag zur Lösung aktueller hydrologischer und wasserwirtschaftlicher Probleme, die das gesamte oder einen großen Teil des Donaugebietes betreffen, zu leisten.

Um Doppelarbeit zu vermeiden, werden hydrologische und wasserwirtschaftliche Fragestellungen, die bereits von internationalen Organisationen bearbeitet werden, berücksichtigt.

3

An der Zusammenarbeit nehmen Beauftragte und Experten, die von den teilnehmenden IHP-Nationalkomitees benannt werden, teil.

Ferner können sich Vertreter der Nationalkomitees der Länder Schweiz, Italien, Polen und Albanien der Mitarbeit anschließen.

4

Für jedes Thema im abgestimmten Arbeitsplan wird von den Vertretern der IHP-Nationalkomitees auf freiwilliger Basis ein Projektleiter gewählt, der für die Koordinierung und Durchführung des Themas verantwortlich ist.

Für die Durchführung eines Projektes wird folgender Plan vorgesehen:

- *Der Projektleiter arbeitet ein Durchführungskonzept aus (Inhalt, Form, Verzeichnis der benötigten Unterlagen, Terminplan) und sendet es den teilnehmenden Ländern zu.*
- *Stellungnahme der Teilnehmer zum Konzept (schriftlich oder bei einer Sitzung). Einarbeitung der Stellungnahmen seitens des Projektleiters. Nach eventuell notwendiger Abstimmung der Stellungnahmen arbeitet der Projektleiter ein endgültiges Konzept aus und versendet es an die teilnehmenden Länder.*
- *Der Projektleiter führt die erforderliche Bearbeitung durch, sendet die Entwürfe des Schlußberichtes den Teilnehmern zwecks Stellungnahme zu.*
- *Nach Prüfung dieses Entwurfes legen die Teilnehmer ihre Stellungnahmen sowie Vorschläge für etwaige Ergänzungen, Streichungen oder Änderungen dem Projektleiter vor.*
- *Der Projektleiter fertigt den endgültigen Sachbericht an und legt diesen den für die jeweilige sprachliche Fassung verantwortlichen Herausgebern vor (die deutsche Fassung der betreffenden Institution in der Bundesrepublik Deutschland oder in Österreich, die russische Fassung der zuständigen Institution in der Sowjetunion) und sorgt, mit der finanziellen Unterstützung des IHP-Komitees seines Landes, für die Herausgabe des Berichtes als eines Folgebandes der Donaumonographie.*

5

Die Arbeitssprachen sind deutsch und russisch. Im Schriftwechsel sowie bei Sitzungen können beide Arbeitssprachen verwendet werden. Die Ergebnisse werden in Deutsch und Russisch veröffentlicht.

6

Die Gesamtkoordination der Zusammenarbeit wird vom IHP-Komitee eines der teilnehmenden Länder durchgeführt (im folgenden Koordinator genannt). Dem Koordinator obliegen die formale Ausrichtung der Veröffentlichung der Ergebnisse sowie Hilfeleistung bei der Einberufung von Arbeitssitzungen. Die Gesamtkoordination wird einvernehmlich, den IHP-Phasen angepaßt, turnusmäßig gewechselt.

7

Bei Bedarf, in der Regel jährlich, sollen Arbeitssitzungen stattfinden. Das IHP-Nationalkomitee des Gastlandes lädt zur Sitzung unter Mitteilung des Sitzungsortes und der Sitzungszeit sowie der mit dem Koordinator abgestimmten vorläufigen Tagesordnung rechtzeitig ein.

Das Sitzungsprotokoll ist vom Gastland in Zusammenarbeit mit dem Koordinator vorzubereiten. Im Protokoll soll auch festgehalten werden, wo und ungefähr wann die nächste Sitzung stattfindet.

8

Reise- und Aufenthaltskosten der an den Sitzungen teilnehmenden Fachleute sind vom Entsenderstaat zu tragen. Die Kosten für die eigentliche Veranstaltung (Miete, *Dolmetschergebühren, Kosten für Schreib- und Vervielfältigungsarbeiten sowie für örtliche Transportmittel, usf.) sind vom nationalen IHP-Komitee des jeweiligen Gastlandes zu tragen.*

9

Die vorliegenden Grundsätze finden am Tag der Unterzeichnung durch die Vertreter der IHP-Nationalkomitees aller acht Donauländer für die dritte Phase des IHP Anwendung. Ihre Gültigkeit erstreckt sich, vorbehaltlich Regierungsbeschlüsse, zunächst auch auf die vierte Phase des IHP.

Diese Grundsätze wurden den acht IHP-Nationalkomitees zur offiziellen Stellungnahme und zum Vollzug zugeleitet. Während der Sitzung in Budapest wurde das deutsche IHP-Nationalkomitee gebeten, für die verbleibende Periode der 3. Phase des IHP, das heißt bis einschließlich 1989, die Koordinierung der Arbeit vorzunehmen. Die deutsche Koordinierung wurde auf allgemeinen Wunsch bis Ende 1992 fortgeführt. Seit 1993 erfolgt die Koordinierung durch das österreichische IHP-Nationalkomitee.

Auf der 1. Arbeitssitzung nahmen aber auch fachspezifische Aspekte einen breiten Raum ein. Die Initiative hierzu ging wiederum von Ungarn aus. Es wurde ein Themenkatalog mit zwölf Vorschlägen eingehend erörtert:

1. *Geschiebe- und Schwebstofführung der Donau und ihrer wichtigeren Zubringer, mit besonderer Rücksicht auf beobachtete und erwartete Änderungen infolge natürlicher Ursachen und anthropogener Eingriffe*

2. *Temperatur- und Eisverhältnisse der Donau und ihrer wichtigeren Zubringer, mit besonderer Rücksicht auf beobachtete und erwartete Änderungen infolge natürlicher Ursachen und anthropogener Eingriffe*

3. *Untersuchung der beobachteten und zu erwartenden Änderungen des Abflußregimes der Donau und ihrer wichtigeren Zubringer (hauptsächlich auf der Basis des Datenmaterials des ersten Bandes der fertiggestellten Monographie)*

4. *Erstellung wasserwirtschaftlicher Längsschnitte für die Donau und ihrer wichtigeren Zubringer für die Entwicklungsstufen 1990 (Gegenwart) und 2010 (Vorhersage)*

5. *Untersuchung der langfristigen Trends in den Niederschlags-Zeitreihen des Donau-Einzugsgebietes*

6. *Untersuchung des Retentionsverhaltens der Teileinzugsgebiete des Donauraumes auf der Basis von Abflußzeitreihen*

7. *Untersuchung der Gleichzeitigkeit von Hochwasserwellen entlang der Donau und ihrer wichtigeren Zubringer*

8. *Statistische Untersuchung der Niederwassergeschehen an der Donau und ihren wichtigeren Zubringern*

9. *Abschätzung des Anteils des unterirdischen Abflusses im Donau-Einzugsgebiet (als eine Ergänzung von Kapitel III der fertiggestellten Monographie)*

10. *Untersuchung der Stabilität der langjährigen mittleren Hochwasser- und Niederwasserabflüsse im Donau-Einzugsgebiet*

11. *Hydrographischer Atlas des Donau-Einzugsgebietes*

12. *Detaillierte hydrologische Wasserbilanz für das Donau-Einzugsgebiet (eine wiederholte, ausführlichere Version des Kapitels III der Monographie) unter Benützung von um 20 Jahre längeren Datenzeitreihen sowie der im Projekt Nr. 11. enthaltenen Informationen.*

Die Teilnehmer der 1. Arbeitssitzung einigten sich auf die Themen 1, 2, 5 und 7 und auf folgenden Bearbeitungsmodus:

Geschiebe- und Schwebstoffregime der Donau und ihrer wichtigeren Zubringer Projektleiter : Dr. L. Rákóczi, Ungarn	Temperatur- und Eisregime der Donau und ihrer wichtigeren Zubringer Projektleiterin : Dr. A. Stancikovà, Tschechoslowakei
Hochwasserkoinzidenz der Donau mit ihren wichtigeren Zubringern. Projektleiter: Prof. Dr. S. Prohaska, Jugoslawien	Langfristige Schwankungen des Niederschlags im Donaueinzugsgebiet Projektleiter : Dr. O. Behr, Österreich

Bei den nachfolgenden Arbeitssitzungen wurden im wesentlichen die Pläne zur Bearbeitung der Projekte, ihre jeweilige Durchführung bzw. die Berichte selbst besprochen.

Anfang 1992 konnte das erste Teilprojekt der zweiten Phase der Zusammenarbeit abgeschlossen und 1993 veröffentlicht werden. Rákóczi, L. (1993): Schwebstoff- und Geschieberegime der Donau. In: Die Donau und ihr Einzugsgebiet - Eine hydrologische Monographie. Folgeband I.

Die von Herrn Dr. Behr und der Frau Dr. Stancikovà geleiteten Projekte werden ebenfalls in Kürze abgeschlossen und die Ergebnisse veröffentlicht.

Nach Fertigstellung der genannten Projekte haben die IHP-Nationalkomitees der Donauländer weitere Vorhaben in Planung. Von den bei der ersten Sitzung in Budapest 1987 vorgelegten zwölf Projekten sind erst vier berücksichtigt worden. Als besonders vorrangig erscheint die Aktualisierung der Monographie. Für die einzelnen Kapitel der Monographie, die sich mit dem Wasserhaushalt befassen, kann nun auf einer 20jährigen (1971 - 1990), ergänzenden Periode aufgebaut werden. Wünschenswert wäre auch die Aufnahme einer Periode rückwirkend bis 1931. So könnte eine Beurteilung für die zwei Standard-Perioden der WMO, nämlich 1931 - 1960 und 1961 - 1990, vorgenommen werden.

Zu Beginn dieses Beitrages wurde die Bedeutung der UNESCO, unter der sich die Zusammenarbeit vollzogen hat, besonders hervorgehoben. Während meiner Tätigkeit als Koordinator in den Jahren 1987 bis 1992 habe ich versucht, die Weltorganisation für Meteorologie (WMO), eine Sonderorganisation der Vereinten Nationen, die u.a. für die operationelle Hydrologie zuständig ist, mit einzubeziehen. Die WMO hat ihre Bereitschaft hierzu ausgesprochen. In ihrem 4. Langzeitplan für die Hydrologie und Wasserwirtschaft, aufgestellt für die Jahre 1996 - 2005, ist die Zusammenarbeit mit Flußgebietskommissionen ausdrücklich vorgesehen.

Ein weiterer Aspekt, der mir bei meiner Koordinierungstätigkeit am Herzen lag, betrifft den regen Gedankenaustausch zwischen Donauländern und Rheinanliegerstaaten. Die Rheinanliegerstaaten haben ihre hydrologische Zusammenarbeit ganz ähnlich wie die Donauländer organisiert: Diese findet statt im Rahmen des IHP und OHP, ebenso wurde eine Inventarisierung in Form einer hydrologischen Monographie vorgenommen. Nach deren Fertigstellung wurde die Bearbeitung einzelner Themen, die für alle Anliegerstaaten von Interesse waren, aufgenommen.

In die Zeit der deutschen Koordinierung fiel der politische Umbruch, der für manche Länder zwar Freiheit, aber gleichzeitig auch sehr schwierige wirtschaftliche Verhältnisse zur Folge hatte. In einem Teil des Donauraumes wird gegenwärtig ein erbitterter, blutiger Krieg ausgetragen. Hierunter leidet natürlich auch die Zusammenarbeit der Hydrologen. Ich bin jedoch zuversichtlich, daß auch in Zukunft eine erfolgreiche Zusammenarbeit der nunmehr dreizehn Donauländer erfolgen wird.

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Internationale Zusammenarbeit im Donauraum auf dem Gebiet der Wasserwirtschaft[1)]

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Kurzfassung: Die Entwicklung der internationalen Zusammenarbeit auf dem Gebiet der Wasserwirtschaft im Donaugebiet im Verlauf der vergangenen zwei Jahre wird aufgezeigt. Besondere Schwerpunkte bilden das "Übereinkommen über die Zusammenarbeit zum Schutz und zur verträglichen Nutzung der Donau" sowie das "Umweltprogramm für das Donaueinzugsgebiet" der UNDP.

International Co-operation in the field of Water Management within the Danube River Basin

Abstract: The development of international co-operation in the field of water management within the Danube River Basis during the past two years is shown in this article. Focal tasks are the "Convention on Co-operation for the Protection and Sustainable Use of the Danube River" and the "Environmental Programme for the Danube River Basin" of the UNDP.

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1) Stand: 10.04.94

Einleitung

Die Notwendigkeit zur internationalen Zusammenarbeit im Donauraum auf dem Gebiet der Wasserwirtschaft ergibt sich aus der Bedeutung des Donaustroms für jeden Anrainerstaat und aus der Tatsache, daß die wasserwirtschaftlichen Zusammenhänge an den Staatsgrenzen nicht haltmachen.

Die in diesem Raum gestiegenen Anforderungen an die Nutzung des Wassers, die Belastungen der Gewässer, der Niedergang natürlicher Ressourcen erfordern ein international koordiniertes Handeln.

Mit dem erklärten Ziel, schrittweise zu einer Annäherung der Lebensbedingungen in West- und Osteuropa zu kommen, haben Umweltsanierung und die Wasserwirtschaft, insbesondere der Gewässerschutz, auch im Donauraum neue Dimensionen bekommen.

Im Rahmen der 16. Konferenz der Donaustaaten über hydrologische Vorhersagen und hydrologisch-wasserwirtschaftliche Grundlagen 1992 in Kelheim wurde bereits ein systematisierender Überblick über die internationale Zusammenarbeit der Donauländer auf dem Gebiet der Hydrologie und der Wasserwirtschaft gegeben. Dieser soll hier nicht wiederholt werden, sondern die Entwicklung der vergangenen zwei Jahre dargestellt werden. Insbesondere soll der Fortgang der Donauschutzkonvention und des Umweltprogramms der UNDP für den Donauraum aufgezeigt werden.

Nichtstaatliche Aktivitäten

Die **Internationale Arbeitsgemeinschaft Donauforschung** (IAD) hat im Oktober 1993 ihre 50. Sitzung der Landesvertreter abgehalten. In diesem Gremium wird nach wie vor wichtige Grundlagenarbeit für die Gewässer des Donauraums geleistet. Die wissenschaftliche Buchreihe "Ergebnisse der Donauforschung" wurde mit den Bänden über die "Ergebnisse der internationalen Donauexpedition 1988" und über die "Wasserbeschaffenheit der Donau von Passau bis zu ihrer Mündung" fortgesetzt. Weitere Veröffentlichungen über "Limnologischer Zustand und Güteverhältnisse der bayerischen Donau und ihrer großen Zubringer" sowie über "Zooplankton, Phytoplankton und Zoobenthos der Donau" sind in Vorbereitung.

Die **Cousteau-Foundation** hat ihr Projekt "Die Donau: Für wen und wofür?" mit einem Schlußbericht beendet. Die Ergebnisse sind auch als Videos und Broschüren veröffentlicht.

1993 wurde die **Arbeitsgemeinschaft der Wasserwerke im Donaueinzugsgebiet** gegründet. Diese will die Anstrengungen bei der Sanierung der Donau unterstützen mit dem Ziel, die Donau überall für eine sichere Trinkwasserversorgung nutzbar zu machen.

Im September 1993 war von der slowakischen Umweltgesellschaft eine internationale wissenschaftliche Konferenz **"Die Donau - gemeinsame Arterie Europas"** vorgesehen.

In Deggendorf (Bayern) hat im November 1993 eine **ökologische Donaukommission** getagt, die sich hauptsächlich mit Fragen im Zusammenhang mit anstehenden Ausbaumaßnahmen an der Donau befaßt hat.

Vom 19. - 21. April 1994 findet in Ulm ein Internationales **Kolloquium "Lebensraum Donau - Europäische Ökosysteme"** statt. Dabei werden neben den Auswirkungen stofflicher Belastungen und struktureller Veränderungen auch die Bedeutung von Ökosystemen sowie Perspektiven für die Donaulandschaft behandelt.

Getragen von den NGOs jeden Donaustaates hat sich unter Führung von Bulgarien und Rumänien ein **NGO-Donau-Forum** gegründet. Dieses will die Bewußtseinsbildung bei der Bevölkerung über Umweltbelange fördern und eine verstärkte Beteiligung der Öffentlichkeit bei den verschiedenen Aktionsprogrammen im Donauraum erreichen. Hierzu wurden zahlreiche Aufklärungstreffen veranstaltet und Empfehlungen erarbeitet, die insbesondere auch in den Arbeitsplan des UNDP-Programms einfließen sollen.

Internationale und multilaterale Aktivitäten

Im Rahmen der **Bukarester Deklaration** hat die Arbeitsgruppe "Gewässerbeschaffenheit" ihr Untersuchungsprogramm fortgesetzt. 1993 wurde auf freiwilliger Basis ein erster Ringversuch mit rund 50 Untersuchungslabors des Donauraums zum Vergleich von Analysenergebnissen durchgeführt. Die Arbeitsgruppe "Hochwasser" hat einen Katalog über die erforderlichen Datenstationen, Hochwasser-Meldestellen und über die Meldewege erarbeitet.

Das Augenmerk Europas richtet sich zunehmend auf den Donauraum: Vom 14. - 15. Oktober 1993 hat die **2. Interparlamentarische Konferenz** des Ausschusses für Umwelt, Raumordnung und Kommunalfragen im Europarat mit dem Thema "Der Donauraum" in Regensburg stattgefunden. Der Ausschuß verabschiedete eine Schlußerklärung für eine Europa-Charta des Donauraums

- ein Donaurat soll Initiativen auf dem Gebiet der Landesplanung sowie von Verkehrs- und Umweltfragen im Donauraum koordinieren. Sitz des Rates sowie des zugehörigen Sekretariats soll Rumänien sein.

- Grundlage hierfür sollen Beschlüsse der jeweiligen National- oder Regionalparlamente sein, die noch 1994 gefaßt werden sollen.

Über die weitere Umsetzung ist noch nichts bekannt geworden.

Ökologische Donaukonvention

Zur ökologischen Konvention für das Donaugebiet, die neben der Donau-Gewässerschutz-Konvention entstehen soll, ist unter der Federführung Ungarns ein zweiter Entwurf erarbeitet worden. Dieser wurde im Januar 1993 in Budapest eingehend erörtert. Leider konnte hierüber kein Einvernehmen erzielt werden. Die sehr kritische Diskussion hat ergeben, daß der Entwurf grundlegend überarbeitet werden muß. Man wollte nun versuchen, die Konvention in Anlehnung an die Alpenkonvention aufzubauen.

Der dritte Entwurf dieser Konvention vom Februar 1994 enthält nun Elemente der Alpenkonvention, insbesondere hinsichtlich der allgemeinen Verpflichtungen. Es sind aber auch Teile der Inhalte der Konventionen über die biologische Vielfalt und über die grenzüberschreitende Auswirkung von industriellen Störfällen sowie über Schutz und Nutzung grenzüberschreitender Wasserläufe und internationaler Seen eingearbeitet. Auch der Entwurf der Konvention über die Zusammenarbeit zum Schutz und zur verträglichen Nutzung der Donau hat Pate gestanden.

Durch Zusammenarbeit im Rahmen bilateraler oder regionaler Übereinkommen sollen die geeigneten Maßnahmen auf den Gebieten

Schutz der Biosphäre, Wasserwirtschaft, Luftreinhaltung, Bodenschutz, Energie, Verkehr, Fremdenverkehr und Erholung, Abfallbewirtschaftung, Bevölkerung und Kultur

getroffen werden. Dieser Entwurf soll im Laufe des Jahres 1994 nun diskutiert werden.

Umweltprogramm des UNDP für den Donauraum

Kurz zur Erinnerung: Im Februar 1992 waren Arbeitsprogramm und Strukturen des Programms festgelegt worden. Mithilfe von Arbeitsprogrammen, internationalen Beratern und einem Konsortium von Geldgebern sollen in der auf drei Jahre ausgelegten 1. Phase die Grundlagen für ein umfassendes Umweltprogramm (Phase 2) erarbeitet werden.

Diese Arbeiten sind weit fortgeschritten:

- die Nationalberichte sind abgeschlossen. Derzeit werden die harmonisierten Kurzfassungen erstellt;

- der Warn- und Alarmplan für Gewässerverunreinigungen bzw. Störfälle ist auf der Grundlage nationaler Warn- und Alarmpläne sowie nationaler Alarmzentren weitgehend entwickelt und soll in Kürze abschließend behandelt werden.

- Für die Bereiche Überwachung, Datenverarbeitung, Laborstandards sind die Strukturen ebenfalls festgelegt; sie sollen in spezialisierten Untergruppen weiter bearbeitet werden. Eine Koordinierungsgruppe soll die Tätigkeiten überwachen, Schulungen veranlassen, Überwachungsstrategien empfehlen und internationale Verbindungen herstellen.

Daneben wurden von internationalen Beraterfirmen umfassende Untersuchungen zu besonderen Themen im Donaugebiet durchgeführt:

- über wasserbezogene Gesundheitsaspekte im Donauraum, insbesondere für die Trinkwasserversorgung,

- eine integrierte Umweltstudie über Nährstoffbelastungen, deren 2. Phase mit der Erarbeitung von Zielen und Kostenschätzungen in Kürze abgeschlossen werden soll.

- Im September dieses Jahres soll in Bled ein Workshop über "GIS und Umweltmanagement für das Donaugebiet" abgehalten werden.

- Auch soll ein Kataster der biologischen und ökologischen Ressourcen angelegt werden.

Mit internationaler Unterstützung wurde daneben eine Reihe von Pre-Investment-Studien für zahlreiche Nebenflüsse der Donau erstellt, z.B. für Drau, Morava oder Arges. Sie sollen dazu dienen, die notwendigen Maßnahmen samt ihrer Priorität festzulegen und deren Auswirkungen sowie Umsetzungsmöglichkeiten in der 2. Phase aufzuzeigen.

Zur Konfliktlösung müssen Strategien entwickelt werden. Diese haben für grenzüberschreitende Flüsse eine besondere Dimension, weil hier der Schutz der Gewässer und des Lebensraumes in internationalem Zusammenhang gesehen werden muß. Daher ist derzeit ein Strategischer Aktionsplan (SAP) für die Umsetzung des Programms in Bearbeitung. Je ein Vertreter für drei Ländergruppierungen sowie Mitglieder internationaler Finanzierungsinstitute haben in sehr dichten Arbeitssitzungen ein Instrument entworfen, daß dazu dienen soll, prioritäre Aktionen und Investitionen für den Donauraum herauszufiltern sowie deren Umsetzung zu fördern.

Der SAP soll teilweise als Instrument zur Erfüllung der Anforderungen der Donauschutzkonvention dienen und soll auch möglichst die strategischen Ziele im Zusammenhang mit der Ökologiekonvention erfassen. Im Juli soll das Endergebnis der Arbeitsgruppe im Rahmen der Task-Force erörtert werden, im September/Oktober soll die Endfassung festgelegt und eine Deklaration für die Umweltminister der Donaustaaten hierzu für Oktober/November vorbereitet werden.

Vorher wird noch im Mai die 4. Sitzung der Task-Force in Wien stattfinden. Auf der 3. Sitzung im Oktober 1993 hatte sich gezeigt, daß die Mitarbeit der NGOs am Umweltprogramm sich nicht einfach gestalten wird. Die "NGO-Gruppe aus den Donauländern" schlägt vor, eine Verbindungsperson als Mittler zu benennen. Die Task Force bietet an, daß zwei Repräsentanten der NGOs jeweils zu den Treffen eingeladen werden. Bei der Vielzahl der NGOs im Donauraum, bei deren vielfältigen Ansichten und Zielen, wird es schwierig werden, hier zu einer konstruktiven Mitarbeit zu finden.

Übereinkommen über die Zusammenarbeit zum Schutz und zur verträglichen Nutzung der Donau

Globale Probleme wie die Verschmutzung der großen Ströme erfordern national und international koordiniertes wirksames Handeln. Die Barrieren für eine länderübergreifende Zusammenarbeit sind auch im Donauraum gefallen.

Die Arbeitssitzungen zur Erarbeitung der - in Kurzform - Donauschutzkonvention sind erfolgreich abgeschlossen. Im 2. Sachverständigengespräch im März 1993 in Bratislava konnten zwar Fortschritte erzielt werden, aber noch keine Übereinstimmung. Erst nach einer Aussprache der Umweltminister der Donaustaaten am Rande der IFAT im Mai 1993 in München wurde in der 3. Sitzung im September 1993 in Bukarest über die fachlichen und organisatorischen Fragen weitgehend Einvernehmen erzielt. Einige mehr politisch zu entscheidende Fragen wurden in einer Sitzung Ende November/Anfang Dezember 1993 in Sofia geklärt. Ein weiteres Arbeitsgespräch im März dieses Jahres in Prag hat alle noch nötigen Voraussetzungen für die Unterzeichnung der Konvention geschaffen. Diese soll nun am 29. Juni in Sofia stattfinden.

Der Entwurf der Donauschutzkonvention baut auf dem ECE-Übereinkommen vom 17.03.1992 zum Schutz und zur Nutzung grenzüberschreitender Wasserläufe und internationaler Seen auf. Die Konvention soll für das gesamte Einzugsgebiet der Donau gelten. Ihre Ziele und Grundsätze sind vor allem

- eine verträgliche und gerechte Wasserwirtschaft
- Erhaltung, Verbesserung und rationelle Nutzung der Oberflächengewässer und des Grundwassers,
- Abwehr von Gefahren aus Störfällen mit wassergefährdenden Stoffen, aus Hochwasser und Eis,
- die gegenwärtigen Verhältnisse im Bereich der wasserbezogenen Umwelt nach Möglichkeit verbessern, nachteilige Einwirkungen verringern, schädliche Veränderungen vermeiden,
- Verbessern der aquatischen und litoralen ökologischen Bedingungen.

Das Verursacherprinzip und das Vorsorgeprinzip, der Stand der Technik und die beste Umweltpraxis sind Grundlagen des Handelns. Für die Umsetzung ist es notwendig, Gewässerbeschaffenheitsziele zu entwickeln, Emissionsbegrenzungen zu vereinbaren, Überwachungssysteme einzurichten, Untersuchungs- und Aktionsprogramme aufzustellen.

Neben der Gewässerqualität werden aber auch Wasserbenutzungsanlagen, Wasserbauarbeiten, Hochwasserschutzmaßnahmen, Fragen der Hydrologie und der Erosion vom sachlichen Geltungsbereich der Konvention erfaßt.

Zur Umsetzung des Übereinkommens wird eine Internationale Kommission eingerichtet, in der die Vertragsparteien zusammenarbeiten. Die Kommission wird von einem Sekretariat mit Sitz in Wien unterstützt. Neben einer Ständigen Arbeitsgruppe werden für einzelne Arbeitsgebiete und für spezielle Fragen Sachverständigengruppen eingesetzt.

Es besteht die Erwartung, daß die Aktivitäten der Donauschutzkommission nach der Unterzeichnung der Konvention - auf zunächst interimistischer Basis - rasch anlaufen werden. Es sind auch rechtzeitig die Weichen zu stellen, daß die im Rahmen des Umweltprogramms der UNDP eingeleiteten Maßnahmen - soweit sie in den sachlichen Geltungsbereich der Donauschutzkonvention fallen - vom Sekretariat der Donauschutzkonvention übernommen und - mit weiter gewährter internationaler finanzieller Unterstützung - zielgerichtet fortgeführt werden können.

Ausblick

Im Rahmen dieses Beitrags die Aktivitäten des IHP im Donauraum darzustellen, hieße Donauwasser nach Budapest tragen. Zudem wird von berufenerer Seite ausführlich darauf eingegangen. Dieser Darstellung ist zu entnehmen, daß die gute und erfolgreiche Zusammenarbeit in diesem Bereich nach wie vor besteht.

Auch nach Unterzeichnung und Inkrafttreten der Donaukonventionen, insbesondere der Donauschutzkonvention, kann auf die wissenschaftliche Grundlagenarbeit im Rahmen des IHP nicht verzichtet werden. Es muß daher rasch ein Weg gefunden werden, die fachliche Kompetenz dieser Zusammenarbeit in die Kommissionsarbeit einzubringen und im Vollzug der Konventionen umzusetzen.

XVII. KONFERENZ DER DONAULÄNDER
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STATEMENT AT OPENING BY WMO REPRESENTATIVE

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Abstract

This paper briefly reviews water issues in the United Nations in the wake of UNCED. It discusses WMO's activities in hydrology and how these relate to the Danube basin. It looks to the future and the contribution of the Danube to the improvement of global knowledge of the hydrological cycle.

The Danube is the most international river of the world. It has 10 riparian countries and 18 catchment-sharing countries, of which five have minor shares in the basin. It constitutes a basic and important lifeline for socio-economic development of the countries concerned. The paramount importance of, and the need for international cooperation in various fields of activity was already recognized many years ago.This XVIIth CONFERENCE OF THE DANUBE COUNTRIES ON HYDROLOGICAL FORECASTING AND HYDROLOGICAL BASES OF WATER MANAGEMENT,with already a history of more than three decades and which will address a number of current world-wide and basin-related water problems,is a good example of such co-operation.

Until recently, water was taken for granted, and its availability appeared infinite. But a rapidly expanding world population (especially in less developed countries) and growing economic activity have led to demand outstripping supply in many regions. In addition, contamination of both surface and ground water has led to a universal recognition that the resource is both finite and fragile.

Most individuals and governments are now aware of the problems of the deteriorating global environment and of the possible consequences of climate change. However, not all are aware of the increasing pressures being exerted on water resources, both as regards scarcity and quality - water being the foremost casualty of human activities and of likely climate changes. These pressures can be intense within national borders and even more intense between nations sharing the same river basin. At the same time virtually every socio-economic development is demanding more and more water. A recent report (1994) of the Committee of Natural Resources of the UN Economic and Social Council, indicates that some 80 countries are already suffering serious water shortages and, in many cases, scarcity has become the limiting factor in social and economic development. Contamination of surface and ground waters from industrial effluents, agricultural pollution and human wastes is reaching critical dimensions in many parts of the world. Added to the above may be the threat to life and property from floods, droughts and other forms of water-related disasters. While uncertainty remains about the future climate at global, regional and smaller scales, there is no uncertainty that water resources will be directly affected by any such change and that these effects will in turn have impact on other sectors, e.g. agriculture and energy. The above trends may endanger the integrity of natural ecosystems, threaten human health and quality of life and constrain socio-economic development.

Water issues, affecting both developing and developed countries, should not be compartmentalized nor should they be viewed in isolation from other environmental and developmental issues. The need for the holistic approach to freshwater management, within the framework of overall resource management, is now well appreciated. Similarly, water issues should be tackled in conjunction with land use issues; and water systems on and beneath the land surface are linked to the atmospheric system above and to the seas which eventually receive the flow. Water quality is intimately related to water quantity and these two prime aspects of the water resource base must be approached together.

Integrated management within international river basins poses particularly difficult challenges, as does the cooperation in these basins. About one quarter of the world's countries are situated entirely in international river basins and, in more than half, the areas belonging to such basins exceed 50% of the total country area. The problems concerning international basins have certain similarities from one part of the globe to another. These problems are mainly legal and political, but their repercussions also have an impact on many technological developments including those in hydrology. Indeed, cooperation plans for the development of international basins frequently hinge much more on hydrological data than those of national basins. Questions related to the interest and responsibility of riparian owners can objectively be analyzed only if the streamflow regime and quality of water from the different parts of the basin are known sufficiently well.

The Dublin International Conference on Water and the Environment (ICWE) (1992) made the case for effective integrated planning and development of transboundary river and lake basins. Governments were recommended to take actions, among others, regarding the promotion of cooperation of riparian countries within transboundary basins and the establishment of appropriate legal, institutional and operational mechanisms.Agenda 21 of the UN Conference on Environment and Development (UNCED) (Rio de Janeiro, 1992) reflected these views and stressed the desirability of taking into account the interest of all riparian states concerned with transboundary water resources. This cannot be achieved without an adequate and regular hydrological assessment of the shared river basin or groundwater province concerned.

The riparian and catchment-sharing countries of the Danube have long recognized the need for reliable and timely data on water quantity and quality, and their use for water resources assessment and for planning, design, management and forecasting purposes. This is clearly evidenced by some 14,000 rainfall stations, 500 evaporation, 7,500 discharge and 4,200 water quality stations which according to WMO statistics (INFO-HYDRO, WMO-No. 683) were being operated in 1993 by national hydrological, hydrometeorological and meteorological services of Danube basin-sharing countries. As such, it can be considered as one of most dense networks in the world. Nevertheless, it is also a fact that the national hydrological agencies in a number of these countries are currently facing a contradictory situation: on the one hand there are increasing demands on their services while, on the other, the budgetary allocations to support these activities are being subjected to important reductions. All this has brought to the fore the importance of international co-operation regarding water matters.

In the light of international co-operation WMO has been entrusted by its some 175 Members to facilitate world-wide co--operation in the fields of meteorology and operational hydrology. The Organization's involvement in the latter field is through its Hydrology and Water Resources Programme. This Programme is geared to assist Hydrological and Hydrometeorological Services of Members to meet increasing demands for the assessment and development of water resources,on the one hand, and for the protection from the threat of natural disasters, on the other, all in support of sustainable development of water resources and of environmental management. Thus, this programme has supported national services as regards their responsibilities for the collection, processing and analysis of data for water resources assessment, for water quality protection and for flood forecasting. The overall objective of this Programme for the decade 1992-2001 is:

"To ensure the assessment and forecasting of the quantity and quality of water resources, in order to meet the needs of all sectors of society, to enable mitigation of water-related hazards, and to maintain or enhance the condition of the global environment".

The HWRP also promotes co-operation between countries at regional and sub-regional levels, especially when there are shared basins. In the specific case of the Danube countries, the following might be mentioned:

a) In 1962 an exchange of letters between the Danube Commission and WMO formalized a working agreement between the two organizations. An important milestone in this cooperation was the publication of recommendations regarding: (i) the coordination of the hydrometeorological services on the Danube; and (ii) the actions to be taken to determine river-flow data. One of these recommendations consisted of codes used for transmission of hydrological observations and forecasts within the Danube basin countries, some using the Global Telecommunication System (GTS) of WMO's World Weather Watch (WWW). These codes formed the basis of two standard international code forms: one for basic hydrological data transmission and processing (HYDRA) and one for hydrological forecasting (HYFOR). The codes were adopted for broader use by WMO in 1974, and adopted for their introduction in the Danube basin as of January 1977.

b) Since its inception in 1981, the Danube countries have had an important participation, in WMO's Hydrological Operational Multipurpose System (HOMS), established for the institutionalized transfer of operational hydrological technology. Over the years all the countries established their HOMS National Reference Centres (HNRCs) and thus became part of the HOMS system. Although basin countries are net suppliers of technology, having contributed altogether some 70 operational hydrological technologies in form of components to HOMS, they are also users of the advantages offered through HOMS. Until May 1994 385 requests had been received for these components, and basin countries have made 190 requests for technology generated elsewhere. With the recent changes the newly independent states of the region have expressed their interest in HOMS and some of them have already established their HNRC.

c) A number of Danube countries participated, during the late eighties, in the regional UNDP/WMO project on the development of HOMS components in the field of application of hydrology to energy production. The project's aim was to identify, select, standardize, test and develop technologies operationally used in the European region. As a result some 30 components were prepared, which were transferred internally and externally. Training workshops were organized, the number of experts having participated exceeding one hundred. An excellent co-operative relationship was established between the agencies of the participating countries. Although the project was originally aimed at hydrological technologies for energy production, an important part of which involves forecasting future river flows, the results can be applied in a broader range. There are proposals to develop a follow-up project on regional transfer for prevention of natural disasters, under the aegis of the International Decade for

Natural Disaster Reduction (IDNDR), but as yet no source of funding has been identified.

d) Over the years, experts in the field of hydrology from Danube countries have had an important participation in activities of the WMO Commission for Hydrology and the Regional Association VI (Europe). They have been involved either as members or rapporteurs of subject-oriented working groups of CHy and/or of the RA VI working group on hydrology (WGH). One recent product has been a technical report on "Hydrological co-operation in selected international river basins within Europe", prepared by the RA VI WGH and published in 1992.

As regards future developments, WMO and UNESCO, with the support of the World Bank, are promoting a major long-term initiative to improve knowledge of the hydrological cycle through a World Hydrological Cycle Observing System (WHYCOS). WHYCOS is in direct response to the need expressed by the ICWE and in Chapter 18 of Agenda 21 for an improved knowledge base in terms of quantity and quality. WHYCOS would consist initially of about 1,000 stations world-wide sited on the major rivers. Each station would monitor about 15 variables such as flow, load, water chemistry and on-bank meteorological variables. Many of these stations already exist, mostly in the developed world. The data collected would be transmitted via geo-stationary satellites, such as METEOSAT, to national, regional and global centres, employing the WMO WWW system where applicable. In turn, WHYCOS would contribute data to WWW and to the Global Climate Observing System (GCOS), as well as to the Global Terrestrial Observing System (GTOS). The concept is currently being developed for Africa, Latin America and the Caribbean, for countries bordering the Mediterranean Sea and for the Aral Sea basin. It is expected that the hydrological networks of the Danube countries will also form part os WHYCOS:

From the topics it can be seen that the Conference will address a number of world-wide current water problems which have been mentioned above, as well as specific problems connected with transboundary rivers and the international character of the Danube basin. It is expected that the exchange of information on technical matters will be of benefit not only for the basin countries, but also for the global hydrological community. It might also perhaps lead to further joint activities in the future, thus continuing the many years of fruitful co-operation for the benefit of the countries of this basin. In this context, WMO will be pleased to continue and increase its association with the Danube countries in the undertaking of new joint ventures.

THEMA/THEME

1

Methoden zur Gewinnung, Bearbeitung und Bereitstellung hydrologischer Daten, einschließlich der Fragen der Hydrometrie, Standardisierung und Regionalisierung

Methods of collecting, processing and disseminating hydrological data including the aspects of hydrometry, standardization and regionalization

Gutachter/Convener

Professor Dr. R.F. Schmidtke

XVII. KONFERENZ DER DONAULÄNDER
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Einführungsvortrag

METHODEN ZUR GEWINNUNG, BEARBEITUNG UND BEREITSTELLUNG HYDROLOGISCHER DATEN EINSCHLIEßLICH FRAGEN DER HYDROMETRIE, STANDARDISIERUNG UND REGIONALISIERUNG

R.F. Schmidtke

Kurzfassung: Die Einführung in den Themenbereich 1 stellt die 15 hierzu angenommenen Konferenzbeiträge kurz vor. Dabei wird eine Gliederung nach Meßnetzplanung, Meß- und Erfassungsmethoden, Regionalisierung hydrologischer Daten und Informationssysteme vorgenommen. Außerdem liefert sie Hinweise für die sich verstärkende Notwendigkeit zur Standardisierung und Qualitätssicherung sowie zur Ermittlung des wirtschaftlichen Werts gewässerkundlicher Daten und Dienste.

Methods of Collecting, Processing and Dissiminating Hydrological Data Including the Aspects of Hydrometry, Standardization and Regionalization

Abstract: The paper gives an introduction into conference theme 1. It disposes the 15 contributions accepted for oral presentation according to the topics: design of hydrological networks, measurement and survey methods, regionalization of hydrological data and information systems. In addition, it puts emphasis on the increasing needs for standardization and quality-control as well as for evaluating the economic benefits of meteorological and hydrological information and services.

Einleitung

Die gewässerkundlichen Dienste vieler Länder stehen heute vor einer besonderen Herausforderung: Auf der einen Seite steigen die Anforderungen an Qualität und Quantität hydrologischer Daten, was durch den generell zunehmenden Informationsbedarf, vor allem aber durch die sich verengenden Möglichkeiten zum Interessenausgleich zwischen den verschiedenen mit der Ressource Wasser verknüpften Nutzungs- und Schutzfunktionen bedingt ist. Auf der anderen Seite zeigen sich immer deutlicher die Leistungsgrenzen der staatlichen Verwaltungen, was dazu führt, daß an die finanzielle und personelle Ausstattung strengste Maßstäbe angelegt werden müssen.

Zudem wird heute die bisher vorherrschende Sichtweise, es handele sich bei diesem Bereich um öffentliche Informationsinfrastruktur, zur Diskussion gestellt und zwar im Hinblick auf die Frage, inwieweit eine Wahrnehmung solcher Aufgaben dem Marktgeschehen anvertraut werden kann. Dem hier vorzustellenden Themenbereich kommt daher eine wesentlich größere Bedeutung zu als der alleinigen Darstellung des naturwissenschaftlich-technischen Erkenntnisfortschritts.

Von den 15 angenommenen Konferenzbeiträgen beziehen sich auf Fragen der

- Meßnetzplanung	1 Referat
- Meß- und Erfassungsmethoden	3 Referate
- Regionalisierung hydrologischer Daten	8 Referate
- Informationssysteme	3 Referate

Im folgenden sollen dazu einige knappe Bemerkungen gemacht und zusätzlich auf die nicht behandelten, aber im Sinne der vorangestellten Rahmenbedingungen für wichtig erachteten Aspekte

- Standardisierung und Qualitätssicherung sowie
- wirtschaftlicher Wert gewässerkundlicher Daten

kurz eingegangen werden.

Meßnetzplanung

Hydrologische Meßnetze haben sich meistens schrittweise über viele Jahrzehnte entwickelt. Ihr Auf- und Ausbau erfolgte nach dem jeweiligen empirischen Erkenntnisstand. Erst in jüngerer Zeit kommen analytische Planungsmethoden zum Einsatz, etwa bei der Revision bestehender Netze, der konzeptionellen Gestaltung neuer Meßaufgaben (z.B. der Grundwasserbeschaffenheit und der Deposition) oder bei der Entwicklung integrierter Meßnetze. Einen guten Überblick über das vorhandene Wissen und laufende

Aktivitäten zur Methodenverbesserung liefern die Berichte zum Internationalen WMO-Workshop über die Planung von Beobachtungs netzen, der im November 1991 in Koblenz/Deutschland veranstaltet worden ist.

Im Prinzip geht es bei der Lösung dieser Aufgabenstellungen stets um Fragen der Meßnetzoptimierung. Der hier vorzustellende Beitrag von PESTI zeigt dazu ein Beispiel, wobei er die Informationszuverlässigkeit bei variierter Meßnetzdichte über ein Mehrkriterienverfahren bewertet und auf diese Weise das Auswahlproblem löst.

Meß- und Erfassungsmethoden

Zu diesem Teilbereich liegen 3 Berichte vor, die sich mit sehr unterschiedlichen Problemstellungen auseinandersetzen. Der Beitrag von WEIGL und DIETZER widmet sich der quantitativen Niederschlagsbestimmung mit Radar. Er zeigt den Ausbaustand des Radarverbundnetzes des Deutschen Wetterdienstes auf und erörtert die Qualitätsfragen der Radarniederschlagsdaten. ADLER stellt ein neuartiges Gerät zur Durchfluß- und Strömungsmessung an größeren Flüssen vor, das mit der Ultraschall-Doppler-Technik arbeitet. Es hat sich bei seinem Einsatz während des Dezember-Hochwassers an Rhein und Mosel bestens bewährt, wobei erstmals die Abflußkurven im Bereich sehr seltener Ereignisse mit Meßdaten belegt werden konnten.

Angesichts der Hochwasserkatastrophen der letzten Jahre und der damit wieder stärker ins gesellschaftliche Bewußtsein gerückten Hochwassergefahren besitzt der Beitrag von BRILLY über die kartographische Erfassung von Überschwemmungsgebieten speziell in Flußoberläufen auch einen sehr aktuellen Bezug.

Regionalisierung

Mit 8 Beiträgen bildet der Fragenkomplex "Regionalisierung" den Schwerpunkt des Konferenzthemas 1, womit seine Bedeutung eindrucksvoll unterstrichen wird. NOBILIS und SKODA präsentieren das Konzept der einheitlichen Starkniederschlagsauswertung und -regionalisierung für Österreich. Für eine Regionalisierung von Abflußwerten im Niedrig-, Mittel- und Hochwasserbereich gibt SCHILLER grundlegende Erläuterungen und stellt Ergebnisse für den bayerischen Donauraum vor. Mit Hochwasserinformationen für das Gebiet Serbiens befassen sich PETKOVIC, der eine Methodik für unbeobachtete Einzugsgebiete vorstellt, und PROHASKA, der eine regionale Analyse maximaler Jahresabflüsse behandelt.

Für den Niedrigwasserbereich faßt die Untersuchung von DEMUTH eine umfangreiche Literaturstudie über die Anwendung und den

Einsatz statistischer Verfahren zur Übertragung einschlägiger Kenngrößen zusammen. Konkrete regionale Niedrigwasseranalysen stellen TRNINIC für das Flußgebiet der Drava in Kroatien sowie IGNJATOVIC und NIKIC für das Gebiet Serbiens vor.

Die Präsentation von KOWALSKI und Mitautoren über die von ihnen entwickelte Methode zur Bewertung von Hochwasserscheiteldurchflüssen ist bewußt als Abschluß dieses Themenkomplexes gewählt, da hierbei in richtungsweisender Form ein geographisches und ein hydrologisches Informationssystem zur Anwendung gelangen und damit ein logischer Übergang zum nächsten Teilbereich "Informationssysteme" geschaffen werden kann.

Informationssysteme

Die Nutzungsmöglichkeiten hydrologischer Informationen hängen ganz wesentlich von ihrer Verfügbarkeit und dem effizienten Zugriff ab. Diese Erkenntnis hat sich heute allgemein durchgesetzt, weshalb dem Aufbau ädequater Informationssysteme hohe Priorität zugemessen wird. Bei der Komplexität der Materie sind die dabei zu überwindenden Schwierigkeiten nicht zu übersehen. Ein internationaler Gedanken- und Erfahrungsaustausch auf breiter Basis wäre dazu sicherlich von großem Nutzen. Insofern sind die 3 zu diesem Teilbereich vorzustellenden Beiträge als Plattform für weitergehende Diskussionen sehr zu begrüßen.

GERGOV und SLAVOV berichten über das nationale bulgarische Informationssystem Sedimentdaten, das mit einer Reihe zusätzlicher hydrologischer Daten ausgestattet ist. Die On-line- bzw. Off-line-Datenverarbeitung im Hydrometeorologischen Dienst Serbiens stellen PALMAR B.P. bzw. PALMAR B.I. und jeweilige Mitautoren vor.

Standardisierung und Qualitätssicherung

Als allgemeine Anregung und ein etwaiges Thema für die nächste Donauländerkonferenz sei auf die sich immer stärker abzeichnende Notwendigkeit zur Standardisierung und Qualitätssicherung hingewiesen.

Die Wasserwirtschaft selbst und viele mit wasserwirtschaftlichen Fragestellen berührten Institutionen stützen sich auf hydrologische Meßergebnisse, die mit verschiedenartigen Meß- und Analyse verfahren gewonnen werden. Um einheitliche Anforderungen an die Meßergebnisse bzw. den Meßaufwand sowie eine gute Vergleichbarkeit der Untersuchungsergebnisse zu gewährleisten, bedarf es einer entsprechenden Qualitätssicherung.

Diese ist um so erforderlicher, je weitverzweigter die datenerhebenden Institutionen getrennt sind, deren Informationen gemeinsam ausgewertet werden sollen. Das trifft ganz besonders für große Flußgebiete zu, für die staatenübergreifend hydrologische Fragestellungen zu bearbeiten sind, damit auch konkret für den Donauraum.

Qualitätssicherung ist mithin ein Sammelbegriff für alle Maßnahmen, die Aussagen über Qualität und Fehler von Meß- und Untersuchungsbefunden ermöglichen. Dazu gehören alle Schritte des Vergleiches von Meßgeräten und -methoden, die Durchführung von Messungen bis hin zur Auswertung der Meßergebnisse und ihre Dokumentation.

Zweifellos kann die Durchführung qualitätssichernder Maßnahmen einen gewissen Mehraufwand bedingen, der bei gleichzeitig geforderten Einsparungen an Personal und Finanzmitteln problematisch anzusehen ist. Wenn aber hydrologische Daten zunehmend einer Überprüfung durch Dritte standhalten und großräumige Bilanzierungen und Vergleiche zulassen sollen, dann ist die darauf abgestellte Qualitätssicherung eine unverzichtbare Voraussetzung.

Die standardisierte, zumindest aber die harmonisierte Datengewinnung ist dabei Bestandteil dieser Überlegungen. Eine wertvolle Hilfestellung kann die verstärkte Beachtung des "Guide of Hydrological Practices" und der "Technical Regulations, Volume III - Hydrology" der WMO leisten.

Wirtschaftlicher Wert gewässerkundlicher Daten und Dienste

Abschließend sei noch auf einen zweiten Punkt hingewiesen: Der Wert hydrologischer Daten muß stärker in das Bewußtsein derjenigen gerückt werden, die über die finanzielle und personelle Ausstattung der gewässerkundlichen Dienste entscheiden. Auch wenn hierzu in dieser Konferenz kein Beitrag enthalten ist, so zeigen doch laufende Aktivitäten, wie beispielsweise eine weitere unmittelbar bevorstehende Tagung der WMO über den ökonomischen Nutzen der Meteorologischen und Hydrologischen Dienste, daß dieses Thema hohe Aktualität besitzt. Es gilt, diese Bestrebungen nach Kräften zu unterstützen.

Anschrift des Verfassers

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XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
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Integrated observation network design for hydrogeologic site characterization

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Abstract: A methodology to design measurement networks, in view of hydrogeologic site characterization, is presented. Observation networks combining different types of measurement techniques are considered. The "most appropriate" measurement network is selected based on two often conflicting objectives: (1) minimizing the uncertainty in characterizing the spatial distribution of parameters, and (2) minimizing the observation cost. Uncertainty is characterized by a combination of average and maximum kriging variance. The approach combines two common techniques, geostatistics and multi-criteria decision making to determine the "best" measurement network. The methodology is illustrated for a study area located near Ashland, Nebraska, USA.

Integrierte Messungsnetz Verfahren um hydrogeologische Gebiete zu Charakterizieren

Abstrakte: Ein Verfahren zum Konstruieren eines Messungsnetzes für die Charakterisierung eines hydrogeologischen Gebietes ist vorgestellt. Die Beobachtungsnetze, die verschiedene Typen von Messungstechniken kombinieren, sind in Betracht gezogen. Das "beste geignete" Messungsnetz kann an der Basis von zwei in Konflikt stehende Zielen gewählt werden: (1) Minimizierung der Unsicherheit der Charakterisierung von der räumlichen Parametern Verteilung, und (2) Minimizierung der Beobachtungskosten. Die Unsicherheit ist charakterisiert durch kombinieren des Mittelwertes und die maximum Kriging-Abweichung. Die Annäherung kombiniert zwei gewöhnlichen Techniken, Geostatistischen und Multi-Kriterium Entscheidungs Methoden zum bestimmen das "beste" Messungsnetz. Das Verfahren ist für ein Untersuchungsgebiet in der Nähe Ashland (Nebraska, U.S.A) illustriert.

1. Introduction

The purpose of this paper is to present a method for observation network design which simultaneously minimizes parameter uncertainty and observation cost, and can be used for characterizing a site with respect to spatially dependent variables such as hydrologic or hydrogeologic parameters.

A common objective of measurement network design is to minimize the number of measurements required to achieve an acceptably low estimation error (Barnes, 1989). Observation network design for the purpose of quantifying hydrogeologic and solute transport parameters are described by, among others, McBratney et al (1981), Bogardi et al (1985), Knopman and Voss (1989), and Cleveland and Yeh (1990). Measurement network design for surface and ground water quality monitoring purposes has been studied by Carrera et al (1984), Pintér and Somlyódy (1986), Meyer and Brill (1988), Loaiciga (1989), and McKinney and Loucks (1992), and for remediation by Ahlfield et al (1988) and Woldt (1990). An observation network may include several types of measurement techniques. In Pesti et al (1994), for instance, hydrogeologic data are obtained directly from wells (eg. layer thicknesses determined from well logs, or hydraulic conductivities estimated from well capacity tests), and indirectly from geophysical measurements (eg. layer thicknesses and transmissivities derived from the interpretations of resistivity measurements). Data obtained by different measurement techniques may differ in their accuracy and in the support volume which they represent.

In this paper a common case, where observation data are insufficient to depict the spatial distribution of hydrologic/hydrogeologic variables, is considered. Two common techniques, geostatistics and multi-criteria decision making (MCDM) are combined to determine the "best" measurement network. Geostatistics are used to determine spatial distribution of estimation variances for the hydrologic/hydrogeologic parameters obtained from different sources. MCDM is utilized to evaluate observation network alternatives based on their cost and the estimation variances associated with them.

2. Problem description

Consider an area with a sparse observation network where the available data are insufficient to properly characterize the site regarding a set of K spatially dependent variables $\mathbf{z}=\{z_k, k=1,\ldots,K\}$, and thus additional measurements are necessary. The "best" measurement network is expected to have the least cost and provide the most accurate information on the spatial variation of $\mathbf{z}$ among all candidate networks.

Thus, one objective is to maximize the estimation accuracy in characterizing the spatial distribution of $\mathbf{z}$. The estimation accuracy can be expressed as the variance of estimation error such as average and maximum kriging variance (Journel and Huijbregts, 1978). The two variance criteria and their individual characteristics with respect to sample design for geologic site characterization are discussed in detail by Barnes (1989). Sampling design based on any one of these criteria may lead to a different "optimum" network. Unlike the average, maximum kriging variance, as a point measure, does not reflect the overall level of uncertainty over a region. Thus, minimizing only the maximum kriging variance could lump observations in areas of high uncertainty at the expense of the characterization of the remainder of the region. On the other hand, minimizing the average kriging variance alone, the uncertainty of some unsampled but "valuable" areas may remain relatively high. A better result can be expected using a proper combination of the two variance criteria.

Another objective is to minimize the observation effort characterized, here, by a single criterion, the observation cost. It generally increases with the density of measurement networks; thus simultaneous minimization of cost and estimation variance are often conflicting objectives.

3. Methodology

3.1. Variogram calculation using initial data

To detect spatial dependencies pertinent to $\mathbf{z}$, experimental variograms (Journel and Huijbregts, 1978) are calculated, and variogram models are fitted to them. The variograms and fitted variogram models determined from the initial data set are assumed to be representative of the actual spatial covariance functions for $\mathbf{z}$ over the entire area of interest.

If only limited or no existing observations are available, variograms can not be estimated; then one may claim that it is better to design a network assuming spatially independent yield and travel time. Such a spatial independence assumption may yield, in many cases, smaller estimation variances than would a spatially dependent assumption. This fact may result in underestimating the required network. Thus, for any network design model one must have some information on the overall areal variation of the parameter to be observed. Even if no measurement data exist, regional information, experience, or samples from part of the area may be available.

3.2. Estimation variances for the initial and expanded candidate networks

Techniques, such as cokriging (Journel and Huijbregts, 1978), kriging with uncertain or noisy data (de Marsily, 1984) and compound kriging (Delhomme, 1979; Woldt, 1990) are alternative techniques to characterize spatial variability where data are available from several sources. Here compound kriging, a method that accounts for the different accuracy and support for the differently measurement data is used. In fact, kriging itself is not performed, only the estimation variance is calculated which depends only on the variogram (spatial covariance function) and the geometry of the existing observation network (i.e., number and density of measured locations). Kriging variances are determined on a grid covering the entire study area, and then the average and maximum estimation variances are calculated. Assuming that the empirical variogram determined from the existing network is a good approximation of the actual spatial covariance functions for z, the average and maximum estimation variances are similarly calculated for each measurement network alternatives.

3.3. Observation network costs

The total cost C_T of a particular observation network combining measurements of m types with different number of observations for each type (n_i, $i=1,\ldots,m$) is defined as

$$C_T = \sum_{i=1}^{m} c_i n_i \tag{1}$$

where c_i is the unit cost associated with the measurement method of type i.

3.4. Selection of the "best" observation network

Finally the "best" observation network alternative is selected jointly considering the variance reduction for each element (hydrogeologic parameter) in z and the costs of the alternatives; that is a multi-criteria decision making (MCDM) problem. In the ideal situation, the cost would be zero and the variance reduction would approach 100%; obviously this is not feasible. Composite programming (CP) (Bogardi et al, 1984), one of the numerous distance based techniques is used here to evaluate each network alternative by measuring its "distance" from the ideal network. In the present case each network alternative is represented by its cost and the average and maximum kriging variances for z. The best alternative is selected based on these indicator variables called first level or basic indicators. The structure of the CP model is defined by a successive grouping of the indicator variables through several levels (Figure 1). This grouping process leads to a two-dimensional problem that aggregates the character of the basic indicators in two composite values; one for variance reduction and one for cost.

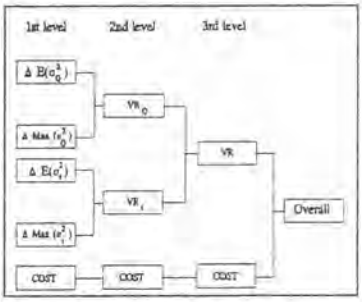

Figure 1: Structure of the CP problem; $\Delta E(\sigma^2)$, $\Delta Max(\sigma^2)$: reduction in the average and max. kriging variance; VR: composite variance reductions.

4. Application

The methodology is illustrated using real data from a rectangular study area of 108 km^2 located near Ashland (Nebraska, USA). The layout of the Ashland well field is shown in Figure 2. The general geologic section of the site can be characterized as a leaky aquifer with relatively thin (less than 1.5 m) top layer composed of soils, sandy silts, and clays, underlain by a saturated near surface clay unit over a sand and gravel aquifer. Depth to the water table is 2 to 3 meters, and the depth to the bedrock ranges from 17 to 29 meters.

The objective is to characterize the site regarding the most appropriate areas for water supply wells. An area is considered the "best", where the sustainable pumping rate and the degree of protection for the well are the possible maximum. The level of protection is measured by the travel time for a fixed wellhead protection zone radius. Yield and travel times are calculated in terms of directly measured and geophysically estimated hydrogeologic parameters. Details on the yield and travel time calculation for the leaky aquifer of Ashland are given by Pesti et al (1994). Data are available from well logs and specific capacity tests from 36 irrigation wells (direct data). These wells are considered as the existing observation network.

First, yields and travel times were calculated for each measured location. Next the spatial dependencies (variograms) were determined, and spherical models were fitted for both yield and travel time. Then, estimation variance maps were calculated by compound kriging using data from the existing network. Figure 3 shows the variance map for yield. The map shows two relatively large interconnected areas of high estimation variances located between the two main groups of wells. The existing observation network does not allow a reliable characterization of the spatial variability of yield and travel time. Thus, an expansion of the existing network is necessary.

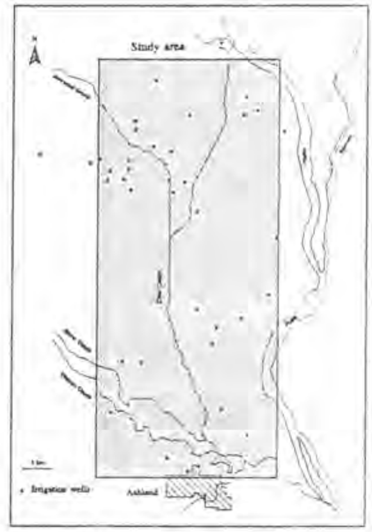

Figure 2: Current state, network 0

Two sets of measurement network alternatives, 3 networks in each, are defined to reduce the estimation variance. Each alternative includes the existing network and additional vertical electrical sounding (VES) measurements (Zohdy et al, 1974). The two groups differ only in network density; 1 VES/km^2 for the first group (Figure 4) and 1 VES/2 km^2 for the second. The first alternative in both groups, network 1 and 4 consist of 108 and 54 vertical electrical soundings respectively. Soundings are performed on a 1 km uniform grid covering the entire study area. They do not consider the location of existing wells and thus are not expected to be most effective alternatives. The second alternative in each group, network 2 and 5 are subsets of networks 1 and 4; they consist of 39 and 19 VES measurements in addition to the existing wells. Sounding locations cover the areas of highest estimation variances on the map variance of the current state. Networks 3 and 6 represent a middle way between the previous alternatives; seven sub-regions are defined for VES measurements covering most of the high variance locations. Networks 3 and 6 consist of 75 and 37 VES measurements, respectively.

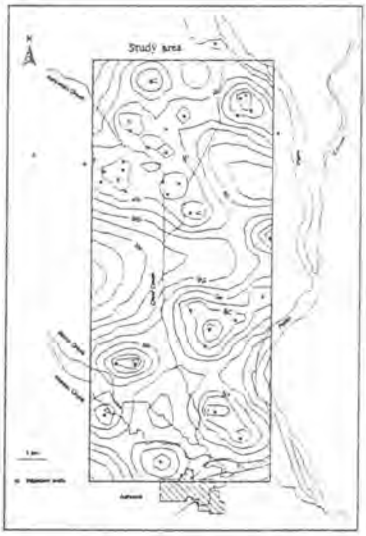

Figure 3: Estimation variance for yield, Q (gpm)^2 based on data from network 0

Estimation variances for each candidate network were calculated as for the existing measurement network. The reduction (%) of the mean and maximum estimation variance relative to the current state (i.e., mean and maximum estimation variances for the existing network) was also determined (Table 1). The relative reductions

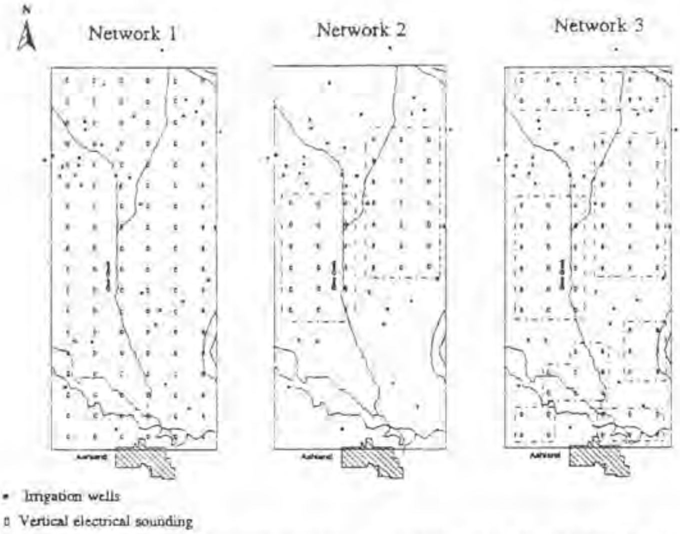

Figure 4: Observation network alternatives using wells and vertical electrical soundings of 1/km^2 density.

in mean and maximum estimation variances for yield and travel time and the costs of the candidate networks are the basic indicators in the MCDM analysis for selecting the "best" network alternative. Using composite programming, the set of basic indicators is aggregated through several steps into two composite variables, the overall variance reduction (VR) and the cost. These variables as well as the basic indicators are normalized to the interval [0,1]. The weights and balancing factors used in each group and level of the CP-structure are 0.5 and 2 respectively. Other weighing schemes would probably result in different solutions as has been shown in a sensitivity analysis (Pesti et al, 1994). Figure 5 shows the variance versus cost relationship for the six alternatives and the current state (alternative 0) where the ideal point is [0,1]; each alternative is represented by a point. The closer an alternative is to the ideal point the better it is. Here alternative 6 appears to be the "best" observation network.

Table 1. Reduction Δ(%) in maximum and average kriging variances, max(σ^2) and E(σ^2).

Network	$\Delta\max(\sigma^2_Q)$ (%)	$\Delta E(\sigma^2_Q)$ (%)	$\Delta\max(\sigma^2_t)$ (%)	$\Delta E(\sigma^2_t)$ (%)
1	29	41	37	37
2	0	19	5	19
3	19	35	30	33
4	11	29	21	27
5	0	15	5	15
6	11	26	21	26

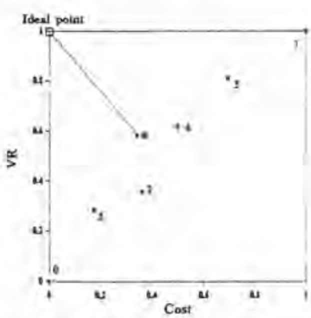

Figure 5: Variance reduction (VR) vs. cost. Cost and VR are equally weighted.

5. Conclusions

Results of this paper lead to the following conclusions:

1. The approach described here may be effectively used to evaluate and rank measurement network alternatives based on their accuracy and cost.
2. The advantage of combining geostatistics and MCDM is that the spatial characteristics of hydrogeologic parameters (Q and t), and the relative importance of accuracy (variance reduction) and observation cost associated with each network alternative can be jointly accounted for.
3. An observation network combining several different measurement techniques (e.g., observation wells and properly located geophysical measurements) may significantly and cost-effectively improve the accuracy of site characterization.
4. Though in the presented application only VES measurements were used to expand an existing network of wells, the approach allows the combination of several different measurement techniques (e.g., VES, profiling, electro-magnetic methods).

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Quantitative Niederschlagsbestimmung mit Radar im Deutschen Wetterdienst

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Zusammenfassung: Das Radarverbundnetz des DWD besteht derzeit aus fünf C-Band-Radargeräten in Berlin, Essen, Frankfurt, Hamburg und München. Der Ausbau auf insgesamt 16 Standorte ist geplant, damit die Bundesrepublik Deutschland möglichst flächendeckend mit quantitativen Radarniederschlagsinformationen versorgt werden kann.
Der größte Vorteil der Radarmessung ist die flächendeckende Darstellung der Niederschlagsverteilung in einer räumlichen Auflösung von einem Quadratkilometer. Nach Unterdrückung von Boden- und Festzielechos und der Aneichung an Messungen von (Boden)-Niederschlagsstationen im Off-Line-Betrieb erhält man in einem ersten Schritt eine realistische Verteilung der täglichen Niederschlagshöhen für jeden Quadratkilometer im Umkreis von 100 km Radius des Radarstandortes.

Measurement of Precipitation with Radar of the Deutscher Wetterdienst

Abstract: The radar network of the Deutscher Wetterdienst now consists of five reflectivity-only C-band radars installed at Berlin, Essen, Frankfurt, Hamburg and Munich. The network will be extended to 16 locations to establish a coverage of the Federal Republic of Germany as complete as possible.
The greatest advantage of radar measurement is that the high spatial resolution of one square km allows an extensive representation of the distribution of precipitation. After suppression of ground clutter and calibration with rain gauges in non real-time in a first step one can obtain a realistic distribution of daily precipitation amounts for each square km within 100 km radius of the radar location.

1. Einleitung

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 Niederschlagsgebieten zurückgestreut, wobei die Niederschlagsintensitäten von der Größe und der Dichteverteilung der Hydrometeore (Regentropfen Schneekristalle u.a.) innerhalb des Niederschlagsgebietes abhängen.

Im Radarverbundnetz des DWD (s. Abb. 1) erfassen derzeit fünf C-Band-Radargeräte während ihres quantitativen Meßzyklus den Niederschlag im Fünf-Minuten-Takt. Daraus werden die stündliche und tägliche Niederschlagshöhe in einem Umkreis von 100 km jedes Radarstandortes (Berlin, Essen, Frankfurt, Hamburg und Fürholzen bei München) berechnet.

Der Ausbau des Radarverbundes auf insgesamt 16 Standorte ist aus hydrometeorologischer Sicht eine Minimalforderung, um eine möglichst vollständige Flächenabdeckung der Bundesrepublik Deutschland mit quantitativen Radarinformationen zu erreichen. Bis Anfang 1995 sollen sukzessive die nächsten fünf Radargeräte in Hannover, Emden, Neuhaus, Rostock und Berus installiert werden.

Der große Vorteil der Radarniederschlagsmessung liegt in der hohen räumlichen Auflösung von einem Kilometer und einem Grad Azimut, die eine flächendeckende Darstellung der Niederschlagsverteilung erlaubt. Diese ist besonders für wasserwirtschaftliche und landwirtschaftliche Anwendungen sowie für Witterungsgutachten von großem Nutzen.

Die Qualität der Radarniederschlagsdaten ist wegen verschiedener Ursachen noch unbefriedigend, so daß vor einer Abgabe der Daten umfangreiche statistische Aufbereitungen durchgeführt werden müssen. Schwerpunkte in der Entwicklung von Methoden zur Qualitätsverbesserung sind die Unterdrükkung von Boden- und Festzielechos und die Aneichung an Messungen von (Boden-) Niederschlagsstationen.

Im folgenden wird am Beispiel des vom Frankfurter Radar erfaßten extremen Niederschlagsereignisses am 20. August 1992 die Radardatenaufbereitung im Off-Line-Betrieb vorgeführt, die notwendig ist, um aus der fehlerhaften Original-Radarniederschlagsmessung eine realistische Niederschlagsverteilung zu erhalten.

2.Unterdrückung von Boden- und Festzielechos

Das Originalradarbild vom 20. August 1992 (s. Abb. 2; Radarstandort Frankfurt/M.-Flughafen in der Bildmitte) zeigt außer einigen Schauerstraßen vor allem den von Boden- und Festzielechos verseuchten radarnahen Bereich (in der Abb. als dunkelblaue Flächen mit der scheinbaren Niederschlagsklasse über 70 mm belegt), der die Aussagekraft der Radarmessung in diesem Gebiet stark verringert.

Da die Bodenechos im Gegensatz zu den Festzielechos leider nicht konstant, sondern von den atmosphärischen Ausbreitungsbedingungen der Radarstrahlen und damit von der Wetterlage abhängig sind, muß zu deren Unterdrückung die zeitliche Komponente berücksichtigt werden.

So wird eine laufend aktualisierte Cluttermap (Referenzkarte mit Boden- und Festzielechos) aus zurückliegenden Radarmessungen erstellt. Die als Clutter gekennzeichneten Radarpixel werden in mehreren Schritten mit Hilfe der umliegenden Niederschlagswerte interpoliert.

Nach einem Abgleich mit den Bodenniederschlagsparametern "Maximaler Niederschlagsgradient der (Boden-) Stationen" und "Maximale Niederschlagshöhe der (Boden-) Stationen" erhält man das bodenechounterdrückte Radarbild. Sowohl zu hohe, unrealistisch wirkende räumliche Strukturen der Niederschlagsverteilung als auch eine allgemeine Über- oder Unterschätzung des Niederschlagsfeldes werden damit schon vor der eigentlichen Aneichung weitgehend beseitigt.

3. Aneichung

Wie ein Vergleich der quantitativen Radarniederschlagsdaten mit den Messungen von (Boden-) Niederschlagsstationen zeigt, sind erhebliche Unterschiede beider Meßsysteme festzustellen. Bei den Tageswerten muß mit einer Unterschätzung des Radar-Niederschlages um den Faktor zwei gerechnet werden; diese Unterschätzung wächst bei noch größerer zeitlicher Auflösung weiter an. Zudem sind auch genügend Fälle einer Überschätzung des Radar-Niederschlages bekannt. Somit geht es ohne Aneichung des Radar-Niederschlages an den "Boden-Niederschlag" nicht.

Der off-line-Vergleich bzw. die Aneichung erfolgt z. Z. auf der Basis von Tageswerten der Niederschlagshöhe aller zur Verfügung stehender Niederschlagsstationen. Für jede Niederschlagsstation wird ein Boden-Radar-Faktor bestimmt. Die Auswahl des zugehörigen Radarpixels wird dabei insoweit modifiziert, daß dasjenige Radarpixel aus dem Neunerfeld (zentraler und dessen acht benachbarte Radarpixel) ausgesucht wird, dessen Niederschlagswert die geringste Differenz zum Stationswert aufweist.

Die Faktoren werden auf die Fläche des Radarkreises interpoliert, so daß zu jedem Radarpixel ein eigener Aneichfaktor gehört (sog. pixel-interpolierte Aneichung). Die Multiplikation dieser Aneichfaktoren mit den entsprechenden bodenechounterdrückten Radardaten ergibt das off-line--angeeichte Radarbild (s. Abb. 3), welches einige bedeutende Verbesserungen gegenüber dem Originalradarbild bzw. den (Boden-) Niederschlagsmessungen herkömmlicher Art zeigt.

Am auffallendsten ist die starke Unterschätzung des Niederschlags im nicht-angeeichten Radarbild im NNW-Sektor, der vom nur etwa 25 km entfernten Taunus zum großen Teil abgeschattet wird. Gerade in diesem Gebiet hat, wie der Ausschnitt von Limburg (s. Abb. 4) zeigt, eine Schauerzelle Starkniederschläge bis zu 100 mm gebracht. Die in Abb. 4 mit den zugehörigen Niederschlagswerten versehenen Stationen liegen nicht im Zentrum der Schauerzelle und unterschätzen die Niederschlagshöhe im betreffenden Gebiet um die Hälfte.

Eine weitere und ebenso als realistisch zu bewertende Tatsache ist die räumlich mehr strukturierte Verteilung der Niederschlagshöhe im angeeichten Radarbild als bei interpolierten (Boden-) Niederschlagsmessungen. Schmale, aber intensive Schauerzellen werden somit hervorgehoben.

Für die Aneichung in Echtzeit ist von einer Reduzierung der verfügbaren Niederschlagsstationen als Aneichstationen auszugehen. Dies bedingt, 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 können aufgrund eines Boden-Radar-Vergleichs über einen längeren Zeitraum (mind. ein Jahr) hinweg untersucht werden.

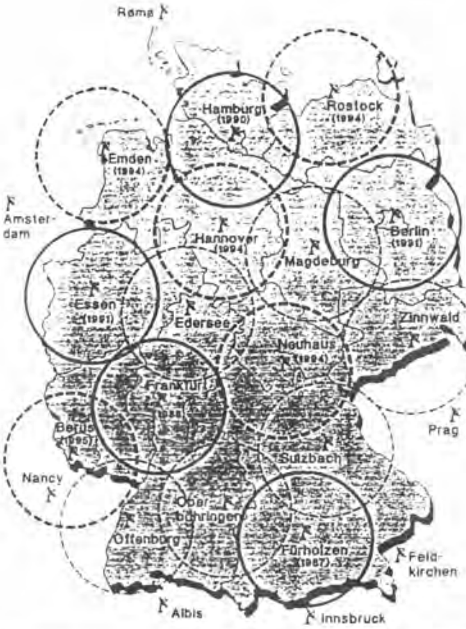

Abb.1: Standortplanung des Radarverbundnetzes des DWD
---- in Betrieb
- - in Planung

Fig.1: Locations of the German weather radar network
---- operation
- - planned

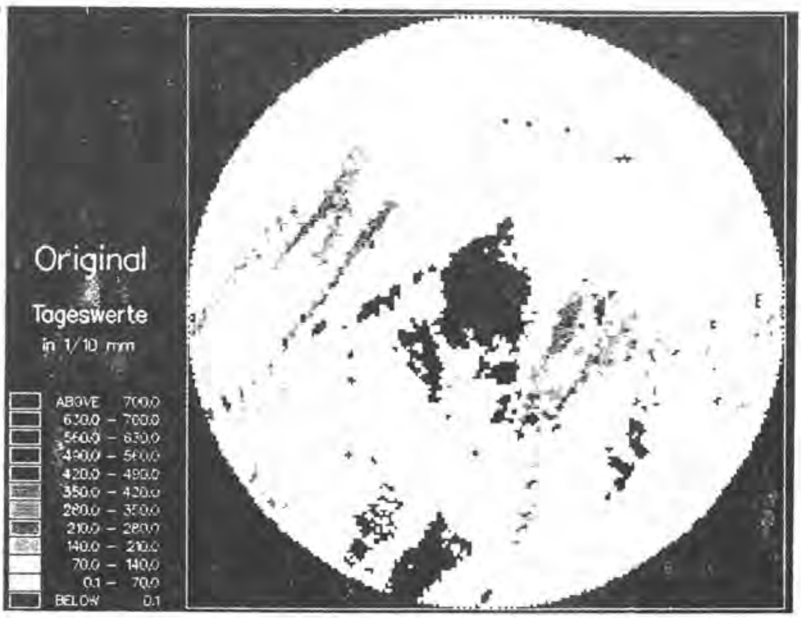

Abb.2: Original-Radarbild v. 20.8.92 (w. Erklärung s. Text)
Fig.2: Original radar map of August 20 th, 1992 (further declaration s. text)

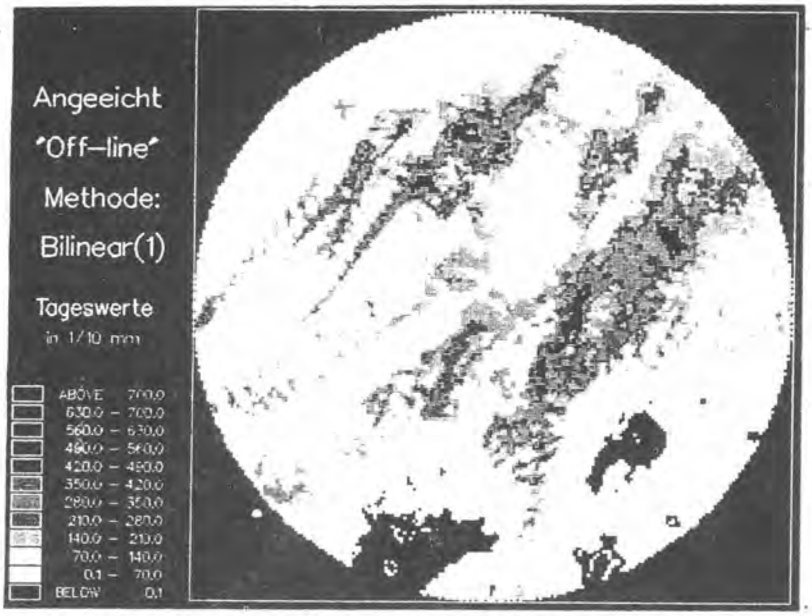

Abb.3: Off-Line-ange.Radarbild v. 20.08.92 (w. Erkl. s.Text
Fig.3: Radar map of August 20 th, 1992 after calibration
f. declaration s. text)

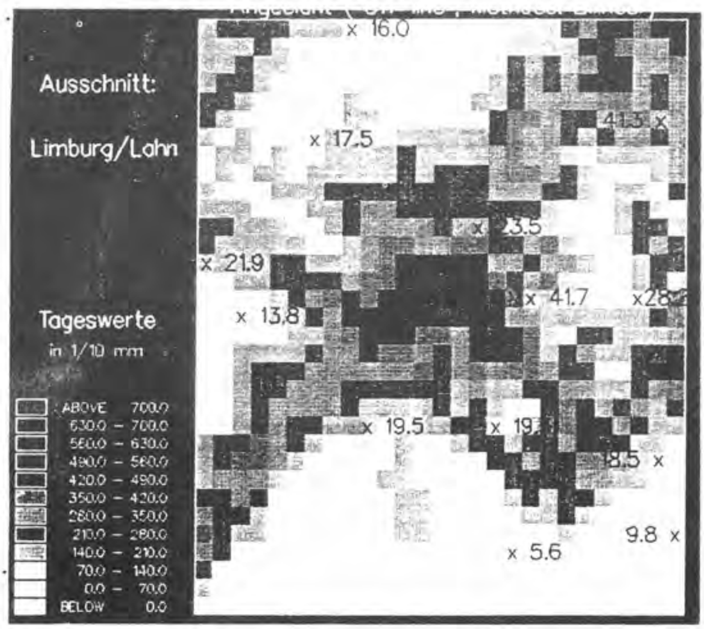

Abb.4: Ausschnitt "Limburg" v. Abb.3 (w. Erklärung s. Text)
Fig.4: Extract "Limburg" of Fig.3 (f. declaration s. text)

XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
hydrologisch-wasserwirtschaftliche Grundlagen

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Messungen von Durchflüssen und Strömungsprofilen mit einem Ultraschall-Doppler-Gerät (ADCP)

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Die Bundesanstalt für Gewässerkunde verwendet ein neuartiges Gerät zur Durchfluß- und Strömungsmessung, das mit der Ultraschall-Doppler-Technik arbeitet. Es wird in den USA hergestellt und trägt die Bezeichnung Acoustic Doppler Current Profiler, ADCP.
Durchflußmessungen mit dem ADCP sind wesentlich schneller und kostengünstiger als Messungen mit Flügeln. Diese Vorteile kommen vor allem bei der Erfassung instationärer Wasserbewegungen zum Tragen, z. B. bei Tideströmungen oder Hochwasserwellen.
Der folgende Bericht gibt einen Überblick über Handhabung und Funktionsprinzip dieses neuartigen Gerätes. Anschließend wird auf praktische Erfahrungen sowie die meßtechnischen Grenzen beim ADCP-Einsatz eingegangen.

Measurement of Discharge and Current Profiles with an Acoustic Doppler Current Profiler (ADCP)

by Matthias Adler

The Federal Institute of Hydrology of Germany is using a new instrument for discharge and current measurements. It operates on the basis of the ultrasonic Doppler principle. It is called Acoustic Doppler Current Profiler (ADCP) and is offered by a US manufacturer.
ADCP measurements are much faster and thus more economical than traditional propeller-meter measurements. These advantages yield most under unsteady flow conditions, e. g. during floods or in tidal rivers.
This paper describes the handling of the instrument and outlines its functional principle. Practical experiences with the ADCP as well as limitations in the application of the instrument are presented.

1 Beschreibung der ADCP-Sonde

ADCPs gibt es in verschiedenen Bauarten. Der hier vorgestellte 1.200 kHz Breitband-ADCP ist für Gewässer mit Tiefen zwischen 2 und maximal 20 m geeignet. Das Gerät wird im Meßschacht eines trailerbaren Kunststoffbootes installiert (Bild 1). Systemkonfiguration und Hauptabmessungen einer ADCP-Meßeinheit sind im Bild 2 dargestellt. In dem zylinderförmigen Gehäuse sind die Elektronik, eine Uhr, ein Thermometer, ein Pendel sowie ein Magnet-kompaß untergebracht. An einem Ende des Zylinders sitzen 4 Schallwandler. Dies sind Keramikplatten, die im kurzzeitigen Wechsel als Sender und Empfänger von Ultraschallimpulsen arbeiten. Die Kabelverbindung am anderen Ende dient der Kommunikation zwischen ADCP und DOS-Rechner sowie der Stromversorgung des ADCP.

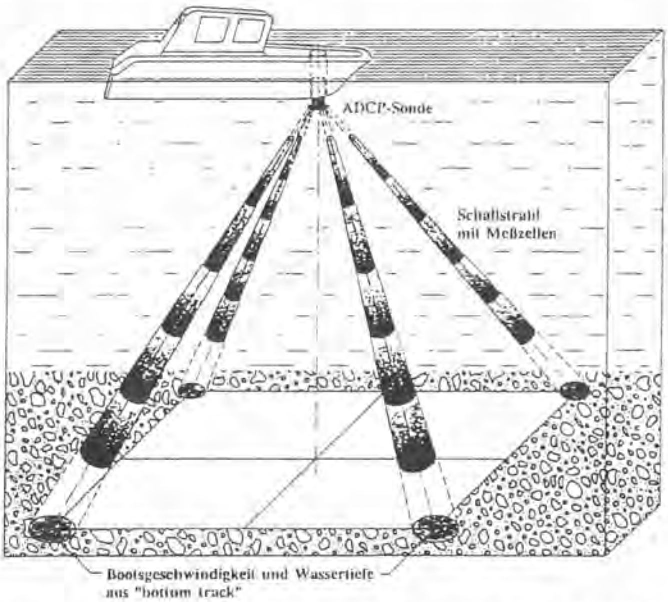

Bild 1: ADCP-Boot und Visualisierung der Schallstrahlen
Fig. 1: ADCP-Boot and visualization of acoustic beams

2 Ablauf einer Messung

Eine Durchflußmessung läuft schnell und ohne Hilfsgeräte ab. Insbesondere bedarf es keiner Positionsbestimmung zu einem Referenzpunkt am Ufer, wie bei der Flügelmessung. Der ADCP wird im Meßschacht des Bootes so weit abgesenkt, daß die Wandler unter dem Kiel des Bootes vorstehen. Das Boot fährt auf beliebigem Weg von Ufer zu Ufer, der Meßpfad muß also nicht wie bei der Flügelmessung rechtwinklig zur Strömung verlaufen. Das Boot kann den Fluß auch zum Beispiel schräg oder im Zickzackkurs überqueren. Es muß auch keine bestimmte oder gleichmäßige Bootsgeschwindigkeit eingehalten werden. Während der Fahrt wird der Wasserkörper unter dem ADCP akustisch "abgetastet". Die Meßdaten werden in Echtzeit verarbeitet. Der Durchfluß zwischen dem Startpunkt und der momentanen Position im Querschnitt wird ständig angezeigt und aktualisiert. Die Meßdauer beträgt ca. 1 Minute für 100 m Meßweg. Am Ende der Messung ist der Durchfluß zwischen Start- und Endposition des Bootes ermittelt.

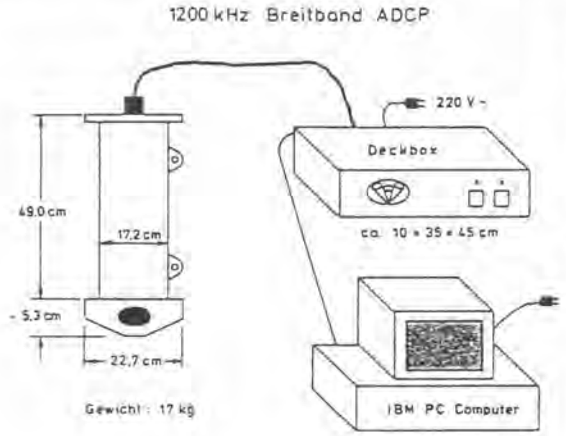

Bild 2: 1200 kHz Breitband ADCP, Systemkonfiguration und Hauptabmessung

Fig. 2: 1200 kHz broad-band ADCP, system configuration and main dimension

3 Durchflußermittlung mit dem ADCP

Der ADCP enthält vier verschiedene Sensoren:

- 4 Ultraschall-Wandler
- 1 Pendel
- 1 Magnetkompaß
- 1 Thermometer

Pendel, Kompaß und Thermometer sind zur Durchflußmessung nicht essentiell notwendig. Es sind Hilfssensoren, die Zusatzinformationen liefern und die Meßdatenqualität verbessern.

Das Pendel dient z. B. dazu, Stampf- und Rollbewegungen des Meßbootes und eine ungewollte schräge Aufhängung des ADCP zu registrieren und die Meßdaten entsprechend zu korrigieren.

Die Durchflußermittlung kommt prinzipiell mit dem Ultraschall-Doppler-Meßsystem aus. Es ermittelt drei Größen:

- die Wassertiefe
- die Geschwindigkeit des Bootes
- die Verteilung der Strömungsgeschwindigkeiten.

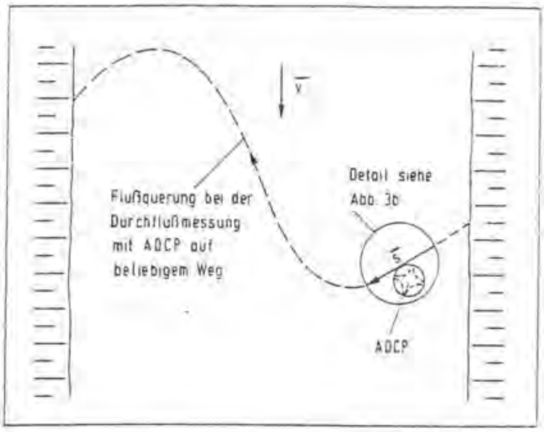

Bild 3a: Definitionsskizze zur Durchflußermittlung mit dem ADCP

Fig. 3a: Definition sketch for discharge determination with ADCP

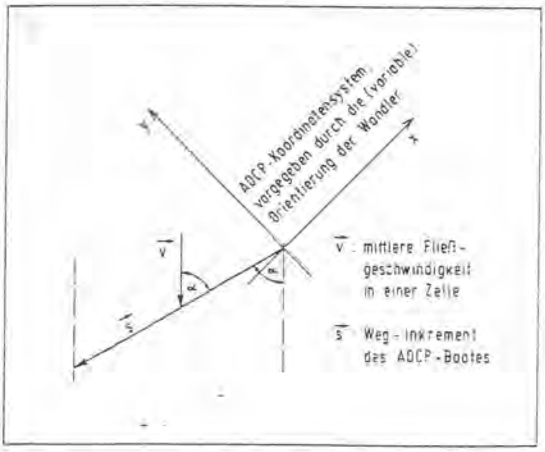

Bild 3b: Definitionsskizze, Detail aus Bild 3a

Fig. 3b: Definition sketch, detail from Fig. 3a

Die Geschwindigkeiten des Bootes und der Strömung werden vektoriell, d. h. in Größe und Richtung bestimmt.

Der ADCP unterteilt den Meßquerschnitt in eine Vielzahl sogenannter Zellen. Sie haben eine konstante Höhe von z. B. 25 cm (wählbar) und eine variable Breite, die von der Schallimpulsfolge und der Bootsgeschwindigkeit abhängt. Für jede Zelle wird ein Teildurchfluß ermittelt. Die Summe aller Teildurchflüsse ist der Gesamtdurchfluß. Die Berechnung des Gesamtdurchflusses läßt sich mit diesem Verfahren auf die Berechnung eines Durchflußinkrements, den Teildurchfluß ΔQ einer Zelle reduzieren. Er wird durch vektorielle Verknüpfung von Boots- und Strömungsgeschwindigkeiten errechnet.

In Bild 3a ist der willkürliche Meßpfad eines ADCP - Bootes von Ufer zu Ufer dargestellt. Eingekreist ist ein Wegincrement s. Die Verhältnisse sind in Bild 3b detailliert dargestellt. Im einzelnen sind zu sehen:

- Das durch die Orientierung der Wandler vorgegebene Koordinatensystem des ADCP zur Beschreibung der Vektoren $\vec{v}$ und $\vec{s}$ (s.u.).
- Das aus Bootsgeschwindigkeit und Fahrzeit berechnete Weg - Increment $\vec{s}$.
- Der Winkel α zwischen Weg- und Geschwindigkeitsvektoren $\vec{s}$ und $\vec{v}$

Zum Zellendurchfluß, ΔQ, trägt nur die Komponente von $\vec{v}$ bei, die senkrecht auf dem Meßweg $\vec{s}$ steht.

$\Delta Q = |\vec{v}| \cdot \sin\alpha \cdot |\vec{s}| \cdot \Delta h$ (wobei Δh die Zellenhöhe darstellt)

Dieselbe Gleichung vektoriell geschrieben lautet:

$$\Delta Q = |\vec{v} \times \vec{s}| \cdot \Delta h$$

4 Geschwindigkeits- und Tiefenmessung mit dem ADCP

Grundlage der im vorhergehenden Abschnitt beschriebenen Durchflußberechnung sind die Bootsgeschwindigkeit und die Strömungsgeschwindigkeiten in den einzelnen Zellen. Sie werden mit Hilfe des Dopplereffektes ermittelt.

Strömungsgeschwindigkeiten

Die von einem ADCP-Wandler ausgesandten Ultaschallimpulse werden von Partikeln im Wasser, z. B. Schwebstoffen, reflektiert. Man kann annehmen, daß sie sich im Mittel wie die sie tragende Strömung bewegen. Der Wandler empfängt die reflektierten Strahlen mit einer anderen Frequenz, als er sie ausgesandt hat, falls es zwischen Wandler und Reflektoren eine Relativgeschwindigkeit in Richtung des Schallstrahles gibt (Radialgeschwindigkeit). Die Frequenzverschiebung wird als Dopplerverschiebung bezeichnet. Mit ihr läßt sich die Radialgeschwindigkeit berechnen.

Der ADCP hat vier Wandler. Sie strahlen den Schall schräg nach unten in verschiedene Richtungen ab und zwar in einem Winkel von 30 ° zur Vertikalen. Die Schallstrahlen laufen wie die gedachten Kanten einer Pyramide, in deren Spitze sich der ADCP befindet.

Vier Schallstrahlen messen vier Geschwindigkeitskomponenten der Strömung. Sie können durch trigonometrische Umformungen in räumliche Geschwindigkeitsvektoren transformiert werden.

Der ADCP empfängt von Partikeln reflektierte Schallechos aus dem gesamten Wasserkörper unter den Wandlern. Um daraus ein Strömungsprofil zu ermitteln, wird das Echo in "Zeitfenster" zerlegt. Jeder Tiefenzelle wird eine Reflektionszeit zugeordnet, die sich aus der Entfernung der Zelle von den Wandlern und der Schallgeschwindigkeit ergibt. Aus dem Echo einer Tiefenzelle wird die mittlere Strömungsgeschwindigkeit dieser Tiefenzelle ermittelt.

Bootsgeschwindigkeit

Die Bootsgeschwindigkeit, genauer gesagt, die Geschwindigkeit des ADCP über Sohle, wird ähnlich wie die Strömungsgeschwindigkeit mit Hilfe des Dopplereffektes bestimmt. Sie läßt sich aus der Dopplerverschiebung des an der Sohle reflektierten Schalls ermitteln.

Wassertiefe

Sie wird nach dem Prinzip des Echolotes bestimmt und errechnet sich aus der Laufzeit des Schalls vom Wandler zur Sohle und zurück.

5 Meß- und Randbereiche bei der Durchflußermittlung

Die wichtigste Leistung des ADCP ist die Strömungsprofilmessung. Sie ist jedoch aus gerätetechnischen Gründen nur im Meßbereich (Kernbereich) des Querschnitts möglich, in Ufernähe sowie über und unter dem Kernbereich gibt es Zonen ohne Meßwerte. Ihre Durchflußanteile werden durch Extrapolation der Meßwerte des Kernbereichs berechnet. Der Kernbereich und damit die Genauigkeit der Messung wächst mit zunehmender Wassertiefe. Die Relation zwischen Kern- und Extrapolationsbereich ist in Bild 4 am Beispiel des Querschnitts Brohl, Rhein, dargestellt.

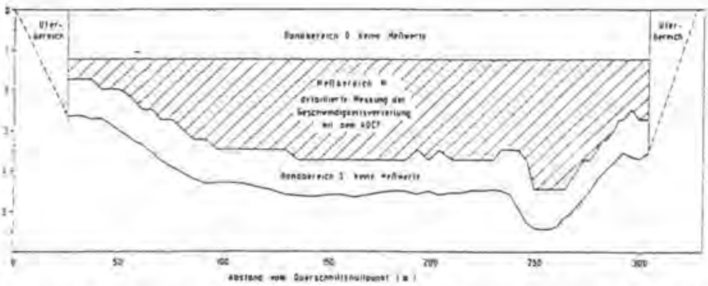

Bild 4: Meß- und Randbereiche am Beispiel der Meßstelle Brohl, Rhein

Fig. 4: Measuring and border areas in the case of the gauging station Brohl, Rhein

6 Darstellung der Meßdaten

Der ADCP sendet während der Messung Rohdaten an den angeschlossenen DOS-Rechner. Sie werden dort auf Festplatte gespeichert, in Echtzeit weiterverarbeitet und dargestellt.

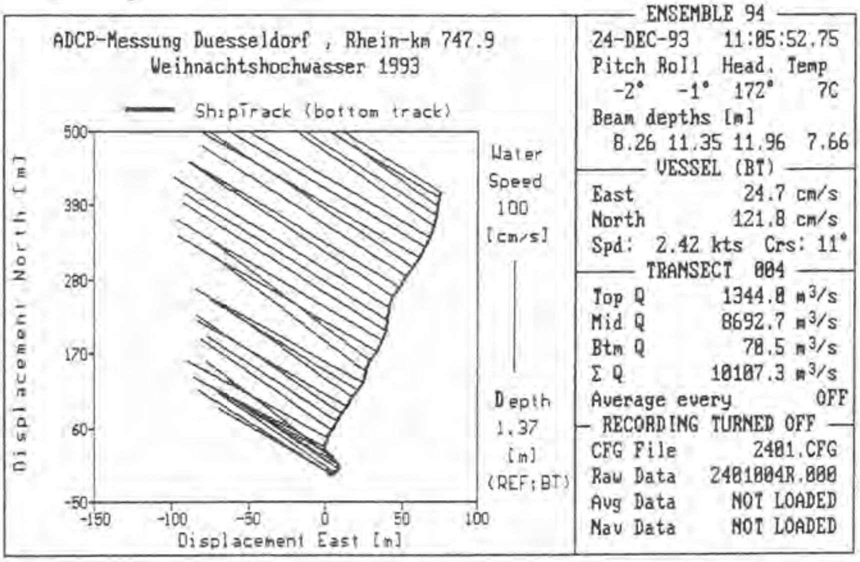

Bild 5: Darstellung der ADCP-Meßdaten: Meßpfad und Strömungsvektoren
Fig. 5: Representation of measured ADCP data: measuring path and flow vectors

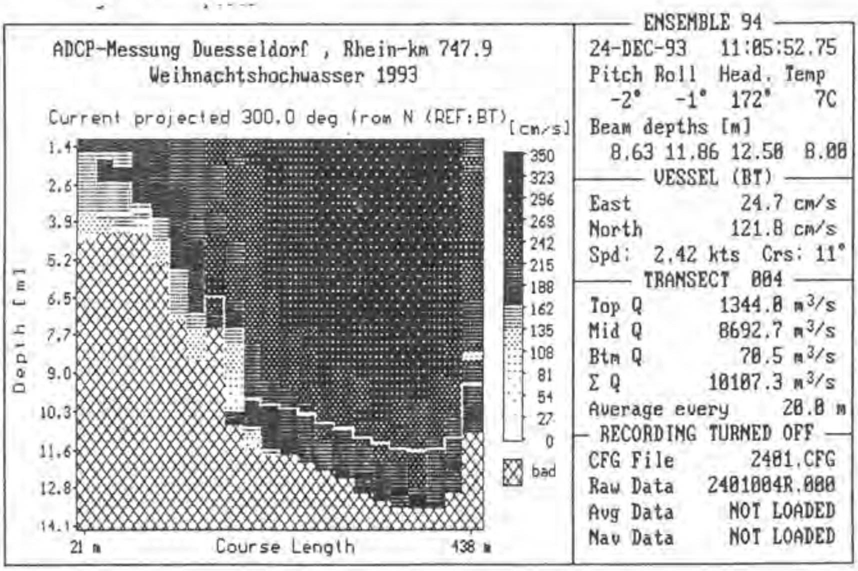

Bild 6: Darstellung der ADCP-Meßdaten: Meßquerschnitt und Strömungsprofil
Fig. 6: Representation of measured ADCP data: measurement cross-section and flow profile

Der Bildschirm ist in einen kleinen Bereich mit festem Format und einen größeren Bereich mit vom Anwender wählbarer Darstellungsart gegliedert.

Auf dem permanenten Bildschirmausschnitt wird der aktuelle Wert wichtiger Meßdaten angezeigt, unter anderem:

- akkumulierter Durchfluß zwischen Startpunkt und momentaner Position
- Wassertiefen; 1 Wert je Wandler
- Roll- und Stampfwinkel
- Kompaßwinkel
- Wassertemperatur
- Meßdauer

Im variablen Bildschirmausschnitt bietet das Präsentationsprogramm eine Reihe von Darstellungsmöglichkeiten zwischen denen man auch während einer laufenden Messung umschalten kann.

Eine der wählbaren Grafiken stellt den Meßpfad und die Strömungsvektoren dar (Bild 5).
Der Meßpfad erscheint als dicke Linie, die Strömungsvektoren als Nadeln. Es werden die Strömungsvektoren in einer wählbaren Tiefe gezeigt. Ihre Länge entspricht der absoluten Horizontalgeschwindigkeit. Eine andere Darstellung zeigt den Meßquerschnitt (Bild 6). Zu sehen ist der Sohlverlauf und die Verteilung der Strömungsgeschwindigkeiten. Die übliche Farbskala, mit der jeder Zelle eine Strömungsgeschwindigkeit zugeordnet wird, ist hier durch Scharz-Weiß-Muster ersetzt. Die weiße, stufige Linie in Sohlnähe trennt Kern- und unteren Randbereich (siehe Abschnitt 5).

7 Das ADCP-Meßboot der Bundesanstalt für Gewässerkunde

Als die BfG vor 1992 ihre ersten ADCP-Messungen machte, wurde das Gerät am Bug von Arbeitsschiffen aus Stahl montiert. Dieses Verfahren ist jedoch mit einigen Nachteilen verbunden, die bei dem neuen ADCP-Boot, der "M1", ausgeräumt sind. Es handelt sich um ein trailerbares Kunststoffboot, wiegt ca. 1,7 t und ist 6 m lang. Das Meßgerät ist in einem Schacht im vorderen Teil des Bootes untergebracht und dort optimal gegen Stoßbeschädigungen gesichert. Anders als beim Stahlboot arbeitet der ADCP-Kompaß zur Bestimmung der Strömungsrichtung ungestört. Wegen der geringen Wasserverdrängung wird die natürliche Strömung nicht beeinflußt, während sich vor dem Bug von Schiffen mit größerem Tiefgang ein Strömungsstau ausbildet.
Die Eintauchtiefe des ADCP geht als wichtige Rechengröße in die Durchflußberechnung ein. Sie ist bei einem mehrere Tonnen schweren Boot in Fahrt wegen der Bugwelle jedoch praktisch nicht genau feststellbar und kann sich um Dezimeter von der Eintauchtiefe im Stillstand unterscheiden. Im Meßschacht eines leichten Kunststoffbootes ist die Eintauchtie-

fe dagegen einfach und exakt bestimmbar. Sie ist bei Stillstand und langsamer Fahrt gleich.
Eine praktischer Vorzug eines trailerbaren Bootes besteht darin, daß es auf der Straße rasch von Meßstelle zu Meßstelle transportiert werden kann.

8 Einschränkungen beim ADCP-Einsatz

Die Bundesanstalt für Gewässerkunde hat die wichtigsten ADCP-Daten - Strömungsgeschwindigkeiten, Wassertiefe, "bottom track" und Durchfluß - unter verschiedenen Bedingungen im Feld mit Flügeln als Referenzgerät überprüft und eine gute Übereinstimmung der Werte beider Meßsysteme festgestellt [2]. So wichen z. B. die Durchflüsse in keinem Fall um mehr als ± 4 % voneiander ab. Dennoch gibt es Meßbedingungen, bei den der ADCP unvollständige, fehlerhafte oder keine Daten liefert.

Die gravierendste Einschränkung für den ADCP-Einsatz ist eine minimale Wassertiefe von 2 m. In diesem Grenzfall ist jedoch der Kernbereich der Strömung, in dem die Fließgeschwindigkeiten meßbar sind so klein, daß die Durchflußermittlung mit einer Unsicherheit behaftet ist, die der der Einpunkt-Flügelmessung entspricht. Mit zunehmender Wassertiefe steigt die Zahl der Meßzellen und damit die Genauigkeit der Durchflußwerte. Problemstellungen bei denen Sohl- oder Oberflächengeschwindigkeiten relevant sind, z. B. Stofftransport, können mit ADCP-Messungen grundsätzlich nicht gelöst werden (s. Abschnitt 5).

Hoher Schwebstoffgehalt des Wassers sowie bewegte Bodenschichten können sich ungünstig auf die Ausbreitung der Ultraschallsignale bzw. deren Echos auswirken. Bisher ist wenig darüber bekannt, bei welchen Bedingungen die Grenzen der Einsetzbarkeit liegen. Die schwierigsten Verhältnisse, unter denen die Bundesanstalt für Gewässerkunde ihr ADCP eingesetzt hat, traten beim Weihnachtshochwasser 1993 im Rhein auf. Trotz vermutetem starkem Geschiebetrieb und Schwebstoffkonzentrationen von bis zu 500 mg/l arbeitete das Gerät zuverlässig.

Von anderen Anwendern wurden jedoch unter bestimmten Bedingungen Ungenauigkeiten beim "bottom tracking" festgestellt. Eine Untersuchung des GKSS-Forschungszentrums Geesthacht in der Tideelbe ergab Fehler bei der Durchflußermittlung von bis zu 10 % [5]. Das Ausmaß der Störung des Bodenechos hängt wesentlich von der Konsistenz der bewegten Bodenschichten ab. Nach Kolb [5] ist die Beeinflussung besonders groß, wenn Wasser hoher Schwebstoffdichte über unkonsolidiertes, akustisch weiches Sediment strömt.

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FLOOD PLAIN MAPPING FOR FLOOD PROTECTION ON HEADWATER STREAMS

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Abstract

On the headwater streams time is measured in hours. Operations should be organised to do themselves without strict control or guide. The Treated settlements, owners of treated property, members of civil defence, fire services should be informed about operation plans, local characteristics of flood events, local flood zoning, flood safety rules related to local conditions, flood proof operations on theirs facilities etc.The flood plain zoning is well known non structural measure and powerful tool in different aspects of flood protection management. On the headwater streams we suggest that river bank erosion should be incorporate in flood plain maps. Mapping of flood plains has a long tradition in US and flood zoning scheme with adequate coding was developed similar like used by FEMA (Federal Emergency Management Agency)

Zusammenfassung

Im obersten Einzugsgebiet wird die Zeit in Stunden gemessen. Operationen sollten so organisiert sein, daß sie von selbst, ohne Führung und Kontrolle ablaufen. Die gefährdeten Siedlungen, Eingentümer von Liegenschaften sowieg Mitglieder des Zivilschutzes oder der Feuerwehr sollten über den Ablauf der Operationen, die Eigenheiten von lokalen Hochwasserereignissen, lokale Überflutungszonen, die von den lokalen Verhaltnissen abhängigen Sicherheitsvorkehrungen bei Hochwasserereignissen, Sofortmaßnahmen in ihren Anlagen usw. informiert werden. Die Ausscheidung von Ü berflutunfsgefahrenzonen ist eine bekannte Maßnahme und ein wirksames Hilfsmittel für verschiedene Aspekte des Hochwasserschutzes. Wir shlagen vor, daß in den oberen Einzugsgebieten Ufererosion in die Karte der Ü berflutungsgefahrenzonen integriert werden soll. Das Ausscheiden von Ü berflutungsgefahrenzonen hat in den USA eine lange Tradition. Eine Methode zur Ausscheidung von Überflutungsgefahrenzonen mit einer adäquaten Kodierung wurde entwickelt. Sie ist mit der von FEMA benützten Methode vergleichbar.

1. Introduction

Slovenia is positioned south-east side of the Alps where a lot of heavy floods have happened in the last few years due to typical frontal orographic precipitation. Here are situated upstream watershed in areas of the Sava and the Socha rivers. The mountainous alpine and hilly area with deep narrow valleys is threatened by heavy rain and flash floods.

Only four hundred twenty square kilometres (two percent) of total area is flooded, but nonetheless contains areas of intensive agricultural production, heavily urbanised sections, and vital traffic connections. Surface erosion and landslides affect on area of four thousand seven hundred square kilometres. Mainly damages are caused by landslides and river bank erosion.

On the headwater streams time have been measured in hours. In detail operating plans with instruction have to be done and personas interested in have to be informed. Operations should be organised to do themselves without strict control or guide. The Treated settlements, owners of treated property, members of civil defence, fire brigades (who have been established in each village in The Slovene) etc. should be informed about operation plans, local characteristics of flood events, local flood zoning, flood safety rules related to local conditions, flood proof operations on theirs facilities etc.

The flood plain zoning is well known non structural measure and powerful tool in different aspects of flood protection management. On the headwater streams we suggest that river bank erosion should be incorporate in zoning. A few hours of flooding can't damage structure as soil erosion and river bank erosion can do. Potential erosion could be estimate by hydraulics calculation of sediment transport, geological data, and experiences on previous floods.

2. Mapping of flood hazards

The determination of flood plains on maps is a basic necessity for flood protection management. The flood plain maps support a variety of structural and non structural flood damage reduction measures and are also useful for planning of flood protection activity.

Mapping of flood plains has a long tradition in US. Tennessee Valley Authority began mapping flood plains in 1953. Other federal organisations began producing flood plain maps a short time later. Federal mapping of flood plains is under supervision and control of Federal Emergency Management Agency (FEMA 1990, 1992, ARC 1992). Guide of flood insurance rate maps and other acts for uniform mapping were issued.

3. Mapping for headwater streams

Flood zoning scheme with adequate coding was developed similar like used by FEMA (ARC 1990). Proposed scheme (table 1) give enough information for flood management, physical planning, civil defence, and settlements. For different zones recommendations, and proposals were done. Flood defence organisation and planing is related to conditions in head-water streams (figure 1, Brilly 1992).

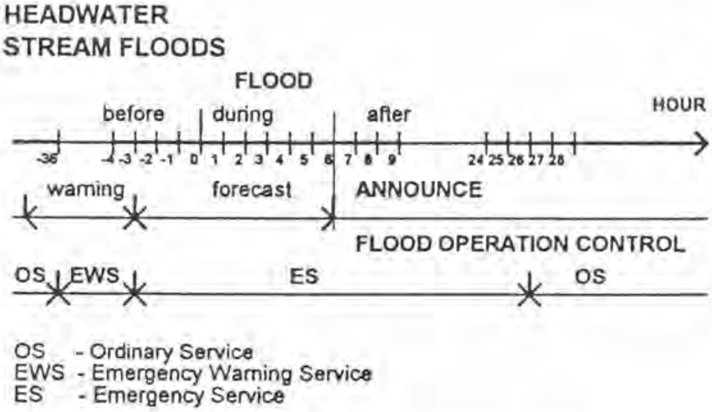

Figure 1. Time shedule of flood protective operating plan

Table 1

Zone symbol	Description
Q	Flood way area with significant velocity of water (0.5 m/sec)
P10	Flood plain for ten years return period flood
P100	Flood plain for hundred years return period flood
PMM	Flood plain for maximum possible flood
H	Area of mud flow hazards
O	Area under dam and dike break hazards or by stop up of bridges, outfalls and drainage channels.
I	Area of special flood related bank erosion hazards
X	Area estimated with low accuracy

Differences are in the mapping of flood plain related to return period of flood including a maximum possible flood (figure 2), additional mapping of area treating by dam and dike break or by stop up of bridges, outfalls and drainage channels. Information about flood plain areas with different return periods is basic for evacuation of 'reated citize s and their goods on safe places out of flood hazard.

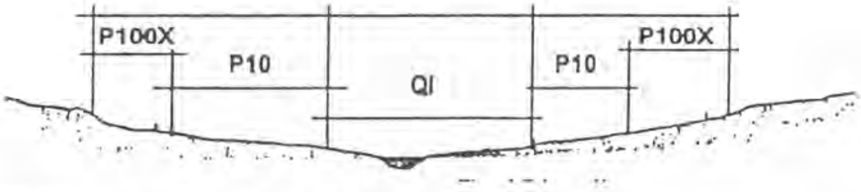

Figure 2. Stream cross section with zones

Mapping of flood is oriented to flood protection at first. Most important part of flood plain is a floodway (stream itself and surrounding area). It is part of flood plain with significant velocity of water (Q) and should be under special treatment and supervision of water authority. The floodway zone also should have special treatment during the flood event. It is very dangerous for crossing a specially areas with possible bank erosion (QI).

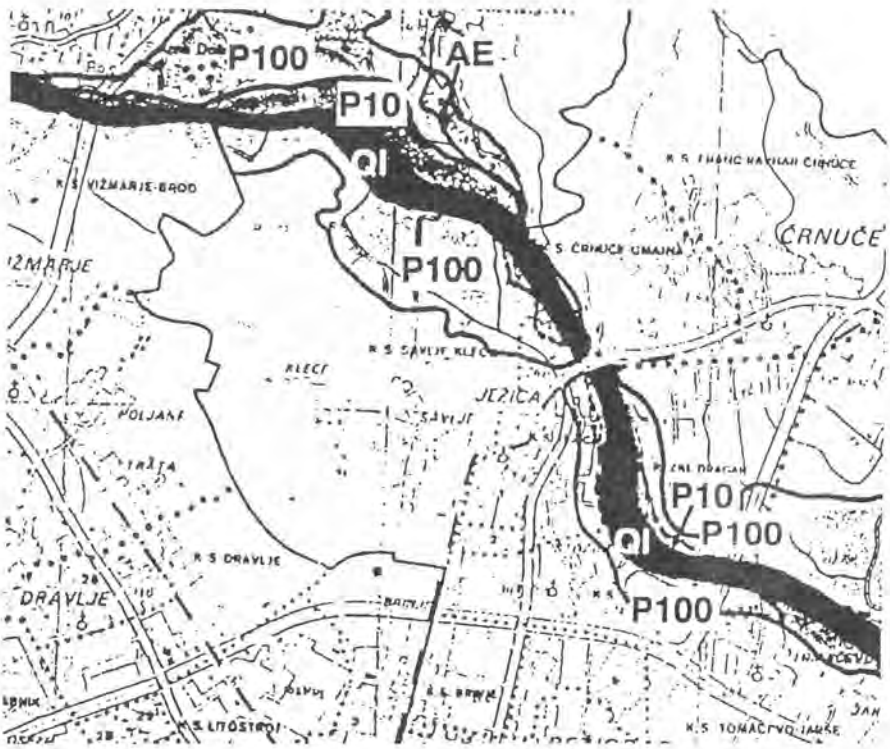

Figure 3. Map wit flood plains

Accuracy of mapping is crucial question. The flood lines could be determined by sophisticated hydrological and hydraulics modelling based on historical data and field measurement or only by expert analysis of map and field prospecting. The first way give us accurate results but take a time and lot of many. The second one isn't expensive and could give us enough good results in short period of time. Maps should be made as soon as possible and later related to flood damage and hazard they could be corrected with more accurate data. An example of flood plain map in Slovenia is presented on figure 3

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AUSWERTUNG UND REGIONALISIERUNG VON STARKREGEN FÜR HYDROLOGISCHE ZWECKE IM PROJEKT ÖKOSTRA-93

Von F. Nobilis und G. Skoda

Zusammenfassung

Ein österreichweit einheitliches Konzept der Starkniederschlagsauswertung und -regionalisierung wird vorgestellt. Es stützt sich auf bewährte Vorarbeiten, neue Studien aus Nachbarländern und wird durch Vorschläge ergänzt, die vor allem im alpinen Gelände Berücksichtigung finden können. Ein Flußdiagramm erläutert die Vorgangsweise. Der Regionalisierung wird besonderes Augenmerk geschenkt.

Abstract

The authors present the Austrian concept of evaluation and regionalization of remarkable precipitation. It is besed on tested former studies, new publications from neighbouring countries, and will be supplemented by proposals which might prove successful especially in Alpine regions. A flow-chart explains the procedure of evaluation. Special attention is directed to the regionalization of data.

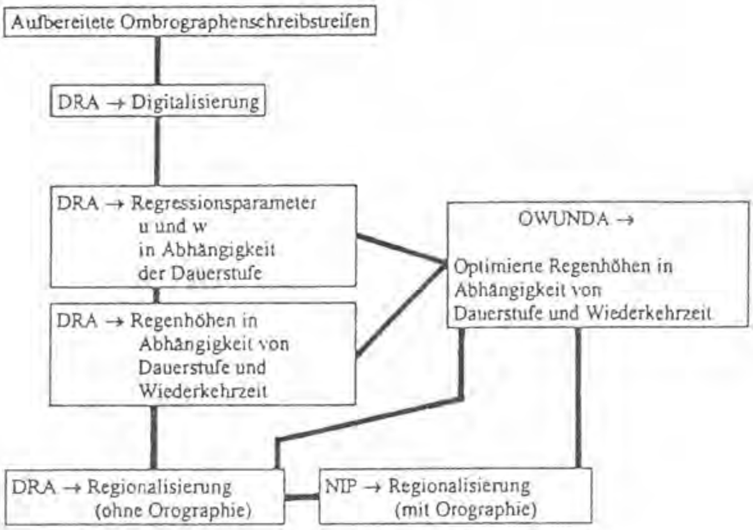
ÖKOSTRA-93

Die Strategie einer österreichischen koordinierten Starkniederschlagsregionalisierung und -auswertung (siehe ÖKOSTRA-93, Heft 1, 1990) beruht auf einer Nutzung bewährter Basiselemente, die sich im Laufe der letzten Jahrzehnte in Mitteleuropa - grenzüberschreitend - harmonisch entwickelt haben. Diese Elemente zählen zu den anerkannten Standardverfahren; Sie werden insbesonders in den Untersuchungen von Auer et al., 1984; Deutscher Wetterdienst, 1990; DVWK, 1985; Geiger et al., 198 ÖKOSTRA-93, Heft 1, 1990; ÖKOSTRA-93, Heft 2, 1991; ÖKOSTRA-93, Heft 3, 1992; Schimpf, 1970; Steinhäusser, 1985 und Verworn, 1993 behandelt.

Um möglichst rasch zu homogenem Datenmaterial zu gelangen, wurden im Jahre 1991 200 Monate (aus Mai bis September), aus 1992 300 Monate (aus Mai bis September) sowie aus 1993 400 Monate (aus Mai bis September) rückwirkend aufbereitet und digitalisiert. Dabei beschränkte man sich auf die klimatisch

äußerst vielseitige "Region Salzkammergut", die überdies eine hohe Stationsdichte aufweist (SKODA, G. und F.HOLAWE, 1991). dieser Raum wurde nicht zuletzt wegen seiner starkgegliederten Topographie, die erfahrungsgemäß bei der Regionalisierung die größten Probleme bereitet, als Modellgebiet für ÖKOSTRA-93 ausgewählt.
In jenen Teilbereichen, in denen die Standardroutinen, etwa auf Grund allzu einschränkender Annahmen im Bereich Sttistik oder wegen ausgeprägter topographischer Einflüsse Versagen (müssen), wird versucht, durch Zusatzmodule Verbesserungen zu erreichen. Diese umfassen insbesonders einen verbesserten statistischen Ausgleich über die Regen-Dauerstufen und die räumliche Interpolation und Darstellung von Niederschlagsfeldern, die sogenannte Regionalisierung.

Dem Benutzer der Programmdisketten bieten sich die nachstehend vorgestellten Möglichkeiten (SKODA, 1993):



Regionalisierung klimatologischer Starkniederschläge

Bei der Ermittlung von Gebietsniederschlägen ist eine gewichtete Berücksichtigung der Punktwerke unumgänglich. Für die Interpolation klimatologischer Starkniederschläge in orographisch gegliedertem Gelände hat HAIDEN (in: ÖKOSTRA-93, Heft 3, 4., 1992; 1994) einen Algorithmus entwickelt, der theoretische Beziehungen zwischen Orographie und Niederschlag sowie geeignete Gewichtsfunktionen in der räumlichen Interpolation verwendet. Ein Beispiel für eine bereits ansprechende Stationsdichte zeigt Abbildung 1.

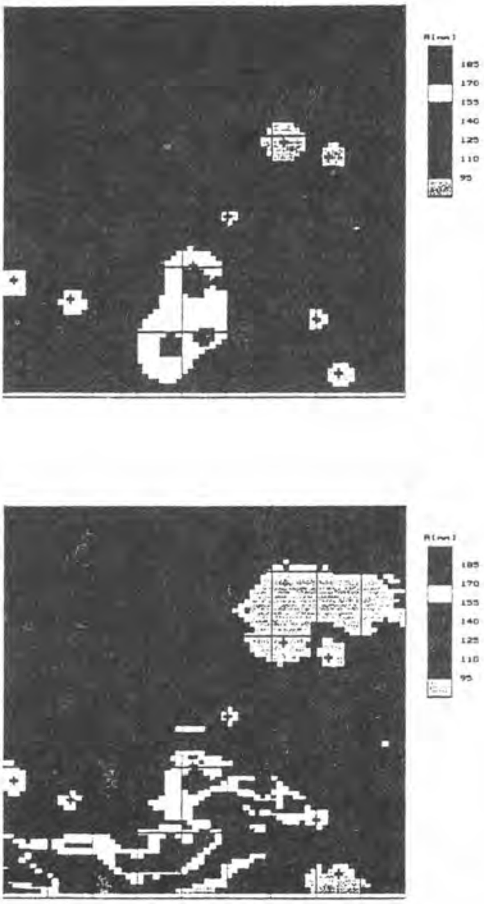


Abbildung 1: Interpoliertes Niederschlagsfeld für die Dauerstufe 24 Stunden und eine Wiederkehrperiode von 100 Jahren. Daten gewonnen an 29 Klimastationen aus langjährigen (unkorrigierten) Tagesmeßwerten. Kreuze markieren Stationsorte. (HAIDEN, aus: ÖKOSTRA-93, Heft 3, 4. 1992).
Oben: Reine (quadratische) Interpolation (Orographie nicht berücksichtigt).
Unten: Kombination aus interpoliertem Feld und Modellrechnung.

Die Stationsdichte ist ausreichend, so daß auch ohne Berücksichtigung der Orographie in der Interpolation der staubedingte Niederschlagsgürtel erkennbar wird. In der kombinierten Verteilung ergeben sich zusätzliche Strukturen, wie z.B. markante Maxima an den Nordrändern der größeren Bergmassive sowie eine abruptere Abnahme der Werte im Ennstal.

In der Literatur wird bei der Möglichkeit der Erfassung räumlicher Strukturen im Starkniederschlagsfeld auf ein großes Maß an Unsicherheit hingewiesen. Als Gründe werden ungünstige Stationsverteilungen, Meßfehler und komplexe Wechselwirkungen zwischen meteorologischen und topographischen Einflüssen genannt. Hier können andere Meßsysteme, wie z.B. Satellitenbeobachtungen oder Radarmessungen weiterhelfen: Die bei Einzelereignissen bekannten Maßzahlen von Niederschlagsfeldern (wie etwa Dimensionsgrößen) stellen eine wertvolle Zusatzinformation bei der räumlichen Interpolation dar.

Ausgehend von bekannten Meßpunkten (Stationen) kann das gesuchte Niederschlagsfeld unter Beibehaltung der von der Natur vorgegebenen (beobachteten !) räumlichen Strukturen (fast) beliebig verfeinert werden. Die neu hinzugewonnenen Meßdaten sind stochastischen Charakters, d.h., sie stellen als einzelne Punktwerte nur eine von vielen möglichen Realisierungen dar, gemeinsam als Feld beschreiben sie jedoch die Strukturen der räumlichen Verteilung von Niederschlägen optimal:

Die simulierten Felder sind im statistischen Sinn von Beobachtungen nicht zu unterscheiden !

Als leistungsfähiges Interpolationsverfahren, das auf Dimensionszahlen in geeigneter Weise anspricht, schlagen wird die "Methode der zufallsgesteuerten Mittelpunktsverschiebung" nach SAUPE (1988) vor. (Diese rekursive Technik ist u.a. bei der Gestaltung von Phantasielandschaften am Bildschirm bekannt geworden).

Es gibt also erste erfolgversprechende Simulationen von Starkniederschlägen an beliebigen Ortspunkten. Für die Hydrologie ergeben sich somit zusätzliche Möglichkeiten im Hinblick auf die Beantwortung von Bemessungsfragen.

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Regionalisierung von Abflüssen mit Hilfe von Spendenlängsschnitten und dimensionslosen Kenngrößen

H. Schiller

Kurzfassung: Bei der Regionalisierung, d. h. der Schaffung von Grundlagen zur Ableitung von Abflußgrößen für Einzugsgebiete ohne Pegelmessungen, werden die Bereiche Mittelwasser (MQ), Niedrigwasser (NQ) und Hochwasser (HQ) getrennt voneinander behandelt. Gemeinsame Strategie für alle drei Bereiche ist es, zunächst linienförmig entlang der Flußläufe zu beginnen und dann mit den Längsschnitten und einzelstehenden Pegeln einer Region in die Fläche überzugehen. Um die Werte vergleichen zu können, werden sie durch Teilen mit einem kennzeichnenden Parameter normiert.

Für einen Teil des bayerischen Donaugebietes wird mit einer Auswahl von Pegeln gezeigt, wie Mittel-, Niedrig- und Hochwasserwerte mit Hilfe von Spendenlängsschnitten und normierten Kenngrößen dargestellt werden können.

Regionalization of discharge applying longitudinal specific flow sections and specific values

Abstract: In regionalization, i. e. the development of a tool for derivation of hydrological parameters for ungauged sites anywhere in a given region, mean flow, low flow and flood flow are investigated separately. The strategy applied begins with the stations along the rivers and progresses to use their longitudinal sections as a link to the stations within the area. To allow comparison of the hydrological values they are normalized by division using a characterising parameter.

Hydrological low flow, mean flow an flood flow characteristics will be shown for a selection of stations within the Bavarian Danube Basin using longitudinal sections and normalized values.

1. Aufgabenstellung und Vorgehensweise

In einem dichtbesiedelten Land ist es notwendig, die für wasserbauliche und wasserwirtschaftliche Planungen sowie zahlreiche weitere Zwecke benötigten Abflußgrößen an nahezu jeder beliebigen Stelle des Gewässernetzes mit guter Genauigkeit angeben zu können. Die Grundlage dafür bildet das Pegelnetz mit seinen Meßergebnissen. Die Aufgabe bei der vorzunehmenden Regionalisierung besteht nun darin, aus den Auswertungsergebnissen der Pegel landesweit Arbeitsunterlagen zu entwickeln, mit deren Hilfe die benötigten Werte für jede beliebige Stelle mit genügender Genauigkeit in einfacher Weise abgelesen, interpoliert oder extrapoliert werden können. Dieses Ziel wird sich allerdings nur insoweit erreichen lassen, als die Konzeption des Pegelnetzes auch darauf abgestellt ist. Die Arbeitsergebnisse sind daher zugleich eine Grundlage für eine Verbesserung bzw. Revision des bestehenden Pegelnetzes /2/.

Die Regionalisierung wird zweckmäßigerweise für die drei Bereiche Mittelwasser, Niedrigwasser und Hochwasser getrennt vorgenommen.

Der jeweils erste Schritt besteht in einem linienhaften Vorgehen entlang der Wasserläufe der größeren Gewässer, an denen mehrere Pegel vorhanden sind. Um die Auswertungsergebnisse der einzelnen Pegel in Form eines hydrologischen Längsschnittes miteinander vergleichen und entlang der einzelnen Linien interpolieren zu können, müssen sie allerdings auf eine zumindest einigermaßen einheitliche Basis gebracht werden. Am besten geeignet wäre eine einheitliche Beobachtungsperiode mit einer repräsentativen, d. h. möglichst langen Dauer. Zugleich wird der Einstieg in die Normierung vorgenommen, in dem man die Abflüsse durch die Fläche des Einzugsgebietes teilt und alle Werte als Spenden ($l/s*km^2$) darstellt. Das bedeutet, daß die hydrologischen Längsschnitte sowohl als Abflüsse in Bezug zum Einzugsgebiet (bzw. auch Flußkilometer) und als Spenden in Bezug zum Einzugsgebiet aufgetragen werden, wobei letztere für den nun folgenden Übergang in die Fläche notwendig sind. Dazu werden die hydrologischen Längsschnitte für eine ganze Region mit den Werten der einzelstehenden Pegel zusammengefaßt, wobei vor allem die Längsschnitte der Oberläufe das Bindeglied von der Linie zur Fläche sind.
In den einzelnen Abflußbereichen Mittel-, Niedrig- und Hochwasser ergeben sich außer bei der weiteren Normierung auch noch verschiedene andere Unterschiede.

2. Mittelwasser (MQ)

Die Darstellung des Mittelwassers als Spenden ergibt bereits eine so gute Vergleichbarkeit in der Menge, daß eine weitere Normierung zu diesem Zweck - z. B. Teilen der MQ der einzelnen Pegel durch das langjährige MQ eines größeren Flußgebietes - nicht nötig ist. Zur Kennzeichnung hydrologischer Regime ist es allerdings üblich, die Quotienten zwischen den langjährigen Monats-MQ mit dem langjährigen Jahres-MQ zu bilden (Pardé-Koeffizienten).

Als einheitliche Jahresreihe wird die Periode 1961/90 verwendet. Das hat einerseits den großen Vorteil, daß eine einheitliche Vergleichsgrundlage gegenüber anderen solchen Perioden, z. B. 1901/31, 1931/60 und den davon unterschiedlichen längeren und kürzeren Beobachtungszeiten der einzelnen Pegel vorhanden ist. Auf der anderen Seite ist aber zu berücksichtigen, daß sich das Mittelwasser in den unterschiedlichen hydrologischen Regionen Bayerns bei einer 30jährigen Beobachtungsdauer auch nur mit unterschiedlichen Genauigkeitsgraden einstellt. Zum Erreichen einer Genauigkeit von ± 10% gegenüber dem Wert einer sehr langen Reihe genügen für die Donau und das südlich von ihr liegende Gebiet Beobachtungsdauern von rd. 20-30 Jahren, während im nördlichen Donaugebiet und im Main- und Elbegebiet dazu Beobachtungsdauern von 30 bis 80 Jahren notwendig sind. Für das Erreichen einer Genauigkeit von ± 15% von MQ genügen für die Donau und das südliche Einzugsgebiet 10 - 20 Jahre, während im nördlichen Donaugebiet 20 - 30 Jahre nötig sind. Im Main- und Elbegebiet sind es überwiegend 30 - 40 Jahre und gebietsweise bis zu 60 Jahre /1/.

Mit der flächenhaften Darstellung des Mittelwassers in Form von Isolinien, die außer für die Spende in $l/s*km^2$ auch analog dem Niederschlag in mm/Jahr gebräuchlich ist, kann bei durchlässigem Untergrund wie z. B. Karst und Schotterflächen nur die potentielle Abflußbildung dargestellt werden. Sie sagt nichts darüber aus, wo dieser Abfluß nun auch tatsächlich an der Oberfläche erscheint. Dies zeigt wiederum ein Lageplan (Abb. 2), bei dem die Mittelwasserspende bei den einzelnen Pegeln angeschrieben ist.

3. Niedrigwasser

Es hat sich gezeigt, daß das "mittlere Niedrigwasser" (MNQ bzw. als Spende MNq) als Niedrigwasserkenngröße nicht brauchbar ist, da dieser Wert sehr häufig anthropogen beeinflußt ist und in keinem Zusammenhang mit den Ergeb-

nissen der Niedrigwasserstatistik steht. Aus diesem Grund sind bereits einige Länder dazu übergegangen, als Niedrigwasserkenngröße einen Wert aus der Dauerlinie zu verwenden. In Bayern ist man übereingekommen, dazu den 20tägigen Unterschreitungswert 20Q der langjährigen Dauerlinie zu verwenden.

Als einheitliche Jahresreihe wird wiederum wegen der guten Vergleichbarkeit die Jahresreihe 1961/90 verwendet. Über die Abhängigkeit der erreichbaren Genauigkeit von der Länge der Beobachtungszeit gibt es noch keine Untersuchungen. Im Vergleich zum Mittelwasser dürfte hier ein deutlich niedrigeres Niveau zu erwarten sein, da einzelne trockene Jahre das Ergebnis stark beeinflußen können.

Über die Spenden ist zwar beim Niedrigwasser auch schon eine sehr gute Vergleichbarkeit gegeben. Eine Normierung mit dem Verhältniswert 20Q : MQ ergibt darüber hinaus noch einen Kennwert für das Speichervermögen der einzelnen Einzugsgebiete. Allderdings ist dabei eine Abhängigkeit von der Größe des Einzugsgebietes, und generell eine Zunahme der Verhältniswerte flußabwärts bzw. mit zunehmender Einzugsgebietsgröße zu beachten. Im Längsschnitt lassen sich Niedrig- und Mittelwasser gemeinsam darstellen (Abb. 1). Im Lageplan zeigen Spenden und Verhältniswerte an den Pegeln an, wo erhebliche unterirdische Abflußanteile am Pegel vorbeifließen oder von einem anderen Einzugsgebiet hinzukommen (Abb. 3 und 4).

4. Hochwasser

Die Behandlung der Hochwasserverhältnisse ist im Vergleich zum Mittel- und Niedrigwasser weitaus schwieriger als in den beiden anderen Abflußbereichen. Der Grund dafür besteht im wesentlichen darin, daß der als Auswertungsziel vorgegebene 100jährliche Hochwasserscheitelabfluß (HQ_{100}) nicht durch eine einfache Berechnung aus den Beobachtungsergebnissen gewonnen werden kann, sondern das Ergebnis einer Extrapolation ist. In Abhängigkeit von der Länge der Beobachtungsreihe und den verschiedenen Verteilungsfunktionen können die gewinnbaren Extrapolationswerte in einem sehr weiten Umfang streuen. Allein um eine Genauigkeit beim arithmetischen Mittelwert MHQ, der dem $HQ_{2,3}$ entspricht, von nur ± 20% zu erreichen, sind in den meisten Teilen Bayerns Beobachtungsreihen von 20 - 40 Jahren, teilweise bis zu 60 Jahren erforderlich. Nur in einigen Gebieten Südbayerns, vor allem im alpinen Bereich, genügen dazu Beobachtungsreihen von 10 - 30 Jahren. Ziel ist jedoch, beim

HQ_{100} eine Genauigkeit von mindestens 20% zu erreichen, weshalb die Beobachtungsreihen möglichst lang sein müssen. Je nach Pegel können dazu noch Probleme mit der Qualität der Daten kommen, wenn die Abflußkurven im oberen Bereich mehr oder weniger weit extrapoliert sind oder unklare Strömungsverhältnisse auftreten. Gute Ergebnisse lassen sich meist nur dadurch gewinnen, daß man an jedem Fluß von den Pegeln mit dem besten Informationsgehalt ausgeht, d. h. solchen mit sehr langen Beobachtungsreihen und zuverlässigen Daten, und die weniger gut belegten Nachbarpegel mit allen einsetzbaren Möglichkeiten an diesen Informationswert anschließt. Neben dem Vergleich von Abflüssen und Spenden im Längsschnitt wird dafür vor allem der Verhältniswert HQ_{100} : MHQ (normierte Verteilungsfunktion) und die Erhöhung der Repräsentanz des arithmetischen Mittelwertes MHQ der Stichprobe durch Regression mit benachbarten längeren Hochwasserkollektiven eingesetzt. Dazu kommt noch die Prüfung der Kollektive auf Homogenität /3/.

Die Ergebnisse - Hochwasserabflüsse verschiedener Eintrittswahrscheinlichkeiten HQ_1 bis HQ_{100}, mittlere Hochwasserabflüsse MHQ mit Verhältniswert HQ_{100} : MHQ - werden dargestellt in Spendenlängsschnitten und Lageplänen mit eingetragenen Verhältniswerten HQ_{100} : MHQ. Der Übergang in die Fläche erfolgt ähnlich wie bei den anderen Abflußbereichen durch Zusammenstellen von Spendenlängsschnitten MHq mit eingetragenen Verhältniswerten HQ_{100} : MHQ einer Region, ergänzt mit den entsprechenden Werten der alleine stehenden Pegel (Abb. 5 und 6). Es zeigt sich dabei eine erstaunliche Systematik bei den Verhältniswerten HQ_{100} : MHQ in Form einer Zunahme entlang der Flüsse vom größeren zum kleineren Einzugsgebiet, einer Zunahme in Südbayern von West nach Ost und einer Beziehung zu Höhe der mittleren Hochwasserspende bezogen auf gleiche Einzugsgebietsgrößen /4/.
Besonderheiten aufgrund inhomogener Kollektive, z. B. Karst, durchlässige Talverfüllungen, Schotterfelder, Löß usw., zeigen sich je nach Ausprägung in mehr oder weniger großen Verhältniswerten HQ_{100} : MHQ. Dieser Verhältniswert läßt sich deshalb für Einzugsgebiete ohne Pegel jedenfalls mit besserer Genauigkeit abschätzen als die mittlere Hochwasserspende. Letztere ist sowohl von der Größe des Einzugsgebietes, als auch von der jeweiligen Region und sicher auch noch von weiteren Faktoren abhängig. Zur besseren Abschätzung der mittleren Hochwasserspende für beliebige Standorte wäre es wünschenswert, noch eine weitere Abschätzhilfe zur Verfügung zu haben. Ein Versuch, eine solche Unterlage zu entwickeln, ist für die Zukunft vorgesehen.

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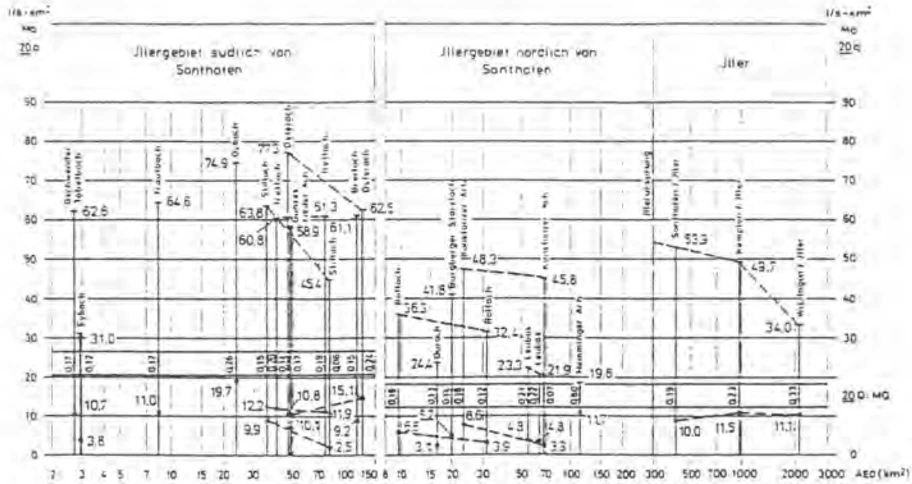

Abb. 1 *Mittel- und Niedrigwasserspenden (20q) der Pegel im Illergebiet: vor allem das 20q gibt deutliche Hinweise auf den unterirdischen Abflußanteil, z. B. Eybach, Stillach, Memminger Ach.*

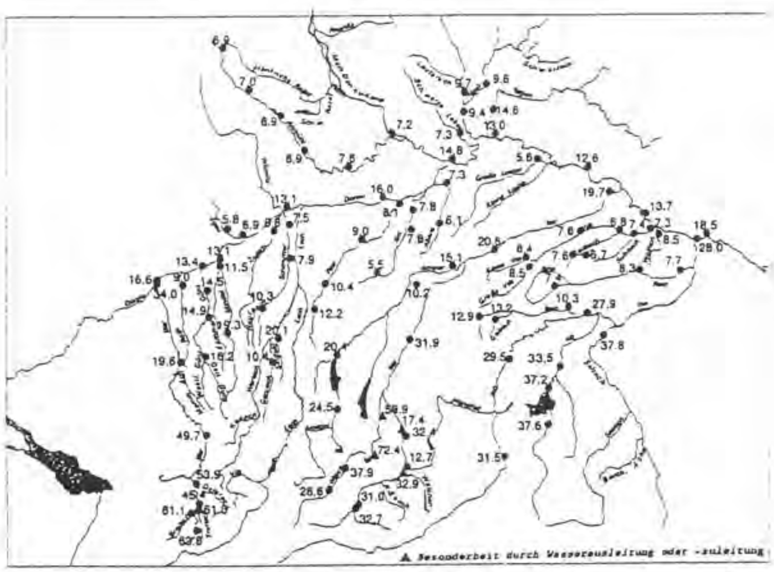

Abb. 2 ***Übersichtslageplan mit einigen Pegeln im bayerischen Donaugebiet und zugehörigen Mittelwasserspenden Mq ($l/s*km^2$): Es ergeben sich erste Hinweise auf Besonderheiten beim unterirdischen Abfluß.***

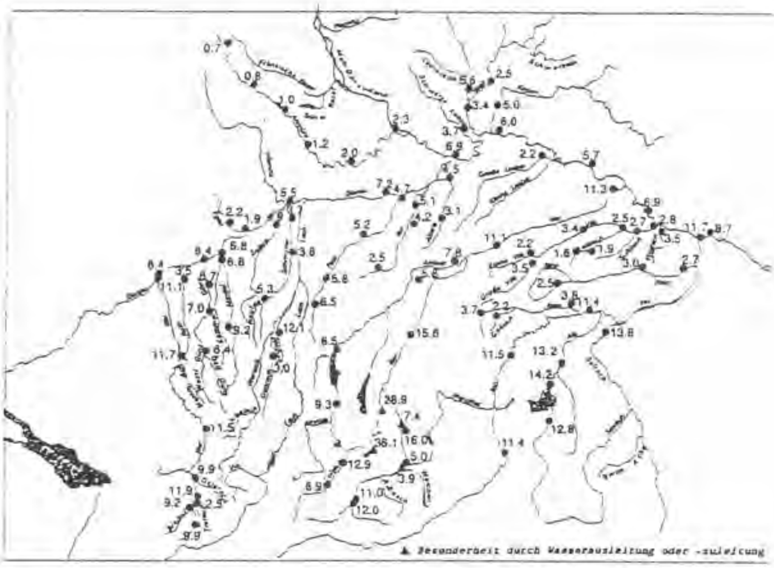

Abb. 3 *Übersichtslageplan mit einigen Pegeln im bayerischen Donaugebiet und zugehörigen Niedrigwasserspenden <u>20</u>q (l/s*km²): Es ergeben sich konkrete Hinweise auf Besonderheiten beim unterirdischen Abfluß, z. B. Zustrom von der Gennach zur Singold.*

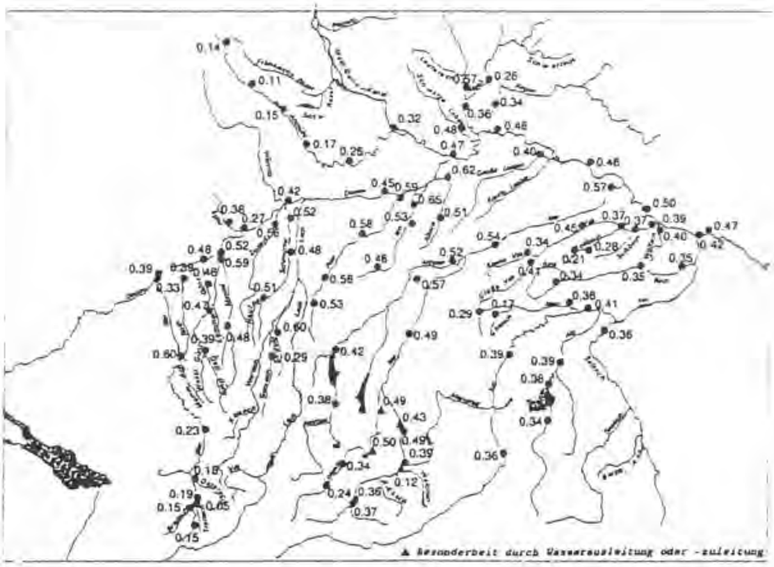

Abb. 4 *Übersichtsplageplan mit einigen Pegeln im bayerischen Donaugebiet und Verhältniswert <u>20</u>Q : MQ, aus dem sich ebenfalls Hinweise auf den unterirdischen Abfluß, insbesondere das Speichervermögen, ergeben.*

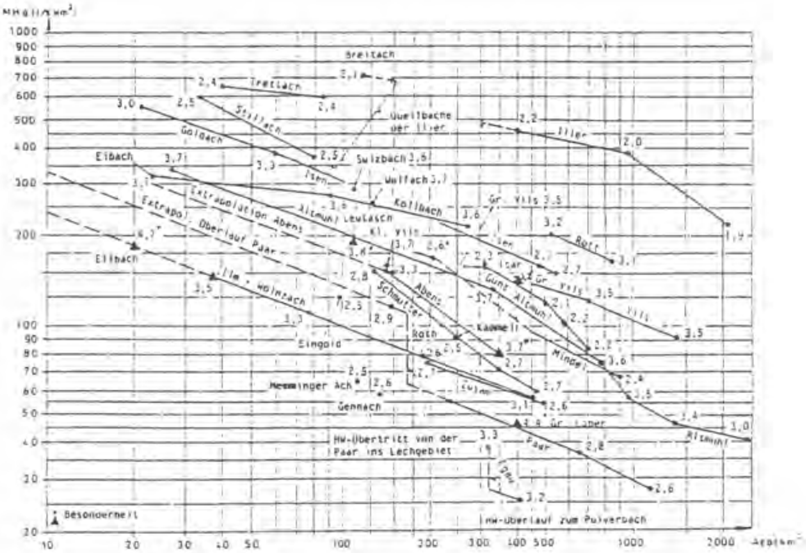

Abb. 5 *Mittlere Hochwasserspende und Verhältniswerte HQ_{100} : MHQ für einige Flüsse und Pegel im bayerischen Donaugebiet.*

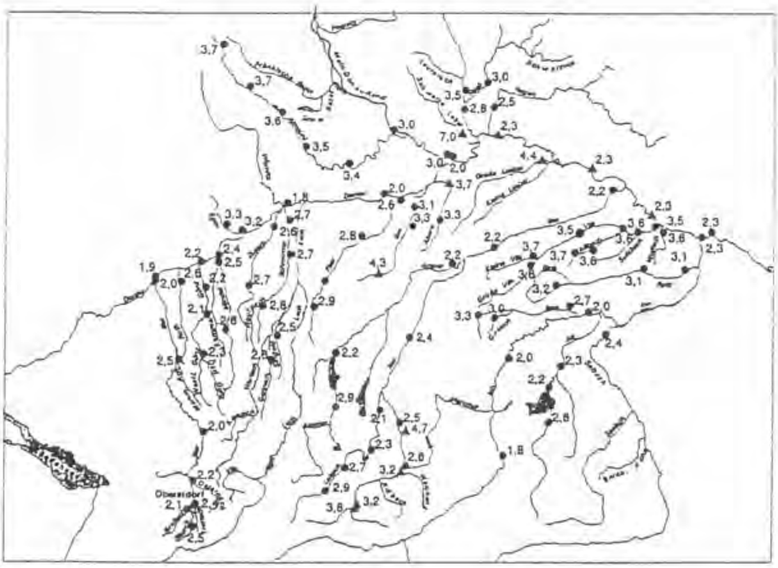

Abb. 6 *Übersichtlageplan mit Pegeln und Verhältniswerten HQ_{100} : MHQ.*

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über hydrologische Vorhersagen und
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REGIONALIZATION OF THE PARAMETERS OF BOUNDARY RUNOFF INTENSITY THEORY ON THE TERRITORY OF SERBIA

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SUMMARY:

The paper presents the procedure for regionalization of the basic parameters of the boundary runoff intensity theory for calculation of the maximum flow on the territory of Serbia. The procedure is based on maximum use of all peak discharges records at hydrological researched profiles, identification of the basic parameters of boundary runoff intensity theory and investigation of their regional homogenization at the wider catchment areas.

The paper will be illustrated with some regional homogenous areas for basic parameters of boundary intensity method on the territory of Serbia.

Also presented are the results of computation of flood peak discharges on hydrologically unresearched profiles in the catchment area of the Nishava and Juzna Morava.

REGIONALISIERUNG VON PARAMETERN DER THEORIE DER ABFLUßGRENZINTENSITAT AUF DEM TERRITORIUM SERBIENS

KURZFASSUNG:

In der Arbeit ist das Regionalisierungsverfahren für die Grundparameter der Theorie der Abflußgrenzintensität für die Berechnung des maximalen Abflußes auf dem Territorium Serbiens dargestellt. Das Verhafren beruht auf der maximalen Benutzung aller an den hydrologisch erforschten Profilen bemerkten größten Durchflüße, der Indentifizierung der Grundparameter der Theorie der Abflußgrenzintensität und auf der Prüfung ihrer räumlichen Homogenität auf dem breiteren Flußgebiet.

In der Arbeit sind alle Grundparameter der Theorie der Abflußgrenzintensität fut einzelne regionale homogene Gebiete auf dem Territorium Serbiens dargestellt.

Dargestellt sind auch die Ergebnisse der Berechnungen des maximalen Wasserdurchflußes auf den unerforschten Profilen in den Flußgebieten der Nisava und Juzna Morava.

1. Introductory Notes

Sudden increase in the use of water resources first requires good knowledge of water regime of given waterways or territories. Thus maximum flood represents one of the main elements of water regime on which depends, to the greatest extent, the stability and economy of hydraulic structure or system.

It is well known that the calculation of maximum flood has its significant characteristics depending on the fact whether systematic hydrological observation exists or not on given watercourse. If it does, the task is to choose that statistical scheme which describes the distribution function of existing sample (series of observed values). In the second case, where systematic hydrological observation does not exist, various calculation schemes are based on theoretical notion of discharge forming processes. Thus the maximum flood calculation on small, hydrologically unexamined catchment based on the theory of boundary runoff intensity theory has the best theoretical foundation.

2. Computation methodology

According to the theory of boundary runoff intensity,maximum discharge can be defined with the help of the equation (Alexeev, 1966)

$$Q_{max,p\%} = 16.67\ \bar{i}_{max,p}\ (\tau)\ \varphi\ F \qquad (1)$$

or introducing the concept of so called "heavy rain reduction curves"

$$q_{max,p} = \frac{Q_{max,p}}{F} = 16.67\ \varphi\ \bar{\psi}_p\ (\tau)\ H_{max,dn,p} \qquad (2)$$

where $Q_{max,p\%}$ - peak flow discharge (m^3/s), φ - total coefficient of runoff, $\bar{i}_{max,p}(\tau)$ - maximum mean rain intensity for computed rain duration $t_k = \tau$, τ - time of concentration (min), F - drainage area (km^2), $H_{max,dn,p}$ - maximum daily rainfall (mm), p - probability of occurence, $\bar{\psi}_p(\tau)$ - rainfall reduction curve ordinate of mean intensity.

The expression of the computation of maximum runoff on unexamined watercourse (1) or (2) is closely connected with previous defining of coefficient φ, time of concentration τ and mean rain intensity for calculated rain duration $\bar{i}_{max,p}(\tau)$ (time of rainfall concentration).

Coefficient definition φ for unexamined watercourse is the most responsible part of the task of maximum flood calculation. If there exists a basin (watercourse) that can serve as "analogue" then the coefficient φ can be defined using the expression (2) from the relation (Anon,1973).

$$(\varphi\ H_{max,dn})_{p,a} = \frac{q_{max,p,a}}{16.67\ \bar{\psi}(\tau_a)} \qquad (2)$$

or modification of the same relation (Anon, 1984; Petković et al., 1990) introducing the catchment area and mean slope of the basin, where "a" denotes analogue, $q_{max,p}$ - specific peak flow ($m^3/s/km^2$).

In the case where "analogue" catchment areas do not exist then it is proper to consider separately the basic parameters of maximum discharge of the product of runoff coefficient φ and maximum daily rainfall $H_{max,p}$, that is conditional runoff depth or total hydrometeorological parameter φ H_{max} (Alexeev, 1966; Prohaska et al. 1990).

On the basis of systematic hydrological observation in homogeneous area from the aspect of this parameter, in inversion calculation procedure, regional empirical dependency can be formed

$$X_p \equiv (\varphi\ H_{max,d})_p = f\ (F,\ J,\ J_{sl},\ TZ,...) \tag{3}$$

where J - mean slope of the main channel, J_{sl} - mean slope of the basin, TZ -prevailing soil type on the catchment.

Dependency (3) is the basis for the calculation of conditional runoff depth on hydrologically unexamined catchments in certain region. This is the objective mode of defining the value of total hydrometeorological parameters, avoiding subjective defining of particular coefficient φ and uncertain mean daily rainfall on the catchment $H_{max,dn,p}$ which form maximum flood.

Total travel time on the catchment (time of concentration) is in general the function of channel lag and overland lag time.

But, however, since for the most watercourses where systematic hydrological observations are caried out there are no data on average slope lengths, their slopes and geomorphological characteristics typical for surface runoff, it seems justified to express the time of concentration τ through travel time of water along watercourse channels τ_k (Alexeev, 1966; Petković et al. 1990) that is

$$\tau = K_\tau\ \tau_k \tag{4}$$

where K_τ is the proportion coefficient and represents the relation between total travel time and travel time of water along the watercourse.

Travel time of water along the main watercourse can be defined as per the expression (Anon 1973, 1984)

$$\tau_k = \frac{1000\ L}{m\ J^{1/3}\ Q_{max,p}^{\ 1/4}} \tag{5}$$

where m - is the parameter depending on mean roughness along the watercourse, mean slope of the main channel and river bed characteristics, L- the main watercourse length.

The parameters defined in this way are necesary for the calculation of maximum discharge on unexamined waterways.

3. Parameter regionalization procedure

Using all the available data on maximum discharges on hydrological stations on the territory of Serbia, the processed heavy rain results on all the pluviographic stations given in the form of rain reduction curves (reduction curves $\psi(\tau)$ and $\bar{\psi}(\tau)$) for each hydrological station the relative values are computed of the total hydrometeorological parameters $Z_p \equiv (\varphi\ H_{max,dn})_p$ using the expression (2).

Research carried out afterwards showed that for certain regions (large catchment areas) this parameter depends mostly on the catchment area and that relationship can be approximately defined by two-parameter relationship.

$$(\varphi\ H_{max,dn})_p \equiv X_p = \frac{\dot{X}_p}{(1 + \alpha \sqrt{F})^2} \qquad (6)$$

where $\dot{X}_p$ -regional hydrometeorological parameter for elementary catchment, and α - regional reduction coefficient.

In the process of such analysis it became evident that parameters $\dot{X}_p$ and α depend on probability of occurence. So, for example, in Table 1 values of such parameters are given for the basin of the river Nishava and middle and upper part of the basin of the Juzna Morava.

Table 1. Parameter values $\dot{X}_p$ and α

p%	basin Nishava		basin J.Morava	
	$\dot{X}_p$	α	$\dot{X}_p$	α
0.1	85.1	0.0130	77.0	0.0075
1	52.8	0.0090	55.0	0.0060
5	34.0	0.0060	38.0	0.0050
10	28.0	0.0050	30.0	0.0045

Adequate relationship is defined also for other regions on the territory of Serbia.

In such analyses parameter m in the equation (5) is defined using the general relation between the main runoff and inflow water elements in river network, and on the basis of recorded extreme flood waves.

These values are brought into the function of mean slope of the main channel. In Table 2 characteristic values of this parameter are given.

Table 2. Dependency m=f(J)

J(%.)	5	10	20	30	40
m	11	9	8	7.5	7.0

Parameter K_τ in the expression (4) is defined on the basis of observation from examined watercourse (including small experimental catchments too) in the procedure of calculation inversion using reduction curve of mean rain intensity $\bar{\psi}(\tau)$ and expression (2), that is

$$\bar{\psi}(\tau) = \frac{q_{max,p}}{16.67\ (\varphi\ H_{max,dn})_p} \quad ; \quad \tau = f(\bar{\psi}) \tag{7}$$

on the basis of which and with the known travel time of water along the main watercourse τ_k, the following relation is given

$$K_\tau = \frac{\tau}{\tau_k} \tag{8}$$

The analyses made on such occasions showed that the coefficient K_τ depends to a great extent on the catchment area. Table 3 contains some characteristic values of this dependency.

Table 3. Dependency $K\tau = f(F)$

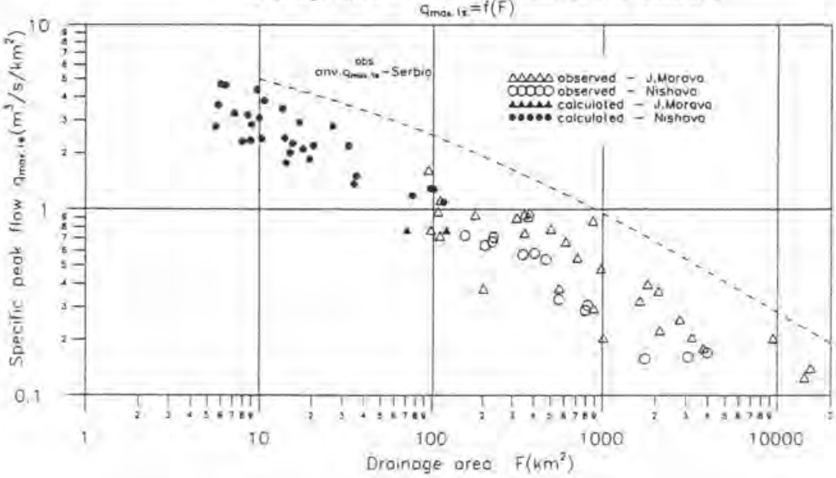
F (km^2)	5	10	20	40	60	100	200	300
K_τ	4.1	4.0	3.7	3.4	3.2	2.9	2.5	2.2

In this way relevant parameters are defined for the calculation of maximum discharge on unexamined catchments.

4. Results of the application in practice

Explained methodology and carried out analyses served for the calculation of maximum water discharge on hydrologically unexamined catchments on the profiles of future reservoirs in the preparation of Water management basis of Serbia as well as on profiles of intersected rivers of future roads.

Fig.1.Relationship between specific peak flow and drainage area for the catchment of the J.Morava $q_{max.ts}=f(F)$



Obtained results of these computation are the starting point in the first phase of designing of these constructions. For the purpose of developed methodology, as an example, graphical display (Fig.1) shows the dependency of specific peak flow on the drainage area $q_{max,1\%}$ =f(F) for the basin of the Juzna Morava with belonging basin of the Nishava and on the basis of observed values.

The same graphic display shows relative values of maximum discharge of unexamined profiles. The analyses of such dependency as well as dependency of other regions in Serbia show that computed maximum water discharge values on unexamined watercourse correspond to the general relation of reduction of maximum specific discharge, so that the results can be accepted for this designing level.

5. Conclusion

Explained computation methodology is suitable for the examination of basic parameters of flood hydrographs in the planning phase of hydraulic structures when various alternative solutions are considered. But, however, for the purpose of higher designing phases, and especially for the level of main design, additional hydrometeorological field research is necessary which can confirm or reject assumption series made in such analyses. And if this is not done, the security and economy of future constructions can be jeopardized in the construction phase and also in exploitation phase.

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Regionalization of low flows using a multiple regression approach. - A Review.

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Abstract

Since many years the multiple regression approach has been a popular tool within hydrology to estimate flow parameters at the ungauged site. This method of regionalization has been especially applied to flood statistics and mean flows. Yet only little is know about regionalization of low flow parameters. The objective of this study is to summarize an extensive literature study carried out by investigating about 120 regression models on a world wide scale. In a first step the study investigates the type of basin characteristics used in the regression models and their significance. Secondly it was of interest to which extent the type of low flow parameter to be estimated was influencing the significance of the basin characteristics in the models.

Zusammenfassung

Seit vielen wird die multiple Regressionsanalyse in der Hydrologie für die Regionalisierung von Abflußkenngrößen verwandt. Dieses statistische Verfahren wurde bislang vorwiegend für die Abschätzung von Hochwasserkenngrößen sowie dem mittleren Abfluß herangezogen. Weltweit gibt es nur wenige Studien, die sich mit der Regionalisierung von Niedrigwasserkenngrößen befassen. Diese Untersuchung faßt eine umfangreiche Literaturstudie über die Anwendung und den Einsatz statistischer Verfahren zur Übertragung von Niedrigwasserkenngrößen zusammen. Dabei wurden über 120 statistische Schätzmodelle gesichtet und ausgewertet. Zuerst wurde die Art der Gebietsparameter, die als signifikante Kenngrößen in die statistischen Modelle eingingen, untersucht. Danach wurde untersucht, inwieweit die Auswahl der Gebietsmerkmale zur Schätzung der Niedrigwasserkenngrößen von der zur schätzenden Niedrigwasserkenngröße selbst abhängt.

1 Introduction

In our changing environment hydrological extremes become more and more important especially when dealing with water quality management. In the past few years a log of effort was made to establish low flow procedures and to evaluate methods to estimate low flow parameters at the ungauged site. The most popular tools in this type of regionalization are based on empirical methods or statistical approaches (Stall 1962, Goddard 1963, Speer et al. 1964). The empirical methods need beside detailed knowledge of the basin physiography (e.g. morphology, topography) additional information about the hydrological behaviour of the basin under investigation. Dyck 1976 e.g. introduced the 'specific runoff method' based on the catchment area. Hayes 1990 applied a similar approach to estimate low flow probability parameters. The statistical approaches can be separated into the correlation analysis and the multiple regression analysis. Latter is a simple method to estimate flow parameters at the ungauged site and has to be considered the most used method in hydrology and water resources management. This method has been applied in regionalization since 1960 in ca. 30 studies to estimate low flows based on 120 regression models. This paper summarizes the results of an extensive literature study carried out by the author looking at both: (1) the basin properties significant in the models and (2) the type of basin properties significant due to different low flow parameters to be estimated. The geographical extent of the studies covers only a few regions in the world. Most of the studies were carried out in the United States of America and Canada (45 and 1), Western Europe including the Scandinavian countries (70) and only very few studies in Africa (Malawi, Tanzania and Zimbabwe) with altogether 4 studies. For the regions of the entire Eastern European countries, Asia and Middle and Latin-America and Australia no literature was available at all. Therefore the study covers only part of the world and may be biased.

A first comprehensive study to regionalize various runoff parameters such as flood statistics, mean flow and low flow parameters for different regions within the United States were carried out by Thomas & Benson 1970 in the latest sixties. In Europe the first statistical estimation procedures for low flows have been developed for catchments in the United Kingdom and in Scotland. Compared to the work carried out in the United States the studies in Europe are based on a smaller sample size (Wright 1970). In general the most extensive study to regionalize low flows have been carried out in the framework of the FREND-Project (1985-1988) for the region of Western Europe (Gustard et al. 1989). In this study both type of models were developed: global statistical models for the entire study area and detailed regional statistical models covering single countries or clusters of countries or single regions only (Gustard & Gross 1989, Demuth 1989). There the statistical models are based in some case on up to 1500 basins. A comprehensive study focused on regionalization of the base flow and the parameters of the base flow recession were carried out by the author for the state of Baden-Wuerttemberg (Southwest Germany) and the South of the Black Forest (Demuth 1993).

Tab. 1 **Summary of the ten most frequent basin properties derived from 120 statistical low flow models**

Die zehn häufigsten Gebietsmerkmale aus insgesamt 120 Niedrigwasserschätzmodellen

	Basin properties	Acronym	Frequency
1.	Catchment area [km^2]	AREA	66%
2.	Annual average rainfall [mm]	GAAR	49%
3.	Soil index	SOIL	22%
4.	Median altitude [m]	HMEAN	15%
5.	Lake percentage [%]	FALAKE	13%
6.	Proportion of the catchment above the tree line [%]	MOUNT	13%
7.	Stream channel slope [km.km^{-2}]	SL1085	12%
8.	Weighted lake percentage [%]	WPLAKE	11%
9.	Base flow index	BFI	10%
10.	Drainage density [km.km^{-2}]	DD	10%

2 Model evaluation based on catchment characteristics and low flow predictors

Due to the large amount of basin characteristics (46 in total) used in the statistical low flow models the most important and frequent characteristics were evaluated from the 120 different models. Table 1 summarizes the ten most important basin characteristics according to the frequency of their occurrence. The result shows clearly that the catchment area (AREA) with a frequency of 66% and the annual average rainfall (GAAR) with 49% are the two most basin characteristics which have been set up so far in low flow estimation models. The other basin properties achieve only frequencies between 10 and 22%. Based on these findings the hydrologiste in practise wanting to estimate low flows can in general restrict on a selection of these ten basin properties. However to estimate special low flow statistics (e.g. frequency parameters, parameters derived from the flow duration curve) the restriction towards ten basin properties does not suffice.

The selection of basin properties used to estimate low flow parameters depends also on the type of low flow parameters itself. These findings are known from investigations of regionalizing flood statistics and mean flows (Aschwanden 1985). The verification of this statement was proofed by examination of 120 regression models in this study. In order to find any significant difference in the composition of the predictors the 120 models (Table 2) were classified into five groups according to the type of low flow parameter to be estimated. The following groups were chosen: Group I Models to regionalize parameters of the frequency curve; Group II Models to regionalize parameters of the hydrograph; Group III Models to regionalize parameters of the duration curve; Group IV Models to regionalize parameters of the recession curve; Group V Models to regionalize the base flow. Table 2 summarizes the studies by author in chronological order according to the five different groups. The values in brackets represent the percentage of the special model group on the total of 120 models evaluated.

Tab. 2 Result of the investigation of the 120 statistical models according to the type of models

Ergebnisse der Auswertung der 120 statistischen Modelle nach Modellgruppen und mit Angabe der Autoren

Model-Groups	Authors
Group I Frequency analysis (44.0 %)	THOMAS & BENSON (1970); BROWN (1971); ARMBRUSTER (1976); CHANG & BOYER (1977); BINGHAM (1982); FUCHS & RUBACH (1983); ARIHOOD & GLATFELTER (1986); WETZEL & BETTANDORFF (1986); MOLTZAU (1990)
Group II Hydrograph (22.5 %)	WRIGHT (1970, 1974); BROWN (1971); INSTITUTE OF HYDROLOGY (1980); GUSTARD (1983); PILON & CONDIE (1986); GUSTARD, MARSHALL & SUTCLIFF (1987); GUSTARD & GROSS (1989); SMYTH (1980); KROKLI (1989); TALLAKSEN (1989); MOLTZAU (1990)
Group III Duration curve (22.5 %)	INSTITUTE OF HYDROLOGY (1980); ARNELL, BROWN & REYNARD (1990); KUUSISTO (1986); WETZEL & BETTANDORFF (1986); GUSTARD, MARSHALL & SUTCLIFF (1987); ASCHWANDEN & SCHÄDLER (1988); WILCOCK & HANNA (1987); GUSTARD & GROSS (1989); BULLOCK et al. (1990); SIMONSEN (1992)
Group IV Base flow (6.0 %)	DEMUTH (1989); LINDER (1990); GÖRIG (1992)
Group V Recession parameters (6 %)	PEREIRA & KELLER (1982); DEMUTH (1989); DEMUTH & HAGEMANN (1993)

The high percentage (44 %) of the statistical models in Group I is obvious. This is due to the fact that there is a high demand especially in the field of water resources management to work with statistics from the low flow frequency curve. Furthermore most studies using values from frequency analysis were made in the eighties, the decade where the most low flow periods occurred. Thomas & Benson 1970 developed the first models estimating low flow parameters from the frequency curve at the beginning of the seventies for various regions in the United States. Recently Moltzau 1990 successfully finished a comprehensive study in Norway estimating different low flow statistics derived from the frequency analysis with the objective to define homogeneous low flow regions.

The models to regionalize parameters of the hydrograph and the flow duration curve (Group II and III) show with 22.5% and 21.5% similar percentages. The first studies were already published at the beginning of the seventies for areas in Scotland and Southwest England (Wright 1970 and 1974). Models to transfer parameters of the flow duration curve appeared for the first time at the beginning of the eighties in the 'Low Flow Studies' in Great Britain and Ireland (Institute of Hydrology 1980). Models estimating base flow (Group IV, 6%) and parameters of the recession curve (Group V, 6%) are only minor represented in the 120 statistical models. In case of recession parameters the first studies were carried out by Pereira & Keller 1982 based on 11 catchments in a prealpine Swiss region. In connection with regionalization the group of base flow models (Group IV) has just recently become interesting to the scientific community. The first models were developed by the author based on data from the European Water Archive (subset of small research basins) applying a global model for Western Europe and a regional model for Finland (Demuth 1989). Based on the experience of the FREND-project additional studies were carried out for subregions in Germany and the State of Baden-Wuerttemberg (Linder 1990, Görig 1992).

In a next step the different model groups were investigated by looking at the composition of the predictands within a single group. Table 3 summarizes the result of this investigation. Here the predictands (catchment characteristics) were classified into different types: morphometric properties, cover properties, geological and pedological properties, climatic and hydrological properties. In addition Table 3 shows which catchment characteristic were used to estimate a particular flow parameter (Group I - V) and which catchment characteristics are the most significant in the group considered. E.g. to estimate a low flow parameter from the frequency curve (Group I) the most important parameter is the catchment area (AREA), 77%; the parameter AREA occurs in 77% of the models), the annual average rainfall (GAAR, 53%), the soil index (SOIL, 28%), the stream channel slope (SL1085, 23%), the median altitude (HMEAN, 21%). The other parameters are of minor importance in the models. In models estimating base flow (Group IV) the annual average rainfall (GAAR) occurs in each model (100%).

3 Conclusion

The results of the 30 studies indicate that the models to regionalize parameters derived from Group I (frequency analysis), Group II (hydrograph analysis) and Group III (flow duration curve) show a similar structure considering the composition of predictands (physiographical, climatic and hydrological catchment characteristics). However, characteristic differences among these three model groups become obvious only by considering single relevant predictands. These differences can be usually explained by differences in the physiography of the region itself. The most frequent used predictand in the three model groups is the catchment area (AREA) followed by the climatic variable annual average rainfall (GAAR). The application of the basin properties such as WPLAKE, SOIL, BFI, SL1085, HMEAN and MOUNT are highly dependent on the regional characteristics and the background of the author. Furthermore it is obvious that apart from the hydrological characteristic base flow index the predictands are exclusively physiographical basin properties. Among the first three model groups these physiographical basin characteristics are more important than the climatic

Tab. 3 **Frequency of the Drainage basin properties in the five model groups**

Häufigkeit der Gebietsmerkmale in den 5 verschiedenen Modellgruppen

	Predictands	Acronym	Percentage within the model groups				
			Frequency Analysis	Hydrograph	Duration Curve	Base flow	Recession Analysis
			I	II	III	IV	V
Morphometric properties							
1.	Catchment area [km²]	AREA	77	59	62	43	43
2.	Stream channel slope (10-85%)	SL1085	23	-	-	-	-
3.	Main river length [km]	MSL	-	-	-	14	-
4.	Median altitude [m]	HMEAN	21	-	19	29	
5.	Maximum altitude [m]	HMAX	-	19			
6.	Length of the catchment [km]	AXIS	15	-	-	-	-
7.	Relief	RELIEF	-	15	-	-	-
8.	Catchment width [km]	WIDTH	-	15	-	-	-
9.	Drainage density [km.km⁻²]	DD	-	-	-	86	57
10.	Strahler's bifurcation ratio	RB	-	-	-	-	14
Cover properties							
11.	Percentage of forest [%]	FOREST	-	-	-	43	29
12.	Weighted lake percentage [%]	WPLAKE	-	30	-	-	-
13.	Percentage of lake, reservoir [%]	FALAKE	15	-	19	-	14
14.	Catchment above tree line in %	MOUNT	19	22	-	-	-
15.	Urban development in %	URBAN	-	11	12	-	-
16.	Volume of growing stock [m³.ha⁻¹]	VGS	-	-	-	-	14
17.	Percentage of pasture [%]	PAST	-	-	-	-	14
Geological and pedological properties							
18.	Soil index	SOIL	28	19	23	-	-
19.	Hydrogeological index	GEO	-	-	-	-	71
Climatic properties							
20.	Annual average rainfall [mm]	GAAR	53	48	38	100	14
21.	Distance to sea to the west [km]	WSEA	-	11	-	-	-
Hydrological properties							
22.	Base flow index	BFI	-	15	27	14	
23.	Runoff ratio (Q20/Q90)	RATIO	17	-	-	-	-
24.	Recession constant	KST	-	15		-	-

and hydrological predictands in low flow regionalization. The models to regionalize the base flow and the parameters of the recession curve show a significantly different structure in the composition of the predictands in comparison to the model groups above (Group I-III). In some cases other characteristics are used e.g. bifurcation ratio (RB) according to Strahler or the mean river length (MSL). The totally changed frequencies resulted in a completely changed weighting of the single predictands e.g. the frequency of the climatic characteristic annual average rainfall (GAAR), which is present in all base flow models. In model group V (models regionalizing parameters of the recession curve) the geological characteristic (GEO) occurs most frequent, followed by the drainage density (DD). Concerning the significant basin characteristics the regionalization of low flows has to be ranked between the regionalization of mean and flood flows. In case of regionalizing mean flows the climatic basin characteristics are dominant, whereby the physiographical characteristics are dominant in regionalization of flood statistics.

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REGIONAL HYDROLOGIC ANALYSIS OF LOW STREAMFLOW IN THE DRAVA RIVER CATCHMENT IN CROATIA

REGIONALE HYDROLOGISCHE ANALYSE DER KLEINWÄSSER IM DRAVA FLUSSGEBIET IN KROATIEN

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ABSTRACT

Based on the hydrologic data for the period 1960-1989, a regional hydrologic analysis of low streamflow has been developed for the Drava River catchment in Croatia. The basic low streamflow parameters were $Q_{30,80\%}$, $Q_{30,95\%}$ (minimum average 30-day discharge of 80 and 95% probability) and Q_{min} (absolute minimum annual discharge).

We have also presented the hydrologic analysis of low streamflow for small catchment areas on which there are insufficient or no available data.

ZUSAMMENFASSUNG

Für Drava Flußgebiet in Kroatien an der Basis der hydrologischen Daten aus dem Periode 1960-1989 wird die regionale Analyse der Kleinwässer ausgearbeiten, Die Grundindizen der Kleinwasser werden $Q_{30,80\%}$, $Q_{30,95\%}$ (minimaler mittlerer 30-jähriger Tagesdurchfluß mit 80 und 95 % Wahrseheinligkeit) und Q_{min} (absoluter minimaler ..esdurchfluß).

Auch die hydrologische Analyse der Kleinwässer für k Flußgebiete, von denen gibt es wenig oder gar keine Daten, w.. dargestellt.

1. INTRODUCTION

The increasing water demand, both from quantitative and qualitative aspect, changes the orientation of the water management projects towards the low streamflow courses. On the other hand, the network of hydrological gaging stations was meinly developed in the large and medium-size rivers. However, the practice increasingly requeste water regime analyses for low streamflow courses for which there are no measurements or they are of short duration. For these reasons the present regional low streamflow analysis has been prepared on the basis of data for large and medium-size rivers, and the low streamflow equations have been presented.

3. ANALYSIS RESULTS

In low streamflow regional analysis, the discharge data were used from 16 gaging stations in the Drava River catchment for the period 1960-1989. Three characteristic low streamflow reference values were calculated, expressed as specific values $q_{30,80\%}$, $q_{30,95\%}$ (specific minimum mean 30-day discarge of 80 and 95% probability) and q_{min} (specific minimum annual discarges). The specific inflows of low streamflow ($l\ s^{-1}km^{-2}$) in the Drava River catchment are shown in Table 1.

Table 1. Characteristic specific inflows of low streamflow ($l\ s^{-1}km^{-2}$) in the Drava River catchment

Tabelle 1. Charakteristische spezifsche Ergiebigkeiten der Kleinwässer ($l\ s^{-1}\ km^{-2}$) in Drava Flußgebiet

No.	STATION	RIVER	A (km^2)	$q_{30,80}$	$q_{30,95}$	q_{min}
1.	BEZDAN *	DUNAV	210250.0	4.80	4.17	3.76
2.	BOGOJEVO *	DUNAV	251593.0	5.32	4.67	4.23
3.	BOTOVO	DRAVA	31038.0	6.99	5.99	2.58
4.	D. MIHOLJAC	DRAVA	37142.0	6.41	5.68	4.42
5.	G. RADGONA *	MURA	10197.0	5.95	5.22	4.31
6.	JANDRAŠIČEK	TRNAVA	105.1	0.48	0.27	0.03
7.	KOPRIVNICA	KOPRIVNICA	122.0	0.57	0.43	0.03
8.	LETINA	MURA	13148.0	5.06	4.06	2.99
9.	LUDBREG	BEDNJA	547.0	2.21	1.67	0.41
10.	MIKLEUŠ II	VOĆINKA	173.0	0.76	0.57	0.10
11.	MLAČINE	GLIBOKI	84.0	0.54	0.01	0.00
12.	M. SREDIŠĆE	MURA	10891.0	5.91	5.10	3.85
13.	NOVIGRAD P.	KOMARNICA	48.0	0.25	0.08	0.00
14.	TEREZINO P.	DRAVA	33916.0	6.40	5.34	3.18
15.	TORMAFOLDE *	KERKA	978.0	0.87	0.68	0.35
16.	ŽELEZNICA	BEDNJA	308.0	1.74	1.30	0.71

*** stations outside the Croatian territory**

The graphical interpretation of the above values, using isolines, in given in Figs. 1, 2, and 3.

Fig. 1. Isolines of specific minimum mean 30-day discharge of 80 % probability ($q_{30,80\%}$)

Abb. 1. Isolinien der spezifischen minimalen mittleren 30-jährigen Tagesdurchflüße mit 80 % Wahrscheinligkeit ($q_{30,80\%}$)

Fig. 2. Isolines of specific minimum mean 30-day discharge of 95 % probability ($q_{30,95\%}$)

Abb. 2. Isolinien der spezifischen minimalen mittleren 30-jährigen Tagesdurchflüße mit 95 % Wahrscheinligkeit ($q_{30,95\%}$)

Fig. 3. Isolines of specific minimum annual dischareges (q_{min})
Abb. 3. Isolinien der spezifischen minimalen Jahresdurchfluß (q_{min})

According to the obtained study results it is clear that the largest values of $q_{30,80\%}$, $q_{30,95\%}$ have been obtained for the Drava and Mura Rivers data. The specific parameters for the smaller water courses have considerably smaller values.

3. HYDROLOGIC ANALYSIS OF LOW STREAMFLOW IN INSUFFICIENTLY ANALYZED WATER COURSES

According to the UNESCO Recommendations (1982), Vladimirov's method has been applied in low streamflow analysis for insufficiently studied water courses (catchments). For data obtained from the nine gaging stations in low streamflow courses in the Drava River catchment area ($48.0 < A < 173.0$ km^2) for the period 1980-1989, through a relation:

$$Q_{30,80\%} = a\ A^{b} \qquad (1)$$

where:

$Q_{30,80\%}$ - minimum mean 30-day discharge with 80% probability (l s^{-1})
A - catchment area (km^2)
a, b - unknown coefficients,

the below analytical expression has been obtained:

$$Q_{30,80\%} = 0.0116\ A^{1.868} \qquad r = 0.890 \qquad (2)$$

Applying the transition coefficient, the expression for the second parameters was obtained:

$$Q_{30,95\%} = 0.690\ Q_{30,80\%} \tag{3}$$

Conclusively, the practical expressions have been obtained which can be used for small catchments (48.0 < A < 173.0 km^2) the data on which are lesser or unavailable. It is clear that the objective is an application of measured values and the above relations could not be verified without them.

4. CONCLUSION

The basic conclusion is the need for increasing number of quality hydrologic measurements, both on large and medium-size rivers and on low streamflow courses. Only measurements can verify and improve the regional analysis data.

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XVII. KONFERENZ DER DONAULÄNDER
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REGIONAL ANALYSIS OF LOW-FLOWS FOR THE TERRITORY OF THE REPUBLIC OF SERBIA

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ABSTRACT

From the water management point of view, drought has significant economic and social influence. Extremely low-flows can cause shortage, decreased production, pollution and various other damages.

According to the legal regulations, prescribed by the Republic of Serbia, concerning either water resources development, or land use management or any other environmental aspect, only the monthly average low-flow discharge, with 0.95 probability of occurrence is determined as the designed low-flow value. On the contrary, hydrological analysis of low-flow regime for the territory of the Republic of Serbia have shown that the 30 days average low-flow discharge, with 0.95 probability of occurrence ($Q_{95\%}$) should be used. This variable has a physical meaning (not only the numeric value of the discharge is defined, but the duration of the drought as well) and is not liable to the influence of overestimation of the discharge, due to fixed time intervals (calendar one month).

Estimation of the designed low-flow value for hydrologically unexplored areas, or for the short runoff records, was done by the regional analysis. Up to the present, all studies of low-flow characteristics have proved that the territory of the Republic of Serbia can not be treated as homogeneous. It is necessary to apply low-flow analysis for subregions. The basic information are the measured daily discharges at gauging stations. The time series of all characteristic low-flow variables and required meteorological parameters were determined using systematic observation from the basic hydrological and meteorological network. For relatively

homogeneous areas, general relationship was obtained, between the 30 days average low-flow discharge, with 0.80 probability of occurrence and the catchment area such as $Q_{80\%} = a(A)^n$. (To obtain the 30 days average low-flow discharge, with 0.80 probability of occurrence discharge ($Q_{80\%}$), we used three-parameter Weibull and two-parameter log PIRSON III probability distribution functions). By the similar procedure the designed low-flow discharge is determined by function $Q_{80\%} = c(Q_{80\%})^m$. During this process only the watershed areas less then 2000 km^2 were analyzed, due to impossibility of low-flows coincidence, different low-flow characteristics and substantial heterogeneity of hydrogeological characteristics.

Entire watershed area of the territory of the Republic of Serbia, concerning the low-flow characteristics, the hydrogeological characteristics, the multi-annual precipitation and the average elevation, has been divided into several regions and subregions.

This approach for estimation of the 30 days average low-flow discharge characteristics of unexplored catchments has given satisfactory explanation during the survey of exceptions.

1. INTRODUCTION

To attain optimal water use, the consumers should be supplied with water at the rate and quality required to meet its justified demand. Drought (duration, deficit and occurrence time) has significant influence on it as economic feature of water resources. Intention to design any hydrotechnical system (water supply systems, irrigation, waste water treatment plants, etc.) requests the designed low-flow to be estimated, as a minimum discharge for main aims to be fulfilled.

Having on mind the fact, discharge is a random variable, there is no economic approval to define the recorded (absolute) minimum value as the designed low-flow. Low-flow has been analyzed for purposes of safety of water supply for given water demands.

The main intention of this paper is to find possibilities for quick and reliable estimation of the designed low-flow in hydrologically unexplored areas for various hydrotechnical purposes.

2. STATISTICAL ANALYSIS OF LOW-FLOW

The following watershed areas are included in the statistical analysis of low-flow characteristics for the territory of the Republic of Serbia:

(1) The Drina catchment
(2) The Kolubara catchment
(3) The V. Morava catchment
(4) The J. Morava catchment
(5) The Nisava catchment
(6) The Toplica catchment
(5) The Z. Morava catchment
(8) The Ibar catchment
(7) The Timok catchment
(10) The Homolje catchment
(9) The Dragovištica catchment
(12) The Drim catchment

Time series of all characteristic low-flow variables and required meteorological parameters were determined using systematic observations from the basic hydrological and meteorological network. Basic dates are the measured daily discharges at gauging stations. In order to determine accurate time series of low-flow the quality control and improvement of data were done. Continuous and homogeneous time series of average low-flow were defined for different time units: one day, ten, twenty and thirty days and monthly period. To estimate the low-flow characteristics, fitting was done by three-parameter Weibull and two-parameter log PIRSON III theoretical probability distribution functions. Goodness of fit tests was done applying the Kolmogorov test.

As a result of this analyses, the best fitted theoretical probability distribution functions are selected and the 30 days average low-flow discharges, with 0.80 probability of occurrence ($Q_{80\%}$) are estimated.

3. REGIONAL ANALYSIS OF LOW-FLOWS

3.1 General remarks on regional analysis of low-flows

One of approaches for estimation of low-flow characteristics in hydrologically unexplored areas is to use empirical relations between the minimum discharge and the catchment area. For relatively homogeneous areas (concerning the hydrogeological characteristics, the multi-annual precipitation, the average elevation, afforestation, etc.) the correlation equation between the 30 days average low-flow discharge, with 0.80 probability of occurrence and the catchment area can be written as (Fig. 1 and 3):

$$Q_{80\%} = aA^{b} \qquad (3.1)$$

where:

$Q_{80\%}$ - is a low-flow discharge as a thirty days average, with 0.80 probability occurrence in m^3/s
A - is the area in km^2
a, b - are the areal constants

By the similar procedure, depicted in the Figure 2 and 4, the designed low-flow discharge ($Q_{95\%}$) is determined by function written in the form

$$Q_{95\%} = c(Q_{80\%})^{m} \qquad (3.2)$$

where:

$Q_{80\%}$ - is a low-flow discharge as a thirty days average, with 0.80 probability occurrence in m^3/s
c, m - are the areal constants

During this process only the watershed areas less then 2000 km^2 were analyzed, due to impossibility of low-flows coincidence, different low-flow characteristics and substantial heterogeneity of hydrogeological characteristics.

3.2. Hydrogeological aspects for the low-flow regional analysis

Territory of the Republic of Serbia is characterized by complex geological fabric, vary heterogeneous lithologic composition, different and active tectonic with numerous erosion processes. To understand correctly the role of hydrogeology in space and time, at regional analysis of low-flow, the thorough knowledge about terrain geological composition, its structure and tectonic, is indispensable. It is, also, necessary to have information about the other elements and factors which make an direct and/or indirect influence on the state of ground water at the present, namely hydrogeological features of certain space.

Carrying out of this project was based on Serbian general hydrogeological regional division. Considering the geology-structural, hydrogeological, facial and lithological characteristics in common with physic-geographical features (climate, topography, etc.) the territory of the Republic of Serbia is divided to six regions (1):

1. The area of Carpatho-Balcanian mountain-range
2. The area of Serbian crystalline core
3. The area of Central and South Serbia
4. The area of Western Serbia
5. The area of Panonian basin
6. The area of Dacian basin.

The low-flow regional division is made for the first four regions.

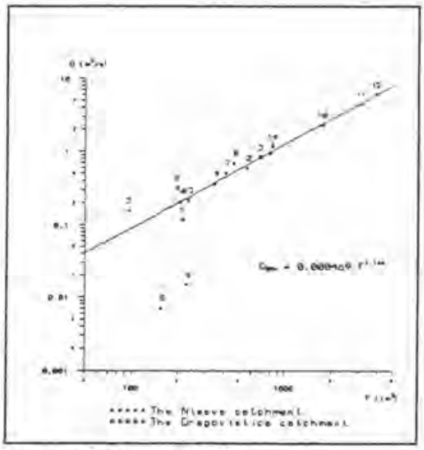

Figure 1 $Q_{80\%} = f(A)$

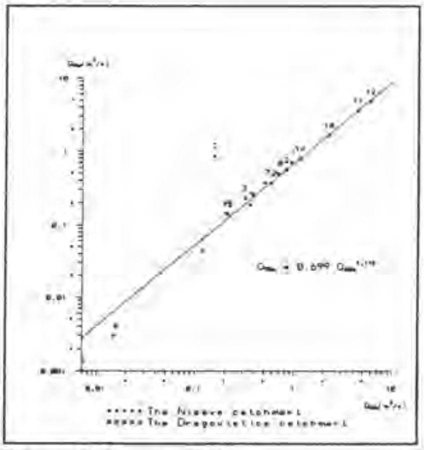

Figure 2 $Q_{95\%} = f(Q_{80\%})$

Referring to specific structural-geological, hydrogeological and geomorphological units, the mountain (fold) structure (Vlasinski, Velikorzavski, etc.) and the basin structure (Metohijski, Mačvanski, etc.) subregions were separated. The correlation relations for this different regions are shown in the figures 1 and 2 - for the mountain structure, and in the Figure 3 and 4 for the basin structure.

Hydrological units are conditioned by lithological composition and geomorphology of the terrain. As a consequence of diversity in seepage characteristics and space relations, different hydrological functions are caused, regardless of lithological composition. According to the rock mass geometry and seepage characteristics and its interaction, on the territory of the Republic of Serbia, five tics. hydrological different types of terrain are divided (2):

- terrain with intergranular porosity of aquifer
- terrain with intergranular and fractured porosity of aquifer
- terrain with cavernous - fractured porosity of aquifer
- terrain with fractured porosity of aquifer
- terrain mostly without aquifer

For example, in the area of alluvial flats, during the average or high water level, ground water in sand-gravel water-bearing formation is of sub-artesian characters. In the elevated loam, "free-phreatic aquifer" exists, at the same time. At low-water level sand-gravel water-bearing formation, amount of ground water is insignificant.

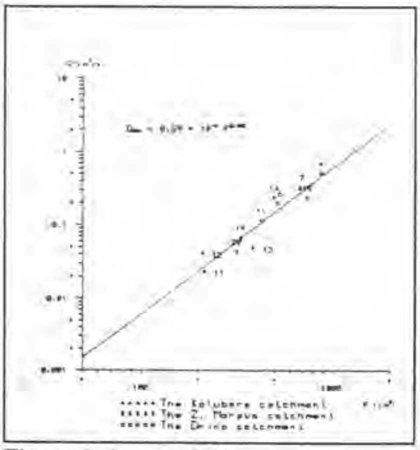

Figure 3 $Q_{80\%} = f(A)$

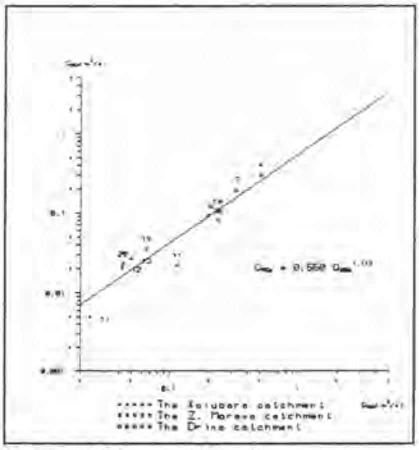

Figure 4 $Q_{95\%} = f(Q_{80\%})$

4. CONCLUSIONS AND REMARKS

As a result of this research, the map of Srbija showing divided subregions with different low-flow characteristics has made. The correlation equations 3.1 and 3.2 have defined for every subregion. Although the estimation of low-flow characteristics in hydrologically unexplored areas, based on the catchment area characteristics, is generally speaking, rough, increasing requirements for those analyses in water resources development and management and other environmental aspects justify their application. The major advantage of this approach is the possibility of quick estimation of the design low-flow value in hydrologically unexplored areas.

Exposed approach give us possibility to make a look at ground water forming conditions in certain environment circumstances and their changes in time. Our concrete investigations confirm the fact, this approach is exact way low-flow regional analysis.

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REGIONAL ANALYSIS OF ANNUAL MAXIMUM DISCHARGES IN THE TERRITORY OF SERBIA

by

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ABSTRACT

In this paper the results of regional analysis of the basic parameters of the flood flows (maximum annual discharges) are presented. The regional relationships are defined on the basis of data from 147 gauging stations on the territory of Serbia with the period of observation over 30 years. The applied methodology is based on space-time analysis using the technique of development of the regional growth curves. The paper is illustrated with the most important general results of carried out regional analysis.

REGIONALE ANALYSE MAXIMALER JAHRESDURCHFLÜβE AUF DEM TERRITORIUM SERBIENS

ZUSAMMENFASSUNG

In der Arbeit sind die Ergebnisse der regionalen Analyse von Grundparametern der Groβgewässer (maximale Jahresdurchflüβe) dargestellt. Es sind regionale Abhängigkeiten aufgrund von Beobachtungsangaben der 147 Wassermeβstationen auf dem Territorium Serbiens für den Zeitabschnitt mehr als 30 Jahre definiert. Die angewandte Methodik beruht auf der räumlich-zeitlichen Analyse unter Benutzung der Technik normalisierter Verteilungskurven. Die Arbeit ist durch die wichtigsten allgemeinnen Ergebnisse der durchgeführten Regionalanalyse illustriert.

INTRODUCTION

Proper choice of relevant maximum discharges for the purpose of designing on wider area is possible only after comprehensive spatial-time analysis of its basic statistical parameters. For the purpose of such analysis very long series of maximum annual discharge are necessary. Unfortunately, in the practice of most Danube countries existing series of maximum annual discharge are limited in time. The consequence is that statistical parameters, computed on the basis of them, can be very unreliable and burdened by significant errors. Spatial variability which can be obtained in analysing these parameters can be the consequence of the nature of the process of maximum annual discharge, but also the error in its computing.

For the purpose of understanding of spatial variability of the process of maximum annual discharge on the territory of Serbia and investigating the possibility of its regionalization detailed spatial-time analysis of existing time series has been done. Preliminary results judging by spatial regionalization and homogenization of the series of maximum anuual discharge are given in this paper.

REGIONALIZATION PROCEDURE OF DISTRIBUTION CURVES OF MAXIMUM ANNUAL DISCHARGE

The basis for the regionalization of the series of maximum discharge on the territory of Serbia are the results of the computation of occurence probability on 147 gauging stations. Theoretical probability values are obtained with the help of Pearson III and Log-Pearson III distribution functions. In this case ll the analyses were carried out with the normalized distribution functions in the mode of:

$$K_p = \frac{\frac{Q_p}{\overline{Q}} - 1}{C_v}$$

where:

- K_p - ordinate values normalized by the distribution function for probability p
- Q_p - maximum annual discharge for probability p
- $\overline{Q}$ - mean value of the series of maximum annual discharge
- C_v - variation coefficient of the series of maximum annual discharge

Normalized distribution functions of the maximum annual discharge probability were computed for all the gauging stations having the series longer than 30 years. On the basis of obtained ordinates of all the gauging stations the fluctuation amplitudes of normalized values for the probability characteristics were defined by:

$$A_p = K_{max,\,p} - K_{min,\,p}$$

where:

- A_p - fluctuation amplitudes of the ordinate values of normalized distribution functions for probability p,
- $K_{max,\,p}$ - maximum ordinate of distribution functions for probability p,
- $K_{min,\,p}$ - minimum ordinate of distribution functions for probability p.

Value of fluctuation amplitude is then divided on n class interval of the value:

$$\Delta K_{p,\,i} = \frac{A_p}{n} = const.$$

where:

$\Delta K_{p,i}$ - class interval value,
n - total number of class interval,
i - ordinal number class interval.

Class intervals are defined, in general, as:

$$\Delta K_{p,i} = UL_{p,i} - LL_{p,i}$$

where:

$UL_{p,i}$ - upper limit of class interval,
$LL_{p,i}$ - lower limit of class interval.

In defined case:

- for i = 1

$$\Delta K_{p,1} \qquad LL_{p,1} = K_{\min,p}$$
$$UL_{p,1} = K_{\min,p} + \Delta K_{p,i}$$

- for i = 2

$$\Delta K_{p,2} \qquad LL_{p,2} = K_{\min,p} + \Delta K_{p,i}$$
$$UL_{p,2} = K_{\min,p} + 2 \cdot \Delta K_{p,i}$$

- for i = i

$$\Delta K_{p,i} \qquad LL_{p,i} = K_{\min,p} + (i-1) \cdot \Delta K_{p,i}$$
$$UL_{p,i} = K_{\min,p} + i \cdot \Delta K_{p,i}$$

- for i = n

$$\Delta K_{p,n} \qquad LL_{p,n} = K_{\min,p} + (n-i) \cdot \Delta K_{p,i}$$
$$UL_{p,n} = K_{\min,p} + n \cdot \Delta K_{p,i} = K_{\max,p}$$

Computed ordinates of normalized distribution functions for all the gauging stations were classified in relevant class intervals and adequate identification number INB were given to them which correspond to the ordinal number of class interval. The frequency of identification number in the probability occurence function was analysed as per whole territory of Serbia and as per gauging stations. The prevailing identification number for the certain gauging station is obtained as the weight mean value.

$$MINB = \frac{\sum_{i=1}^{n} i \cdot INB}{n}$$

where:

$MINB$ - prevailing value of identification number of the certain gauging station.

Average value of identification number in the function of occurence probability for the territory of Serbia is computed as per the formula:

$$MINB_p = \frac{\sum_{j=1}^{N} INB_{j,p}}{N}$$

where:

$MINB_p$ - average identification number for the territory of Serbia for the occurence probability p;

$INB_{j,p}$ - identification number of j - th gauging station for probability p;

N - total number of gauging stations on the territory of Serbia.

RESULTS OF PRACTICAL PROCEDURE APPLICATION FOR REGIONALIZATION OF DISTRIBUTION CURVES OF MAXIMUM ANNUAL DISCHARGE

Explained procedure of regionalization of distribution curves of maximum annual discharge is applied on 147 gauging stations on the territory of Serbia which had the observation period longer than 30 years. In the following text the computation results in numerical and graphical mode are given.

All the computed ordinates of normalized distribution curves of maximum annual discharge priobability as per gauging stations are classified in relevant class intervals, that is, relevant identification number INB_j is given to them where i=1,2,...n(n=10). The example of these computations is shown in *Table 1* on key profiles of gauging stations on the territory of Serbia. The Table also contains relevant statistical parameters like: mean values MINBp, standard deviation SDINp, variation coefficient CVINBp, asymmetrical coefficient CSINBp.

Survey of Identification Number on Key Gauging Stations in Serbia

Table 1

N°	Gauging station	River	Area	Probability in %						
				50	20	10	5	2	1	0.1
1	Bezdan	Danube	210 250	6	6	5	3	2	2	1
2	V.Gradište	Danube	670 375	7	6	5	3	2	2	1
3	Senta	Tisa	141 715	5	5	5	4	3	2	1
4	S.Mitrovica	Sava	87 996	5	5	5	4	3	2	1
5	Lj.Most	V.Morava	37 320	6	6	5	3	2	2	1
6	Radalj	Drina	17 493	4	4	5	4	4	3	2
7	Vrbnica	B.Drim	4 381	4	5	6	5	4	3	2
8	Orćuša	Plavska	252	3	1	2	1	2	2	3
147	Drelje	Pećka Bis.	120	1	7	10	10	10	10	10
Teritory of Serbia			MINBp	3.5	4.1	4.8	3.9	3.5	3.3	2.9
			SDINBp	1.4	1.4	1.2	1.0	1.0	1.1	1.7
			CVINBp	0.4	0.4	0.3	0.3	0.3	0.3	0.6
			CSINBp	1.4	0.0	0.0	1.1	1.6	1.6	1.7

Representive normalized distribution curve of maximum annual discharge on the territory of Serbia computed as mean value of upper and lower limit of confidence interval in the function of occurence probability is shown on Fig.1. Relevant identification number INB_j is added to each representative curve. The same drawing also contains average normalized curve for the whole territory of Serbia.

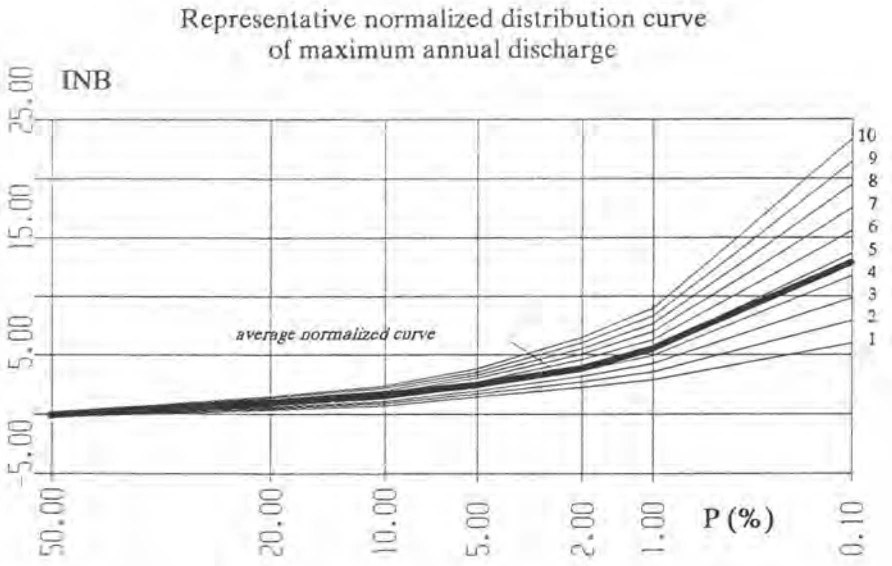

Figure 1

Table survey of representatives of certain identification number on key profiles of gauging stations in Serbia is shown in Table 2. In the same table certain statistical parameters are given as well: mean value $MINB_i$, standard deviation $SINB_i$, coefficient of variation $CVINB_i$ and coefficient of asymmetry $CSINB_i$.

Survey of Representation of Identification Number on Key Profiles of Gauging Stations in Serbia

Table 2

N^O	Gauging station	River	Identification number										MINB
			1	2	3	4	5	6	7	8	9	10	
1	Bezdan	Danube	1	2	1	0	1	2	0	0	0	0	3.57
2	V.Gradište	Danube	1	2	1	0	1	1	1	0	0	0	3.71
3	Senta	Tisa	1	1	1	1	3	0	0	0	0	0	3.57
4	S.Mitrovica	Sava	1	1	1	1	3	0	0	0	0	0	3.57
5	Lj.Most	V.Morava	1	2	1	0	1	2	0	0	0	0	3.57
6	Radalj	Drina	0	1	1	4	1	0	0	0	0	0	3.71
7	Vrbnica	B.Drim	0	1	1	2	2	1	0	0	0	0	4.14
8	Orćuša	Plavska	2	3	2	0	0	0	0	0	0	0	2.00
147	Drelje	Pećka Bis.	1	0	0	0	0	0	1	0	0	5	8.29
Teritory of Serbia		MINBi	0.3	1	1.7	2.1	1.3	0.4	0.1	0.0	0.0	0.1	3.72
		SDINBi	0.6	0.8	1.1	1.4	0.9	0.7	0.2	0.2	0.1	0.5	0.66
		CVINBi	2	0.8	0.6	0.6	0.7	1.7	5.1	6	12	7.6	0.18
		CSINBi	2.6	1.2	1	0.3	0.4	1.5	5.5	5.8	12	9.2	2.27

Total survey of representation of relevant identification number (annual number MINB) for certain gauging station on the territory of Serbia is shown graphically on Fig.2 in the mode of frequency and representation curves

Frequency and representation curves
of mean identification number MINB

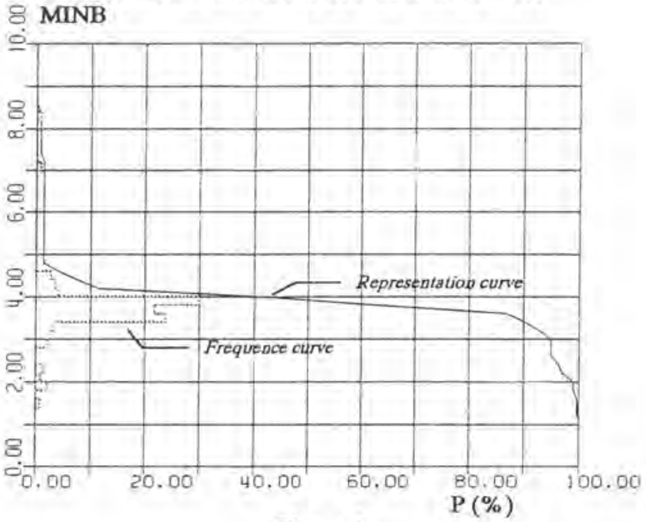

Figure 2

CONCLUSION

Numerical and graphical indices of results of carried out analyses show that not a single profile of gauging station on the territory of Serbia can be singled out as uniform regional normalized distribution functions of maximum annual discharge. Almost each particular gauging station in the probability occurence of 50 % to 0,1 % correspond from three to more defined regional curves. From the standpoint of average values of most represented are regional curves from identification number from 3 to 5. In general, it can be concluded that great spatial identification number of heterogeneity exists in the water function. That only indicates the expressed regionalization of basic statistical parameters of the maximum annual discharge series on the territory of Serbia.

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Kowalski, B., Gabriel, B. und M. Schramm

Erfahrungen und Ergebnisse bei der Berechnung von Hochwasserscheiteldurchflüssen mit Wahrscheinlichkeitsaussage in Südthüringen unter Nutzung eines geographischen und eines hydrologischen Informationssystems
(POSTER)

Das Verfahren *HQ-REGIO* wurde bereits auf der Konferenz der Donauländer 1992 in Kelheim vorgestellt.
Es wurde auf der Basis angepaßter Verteilungsfunktionen der Jahres-Hochwasserdurchflüsse (HQ) und einzugsgebietsabhängiger Faktoren, die direkt oder in transformierter Form eine statistische Abhängigkeit zu den HQ- Werten aufweisen, entwickelt und dient der Ermittelung von Hochwasserscheiteldurchflüssen mit Wahrscheinlichkeitsaussage in hydrologisch unbeobachteten Gebieten.

Im Einzugsgebiet der oberen Werra erfolgte die Modellanpassung auf der Grundlage der Daten von 24 Pegelstationen mit Reihen von 20 bis 100 Jahren sowie den, mit Hilfe des geographischen Informationssystems (GIS) *ARC/ INFO*, ermittelten Geofaktoren.

Die praktische Anwendung für unbeobachtete Einzugsgebiete setzt entweder den ständigen Einsatz eines GIS für diese Aufgabe oder die einmalige Ermittelung der Geofaktoren für ein Netz ausgewählter kleiner Flächen voraus. In Thüringen wird der zweite Weg beschritten.
Die Bestimmung der mittleren Gebietsniederschläge und -abflüsse erfolgt mit Hilfe des hydrologischen Informationssystems *GEOFEM*, das außerdem die Ermittelung langjähriger Werte von

- potentieller Gebietsverdunstung
- realer Gebietsverdunstung
- Direktabfluß und
- Grundwasserneubildung mit schnellen und langsamen Anteilen

ermöglicht. Die dem System zugrundeliegenden Berechnungsalgorithmen gelten prinzipiell nur für den Festgesteinsbereich. Durch die verwendete spezielle Rasterung mit Einheiten von 500 × 500 m ist die detaillierte Erfassung stark variierender Ausgangsparameter einer kleinen Gebietsfläche möglich.

Für den Grad der Abhängigkeit der Hochwasserwahrscheinlichkeit von den Einflußfaktoren liefert der multiple Korrelationskoeffizient eine Aussage. Im Südthüringer Raum liegt er nach den letzten Anpassungstests zwischen 0,94 und 0,97. Die vorliegenden Ergebnisse, die im Poster näher erläutert werden, sind für Gebiete ≥ 10 km^2 akzeptabel.

An der Verbesserung der Anpassung für kleinere Gebiete wird gearbeitet. Insbesondere erscheint die Berücksichtigung extremwertstatistisch berechneter Starkniederschläge als aussichtsreiche Möglichkeit zur Beseitigung der vorhandenen Mängel.

Perspektivisch ist die Einbindung von *HQ-REGIO* und *GEOFEM* in ein übergreifendes wasserwirtschaftliches Informationssystem auf der Basis von *ArcView* vorgesehen. Auf diese Weise wird der geographische Bezug zu beiden Verfahren hergestellt.

Die bereits realisierten Lösungsschritte sollen am Posterstand an einem PC demonstriert werden.

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NATIONAL INFORMATION BANK OF SEDIMENT DATA

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S U M M A R Y

A National Information Bank of Sediment Data (NIBSD) has been developed. It covers the National wide gage network of Bulgaria. Data about the suspended sediment concentration/load; sediment organic concentration; grain-size distribution; river sediments specific weight have been included in. In addition one should find the water discharge data as well as the water level and temperatue; water quality and heavy metal content. The precipitation data is on the list as it is required when the surface erosion is considered. The output of the NIBSD is on three level according to the way the data has been treated. This make sense when the data market is conserned.

The Bank, the catalog and the retrieval system is computerized and this allow a direct fast access to the information.

NATIONAL INFORMATION BANK OF SEDIMENT DATA

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The project designs of water intakes, channels, ponds and dams and much more engineering constructions require appropriate sediment load data about the rivers. The present day computer facilities permit their bank storage and multidirectional retrieval and usage. There isn't many references on the sediment data bank structure, function and maintenance [Proceedings 1980, Guidlines, 1985]. It is hard to find the links with some other water resources information banks. To add one should say, some papers [Мандаджиев, Божкова, 1987] etc. recommend the development of sediment data bank without any details.

In 1992-93 the authors have done a complete National Information Bank of Sediment data for the Bulgarian rivers - fig.1.

It allows the storage on a disk the valuable information both on suspended load, that has been gathered since 1952 and water discharge, measured since 1935, as well as the water temperature, the atmospheric precipitation, the water chemical composition etc. It is intended to build it in as a separate part of the total National Information Bank of Hydro-meteorological data, stationed at the National Institute of Meteorology and Hydrology, Sofia.

The sediment data bank consists of four units - enter - [1], computation - [2], management - [3], exit -[4].

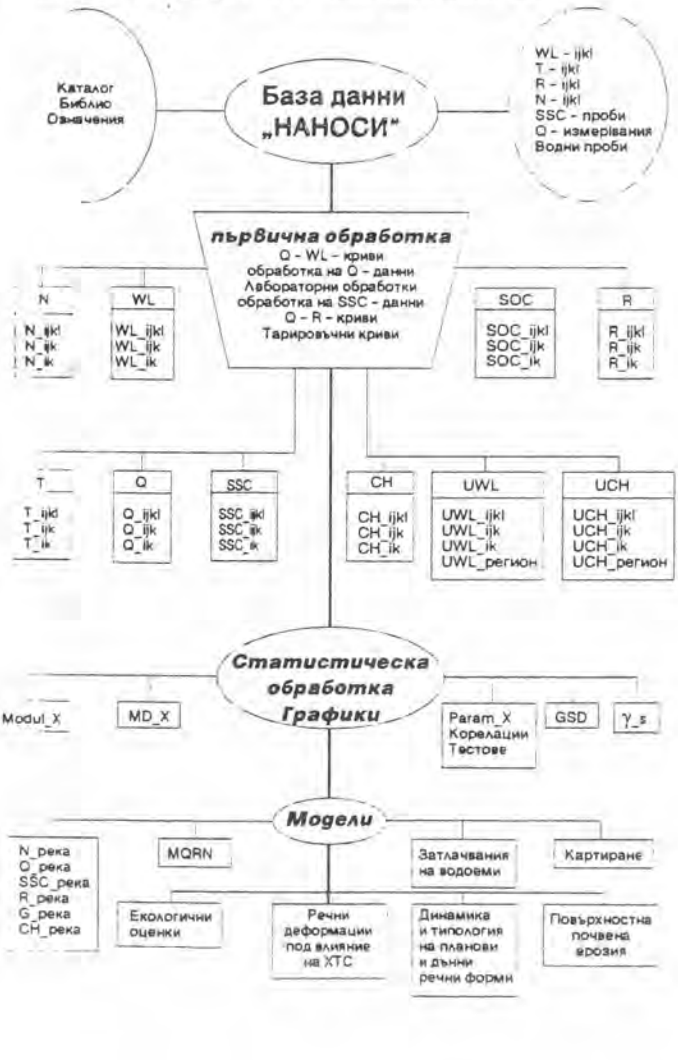
The basic conception we share is that all the data either observed or measured at the gage network is "equidistant" - [1.1]. A permanent separate part of the "entrance" unit one should consider a computerized catalogue of rivers -[1.2]. It contains detailed information about the watersheds - the areas, the mean altitudes above sea level, the length of the rivers and the distances of the gage stations from the months and the sources etc. The catalogue might be adjusted according to any changes of the locations of the gage stations.

The next separate part of the "entrance" unit consists of a "Biblio" catalogue -[1.3] with the main needed references.

A part of the treatment required - [2], or in some cases - whole procedure, might be computerized [Автоматизация, 1988]. Another part of the first step raw data treatment includes a computerized module for suspended sediment laboratory data calculations on the concentration as well as on the load values. The later software has been developed by the authors and it is applied at the National Institute of Meteorology and Hydrology in Sofia for two years already. Thus the data management is speeded up and one should enlarge the sample's numbers in spite of.

The exit itself is devided in three levels according to the degree the information is treated - the first level being the tables of everyday water and suspended sediment discharges after they are developed by means of current meter calibration curves and discharge rating curves.

The second "exit" level of the bank includes some sophisticated statistical parameters -[4.2], the assessment of their accuracy; the mountly and seasonal distribution; the annual and multiannual water and sediment yield data; the statistical tests solution etc.. presented by appropriate useful tables or graphics, that are mainly used by the practicing engineers. We have set two more modules on that level, that contain the sediment grain-size distribution data and specific weight of sediments as they are of special interest for the engineers.



The last, third "exit" level of the National Information Bank of Sediment Data - [4.3] is assembled by some especially developed software to improve the water resources management, as the man-made water lakes balances: the reservoirs silting: the river erosion/aggradation downstream the dam: the pollution spread and control: along the river: the anthropogenic impact on the river abiota etc. A part of the models mentioned could be stochastic and the rest - dynamical, according to the cases analysed or the officer's performances.

A great part of the information processed in the Bank is treated by well known programs Excel, As Easy As, @ Pro, Lotus, Surfer, Grapher, HG etc. They allow some further data treatment in addition or graphical presentation that could facilitate the proper use of data.

The suspended sediment data about the Bulgarian rivers has been stored recently and could be used for scientific research, in engineering design or in some ecological assessments of the river abiota and environment as well as in the students' lecturing in the country or abroad.

Acknowledgement: the study has been sponsored by the National Science Fondation of Bulgaria in 1991-92.

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THE PC SYSTEM FOR THE REAL TIME DATA PROCESSING IN THE HYDROMETEOROLOGICAL SERVICE OF SERBIA

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ABSTRACT

The hydrological forecasting department of the Republic Hydrometeorological Service of Serbia has intensively modernized since the 1990. This paper gives an overview of the PC System 'FORECAST' for the real time processing and dissemination of hydrological and meteorological data. The PC System 'FORECAST' in RHMS of Serbia consists of the independent procedures that enable the efficient communication, data processing and the simple data access, as well as the graphical presentation.

DIE ECHTZEITDATENVERARBEITUNG IM HYDROMETEOROLOGISCHEN DIENSTE SERBIENS

ZUSAMMENFASSUNG

Die Hydrologishe Vorhersageabteilung des Republischen Hydrometeorologischen Dienstes Serbiens wird ab 1990 intensiv modernisiert. Diese Arbeit gibt die Uebersicht des Computersystems "VORHERSAGE" fuer die Verarbeitung und Distribution der hydrologischen und meteorologischen Echtzeitdaten. Das Computersystem "VORHERSAGE" im RHM Dienste besteht aus den unabhaengigen Prozeduren, welche wertvolle Kommunikation, rechnerische Datenverarbeitung und einfachen Datenzutritt sowie eine graphische Praesentation ermoeglichen.

INTRODUCTION

It is well known that basic activities in the hydrological service 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 water management, hydroelectric power production management and the flood protection services.

The PC System 'FORECAST' in RHMS of Serbia consists of the independent procedures that enable the efficient data acquisition and dissemination, simple data access and data processing, as well as the graphical presentation.

The PC System 'FORECAST' is a non--WINDOWS application.

PC SYSTEM 'FORECAST'

The primary menu of the PC System 'FORECAST' looks like this:

F O R E C A S T

1* Hydrological Data
2* Meteorological Data
3* Thematic Maps
4* Ice Forecasting Models
5* Forecasting -- FlowRouting Models
6* Forecasting -- Conceptual Models
7* Periodical Reports
8* Weather Forecasting
9* Data Acquisition
10* Data Dissemination
11* Graphical Support
12* System Maintaining

Choosing, for instance, the **Option No. 1* Hydrological Data**, one can choose between further sub-options:

1-1* Water Level Overview
1-2* Discharges Overview
1-3* Discharges Processing
1-4* List of stations

The **Option No. 1-1*** gives the tabular water level overview for 5 days from the chosen day backward (default date: today) for all network stations. Almost every option has a sub-option for choosing a date:

date : 7. 1.1994

The **Option No. 1-2*** gives the tabular discharge overview for 5 days from the chosen day backward (e.g. today). The **Option No. 1-3*** processes discharges (using rating curves or equations). The **Option No. 1-4*** lists the stations and their characteristics.

The **Option No. 2* Meteorological Data** gives the tabular overviews of the meteorological data interesting for the hydrological forecasting: air temperature, precipitation, snow package.

The **Option No. 3* Thematic Maps** makes the series of thematic maps of the hydrological data for the chosen date: discharge, water stage differences within 24 hours, water temperature, ice, as well as meteorological data.

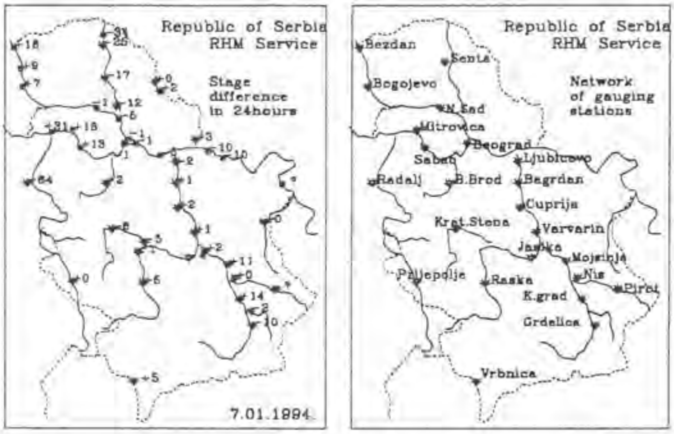

Fig. 1. Stage difference thematic map with station network map

The **Option No. 4*** gives the tabular overviews of water temperature and coded ice data for 5 days (as in Option No. 1*). This option also makes ice forecasts and ice reports.

Choosing the Option No. 5* or the Option No. 6*, one has further options for choosing between several discharge forecasting models.

The **Option No. 5* Flow Routing Forecasting Models** includes sub-options for choosing model : Riflow, Muskingum, MANS (modified Kalinin--Milyukov model, developed in RHMS of Serbia), AR models.

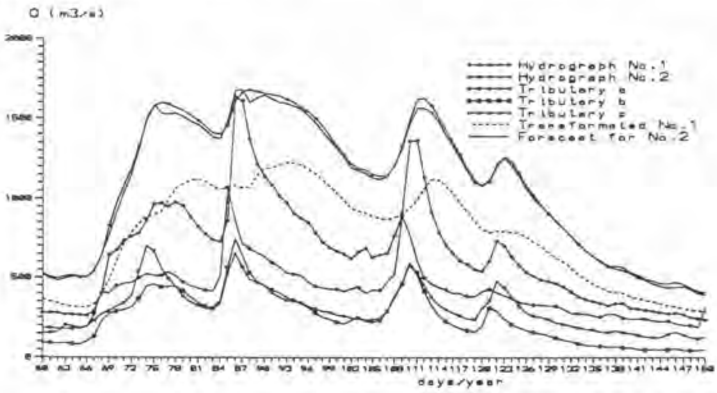

Fig. 2. River Sava and tributaries hydrographs with forecast for S.Mitrovica by model MANS

Choosing the **Option No. 6* Conceptual Models** there is another popup menu for making a decision which one of the conceptual moisture accounting models to run:

6-1* Model H*B*V
6-2* Model T-A-N-K
6-3* Model S.S.A.R.R.

Choosing, for instance, the **Option No. 6-1* Model H*B*V** (there is the lumped and the semi-distributed version of a model):

6-1-1* Morava Basin
6-1-2* Drina Basin
6-1-3* Kolubara Basin

The **Options No. 7-1*** through 7-3* make various types of reports for users in water management by the automatic procedures for the chosen date:

7-1* Daily Reports
7-2* Weekly Reports
7-3* Other Reports

The **Option No. 7-2*** make reports which are included in The Weekly Bulletin.

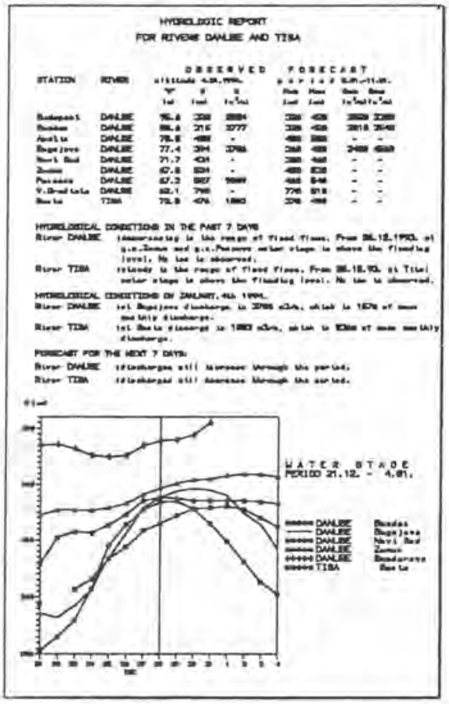

Fig. 3. Weekly Bulletin for river Danube and Tisa catchment

By the **Option No. 8*** the connection with the Weather Forecasting Department is made. There are possibilities of viewing the digitized satellite maps of Europe, the digitized radar display of Serbia and the weather forecasting maps.

Data acquisition and data dissemination is assembled through the **Option No. 9*** and the **Option No. 10***. Our PC forecasting system is connected to GTS network by the front-end computer VAX in the telecommunication center of the RHMS. Most of the observed data in Serbia are collected by radio-link. There are also several gauging stations with the automatic data acquisition system. The modem connection is used for the dissemination our reports, forecasts, bulletins and flood warnings. We also accept reports from the water management services by modem connection. For the telex coding and decoding there are automatic procedures. Files of hydrological and meteorological data are organized as direct access data base (binary coded, record = date).

The **Option No. 11* Graphical Support** includes 3 sub-options:

11-1*TimeSeriesDiagrams
11-2* Catchment Maps
11-3* Demo 1,2,3

The **Option No. 11-1*** plots the time series diagrams for the chosen period of time and the chosen catchment.

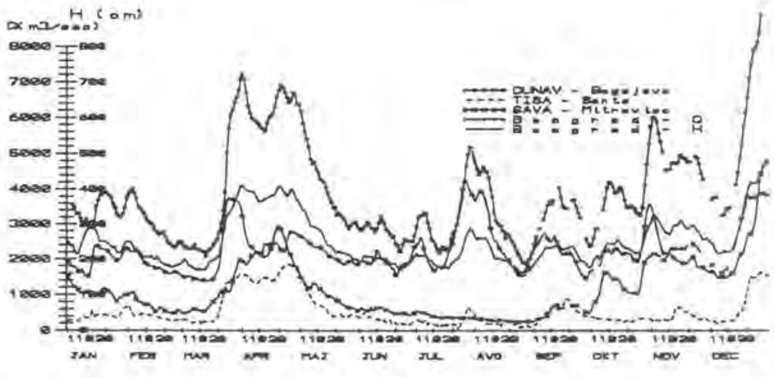

Fig. 4. Sample hydrographs: river Danube, river Tisa and river Sava

The **Option No. 11-2*** plots hydrographical map of catchments, with the gauging station network: basins of Danube, Tisa, Sava, Morava, White Drim, etc.

The **Option No. 11-3*** gives the presentation of diagrams and maps using graphical animation program packages.

The **Option No. 12*** consists of the system maintaining software: file back-up utilities, graphical and tabular data control and analysis (by records and by stations), the year-book reports, etc. Using this option data can be interchange with non real time data processing system; data can be prepared for model calibration and other purposes.

Fig. 5. Tisa river basin.

CONCLUSIONS

The main conditions for the efficient work of a hydrological forecasting service (A.Szollosi-Nagy,1987), are:

- A well developed network of hydrological and meteorological gauging stations,
- Facilities for rapid and reliable communications in collecting and disseminating hydrological and meteorological information,
- Well documented hydrological and meteorological records with facilities for data processing, storage and rapid retrieval,
- A number of specialists available,
- Feedback information on the water management operations and flood protection systems such as reservoirs, irrigation and drainage projects.

The PC System '**FORECAST**' for the real time data collecting, data processing and data dissemination in RHMS of Serbia has accomplished all of the main conditions for the efficient data management.

The modern hydrological forecasting service must be in a permanent state of development and improving of system performances.

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HYDROLOGICAL NON REAL TIME DATA PROCESSING IN THE HYDROMETEOROLOGICAL SERVICE OF SERBIA

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ABSTRACT

This paper presents non real time data processing system developed in the Republic Hydrometeorological Service of Serbia (RHMS). Non real time data processing system is a sub system of HYDROLOGICAL INFORMATION SYSTEM OF SERBIA (HIS).

System consists of the program package BALANCE linked to HYDROLOGICAL DATA BASE under UNIX operating system. The variety of computer programs for hydrological data analyses are also developed including 'MCL' model (National HOMS component).

Software characteristics, specific data processing methods, interconnection between system components, present state and future plans for system development are particularly stressed in this paper.

DIE NICHTECHTZEIT - DATENVERARBEITUNG IM HYDROMETEOROLOGISCHEN DIENSTE SERBIENS

ZUSAMMENFASSUNG

Diese Arbeit praesentiert die im Dienste Serbiens entwickelte Nichtechtzeit-Datenverarbeitung. Das System besteht aus dem Programmpaket BILANZ (Wasserbilanz), das unter dem DOS entworfen wurde. Die Hydrologische Datenbase unter dem Operativsystem UNIX entworfen wurde BILANZ mit der Base verbunden ist. Auch wurde in der Abteilung die groessere Anzahl der verschiedenen Programme fuer die Analyse der hydrologischen Daten, eingeschlossen das Modell MCL (Reihenvervollstaendigungs- und -verlaengerungsmodell) entwickelt.

In dieser Arbeit wurden insbesondere Software charakteristiken, spezielle Datenverarbeitungsmethoden, gegenseitige Beziehung der Systemkomponenten sowie jetziger Zustand und kuenftige Plaene betont.

INTRODUCTION

The intensive development of hydrological data acquisition techniques, data processing and data dissemination in **RHMS of Serbia** in past few years, resulted in adopting of new data processing methods and standards.

Centers for data collecting and primary processing are Hydrological District Offices. All of the District Offices are supplied with personal computers with appropriate software for non real time data primary processing. Data prepared in previously defined form are sent to central office of RHMS where data conversion and archiving has been done in the Hydrological Data Base (HDB). Data can be send in remote way (diskettes) or by modems.

1. PROGRAM PACKAGE 'BALANCE'

Program package **BALANCE** for hydrological non real time data processing is designed under DOS operating system in FORTRAN language.

Easy data modification is achieved through user dialog menus and panels for the input/output process. These panels make a program friendly, visually appealing, easy to learn, and easy to use. Input forms are prepared according to standard document formats used on field.

Data are stored in direct access data base that enables fast data access and minimizes needed storage space.

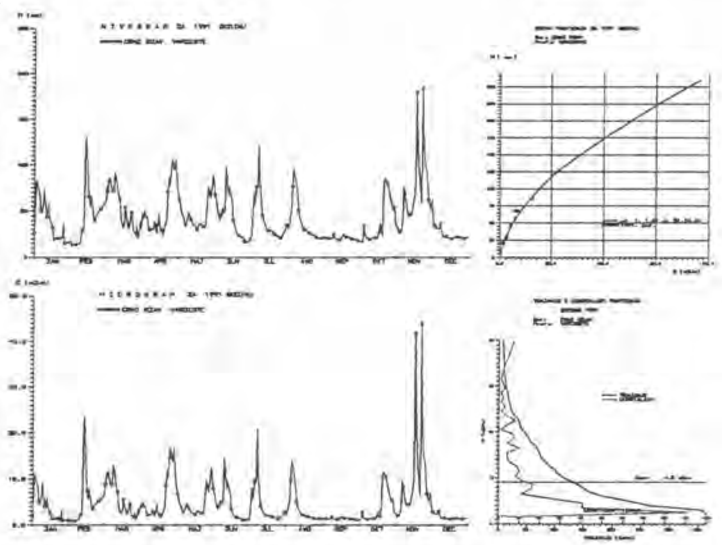

Fig. 1 Sample charts for river Rzav: hydrographs, rating curve, and flow duration curve

Extensive graphical support is realized using Golden Software's GRAPHER software package. Programs are preparing data in the Grapher data format. Users can benefit using variety of Grapher's functions and drivers for different types of printers and plotters.

System **BALANCE** consists of procedures -- programs that can be installed independently. Procedures are developed for:

- Processing of the discharge measurement data,
- Digitalization of water stage records,
- Discharge data processing (stage discharge relation),
- Water balance criterion control,
- Tables and graph processing,
- Year book out print,
- Import, export and format conversion.

Digitalization program uses specific algorithm for sampling of continuous water stage records. Main goal of method used is to preserve data precision of original record using minimum data storage space.

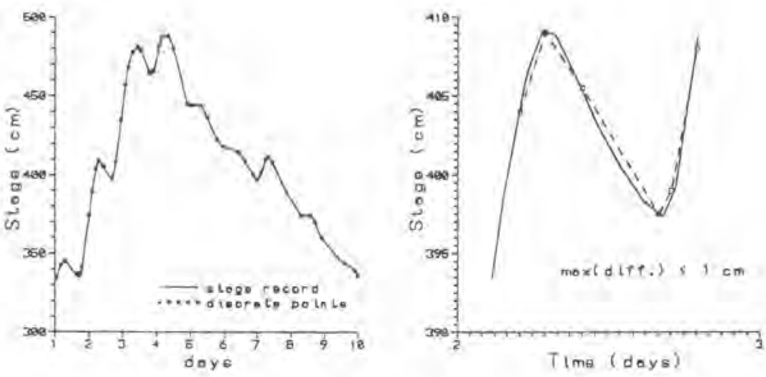

Fig. 2. Sample chart of limnograph at gauging station Kratovska Stena, river Z.Morava

Water balance program offers graphical and numerical criterion control of monthly mean flows and total volume using flow duration curves.

2. HYDROLOGICAL DATABASE (HDB)

RHMS Hydrological Data Base project started in 1991. Database hardware and software solutions are determined by experts from the Institute 'Vinca'. HDB enables simple and easy modification of all data collected in database and uniform data utilization for statistical, regional and other types of analyses.

Database is accomplished under UNIX multi - user environment with PC 486 server.

The database is designed using ORACLE Computer Aided System Engineering (CASE) tools for system development. In march 1992 the hydrological database was put in effect.

The selected Relational DataBase Management System (RDBMS) is based on the structured query language (SQL) and offers the installation of database software on different platforms (such as IBM's mainframe system).

ORACLE RDBMS software enables work under multi-user environment, high data integrity and high system performances.

ORACLE RDBMS manages user -- program dialog by menus. Data are entered in previously defined forms, fields, pages, blocks or through windows. All of the functions and queries can be realized simple and easy by menus, forms and views. User can retrieve needed data through queries using clauses, functions, expressions and operators. Almost every column in the data table can be used as a key.

ORACLE RDBMS network software enables data and applications linking on different units and makes possible connection between different computer networks and operating systems.

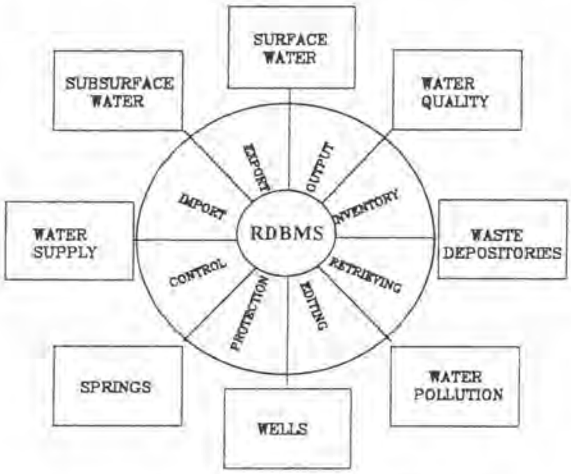

Fig. 3. General structure of Hydrological Data Base

Hydrological Data Base HDB consists of 8 sub bases:

- Surface water
- Subsurface water
- Water quality
- Water supply structures
- Wells
- Springs
- Waste depositories
- Water pollution

Surface water sub base includes basic network data and measured data: water level, discharge, suspended load, water temperature, as well as catchment characteristics: topographical and other. Cartographic catchment characteristics data base modules are defined in cooperation with Faculty of Civil Engineering, University of Belgrade according to recommendations of the FRIEND AMHY project.

Subsurface water sub base includes basic network data and measured data: water level and water temperature, as well as geological and hydrogeological aquifer characteristics.

Water quality sub base includes basic network data and measured data: chemical, physical, biological and bacteriological water quality indices. More than 30 water quality indices are covered as well as 16 indices for highly toxic materials. Quality of surface water and quality of sub surface water are monitored.

Water supply structures, wells, springs sub bases include basic and measured data: water level, discharge, water temperature, water quality, as well as aquifer characteristics and other characteristics depending of water supply structure specified.

Waste depository sub base includes basic properties of potential water pollutant deposited. Depositories are classified due to hazardous materials deposited.

Water pollution sub base includes basic physical, chemical, radioactive, biological and bacteriological waste water indices. Data for different types of pollutant originated from industries as well as municipal wastes are collected.

3. HYDROLOGICAL ANALYSES

Hydrological data base HDB offers simple and uniform data utilization for different needs mainly in water resources management and legislation. RHMS experts have carried out number of hydrological analyses and studies of flood flow, mean flow and low flow characteristics as well as suspended load transport characteristics using **HDB's Surface Water sub base** as a powerful tool.

RHMS experts had developed own software solutions for:

- Duration curves, double mass curves,
- Unit hydrograph analyses,
- Frequency distribution analyses of one and two variables, conditional probability analyses,
- Regression and correlation analyses,
- Multivariate AR(1) model for stream flow simulation,
- **Model for Completing and Lengthening** *'MCL'*, AR(1) multivariate model for completing of missing records (National HOMS component).

Statistical analyses of precipitation records are used to determine flood flow from natural and urban areas. Methodology for flood flow analysis based on unit hydrograph theory and SCS method for effective precipitation computation has been adopted.

Envelope curves for flood flow are constructed based on statistical analyses of flood flows records for more than 130 gauging stations in the Republic.

Low flow analyses are carried out to determine regime of critical flows and measures that have to be taken in order to preserve water quality. The areal distribution of low flow characteristics is used to compute critical flows for remote areas.

The regional analysis was carried out to compute mean flow and specific discharge distribution.

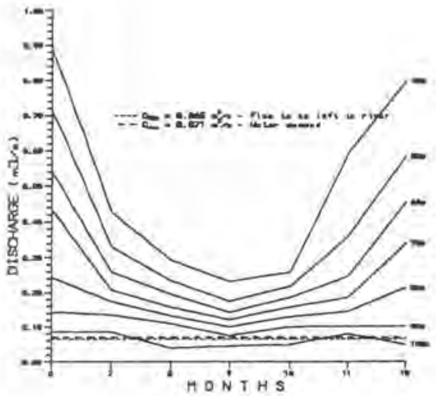

Fig. 4. Reliability of meeting water demand

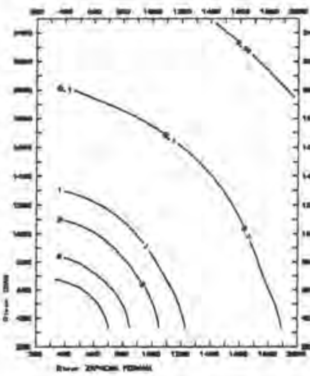

Fig. 5. Flood flow frequency analysis

CONCLUSIONS

This paper presents an overview of hydrological non real time data processing in RHMS of Serbia. The role of the Surface Water Sub Base of the Hydrological Data Base in water resources analyses and water management is particularly stressed.

Efficient computer system for distributed hydrological non real time data processing is made. All procedures of the program package BALANCE are developed in RHMS allowing further improving and modification. New version will be designed under Windows environment sharing data via computer network with UNIX HDB server.

Next step in HIS building is development of Geographical Information System. GIS will enable direct access to areal data such as topographic maps, pedological maps and other thematic maps needed for regional hydrological analyses. GIS will provide graphical user interface for HDB making it more user friendly.

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NOTES

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PROBLEMS OF HYDROLOGICAL MONITORING NETWORK OPTIMIZATION IN SLOVAKIA

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Summary
With regard to the problems due to reducing of the budget available for monitoring, as well as the need to ensure some activities have not been performing till now, a new optimization of the hydrological monitoring networks seems to be necessary. In paper, there is mentioned an analysis of this problematics in Slovakia and some measures being applicated, too.

Optimierung der hydrologischen Uberwachungsnetze in Slowakei

Kurzfassung
Unter Berucksichtung der Probleme mit der Kurzung des zur Uberwachung bestimmten Budgets and mit Rucksicht auf die bisher nicht eingefuhrten Tatigkeiten ist eine neue Optimierung der hydrologischen Uberwachungsnetze notwendig. Der Beitrag enthalt eine Analyse dieser Problematik fur den Fall der Slowakei und erlautert die Massnahmen, die in dieser Hinsicht getroffen wurden.

I. INTRODUCTION

Hydrological monitoring has been performed in Slovakia since 1865 when regular observing of the water stages on the Danube in

Bratislava and Komarno began. Further development can be characterized by gradual transition also in the sphere of the groundwaters and water quality in the last decades. In the recent years there can be indicated some basic problems in result of the general transformation of society towards the democratic basis, changes of the institutional and economic relations, change of the role of the state in the sphere of the water management and environmental policy. The network optimization tasks in the past could be practically solved without regard on for instance economic aspects - at the present times a multitask solution is demanded. A substantial reduction of the budgets and their restructuralization are the main causes of the network optimization process which takes place at the present.

2. THE MAIN ASPECTS OF MONITORING SYSTEMS

The Slovak Hydrometeorological Institute provides monitoring activities in the spheres of hydrology (both quantity and quality, surface and ground water, regime and operational), meteorology, climatology, air and environment protection. Individual systems operate separately, their interaction on the level of the central database is relatively limited. In the sphere of the hydrological monitoring there are distinguished subsystems as follows:

a) Surface water quantity - regime monitoring

506 hydrological locations are monitored in Slovakia. Water levels, temperature and ice phenomena are monitored. Flow measurements are carried out on a regular basis in order to update the stage-discharge relations. At most locations paper water-level recorders have been installed.

b) Surface water quantity - operational service

The main concern of the operational centre is the prediction of water levels and discharges along the Danube river and other important rivers in the Slovak Republic. There is 76 prognostic stations (52 equipped by remote automatic facilities). Various forecasting techniques are applied to increase the reliability of the prediction. Depending on the alert warnings are sent out regularly.

c) Ground water quantity

The ground water monitoring network of the Slovak Hydro Meteorological Institute includes 1908 locations (1392 boreholes and 516 springs).There are 140 locations with automated instruments, while the remaining locations are observed by volunteers. Measured variables include ground water level (bore holes), yield (springs) and water temperature. The frequency of observation ranges from continuously (water-stage recorder) to hourly for automated instruments and weekly for the remaining objects.

d) Surface water quality

The surface water quality is monitored at 295 river locations. The samples are taken and analyzed by the Water Boards. The parameters are: 4 physical/chemical indicators, 4 characteristics of oxygen content, 11 characteristics of mineral content, 8 nutrients or characteristic of nutrients, 7 specific and nonspecific organic pollutants, 1 sulfide, 10 heavy metals, 8 specific pollutants-radioactivity, 3 biological indicators, and 6 microbiological indicators. A monthly sampling frequency is maintained at most locations. Surface water is divided into five classification categories according to water quality.

e) Ground water quality

Altogether 294 ground water monitoring stations are listed for Slovakia. Sampling frequency is 2/year for all determinands. Number of specific determinands in different determinand groups are: 4 physical/chemical indicators, 5 characteristics of oxygen content, 16 characteristics of mineral content, 5 nutrients or characteristic of nutrients, 51 specific and non-specific organic pollutants, 2 specific inorganic pollutants, 15 heavy metals, 1 specific pollutants - radioactivity, 7 biological indicators, and 11 microbiological indicators.

3. EVALUATION OF MONITORING SYSTEMS

An optimization of quantitative hydrological network was performed for several times in the past. Actual location of the stations is a result of a long-term development, during which various aspects of the societyns needs were taken in account. The main goal was to realize demands of the water management. A great attention was paid to the continuity of the observation series and their homogeneity. Before including of the stations into regular network a stage of a detailed aim-oriented measurements usually took place.

In the sphere of the surface water quantity monitoring network can be stated relatively high representativeness and good data quality. Maintenance of the field stations is demanded but not very expensive. The local registration on computer medium is still incipient. Investments being prepared for registration equipments will substantially change the situation. Processing of the hydrological materials is of a satisfactory quality.

The operational stations network of the river system is prevailingly equipped by automated stations with remote transmission in real time. Deficiently seems to be obsoleteness and the break-down rate of the automated stations. This year has began a process of the replacement of the stations for the stations of a new type which conform to demands also for the data registration both for regime observations and operational tasks.

In the sphere of the groundwater monitoring there still does not exist quite satisfactory representativness of the location. The greatest problem is presented by the network maintenance. Many of the bore holes are very old and investments for their reconstruction are very high. The only automated is the ground waters registration in the area of the water power plant

Gabcikovo and on the Zitny Island as a whole.

Although a relatively high amount of money goes for the surface waters quality monitoring , the obtained results do not seems to be adequate ones. The network is very extent and the list of the monitored parameters is nearly constant and extent in all river profiles. There is not distinguished the basic network which ought to fulfill demanded needs of the trends monitoring and the standards testing from the network specially controlling only certain group of the specific pollutants. Still there has not been monitored quality of the suspended solids and river bed sediments, as well as quality of the living organisms. Also the screening process for analysing the occurence of parameters unincluded into the list of the standard packet has not been implemented on the regular basis. As the emission principle of the pollution monitoring is a subject of the legislative solution it is necessary to prepare a reconstruction of the network. Emission control monitoring systems require direct monitoring of the waste water discharges and specific methods of analysis of the samples. A greater attention has to be paid to the sampling problem from the point of view both of the representativeness in the river profile and time. Of a great importance are also technological discipline during the transport and conservation of samples.

In the sphere of the ground water quality monitoring are in force most of comments mentioned in the case of surface water quality.

4. ACTUAL MEASURES

Reduction of the SHMI budgets in 1993 and 1994 nearly by 50 % in comparison with the 1991 budget in real price units, unevitably had to be demonstrated in the monitoring stations reduction, too. Operational costs for networks monitoring quantity are relative low. Because of this reason and also with regard to relatively high effectiveness we have reduced these networks only by approximately 10 % since 1993. In reduction both the ground water and surface water quantity monitoring networks we followed criteria as follows: - low hydrological representativeness
- unconvinient technical conditions
- existence, resp. implementation of the automated stations.

In the sphere of the water quality monitoring which is very expensive there was necessary to reduce not only the total costs but also to redistribute the rest costs to ensure development also of activities have not established till now. This shift could not been realized at once, it is of a long-term character. In 1993 there was realized a first stage: - first but very small reduction of the number of the stations
- excluding of the monitoring of six general parameters in semi-real time mode (three times weekly). The monitored parameters are not representative for the water quality situation in a river basin. Two automated stations for continual monitoring of these parameters have been put into operation

- reducing of the frequency from monthly to quarterly in some parameters (first of all of micropollutants)

In 1994 there have been continuing the further reduction of the number of the stations, parameters and frequencies. However, there was put into the operation monitoring of the suspended solids quality and in less extent of the river sediments, too. Anyway there was implemented screening of relatively very high number of pollutants in the Nitra basin. In the sphere of the ground water quality monitoring, the stations were divided into small group for monitoring in full extent of parameters and big one with very reduced list of parameters. Performing of the complete analysis of this reduced group in case of indication of the summary parameters exceeding (for instance NEL, AOX, and so on) is taken in account.

CONCLUSION

An aim of re-evaluation of the monitoring stations is partially to consider reduced amount of money available for monitoring and on the other hand to redistribute a part of financial means for ensuring of activities which have not been performed till now.

THEMA/THEME

2

Methoden der kurz- und langfristigen Wasserstands- und Abflußvorhersage

Methods of short- and long-range forecasting of water stages and discharges

Gutachter/Convener

Associated Professor Dr. J. Szolgay

XVII. KONFERENZ DER DONAULÄNDER
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Die Erstellungstechnologie von langfristigen landesweiten Frühjahrsabflussvorhersagen für Flachlandeinzugsgebiete mit verschiendenen Zeitdauern

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Kurzfassung: Das langfristige Frühjarsabflussvorhersagesystem für das Flachlandesgebiet der Ukraine ermöglicht Abflusshöhen und Höchstwassermengen mit verschiedenen Zeitdauern und räumlicher Detaillisierung vorherzusagen. Mittels der erstellten Mehrvariantentechnologie werden die Vorhersagefriste, Zeitdauer, Eintrittsdatenumfangs und Stufen der räumlicher Detaillisierung berücksichtigt. Automatische Darstellungen von Vorhersageergebnissen auf der Karte erlauben die Abflusswerte sogar für unbeobachtende Einzugsgebiete abzuschätzen.

The technology of long - term area spring runoff forcasting with various earliness.

Summary : The long - term forecasting system of spring runoff for plane territories gives possibility to have forecasts of runoff depth and maximum disharge.This forecasts may be issued with different earliness and area detailization. This many-variant technology permits to take into account the dates of forecast issues, information volume and levels of area detailization.

1. Einleitung

Die Vorhersagen der Frühlingsabflüsse, die ein Hauptteil der Wasserbilanz in der Landesgebiet von der Ukraine betragen sind, haben aktuelle Bedeutung infolge der Wasservorratsbegrenzung.

Das ausarbeitende langfristige Frühlingsabflussvorhersagesystem erlaubt verschiedene Abflusswerte wie Abflusshöhen und Höchstwassermengen für die Einzugsgebiete im Flachland von Ukraine und Weissrussland zu bekommen. Auf diesem Territorium befinden sich die Einzugsgebiete von den Flüssen Ober-, Mittel - und Niederdnipro, Pripjat, Siwerskij Donez, Südlicher Bug.

Das Vorhersagesystem hat die Möglichkeit, Abflusshöhen und Höchstwassermengen mit verschiedenen Zeitdauern und räumlicher Detaillisierung vorherzusagen, einschliesslich auch der radiumverunreinigten kleinen Einzugsgebiete auf dem Polissja-Gelände.

Für das Flachland von Ukraine sind unständige Winterwetter und veränderliche Frühlingswetter kennzeichnend. Es kommt vor, dass ein Frühlingshöchtwasser um vieles kleiner als ein Winterhochwasser ist. Das geschieht fast jeder Winter infolge der häufigen Tauwetter (5 - 10 Mal in Winter).

Das veränderliches Temperaturregime wird Schneeansammlungsvorgänge erschwert und Bodenzustände beeinflusst.

2. Methodische und mathematische Versorgung

Die Grundlage dieses Systems ist mathematische Abflussmodell "Sloj-2". In der Untersuchung wird die Wasserbilanzmethode angewendet, welche an die empierische Abhängigkeiten des Abflusshöhe von den Schneevorräten, Niederschlägen Luftemperaturen der Schneeschmelzperiode und Kennwerten des Einzugsoberflächenzustandes gegründet.

Die Schmelzwasserverluste sind in der Moldell durch den Abflusskoeffizienten berechnet. Nach der Modell werden die Änderungen der Winter- und Frühlingsprozesse auf dem Einzugsgebiet modelliert und Grössen der Winterhochwasser und Schmelzfrühlingsabflusse eingeschätzt. Die Bewertung der Dynamik der Wasserspeicherung im Boden und an der Einzugsoberfläche, Tiefe der Bodendurchfrierung wird sich unter Berücksichtigung von dem Einfluss der Tauwetter und veränderlichen Wasserbeckenrauminhalts erfüllt.

Dabei ist es möglich nicht nur Beobachtungsdaten, sondern auch durch Modellierung in täglichen Zeitspannen errechneten Angaben auszunutzen. Es handelt sich um Wassergehalt der Schneedecke, Tiefe der Bodendurchfrierung und Bodenfeuchtigkeit. Für das Landesgebiet von Ukraine, wo jedes Winter die Tauwetter geschehen, errechneten Angaben sind mehr sicher.

Ein Schneedeckenwassergehalt S wird laut täglicher Niederschläge seit dem Winteranfang durch die folgende Formel berechnet:

$$S = P_1 + P_2 + P_3 - \Sigma h_c - z \qquad /1/$$

wo P_1 - feste Niederschläge in einer Winterperiode,
P_2 - feste Niederschläge in einer Schneeschmelzperiode,
P_3 - flüssige Niederschläge in einer Schneeschmelzperiode,
Σh_c - Wasserabgabe aus dem Schnee in alle Tauwetter,
z - Verdunstung in einer Wintersperiode.

Die Bodenfeutigkeit W wird folgenderweise berechnet:

$$W = W_0 + \Delta W_1 + \Sigma \Delta W_i \qquad /2/$$

wo W_0 - Bodenfeutigkeit nach letzter Herbstbeobachtung,
ΔW_1 - Veränderung der Bodenfeutigkeit von letzter Herbstbeobachtung bis zum Anfang der Schneeansammlung aufs Wassergebiet,
$\Sigma \Delta W_i$ - Ergänzugsbefeuchtung des Bodens für alle Tauwetter.

Ins Modell wird Frühlingsabflusshöhe durch die Formel ausgedruckt:

$$H = \eta (S+P) - \Delta H + H_0 \qquad /3/$$

wo η - Abflusskoefizient,
P - Niederschläge in einer Frühlingsperiode,
ΔH - Oberflächenretention,
H_0 - Grundabfluss.

Der Parameter ΔH ist der Einfluss von Verhältnissen der Einzuggebiete auf die Abflussverlusten berücksichtigt (z.B., die Neigung, Versumpfung, Verwaldigkeit, künstliche Abflussregulierung usw). Dieser Parameter wird nach den Abhängigkeiten, die zonale Landschafsverhältnisse der Einzugsgebiete verallgemeinern, berechnet (Polissja-Gelände, Steppe, Waldsteppe).

3. Erstellungstechnologie von Vorhersagen

Die Prozesse von der Abflussformierung wurden in die Modellstruktur für die operativen Berechnungen beschrieben.

Für die Systemverwirklichung wird die Mehrvariantentechnologie ausgearbeit, die Vorhersagefriste, Zeitdauer, Eintrittsdatenvolum und Stufen der räumlicher Detaillisierung berücksichtigt. Dabei ist es möglich eine ununterbrochen Abflussvorhersagung seit ersten Februardekade mit stufenweise Genauigkeitsverbesserung der Vorhersagen ausgeführen.

Das langfristige Frühjarsabflussvorhersagesystem schliesst einen Komplex der programierten Mittel ein, die eine Auswahl, Aufschreiben, Analyse, Korrigierung der Daten, Berechnung und Vorhersageerstellung der Abflusshöhen und Höchstwassermengen mit verschiedener Wahrscheinlichkeit, gewährleistet werden.

Zwei Haupteinheiten dieses Systems AUTOPOL und SLOJ stellen die Programmen dar:

-für die Auswahl der Eintrittsdaten aus operativen hydrometeorologischen Basissätzen;

-für das Aufschreiben der Daten in dem Eingangsmassiv des mathematischen Modells;

-für die Berechnung mit Hilfe des Modells und automatische Darstellung von Vorhersageergebnissen auf der Karte.

Der programierte Komplex AUTOPOL ermöglicht Auskunfte vom Zustand der Basisdaten auszunutzen, nötige Volumen der meteorologischen Grössen einzunehmen und korrigieren. Durch den programierten Komplex SLOJ ermöglicht eine Bewertung des Eintrittsdatenzustandes, die Korrigierung abgesonderter Massive zu verwirlichen. Es gibt auch die Möglichkeit für die Beschreibung des Entwicklungsganges der Prozesse, die sich auf dem Einzugsgebiet während der Winterperiode ereignet.

Die Eintrittsdaten des Modells sind tägliche Mittel- und Maximaltemperaturen, Niederschläge laut der Standardbeobachtungen von 1. November bis zur Vorhersage- oder Berechnungfrist und auch Bodenfeuchtigkeit nach der Herbstende. Meteorologische Kenngrössen für die Zeitdauern werden als Warscheinlichkeitswerte vorgestellt.

Vor der Vorhersageerstellung werden folgende Kenngrössen,wie Dauer der Schneeschmelzperiode und Frühlingsabflüsse, Schneeschmelztemperatur, Niederschläge in dieser Periode und Niederschläge während der Frühlingsabflussperiode, in die Basissatze von BASPOL eingetragen, von wo diese Parameter ins SLOJ ausgewählt werden konnen.

Die Hauptvorhersageerstellungen werden 15-30 Tagen vor dem Scheeschmelzbeginn verwirklicht. Der

Eintrittdatenumfang schliesst die Beobachtungen aus der 100 Meteostationen ein.

Auf Grund obergenaunten Eintrittdatenumfang werden landesweite Abflussvorhersagen für Gebiete mit gemeinsamen Flächen 380000 (Ober-, Mitteldnipro), 90000 (Siwerskij Donez), 64000 km² (Südlicher Bug) vorhergesagt. Dabei ist es möglich auch die Abflussvorhersage für kleinere Einzugsgebiete (mit Flächen 5- 10 km²) zu erstellen, das sogar für Frühjarsabflussvorhersage in verunreinigten Gebiete auf dem Polissja-Gelände (Tschornobylzone) ausgenutzt wird.

Um die Vorhersagewerte noch genauer zu haben, kann man ihre Erstellung nach der Schneeschmelze ausführen.

Das oben beschriebene Modell wurde seit 1989 im Frühling jedes Jahres erprobt. Die Eintreffung der Vorhersagen mit Zeitdauern 30-40 Tagen beträgt 80-95%.

Automatische Darstellungen von Vorhersageergebnissen auf der Karte erlauben die Abflusswerte sogar für unbeobachtende Einzugsgebiete abzuschätzen. Diese Möglichkeit kann man die Berechnungen für Anfüllungsregimes der kleinen Wasserbehälter ausnutzen.

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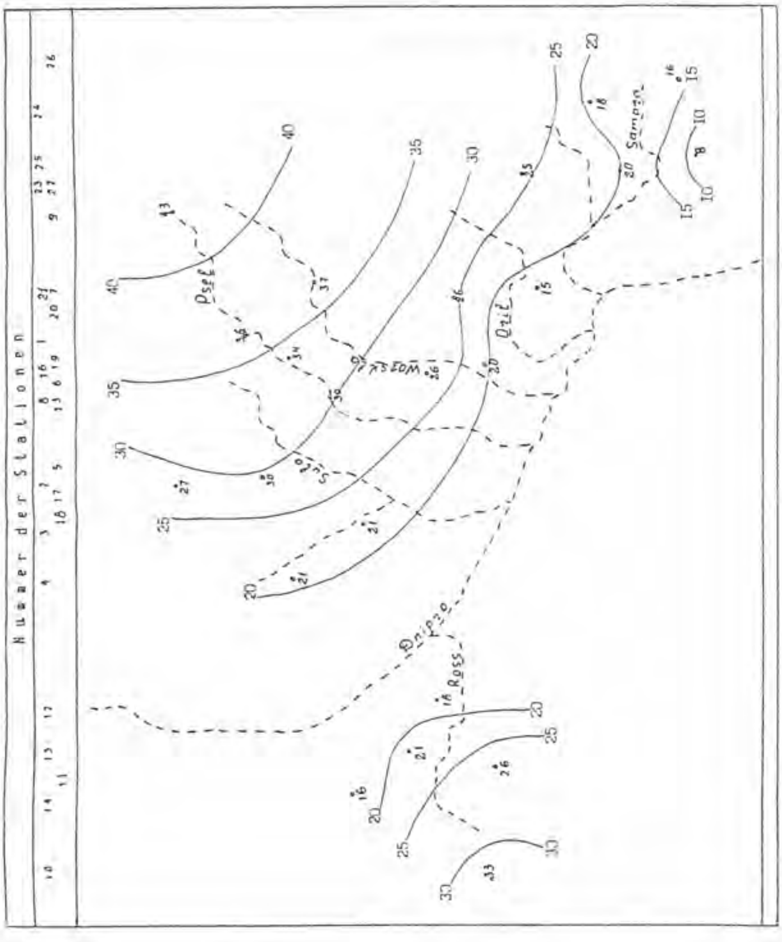
Vorhersage
der Frühlingsabflusshöhen

20. 02. 1993



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Experience with a Forecasting Modelling System

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Abstract
For making forecasts at the outlet of the Bohemian part of the Elbe River basin, the MUFSYS-4 modelling system has been selected. Its structure allows to include various modelling techniques. Following a complex river formation of this part of the Elbe River, the APIC rainfall-runoff model, the PACK snow model and the TDR diffuse-translation model were applied. This paper presents some of the problems which were met when validating these models.

Zusammenfassung
Für die Berechnung der Vorhersagen im Schlußpegel an der tschechischen Elbe wurde ein Modellierungsystem MUFSYS 4 benutzt. Seine Structur ermöglicht verschiedene Modelltechniken einzugliedern. In den komplizierten Flußbedingungen dieses Teiles des Elbe wurde ein Niederschlag-Abflußmodell APIC, Schneemodell PACK und Transformations-modell TDR auswählt. Dieser Beitrag skizziert einige Problemme mit welchen die Prognostiken bei der Kalibration der Modellen aufstoßen mußten.

1. Introduction

The MUFSYS-4 forecasting system (Multipurpose Unsteady Flow Simulation System) has recently been a subject of interest and it has been studied by many hydrological forecasting centres in Bohemia. It concerns a modelling system allowing to combine, for a given territorial unit, various modelling techniques in such a way that the runoff from the entire basin is determined as precisely as possible. The Elbe River, for which MUFSYS has been applied, drains nearly entire territory of Bohemia and, in terms of the Elbe Basin as a whole, it covers its upper part with the area of over 50 000 km^2. The forecasting model performs functions of a river basin with a number of components representing river reaches with relevant subbasins, following the complex structure of the river network in the Elbe River basin. A modular structure presents the system with features of a versatile hydrological construction set, a quality that was important at a time of deciding how to apply the model for the Elbe Basin. In the first phase, the system was applied separately at five particular territorial units with a possibility of their future interlinking. In effect, it meant to find an optimum set of parameters for each of the investigated basins. After introducing the forecasting version of the model at the central office, where forecasts are being prepared for the closing section of the Elbe River at the Ústí n. Labem site, it will be possible to include the other four systems into the basic outline and to increase the lead time of the forecast.

2. Modelling techniques applied

In the MUFSYS-4 modelling system applied for simulation and forecasting water discharge, the following modelling techniques were used:

APIC model - for simulating rainfall induced runoff

PACK model - Anderson's snowmelt model based on energy balance equation

TDR model - for transformation of channel water movement

The APIC model includes:

8 parameters of the so-called seasonal quadrant

5 parameters of rainfall quadrant

1 parameter of retention quadrant

Purpose and mathematical expression of relationships between these parameters are given in (4). Initial parameter values of the APIC rainfall-runoff model were estimated using a computerized optimization of the coaxial correlation parameters, by which 25 subbasins on the territory of the Czech Republic were analyzed with results serving as analogues also for other basins.
The Anderson's PACK snow model (1) contains approx. 20 parameters that can be initialized through physiographic characteristics of the basin and using meteorological data collected from a network of climatological stations while following the model description, which is sufficiently straightforward. The following are the main parameters:

UADJ effect of average wind speed above the snow cover

SCF rainfall correction factor

MFMAX maximum snowmelt factor

MFMIN minimum snowmelt factor

SI average water equivalent corresponding to snow layer covering the entire basin

Secondary parameters are as follows:

NMF maximum negative snowmelt factor

TIMP antecedent temperature index

PXTEMP temperature at a boundary between rain and snowfall

PLWHC capacity of snow cover to contain liquid water

MBASE basic snowmelt temperature at periods without precipitation

DAYGM snowmelt amount at a boundary between snow and soil

The TDR diffuse-translation model comprises the following parameters:

C channel water velocity km/h

K diffusivity km^2/h

D river section length km

The principles of the diffusion equation and a general procedure to specify the parameters are referred to in (2). For the Elbe River subbasins, the relevant parameters for particular sections were derived from the average hydraulic and geometric characteristics of the channel. These values were calculated or estimated from longitudinal and cross sections. The average velocities were determined by using travel time curves. A three layer TDR model was applied in all the basins, that is, the parameters were determined for low, medium and high discharge.

3. Model structure

A simulation version of the MUFSYS-4 forecasting system is operated by the Czech Hydrometeorological Institute for five territorial units.

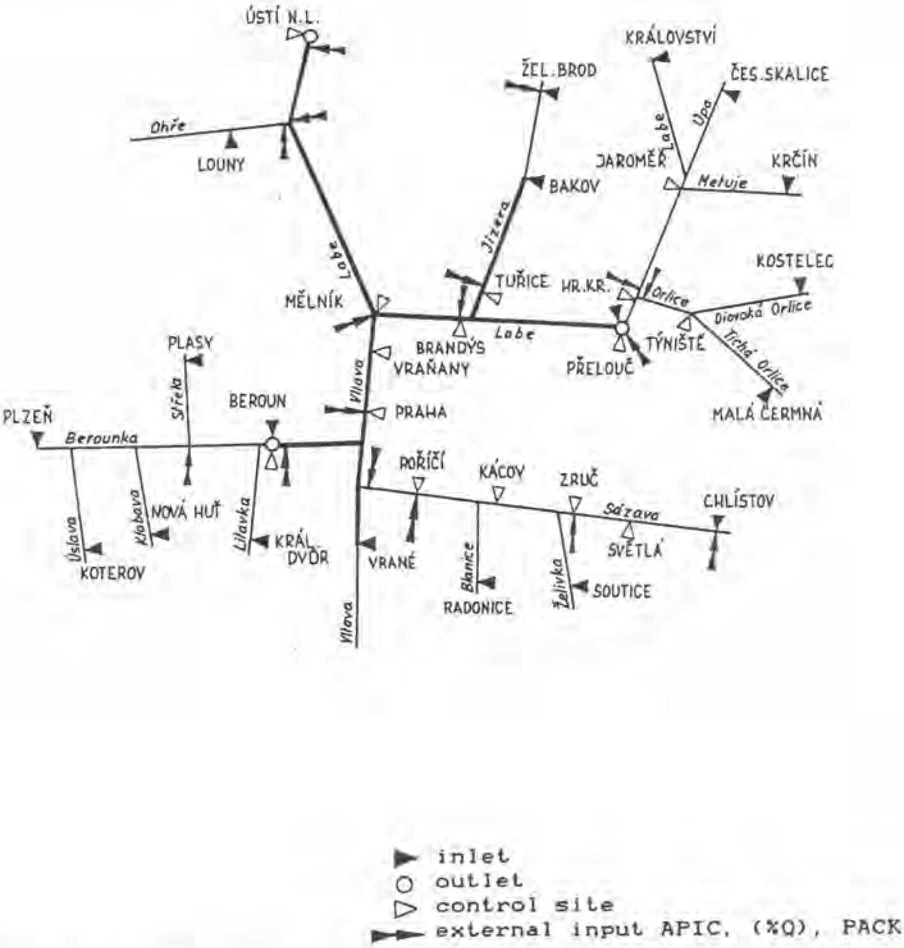


Fig. 1 STRUCTURE OF THE RIVER NETWORK FOR MUFSYS-4

The following table presents some of the basic data.

RIVER	OUTLET	TOTAL AREA [km²]	NO. OF RIVER SECTS. (TDR)	INTERBASIN AREA [km²] (API)	NUMBER OF PRECIPITATION GAUGING STATIONS
BEROUNKA	BEROUN	2428,8	7	476,5 1195	3 4
SÁZAVA	CONFLU. WITH VLTAVA	4349,2	9	794,3 625,5 1519,3 348,5	3 3 4 2
JIZERA	TUŘICE	2159,2	2	791,0 509,1	3 3
LABE	PŘELOUČ	3710	9	660 850 2200	4 4 4
	ÚSTÍ N.L.	9458	9	621,6 2023,4 5063,4 865,5 630,7 253,1	4 4 9 2 2 2

Validation procedures for particular modelling techniques were not identical for all of the basins. The first trials comprising the rainfall-runoff relationships and snowmelt processes were made for small, homogeneous units. A transformation procedure was, on the other hand, applied for large basins. The relevant results were subsequently used in the MUFSYS-4 modelling system.

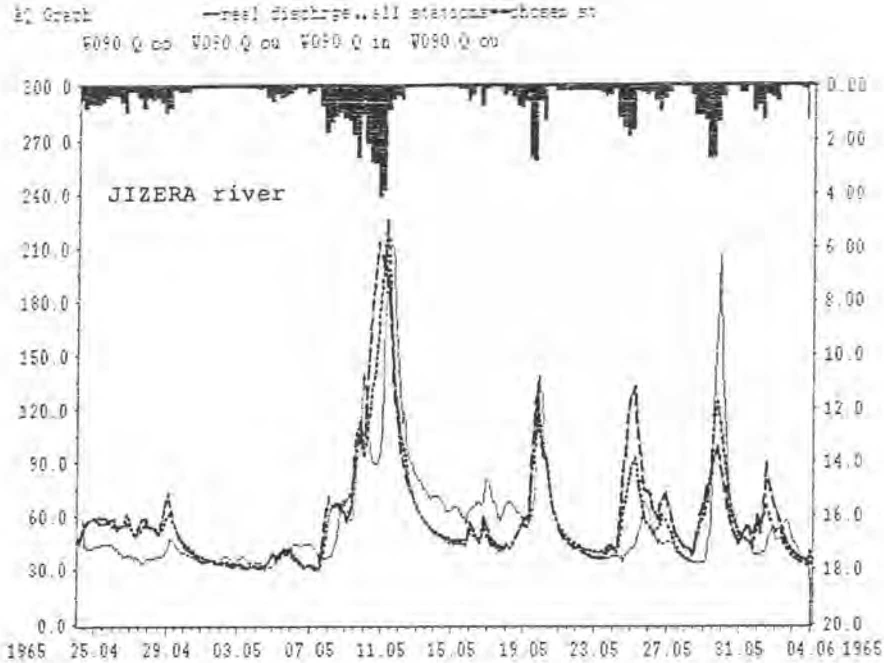
4. Input data

For estimation of the relevant parameters, a recent 30-year series of flood hydrographs with peak discharges over 1/2-a-year flow was used. Precipitation data were obtained from the network of precipitation gauging stations, that is, for simulation purposes from those stations where data were available only for past periods, or, from a network of reporting stations for real-time data. Based on the frequency of reporting, the stations can be classified as regular with daily reports giving precipitation depths for every six-hour intervals, regular with daily reports showing 24-hour precipitation depths, and finally sites with irregular reports giving data at a time of exceeding a limit. Stations with a possibility of automatic transmission of data are not, so far, operated by the Czech Hydrometeorological Institute. One of the advantages of the system is a possibility of not restricting the input data to a single time interval, as the missing data are automatically interpolated.

5. Assessment of results

The simulation results were not at all identical, and the individual experts had different criteria for their assessment. The basic forecasting system and the principal site at Ústí n. Labem (indicated by a thick line in Fig. 1) were tried by validating the TDR model. The inflow from interbasin was estimated, in the first phase, as one per cent of inflowing discharge. In the second simulation phase, this lateral percentage increment was replaced by inflow calculated by the APIC model rainfall-runoff procedure. The obtained results appeared inaccurate. The main reason was found in incorrect estimation of runoff from the effective rain. The effects of the basin transformation function, modifying subsequently a shape of the runoff hydrograph into its final form, are rather limited and the results have clearly indicated that without a relatively precise determination of the rain-related runoff, it is not possible to arrive to the required shape of the hydrograph by changing parameters of the diffusion-translation equation. A similar conclusion was formulated by an expert operating a forecasting system of the Berounka River, where the identical procedure had been applied - the rainfall-runoff procedure had been employed after validation of the TDR model, however, results from the APIC model were at the same level with those using a percentage increment. For the upper and middle Elbe Basin with a closing site at the Přelouč locality, parameters of the transformation and rainfall-runoff models were estimated simultaneously. The final results were the best of all of the investigated territorial units, the simulated discharge at the outlet fitted well the observed values, so the model for that basin appeared applicable.

The first trials with a rainfall-runoff model combined with a snowmelt procedure were made for a mountainous basin of the Jizera (790 km^2) and for the Sázava River running through a hilly lands region. The results of simulations of flood flow resulting from snowmelt on the Jizera River were surprisingly good, results for the other river were not as much successful. In subsequent experiments, the two basins were incorporated into a model which was set for entire basins and the parameters were estimated on the TDR model for summer flood flows. The longest uninterrupted investigated period - 4.5 months was represented by floods in 1965. In terms of snow accumulation, it concerned the most significant recent period, when there was snow cover laying, to a high degree, also in lowlands in Bohemia. A drawback of this period was unsystematic measurement of water equivalent of the snow cover, so it often had to be estimated from available analogous data. Simulations for the two basins were made in two versions - with all of the data available from the hydrological and climatological observing networks (their number was at least double of those given in the table) and with exclusively those input data which would be available in the operation stage (their number is given by the table). The flows simulated while using a network of operational stations were usually higher (by 5 to 25 %). An intercomparison is shown in the following figure.



Conclusions

Based on the available results, it is clear that out of the above mentioned modelling techniques applied in the Elbe River forecasting system, the least suitable one appears to be the APIC model. Its suitability was demonstrated for small basins, particularly for those where the runoff was just being formed. Relatively promising results were reached by simulations of long uninterrupted periods, if the simulation started at low-flow periods. However, for inhomogeneous regions, the simulations did not bring the expected results, as was the case with periods with high-intensity initial rainfall. For continuing experiments, a possibility comes into consideration of replacing the APIC model by a more suitable rainfall-runoff relationship.

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Landesweite Frühjahrsabflussvorhersagen in Gebirgsgebieten auf Grund der mathematischen Modellierung

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Kurzfassung

Um die Nutzbarkeit der Abflussvorhersagen in der Karpatenregion zu erhöhen, wird man methodische Grundlagen für ihre Erstellung in landesweiter Form verwendet. Mit dieser Ziel wird zwei mathematische Frühjahrsabfluss-Modelle ausgenutzt, die im Zusammenhang funktionieren. Die Modelle errechnen Abschätzungsgrössen der Wasserabgaben für die bestimmten Höhenzonen auf Basis von meteorologischen Messwerten und stellen sie in räumliche Abbildung. Deshalb gibt es die Möglichkeit Zuflussfüllen zu beliebigen Flussstrecken oder Flussquerschnitten vorherzusagen, wo sogar Beobachtungen abwesend sind.

Spatial spring runoff forecasting in a mountain country on the basis of mathematical modelling

Abstract

For a value heigthen of water runoff forecastes is used methodical basis for their composition in a spatial form. With that end in view two mathematical models of spring runoff employ which function in the interrelation. The models calculate water yield data at the appointeed high-zones on the basis of meteorological observation and represent theirs in the spatial form. Therefore it is possible to obtain of the inflow forecastes to any stretch or profil of a river even if the hydrological measurement is absented.

1. Einleitung

Für die Vorhersagen der Hochwasserabflüsse werden Methodiken verschniedener Strukturen mit konzentrierten oder verteilten Parametern genutzt. Aber dabei kann man sie meistens nur für Flussquerschnitten erstellen, wo die entsprechenden Messungen geführt werden. Aus der praktischer Sicht sind der Wert und die Anwendbarkeit solcher Vorhersagen begrenzt, weil es für mehrere Bedürfnisse, insbesondere in Gebirgsregionen bei Siedlungsschutzmassnahmen, nötig ist, Information und Warnungen entlang einem Flusse zu haben.

Befriedigende Lösung dieser Aufgabe kann man auf Grundsätzen der landesweiten Abflussvorhersagen beruhen. Solches System ist für die Frühjahrsabflussvorhersagen im Flussgebiet von Tyssa innerhalb der Ukraine-Grenzen bereitge - stellt (d.h. für die Flüsse Obere Tyssa, Tereswa, Rika, Borshawa, Latoryzja, Ush).

2. Methodische Grundlagen

Zu methodischen Grundlagen des Vorhersagesystems wurden mathematische Modelle SLOJ-3 und SNIH-3 gebraucht /1-3/. In den Modellen sind die Prozesse der Frühjahrsabflussformierung, die auf dem Flussgebiet sich ereignen, so schematisiert, dass sie durch die Standardbeobachtungen zu berücksichtigen ermöglichen. Die Strukturen dieser Modelle schliessen Eigenheiten der Abflussbildung, die den Karpaten -Einzugsgebieten eigen sind: vertikale und landweite Veränderlichkeit der hydrometeoroligischen Grössen, oft geschehende Tauwetter.

Auf dem Modell SLOJ-3 stützt sich kontinuierliche Modellierung den ganzen Winter der Dynamik der Bodendurch - frierungstiefe, Bodenfeuchtigkeit, Schneeansammlung und -schmelze während jedes Tauwetters. Erhaltene Angaben werden als Eingangsgrössen für die langfristige Frühjahrsabflusshöhenvorhersagen gebraucht.

Abflussgangvorhersagen während Tauwetter und Frühjahrsschneeschmelzen werden mittels des Modells SNIH-3 erstellt. Dieses Modell hat drei Subsysteme, die folgende Prozesse vorstellen: Schneeschmelzen, Tauwasserabgaben, Abflussregelungsvorgänge durch Einzugsgebiete und Flussnetze, Wellenabläufe in Flussstrecken.

Beide Modelle funktionieren im Zusammhang. Erhaltene durch SLOJ-3 vor Beginn einer Frühjahrsschneeschmelze Angaben dienen zu kurzfristigen Vorhersagen mittels SNIH-3.

3. Technologie der Systemanwendung

Der Anwendungs prozess dieses Vorhersagesystems besteht aus foldenden Verfahren.

(a) Für die langfristigen Abflussfüllenvorhersagen wird geschätzt
  - Wasserabgaben im Frühjahr für Beobachtungsstellen unter Berücksichtigung wahrscheinlicher Niederschläge,

- Wasserabgaben im Frühjahr für bestimmte Hochzonen,
- Mittelabflusshöhen für Flächen, die an bestimmte Flussstrecken grenzen, und entspechende Zuflussmengen,
- Abflussfüllen in Querschnitten.

(b) Für die kurzfrictigen Abflussgangvorhersagen wird in jeden 6 Stunden berechnet
- Wasserabgaben für bestimmte Hochzonen,
- Wasserabgaben für bestimmte Flussstrecken,
- Transformation erhaltener Wasserabgaben und der Abflusswellen mittels Einflussfunktionen (Impulsantwort).

Für die Bewertung der Parameter der Einflussfunktion /4/ kann man folgende Gleichungen benutzen:

(a) für Oberflächenabflüsse

$$\tau_1 = 1.00 \qquad n_1 = 0.04L - 0.085I + 2.20$$

(b) für Unterflächenabflüsse

$$\tau_2 = 3.00 \qquad n_2 = \begin{cases} 0.13L - 0.115I + 2.40, & L < 25 \\ 5.650 - 0.115I, & L \geq 25, \end{cases}$$

wo L - Flussstreckenlänge, km
I - Flussgefälle, ‰.

4. Beispiele

Das erste Beispiel (Abb.1,Tabelle) zeigt die Anwendungsergebnisse des obergenannten Systems für die Vorhersage der Frühjahrsabflusshülle entlang dem Fluss Latoryzja.

Aus der Abbildung 2 ist es klar zu sehen, wie die Hochwasserwelle in den Flussabschnitten wechselt (der Kurzfristvorhersage nach).

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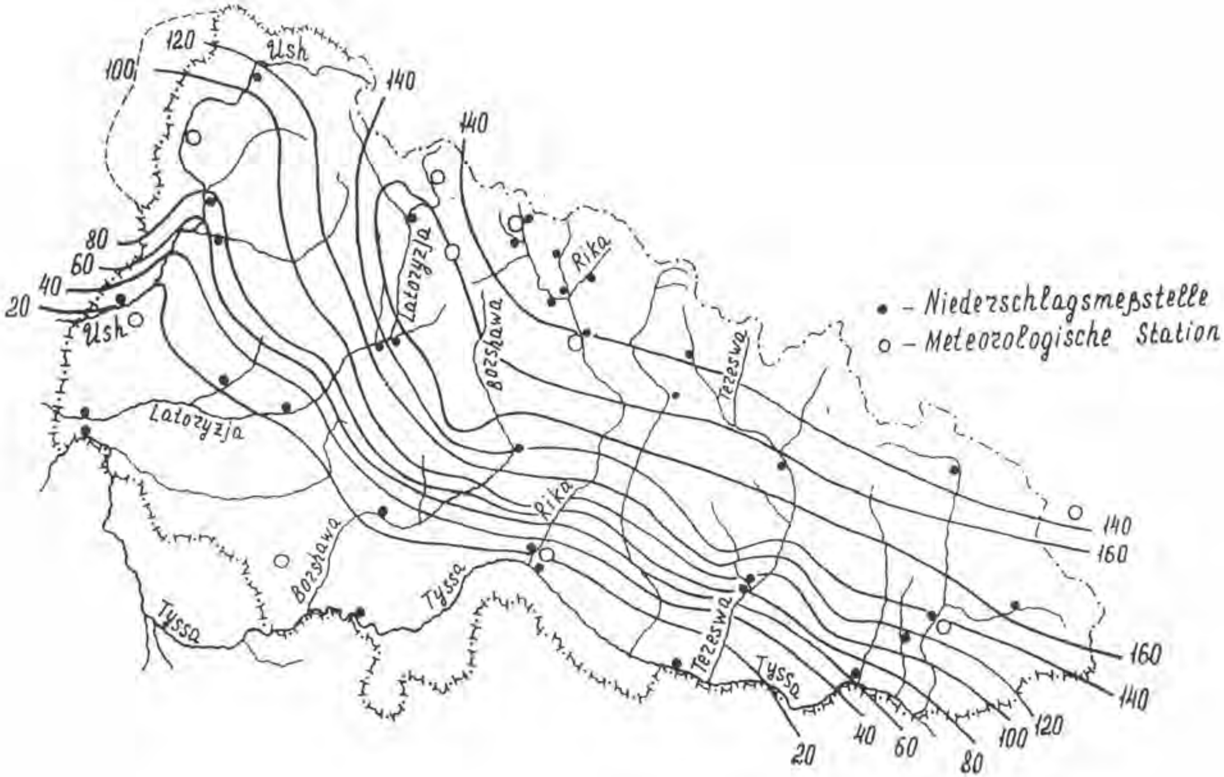

Abb.1. Tyssa-Flussbecken. Vorhersage von Abflusshöhe im Frühjahr 1978
Fig.1. River basin of Tysa. Depth of runoff forecast in spring 1978

Zuflussvorhersage im Frühling 1978 längs des Flusses Latoryzja

Inflow forecast in spring 1978 along Latorycia

Kenn-werte	Entfernung vom Ursprung des Flusses										
	0		10		20		30		40		50
ΔF			135		135		125		120		120
berechnete											
Hs		140		150		162		160		135	
Hq			140		145		150		152		151
V			19		39		59		78		96
ΔV			19		20		20		19		18
gemessene											
Hs					153						
V					41						

Kenn-werte	Entfernung vom Ursprung des Flusses								
	50		60		70		80		90
ΔF	120		410		120		110		110
berechnete									
Hs		105		80		48		18	
Hq	151		132		126		120		112
V	96		138		147		153		155
ΔV	18		42		9		6		2
gemessene									
Hs									102
V									141

Anmerkungen.

ΔF - Zunahme der Einzungsgebietsfläche (km^2)
Hs - Mittlere Abflusshöhe auf der Flussstreckenfläche (mm)
Hq - Abflusshöhe am Flussquerschnitt (mm)
V - Abflussfülle am Flussquerschnitt (Mio m^3)
ΔV - Zunahme der Abflussfülle (Mio m^3)

Annotation.

ΔF - increases of the catchment area (km^2)
Hs - mean runoff depth on the area of stretch of the river (mm)
Hq - runoff depth in the profil of the river (mm)
V - runoff volume in the profil of the river (mio m^3)
ΔV - increases of the runoff volume (mio m^3)

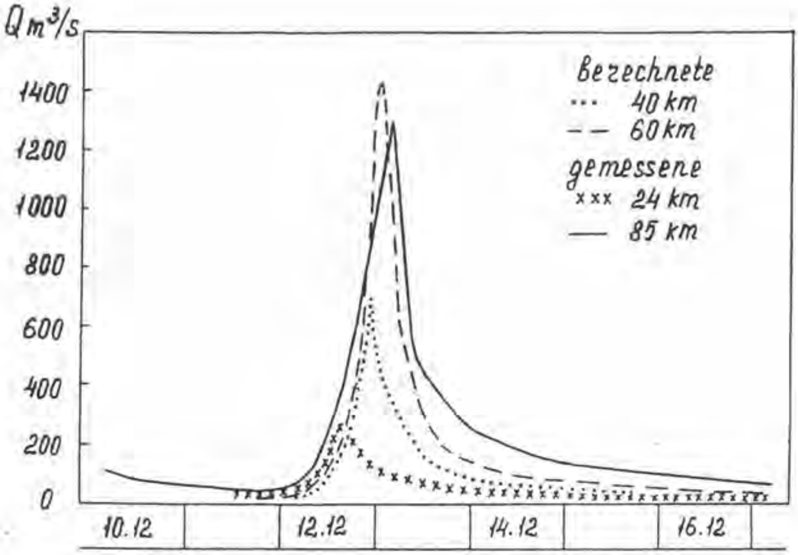

Abb.2. Ganglinien des Hochwassers im Dezember 1981 am Fluss Latoryzja

Fig.2. Flood hydrograph in December 1981 on the river Latorycia

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OPTIMIZATION, SIMULATION AND FORECASTING WITH 'HBVB' SYSTEM IN THE HYDROMETEOROLOGICAL SERVICE OF SERBIA

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ABSTRACT

The model HBV is applied in the Forecast Department of the Republic Hydrometeorological Service of Serbia since 1988. Software is gained as WMO HOMS component (author Bergstroem, S., D.Sc. SMHI, Norrkoeping, 1976). Model is applied on sub basins of the river Drina, river Kolubara and river Morava (catchment area from 500 to 5000 km^2).

The PC System 'HBVB' based on the original HBV package is developed in RHMS. System enables additional functions for easier model calibration, runoff simulation and forecasting. System uses the graphic and the mapping software packages, the interactive (menu) communication software, and the self-made data processing software. In this paper we put an accent on the optimization methods used for calibration of model parameters.

DIE OPTIMIZATION, DIE SIMULATION UND DIE VORHERSAGEAUSARBEITUNG MIT DEM 'HBVB' SYSTEM IM HYDROMETEOROLOGISCHEN DIENSTE SERBIENS

ZUSAMMENFASSUNG

Das HBV-Modell brachte man in der Vorhersageabteilung ab 1988. zur Anwendung. Das Software wurde als eine WMO-Komponente erhalten, (der Verfasser dr. S. Bergstroem, SMHI, Norrkoeping, 1976). Das Modell ist bis jetzt auf die Unterflussgebiete der drei Fluesse: Drina, Kolubara und Morava angewendet (oberflaeche von 500 bis 5000 km^2).

Das auf dem originellen HBV-Paket grundlegende Computersystem "HBVB" ist im hiesigen Dienste entwickelt. Das System ermoeglicht zusaetzliche Funktionen fuer eine einfachere Kalibration der Modellsparameter, die Simulation der Abfluesse und die Vorhersageausarbeitung. Das System benutzt graphische und kartierende Software - Pakete, interaktives Kommunikations - Software und selbsthergestelltes Software. In dieser Arbeit wurden die Optimisationmethode fuer die Kalibration der Modellparameter betont.

INTRODUCTION

Basic activities in the hydrological service in real time include data observation, data collection, data processing and forecasting. Program system 'HBVB' is a part of real time data processing system.

The System 'HBVB' consists of the independent procedures that enable the efficient and simple parameter file access, data manipulation, data processing and the graphic presentation.

Program System HBVB is designed under DOS operating system in FORTRAN language. Input and output files are ASCII coded. For graphic support the Golden Software's package GRAPHER is used. The Golden Software's package SURFER is applied for map viewing.

Procedures are developed for:

- Data input processing (hydrological and meteorological)
- The model parameters overview
- The model state overview
- The model parameter optimization
- The runoff simulation
- Graphical support
- The runoff forecasting

1. OPTIMIZATION OF MODEL PARAMETERS AND STREAM FLOW SIMULATION

In this section we will describe the methods for model parameters optimization. The iterative method used consists of two steps. The first step is the identification of the region of the optimal solution for selected pair of parameters. STEP and MAP procedures are used first for evaluation and mapping of criterion function.

Fig 1. Main selection panel for HBVB system

In the second step automated procedure for multivariate function optimization is used. Steps are to be repeated successively until optimal solution is reached.

The STEP method is a simple search method. Values of criterion function are determined in the grid points of two dimensional space. The initial grid size and limits selected can be changed in the next step of the search, inquiring criterion function near the local extreme.

The MAP method is based on the output grid from the STEP method. The surface of criterion function can be mapped in 2 or 3 dimensional space. For the graphics presentation of criterion function the TOPO or SURF program are used.

Fig 2. Selection panel for STEP and HILLCLIMB method

For automatic optimization the ROSENBROCK HILLCLIMB method of maximization of multivariable nonlinear functions subject to non linear inequality constrains is used. This method is based on the Rosenbrock sequential search technique (1960). Methods assumes a unimodal function. Several sets of starting values for the independent variables should be used if it is known that more than one minimum exists, or if the shape of the surface is unknown.

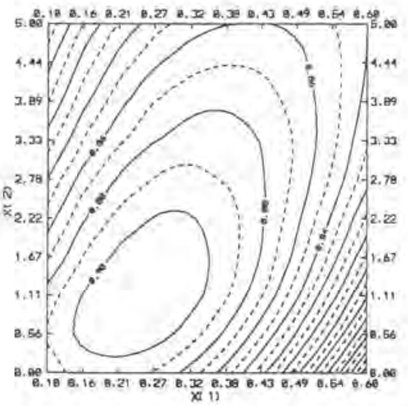

Fig. 3 Criterion function represented with contour lines

To make the methods user friendly, set of programs is developed for selection of model parameters, as well as initial step size, starting values and constrains input.

In both methods weighted combination of numerical criteria is applied for criterion function. The basic set of criterion is selected according to Operational Hydrology Report on the WMO Project on Intercomparison of Models of Snowmelt Runoff.

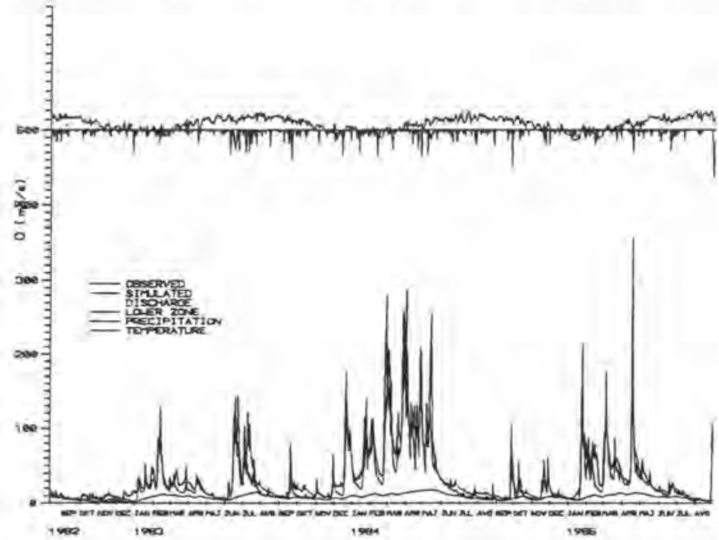

Fig. 4. Simulation plot for river Zapadna Morava at station Kratovska Stena

The iterative method of optimization is find to be the most efficient. The Step method and the Hillclimb method are used successively leading to optimal solution. Parallel to criterion control, visual inspection of hydrograph, scatter diagrams and duration curves is applied.

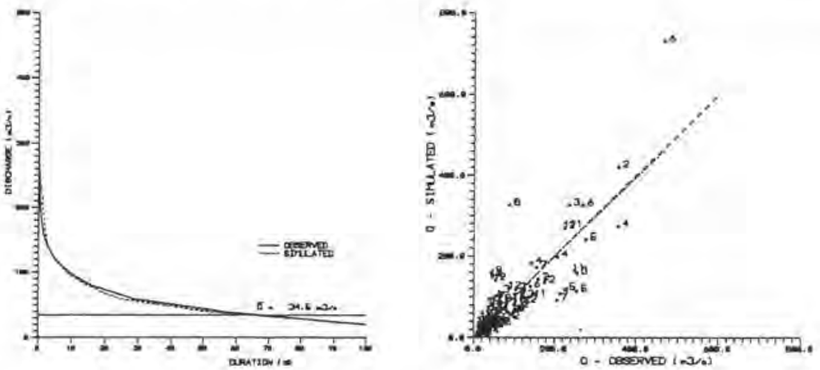

Fig.5. Flow duration curve and scatter diagram for river Zapadna Morava (3000 km^2)

The model has been calibrated in a semi-distributed version for sub basins of the river Drina, the river Morava and the river Kolubara.

The river Zapadna Morava (3000 km^2) catchment was divided into five sub basins of area from 250 to 900 km^2. Sub division was necessary because of the non-homogeneous topographic, geologic, pedologic and climatic catchment characteristics. Sub models with two to five elevation zones are used accounting different precipitation and snow melt regime. Five precipitation and temperature stations are used as well as three stations for evaporation data. On this catchment there are two automated precipitation station and one automated hydrological station for on line hydrological forecasts purposes.

Model is found to be robust giving excellent results especially for snow melt runoff.

Fig. 6. The river Morava catchment

Model is used for the discharge simulation as well as the data quality control considering possible origins of simulation errors:

- input data errors (stage, precipitation, temperature, evaporation),
- rating curve errors (extrapolation errors, rating curve shift).

It is also possible to use model calibration techniques for the optimal design of the precipitation areal network. The *optimal design* is a system design based on the selection or combination of all pertinent variables so as to maximize some objective function with the requirements of the design criteria.

2. FORECASTING WITH MODEL HBV IN RHMS

The forecasting procedure is incorporated in the real time data processing system **FORECAST**. Forecasting procedure uses direct access data base. Choosing the Model HBV from **FORECAST**'s main menu new menu will be enabled:

- Morava Basin
- Drina Basin
- Kolubara Basin

After selecting the river basin, next selection menu will be given:

- Forecast
- Model States
- Model Parameters
- Graphical Support

In the option ***Forecast*** there is an input menu for Quantitative Precipitation Forecast (QPF) and air temperature fields forecast. Forecasts for up to ten days are given as areal averages.

The option ***Model States*** enables changing of initial values of soil moisture, snow accumulation, melted water in snow or water storage in lower and upper zone.

The option ***Model Parameters*** gives an overview of the calibrated model parameters.

The option ***Graphical Support*** enables graphical overview of input variables, observed, simulated and forecasted hydrographs as well as model states.

Updating of simulated discharges is made using manual - interactive procedure on the basis of 15 to 30 simulated values before the forecasting period. Adjustment can be done either by the correction of input variables (rainfall or snow melt) or by changing model state variables.

CONCLUSIONS

The HBVB system in RHMS of Serbia based on original HBV software enables additional functions for more efficient model parameter calibration. STEP, MAP and HILLCLIMB procedures facilitate the process of the parameter optimization, still relationship between them must be taken into the consideration.

Forecasting procedures enables on-line data processing and dissemination. Forecasting are made up to ten days ahead on the basis of QPF. Automated updating procedures will be incorporated in the new version of system. New version of the **PC System 'HBVB'** will be in C language with user dialog designed in Visual Basic or SDK for Windows.

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OPERATIONAL PROCEDURE FOR THE PREDICTION OF THE DAILY DISCHARGES

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Abstract: The operational procedure for the prediction of the daily discharges is made of three components:

- a simulation model for the water runoff propagation on the characteristic river sectors (non-linear model type transfer function) for which the inputs are obtained with the help of some graphic correlations and of some simple mathematical relationships;
- an up-dating method (necessary for using the procedure in real time) which allows to correct the simulated discharges over the entire prediction interval on the basis of the errors between the simulated discharges and those recorded on the hydrometric forecasting station;
- a series of simpler prediction methods in the sections what are the inputs in the simulation model.

In the work, the application of the procedure for the prediction of the daily discharges with 5 days anticipation on the river Mureş is also presented.

OPERATIONSVERFAHREN ZUR PROGNOSE DER TÄGLICHEN WASSERMENGEN

Kurzfassung: Das Operationsverfahren zur Prognose der täglichen Wassermengen ist aus zwei Bestandteilen zusammengesetzt:

-ein Modell zur Simulation der Wasserflußpropagation in charakteristischen Flußabschnitten (Übertragungsfunktionsarti-ges, nicht lineares Modell), für das die Eingangsgrößen mittels graphischer Korrelationen und einfacher mathematischen Beziehungen erhalten werden;

-eine Wiederaktualisierungsmeeethode (notwendig zur Echtzeitanwendung des Verfahrens),die eine Korrektion der im ganzen Lauf der Prognosezeit simulierten Wassermengen aufgrund der Abweichungen ermöglicht, die zwischen den simulierten und den in der hydrometrischen Prognosewarte registrierten Wassermengen auftreten;

- eine Serie von einfachen prognostischen Methoden in den Abschnitten die Eintritte in dos simulation Modell bilden.

In der Arbeit wird auch die Anwendung des Verfahrens zur Prognose der taglichen Wasssermengen mit einer Vorhersage von 5 Tagen auf dem Mureş-Fluß vorgesstellt.

INTRODUCTION

The operational procedure for the prediction of the daily discharges is made of a simulation model of the runoff propagation and an up-dating method for the simulated discharges, at which a series of simpler prediction methods is added in order to increase the prediction anticipation period.

THE SIMULATION MODEL

The Muskingum model elaborated by McCarthy (1935) and presented in the work (xxx, 1960) is one of the expedite procedures frequently used in practice for the flood waves propagation in the river beds.

The processing of the propagation process with the help of the systems theory leads to an improvement of the classic Muskingum model because it gets a better flexibility in the numerical simulation of the different practical cases of the runoff propagation.

The behaviour of a river reach from the point of view of the runoff propagation can be approximated with that of a linear system of the Muskingum type (Fig. 1) described by the state equation:

$$k(1-x)\frac{\mathrm{d}Q_d}{\mathrm{d}t} + Q_d = Q_a - kx\frac{\mathrm{d}Q_a}{\mathrm{d}t} \qquad (1)$$

where Q_a, Q_d are the affluent and the deffluent discharge respectively, of the river reach; k, x- model parameters; t-time.

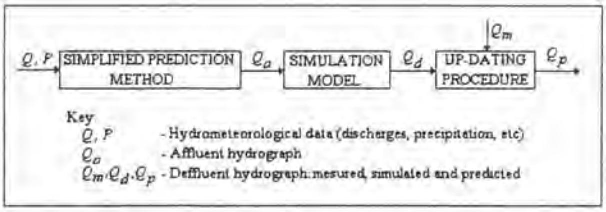

Fig. 1 Operational procedure for the prediction of the daily discharges

According to the linear systems theory, the output of the system is given by the equation:

$$Q_d(t) = \int_0^t Q_a(\tau)h[t-\tau, Q_a(\tau)]\,\mathrm{d}\tau \qquad (2)$$

where $h[t-\tau, Q_a(\tau)]$ is the ordinate at the moment t-τ of the nucleus function of the system, corresponding to the affluent discharge $Q_a(\tau)$.

For a system of the Muskingum type the nucleus function is (Dooge, 1973):

$$h(t)=\frac{x}{x-1}\delta(t)+\frac{1}{k(1-x)^2}e^{-\frac{t}{k(1-x)}} \qquad (3)$$

where $\delta(t)$ is the Dirac function.

Because the input and the output of the system are known over discrete time intervals, the equation (2) becomes (Şerban & Corbuş, 1987):

$$Q_d(m\,\Delta t)=\Delta t\sum_{i=p}^{m}Q_a(i\,\Delta t)U_i[(m-i+1)\Delta t],\ m=1,2,\ldots \qquad (4)$$

$$U(j\,\Delta t)=\begin{cases}1-\frac{k}{\Delta t}\left[1-e^{-\frac{\Delta t}{k(1-x)}}\right], & \text{for } j=1\\ \frac{k}{\Delta t}\left[1-e^{-\frac{\Delta t}{k(1-x)}}\right]^2 e^{-\frac{j\,\Delta t}{k(1-x)}}, & \text{for } j=2,3,\ldots\end{cases} \qquad (5)$$

$$p=\begin{cases}1, & \text{if } m\le n\\ m-n+1, & \text{if } m>n\end{cases}$$

where $Q_d(m\,\Delta t)$ is the ordinate at time $m\,\Delta t$ of the deffluent simulated hydrograph of the river reach; $Q_a(m\,\Delta t)$ - affluent mean discharge over the time interval $[(i-1)\,\Delta t, i\,\Delta t]$; $U_i[(m-i+1)\Delta t]$ - the ordinate at time $(m-i+1)\Delta t$ of the nucleus transfer function of the system at an unitary impulse $Q_a(i\,\Delta t)$ evenly distributed over the time interval Δt; n- number of ordinates of the transfer function.

The nucleus function $U(j\,\Delta t)$ of a Muskingum type system has 2 parameters k and x. The first parameter represents the duration of propagation of the discharges under permanent regime and it is variable, in terms of the affluent discharge on the river reach, and the second one shows the attenuation degree of the discharges.

With the condition that the ordinates of the nucleus function should be positive, there results that the parameters of this one should accomplish the following restrictions:

$$
\begin{aligned}
& x \leq 1+\frac{\Delta t}{k \ln\left(1-\frac{\Delta t}{k}\right)}, \text{ if } \frac{\Delta t}{k}<1 \\
& x<1, \qquad\qquad\qquad \text{if} \frac{\Delta t}{k} \geq 1
\end{aligned} \tag{6}
$$

The use of the equation (4) and (5) in the calculation of the runoff propagation offers some advantages out of which the following can be mentioned:

- the extension of the variation field of the parameter x from $[0 \div 0.5]$ to $(-\infty \div 1)$ which, with the help of the systems theory gives to the Muskingum solved model a larger flexibility of the calculation of the numerical simulation of the runoff propagation of the inferior reaches of the rivers with great easily flooded meadows;
- the k parameter can be considered as variable in terms of the discharge propagated by the river reach;
- the preservation of the affluent flood wave volume over the considered river reach.

CALIBRATION OF THE SIMULATION MODEL PARAMETERS

In order to calibrate the parameters of the daily discharges prediction model, the topology scheme of the hydrographic network has been first carried out implying the division of the water flow into characteristic reaches. This division has been dictated by the Mureş river configuration over the considered reach (Glodeni-Nădlag) as well as by the position of the prediction sections where there are hydrometric stations, taking into account at the same time the hydraulic and geometric characteristics of the Mureş bed. The prediction sections taken into account are: Târgu Mureş, Luduş, Ocna Mureş, Alba Iulia, Acmariu, Gelmar, Branişca, Burjuc, Săvârşin, Rodna, Arad and Nădlag. The confluences of the main affluents Niraj, Lechinţa, Arieş, Târnava, Ampoi, Sebeş, Strei and Cerna have also been taken into account.

Although the remaining parts of the basin between the hydrometric stations taken into account are not explicitly modelled, their influence is indirectly taken in the calculation, by introducing the up-dating procedure.

The optimum values of the parameters of the simulation model have been determined by the propagation of some typical cases of discharge hydrographers occurred.

UP-DATING PROCEDURE

The simulation model is entirely based on the upstream discharges (measured and estimated) without taking into account the discharges recorded at the downstream hydrometric station where the prediction is carried out. In order to use this model in real time it is necessary to elaborate an up-dating procedure which, based on the errors between the simulated discharges and the discharges recorded till the moment of the prediction elaboration at the downstream hydrometric station, should allow a correction of the simulated discharges over the entire prediction interval.

The up-dating procedure used (Ferral, 1983) is differently applied for the increasing and decreasing branch of the hydrograph simulated at the downstream hydrometric station.

For the increasing branch, the following relationships are used:

$$Q_p(t+1)=Q_m(t)+[Q_d(t+1)-Q_d(t)]C(t) \qquad (7)$$

$$Q_p(t+2)=Q_p(t+1)+[Q_d(t+2)-Q_d(t+1)]C(t+1) \qquad (8)$$

$$C(t)=\left[\frac{Q_m(t)-Q_m(t-2)}{Q_d(t)-Q_d(t-2)}\right]^{0.7} \qquad (9)$$

$$C(t+1)=[C(t)]^{0.7} \qquad (10)$$

$$0.5\le C\le 2 \qquad (11)$$

For the decreasing branch, the relationships (7)-(8) are used but in this case the correction factors C are calculated as follows:

$$C(t)=\frac{Q_m(t)}{Q_d(t)} \qquad (12)$$

$$C(t+1)=\frac{Q_p(t+1)}{Q_d(t+1)} \qquad (13)$$

were $Q_m(t-2)$, $Q_m(t)$ are the discharges measured at moments t-2 and t respectively; $Q_d(t-2)$, $Q_d(t)$, $Q_d(t+1)$, $Q_d(t+2)$ - the simulated discharges at the moments t-2, t, t+1 and t+1 respectively; $Q_p(t+1)$, $Q_p(t+2)$ - the predicted discharges at the moments t+1 and t+2 respectively; $C(t)$, $C(t+1)$ - correction factors at moments t and t+1 respectively; t- moment of the prediction elaboration.

PREDICTION ELABORATION

In order to elaborate the prediction the following input data are necessary:

- the measured and the predicted discharges at the hydrometric station at Glodeni;
- the measured and the predicted discharges at the hydrometric stations considered on the main tributaries of the Mureş river;
- the measured levels at the hydrometric stations on the Mureş river.

SIMPLIFIED PREDICTION METHODS

In order to increase the prediction anticipation the operational procedure has been completed with some simple prediction methods in the sections that are inputs in the simulation model, namely: the trend method (used in the recession phase of the hydrograph, when precipitation and/or snow melting is not expected) the multiple linear regression method (used when the recorded and/or predicted precipitation are known).

CONCLUSIONS

The operational procedure for the prediction of the daily discharges made of a simulation model of the runoff propagation, an up-dating method of the simulated discharges and some simpler prediction methods, gives good results at its application in real time, especially during the first 1-4 prediction days.

The intervention of the forecasting hydrologist in establishing the most probable predicted values is especially important.

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The Extension of the Muskingum Model in the Case of n - Subreaches

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Abstract

Usually, in the case of long reaches they are divided into some subreaches, the routing procedure being applied successively on each subreach from upstream to downstream. Still it should be noted that the intermediary calculated hydrographs are not known. Thus it will be necessary to express the outflow of a reach divided into n-subreaches as a function of the upstream and downstream measured values of discharges.

A successive theoretical routing, based on the Muskingum relationship was applied, obtaining an extension of the Muskingum method in the case of n-subreaches, a mathematical model for parameters calibration, as well as some case studies are also presented.

Ausweitung des Muskingum-Modells im Fall von n Teilabschnitten

Zusammenfassung

In der Praxis wird im Fall von langen Flußabschnitten die Berechnung der Fortpflanzung sukzessive, in der Fließrichtung fortschreitend, für jeden einzelnen Teilabschnitt durchgeführt. Trotzdem muß bemerkt werden, daß keine Meßwerte der Durchflußmengen für die so berechneten Zwischenmengenkurven zur Verfügung stehen. Deshalb ist es notwendig, die flußabwärts auftretenden Wassermengen des in Teilabschnitte aufgeteilten Abschnittes abhängig von den Meßwerten der Eintritts- und Austrittsmengen des Abschnittes auszudrücken.

Durch die sukzessive, mittels der klassischen Muskingum-Beziehung durchgeführte Berechnung der Fortpflanzung, wurde eine Ausweitung dieses Modells auf den Fall von n Teilabschnitten erhalten; ebenfalls werden auch ein mathematisches Modell für die Eichung der Parameter sowie Anwendungsbeispiele vorgestellt.

1 Theoretical and practical bases:

The Muskingum routing method gives the outflow q_t of a river reach as a convex linear combination between the upstream inflows Q_t and Q_{t-1} and the downstream discharge q_{t-1} at the previous moment.

$$q_t = c_0 \cdot Q_t + c_1 \cdot Q_{t-1} + c_2 \cdot q_{t-1} \qquad (1)$$

where :

$$c_0 + c_1 + c_2 = 1 \qquad (2)$$

and besides these : $c_0 \geq 0$; $c_1 \geq 0$; $c_2 \geq 0$.

The coefficients c_0, c_1 and c_2 depend on the travel time T of the flow in steady state through the considered reach, depend on the attenuation parameter θ as well as on the chosen time step Δt:

$$c_0 = c_0(T, \theta, \Delta t); \quad c_1 = c_1(T, \theta, \Delta t); \quad c_2 = c_2(T, \theta, \Delta t) \qquad (3)$$

The Δt routing period must respect the stability Courant condition (P. Serban and others-1989):

$$\Delta t \leq T = \frac{l}{u} \qquad (4)$$

where u is the velocity of the wave and l is the length of the reach.

If the Δt routing period is too small considering T, the outflow from the downstream point is evaluated before the high flood reaches this point. Due to this fact, at the beginning of the computation the first downstream values could result negatives. This type of instability risk is practically eliminated if Δt is nearer to T. At a limit it can be taken equal to this one (Ven Te Chow, 1964): $\Delta t = T$, $\Delta t \leq T$.

On the other hand, Δt is chosen on the condition to define adequately the increasing branch of the flood hydrograph:

$$\Delta t \leq \left(\frac{1}{5} \div \frac{1}{3}\right) t_c \qquad (5)$$

where t_c is the high flood increase period.

Thus, conflicting requirements for the Δt time step could result : on one hand it must be small enough considering t_c, and on the other hand it must be near enough to T. This apparent contradiction can be solved if the travel time acceptable from the stability conditions of the flood routing (thus implicitly the length of the computation reach) is dependent on the Δt time step, chosen on the condition (5) :

$$T = T(\Delta t); \quad l = l(\Delta t) \qquad (6)$$

The more is the Δt time step small the less should be the travel time T respectivelly the length l of the computation reach.

If the travel time T between the gaging stations is greater than Δt, a reach of length L must be divided into n subreaches, where:

$$n = \left[\frac{T}{\Delta t} + 0.5\right] \qquad (7)$$

the routing being accomplished successively on each subreach from upstream to downstream.

Still, it is to be noted that the (n-1) intermediary calculated hydrographs cannot be validated in any way because the recordings are only at the upstream and downstream ends of the reach of length L.

Thus, the downstream outflows must be expressed considering the inflows measured at the upper most point of the n subreaches. That implies the extension of the Muskingum model for repeated runs of the routing relationship (1).

2. The description of the mathematical model

In this model the relation (1) is considered as a multiple linear correlation. The coefficients c_0, c_1 and c_2 represent the weight of the discharges Q_i, Q_{i-1} and q_{i-1} in determining the discharge q_i.

At first, the case of two river subreaches (AB and BC) is taken into account.

The relation (1) can be written thus

$$Q_i^B = a_1 \cdot Q_i^A + b_1 \cdot Q_{i-1}^A + c_1 \cdot Q_{i-1}^B \qquad (8)$$

and

$$Q_i^C = a_2 \cdot Q_i^B + b_2 \cdot Q_{i-1}^B + c_2 \cdot Q_{i-1}^C \qquad (9)$$

where A, B and C represent the corresponding points, a_1, b_1, c_1, and a_2, b_2, c_2, are the coefficients of the equation (1) concerning the two routing subreaches.

The term Q_{i-1}^B from the relation (9) can be obtained from the relation (8) replacing the subscript i by i-1;

$$Q_{i-1}^B = a_1 \cdot Q_{i-1}^A + b_1 \cdot Q_{i-2}^A + c_1 \cdot Q_{i-2}^B \qquad (10)$$

Combining equation (8) and (10) with equation (9) gives:

$$\begin{aligned} Q_i^C &= a_2(a_1 Q_i^A + b_1 Q_{i-1}^A + c_1 Q_{i-1}^B) + b_2 Q_{i-1}^B + c_2 Q_{i-1}^C = \\ &a_2 a_1 Q_i^A + (a_2 b_1 + a_2 c_1 a_1 + b_2 a_1) Q_{i-1}^A + (a_2 c_1 + b_2) b_1 Q_{i-2}^A + (a_1 c_1 + b_2) c_1 Q_{i-2}^B + c_2 Q_{i-1}^C \end{aligned} \qquad (11)$$

This result can be written as follows :

$$Q_i^C = \alpha\, Q_i^A + \beta\, Q_{i-1}^A + \gamma\, Q_{i-2}^A + \delta\, Q_{i-2}^B + \varepsilon\, Q_{i-1}^C \qquad (12)$$

If the flood travel time from A to B is equal with that from B to C and approximately equal with the routing period Δt :

$$t_{AB} = t_{BC} \cong \Delta t \qquad (13)$$

then the discharge $Q_{i-2}^B = Q^B(i\,\Delta t - 2\,\Delta t)$ passed through the point C to the former step and thus can no longer influence the outflow from the section C at the moment i.

If the coefficients $\alpha, \beta, \gamma, \delta, \varepsilon$ from the equation (12) are considered as weights then it is clear that Q_{i-2}^B weight is either very near to zero or even negative.

That means the routing relation, in the case of a reach made of 2 subreaches, becomes:

$$Q_i^C = \alpha\, Q_i^A + \beta\, Q_{i-1}^A + \gamma\, Q_{i-2}^A + \varepsilon\, Q_{i-1}^C \qquad (14)$$

Making a similar calculus for a reach composed of 3 subreaches (AB, BC and CD) the relation will be as follows:

$$Q_i^D = \alpha\, Q_i^A + \beta\, Q_{i-1}^A + \gamma\, Q_{i-2}^A + \delta\, Q_{i-3}^A + \varepsilon\, Q_{i-3}^B + \varphi\, Q_{i-1}^D \qquad (15)$$

Following the same reasoning to the former one, the weight that corresponds to the discharge Q_{i-3}^B (which needs a time roughly equal to $2\Delta t$ to get in the section D) is practically zero.

Thus, in the case of 3 subreaches, the routing relation becomes

$$Q_i^D = \alpha\, Q_i^A + \beta\, Q_{i-1}^A + \gamma\, Q_{i-2}^A + \delta\, Q_{i-3}^A + \varphi\, Q_{i-1}^D \qquad (16)$$

It can be observed that the downstream outputs from the point D is expressed only according to the upstream inputs of the reach (point A) and to the downstream output at the former moment.

Returning to the initial marking, by means of a generalisation, in the case of a number of n subreaches the following relation results

$$q_i = c_0 Q_i + c_1 Q_{i-1} + c_2 Q_{i-2} + \ldots + c_n Q_{i-n} + c_{n+1} q_{i-1} = \sum_{j=0}^{n \geq 1} c_j Q_{i-j} + c_{n+1} q_{i-1} ; \qquad c_j > 0 \qquad (17)$$

It is to be remarked that for n=1, the relation (17) is transformed into the relation (1), applied for a single reach.

In the calibration stage the first coefficients c_j could result negatives which means that the corresponding inputs do not effectively influence the current downstream discharge.

In such cases, the relation (17) will be written

$$q_i = \sum_{\substack{j=k<n \\ i>j}}^{n=k+\lambda} c_j Q_{i-j} + c_{n+1} q_{i-1} \quad ; \qquad c_j > 0 \qquad (18)$$

The number k represents the delay index, and λ shows the number of terms taken into account.

The relation (18) represents the extension of the Muskingum model for flood routing in the case of a reach divided into n subreaches without a considerable contribution of the tributaries.

3. A Mathematical Model for the Parameters Calibration

The relation (18) is considered like the relation (1) - as being a multiple linear correlation. Their coefficients are obtained respecting the condition that the sum of the square deviations from the calculated values of q_i (noted in the following by q_i^c) and the measured outputs q_i^m should be minimal.

In the case of the relation (1) the objective function is written:

$$(\min) Z_1 = \sum_i (q_i^c - q_i^m)^2 \qquad (19)$$

or even

$$(\min) Z_1' = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (q_i^c - q_i^m)^2} = \sqrt{\frac{1}{N} \cdot Z_1} \qquad (19')$$

Replacing q_i with q_i^c, in the relation (1) we have

$$q_i^c = c_0 \cdot Q_i + c_1 \cdot Q_{i-1} + c_2 \cdot q_{i-1}^c \qquad (20)$$

The function (19) becomes minimal in the conditions :

$$q_i^c = q_i^m \qquad (21)$$

Taking into account the relation (21) the following approximation can be accepted:

$$q_{i-1}^c = q_{i-1}^m \qquad (22)$$

This approximation is necessary in the relations (20) and (19) in order to avoid recursive formulations of the calculated downstream output (Drobot, 1987). Thus the objective function Z_1 becomes :

$$(\min) Z_1 = \sum_i (q_i^c - q_i^m)^2 = \sum_i (c_0 Q_i + c_1 Q_{i-1} + c_2 q_{i-1}^m - q_i^m)^2 \qquad (23)$$

The coefficients c_0, c_1 and c_2 can be obtained either by equalling to zero the derivatives of the function Z_1 and by solving the obtained linear system (the classic optimisation), or by means of an algorithm of nonlinear programming.

In the case of this model the constraint (2) is no longer used assuring thus a greater elasticity in the choice of the parameters values. The runs for various real cases lead to sums of the coefficients between 0.98 - 1.01 so close enough to unity. The difference to the unity represents percentual losses of the high flood wave in the main floodplain (infiltration, stagnation, evaporation etc.) or inputs from minor tributaries.

In the case of n subreaches the objective function is as follows:

$$(\min) Z_n = \sum_{i=1}^{N} (q_i' - q_i^m)^2 = \sum_{i=1}^{N} \left[\sum_{\substack{j=k \\ i>j}}^{n=k+\lambda} c_j Q_{i-j} + c_{n+1} q_{i-1}^m - q_i^m \right]^2 \qquad (24)$$

or

$$(\min) Z_n' = \sqrt{\frac{1}{N} Z_n} \qquad (25)$$

The unknown elements are the coefficients $c_k, c_{k+1}, \dots, c_n, c_{n+1}$, all the other values (the downstream and upstream discharges) being known.

To minimise the function Z_n or Z_n' any of the two approches previously shown can be used: the classic optimisation or the nonlinear programming.

4. Validating the model

Using a registered input hidrograph at Orofteana station on the Prut river in Romania, the "mesured" outputs were calculated considering four subreaches with different parameters along the reach:

$c_0 = 0.2$	$c_0' = 0.3$	$c_0'' = 0.1$	$c_0''' = 0.4$
I $c_1 = 0.4$	II $c_1' = 0.2$	III $c_1'' = 0.3$	IV $c_1''' = 0.3$
$c_2 = 0.4$	$c_2' = 0.5$	$c_2'' = 0.6$	$c_2''' = 0.3$

By using the classical Muskingum model for one reach, the obtained coefficients did not all respect the non-negativity condition: $c_0 = 0.201; c_1 = -0.065; c_2 = 0.885$.

Repeated runs considering two, three and finally four subreaches were performed; finally the following routing relation was accepted:

$$q_i = c_2 \cdot Q_{i-2} + c_3 \cdot Q_{i-3} + c_4 \cdot Q_{i-4} + c_5 \cdot q_{i-1} \qquad (26)$$

where: $c_2 = 0.075; c_3 = 0.040; c_4 = 0.186; c_5 = 0.736$

The computed hydrograph after calibration and the "measured" one are almost superposed (Fig. 1.a).

The flood registered in april 1982 on the same river on the reach Orofteana-Radauti was also tested. The flood travel time is about 22 hours; for a routing period Δt=4 hours and 5 subreaches the routing equation is:

$$q_i = c_3 Q_{i-3} + c_4 Q_{i-4} + c_5 Q_{i-5} + c_6 q_{i-1} \qquad (27)$$

were: $c_3 = 0.208; c_4 = 0.105; c_5 = 0.204; c_6 = 0.415$

A graphic representation of the input hydrograph, respectively of the measured and calculated output after parameters calibration is given in Fig. 1.b.

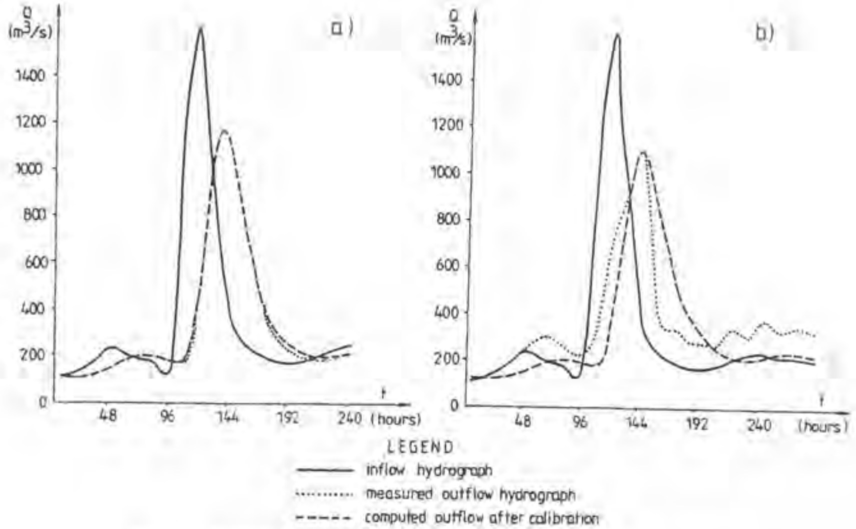

Fig 1. - Reach discharge hydrographs considering n-subreaches
a) downstream fictional case;
b) april 1982 flood on the reach Orofteana-Radauti

5. Conclusion

The proposed model is an extension of the Muskingum relation, useful when the flood travel time is greather than the routing period Δt. The number of subreaches into which the reach is divided depends on the ratio $T/\Delta t$.

The convex linear combination which expresses the output as a function of the former inputs into the reach and the previous output is the relation (17) or (18), the non-negativity condition for all the coefficients having to be satisfied.

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SHORT TERM RIVER FLOW FORECAST FOR THE RIVER DANUBE

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ABSTRACT

The results of short term forecast (one, two and three days ahead) for one section of the river Danube are presented in this paper. Basic assumptions of model DLCM (Discrete Linear Cascade Model) have been applied for the operational forecasting of discharge data. Basic model parameters have been optimized: n (number of resevoirs) and K (travel time storage coefficient). Stochastic part of the model using autoregressive scheme has been defined by AR(2,1) model. Kalman filter has been also applied for real-time parameter updating and forecasting.

DIE KURZFRISTIGE VORHERSTAGE FÜR DIE DONAU

ZUSAMMENFASSUNG

Die Resultate der kurzfristigen Vorhersage (1-tägig,2-tägig, und 3-tägig) auf einem Segment des Donau-Flussgebietes sind in diesem Artikel gegeben worden. Die Grundvoraussetzungen des Modell DLCM (Diskretes lineares Kaskaden-Modell) sind auf die operationelle Vorhersage des Durchflusses angewendet worden. Die grundsätzlihen Parameter des Modells sind optimiert worden: n (die Nummer des Speichers) und K (Koeffizient des Laufwegs des Wasservolumens). Der stochastische Teil des Modells ist mittels der Autoregression bestimmt worden, und ist durch Modell AR(2,1) beschrieben. Für die Prognose und Korrektion der Parameter des Modells in der Realzeit, wurde der Kalman-Filter angewendet.

INTRODUCTION

In the practice of operational hydrological forecasting the main problem is the real-time forecast of runoff. A vast number of different forecasting approaches exist and the decision on their selection should be based mainly on physico-geographical conditions of the basin and the rivers. The availability of necessary data from networks and possibility of applying appropriate computational techniques are important factors, too.

The River Danube receives several major tributaries in the southern part of the Pannonian Basin surrounded by the Carpathian Mountains. Predominantly flat area, absence of small tributaries and considerable lateral inflow make flood routing the most feasible technique to be applied for the river flow forecasting in this area. One of the flood routing techniques is the Discrete Linear Cascade Model (DLCM) given by A.Szöllősi-Nagy (1982) which presents the discretization of the continuous Nash cascade model. The principles of a state-space modeling are used. Discretization of the continuous process was basic prerequisite to use Kalman filter as digital filtering technique for real-time parameter updating and forecasting.

The objective of this paper is to present the results of applying coupled deterministic-stochastic model (DLCM + ARMA) for operational hydrological forecasting on one section of the river Danube, including the selection of the appropriate ARMA model for different lead times (one, two and three days ahead). Also basic equations of state-space representation of the model together with Kalman equations are presented.

DETERMINISTIC DLCM

Introduced by Nash (1957), river section, which is to be analyzed, with inflow U_t and outflow Y_t, is considered to consist of *n* linear reservoirs in cascade with same storage coefficient K. Output of one reservoir is the input to the next one, and output of the last reservoir is the output of the whole system. Discretized form of this approach is developed by A. Szöllősi-Nagy (1982) which assumes that both input U_t and output Y_t are sampled et equidistant sampling intervals Δt. Such representation is given by equations:

$$\underline{X}_{t+\Delta t} = \Phi(\Delta t)\,\underline{X}_t + \underline{\Gamma}(\Delta t)\,U_t \quad (1)$$

$$Y_t = \underline{H}\,\underline{X}_t \quad (2)$$

where $\underline{X}$ is a state variable, eq. amount of water stored in each reservoir of the cascade. State transition matrix and input transition vector are :

$$\left[\Phi(\Delta t)\right]_{ij} = \begin{cases} \dfrac{(k\Delta t)^{i-j}}{(i-j)!}\, e^{-k\Delta t} & ; \; i \geq j \\ 0 & ; \; i < j \end{cases} \quad (3)$$

$$\left[\Gamma(\Delta t)\right]_i = \left(1 - e^{-k\Delta t} \sum_{j=0}^{i-1} \frac{(k\Delta t)^j}{j!}\right) / k \quad (4)$$

H is output vector defined by :

$$\left[H \right]_i = \begin{cases} 0 & i \neq n \\ k & i = n \end{cases} \tag{5}$$

Basic formulae of DLCM, (1) and (2), can be solved using following initial state vector determined by the first n input/output data :

$$\underline{X}_o = \sigma^{-1} \underline{e}_n \tag{6}$$

where σ is the observability matrix :

$$\left[\sigma\right]_{ij} = k \frac{(ik\Delta t)^{n-j}}{(n-j)!} e^{-ik\Delta t} \tag{7}$$

vector e is defined by :

$$\left[e\right]_i = Y_i - \sum_{j=0}^{i-1} h_{i-j} U_j \tag{8}$$

and hj, j = 1,2, ... n, is the j-th ordinate of the impulse response of DLCM.

STOCHASTIC (ARMA) MODEL

Considering error sequence, obtained by applying deterministic DLCM, it is possible to identify a stochastic time series model for residuals, provided that they follow an autoregressive-moving average (ARMA) model.If the residuals follow the ARMA(μ,1) model, appropriate state-space representation is:

$$\begin{bmatrix} X_{n+1,t} \\ \cdot \\ \cdot \\ \cdot \\ X_{n+\mu,t} \end{bmatrix} = \begin{bmatrix} a_1 & a_2 & \cdot & \cdot & a_\mu \\ 1 & 0 & \cdot & \cdot & 0 \\ \cdot & & & & \\ \cdot & & & & \\ 0 & 0 & \cdot & 1 & 0 \end{bmatrix} \begin{bmatrix} X_{n+1,t-\Delta t} \\ \cdot \\ \cdot \\ \cdot \\ X_{n+\mu,t-\Delta t} \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \\ \cdot \\ \cdot \\ 0 \end{bmatrix} w_{t-\Delta t} \tag{9}$$

where the state variables X are error data : $\varepsilon_t = X_{n+1,t}$; $\varepsilon_{t-1} = X_{n+2,t}$, etc. and a_1, a_2, ... a_μ are the parameters obtained by the Yule-Walker equation, Kendall, Stuart(1968). μ is the order of the ARMA model, and w is the white noise sequence. Equation (9) can be presented as :

$$\underline{x}'_t = \Phi_\varepsilon(\Delta t)\, \underline{X}'_{t-\Delta t} + \underline{\Lambda}(\Delta t)\, w_{t-\Delta t} \tag{10}$$

COUPLED DETERMINISTIC-STOCHASTIC MODEL

As both models, DLCM and ARMA, are defined in similar form, it is possible to define joint deterministic-stochastic model defined by the following equations :

$$\underline{x}^*_t = \Phi^*(\Delta t)\, \underline{X}^*_{t-\Delta t} + \underline{\Gamma}^*(\Delta t)\, U_{t-\Delta t} + \underline{\Lambda}^*\, w_{t-\Delta t} \tag{11}$$

$$Y_t = \underline{H}^* \underline{X}^*_t \tag{12}$$

Obtaining augmented column vectors $\underline{x}^*$, Γ^*, and matrix Φ^* is described in detail by A. Szöllősi-Nagy et al.(1986).

DIGITAL FILTERING TECHNIQUE

For the real time parameter updating and forecasting well known linear Kalman filter is applied. First step is prediction of state vector X and error covariance matrix P Δt time steps ahead:

$$\hat{\underline{x}}^*_{t|t-\Delta t} = \Phi^*(\Delta t)\ \hat{\underline{x}}^*_{t-\Delta t|t-\Delta t} + \underline{\Gamma}^*(\Delta t)\ U_{t-\Delta t} \tag{13}$$

$$P_{t|t-\Delta t} = \Phi^*(\Delta t)\ P_{t-\Delta t|t-\Delta t}\ \Phi^{*T}(\Delta t) + \underline{\Delta}^*\ Q\ \underline{\Delta}^{*T} \tag{14}$$

The second step is their updating after receiving the new measurement Yt :

$$\underline{K}_t = P_{t|t-\Delta t}\ \underline{H}^{*T} \left[\underline{H}^*\ P_{t|t-\Delta t}\ \underline{H}^{*T} \right]^{-1} \tag{15}$$

$$\hat{\underline{x}}^*_{t|t} = \hat{x}^*_{t|t-\Delta t} + \underline{K}_t \left[Y_t - \underline{H}^*\ \hat{\underline{x}}^*_{t|t-\Delta t} \right] \tag{16}$$

$$P_{t|t} = \left[I - \underline{K}_t - \underline{H}^* \right] P_{t|t-\Delta t} \tag{17}$$

Its obviously that discrete state-space representation of the coupled deterministic-stochastic model is suitable for applying this linear filter.The computational scheme is recursive and can be easily performed on microcomputers.

MODEL DLCM + ARMA APPLICATION FOR SHORT-TERM FORECASTING

The test data used for the River Danube are daily data from the gauge stations Budapest and Bezdan, (year 1991). Estimation of basic model parameters n (number of reservoirs) and K (travel time storage coefficient) were performed by direct search optimization technique, Harkányi (1982), yielding n = 3, K = 1.29 days. Residuals from the pure deterministic DLCM showed high autocorrelation, leading that stochastic part of the model had to be identified. Six ARMA models were considered: AR(1,0), AR(1,1), AR(2,0), AR(2,1), AR(1,2) and AR(2,2), yielding model AR(2,1) for forecasting one and three days ahead and AR(2,0) for two days. Differences in error statistics obtained by using pure DLCM and DLCM+AR models are given in the following table :

Table 1. Error statistics for forecasts one, two and three days ahead
Tab.No.1 Die grundsätzlichen Fehler-Parameter der 1,2,und 3-tägiger Prognose

	T = 1 day				T = 2 days				T = 3 days			
Statistics	$\bar{\varepsilon}$	σ_ε	$R_\varepsilon(1)$	η	$\bar{\varepsilon}$	σ_ε	$R_\varepsilon(1)$	η	$\bar{\varepsilon}$	σ_ε	$R_\varepsilon(1)$	η
DLCM	46.4	181.7	0.89	-	42.4	226.9	0.88	0.45	38.4	268.0	0.90	0.69
DLCM + AR	0.4	52.8	0.01	0.92	0.8	85.9	-0.02	0.94	0.2	110.0	-0.03	0.95

The mean error $\bar{\varepsilon}$, standard deviation σ and lag-one correlation coefficient $R\varepsilon(1)$ are considerably smaller for all lead times in the case of joint model, together with higher coefficient of effectiveness η (Table 1.). Figure 1. shows the results of the forecasting procedure by applying joint model.

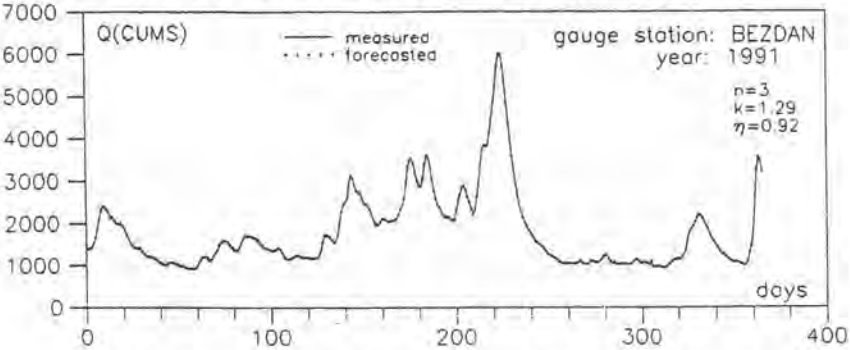

Figure 1. Forecasts one-day ahead obtained with DLCM+AR(2,1) model
Ab.1.Die eintägigen Durchfluss-Prognosen,erreicht mittels Modell DLCM+AR(2,1)

Forecasts one,two and three days ahead are issued in following years, 1992 and 1993, using parameters of model DLCM+AR calibrated for year 1991. Forecasts one-day ahead and innovation sequence are presented in Figure 2.

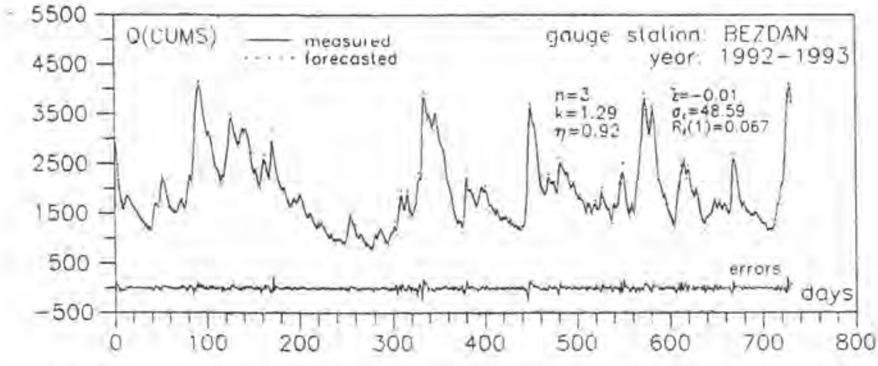

Figure 2. Forecasts one-day ahead with coupled deterministic-stochastic model
Ab.2. 1-tägigen Prognosen erreicht mittels deterministisch-stochastisches Modell

CONCLUSION

The results obtained by applying model DLCM+AR together with Kalman filter for river flow forecasting on considered section of the River Danube are quite acceptable, especially for one-day ahead forecasting. Series of residuals have characteristics of Gaussian white noise, so no error propagation exists. The coincidence of measured and computed hydrographs exists, with better results for the falling tail of hydrograph than for the raising one. Improved results could be obtained by model parameter calibration for high and low flow regimes separately, and also discretized time step could be smaller than $\Delta t = 24$ hours.

For operational real-time forecasting, software package written in FORTRAN programming language was developed and adapted to run on MicroVAX computer. Input data are morning stages observed at gauge stations Budapest and Bezdan. Forecasts are issued as stage/discharge values for one, two and three days ahead and can be graphically presented. This software package need small memory and short computation time (about two minutes). Since 1993, the model has been used in Operational Centar for Hydrological Forecasting in FRY.

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ON THE SHORT RANGE HYDROLOGICAL FORECASTING ALONG THE BULGARIAN PART OF THE DANUBE RIVER

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ABSTRACT: Comparison of different methods for short range forecasting of the Danube water levels and discharges, available at the National Institute of Meteorology & Hydrology - Sofia is the aim of the present paper. Several forecasting techniques for flood rooting like single input single output and multiple input single output linear systems with different methods for the approximation of the corresponding unit hydrographs have been used. An attempt was made to improve the prediction accuracy applying auto regression model over the forecasting residuals. Evaluation and comparison of prediction accuracy at various conditions was performed with emphasis on: the influence of the "Iron gates" on the water level and discharges daily and weekly variations; the importance of the separate consideration of different tributaries in the forecasting model; the use of instantaneous or daily mean values for the levels and the discharges; the seasonal influence and others.

BEZÜGLICH DER KURZFRISTIGEN HYDROLOGISCHEN VORHERSAGEN IM BULGARISCHEN TEIL DES DONAU-FLUßES

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ZUSAMMENFASSUNG: Der vorliegende Artikel beschäftigt sich mit dem Vergleich verschiedener Methoden zum kurzfristigen Vorhersagen der Wasserstände und -mengen, die im NIMH zu Verfügung stehen. Es sind verschiedene prognostische Techniken zur Transformation der hohen Fluten angewandt, wie z. B. die linearen Systeme mit einem Eingang und einem Ausgang sowie mit mehreren Eingängen und Ausgängen, die verschiedene Modelle zur Approximation des jeweiligen Einzelhydrographes verwenden. Es wurde ein Versuch zur Besserung der Vorhersagengenauigkeit mit Anwendung der Autoregression auf die Reste (Nebenprodukte, Differenzen) gemacht. Es wurden Bewertung und Vergleich der Vorhersagengenauigkeit unter verschiedenen Bedingungen unternommen, indem Rechenschaft über folgendes abgelegt wurde : - den Einfluß der "Eisernen Tore" auf die täglichen und wöchentlichen Schwankungen der Wasserstände und -mengen; - die Wichtigkeit der Betrachtung der Nebenflüßeanteilnahme im prognostischen Modell; - die Anwendung der momentanen und mitteltäglichen Werte für die Stände und Mengen; - den Einfluß der Jahreszeiten u.a.

1. INTRODUCTION

The short range forecasting of water levels and discharges along the Bulgarian part of the Danube river is of valuable importance for a number of activities in the region of Lower Danube. In spite of the fact that the practical needs for forecasts of the downstream countries are not identical and depend on the specific industrial and social conditions, the mentioned problem remain as central basic part of various applications. Many problems make the establishment of real time short range forecasting services complex: the operation of Iron Gates, its influence on the daily and weekly water levels and discharges variations and the necessity for real time data availability; the significance of various tributaries contribution and the need for operational access to the data bases of different countries. Taking into account the above mentioned problems, the author presents some results on the short range forecasting at two cross-sections - the village of Novo Selo (located 17 km. downstream the Iron Gates 2) and the town of Ruse (close to the end of the Bulgarian section).

2. DATA SETS AND METHODS USED

The variations of the water levels and discharges at the cross-section of Novo Selo depend practicaly of two main factors - the variations of the inflows at the middle part of Danube and the operation of the Iron Gates 1. Having in mind previous investigations (Dimitrov, 1992), the discharge series of the following cross-sctions were chousen as predictors: Danube - Bogoevo, Sava - Sr. Mitrovica, Tisa - Seged, Vel. Morava - Lubichevski most. Approximate calculations show that the expected leed time of the forecast for the outflow cross-section of Novo Selo should be within 3 days. The other part of the Danube considered, with outflow cross-section at the town of Ruse, was assuned to be predicted by the Bulgarian tributaries: Ogosta - Miziya, Iskar - Oryahovica, and Yantra - Karanci, the Romanian ones Olt - Stoenesti, Jiu - Podari and Arges - Budesti, while the discharge series of Danube - Novo Selo was taken as the Iron Gate 2 outflow. The length of the all series was eight years within the period 1980 - 1987. It was chosen bearing in mind the fact that significant influence of the Iron Gates 1 on the high flow was observed in 1988. All the data used were daily averaged discharges measured in qm/s. The first seven years were used for calibration and the last one was used to verify the forecasting relations found.

The multiple input single output linear technique with non-parametric pulse response function obtained by least squares method was used for flow routing (Kachroo and Liang, 1992). The convolution integral may be expressed in terms of pulse responses, as a series of algebraic equations in the form:

$$Y_i = \sum_{k=1}^{L} \sum_{j=1}^{m(k)} X_{i-j+1}^{(k)} H_j^{(k)},$$

where Y is the outflow series, *X* are the inflow input series, *L* is their length and *m(k)* is the memory length of the system corresponding to the k-th input series. The updating of the model forecasts was done using simple autoregressive (AR) model:

$$e_i = \sum_{j=1}^{p} \phi_j e_{i-j+1} + a_i$$

where e are the residuals, ϕ are coefficients and a is the white noise of zero mean and certain variance. The coefficients were evaluated also by the least square method. All the calculations were implemented by PC using the MS Power Station 32 Fortran compiler.

3. RESULTS AND DISCUSSIONS.

Several simulations were carried out in order to achieve beter results and adjust some of the algorith parameters. Nevertheless some information on the leak time was available, the assumed memory length was matter of fitting. Experimental calculations were done varying the *m(k)* within the range 7 - 30. For the Novo Selo forecasting scheme an optimal memory length of 10 days was found. Shorter memory significantly decreases the forecasting accuracy. For the Ruse forecasting scheme a shorter memory length of 7 days was found optimal, which correspond to the preliminary knowledge about the system. Summary of the final rsults is given in Table 1.

Table 1. Summary of the prediction accuracy.

	Danube at "Novo Selo" cross section			Danube at "Ruse" cross section		
Estimate	Calibration	Verification period		Calibration	Verification period	
	not updated		updated	not updated		updated
Mean of the outflow	$.577.10^4$	$.557.10^4$	$.577.10^4$	$.615.10^4$	$.615.10^4$	$.615.10^4$
Estimated Q mean	$.574.10^4$	$.595.10^4$	$.591.10^4$	$.612.10^4$	$.610.10^4$	$.612.10^4$
Ratio Qobsv./Qest.	1.0054	0.990	0.997	1.004	1.004	1.001
Initial variance	$.559.10^7$	$.747.10^7$	$.747.10^7$	$.611.10^7$	$.772.10^7$	$.772.10^7$
Residual variance	$.237.10^6$	$.326.10^6$	$.165.10^6$	$.398.10^6$	$.047.10^6$	$.011.10^6$
Efficiancy R^2 %	95.76	95.64	97.79	99.35	99.40	99.86
MS Error of peaks	$.518.10^6$	$.461.10^6$	$.399.10^6$	$.084.10^6$	$.052.10^6$	$.046.10^6$

The calculated pulse response functions for the Novo Selo discharges forecasting are goven in Fig. 1. For all predictors (except for the Tisa river) we see several significant lag responses varying from 1 to 6-7 days.The shortest responce is observed at the Vel. Morava river. The river of Tisa has medium values, while the Sava river and Danube - Bogoevo have maximum values up to 7 days. Interesting particularity of the pulse response functions calculated for longer memory lengths is that they have obvious periodical shape with length of the period about one week. Partly this could be seen on Fig. 1 and could be explained with the operation of Iron Gate 1 acumulating water during the weekend. This could be seen also on Fig 3, where the Novo Selo hydrograph of the observed and predicted daily discharges for the verification period - 1987 is shown. The analysis of table 1 - Novo Selo, verification period and the comparison of fig. 3 and 4 shows the significant improvement of the forecast results when the autoregresive updating procedure is used.

Similar results are achieved for Danube - town of Ruse cross-section. A model with seven inputs (including Danube at Novo Selo, the mentioned above

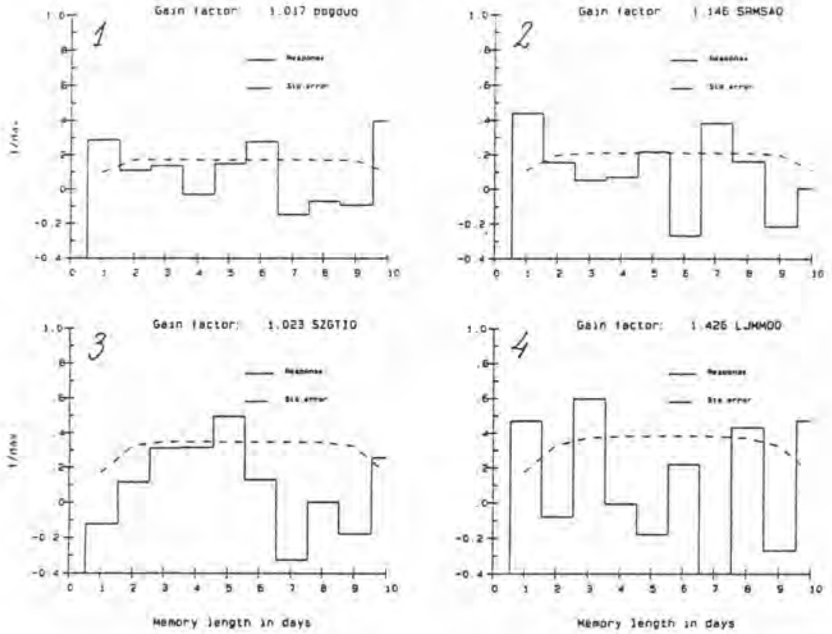

Fig. 1. Pulse response functions for the outflow Danube - Novo Selo and inputs:
1. Danube, 2. Sava, 3. Tisa, 4. Vel. Morava

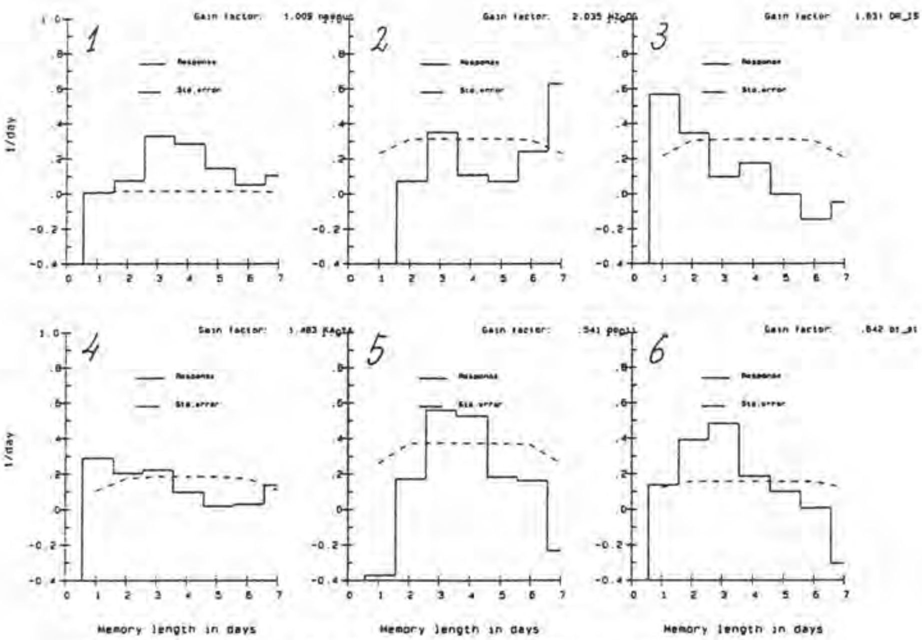

Fig. 2. Pulse response functions for the outflow Danube - Ruse and inputs:
1. Danube. 2. Ogosta, 3. Iskar, 4. Yantra, 5. Jiu, 6. Olt

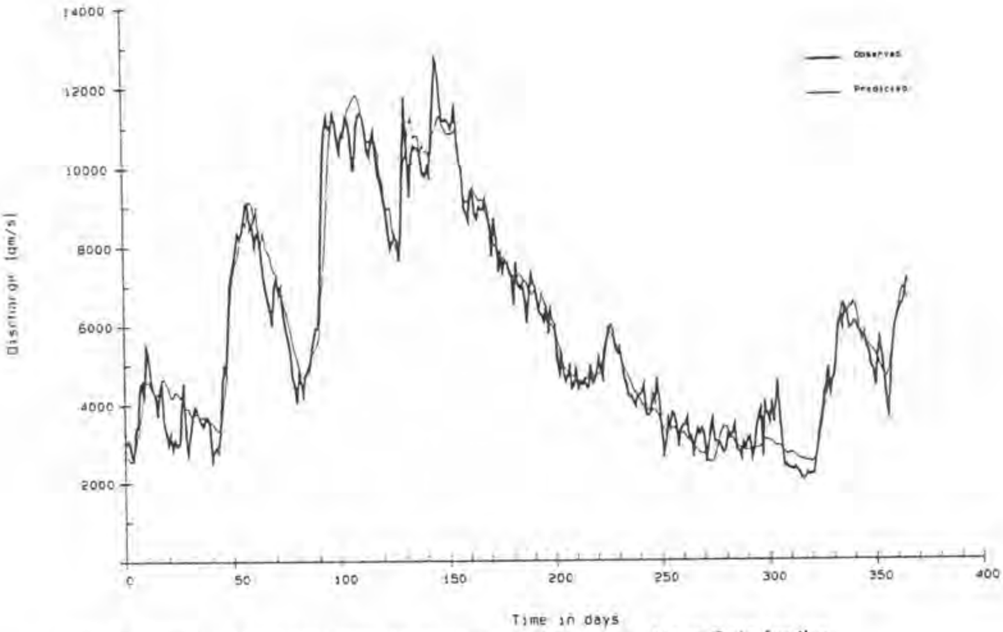

Fig. 3. Observed and predicted hydrographs of Danube - Novo Selo for the verification period - 1987 (without updating).

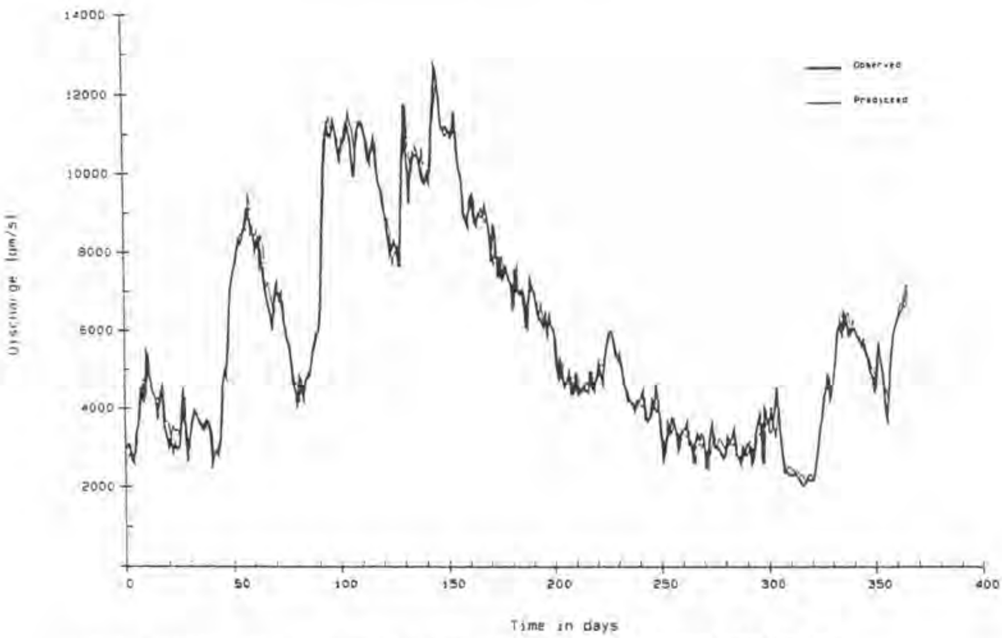

Fig. 4. Observed and predicted hydrographs of Danube - Novo Selo for the verification period - 1987 (with updating).

three Bulgarian and the Romanian tributaries) and one output was experimented. The assumed memory length was shorter in this case. The final pulse response functions displayed on Figure 2 are with length of seven days which correspond to our preliminary knowledge on the flood transformation characteristics of this part of the watershed. The pulse response function of river Arges is not given on the Fig. 2 as far as most of the responseordinates are not significant. The summary of the forecasting accuracy in Table 1 - last column, show that the predictions are much better in this case. This means that if both the Bulgarian and Romanian tributaries are known at real time the forecast for the Danube - Ruse will be almost perfect.

4. CONCLUSIONS

The results, demonstrated most of all by the summary of the prediction accuracy, show that even by those simple linear methods almost perfect results could be achieved for Danube - Ruse cross-section. The same could not be said for the Novo Selo cross-section where the case is more complex and additional information about Iron Gates operations will be necessary at real time. Another important conclusion is that simple AR updating procedures could significantly improve the results and should be applied to the operational techniques.

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ALGORITHM AND CALCULATION PROGRAM FOR THE PREDICTION OF THE DAILY MEAN DISCHARGES

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Abstract: For the prediction of the daily mean discharges, with 5 days anticipation, a mathematical model based on the linear multiple regression has been used, which, in order to increase the anticipation, has been completed with a series of graphic relationships and mathematical simple relationships. These relationships have been applied, related to the hydrological regime phase, for the increase and decrease branches of the hydrograph of the daily mean discharges.

The calculation program created on the basis of the elaborated algorithm has been applied for the prediction of the daily mean discharges at the hydrometric stations considered on the Barcău, Crişul Repede, Crişul Negru and Crişul Alb Rivers.

ALGORITHMUS UND RECHENPROGRAMM ZUR PROGNOSE DER MITTLEREN TÄGLICHEN WASSERMENGEN

Kurzfassung: Zur Prognose der mittleren täglichen Wassermengen, mit einer Voraussage von fünf Tagen, wurde ein mathematisches Modell angewandt, das auf einer vielfachen, zwecks Erhöhung der Antizipation durch eine Reihe von graphischen und mathematischen Beziehungen ergänzten Linearregression beruht. Diese einfachen Beziehungen wurden abhängig von der Phase des hydrologischen Zustandes, für den ansteingenden und bzw. den abfallenden Zweig der Durchflußganglinie der mittleren täglichen Wassermengen angewandt.

Das aufgrund des ausgearbeiteten Algorithmus erstellte Rechenprogramm wurde zur Prognse der mittleren täglichen Wassermengen bei den in Betracht genommenen, auf den Flüßen Barcău, Crişul Repede, Crişul Negru und Crişul Alb gelegenen Warten angewandt.

INTRODUCTION

Following the analysis of the runoff occurrence way, of the existing hydrometeorological network, of the hydraulic structures and of the propagation times for the hydrographic basins of the Barcău, Crişul Repede, Crişul Negru and Crişul Alb rivers, for the prediction of the daily mean discharges, a mathematical model was chosen having at the basis the multiple linear regression which, in order to increase the anticipation period, was completed with simpler forecasting models.

On the basis of the elaborated algorithm program VMEDZI v.1.0 was created (Ungureanu & Corbuş, 1992). This program containing a system of main menus, sub-menus, helps and opening and up-dating file sub-programs with input data, it is made in the Turbo-Pascal programming language and can be run on any IBM-PC/AT compatible computer.

BRIEF PRESENTATION OF THE PREDICTION MODEL

The mathematical model for the prediction of the daily mean discharges uses a multiple linear correlation of the following form (Şerban & Ungureanu, 1982):

$$V_{SP}^{i} = \sum_{j=1}^{NS(i)} \sum_{k=1}^{NA(i,j)} CR(i,j,k)\, V_{S_j}^{DEC(i,j,k)}(i) + TL(i)$$

where: V_{SP}^{i} is for the value forecasted for the forecasting station SP with i anticipation days; $NS(i)$ - number of stations entering in multiple linear correlation for the anticipation day i; $NA(i,j)$ - number of inputs from station S_j in correlation; $CR(i,j,k)$ - correlation coefficients (k values for each station S_j); $V_{S_j}^{DEC(i,j,k)}$ - the value recorded at the station S_j at moment $DEC(i,j,k)$; $TL(i)$ - the free term of the correlation.

CALIBRATION OF THE PREDICTION MODEL PARAMETERS

In order to calibrate the parameters of the prediction model for the daily mean discharges in the hydrographic basins of the Barcău, Crişul Repede, Crişul Negru and Crişul Alb rivers, the hydrometric stations for which the forecasting will carried out were first established (Fig. 1). Then, following the analysis of the propagation times, the hydrometric stations which, at various time lags, stand for the independent variables, were established.

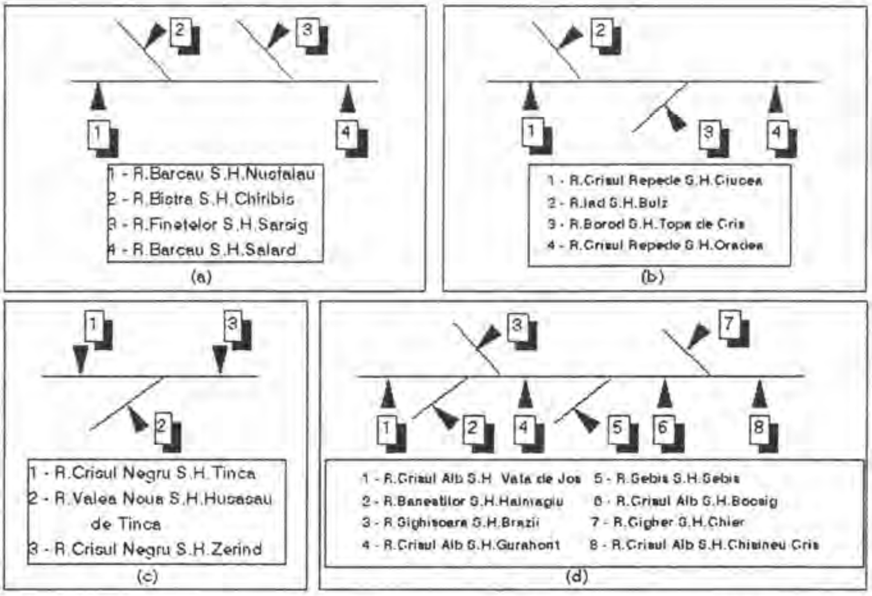

Fig 1 Schematic representation of the hydrographic basins of the Barcău, Crişul Repede, Crişul Negru and Crişul Alb rivers

The next step was the determination of the multiple linear regression coefficients and the analysis of the regression and its variation. Several multiple regression correlations were obtained in terms of the considered variables and time lags. When choosing the most adequate correlation, the following requirements were taken into consideration:

- the number of independent correlations had to be as small as possible so that the corresponding number of input variables for the model should be as small as possible, on the one hand, in order to shorten the period necessary to introduce the data and on the other, to diminish the errors:
- to avoid the use of certain predicted values of the independent variables that can cause errors;
- the multiple correlation coefficient had to be as close as possible to 1.

Having in view the above mentioned requirements, following the regression analysis the hydrometric stations entering in the predictions relationships were established as well as the multiple linear correlations that can be applied in practice for the prediction of the mean daily discharges at the hydrometric stations established for the prediction (Table 1). In the relationships of Table 1, *t* stands for the moment (day) of the achievement of the prediction.

Table 1 Multiple linear correlations use in the prediction of the mean daily discharges

River and forecasting station	Anticipation	River and rivergauging station use in the multiple linear correlation				
Barcau Salard		Barcau Salard	Barcau Nusfalau	Bistra Chiribis	Fanetelor Sarsig	
	t+1	t	t; t-1	t	t+1	
Cr. Repede Oradea		Cr. Repede Oradea	Cr. Repede Ciucea	Iad Bulz	Borod Topa de Cris	
	t+1	t	t	t	t+1	
Cr. Negru Zerind		Cr. Negru Zerind	Cr. Negru Tinca	Valea Noua H. de Tinca	Cr. Negru Beius	Holod Holod
	t+1 t+2	t t	t -	t t+1	- t	- t+1
Cr. Alb Gurahont		Cr. Alb Vata de Jos	Banestilor Halmagiu	Sighisoara Brazii		
	t+1	t, t-1	t	t+1		
Cr. Alb Bocsig		Cr. Alb Gurahont	Sebis Sebis			
	t+1 t+2	t t	t+1 t+2			
Cr. Alb Chisineu Cris		Cr. Alb ChisineuCris	Cr. Alb Bocsig	Cigher Chier	Cr. Alb Gurahont	Sebis Sebis
	t+1 t+2 t+3	t - -	t - -	t t+1 t+2	- t t+1	- t+1 t+2

GRAPHIC CORRELATIONS USED FOR THE PREDICTION OF THE DAILY MEAN DISCHARGES

For the prediction of the daily mean discharges two types of graphic correlations were established allowing the determination of the daily mean discharge forecasted for the increasing branch (type a) and for the decreasing branch, respectively (type b) of the daily mean discharges.

These graphic correlations have the form:

- type a:

$$Q_z = f(P_z)$$

where: Q_z is the predicted daily mean discharge; P_z - the sum of the mean daily precipitation on the basin, recorded or predicted during the previous subsequent days with rainfalls;

- type b:

$$DQ = f(Q_z)$$

where: DQ is the predicted lag of daily mean discharge; Q_z

- the daily mean discharge recorded in the previous day.

The above correlations were done for all the hydrometric stations in the hydrological basin of the Criş Rivers which form the inputs for the prediction mathematical model of the daily mean discharges.

The prediction of the daily mean discharges according to the phase of the hydrologic regime is carried out by using graphic correlations, as it follows:

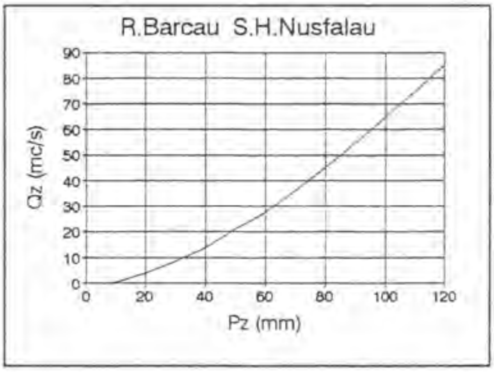

Fig. 2.a Graphic correlation for the increasing branch of the daily mean discharge hydrograph

- in case significant rainfalls, capable of causing large discharge variation are to be predicted, type a graphic correlations are applied (Fig. 2.a). For the first day with forecasted rainfall, a correlation is made with the predicted rainfall for that day, and for the following days, a correlation is made with the sum of mean daily precipitation on the basin from the beginning of the flood and until the day the prediction is carried out. Thus the runoff daily mean discharge is determined by adding the daily mean discharges previous to the occurrence of the flood resulting in the daily mean discharge predicted for the entire flood increasing period (for the entire period over which precipitation are forecasted).

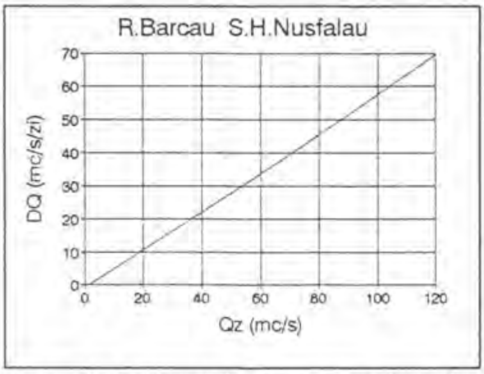

Fig. 2.b Graphic correlation for the decreasing branch of the daily mean discharge hydrograph

- for the decreasing branch of the daily mean discharge hydrograph, in case the precipitation that could modify the recession curve of the hydrograph, type b correlations are used (Fig. 2.b). By making these correlations with the measured or predicted daily mean discharge, the decreasing gradient of the daily mean discharge is determined. By deducing this one from the discharge with which the correlation was done, the daily mean discharge forecasted for the next day is determined.

- for of the stationary regime as well as for the case when weak precipitation are forecasted on the background of a slight decrease of the daily mean discharges, the forecasted daily mean discharge will be taken equal to the daily mean discharge of the day when the forecasting is achieved.

CONCLUSIONS

The tests carried out by means of program VMEDZI v. 1.0 showed that the prediction algorithm of the daily mean discharges, having at the basis the coupled multiple linear correlation, for the increase of the anticipation period, with simple prediction methods, leads to very good results especially for the first 3 forecasting days. The use of multiple linear correlations on discharge classes also leads, in some cases to an improvement of the prediction.

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XVII. KONFERENZ DER DONAULÄNDER
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FLOOD ROUTING MODEL DEVELOPMENT FOR DRAVA AND MURA RIVER IN CROATIA

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Summary

The existing and the planned hydro power plants on the rivers Drava and Mura represent a part of the multipurpose system which would be used for electricity generation, active flood protection, irrigation, drainage and other purposes. For the needs of hydropower system planning and future control, high quality data should be available in each development stage regarding the river basin. Simulation models should be used in all stages. The mathematical model MIKE 11, based on one-dimensional St. Venant equations for gradually varied unsteady flow is under development. Upon carried out verification, the model will be adapted for the needs of system control in the planned Drava basin hydro power plants control center.

DIE ENTWICKLUNG DES NACHAHMUNGSMODELLS FÜR DIE ÜBERFLUTUNGWELLEN AN DEN FLÜSSEN DARAVA UND MURA

Zusammenfassung

Bestehende und planmäßig vorgesehene Wasserkraftwerke an den Flüssen Drava (Drau) und Mura (Mur) stellen einen Teil des Mehrzwecksystems für die Erzeugung der elektrischen Energie, für den Schutz gegen Überschwemmungen, für die Be- und Entwasserung, sowie für verschiedene andere Zwecke dar. Für die Zwecke der Vorausplanung und der künftigen Steuerung des Wasserkraft-systems müssen, für jede Stufe seines Ausbaues, zuverläßige Unterlagen über den Flussbereich vorhanden sein. Man soll Nachahmungsmodelle in jeder Ausbaustufe anwenden. Derzeit wird das mathematische Modell MIKE 11, auf Grund der eindimensionalen St. Venant Gleichung für den stufenweise veränderbaren unstätigen Durchfluss entwickelt. Nach der erfolgreich durchgefürten Überprüfung wird das Modell den Bedürfnißen der Wasserkraftsystem- Steuerung im vorausgeplanten Steuerungs-Zentrum des Drau-Flussbereiches angapasst.

Introduction

The Drava river, being the largest tributary of the Danube in the Republic of Croatia, is an international watercourses which has great significance for several European countries through which it flows: Austria, Slovenia, Hungary and Croatia. Total drainage basin of the Drava river amounts 43.238 km^2. Average annual height of precipitation in this basin is about 990 mm, being the highest in the area of Alps and decreasing towards East. Average flows of the Drava on the territory of Croatia range from 320 m^3/2 in the border area with Slovenia to 555 m^3/s in the area of its mouth into the Danube downstream of the town Osijek.

Total number of 21 hydropower plants have been constructed along the entire course of the Drava river: 11 on the territory of Austria (total capacity of 621 MW and average annual generation of about 2914 GWh), 7 on the territory of Slovenia (total capacity of 533 MW and average annual generation of 2760 GWh) and 3 hydropower plants on the territory of Croatia (total capacity of 247 MW and average annual generation of 1279 GWh). Besides electricity generation, the described system has other purposes, too: increase of flood prevention efficiency, watercourses regulation and similar. By the construction of the above hydro power plants, the water potential has up to now been utilized to a significant degree on the territory of Austria, fully on the territory of Slovenia and to a lesser degree in Croatia.

Besides the three already constructed hydropower plants, the construction of five new hydro power plants on the Drava and four new plants on the Mura river has been planned on the territory of Croatia. Most of this construction is planned to be realized in cooperation with Hungary and Slovenia.

The researches regarding the possibilities for more efficient utilization of the constructed hydropower system (flood prevention and increase in electricity generation) have started in Austria at the end of sixties. In the first phase the researches were directed towards obtaining the earliest possible and most accurate flow forecasts. Further researches and gained experiences in the development of forecasting model and control system gave positive results, and the most recent researches are aimed at further improvement of hydropower plants' control system.

Having in mind the above facts, Hrvatska Elektroprivreda has, several years ago, started the activities on the development of the control system for hydropower plants in series. One of more significant activities is the development of simulation model for the Drava and the Mura river sections in Croatia, which would in the future be applied to the Drava river upstream system.

The multipurpose common mathematical simulation model MIKE 11, developed in Danish Hydraulic Institute has been used as modelling basis. The model enables continuous simulations of one-dimensional unsteady flow in open watercourses and in various water resources management facilities. Furthermore, its additional modules enable the simulation of catchment basin outflows, simulation of water sediments and pollutants spreading and simulation of riverbed morphology changes.

The mentioned model is to be used for establishing the rules for the control of the constructed system as well as in the process of the hydropower facilities' construction planning and complex training of the Mura and the Drava section downstream from the mouth of the Mura. Since the Drava and the Mura are in their longer part border watercourse, it would be better if the mentioned model could be realized in cooperation with appropriate institutions of neighboring countries.

Mathematical modeling of unsteady flow in open watercourses

Open watercourses are constituent part of hydrographic network of a particular catchment basin, which represents fully or partly (in its individual segments) one of constitutive elements of physical part of water resources management system. Systematic approach to solving water resources management problems in the catchment basin treats them as ducts, so that the problems regarding water transport between individual facilities could be treated as a fundamental theoretical hydraulic problem of unsteady flow in open watercourses.

Basic mathematical model of this phenomenon represents the foundation of future development simulation models:

- simulations of consequences resulting from unexpected dam or embankment fracture
- simulation of multiphase flow (problems of river sediments and pollution spreading)
- simulation of changes in riverbed morphology.

The flow of ground waters in riverbeds and on flood areas is in its nature unsteady, turbulent and three-dimensional. The third dimension of flow is in mathematical models presented mainly locally or only in exceptional cases and the impact of turbulence is presented by means of empiric indicators the values of which represent the resistance to water flow.

In mathematical modelling of unsteady flow in longer river sections one-dimensional models are mainly applied since the two-dimensional ones are too detailed and comprehensive. The main feature of one dimensional models is that they can give satisfactory results if the flows in flood areas are in parallel with the flows in main riverbed, what can most often be presumed. Locally, where obvious two-dimensional flows exist in flood areas, the problems could be resolved by the modelling of characteristic transversal and longitudinal flows network by the application of so called quasi-two-dimensional modelling procedure or by the introduction of so called additional flood areas.
Hydraulic simulations of unsteady flows are based on the solution of integer Barre De Saint-Venant partial differential equations system by the application of one of the known numerical methods.
The multipurpose software package MIKE 11, developed in The Danish Hydraulic Institute, has been chosen for the simulation of flood wave transformation. The simulation of flood waves is carried out by numerical solution of integer one-dimensional St. Venant equations. The model is particularly appropriate for the simulation of wide flood areas by the application of quasi two-dimensional procedure.
The structure and concept of program package leans on integrated database and on various calculation modules which commonly share and use data from the database.

Characteristic of the research area

In the first development stage the modelled area comprised the section of the Mura from Slovenian border to its mouth into the Drava and the section of the Drava from Slovenian border to g.s. Botovo (Figure 1).

The flow profile of the Drava and the Mura have wide floodplanes, a number of backwaters and interconnected flows. The width of floodplanes ranges from 400 m to more than 1600 m, causing extremely complex flow regimes during the occurrence and withdrawal of flood waves.
In the modelled area there are several gauging stations, so that a significant number of data is available for hydrologic analysis and model calibration. Main features of available gauging stages are given in Table 1.

Simulation model includes the constructed derivation hydropower plants on the Drava river: HPP Varaždin, HPP Čakovec and HPP Dubrava. By regular hydrologic measurement in hydropower plants a number of data have been acquired which were utilized during the development of simulation model. Main characteristics of the constructed hydropower plants are given in Table 2.

The construction of hydropower plants has significantly shortened the Drava flow, increased the head of water level which resulted in the change of downstream riverbed morphology characteristics, especially as regards sporadic deepening and occurrence of numerous sandbanks.

Fig. 1 MAP OF RESEARCH AREA

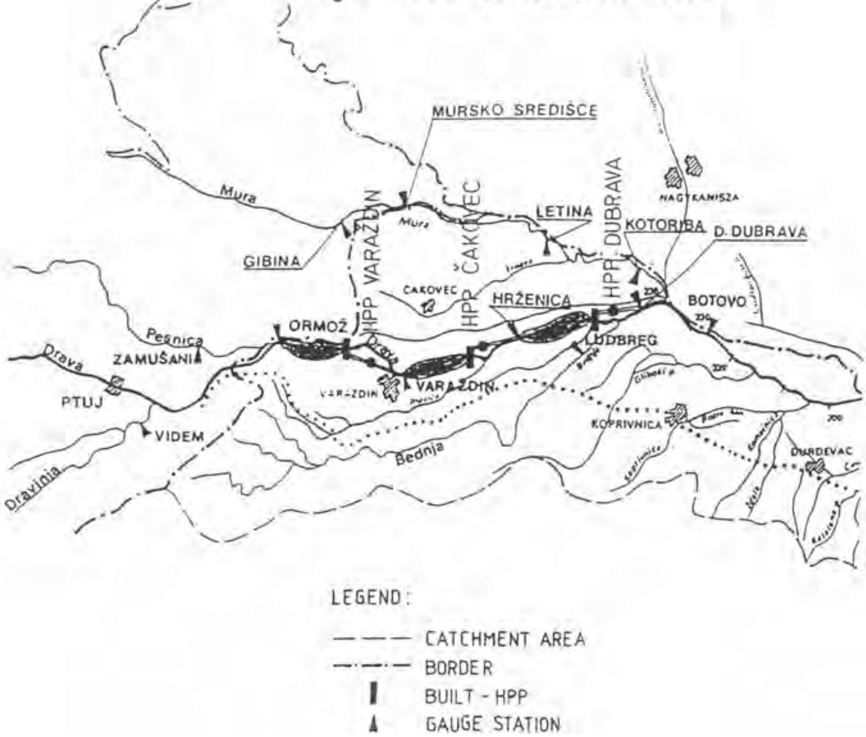

Table 1

Gauging St.	River	Starting Work	Type of Measure	DischargeQ (m^3/s)	100 r.p. (m^3/s)	1000 r.p. (m^3/s)	Period of analysis
Ormož	Drava	-	H	326	-	-	1946-1983
Varaždin	Drava	1821.	H,Q	341	2795	3639	1951-1981
Hrženica	Drava	1984.	H	-	-	-	-
D. Dubrava	Drava	1978.	H	-	-	-	-
Botovo	Drava	1873.	H,Q	524	2851	3519	1951-1990
Gibina	Mura	1956.	H,Q	164	1606	1878	1974-1990
M. Središće	Mura	1888.	H,Q	172	1723	2383	1951-1990
Letina	Mura	1948.	H,Q	166	1667	2324	1951-1990
Kotoriba	Mura	1948.	H	-	-	-	-

According to the available documentation, construction of five new hydropower plants, in addition to the existing facilities, is planned on the Drava section downstream from the mouth of the Mura up to the mouth into the Danube. Furthermore, on the Mura section from the interstate border with Slovenia up to the mouth into the Drava, the construction of four hydropower plants has been envisaged.
The planned facilities are of multipurpose character and, besides electricity generation, their construction would solve a number of other problems related to the utilization of surrounding area: land protection from water flow regulation, protection of flooding river banks and facilities along riverbed from river erosion, catchment of riverbank and seepage waters and establishment of conditions for catchment and irrigation of agricultural land, while on the downstream section of the Drava flow navigable conditions would be established.

Table 2

HPP	Output MW	Qi m^3/s	Total Storage $1000\ m^3$	Year of Construction
Varaždin	86	450	7.350	1975
Čakovec	80.4	500	51.500	1982
Dubrava	80.6	500	93.500	1989

Boundary conditions and calibration

The first phase model, which comprises the Drava and the Mura section from interstate border with Slovenia to g.s. Botovo, has been developed on the basis of horizontal scheme (Figure 2) showing all connections between individual elements of physical part of water resources management system.

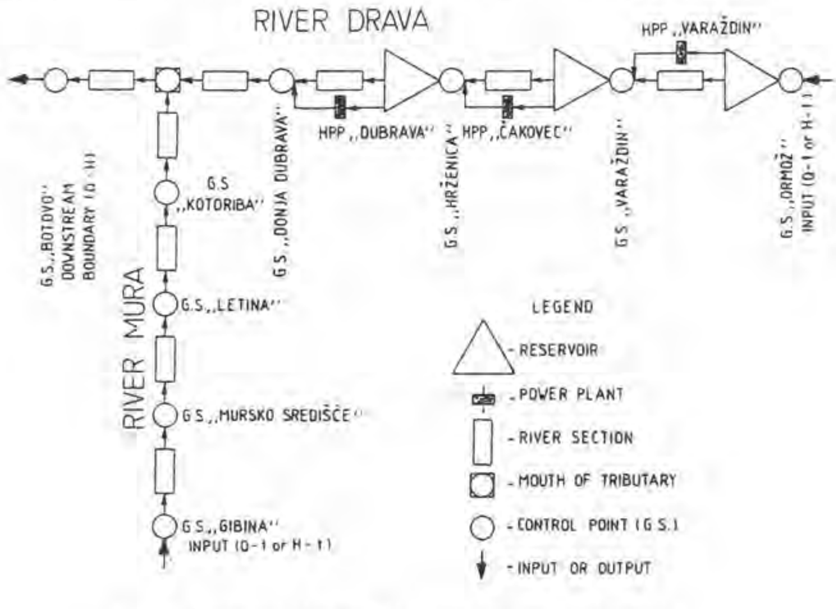

Fig 2 SCHEMATIC MAP OF RIVER SYSTEM

Model input data consist of data on the space, or riverbed geometry, geometry of buildings belonging to the constructed hydropower plants and other facilities in the basin (bridges, hydraulic structures, and similar). Data on geometry include the coefficients of hydraulic roughness.
The measured cross sections have been linked by the development procedure as well as by definition of model hydrologic inputs and outputs, definition of boundary condition and definition of control points for the needs of calibration. In wide flood areas quasi two-dimensional procedure was applied in modelling.
Due to the size of modelled area and limited computer memory, basic model of the Drava section from g.s. Ormož (peak of HPP Varaždin storage basin) up to g.s. Botovo, which includes the Mura river section from g.s. Gibina to its mouth into the Drava, have been divided into three sub-models: (1) sub-model HPP Varaždin, (2) sub-model HPP Čakovec, (3) sub-model HPP Dubrava. Each sub-model encompasses pertaining facilities: storage basins, intake and outlet channels, old Drava riverbeds, left and right floodplaines along old riverbeds.
The sub-model of HPP Dubrava area includes the Drava river flow downstream from the HPP Čakovec restitution up to the g.s. Botovo and the Mura river flow from g.s. Gibina to its mouth into the Drava. The interconnection of sub-models has been carried out through common boundary conditions at the input of individual sub-models. The selection of cross section profiles has been conditioned by available data on recently measured cross-sections (Drava 1987-1991, Mura 1987-1988,) taking into account the appropriate physical layout of profiles, location of gauging stations, mouths of tributaries, locations of structures and similar. The selected profiles intend to provide the highest quality description (represent) of individual sections and preserve approximate linear change of riverbed geometry.
During the calibration procedure, the values of roughness coefficients initially defined according to Strickler (storage basins 30, river bed 20, floodplaines 10, intake channel 70, outlet channel 40) were changed according to the need.
As initial conditions, water levels and discharges were defined for two measured floods in 1989. Hourly values of water level and discharge recorded at gauging stations Varaždin, Donja Dubrava, Hrženica, Botovo on the Drava river and gauging stations Gibina, Mursko Središće and Letina on the Mura river were used.
Hourly data from daily lists of operational states of HPP Varaždin, HPP Čakovec and HPP Dubrava were used for the definition of internal boundary conditions.
Boundary conditions were, due to the specific model development, defined according to previously mentioned sub-models. Since discharge measurement data were incomplete, the H-t diagram at g.s. Ormož has been chosen as the upstream boundary condition of the entire model. As the downstream boundary condition the Q-H diagram at g.s. Botovo has been chosen. The flow of main Drava tributaries (Bednja and Plitvica) and Mura tributaries (Krka with Ledava and Trnava) has been included on the location of mouth as point inflows.
Model values which were calculated were compared to measurement values and proved to be in concordance, i.e. the model correctly simulates natural state. Occasional non-correspondence between simulation results and measurement data resulted from insufficient measuring data, errors in the measurement of discharge/water level and errors in the recording of riverbed and structures' geometry.
The obtained results , which represent the comparison between simulated and measured level (H-t diagram) on the location of HPP Dubrava dam, and the comparison of simulated and measured level (H-t diagram) on the location g.s. Mursko Središće are shown in Figure 3.

All shortcomings recognized during model calibration would be resolved during the verification procedure. For the needs of model verification comprehensive measurement of flood wave were performed at the end of October 1993. The measurements were carried out at a number of permanent and temporary measuring locations on the rivers Drava and Mura, in the section from Slovenian border to the settlement Ferdinandovac between Koprivnica and Virovitica.

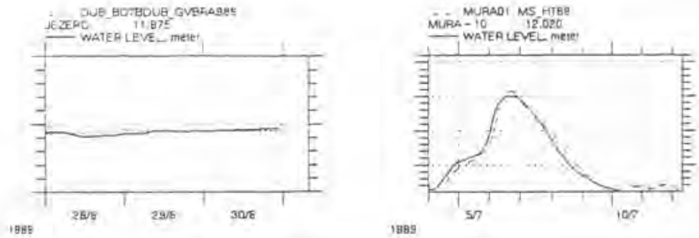

Fig. 3.
COMPARISON OF SIMULATED AND MEASURED WATER LEVELS
RESERVOIR HPP "DUBRAVA" & GS "MURSKO SREDISCE"

MIKE 11

Conclusions

The model described represents the first phase in the modelling of the Drava river catchment basin on the territory of the Republic of Croatia. After the verification and the modelling of minor tributaries runoff from the catchment basin (by the application of additional module NAM), the developed simulation model could successfully be used for planning the operation of the existing hydropower plants in series.
It should be noted that the modelling of the tributaries runoff from the catchment basin is also in progress and that the model of runoff from the Dravinja river catchment basin in Slovenia has been completed. During the model tailoring to the end user needs, i.e. Hrvatska Elektroprivreda, it would be desirable to accomplish link with the gauging stations Slovenian models located in the catchment basin Drava river in Slovenia.
Upon the completion of the first phase of mathematical modelling of the rivers Drava and Mura on the territory of Croatia, further model development will include the section of the Drava river from g.s. Botovo to its mouth into the Danube. These activities should be performed in cooperation with appropriate institutions of Hungary and Slovenia since the Mura and the Drava are mainly border rivers.
Upon the completion of modelling, i.e. verification and tailoring to end user, the developed model could be successfully applied while planning complex land use along the rivers Mura and Drava.
Natural and man-made caused morphological changes of riverbeds construction of the water resources management facilities and other structures which have influence on the flow should continuously be observed and included in the model.

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FLOOD FORECASTING AND MANAGEMENT BY RETENTION BASINS

by
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Svetlana Varga, B.Sc.[2]

Abstract

When retention basins are used flood control, unsteady flow mathematical models can be effectively used for reliable prediction of extreme stages and discharges. Optimal design criteria can be determined by numerical simulation, and the extent of flood attenuation can be planned for two principal goals to be accomplished: (a) to increase the degree of protection by the existing levees, and (b) to increase the degree of levee safety during floods of short return periods but long duration. To illustrate the advantage of hydraulically based predictions, results of the river Tisza case study are presented.

DIE ABLAGERUNGSWASSERBECKEN IN DER UEBERSCHWEMMUNGS-PROGNOSE UND BEI WASSERVERWALTUNG

Kurzfassung:

Bei der Verwendung der Ablagerungswasserbecken zur Ueberschwemmungskontrolle koennen die enormen Abfluesse und Ueberfallhoehen mit Hilfe der mathematischen Modellen fuer die unstationaeren Fliessvorgaenge gut vorgesehen werden. Die optimalen Kriterien koennen durch die nummerische Simulation bekannt werden. Auf diese Weise wird die reduzierte Ueberschwemmung durch die Erfuellung der folgenden Prinzipien vorgesehen: (a) Erhoehung des Prozenten der Ueberschwemmung mit dem bestehenden Abfluss und (b) Erhoehung des Prozenten der Versicherung durch die Ueberschwemmung mit kurzem Zurueckperioden langerer Dauer. Zur Illustration dieser hydraulisch begruendeten Prognose werden die Resultate des Flusses Theiss dargestellt.

1. Introduction

Some rivers of the Danube basin are characterized by flood events of very long duration. For instance, the 1970 flood on the Yugoslav sector of the river Tisza extended over 1.5 months. Under such circumstances, the existing levees may be severely damaged due to effluent seepage. One solution of flood management ensuring levee protection is to form a system of flood relief basins, by which the water stages and discharges can effectively be reduced. Retention basins can also ensure protection against floods which exceede the design flood of the existing levees. For instance, the levees designed for 100-year extreme flows, may prove adequate for 500-year flows, if appropriate retention volume is provided. The degree of flood reduction by retention basins is generally an economic category and depends on many factors, such as topography, value of the land to be potentially flooded, infrastructure, environmental impact, etc.

This paper deals with usage of retention basins along 80 km long reach of the river Tisza in Yugoslavia, between the Hungarian border (km 156+175) and the town Bečej

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(km 76+150) [3]. Several synthetical flood waves of return periods between 20 - 500 years, as well as one recorded flood, have been used in order to investigate the individual and combined effects of one, two, and three retention basins. Hydraulically based predictions of time and space distribution of maximal water stages and discharges have been used in order to formulate the most efficient flood management strategy. An organization scheme of services and activities involved in realization of this project has also been proposed.

2. Retention basins

The concept of retention basins as a means of active flood protection, is applicable whenever the extreme water levels and discharges cannot be significantly attenuated in the flood plains of the given river channel.

Several locations can be potentially used for retention basins on the reach of the river Tisza through Yugoslavia, between the town Bečej (km 76+150) and the Hungarian border (km 156+175). Three such locations have been chosen: "Kanjiža" - near town Kanjiža (km 143+990), "Pana" - upstream from town Senta (km 132+170), and "Veliki rit" - upstream from town Bečej (km 82+100), (Fig.1). Their individual retention capacities are between 105 and 140 million cubic meters, while the flooded areas vary between 1560 hectares ("Kanjiža") and 2123 hectares ("Veliki rit").

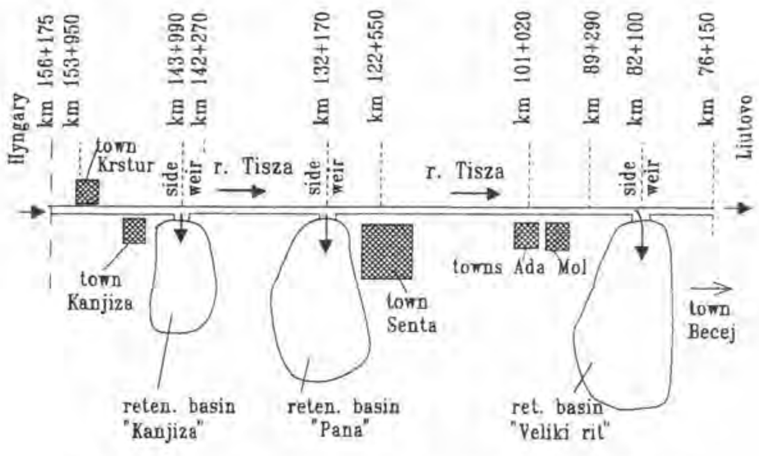

Fig.1 Schematic layout of retention basins on the river Tisza [3]

Each basin is to be provided with one side weir, used for filling and emptying.

The proposed retentions are of the "necessity" type [2], and are to be activated only in the case when maximal stages exceede the crest of the existing levees (in this case, levees have been designed for the 100-year flood), or in the case of emergency, i.e. when the stability of levees is endangered, regardless of the flood wave return period.

3. Design criteria

The hydraulic effects of retention basins have been analysed for the 100, 200, and 500-year synthetic flood waves[3], as well as for one real flood, recorded in 1970, whose peak roughly corresponds to the 50-year maximum (2% probability of occurrence). The following assumptions and design criteria have been accepted:

[3]Other inflow hydrographs may be investigated in future, considering the flood control operational strategy of Hungarian storages on the river Tisza.

(a) The activation of retention basins starts from the most upstream basin ("Kanjiža", see Fig. 1), and proceeds downstream, as the water stage attains a predetermined elevation. In the case of 200 and 500-year floods, this elevation has been set to equal the maximal water level of the 100-year flood, and in the case of the 100-year flood, it is equal to the maximal water level of the 50-year flood.

(b) The side weirs used to fill (and partially empty) the retention basins, have the bottom elevations corresponding to the 10-year maximal water elevations at particular locations, while the length of each weir is to be determined by hydraulic calculations in such a way that the retention capacity is maximal. The side weirs are to be formed as emergency structures or by mines at the moment of emergency. In either case, their formation can be considered instantaneous in the time scale of the flood event.

(c) The crucial locations for evaluation of effects of retention basins are town Senta (km 122+550) and Ljutovo (km 76+150), upstream of town Becej (Fig.1), where maximal water stages must be lowered to a degree which ensures the safety of buildings and other valuable property.

4. Method of computation

The calculation of flood waves propagation has been carried out by numerical integration of the full St. Venant equations, using the well known implicit Preissmann method, the details of which can be found in numerous specialized literature, such as [1].

The flow exchange between the river channel and a retention basin can be treated as broad-crested free weir overflow within the limits of 1D flow modelling. This flow is bidirectional, from the river channel to the retention basin, and vice versa, depending on the instantaneous water surface elevations. The water elevation in each basin is determined by iterative solution of the continuity equation, using the input elevation-volume relationship, and assuming that the water surface in the retention basin is horizontal.

5. Results of computation

Different combinations of initial and boundary conditions have been used in computations, but only some results are presented in this paper.

An optimal length of weirs has been determined first. For a preset weir bottom elevation, it is possible to determine a hydraulically optimal weir length which ensures the maximal retention volume, and consequently, the maximal downstream attenuation of the flood wave. Fig. 2 depicts results of such an analysis for the retention basin "Kanjiža" and the 500-year flood. As can be seen, the optimal weir length is between 50 and 80 m. Since the three considered retention basins are of similar characteristics, the value of 50 m has been chosen for all basins.

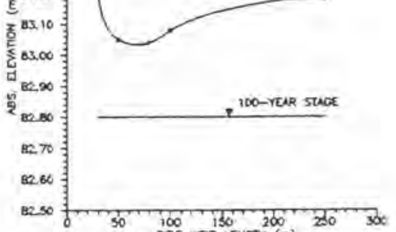

Fig. 2 Maximal stage for the 500-year flood at town Senta for different lengths of the side weir "Kanjiža" [4]

As calculations have shown, the 500-year flood wave cannot be significantly attenuated by the individual use of retentions "Kanjiža" or "Pana". However, if those two retention basins are activated together, the 500-year flood discharge peak of 4500 m^3/s can be reduced to about 4100 m^3/s, which roughly corresponds to the 100-year maximum. The maximal stages are reduced accordingly (Fig. 3).

Analysing the possibility of lowering the 100-year water stages to such a degree that they would roughly correspond to the 50-year flood stages, it has been concluded that

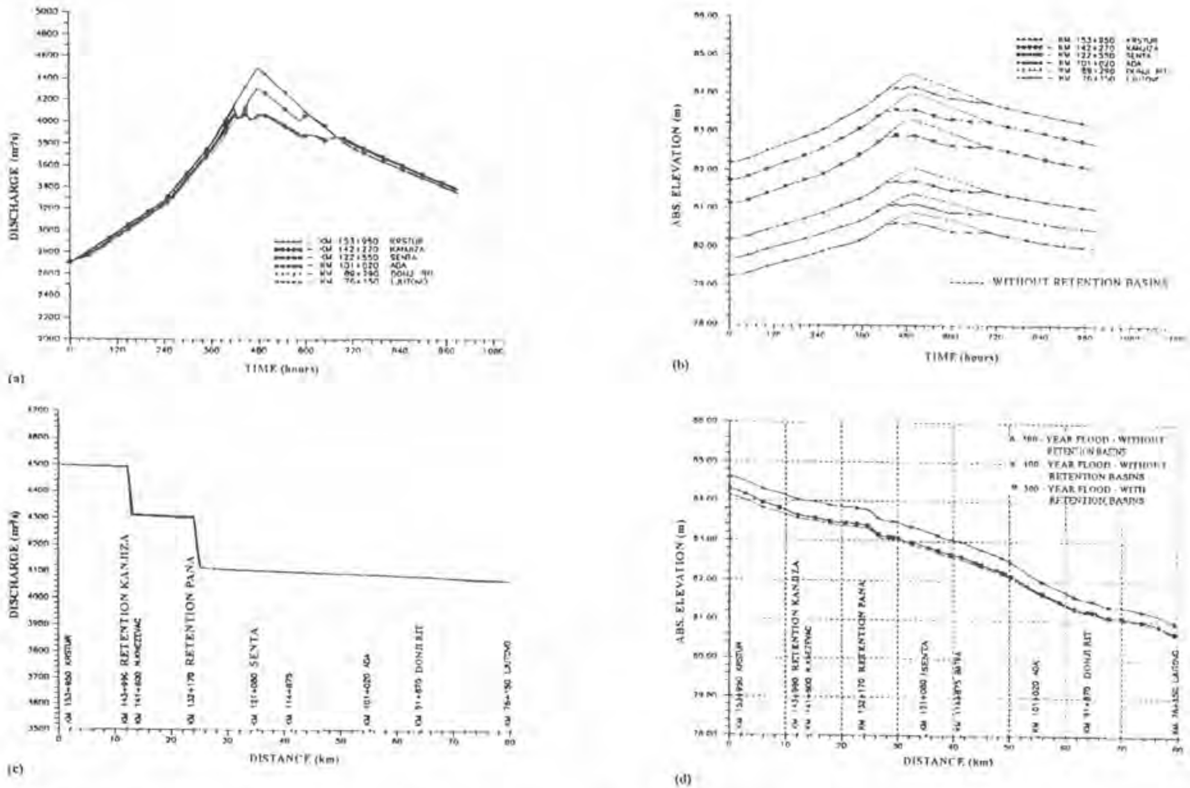

Fig.3 The effects of retention basins "Kanjiža" and "Pana" on the 500-year flood: (a) Discharge hydrographs (b) Stage hydrographs (c) Maximal discharges (d) Maximal absolute elevations

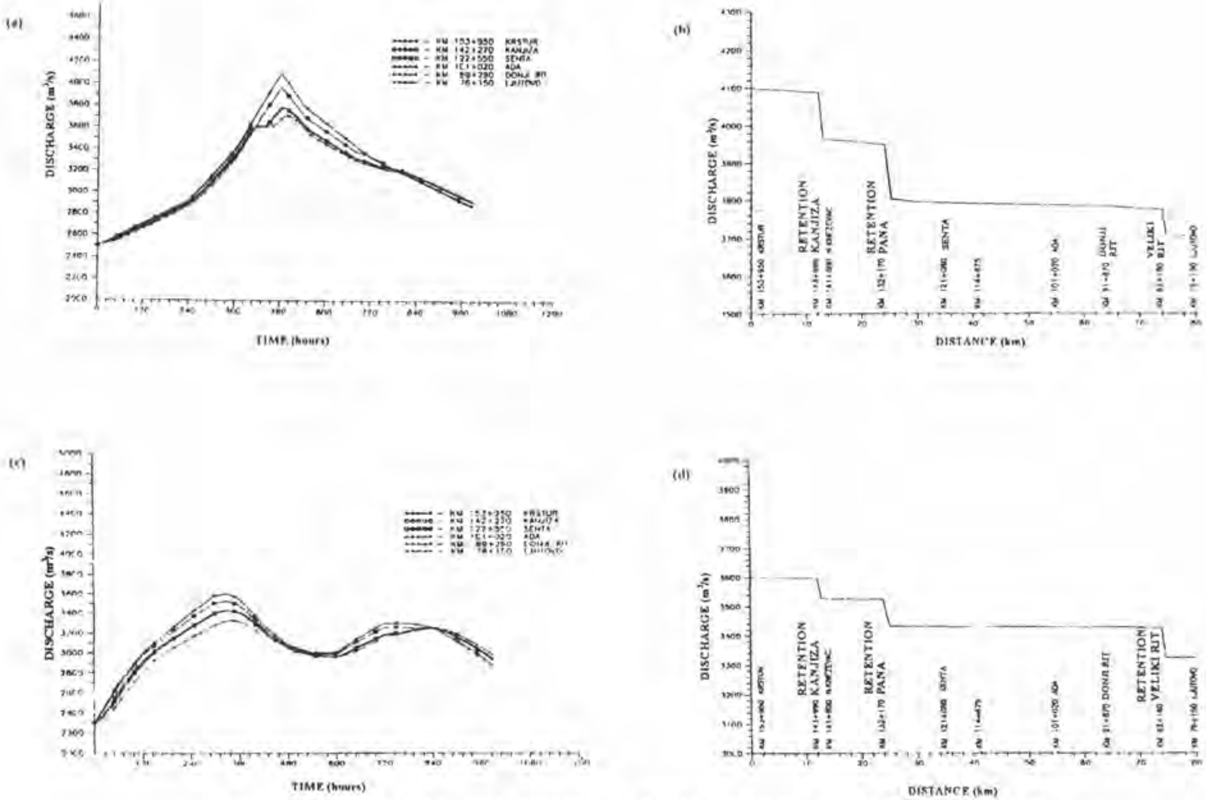

Fig.4 Reduction of the synthetic 100-year flood wave and the 1970 flood wave by the simultaneous use of retentions "Kanjiža", "Pana" and "Veliki rit" (a) 100-year flood: discharge hydrographs (b) 100-year flood: maximal discharges (c) 1970 flood: discharge hydrographs (d) 1970 flood: maximal discharges

this could be accomplished at the downstream end of the river reach only if all three considered retentions are used together (Fig. 4-a,b). In this case, the filling time of the basins "Kanjiža", "Pana", and "Veliki rit" would be 13, 15, and 24 days, respectively.

Investigating the effects of retention basins on the 1970 flood wave (which approximately corresponds to the 50-year flood wave), it has been concluded that the best strategy would be to activate all tree basins at the moment when the water stage reaches their weir bottom elevations. According to design assumptions, these weir bottom elevations roughly correspond to the 10-year flood maximal stages at particular locations. The results of computation are presented in Fig. 4-c,d.

Finally, Fig. 5 shows a proposed organization scheme for this particular kind of active flood control and management, as well as the basic activities necessary for development and maintenance of a decision support system for optimal and prompt operation of retention basins.

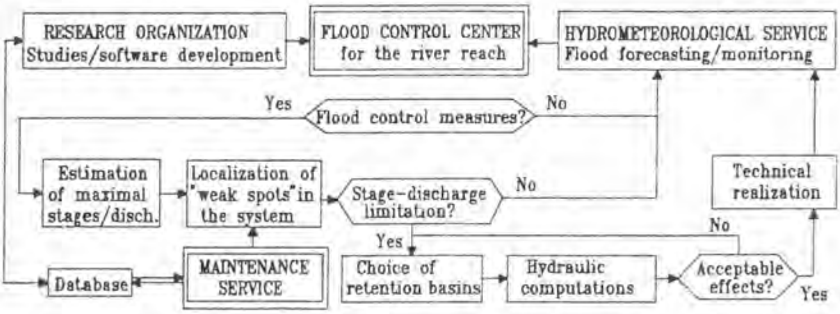

Fig.5 Organization scheme for optimal use of retention basins [3]

6. Conclusions

The retention basins can be efficient means of active flood control and management. Activation of several basins, individually or simultaneously, gives the possibility of reduction of flood stages and discharges, according to specific, predefined goals. Hydraulic computations can be effectively used to determine the optimal construction parameters (side weir bottom elevation and length), or an optimal operational strategy which would enable the existing levee system to withstand floods exceeding the design flood, or to protect levees against damage during very long flood events. The results of the river Tisza case study are presented as an example of flood forecasting and management by retention basins.

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XVII. KONFERENZ DER DONAULÄNDER
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ANALYSIS OF FLOOD CONTROL SOLUTION BY APPLYING A MATHEMATICAL MODEL

Mijo Vranješ[1], Vinko Jović[1], Davor Bojanić[1], Miroslav Braun[2], Mi[illegible] Filipović[2]

ABSTRACT :

In the river's vale, where urbanization is usually develop, one of the major requirements of comprehensive water-resources developments is flood control. The optimal solution of flood protection must be carried out by complex analyses. Efficient analyse may be to do by corresponding mathematical model. The reduction of complex channel or river flow to one dominant direction i.e. to one dimensional model is connected with great number of difficulties and assumptions. The flow through compound cross section generally occurs in the main channel and on the shallow flood plains. It is necessary to introduce into the equations the effects of the momentum distribution i.e. the flow resistance distribution effects. This paper presents an one dimensional model for the unsteady flow based on fully hydrodynamics equations. Model can be use for planning and operational purposes in rivers and channels with hydrotechnic structures. The example of the unsteady flow in the Sava River (system flood protection Middle Posavlje) illustrates application of the model, which is calibrated and tested with different flood events and showed good agreement between observed and simulated flows. The hydrodynamic equations integrated through finite element method and system of nonlinear algebraic equations solves by Newton-Raphson method.

KURTZFASSUNG :

Der Hochwasserschutz ist eine der wichtigsten wasserwirtschaftlichen Aufgaben in Flußtälern, wo gewöhnlich die Urbanisierung des Gebietes betont wird. Die Lösungen werden auf verschiedenen Konzepten gegründet und die optimale Lösung wird durch die komplexen Analysen und zwar mittels entsprechenden mathematischen Modells gefunden. Die Darstellung des zusammengesetzten Fließens in Flüssen und Kanälen durch ein eindimensionalles Modell ist mit einer Reihe von Schwierigkeiten und Vereinfachungen verbunden. Der Wasserlauf durch den Flußquerschnitt stellt das Fließen im Hauptbett und in Inundationen vor. Deshalb ist es nötig, die Effekte der Bewegungsmenge und Flaießwiderstandsverteilung in einem so zusammengesetzten Querschnitt die Grundgleichungen einzuführen. In dieser Arbeit ist ein auf völlig hydrodynamischen Gleichungen gegründetes, eindimensionales Modell für unstationäres Fließen dargestellt. Das Modell kann zum Planen und Steuern in Flüssen und Kanälen mit hydrotechnischen Bauten verwendet werdet. Am Beispiel des unstationären Fließens im Flußlauf der Save (Hochwasserschutzsystem im Mittleren Savegebiet) ist die Anwendung des Modells dargestellt, das durch Überprüfung der verschiedenen Überschwämmungsbedingungen sehr gute Übereinstimmung der gemessenen und berechneten Werte der Flußlaufparameter zeigte. Die Differentialgleichungen werden durch Anwendung der Methode der Endelemente integriert und das System der unlinearen algebrischen Gleichungen wird durch die Newton-Raphson Methode gelost.

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INTRODUCTION

The construction of hydrotechnical structures significantly influences and changes the flow regime; hence, a solution of the problems related to flood protection becomes a complex task. Large hydrotechnical systems frequently occupy wide areas with a network of rivers and channels intended for the control of water masses. The planning, development, construction and exploitation of such complex hydrotechnical systems require a proper approach to the analysis of the optimal solution. Such systems are constructed over several years, generally realized in stages, so that the system can function efficiently in all stages and be continually monitored. In this way the system can be more easily modified and corrected according to the latest findings.

The development of modern computer applications and numerical methods makes it is possible to perform efficient analyses by simulating the operation of the system by applying a suitable mathematical model. The term model implies various approaches to the process simulation or reconstruction. The selected model should correspond to the phenomenon it describes. The selection usually begins by studying the available or previously developed models; subsequently, a group of models best suitable for the process is selected. Since the conditions differ in each system, there is no universal model which can include all elements of a complex hydrotechnical system. This applies also to a multi-purpose hydrotechnical system Srednje Posavlje, for which a specific mathematical model has been developed.

THE MIDDLE POSAVLJE SYSTEM

The multypurpose Middle Posavlje system is situated in the economicaly very developed, central part of Sava River basain (Fig. 1 and 2). It is most inportant function is regulation of flood water regime and flood protection of the wide Sava neighbouring areas, without deterioration the status-quo along the downstream sections. This area includes several flat and swampy regions whics havw been constantly flooded. An enormous area of 2050 km^2 is flooded every year, and 2800 km^2 once in every 50 years, what represent approx. 5% of the total land territory in the Republic of Croatia. The whole system consists of several relief canals, relief storages and water distributing hydrotechnical structures. It is being realised gradually, with the intention of each stage being an optimum step to the final solution. The objective of a complex hydrotechnical intervention was to make the best use of this natural state by reducing the frequency of floods and the size of the affected area. The idea of using the naturally flooded plains in order to alleviate the large Sava flood wave is, at the same time, ecologically efficient. In 1990, one part of that area, Lonjsko polje, was declared a national park.

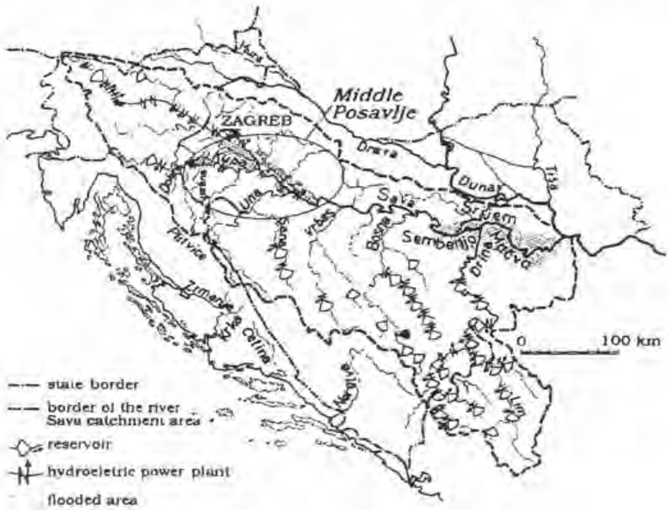
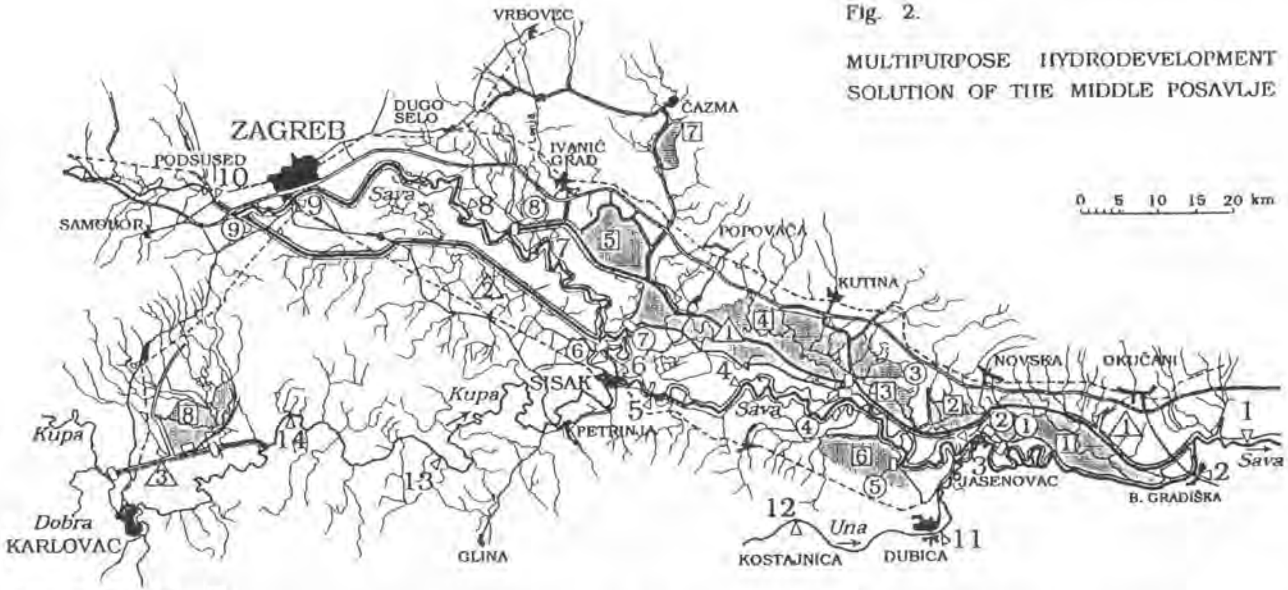


Figure 1. The River Sava Catchment Area

Fig. 2.

MULTIPURPOSE HYDRODEVELOPMENT SOLUTION OF THE MIDDLE POSAVLJE



GAUGING STATIONS : ▽

1- Mačkovac 2- St. Gradiška 3- Jasenovac 4- Gušće 5- Crnac 6- Galdovo 7- Dubrovčak 8- Rugvica 9- Zagreb 10- Podsused 11- Dubica 12- Kostajnica 13- Šišinec 14- Jamnička Kiselica

HYDROTECHNICAL STRUCTURES :

(1)- Košutarica (2)- Jasenovac (3)- Trebež II (4)- Trebež I (5)- Zelenik (6)- Strelečko (7)- Palanjek (8)- Prevlaka (9)- Jankomir

FLOOD PLAINS :

[1] - Mokro polje [2] - Trstik [3]- Opeka [4]- Lonjsko polje [5]- Žutica [6]- Zelenik [7]- Jantak [8]- Kupčina

CHANNELS :

△1 - Lonja-Strug △2 - Odra △3 - Kupa-Kupa

The most important objective was to ensure flood control, and another objective was to make the system flexible and to make the investment economically justifiable. It is difficult to find an optimal solution due to a very strict criterion which does not allow degradation of the natural flow regime.

In addition to flood control, it is necessary to bring into accordance these objectives with other interests involved such as reclamation, navigation, hydropower, urban-planning, forestry, environmental protection, etc.). The entire area has a well-developed hydrographic network of natural streamflows, particularly in the plains. The flood flow is quite complex in such networks, especially when the water from the main channel floods wide plains. Monitoring data and measurements from a great number of gauging stations made it possible to get an insight into the nature of these complex flows, which are a great help in the selection and development of a model. The flow regime in the entire catchment is quiet, unsteady and displays backwater effects. In order to ensure efficient operation of the structures under such conditions, it is necessary to know the discharge Q and the water level h at each time instant.

MATHEMATICAL MODEL

The concept of the model is consistent with the system for which it was developed; it is flexible and after certain modifications can be applied to other systems. This model belongs to a category of models with internal identification, which means that the model structure corresponds to the structure of the process occurring in a system. Since these flows have one dominant direction the model is one-dimensional. Natural streamflows have compound cross-sections (main channel flow and flood plains), so the flow through such cross-sections should be described as precisely as possible [7].

By balancing mass and momentum on a specific section of the streamflow, we obtain:

- continuity equation

$$\frac{\partial Q}{\partial x}+\frac{\partial A_t}{\partial t}=q-f \quad (1)$$

- dynamic equation

$$\frac{\partial Q}{\partial x}+\frac{\partial}{\partial x}\left(\frac{Q^2}{f_1(h)}\right)+gA_a\frac{\partial y}{\partial x}+g\left(A_a\frac{\partial z_0}{\partial x}+\frac{Q|Q|}{f_2(h)}\right)=qv\cos\vartheta \quad (2)$$

where:

x- flow direction, Q- total discharge $[m^3/s]$, q- distributed lateral inflow $[m^3/s/m]$, f- infiltration along the flow $[m^3/s/m]$, A_t- total cross-sectional area $[m^2]$, A_a- active part of the cross-section $[m^2]$, v- average flow velocity [m/s], $f_1(h)$- distribution function of momentum in a compound cross-section, $f_2(h)$- function of flow resistance in a compound cross-section, ϑ- angle of lateral inflow into the main flow

Equations (1) and (2) are numerically integrated. The selection of appropriate numerical methods follows the same criteria which are applied to model selection. These methods are general and are applied in various technical disciplines. Although they are different, it is possible to find, at least to a certain extent, some common features in all of them [2]. The method selected herein, i.e. Finite Element Method, was chosen according to criteria of accuracy, stability and efficiency. Compared to the method of finite differences, for example, this method has an advantage of being more efficient and numerically more stable than differentiation since functions are integrated. The advantages of this method have been confirmed by a great number of examples in papers [4 and 6]. Taking into account the fact that the flow is not prismatic and using functions $f_1(h)$ and $f_2(h)$ representative cross-sections are selected by dividing the entire area into elements. By defining elements and profiles (nodes) a topological scheme with M nodes and N elements is obtained. Since the discharge Q and the water level h change slowly it is sufficient to take linear interpolation functions $\Phi_1(x)$ and $\Phi_2(x)$ on the element. The state on each element j at a certain instant is defined at the upstream boundary by discharge $Q_{j1}(t)$ and by water level $h_{j1}(t)$; at the downstream boundary it is defined by discharge $Q_{j2}(t)$ and $h_{j2}(t)$, and the following functions are obtained for each element:

$$h = h_{i1}(t)\Phi_1(x) + h_{i2}(t)\Phi_2(x) \quad (3)$$

$$Q = Q_{j1}(t)\Phi_1(x) + Q_{j2}(t)\Phi_2(x) \quad (4)$$

Numbers i_1 and i_2 are global expressions for nodes associated to element j according to a topological scheme. Using these approximations and the base function which is equal to one, equations (1) and (2) are integrated on each element, after which two non-linear algebraic equations are obtained [6]:

$$F_{j1}\left(h_{i1}, h_{i2}, Q_{j1}, Q_{j2}\right) = 0 \quad (5)$$

$$F_{j2}\left(h_{i1}, h_{i2}, Q_{j1}, Q_{j2}\right) = 0 \quad (6)$$

Two discharges (upstream and downstream) are computed on each element and the water level values are computed in the nodes. The topological scheme includes N elements and M nodes, wherefrom there are M+2N unknowns. By integration on elements it is possible to obtain 2N equations (5) and (6). Additional M equations are obtained by flow continuity for elements associated to node i.

$$\sum_{j=1}^{m} (-1)^{p} Q'_{jp} + Q_v = 0 \quad (7)$$

where:

m- number of elements associated to node, p=1 for upstream node on the element,
p=2 for downstream node on the element, Q_{jp} discharge on the element, Q_v external inflow

Non-linear algebraic equations are obtained after integration in time.

$$F_3\left(Q'_{jp}\right) = 0 \quad (8)$$

The system of equations (5), (6) and (8) is solved for each time step iteratively by the Newton-Raphson method. Jacobian matrix is developed according to the topological scheme. From the element equations (5) and (6) the following is obtained:

$$\left[\frac{\partial F_j^k}{\partial h_{il}}\right]\left\{\Delta h_{il}\right\} + \left[\frac{\partial F_j^k}{\partial Q_{jl}}\right]\left\{\Delta Q_{jl}\right\} = -\left\{F_j^k\right\} \quad (9)$$

where: k- iterative step, l=1,2

From the nodal equations it follows:

$$\left[\frac{\partial F_3^k}{\partial Q_{jp}}\right]\left\{\Delta Q'_{jp}\right\} = -F_3^k \quad (10)$$

Matrix (M+2N)x(M+2N) is of band type and hence not suitable to be applied, so that in the procedure of assembly the discharge increment is computed from the elements equations (10)

$$\left\{\Delta Q_{jl}^k\right\} = -\left\{F_j^k\right\}\left[\frac{\partial F_j^k}{\partial Q_l}\right]^{-1} - \left[\frac{\partial F_j^k}{\partial h_{il}}\right]\left[\frac{\partial F_j^k}{\partial Q_l}\right]^{-1}\left\{\Delta h_i^k\right\} \quad (11)$$

and it is introduced into (9), so that a band matrix of the system MxM is obtained with the unknown water level increment $\left\{\Delta h_i^k\right\}, i = 1, M$ in nodes. After computing this value it is introduced into (11) and the values of discharge increment $\left\{\Delta Q_{jl}^k\right\}$ are computed so that it is possible to obtain new values of the discharge and water level in the next iterative step

$$\left\{h_i^{k+1}\right\} = \left\{h_i^k\right\} + \left\{\Delta h_i^k\right\} \quad (12)$$

$$\left\{Q_{jl}^{k+1}\right\} = \left\{Q_{jl}^k\right\}\left\{\Delta Q_{jl}^k\right\} \quad (13)$$

where : i=l,M, j=l,N, l=l,2

The integration is performed for one time state until a satisfactory accuracy is achieved which is determined according to the vector norm.

$$\|\Delta h\|, \|\Delta Q\|, |\Delta h_{\max}| i |\Delta Q_{\max}|$$

The programme package was written for PC in FORTRAN and is divided into three parts:

- pre-process (geometry and topology, boundary and initial conditions and graphic control)
- unsteady treatment (computation per time stages)
- postprocess (numerical and graphical presentation of the results)

By using various elements, either simple or including any type of structures (such as hydroelectric plants, locks, spillways, etc.), it is possible to obtain simple topological schemes even for the most complex hydrotechnical systems.

RESULTS

The geometry of the domain is determined by placing several cross-sections, ca 2000, almost perpendicular to the main flows. By selecting 390 representative profiles the streamflows are divided into elements. The topological scheme for the completed structure is presented in Figure 3.

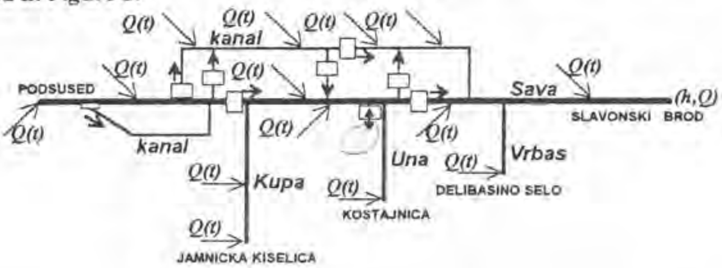


Figure 3. Topological scheme for the completed structure

According to the values of water levels and discharges measured during several hydrological periods at several water gauging stations, a calibration was performed in order to determine the Strickler coefficient values. Since the channel flow is unsteady the calibration should be performed by comparing the measured and computed values of Q-H curves, as presented in Figure 4.

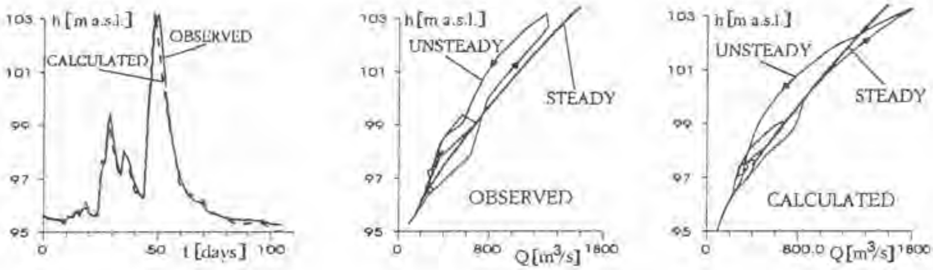


Figure 4. Measured and computed flood wave values at Rugvica Gauging Station for the 1982. year

Considering the present stage of engineering works on the structures the system operation was checked for various hydrological conditions and for 100-year floods. The same applies to the completed construction phase. The results show that the flood wave control is a complex task. The situation is particularly complex on the Sava River on the section where the Una and Kupa confluence into the Sava, which was not taken into account in previous computations. The entire flow of the Sava River is unsteady, which is well evident from the discharge curves for 100-year flood wave as presented in Figure 5. The flow is particularly complex at places where the Sava tributaries flow into it, which is presented by a discharge curve at the confluence of the Kupa River in Figure 6. The river flows upstream in some sections of the system, particularly in the vicinity of the confluence of tributaries or near the hydrotechnical structures. Figure 7 presents the tributaries near the inflow of the Lonja-Strug Channel into the Sava River.

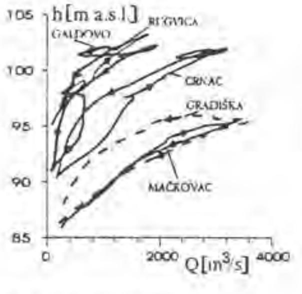


Fig. 5. Discharge curves in the Sava River

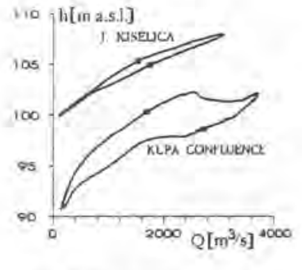


Fig. 6. Discharge curves in the Kupa River

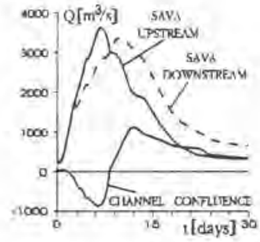


Fig. 7. Discharge in the vicinity of the inflow of the Lonja-Strug Channel

Since this system is complex it was not possible to use simplified computational procedures, i.e. conceptual models (Muskingum) or models based on complete equations, i.e. neglecting some terms from complete set (kinematic wave model). Paper [8] states that simplified models are not suitable even for simple channels with lateral inflows or locks. According to the earlier versions of the model the complex flow in the retentions of the left bank was simulated by several cells, as in a great number of examples from the book [1]; however, in this case it could not be done. The results are much better when the flow is considered to be parallel to the Sava River. It can be concluded that successful modeling can be effected if the type of the process is well-known and if the suitable model and numerical procedures have been subsequently chosen.

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Niederschlagsvorhersagen mit den Regionalmodellen des Deutschen Wetterdienstes

B. Dietzer

Zusammenfassung :
Beim Deutschen Wetterdienst sind neben einem globalen Vorhersagemodell mit einer Gitterweite von ca. 200 km zwei Regionalmodelle im operationellen Einsatz : das sogenannte Europa-Modell (EM) mit ca. 55 km und das Deutschlandmodell (DM) mit ca. 14 km horizontaler Auflösung. An den Gitterpunkten dieser Modelle stehen Niederschlagsvorhersagen bis hin zu einer stündlichen Auflösung zur Verfügung. Die Modelle werden erläutert und die damit routinemäßig erstellten Niederschlagsvorhersagen vorgestellt. Anhand von Beispielen wird gezeigt, wie sich die Qualität der Niederschlagsvorhersage mit den feiner aufgelösten Ausschnittsmodellen verbessert hat.

The Forecast of Precipitation with the Limited Area Models of the Deutscher Wetterdienst

Summary:
At the Deutscher Wetterdienst in addition to a global weather prediction model with a horizontal resolution of about 200 km, two limited area models are in operational use : the Europa-Modell (EM) with a grid distance of about 55 km and the Deutschland-Modell (DM) with 14 km. At the grid points of the limited area models, forecasts of precipitation up to a hourly resolution are available. The paper describes the models and the operational forecast products of precipitation. The quality of the prediction of precipitation has improved with the high resolution models.

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1. Einleitung

Der Niederschlag ist einer der wichtigsten Wetterparameter, den die Wetterdienste vorherzusagen haben. Als Eingabedaten für hydrologische Vorhersagemodelle zur Warnung der Bevölkerung und zum Betrieb wasserwirtschaftlicher Anlagen werden die Vorhersage der Niederschlagshöhe, bezogen auf einen bestimmten Zeitraum, sowie Aussagen zu Art, Beginn, Andauer und Intensitätsverlauf des Niederschlags benötigt. Diese Daten können zunehmend genauer aus numerischen Wettervorhersagemodellen gewonnen werden.

2. Numerische Wettervorhersagemodelle

Die numerische Wettervorhersage versucht mit Hilfe prognostischer und diagnostischer Gleichungen aus Hydro- und Thermodynamik den zukünftigen Zustand der atmosphärischen Variablen, wie Luftdruck, Temperatur, Windkomponenten, spezifischer Feuchte - ausgehend von einem Anfangszustand (Analyse) - zu berechnen. Die Modellatmosphäre wird dabei durch ein 3-dimensionales Gitternetz aufgespannt. In der Vertikalen ist die Atmosphäre vom Boden bis zum Oberrand in mehrere Schichten aufgeteilt. Physikalische Prozesse wie z.B. die Feuchtkonvektion, deren horizontale Erstreckung kleiner ist als der Gitterpunktsabstand, müssen summarisch behandelt werden (Parametrisierung).

Die Güte der Vorhersage der atmosphärischen Variablen ist dabei umso grösser, je feiner das Modellgitter ist, und je mehr Schichten in der Vertikalen benutzt werden. Dem steht aber der enorme Rechenaufwand bei der Lösung der Gleichungen gegenüber, der dazu zwingt, fein aufgelöste Modelle nur in einem eng begrenzten Gebiet einzusetzen. Die Randwerte für ein solches Modell werden von einem grobmaschigeren übergeordneten Modell bereitgestellt.

3. Die Modellkette des Deutschen Wetterdienstes

Beim Deutschen Wetterdienst (DWD) sind drei Wettervorhersagemodelle im operationellen Einsatz, die zweimal täglich, ausgehend vom 00 UTC und 12 UTC Analysentermin, gerechnet werden:

- das Globale Modell (GM), Modellgebiet gesamte Erdkugel, horizontale Gitterweite ca. 200 km, 19 vertikale Schichten, Vorhersage bis 168 Stunden.

- das Europamodell (EM), Modellgebiet Europa/Nordatlantik, Randwerte vom GM, horizontale Gitterweite ca. 55 km, 20 vertikale Schichten, Vorhersage bis 78 Stunden.

- das Deutschlandmodell (DM), Modellgebiet Deutschland/angrenzende Länder, Randwerte vom EM, horizontale Gitterweite ca. 14 km, 20 vertikale Schichten, Vorhersagezeit bis 36 Stunden.

Die Behandlung der zur Niederschlagsbildung führenden physikalischen Prozesse ist im EM und DM weitgehend gleich. In den Modellen wird zwischen stabilem (skaligen) und konvektivem Niederschlag unterschieden. Stabiler Niederschlag entsteht durch großräumiges Aufsteigen stabil geschichteter Luft. Das Niederschlagsgebiet erstreckt sich meist über mehrere 100 km bis etwa 1000 km. Skaliger Niederschlag entsteht im Modell, wenn das durch den Gitterpunkt definierte Volumenelement voll mit Wolkenwasser angefüllt ist. Diese Bedingung ist in der Regel an mehreren benachbarten Gitterpunkten erfüllt, es entsteht großräumiger Niederschlag. In den Modellgleichungen für den skaligen Niederschlag werden die Komponenten spez. Feuchte und Wolkenwassergehalt, sowie Regen und Schnee mitgeführt. Die wolkenphysikalischen Prozesse, die im hydrologischen Zyklus für den skaligen Niederschlag von

Bedeutung sind, werden in parametrisierter Form behandelt.

Der konvektive Niederschlag ist das Ergebnis feuchtkonvektiver Prozesse, die in einer horizontalen Größenordnung ablaufen, die kleiner sind als die Gitterweite. Feuchtkonvektion muß somit in parametrisierter Form im Modell beschrieben werden.

Die entscheidende Verbesserung der Niederschlagsvorhersagen mit dem DM basiert auf der wesentlich genauer darstellbaren Orographie. Die Abb. 1 zeigt die im EM und DM verwendete Geländestruktur. Damit wird eine topographisch bedingte Verstärkung bzw. Abschwächung großräumiger Niederschlagsgebiete besser vorhergesagt. Prä- und postfrontale Niederschlagszonen werden genauer erfaßt. Der Tagesgang der Konvektion im orographisch stärker gegliederten Gelände ist darstellbar.

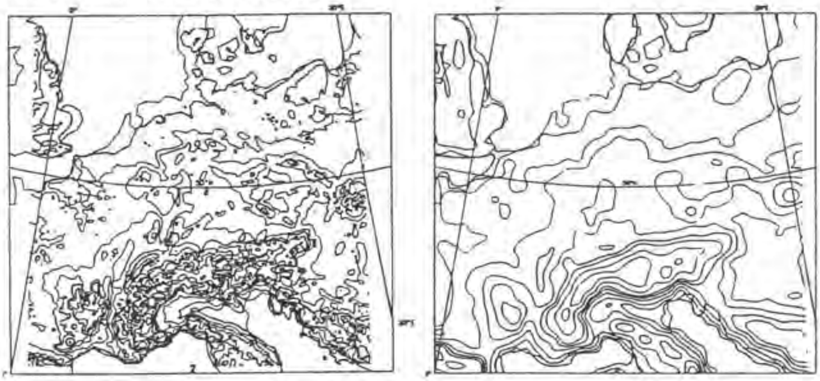

Abb. 1: Orographie im Deutschland- und Europamodell
Isolinien : 20m (fett), 100m, 250m, 500m, 750m (fett), 1000m
1500m, 2000m, 2500m (fett), 3000m

4. Niederschlagsvorhersageprodukte des DWD

Die Niederschlagsprognosen werden in stündlicher Auflösung, getrennt nach Schnee und Regen, sowie konvektivem und skaligem Niederschlag, in einer Datenbank abgespeichert. Über Langwellen-Fax werden Niederschlagsprognosen des EM in Isohyethenform für Mitteleuropa bis 78 Std. routinemäßig verbreitet. Ein Beispiel zeigt die Abb. 2.

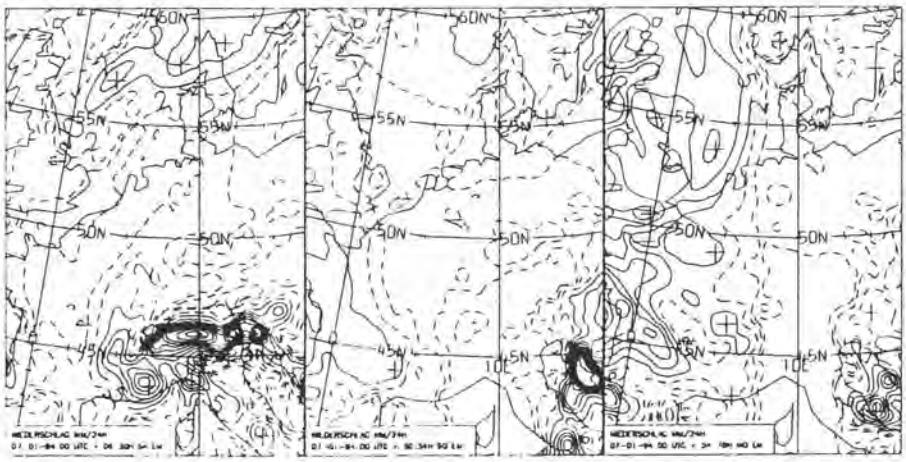

Abb. 2: Routinemäßige Niederschlagsvorhersage des Europa-Modells

Vom DM werden Vorhersagen der Niederschlagshöhe in Rasterform, sowie der Konvektionsform und der Niederschlagsart in Symboldarstellung bis 36 Std. ebenfalls routinemäßig gesendet (Abb. 3).

Spezielle Nutzer werden mit Niederschlagsprognosen für definierte Gitterpunkte über Telex oder DATEX-P beliefert.

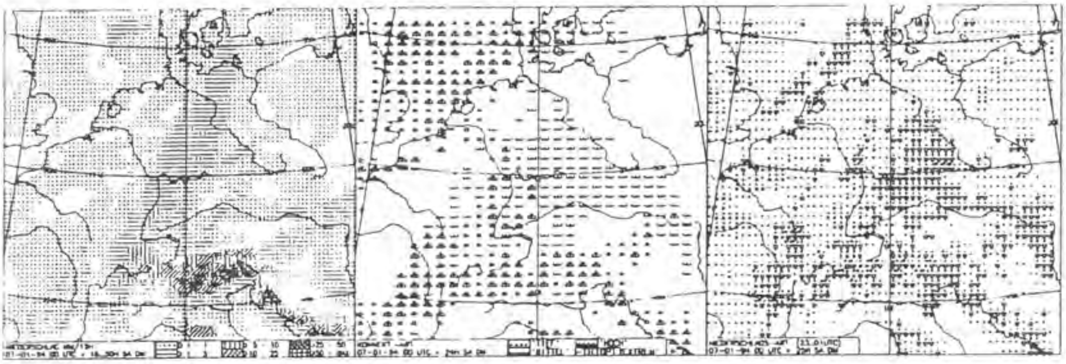

Abb. 3: Routinemäßige Niederschlagsvorhersage des Deutschland-Modells

5. Die Güte der Niederschlagsprognosen

Die Verifikation der Niederschlagsprognosen wird dadurch erschwert, daß es sich bei den gemessenen Niederschlagshöhen um Punktmessungen handelt. Gitterpunktswerte aus der Modellvorhersage dagegen sind eine Art Gebietsniederschlag über die jeweilige Gitterpunktsfläche. Es müssen daher auch Flächenmittel aus Niederschlagsmessungen mit vorhergesagten Flächenmitteln verglichen werden.

Die Abb. 4 zeigt die Summe der täglichen 24 std. Niederschlagshöhen für Oktober 1993 im Vergleich mit den vorhergesagten 24 std. Niederschlagsprognosen für die Vorhersagezeiten T+6 bis T+30 Std. für das Gebiet Deutschland und Schweiz. Man erkennt, daß das DM die lokalen Unterschiede in der Niederschlagsverteilung wesentlich besser simulieren kann, als das EM. So sind die beobachteten Maxima in der Südschweiz und in den Mittelgebirgen auch in den DM-Vorhersagen zu finden.

Abb. 4: Monatliche Niederschlagshöhen für Oktober 1993 aus Beobachtung und Vorhersage T+6 bis T+30 mit Deutschland- und Europa-Modell

Auch bei einer Einzelfallauswertung zeigt sich die Verbesserung der Niederschlagsvorhersagen mit dem DM gegenüber dem EM : die Abb. 5 zeigt den gemessenen 24 std. Niederschlag in der Schweiz vom 24.9.93 (Hochwasser im Tessin) und die Niederschlagsvorhersagen mit EM und DM. Auch hier werden die auf die Südschweiz begrenzten Niederschläge vom DM deutlich besser vorhergesagt, als durch das EM. Auch die Absolutwerte (beobachtet mehr als 110 mm) werden vom DM (ebenfalls 110 mm) wesentlich besser prognostiziert, als vom EM (nur bis 70 mm). Dennoch zeigt die Abbildung auch die Grenzen der numerischen Vorhersage auf : der vom DM vorhergesagte Niederschlag ist auf ein wesentlich grösseres Gebiet verteilt, als in Wirklichkeit. So werden auch für die Ostschweiz Niederschlagshöhen bis zu 50 mm prognostiziert, wo nur weniger als 10 mm gemessen wurden.

6. Schlußbemerkungen

Wie die Abb. 5 zeigt, kann eine Niederschlagsvorhersage mit hochaufgelösten Wettervorhersagemodellen im Detail noch große Fehler aufweisen. Trotzdem ist es mit dem DM gelungen, einen weiteren Schritt in Richtung einer räumlich und zeitlich genauen Niederschlagsprognose zu tun. Verbesserungen in der Parametrisierung der Niederschlagsprozesse und genauere Analysen der Bodenparameter lassen weitere Gütesteigerungen der Niederschlagsvorhersage erwarten.

7. Danksagung

Der Verfasser dankt dem Kollegen Dr. U. Damrath für die Bereitstellung der Niederschlagsverifikationsergebnisse.

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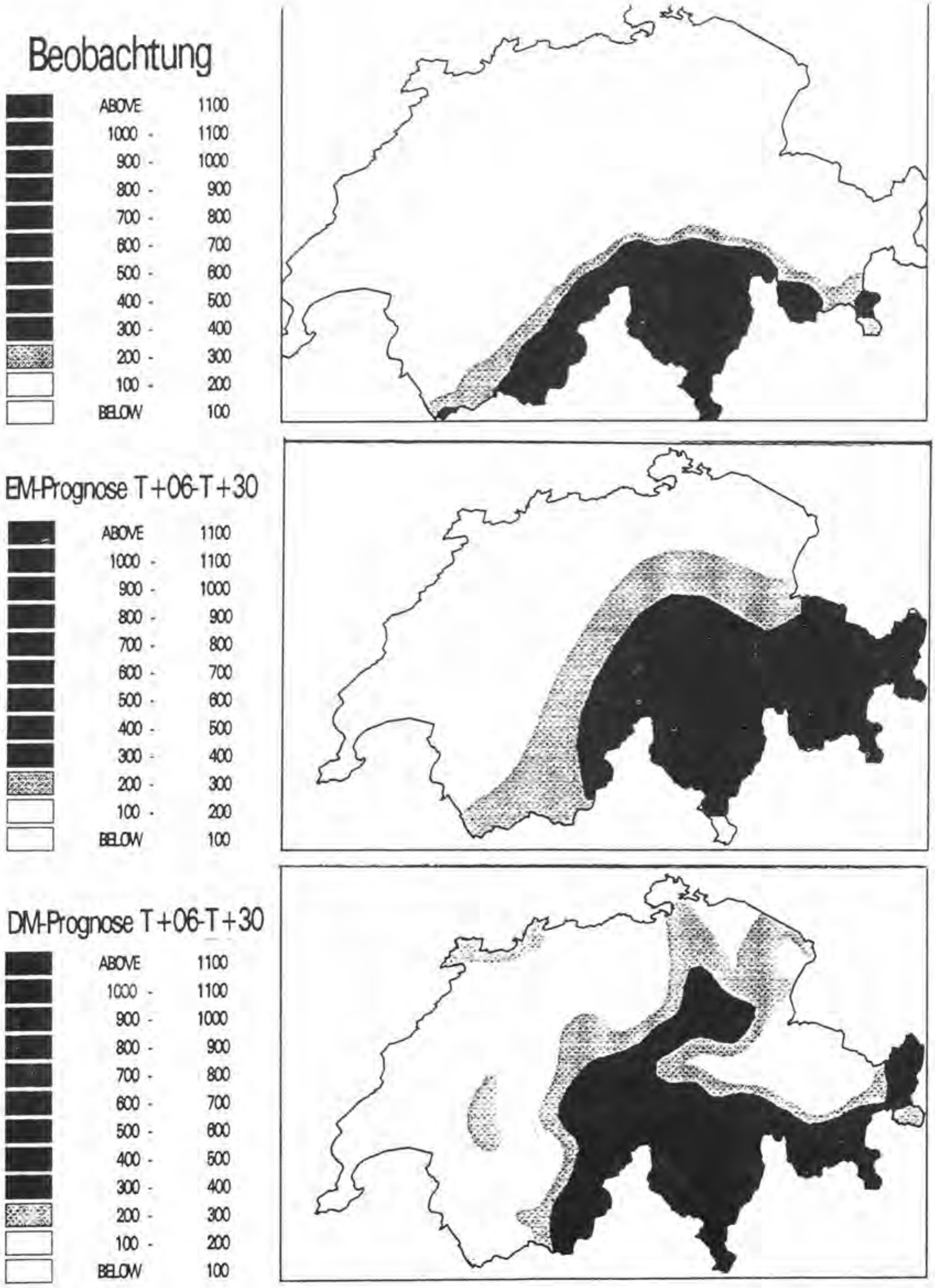

Abb. 5: 24 std. Niederschlag vom 24.-25.09.93 beobachtet, sowie
24 std. Vorhersagen vom 24.09.93 00 UTC (in 1/10 mm).

XVII. KONFERENZ DER DONAULÄNDER
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EVALUATION OF HYDROLOGICAL FORECASTS' ACCURACY ON THE SLOVAK REACH OF THE DANUBE RIVER

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Summary: Since 1920 the short range hydrological forecasts of water stages on the Slovak reach of the Danube river have been regularly carried out. In the past the hydrological forecasting has been provided at the various institutions according to the historical and political situation in the country.
Department of Hydrological Information and Forecasting Service at the Hydrometeorological Institute was established in fifties and from that time it was possible to follow systematically the accuracy of the issued forecasts.
In the paper, the errors' evaluation for forecasts issued in different time periods, is outlined.

DER GENAUIGKEITSAUSVERTUNG VON HYDROLOGISCHEN VORHERSAGEN IM SLOVAKISCHEN DONAUABSCHNITT

Kurzfassung: Die kurzfristigen Vasservorhersagen im slowakischen Donauabschnitt werden schon seit dem Jahre 1920 ausgegeben. In der Vergangenheit wurden hydrologische Prognosen den historischen und politischen Veränderungen im Land entsprechend von verschiedenen Institutionen durchgeführt.
Hydrologischer Informations- und Vorhersagedienst wurde im Hydrometeorologischen Institut in den fünfziger Jahren gegründet, seitdem ist es möglich, die Genauigkeit der ausgegebenen Vorhersagen zu verfolgen.
Im Artikel sind einige Erkenntnisse aus der Genauigkeitsauswertung von hydrologischen Vorhersagen, die in verschiedenen Zeitperioden ausgegeben wurden, aufgeführt.

Hydrological forecasting in Slovakia has been performed at the specialized department of the Slovak Hydrometeorological Institute - Hydrological Information and Forecasting Service (abbreviation HIPS).

HIPS is responsible for hydroprognostic service over all the territory of the Slovak Republic. At the present time HIPS provides prediction for 13 rivers and 28 river sites. For this purpose the extensive monitoring of hydrological, meteorological and water management data has been realized. Further, the hydrometeorological information with the neighbouring states and all Danubian countries is exchanged. Of the longest tradition are the hydrological forecasts on the Slovak reach of the Danube where they have been regularly performed since 1920. In the past, the hydrological forecasting has been provided at the various institutions according to the historical and political situations in the country. That is why it was possible to carry out the systematic processing of hydrological the forecasts' accuracy only from fifties when Hydrometeorological Institute was established.

The accuracy and success of the hydrological forecasting have their development and they depend on the general level of hydrological service, forecasting methods, monitoring's technical level and professional skill of the forecasting service staff.

On the Slovak reach of the Danube there exist four basic forecast river sites: Bratislava, Medveďov, Komárno and Štúrovo.

For several years HIPS is in 2-shift operation from 6 a.m. to 10 p.m. At the present there are prepared forecasts for 6, 24 and 48 hours and estimation for three days, one week and one month for various purposes according to the requirements of the different organizations. In the paper there are presented some results of the evaluation of 24-hours forecast's accuracy, which was done for the longest period and gives the homogeneous series for comparison.

According to the Czechoslovak norm, in the case of short term forecasts issued in regular time intervals, the tolerable error of the forecast is defined by the equation:

$$\delta_d = \pm\ 0.674\ \sigma_d$$

where σ_d is the standard deviation of the changes of the forecasted quantity's real values (d_i) in the forecast period given by:

$$\sigma_d = \sqrt{\frac{\sum_{i=1}^{n} (d_i - d)^2}{n - 1}}$$

and in the relationship for the arithmetic mean:

$$d = \frac{\sum_{i=1}^{n} d_i}{n}$$

are the changes d_i taken into consideration with positive and negative signs.

The evaluation of the accuracy will be done according to the following criteria:

1. percentage of the suitable forecasts in view of the tolerable error in all issued forecasts

2. average error e.g. the arithmetic mean of the absolute values of errors

3. number of errors in % up to 10,20 and 30 (40) cm.

Generally speaking, the antropogenic activities on the Danube has obviously influenced the forecasts' accuracy in the negative way. Due to the water structures construction the gauging stations which were the inputs for the river models (Linz, Struden, Krems, partially Vien-Reichsbrucke etc.) were gradually laid up. Besides, as a result of the main stream's canalization and the other antropogenic effects over the drainage basin, the reaction of the runoff process to the flush of precipitation or water from melted snow was accelerated. In the last ten years the travel times on the reach Linz - Bratislava have been reduced by 20-30%.

The development of forecasts' accuracy in time as well as along the stream can be illustrated by the Table 1. By 1959 were only one hydropower plant in operation in Austria, in the year 1986 already eight ones. The average error in Bratislava was doubled. Errors of the forecasts have increased primarily in the sphere of smaller errors (up to 30 cm) in connection with the uncheckable manipulation of the hydropower stations. The influence of manipulation which took place mainly in the Austrian reach of the Danube gradually dissapears down the stream.

In the Table 3 there are the results of accuracy evaluation of the forecast for Bratislava in the time periods of the years 1959, 1970-1976, 1982-1993. General development may be characterised as the gradual increase of the forecst's errors since the year 1959 up to 1986 when certain stabilization has been achieved, which can be related with extension of monitoring and improvement of forecast's methods. In the year 1993 the forecasts' accuracy has been slightly reduced again.

Bratislava was the important forecasting river site controlling the inflow into the Slovak reach of the Danube. After setting the Gabčikovo structure into partial operation in October 1992, the gauge is under the influence of the Čunovo reservoir. In January 1993 the new gauge has been installed upstream of Bratislava at Devín.

The gauge Medveďov is situated downstream the Gabčíkovo.The forecasts' accuracy was evaluated from the year 1987 up to October 1992 and then from March 1993 up to the end of the year. As may be seen from the results (Table 2), the accuracy has been considerably reduced in all criteria after setting the Gabčíkovo hydropower station into the operation.

The Gabčikovo structure is a new challenge for the hydrological forecasting service. As a consequence of considerably changing runoff conditions, the existing forecasting methods have to be adapted and new methods and models have to be developed.

TABLE 1. Hydrological forecasts' accuracy at Vienna, Bratislava and Komárno

TABELLE 1. Die Genauigkeit von hydrologischen Vorhersagen in Vien, Bratislava und Komárno

Station	Year	Tolerable error (cm)	Suitable forecasts (%)	Average error (cm)	Error up to		
					10 cm (%)	20	30
Vienna	1959		96	7	85	95	96
	1986	21	80	15	56	80	91
Bratislava	1959		97	5	92	97	98
	1986	19	90	10	67	91	97
Komárno	1959		94	4	94	98	99
	1986	12	93	5	90	98	100

TABLE 2. Hydrological forecasts' accuracy at Medveďov

TABELLE 2. Die Genauigkeit von hydrologischen Vorhersagen in Medveďov

Year	Tolerable error (cm)	Suitable forecasts (%)	Average error (cm)	Error up to		
				10 cm (%)	20	40
1987	21	97	7	79	95	99
1988	18	94	9	77	94	99
1989	17	94	7	81	96	99
1990	18	94	7	82	96	100
1991	22	95	8	80	95	99
1992	15	92	6	84	98	100
1993	26	82	16	51	76	92

TABLE 3. Hydrological forecasts' accuracy at Bratislava
TABELLE 3. Die Genauigkeit von hydrologischen Vorhersagen in Bratislava

Year	Tolerable error (cm)	Suitable forecasts (%)	Average error (cm)	Error up to		
				10	20	40
				cm (%)		
1959	19	97	5	92	97	99
1970	30	96	9	74	92	97
1971	16	93	7	83	96	99
1972	17	95	6	83	97	99
1975	19	95	6	87	96	99
1976	19	94	7	78	95	99
1982	19	88	-	-	-	-
1983	19	90	-	-	-	-
1984	16	79	11	-	-	-
1985	23	85	12	-	-	-
1986	19	90	10	67	91	99
1987	26	90	13	59	83	96
1988	24	90	11	60	87	96
1989	22	90	12	50	89	97
1990	31	91	9	67	90	99
1991	30	95	11	66	89	97
1992	21	91	10	68	89	97
1993	20	87	11	63	87	96

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Der hydrologische Vorhersagedienst in der Ukraine - Zustand und Fortentwicklungsperspektiven der methodischen Grundlagen

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Kurzfassung

Im Bericht werden die Struktur von hydrologischem Vorhersagedienst in der Ukraine und Angaben über Vorhersageerzeugungsumfang dargestellt. Die Aufwärtsentwichlung der methodischen Grundlagen verwirklicht sich mittels Einführung der Vorhersagetechnologie, die an der Bildung solcher Systeme orientiert ist, die Abflussvorhersagen in landesweiten, kontinuierlichen und zeitüberdeckenden Formen vorzustellen ermöglichen. Solche lang- und kurzfristigen Vorhersagesysteme werden auf der Basis der mathematischen Abflussmodellierung begründet. In der Perspektive werden die räumlich und zeitlich detaillierten Abflussvorhersagesysteme auf ganzes Landesgebiet von Ukraine verbreitet sein.

The hydrological forecasting service in the Ukraine - situation and further development perspectives of methodical bases

Abstract

The structure of the hydrological forecasting service in the Ukraine and information of forecasting produce volume are represented in the report. The improvement of methodical bases is proceed successfully by means of a introduction of forecasting technology that creates such systems with presentation of runoff forecastes at spatial, continuous and overlaped form. Such long- and short-team forecasting systems are based on mathematical modelling. In perspective spatial and temporal detailed runoff forecasting systems will be extended to all territory of Ukraine.

1. Einleitung

Die Ukraine mit einer Gesamtfläche von 603700 km² erstreckt sich von Norden nach dem Süden in 900 km und von Osten nach dem Westen - in 1300 km. Hier gibt es Ebenen, Anhöhen und Gebierge. Die Landschaften des Flachlandes ändern sich von der Zone der gemischten Wälder bis zur Steppen. Den Gebirgsregionen sind vertikale Änderungen der metheorologischen Grössen eigen. Grosse Differenz zeigt sich auch in Feuchtigkeit des Landesgebiets. Wenn in der Karpaten 800-1200 mm und im Nordwesten 600-700 mm pro Jahr niederfällt, wogegen im Süden nur 350-450mm.

Verschiedenartigkeiten der Klima-, Orographie- und Bodenverhältnisse beeinflussen der Vorgänge der Abflussformierung und bestimmen Besonderheiten der Flussregime. Für ebenes Gelände sind Frühjahreshochwasser infolge der Schneeschmelze, Sommer- und Winterniedrigwasser kennzeichnend. Im Frühjahr fliesst hier gewöhnlich etwa 60-80% von jährlicher Abflussfülle ab, während in der Westukraine,insbesonders in der Karpaten, geschehen fast jedes Jahr und mehrmals Regenhochwasser, die manchmal einen katastrophishen Charakter bekommen.

Wichtiges Problem für die Ukraine gibt es die rationelle Ausnutzung von Wasservorräten. Dises Problem befindet sich unmittelbar im Zussammenhang mit allgemeiner Interessiertheit zur Umweltverbesserung, Naturschatzwiederherstellung und Hochwasserschutze.

2. Die Struktur des hydrologischen Vorhersagedienstes

In der Ukraine konzentriert alle Tätigkeit des hydrologischen Vorhersagedienstes bei den Ämtern, die dem Staatskomitee für Hydrometeorologie unterordnend sind.

Die Ausarbeitung der methodischen Grundlagen für hydrologischen Vorhersagen, mit entsprechenden Programmsysteme einschliesslich, verwirklicht Ukrainisches hydrometeorologisches Forschungsinstitut. Im Institut werden die Methodiken und Systeme der lang- und kurzfristigen Wasserstands-, Abfluss - und Eisverhältnisvorhersagen erarbeitet. Zu diesem Zweck wird auch notwendige wissenschaftliche Untersuchungen erfüllt: Verallgemeinerungen der Beobachtungsangaben, Erforschungen der Gesetzmässigkeiten der Abflussvorgänge usw. Ausserdem widmen die Gelehrten einen breiten Raum der Anwendung von erarbeitenden Methodiken in der Praxis.

Die operative Hauptvorhersagestelle heisst das Ukrainische hydrometeorologische Zentrale (UkrHMZ), die sich in Kyjiw (Kiew) befindet. Die UkrHMZ ist Leitdienststelle für die Regional- und Gebietsdienststellen, die ihre Informationstätigkeit koordiniert. Die UkrHMZ selbst versorgt mehrere Einrichtungen auf der Staatsebene mit verschiedenen hydrologischen Vorhersagen und Beratungen.

Sehr viele Einrichtungen und Betriebe erhalten hydrologische Informationsangaben in verschiedenen Formen von der

Gebietsdienststellen für Hydrometeorologie (GHMD), denen bestimmte Flussbecken zugeteilt sind. Solcherweise dienen diese GHMD in den Fragen über hydrologischen Beratungen als Regionalzentrale des gesamten Vorhersagedienstes (Tab.1).

Die hydrologischen langfristigen Vorhersagen erstellt die UkrHMZ für alles Landesgebiet (es ist ihrer Tätigkeitsbereich). Die Kurzfristvorhersagen werden in den entsprechenden Regionalzentralen vorbereitet.

Tabelle 1.

Standorte der Regionalzentralen des hydrologischen Vorhersagedienstes
Regional centres location of the hydrological forecasting service

Standorte der Regionalzentralen	Die zugeteilten Flussbecken
Lwiw	Dnister, Bug, Prypjat
Ushgorod	Tyssa
Tscherniwzi	Pruth, Siret
Kyjiw (Kiew)	Dnipro, Desna u.andere Zuflüsse
Odessa	Südlicher Bug
Charkiw	Siwerskij Donez, Pryasow'je
Simferopol	Krimflüsse

3. Vorhersageerzeugnisumfang

Hydrologische Vorhersagen beziehen sich auf mehrere Einrichtungen und wirtschaftliche Betriebe. Das sind wichtige Zweige, u.zw. Land-, Wasser- und Gemeindewirtschaft, Hydroenergetik, Verkehrswesen, Fernmeldeleitungen, Hochwasserschutz usw.

Die Charakteristiken des Abflussregimes (Volumen, Abflussgange, Exstremwerte, Hochwasserstände und -abflüsse, ihre Anbruchsfriste) werden, im Betracht von der Erscheinungsform und Flussbeckenfläche,mit verschiedenen Zeitdauern vorgesagt - von einigen Stunden (Regenhochwasser in Gebirge) bis zum 30-90 Tagen (Frühjahrsabfluss- und Wasserspeicherzuflussvolumen am Dnipro).

Der Vorhersageerzeugnisumfang, dass operative Dienststellen des Staatskomittee während eines ganzen Jahres erstellen, macht etwa 1200 langfristigen und mehr als 8 Tausend kurzfristigen Vorhersagen aus (Tab.2).

Ein Lösung der Problem zur rationellen Nutzung der Wasservorräte ist aufs engste mit effektive Funktion der Stauraumkaskaden (vor allem am Dnipro und auch am Dnister, in den Flussbecken vom Süd. Bug und Siw.Donez) verbunden. Im ganzen gibt es in der Ukraine 1094 Wasserspeicher, die 55 km^3 Wasser akkumulieren. Ihre Nutzräume, die für die Abflussregelung und Wasserversorgung gebraucht werden, erreichen 26 km^3 . Von ihnen befindet sich 6 Wasserspeicher mit Nutzinhalt 18,6 km^3 am Dnipro. Aus den Dnipro-

Speichern wird das Wasser in den Donezbecken, Krywyj Rih, Krim, für Landberieselungen (2,6 Mio ha) entnommen. Die Gesamtvolume der unwiederbringlichen Wassernutzung reicht ungefähr 10 km^3.

Perspektive und operative Planung der Speicherfassung und- abarbeitung, Stromerzeugung, Wasserentnahme für Bewässerung, gleichzeitig mit den Anforderungen des Schiffsverkehrs und anderer wirtschaflichen Wasserbedürfnisse, wird unter Berücksichtigung von ganzen Abflussvorhersagekomplex erfüllt. Auf diese Weise kann man fast optimale Zustimmung der Interessen verschiedener Wirtschaftszweige wahrnehmen. Gleichzeitig wird die Naturschutzmassnahmen nicht vergessen.

Tabelle 2

Jährlicher Vorhersageerzeugnisumfang
Annual forecasting produce volume

Kennwerte	Anzahl der Gewässer	Anzahl der Vorhersagen
Langfristvorhersagen		
1. Zufluss		
in einer Jahreszeit	2	20
in 90 Tagen	2	20
in 30 Tagen	5	80
in 10 Tagen	4	188
2. Höchste Frühjahrswasserstände	31	51
3. Höchste Frühjahrsabflüsse	15	20
4. Frühjahrsabflussfülle	25	38
5. Höchster, niedrigster, mittlerer Monatswasserstand	6	743
6. Eisverhälnisse	28	31
Kurzfristvorhersagen		
1. Zufluss		
in 10 Tagen	2	82
in 1 Tag, einigen Tagen	3	2313
2. Höchster Wasserstand	8	38
3. Mittelere Abflussmenge in 5 und 10 Tagen	17	1147
4. Mittlere, niedrigste, höchste Wasserstände in 10 Tagen, tägliche Wasserstände	6	4091
5. Schiffahrtswasserstände	1	400

Auf dem ganzen Landesgebiet der Ukraine können Hochwasserereignisse fast jährlich Risiken, Gefahren und Verlusten hervorrufen. Im Flachland sind es Überflutungen und Zerstörungen hauptsächlich während der Frühjahrshochwasser. Im Pripjat-Flussbecken geschehen noch Regenhochwasser in einigen Sommerjahreszeiten. Aber in den Gebirgsregionen ist solche Gefahr während des ganzen Jahres nicht ausgeschlossen.

So in den Karpaten rufen reichliche Niederschläge und intensive Schneeschmelzen häufige Hochwasser hervor, die öfters katastrophische Charakter haben. Darum in den Flussbecken von Dnister,Tyssa, Pruth und Siret sind Hochwasser- und Murgangwarnung von grosser Bedeutung. Diesem Zweck muss das Vorhersagesystem dienen, dass jetzt in der Einführung gestanden ist. Dieses System gibt die Möglichkeiten, Abflussfüllen und Abflussgänge während des ganzen Jahres vorzusagen.

Wesentliche Bedeutung haben für unseres Land auch rechtzeitige Warnungen über Eiserscheinungen, -bildung und -aufgang. Solche Angaben sind für Wasserverkehr, als auch für den Schutz der Transportstrassen und Fernmeldeleitungen nötig.

4. Weiterentwicklungsrichtungen der methodischen Grundlagen

Eines von Massnahmen für erfolgreiche Tätigkeit des hydrologischen Vorhersagedienstes ist weitere Vervollkommung seiner methodischen Grundlagen mittels Einführung für alle Flussbecken solcher Vorhersagesysteme, die noch höhere Informationswerte haben und vollkommene Technologien benutzen. Der Begriff von Technologie schliesst Vorhersagestrukturen, Programmausrüstungen, Datenbankorganisationen.

Unter methodischen Gesichtspunkt wird die Erstellung der Vorhersagesysteme auf solcher Weise gerichtet, damit sie begünstigen können, Abflusscharakteristiken mit verschiedener Zeitdaüer in folgenden Formen vorzustellen:(a)landesweite, (b) kontinuierliche, (c) zeitüberdeckende. Notwendigesweise ist die Kombinierung der Formvorstellungen möglich.

Solche Vorhersagesysteme werden auf der Basis der mathematischen Modellierung der Abflussprozesse begründet, die in den Einzugsgebiete geschehen und Verhältnisse für die Abflussformierung schaffen. Mit diesem Zweck wurden die Modelle gebildet, dass die Formierung des Regen-, Tau- und Gemischtwasser simulieren /1-4/.

Die landesweiten Vorhersagen mit verschiedenen Stufen von Flächendetaillierung (im Zusammenhang mit Bedürfnisse) haben einen höheren Informationswert. Gegenwärtig werden diese Systeme der langfristigen Frühjahrsvorhersagen für die Flussbecken von den Dnipro - Zuflüssen, Süd. Bug und Siw. Donez ausgenutzt. Es werden die Ausarbeitungen betreffs ihrer Verbreitung auf ganzes Landesgebiet erfüllt. Auch gilt es landesweites Regenabflussvorhersagesystem für die Westukraine zu entwickeln.

Schon funktionieren zwei Systeme der kontinuierlichen Abfluss- und Zuflussvorhersagen mit Zeitdauern von 1-5 bis 30-90 Tagen für die Dnipro-Stauraumkaskade und den Dnister-Wasserkraftkomplex. Die Vorhersagen werden mit der Überdeckung erstellt, darum gibt es Möglichkeit, genauere Angaben regular bei der Verkleinerung von Zeitdauer zu bekommen. Kontinuierliche Kurzvorhersageerstellung der Abflussganges wird während der Regenhochwasser an den Karpatenflüssen angewandt.

Effektive Abflussvorhersagen für Gebirgsflüssen können ohne Niederschlagsvorhersagen unter Verteilung auf orographichen Gebiete nicht gewährleisten. Entspechende Ausarbeitungen werden für das Gebiet der Ukrainischen Karpaten mit Benutzung von Satelliten- und Radiosondendaten erfüllt.

In der Perspektive werden die räumlich und zeitlich detaillierten Abflussvorhersagesysteme auf ganzes Landesgebiet von der Ukraine verbreitet sein.

5. Schlussbemerkung

Die Steigerung der Effektivität vom hydrologischen Vorhersagedienst verlangt Vervollkommung der methodischen Grundlagen und Automatisierung aller seinen Technologiebestandteile. Für unseren Gebirgsregionen sind wesentliche Fortschritte in dieser Richtung ohne Schaffung der automatichen Beobachtungs- und Informationssysteme nicht möglich.

Für die Karpatenregion ist es sehr wichtig, die enge Zusammenarbeit zwischen entsprechenden Diensten von Ukraine, Ungarn, Rumänien, Moldova und Slowakei zu unterhalten.

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XVII. KONFERENZ DER DONAULÄNDER
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Kurzfristbewirtschaftung und Abflußvorhersage im Überleitungssystem Donau-Main

M. Becker und K. Wilke

Kurzfassung: Mit dem Ziel eines Ausgleichs hydrologisch bedingter Standort-Unterschiede zwischen Nord- und Südbayern betreibt der Freistaat Bayern - Wasserwirtschaftsverwaltung - seit 1970 den Bau eines Systems zur Überleitung von Altmühl- und Donauwasser in das Regnitz-Maingebiet. Der Beitrag behandelt neben einigen Gesichtspunkten der Kurzfristbewirtschaftung auch beispielhaft die Verknüpfung von Langzeit- und Kurzfristbewirtschaftung und vor allem die operationelle Hochwasservorhersage im oberen Altmühltal, bei der als Verfahren das Wiener-Mehrkanalfilter zum Einsatz kommt. Es wird über die Berechnung des Mehrkanalfilters, die operationelle Datenbeschaffung und die erstmalige Anwendung des Filters unter Echtzeitbedingungen im Hochwasserfall berichtet.

Short Time Operation and Flood Forecast in the Interbasin Water Transfer System Danube-Main

Abstract: Since 1970 the Bavarian Government pursues the project of the Interbasin Water Transfer System Danube-Main with the aim to balance water resources between northern and southern Bavaria and to prevent that water becomes a minimum factor for the economic development in the northern part of Bavaria. This paper is dealing with some aspects of the short time operation of the system and the use of the Wiener-filter algorithm as a tool for the flood forecast in the upper Altmühl valley. Information is given to the development of the filter model, the data collection under operational conditions and the first real time use of the model in case of flood.

1 Ziel und Konzeption des Überleitungssystems

Ausgangspunkt des Überleitungssystems ist zum einen der Main-Donau-Kanal, der sich zwischen der Regnitzmündung in den Main bei Bamberg und der Altmühlmündung in die Donau bei Kelheim erstreckt (Abb. 1). Der Schiffahrtskanal bietet dabei - ohne bauliche Vergrößerung - eine ideale Möglichkeit, Wasser aus dem Donaugebiet in das Regnitz-Maingebiet überzuleiten. Dazu bedurfte es lediglich einer entsprechend dem wasserwirtschaftlichen Bedarf vergrößerten Kapazitätsauslegung der an den fünf Stufen der Südrampe für die Betriebswasserversorgung des Kanals vorgesehenen Pumpwerke (Becker u.a., 1985).

Um einen möglichst wirtschaftlichen Pumpbetrieb zu realisieren und um kürzere Betriebsunterbrechungen im Fördersystem zu überbrücken, errichtet die Wasserwirtschaftsverwaltung einen Ausgleichsspeicher, den Rothsee (Nutzraum 7 hm^3), der auch für die Freizeit- und Erholungsnutzung bedeutsam sein wird. Das über den Main-Donau-Kanal übergeleitete Wasser kann über die Roth und die Rednitz dem Großraum Nürnberg zugeführt werden.

Da die Entnahme aus der Donau nicht uneingeschränkt möglich ist, auf der anderen Seite aus Effizienzgründen eine gewisse Versorgungssicherheit im Regnitz-Maingebiet gewährleistet werden muß, bedarf die Kanalüberleitung einer Ergänzung. Hierfür ist das zweite Teilsystem, die Altmühl-Brombach-Überleitung (Brombachsystem), vorgesehen. Es besteht aus einem Ausgleichsspeicher im Altmühltal, dem Überleitungsstollen, der die europäische Hauptwasserscheide Donau-Rhein unterfährt und der Brombachtalsperre.

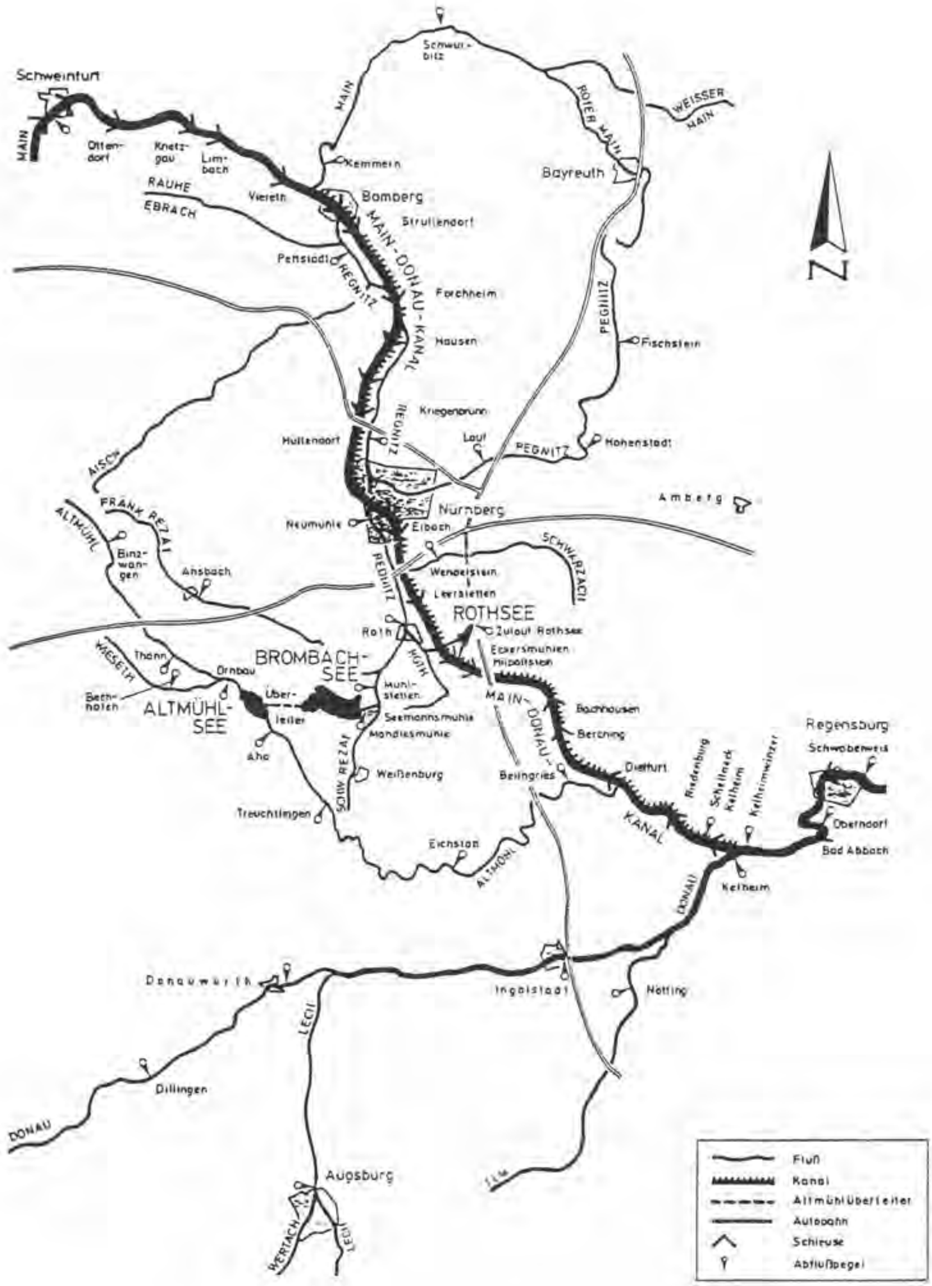

Abb. 1 Übersichtslageplan

Der Altmühlsee (Stauinhalt 13,4 hm³) dient in erster Linie dazu, Hochwasser der oberen Altmühl kurzfristig zurückzuhalten, um sie in den Brombachsee ableiten zu können. Dadurch trägt der Speicher auch zum Hochwasserschutz für die mittlere Altmühl bei. Er ermöglicht außerdem eine begrenzte Niedrigwasseraufhöhung in der Altmühl und örtliche und überörtliche Erholungsfunktionen. Durch eine ca. 120 ha große Flachwasser- und Inselzone werden im See wertvolle ökologische Ausgleichsflächen geschaffen.

Mit einer Wasserfläche von über 9 km² und einem Inhalt von rund 132 hm³ stellt der Brombachsee das Kernstück des Brombachsystems dar. Der Speicher hat primär die Aufgaben, schadenverursachende Hochwasser der oberen Altmühl aufzunehmen und dieses Wasser zur gezielten Niedrigwasseraufhöhung in das Flußsystem von Rednitz-Regnitz-Main abzugeben. Das ist insbesondere bei Niedrigwasser in der Donau erforderlich, wenn dort eine Wasserentnahme nicht statthaft ist, bzw. bei Betriebsstörungen im Teilsystem Main-Donau-Kanal. Eine weitere Funktion liegt in der Bereitstellung wasserorientierter Freizeit- und Erholungsmöglichkeiten im seenarmen mittelfränkischen Verdichtungsraum.

2 Bewirtschaftungskonzeption

Die Entwicklung optimaler Bewirtschaftungs- und Steuerungsvorschriften für das Überleitungssystem vollzieht sich nach einem Rahmenkonzept in drei Stufen (Rosemann u. a., 1980):

- Langzeitbewirtschaftung, d. h. Aufstellung jener Bewirtschaftungsgrundsätze, die die optimale langfristige Auslastung derwasserwirtschaftlichen Anlagen unter Einhaltung der notwendigen Randbedingungen sichern.
- Kurzfristbewirtschaftung, d. h. Entwicklung optimaler operativer Bewirtschaftungsregeln für maßgebliche Belastungsfälle und Anforderungen in Abhängigkeit von bestimmten Systemzuständen. Dabei sind die in der Langzeitbewirtschaftung entwickelten Grundsätze als Restriktionen zu beachten, die jedoch im Wege der Rückkoppelung bei entsprechenden Erkenntnisfortschritten modifiziert werden können.
- Betriebsplan, d. h. Fixierung der Steuerungsregeln in Form einer Anweisung für den Echtzeitbetrieb auf der Basis der Erkenntnisse aus Langzeit- und Kurzfristbewirtschaftung.

Die Bewirtschaftung des Überleitungssystems unter Langzeitaspekten beruht auf einer umfassenden mehrjährigen Untersuchung, die einen vorläufigen Abschluß im Jahr 1984 fand (Fortschreibung 1992). Unter Einsatz eines mathematischen Systemmodells wurde auf der Basis von Abflußwochenwerten der Jahresreihe 1930/85, ohne 1945, der Lösungsraum eingegrenzt und in einem schrittweisen interaktiven Abwägungsprozeß eine optimale Bewirtschaftungsstrategie gefunden.

Mit einer mittleren langjährigen Überleitungsmenge über den Kanal von rd. 125 Mio m³ und von rd. 25 Mio m³ aus der oberen Altmühl kann der Regnitzabfluß bei Hüttendorf (nördlich von Nürnberg) auf rd. 27 m³/s im Sommer und rd. 22 m³/s im Winter aufgehöht werden. Die Wirksamkeit der Aufhöhung beträgt damit mengenmäßig etwas über 98 %. Das Wasser der Altmühl wird dabei zu rd. 80 % bei Abflüssen über MQ, vor allem bei Hochwasser entnommen. Die durchschnittliche Entnahme durch die Wasserwirtschaft von rd. 4,7 m³/s entspricht rd. 1,4 % des mittleren jährlichen Donaudargebots am Pegel Kelheimwinzer unterhalb der Altmühlmündung. Der Hauptanteil dieser Entnahme findet im Sommerhalbjahr statt, wenn die Donau üblicherweise höhere Abflüsse führt. Ab Oktober gehen die Pumpmengen spürbar zurück, da verstärkt Wasser aus dem Brombachsee eingesetzt werden kann. Aus Donau und unterer Altmühl wird kein Wasser entnommen, wenn am Pegel Kelheimwinzer ein Donauabfluß von 140 m³/s erreicht oder unterschritten wird. Dieser Abflußwert, der etwa dem langjährigen mittleren Niedrigabfluß MNQ in diesem Donauabschnitt entspricht, wurde zum Schutz der unterhalb liegenden Donauregionen und zur Sicherung ihrer Entwicklungsmöglichkeiten festgeschrieben.

3 Kurzfristbewirtschaftung

Während die Untersuchungen zur Langzeitbewirtschaftung mit Hilfe eines Bilanzierungsmodells für das Gesamtsystem auf einer einheitlichen Datenbasis von Wochenmittelwerten der Abflüsse und Speicherinhalte abgewickelt wurden, müssen bei der Kurzfristbewirtschaftung Modelle herangezogen werden, die hinsichtlich der verwendeten Algorithmen und Zeitintervalle den Hauptzielsetzungen in den Teilbereichen des Überleitungssystems angepaßt sind.

Aufgrund von besonderen Anforderungen im Vorfeld der notwendigen Rechts- und Genehmigungsverfahren bezogen sich bisherige Kurzfristuntersuchungen auf spezielle Teilaspekte und -räume des Gesamtsystems. Zu nennen sind die Themen

- Erarbeitung von Grundlagen für den vorläufigen Betriebsplan des Teilsystems Kanalüberleitung und des Rothsees,
- Abstimmung der Kanalbewirtschaftung mit der Schiffahrtsverwaltung, die für den Pumpbetrieb am Kanal zuständig ist,
- Bereitstellung von Kühlwasser für thermische Kraftwerke an Regnitz und Main in Trockenjahren,
- Voruntersuchungen für eine Niedrigwasservorhersage am Pegel Hüttendorf/Regnitz,
- Hochwasserbewirtschaftung des Altmühlsees,
- Voruntersuchungen für eine Hochwasservorhersage zum Altmühlsee.

Bei den Untersuchungen zur Kanalbewirtschaftung (Pumpbetrieb) für die Kühlwasserbereitstellung und den Vorüberlegungen zur Niedrigwasservorhersage wurden Bilanzierungsmodelle und Regressionsansätze auf Tageswertbasis herangezogen. Die Bearbeitung der Hochwasserthemen verlangte zeitlich höher aufgelöste Modelle im Stundenbereich.

Die logische Verknüpfung von Langzeit- und Kurzfristbewirtschaftung bis hin zum Betriebsplan soll an der zentralen Aufgabe des Überleitungssystems, der Niedrigwasseraufhöhung der Regnitz, exemplarisch verdeutlicht werden. Hierbei muß erreicht werden, daß selbst in trockenen Jahren auch noch in der kritischen Jahreszeit genügend Wasser für die Aufhöhung verfügbar ist und nicht bereits der Brombachsee oder der Rothsee leer sind, wenn noch große Wassermengen zur Niedrigwasseraufhöhung benötigt werden. Eine optimale Bewirtschaftungsstrategie muß bestrebt sein, Speicherwasser für die kritischen Trockenperioden des Jahres im Spätsommer bzw. Herbst zu sparen, weil in dieser Zeit u. U. kein Donauwasser entnommen werden darf. Das dahinterstehende wasserwirtschaftliche Ziel ist, die mit einer Niedrigwasserperiode einhergehenden potentiellen volkswirtschaftlichen Schäden zu minimieren. Wie Abb. 2 verdeutlicht, ist dies der Fall, wenn durch die Bewirtschaftung große Unterschreitungen des Aufhöhungsziels vermieden, statt dessen häufigere oder länger andauernde, aber geringere Abweichungen zugelassen werden.

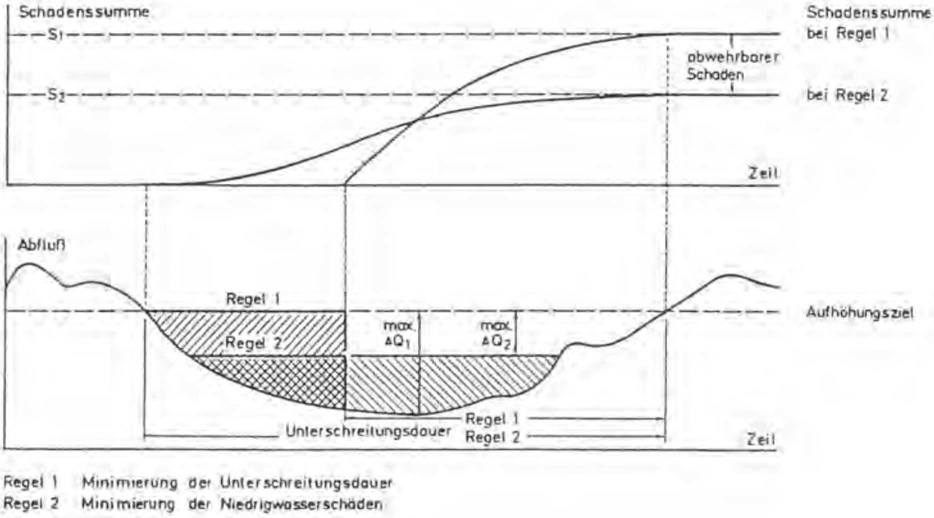

Abb. 2 Qualitativer Zusammenhang zwischen verschiedenen Betriebsregeln zur Niedrigwasseraufhöhung und den nicht verhinderbaren Schäden

Bei der Optimierung unter Langzeitaspekten galt das Ziel, die Summe der quadrierten einseitigen Abweichungen vom angestrebten Aufhöhungsziel (Unterschreitungsmengen) zu minimieren. Zum Vergleich: Die Zielfunktion "Minimierung der Summe der Unterschreitungsmengen" (nicht der Quadrate!) hätte Bewirtschaftungsstrategien mit bestmöglichen Sicherheiten nach Menge, Häufigkeit und Dauer hervorgebracht, jedoch nicht das Schadenspotential minimiert.

Im Rahmen einer Kurzfristbetrachtung läßt sich der Speicherbetrieb weiter optimieren. Dies kann z. B. dadurch geschehen, daß für jedes Zeitintervall eine maximale nicht zu überschreitende Abgabewassermenge festgelegt oder die Abgabe maximal auf einen bestimmten Prozentsatz des Speicherinhaltes begrenzt wird. Eine andere Möglichkeit wäre, für jedes Zeitintervall einen tiefsten Speicherwasserstand zu definieren, der in diesem Intervall nicht unterschritten werden darf.

Für den vorläufigen Betrieb der Kanalüberleitung und des Rothsees wird in Trockenperioden, wenn eine Entnahme aus der Donau nicht möglich ist, die Strategie verfolgt, die Speicherabgaben in Abhängigkeit von bestimmten Seewasserständen stufenweise zu vermindern, um so den erwünschten "Spareffekt" zu erzielen.

Nach der Eröffnung des Main-Donau-Kanals im Herbst 1992 begann die Wasserüberleitung, um den erstmaligen Einstau des Rothsees und die dazu vorgeschriebenen Untersuchungen durchzuführen. Ein mehrjähriger Probebetrieb zur Niedrigwasseraufhöhung der Regnitz soll im Sommer 1994 beginnen.

4 Abflußvorhersage im Teilsystem Altmühl-Brombach-Überleitung

Im Jahr 1986 wurden bereits der Altmühlsee, der Überleiterstollen und die Brombachvorsperre als Teil der künftigen Altmühl-Brombach-Überleitung in Betrieb genommen. Das Teilsystem hat die Aufgabe, im Tal der mittleren Altmühl schadenverursachende Sommerhochwasser weitgehend zu verhindern und das zurückgehaltene Hochwasser dem Brombachsee zuzuleiten, von wo es gezielt zur Niedrigwasseraufhöhung der Regnitz abgegeben wird.

Für die Bewirtschaftung des Altmühlsees ist es daher von zentraler Bedeutung, frühzeitig Kenntnis über die künftigen Zuflüsse zum Speicher zu erhalten. Die gestellte Aufgabe läßt sich mit mathematischen Modellen, z. B. auf der Basis einer multiplen linearen Regressionsanalyse, auf der Basis einer Mehrkanalfilterung oder einer multiplen Frequenz-Response-Analyse lösen. Die Wahl fiel auf das Verfahren der Mehrkanalfilterung nach Wiener, das von der Bundesanstalt für Gewässerkunde in Koblenz bereits seit mehr als 10 Jahren zur kurzfristigen Wasserstandsvorhersage an 16 Rheinpegeln zwischen Speyer und Emmerich verwendet wird.

Im vorliegenden Fall bestand die Aufgabe darin, den Seezufluß für den Zeitraum der nächsten 12 Stunden unter Verwendung momentaner Wasserstände und Abflüsse vorherzusagen.

4.1 Grundlagen

Das Wiener-Mehrkanalfilter gehört wie das Einheitsganglinienverfahren zum Typ der hydrologischen Blockmodelle, bei denen der funktionelle Zusammenhang zwischen Eingangs- und Ausgangsgrößen empirisch aus vorliegenden Beobachtungen abgeleitet wird, ohne dabei die physikalischen Prozeße im Einzugsgebiet näher zu berücksichtigen. Die Stationarität der Zeitreihen wird dabei vorausgesetzt.

Beim Wiener-Filter wird das hydrologische System, z. B. das Einzugsgebiet oder ein Gewässerabschnitt, im mathematischen Sinn als lineares zeitinvariantes Filter angesehen, d. h. allgemein als Übertragungssystem, das eine gegebene diskrete Eingangsfunktion in eine gewünschte Ausgangsfunktion überführt.

Die System- oder Filtereingänge können Wasserstände oder Abflüsse an Pegeln des Hauptflusses und/oder an Nebenflüssen sowie Niederschläge und weitere quantitative hydrologische Variablen sein, daher "Mehrkanalfilter". Die Eingänge werden beim zeitlichen Durchgang durch je ein Filter (Übertragungsfunktion) einzeln so verändert (gewichtet), daß ihre anschließende zeitgerechte Überlagerung oder Superponierung den Filterausgang ergibt.

Die Besonderheit des Wiener-Filters liegt darin, daß die Übertragungsfunktionen ausschließlich aus abgeschätzten Kovarianzen, d. h. nicht normierten linearen Korrelationen zwischen den einzelnen Eingängen sowohl untereinander als auch jeweils mit dem Ausgang berechnet werden, also aus den

- Autokovarianzen der einzelnen Eingänge,
- den paarweisen Kreuzkovarianzen der Eingänge (z. B. den Kreuzkovarianzen des 1. Eingangs mit dem 2. Eingang und des 2. Eingangs mit dem 1. Eingang) sowie
- den Kreuzkovarianzen des Ausgangs mit den einzelnen Eingängen.

Ein Vorhersagefilter erhält man, wenn die Eingänge nicht auf den zeitgleich beobachteten Ausgang, sondern auf den um das Vorhersagezeitintervall verzögerten Ausgang bezogen werden. Die bis zum Vorhersagezeitpunkt vorliegenden Wasserstände oder Abflüsse am Vorhersagepegel können ebenfalls als Eingang benutzt werden, wodurch die sog. Erhaltungsneigung des Ausgangs (autoregressiver Anteil) mit berücksichtigt wird (Wilke, 1984).

4.2 Erstellung des Vorhersagemodells

Zur Berechnung der Übertragungsfunktion standen mittlere stündliche Wasserstände aus den Abflußjahren 1970 - 1983 an den Pegeln Altmühl, Binzwangen, Thann, Ornbau und dem Pegel Bechhofen an der Wieseth, einem rechtsseitigen Altmühlzufluß zur Verfügung (s. auch Abb. 1). Desweitern konnte auf stündliche Niederschlagssummen an 6 Niederschlagsmeßstellen für die Sommerhalbjahre 1978 - 1983 zurückgegriffen werden.

Ausgehend von dieser Datenbasis wurde eine Vielzahl von Übertragungsfunktionen (Operatoren) berechnet und getestet. Zur Verwendung kamen Daten eines gesamten Abflußjahres, mehrer aneinandergereihter Abflußjahre, nur von Sommerhalbjahren und nur von Winterhalbjahren. Die Zahl der Daten einer Meßreihe variierte dabei zwischen mehreren 100 bis zu 30 000.

Der grundsätzliche Arbeitsablauf läßt sich am Beispiel einer Berechnung mit 6stündlichen Wasserstandswerten eines Abflußjahres wie folgt beschreiben:

- Extraktion jedes 6. Stundenmittelwerts aus der Wasserstandsreihe eines Jahres; ergibt 1460 Wasserstandswerte pro Jahr,
- Ermittlung von 6stündlichen Wasserstandsdifferenzen (1459 Werte),
- Berechnung von Übertragungsfunktionen für unterschiedliche Kombinationen von Eingangs- und Ausgangspegel,
- Anwendung jeder Übertragungsfunktion auf alle nicht im Berechnungsintervall verwendeten Daten, d.h. Durchführung von Vorhersageberechnungen,
- Vergleich der vorhergesagten Werte mit den Meßwerten im Vorhersageintervall und Prüfung der Vorhersagequalität.

Die Bewertung der Güte der Vorhersagen erfolgte nicht nur nach statistischen Methoden, die aufgrund ihrer integralen Angaben hier keine genügende Trennschärfe bieten, sondern nach individueller Einschätzung der Differenzen aus Messung und Vorhersagen in der Umgebung der errechneten Hochwasser-Scheitel. Auf diese Weise wurden die Ergebnisse von mehr als 1000 Programmläufen untereinander verglichen. Aus den umfangreichen Berechnungen lassen sich folgende Schlüsse ziehen:

- Der Aufwand zur Ermittlung und Auswahl der Übertragungsfunktionen für das Mehrkanalfilter ist erheblich, das fertige Modell jedoch sehr leicht zu handhaben. Vorhersageberechnungen können auch unter Nutzung von Standardprogrammen zur Tabellenkalkulation oder notfalls sogar auf einem nichtprogrammierbaren Taschenrechner durchgeführt werden.
- Mit Abflüssen anstelle von Wasserständen als Eingangsdaten können im Mittel bessere Ergebnisse erreicht werden. Dies wird darauf zurückgeführt, daß mit den Abflußdaten eine höhere Linearität in den Parametern der Übertragungsfunktionen einhergeht. Wenn man berücksichtigt, daß z. B. am Pegel Ornbau einer betragsmäßig gleichen Wasserstandsdifferenz im Niedrigwasserbereich eine Abflußänderung von weniger als 1 m^3/s, im Hochwasserbereich jedoch eine um mehr als den Faktor 10 höhere Abflußänderung entspricht, dann wird dies verständlich.

Die Einbeziehung von Niederschlägen brachte nur geringfügig bessere Ergebnisse. Zugunsten eines einfacheren Vorhersagemodells wurde auf die Hinzunahme von Niederschlagsinformationen deswegen vorerst verzichtet.
Längere und unmittelbar vorausgegangene Meßreihen zur Eichung der Modellparameter können zu besseren Ergebnissen als kürzere und weiter zurückliegende führen. Für den operationellen Einsatz des Modells kann es daher von Vorteil sein, die Modellparameter in gewissen Zeitabständen an Hand beobachteter Daten von einem oder mehreren zurückliegenden Jahren neu zu ermitteln.
Die größten Abweichungen zwischen Beobachtung und Berechnung am Pegel Ornbau treten unmittelbar zu Beginn von Hochwasserereignissen auf, u. a. da Niederschläge, die innerhalb des Vorhersagezeitraums abflußwirksam werden, vom Modell nicht erfaßt werden können. Im ansteigenden Ast der Hochwasserwelle gehen die Abweichungen bereits wieder deutlich zurück. Die Differenzen liegen meist unter 5%.

4.3 Operationeller Einsatz

Die genannten Pegel Bechhofen, Binzwangen, Thann und Ornbau verfügen seit Ende der 80er Jahre über Anschlüsse zum automatisierten gewässerkundlichen Meßnetz der bayerischen Wasserwirtschaftsverwaltung, das eine jederzeitige Fernabfrage und Übertragung der Wasserstände in die Betriebszentrale des Überleitungssystems ermöglicht.

Der Pegel Ornbau, kurz oberhalb des Altmühlsees gelegen, hat bis zum Jahr 1984 den gesamten Altmühlabfluß erfaßt. Seit 1985 wird bereits oberhalb dieses Pegelstandortes, am "Schöpfkopf Ornbau", der größte Teil des Altmühlabflusses bei Hochwasser über ein neu geschaffenes Gerinne in den Altmühlsee eingeleitet (HQ_{100} = 150 m^3/s). In der alten Altmühl verbleibt nur ein ökologisch notwendiger Abfluß, der bei seltenen Hochwasserereignissen ca. 15 - 17 m^3/s beträgt.

Zu Beginn einer Vorhersageberechnung müssen die momentanen Wasserstände der Pegel Bechhofen, Binzwangen und Thann und die Abflüsse am Schöpfkopf abgerufen und dem Rechenmodell übergeben werden. Das Programm rechnet aus den Wasserständen mittels der Abflußtafeln die zur Vorhersage erforderlichen Abflüsse aus. Filtereingänge sind 3stündliche Abflußdifferenzen der genannten 3 Pegel sowie der Abfluß am Schöpfkopf Ornbau, der den Pegel Ornbau bezüglich des gesamten Speicherzuflusses ersetzt. Vorhersagegröße ist die Abflußdifferenz am Schöpfkopf; für den Benutzer wird der Abfluß direkt ausgegeben. Entsprechend der Anzahl von 12 Koeffizienten einer Übertragungsfunktion werden für jede Eingangsgröße zu Beginn der Vorhersageberechnung 12 vorhergehende 3stündliche Abflußänderungen benötigt. Im Mittel- und Niedrigwasserbereich genügt es, die Vorhersagen z.B. 2mal täglich zu berechnen; im Hochwasserfall sollen sie stündlich für den Zeitraum der nächsten 3, 6, 9 und 12 Stunden erfolgen.

Im Dezember 1993 wurde das Vorhersagemodell erstmals im Hochwasserfall on-line eingesetzt. Bei diesem Hochwasserereignis handeltees sich an der oberen Altmühl um das höchste im Beobachtungszeitraum (für Pegel Thann etwa 30 Jahre). Abbildung 3 zeigt die Bildschirmmaske für die Eingabe, und zwar die ausgefüllte Maske zum Zeitpunkt 21.12.1993, 12.00 Uhr, die zugehörige Vorhersagetabelle für 15, 18, 21 und 24.00 Uhr, sowie zum Vergleich die Abflußganglinie mit den Vorhersagewerten am Schöpfkopf Ornbau (in der Abb. mit Ornbau 2 bezeichnet).

Die Vorhersage ist derzeit aus mehreren Gründen noch mit Fehlern behaftet, die erzielbare Qualität "on-line" daher noch nicht wertbar:

Für den Gesamtabfluß am Querschnitt Schöpfkopf Ornbau müssen derzeit geschätzte Werte eingegeben werden, da der geplante Ultraschallpegel zur "on-line"-Erfassung des Abflußanteils, der direkt in den See eingeleitet wird, noch nicht errichtet ist. Nur der Teilabfluß der "Restaltmühl" wird on-line übertragen.

Aufgrund der gewählten Modellstruktur ist eine möglichst genaue Bestimmung der Abflüsse an dieser Stelle unerläßlich. Hilfsweise kann der aktuelle Zufluß zum See nur indirekt über eine Bilanzierung des Seevolumens aus den Seespiegeländerungen und den Ableitungen aus dem See ermitteltwerden, wobei letztere allerdings an mehreren Punkten zu erfassen sind. Zudem dürften bei dem relativflachen und großen See die Einflüsse der Seeretention und des Windstaus von erheblicher Bedeutung sein.

EINGABEMASKE

Dimensionen: Zeile 1 mit 3 (BI, BE, TH) in m, Zeile 4 (SO) in cbm/s

Spalte	1	2	3	4	5	6	7	8	9	10	11	12	13
Datum	19 12 1993										21 12 1993		
Zeit	24	3	6	9	12	15	18	21	24	3	6	9	12
1 BI	40	43	61	88	104	119	126	123	128	156	153	139	126
2 BE	44	46	50	61	66	77	131	141	143	148	152	150	145
3 TH	233	231	234	242	249	256	265	274	281	299	311	315	323
4 SO	14.4	14.2	14.9	17.8	22.0	26.5	32.8	42.7	61.2	99.5	131.0	141.0	148.0

```
1 = Letzter Wert 4 = Einzeln          7 = Speichern
2 = Zeile        5 = Spalten versch.  8 = Vorhersage
3 = Spalte       6 = Tage versch.     9 = ASCII
Wahl (10 = Ende):
   1(024,019)
```

VORHERSAGE

Datum	Uhr-Zeit	Gemessener Abfluss	Vorhergesagte Abfluesse am Schoepfkopf Ornbau 3Std.	6Std.	9Std.	12Std.
20 12 1993	21	42.7	35.2	30.4	26.0	21.5
20 12 1993	24	61.2	47.0	39.0	32.6	27.1
21 12 1993	3	99.5	66.8	50.9	43.0	34.5
21 12 1993	6	131.0	108.5	71.7	54.2	47.3
21 12 1993	9	141.0	142.3	117.6	76.3	56.7
21 12 1993	12	148.0	148.1	150.1	122.6	79.5
21 12 1993	15		153.8	155.5	158.2	126.9
21 12 1993	18			159.0	163.0	163.5
21 12 1993	21				160.8	170.8
21 12 1993	24					163.1

```
Return = Zurueck zur Eingabemaske...
   1(024,037)
```

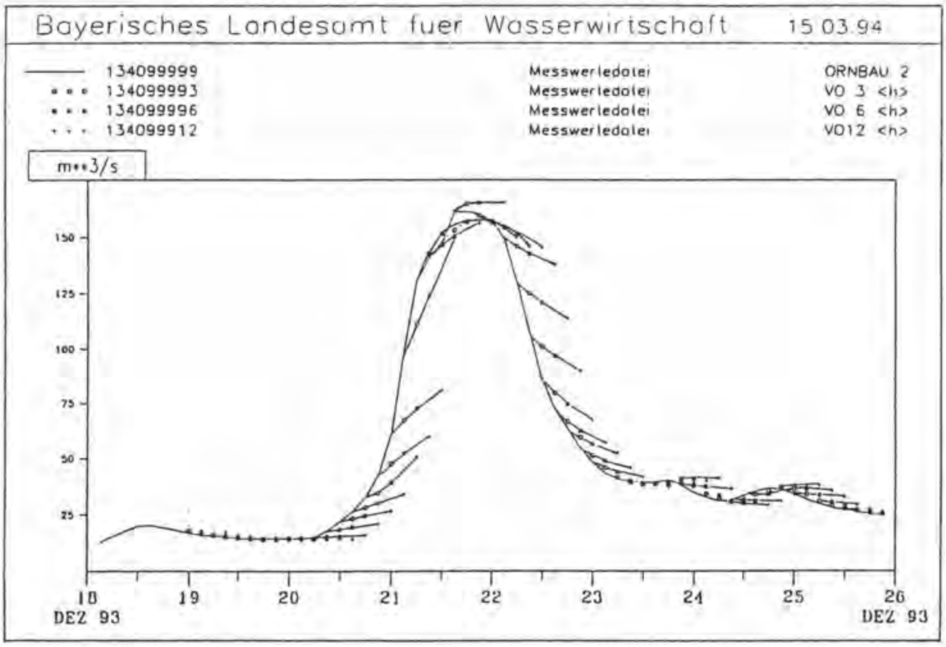

Abb. 3 Eingabemaske, Ergebnistabelle und Abflußganglinie mit Vorhersagewerten

Durch dieses Hochwasserereignis werden die im Modell benötigten Wasserstands-Abfluß-Beziehungen an allen Pegeln im oberen Bereich besser als bisher abgesichert und tragen in Verbindung mit einer Nacheichung - wie vorne erwähnt - zu einer Stabilisierung der Vorhersagen bei.

5 Ausblick

Die anstehenden Untersuchungen zur Kurzfristbewirtschaftung dienen primär dem Ziel, bis zur Inbetriebnahme des gesamten Überleitungssystem weitere Entscheidungshilfen für den endgültigen Betriebsplan und die Steuerung im Echtzeitbetrieb bereitzustellen. Die hierbei noch zu gewinnenden Erkenntnisse können dazu führen, die Langzeitbewirtschaftung zu überprüfen und deren Strategien fortzuschreiben.

In der nächsten Arbeitsphase bilden folgende Themen den Entwicklungsschwerpunkt

- Erstellung einer Abflußvorhersage für den maßgebenden Pegel Hüttendorf/Regnitz unter Einschluß der Speicherabgaben aus Roth- und Brombachsee; ein besonderes Problem bilden hierbei kurzfristige Hochwasser aus sommerlichen Starkregen, die innerhalb der Laufzeit einer Abgabewelle vom Speicher bis zum Kontrollquerschnitt auftreten können.
- Erarbeitung einer mehrtägigen Niedrigwasservorhersage für die Donau im Bereich Kelheim, um die Entnahmestrategie der Kanalüberleitung auf den Verlauf einer Niedrigwasserperiode und den Eintritt des Entnahmegrenzwertes hin zu verbessern.
- Prognostizieren des voraussichtlichen Pumpbedarfs in Abhängigkeit von einer mehrtägigen Abflußvorhersage der Regnitz, um den Pumpeinsatz und damit den Energie- und Kostenaufwand zu optimieren.

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PERIODICITY AS A MAIN COMPONENT OF HYDROLOGICAL PROCESSES (ANALYSIS AND FORECASTING)

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SUMMARY: The hydrological processes are generated by the impact of a number of elements of accidences. It has been established that the various geophysiscal processes are time developed under the influence of both external and internal causes, which form the causuality sequential relationships. It proved that the correlation function of a cyclic process is periodic and depends on the lag of correlation. A proper statistical model for long term river discharge forecasting in real time has been developed.

DER ZYKLUS - EINE HAUPTKOMPONENTE IN DEN STATISTISCHEN MODELLE FUER FLUSSABFLUSSVORHERSAGE

KURZFASSUNG: Es wird den existierten Zyklus in den Naturvorgaengen untersucht. Es ist festgestellt, dass die Entwicklung der geophysikalischen Vorgaenge, einschliesslich des Flussabflusses, von den inneren und aeusseren Ursachen bewirkt wird. Es wird behauptet, dass die Korrelationsfunktion des Zyklus auch eine Zyklo - Daempfungsfunktion ist. Deswegen ist die Vorhersage des Flussabflusses durch die festgestellten Innerreihenverbindungen moeglich.

River flow processes are considered as a stochasic processes, determined by diversity of natural flow formatting factors. Their mutual interchanges when most of the links are hidden and they don't have visual appearance, stipulate its probability character.

Until recently in hydrology it was accepted as possible to reveal the simple causality in the course of formation of a range of a number of natural processes. It turned out that the preconditions for a simple causality do not conform to the existing causality in nature. The last should be regarded as a result of multistep forming of natural processes when the number of so called accidental elements are increasing rapidly (Алехин 1969, Анисимов 1955).

By the term multistep of natural phenomenon formation one should consider the acting causes of every process having their own causes going on the same logic. Thus one should reach prafactors, standing on endles formation stages. In the process of interactions of the corresponding causes arise undetermined interceptions of relationships, which lead to appearance of uncontrolled accidental elements. They are such a phenomenon which can't be defined by a given low. They are results of coincidences and mutual interceptions of the actions of a range of causalities.

2. EXTERNAL INFLUENCES AND INTERNAL CAUSALITY.

In the last decades, in hydrology a specific popularity gained the point of view that the influence of all external causes is coded when the development of the investigated process is concerned. It provokes its internal causality development. This internal causality, invoke development of the process in time and probably is determined by the inertia and the multistep formation of river flow.

On the base of expressed internal causality, the values of the investigated process for the previous moments represent, indicators for future development of the process. That is why the internal causality should be regarded as a sign of the external cause. Internal causality in the development of the natural processes have served as a base for development of the contemporary stochastic methods and models and for their forecasting (Kolmogorov, Box & Jerkins, etc.).

Now, when talking about causality one should have in mind not only the isolated influences but first of all the natural conditioned run and development of the objective existing probabilities by its essence processes.

The development of the separate natural processes in time is determined on the base of the equation:

$$G_t = \sum_{s=1}^{u} f_s(E_{s,t}) + \sum_{s=1}^{z} f_s(I_{s,t}) + \Theta(t), \qquad (1)$$

i.e. under the influence of external $E_{s,t}$ and internal $I_{s,t}$ causes which are transferred by probability cause and effect connections during the process formation. The third term Θ (t) is the general influence of the so called the residual element of the accident:

$$\Theta(t) = \sum_{i=0}^{v} \sum_{j=0}^{k_i} \Theta'_{i,j}, \qquad (2)$$

where v is the number of the medial degree of formation and k_i - the number of the elements of accident of every i degree of formation.

By introduction of the accident criteria δ the general indefiniteness of the investigated process with regard to the external and internal causes can be evaluated, i.e.

$$\delta = D_\theta / D, \qquad (3)$$

where D_θ and D are correspondingly the accident component, revealing under the influence of the accident elements and dispersion of the range G_t.

At $D = 0$, $\delta = 0$, $\Theta(t) =$ constant the influence of the external and internal causes simply determine the process G_t. Taking into account probable nature of the process G_t and probable character of the hydrological processes in general - this situation is in principle impossible.

At $D_\theta = 0$, $\delta = 1$, $G_t = \Theta(t) = 0$ - the influence of the external and internal causes do not reveal. In this case the development of the process in time is completely determined by the influence of the accidental elements. The forecasting of a similar process is in general absurd.

It proved that the whole class of natural processes get into the values range between $\delta = 0$ and $\delta = 1$.

One should have in mind that the accidental criteria of every process depends first of all on the causes included. That is why as longer the time period between the causes and their effects is (i.e. as bigger the number of the intermediate stages in process formation) as bigger the accident criteria regarding this causes is and vice versa.

3. ACCIDENTAL ELEMENTS - FLOW FLUCTUATIONS

It is necessary the hypotheses that all geophysical processes are developed under the influence of statistical and dynamic regularity to be introduced i.e. under the influence of a big number of accidental elements. Their resultant should pulsate in time, which means it is subjected to fluctuations, which have a cyclic character. From here it comes out the nature of the statement that the time series which describe the evolution of a natural processes should be cyclic with comparatively short periodic fading correlation functions. The investigations in this field proved that the cyclic recurrence and rhythm appears as universal characteristic feature of the natural processes. Moreover the presence of cyclic recurrence in anyone process determine cyclic modification of its correlation function. Let's suppose that a given cyclic variation process

$$\xi(t) = \alpha \cos \lambda t + \varkappa \sin \lambda t, \qquad (4)$$

satisfying the condition

$$M\,\alpha\varkappa = 0, \quad M\,\alpha^2 = M\,\varkappa^2 = b, \qquad (5)$$

where M is a symbol of the arithmetic mean.

Than the correlation function of this process have the following description:

$$R(\tau) = \frac{1}{\sigma^2} M \left| \xi(t) + \xi(t-\tau) \right|, \qquad (6)$$

where σ is the dispersion of the series $\xi(t)$.

Setting (4) in (6) it come out:

$$R(\tau) = \frac{1}{\sigma^2} M \Big| [\alpha \cos \lambda t + \varkappa \sin \lambda t] \,.$$

$$[\alpha \cos \lambda(t-\tau) + \varkappa \sin \lambda(t-\tau)] \Big| =$$

$$= M\,\{\alpha^2 \cos \lambda t \cos \lambda(t-\tau) + \alpha\varkappa\,[\cos \lambda t \sin \lambda(t-\tau) +$$

$$+ \sin \lambda t \cos \lambda(t-\tau)] + \varkappa^2 \sin \lambda t \sin \lambda(t-\tau)\} =$$

$$= b\,[\cos \lambda t \cos \lambda(t-\tau) + \sin \lambda t \sin \lambda(t-\tau)] =$$

$$= b \cos \lambda t, \qquad (7)$$

i.e the correlation function of the cyclic modifying process should be cyclic too. Increasing the number of summing sequences (4), the expressiveness and cyclic recurrence should increase in order with the stability and internal correlation by the low:

$$R(\tau) = \sum_{\mu=1}^{n} b_{\mu} \cos \lambda t. \qquad (8)$$

That is why every process which is constituted by n elements of an accident should be cyclic and beside this to have internal correlation.

The whole variety of correlation function of the natural processes schematically can be approximated by three equation types given on Figure 1.

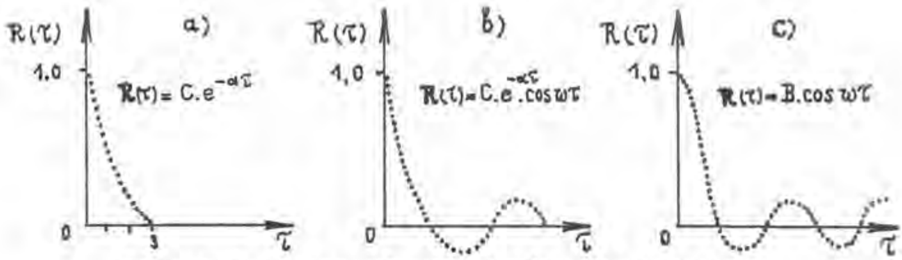

Figure 1. Types of correlation functions.

The first of them (a) is an asymptote, the second (b) - an asymptote with imposed harmonic, and the third (c) by B = constant - a not fading harmonic. The first two equations are applied for description of correlation function of the processes from the type of a simple Marcovian chains. These are the fluctuation processes (wind speed and flow in a given point), the broad class of processes in ecosystems, radio systems and in general all processes, entering in the concept stationary accidental functions. The correlation functions of this processes differ from each other, especially by the inclination and fall of their asymptotes, but have a characteristic feature - a limited range of delay. The third of this equations proved to be most suitable for description of correlation functions of a broad class of natural processes and especially for the river flow. In contrast to the other two (a) and (b), the correlation function of this type differ by unlimited range of delay.

This allow increasing the number of terms which will be included in a forecast equation, use of an optimal volume of process prehistory, which contribute to increase forecast precision.

Taking account of (8) every process G_t formed by a multitude of accidental elements should be cyclic and have internal correlation. This gives a reason for obtaining information for presence of feed-back in the process, of the type:

$$G_{t+p} = f (G_t , G_{t-1} , G_{t-2} , \ldots , G_{t-n}) \qquad (9)$$

owing to which every next value is like fated (with probability P < 1) by a range of quantities in its prehistory. To this effect are the existing dynamic and statistical regularities, which are inherent characteristics of the investigated process.

Actually this is a prerequisite for transition to studding of internal reasons in the processes - derivative from their external causes. Therefore it is accepted as a fact that the whole multitude of the external causes in their diversity of accidental combinations are coded in the values of the natural processes. Therefore the interaction of the external causes, their internal manifestation and development of internal causes of the investigated process give reason to forecast its future values on the base of determined inter range structural connections (specific for every process) of the runoff Q(t) by the equation:

$$Q_{t+m-1} = - \sum_{\tau=1}^{\tau_{max}} K_m (\tau) \, Q(t - \tau) , \qquad (10)$$

where $K_m(\tau)$ is the function of the optimal inter range connections, computed for a set forecasting terms; τ_{max} - the maximum set delay of the correlation function.

The utilization of the suggested approach reveal possibilities for investigation and optimal forecasting of a broad class of geophysical processes including the river runoff.

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ANALYSIS AND LONG-RANGE FORECASTING OF WATER STAGES OF THE DANUBE RIVER AND NAVIGABLE TRIBUTARIES

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ABSTRACT

The analysis of stochastic characteristics of annual mean, minimum and maximum water stages is carried out on the basis of long-range forecasting of water stages on the Danube river and its main tributaries. A mathematical model has been established. For trend, periodic, and stochastic components the variance for the complex model has been determined. The problem has been solved by decomposition on deterministic and stochastic components. An analysis of existence and influences of each particular component has been done for each cross-section and for all variables. General conclusion referring to the applications of the model, as well as its predictive accurracy have been drawn.

ANALYSEN UND LANGFRISTIGE VORHERSAGUNGEN DES WASSERSTANDES DER DONAU UND DER BEFAHRBAREN ZUFLÜSSE

KURZFASSUNG

Auf Grund langfristigen Beobachtungen des Profils der Donau und der wichtigsten Zuflüsse in Jugoslawien, wurden Analysen der jährlichen stochastischen karakteristiken des durchschnittlichen, maximalen und minimalen Wasserstandes gemacht. Für jede Serie wurde die Dekomposition für die deterministischen und stochastischen Komponent gemacht, um das mathematische Model für das Komponent des Trendwertes, des periodischen Wertes und des stochastischen Wertes festzustellen. Für jedes Profil und jede Veränderlich keit wurde eine Analyse des Bestehens und des Einflusses der Komponenten gemacht. Allgemeine Schlussfolgerungen auf Hinsicht der Möglichkeit, diesen Typ des Modeles zur Prognose zu benutzen, wurde gezogen, so wie die Genauigkeit die man bei der Voaussagungerwarten kann.

INTRODUCTION

It is very important to analyse changes in long-range hydrological series for various purposes: inland navigation on large rivers, design of water intakes on small rivers, plans for flood protection measures, etc.

Previous analyses showed the existence of variations of long-range hydrological values on the river Danube and its tributaries [3]. The reference [3] presents some examples of maximum water stage variations which have occurred as a consequence of river regulation. We tried to model, in more detail, all components of series for profiles on the river Danube and the tributaries of navigable rivers with a view to indicate the existence of variation regularity and to quantify influence of particular components.

DATA AND METHODOLOGY

Annual data of minimum, mean and maximum observed water levels, expressed as absolute elevation above Adriatic sea level, has been considered for four profiles of river Danube and two profiles of its tributaries (river Tisza and river Sava). Table 1. gives the locations of analyzed profiles, periods of observation and basic statistic characteristics of the series.

Table 1. BASIC CHARACTERISTICS OF OBSERVED DATA

River	No	gauging station	distance	period of observation		sample size	average	variance	standard deviation	coeff. of variation
DANUBE	1.	BEZDAN	1425.5	1876-1990	min	115	81.39	0.690	0.831	1.021
					mean	115	83.54	0.637	0.798	0.955
					max	115	86.31	0.641	0.800	0.927
DANUBE	2.	BOGOJEVO	1367.4	1890-1990	min	101	78.35	0.396	0.629	0.803
					mean	101	80.49	0.437	0.661	0.821
					max	101	83.20	0.787	0.887	1.066
DANUBE	3.	PANCEVO	1153.3	1876-1989	min	114	67.63	0.643	0.802	1.186
					mean	114	69.97	0.499	0.707	1.010
					max	114	72.82	1.007	1.004	1.378
DANUBE	4.	GRADISTE	1059.8	1926-1989	min	64	64.52	4.032	2.008	3.112
					mean	64	66.59	2.760	1.661	2.495
					max	64	69.11	1.203	1.097	1.587
TISA	5.	SENTA	122.0	1923-1990	min	68	72.37	1.653	1.286	1.777
					mean	68	74.99	1.060	1.030	1.373
					max	68	79.01	1.542	1.242	1.572
SAVA	6.	MITROVICA	136.0	1920-1987	min	68	72.85	0.112	0.335	0.460
					mean	68	75.28	0.288	0.536	0.712
					max	68	78.86	0.385	0.620	0.787

For investigation of time-dependent hydrological series, in addition to the basic statistics (averages,variances, etc.), it is necessary to establish parameters of the internal structure of stochastic processes (autocorrelation function-ACF, partial autocorrelation function-PACF, periodogram). Analyses can be performed in the time domain or in the frequency domain. In this paper a combined approach is applied, i.e., the periodical component has been analyzed in the frequency domain, while all other components have been treated in the time domain.

In principle, the mathematic modelling of any time dependent series, can be accomplished in two ways:

(i) by decomposing complex stochastic phenomenon on basic

components, and choosing an adequate model for each one of them, or

(ii) by integral modelling of a complex process with a priori adopting a certain model type, and optimizing its complexity. In either case, is necessary to consider the standard procedure of the model, development, which includes identification, calibration and verification.

Each one of the two approaches has its advantages and disadvantages. For instance, if the second approach is chosen, the final solution is obtained faster, but there is no insight into the influence of some components which could have physical interpretation (trend and periodicity).

In this paper, the first of the two approaches has been used, because the decomposition of a complex stochastic process on basic deterministic and stochastic components, enables quantification of the importance of each component and gives the information about the influence of each component in the complex model.

A hypothesis has been made that the annual water elevations series are complex, stochastic time dependent series, that may generally include deterministic components:

trend and periodicity, and stochastic components such as: the random component and outlayers. In the analyzed series no outlayers are present, so analysis is reduced to the three components, assuming that the series are stationary and ergodic. Sometimes, for the sake of easier detection of some components, the removal of mean values from hydrological series is done.

The procedure includes the following steps [6]:

a) presentation of characteristics of the considered series (graphic presentation of series,basic stochastic characteristics);

b)modelling of a component (choice of model type,calibration,verification);

c)forming of new series (by removing component for which the model is determined) and back to step a);

d)when modelling of each component is completed, an integral model is established and analyzed by comparing modelled and observed values and/or by residual analysis.

Steps a) to c) are repeated with sequential removing of the following components: the mean value, trend, periodicity and stochastic component.

The previous analysis in ref.[3] has shown the linear trend is applicable. Calibration has been done by the least squares method.Periodical component is modelled by the Fourier's transforms [5]. The significance of the various harmonics are tested using Ficher's "g" statistics [2]. The random component is modelled by a general ARIMA (p,d,q) model. The order of the ARIMA model is chosen by ACF and PACF [1].Verification is done with the "Portmanteau" test. In a detailed study [4], alternative models are compared, as well as the influence of overestimation.

For final models of complex series, the percentages of explained variations for each one component are calculated, and a quality of final complex model is analyzed with residual characteristics.

RESULTS

According to the described procedure. the values of the minimum, mean and maximum water levels have been analyzed independently. The complete overview is given in ref. [4].

As an illustration of the applied procedure, the results for the minimum water level stages on the location Bezdan of the river Danube (km 1425.5)are shown in Fig.1.

A summary for all analyzed profiles and for all characteristic water levels is given in Table 2. A definite residual distribution after removing all existing components is also presented in the same table.

CONCLUSIONS

Results of stochastic analyses have shown that a linear trend component exists on all profiles and for all characteristic water stages,except for minimum stages on river Sava (profile No.6, see table 2.).For the same profile, the existence of the periodical component for the minimum and the maximum stages is not detected. The periodical component appears on all other profiles for the minimum and the mean water levels, except for the profile No.2. on river Danube.

The periodical component for the maximum water levels is detected only on profile No.4. on river Danube. The number of important harmonics varies from one to three. The random component exists for the minimum and the mean water levels in all cases (except for profile No.6.), and for the maximum levels only in one case (profile No.4..river Danube). It is shown that (if existing) the random component can be simulated with the AR(1) or MA(1) models. The residuals in all cases have characteristics of "white noise", which means that the complex models are adequately chosen.

The length and homogenity of the time-series data are crucial for the quality of results.

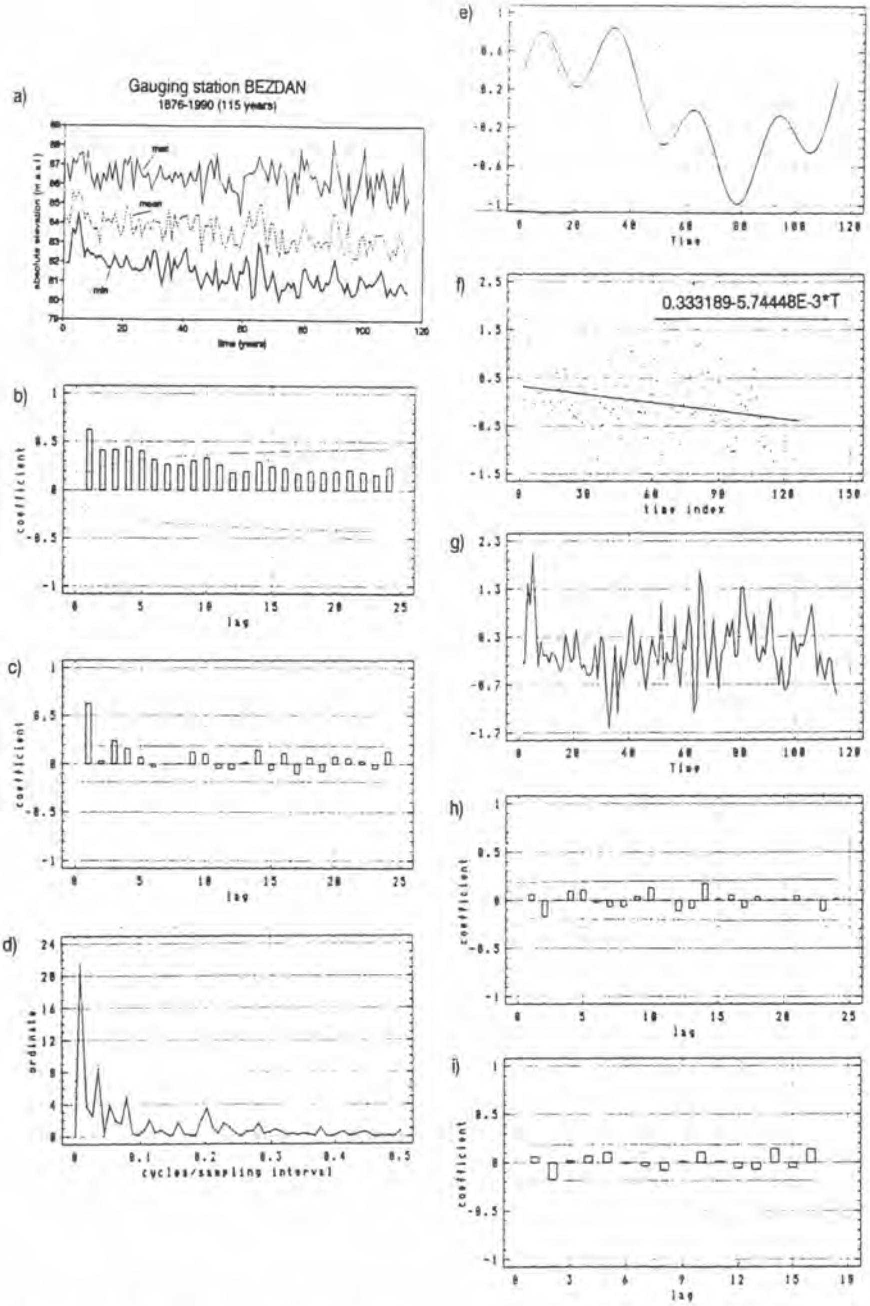

Fig.1.CHARACTERISTIC DIAGRAMS FOR MIN. LEVELS ON THE GAUGING STATION NO.1.

a) the original series, b)original series ACF, c)original series PACF, d) original series periodogram, e)periodical component, f)trend, g)random component, h)ACF of residuals and i) PACF of residuals.

Table 2.MODEL CHARACTERISTICS FOR WATER LEVEL SERIES

St. No.	Mean value	Linear trend Yes/No	Linear trend Pos./Neg.	Periodic component Yes/No	Periodic component No.of harm.	Random comp. Yes/No	Random comp. Type	Residual distribution
/a/ minimum water stages								
1	81.39	Y	N	Y	2	Y	AR(1)	N(0;0.34)
2	78.35	Y	N	Y	1	Y	MA(1)	N(0;0.28)
3*	67.63	Y	P	Y	2	Y	AR(1)	N(0;0.39)
4*	64.52	Y	P	Y	2	Y	AR(1)	N(0;0.56)
5*	72.37	Y	P	Y	3	Y	MA(1)	N(0;0.31)
6	72.85	N	-	N	-	N	-	N(0;0.11)
/b/ mean water stages								
1	83.54	Y	N	Y	2	Y	AR(1)	N(0;0.43)
2	80.49	Y	N	N	-	Y	MA(1)	N(0;0.38)
3	69.97	Y	P	Y	1	Y	AR(1)	N(0;0.42)
4*	66.59	Y	P	Y	3	Y	MA(1)	N(0;0.50)
5*	74.99	Y	P	Y	2	Y	MA(1)	N(0;0.73)
6	75.28	Y	N	Y	2	Y	AR(1)	N(0;0.18)
/c/ maximum water stages								
1	86.31	Y	N	N	-	N	-	N(0;0.59)
2	83.20	Y	N	N	-	N	-	N(0;0.78)
3*	72.82	Y	P	N	-	N	-	N(0;1.20)
4*	69.11	Y	P	Y	2	Y	AR(1)	N(0;0.97)
5*	79.01	Y	P	N	-	N	-	N(0;0.54)
6	78.86	Y	N	N	-	-	-	N(0;0.38)

note (*): cross-sections under back water influence

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XVII. KONFERENZ DER DONAULÄNDER
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LONG TERM PREDICTION OF THE HYDROLOGIC REGIME OF THE DANUBE

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Abstract: The impact of different operation rules of the Gabčíkovo diversion type hydro-power station on the runoff regime of the River Danube and the energy production of the power station has been studied. A methodology for the simulation of the system operation with a daily time step using mathematical models has been developed. Eighty five years of the system operation using mean daily discharge data from the period 1901-1985 were simulated. The long term influence of the system operation on the changes of the basic statistical characteristics of the discharge regime has been evaluated. Electric energy production of the power plant has been predicted with a daily time step. The effects of the system operating scenarios on the energy production were studied.

LANGZEITVORHERSAGE DER ENTWICKLUNG DES HYDROLOGISCHEN REGIMES DER DONAU

Kurzfassung: Der Einfluss von verschiedenen Betriebsplänen des Wasserkraftwerks Gabčíkovo auf die zukünftige Entwicklung des Abflussregimes der Donau wurde untersucht. Die Abflusstransformation durch das komplexe System Flussbett - Stauraum - Kraftwerk - Aulandschaft wurde durch mehrere matematische Modelle beschrieben. Fünfundachtzig Jahre täglichen Kraftwerkbetriebes wurden auf der Basis von Durchflussdaten aus der Periode 1901 - 1985 simuliert. Die Langzeitwirkung des Betriebes des Systems auf das zukünftige Verhalten des hydrologischen Regimes der Donau wurde statistisch untersucht. Die Energieprodukion des Wasserkraftwerks wurde auch errechnet und ausgewertet.

1. INTRODUCTION

The present technical realization of the Gabčíkovo diversion type hydroelectric power station consists of a weir on the river Danube at Čuňovo, which diverts a part of the discharge of the Danube to an 17 km long artificial diversion canal with a capacity of 4000 m^3/s. The canal, which is used for navigation too, is led outside of the former flood protection dams on the left bank of the river. The power head at the hydropower plant in Gabčíkovo varies from 16 to 21.5 m depending on flow conditions.

The area between the weir and the confluence of the power plant outlet with the Danube at Palkovičovo consists of forested flood plain ecosystems on both sides of the Slovak Hungarian border reach of the Danube. Water levels in the river represent the dynamic boundary condition for the groundwater regime of the flood plains and adjacent areas.

One of the most controversial issues concerning the operation of the system is the amount of water, which should be released into the old river bed at Čuňovo. Environmentalists prefer the restoration of the original dynamics of the discharge regime by using the diversion canal for navigation only with the consequence of negligible energy production. However in the recent decades increased erosion in the old river bed has been observed and therefore the restoration of the natural discharge regime might not be sufficient to maintain the existing ecological conditions in the flood plains.

Water management specialist suggest to stabilize the old river bed level and to rise the water levels by a series of fixed weirs. This system together with the existing fixed weirs in the flood plains on both sides of the Danube and channels for surface irrigation from the Čuňovo reservoir and the diversion canal could be used for flood plain management. This solution would enable the operation of the power station. At present time the Slovak part makes intensive use of the possibility to feed river arms in the flood plains with water withdrawn from the diversion canal. No river regulation has been made in the main river and a final intergovernmental agreement on the discharge regime of the Danube has not been reached yet.

In Šoltész and Szolgay (1993) an interim solution for the draw-off problem has been studied. Based on the extensive monitoring of groundwater levels in the project area in the period from 1987 to 1990 and results from mathematical modelling of groundwater flows in the flood plains, the effect of different mean monthly discharge releases on groundwater levels has been studied. Result of this study was a proposal for variable mean monthly releases, which are listed in table 1. Release values were selected with the goal to preserve the observed mean groundwater regime characteristics from the monitored period. It has to be noted, that the monitored groundwater level regime was influenced by the present river bed [illegible]y, which [illegible] affected by erosion.

Table 1. Mean monthly releases in m^3/s as proposed in Šoltész and Szolgay (1993)
Mittlere monatliche Restwassermengen im m^3/s nach Šoltész und Szolgay (1993)

Month	11 - 2	3- 5	6	7	8	9	10
Release	500	500 (750)	750	1250	1000	500 (750)	500

In this paper the methodological background for the above proposal is presented together with selected results of the extensive simulations of the effect of different mean monthly releases on the hydrological regime of the Danube and the energy production.

2. DESCRIPTION OF THE MATHEMATICAL MODELS

The influence of several possible future operation rules of the Gabčikovo system on the hydrological regime has been studied in detail in Szolgay (1991) and on the groundwater table in Šoltész (1992). For this study mathematical models developed for the simulation of the original Slovak - Hungarian joint project (the Gabčikovo - Nagymaros system), described in detail in Szolgay (1991), have been modified to predict the consequences of the present technical realization.

The simulation problem was decomposed as follows:
(a) routing of flows in the Danube and through the Čuňovo reservoir from the nearest gauging station in Bratislava to the weir in Čuňovo,
(b) simulation of the water balance and the different release rules,
(c) routing of flows from Čuňovo through the river and the flood plains (the old river bed) to the confluence of the Danube with the outlet of the power station,
(d) routing of flows in the diversion canal and computation of the generated hydropower,
(e) statistical analysis of simulated flows at three sites.

The flood plains significantly contribute to the attenuation of the flood waves passing through the study area. Travel time of the flood peaks is variable and wave form and discharge dependent. To account for this with sufficient accuracy, a multilinear conceptual flood routing method has been applied. In the simulations two linear sub models were used both consisting of a series of linear reservoirs. The first routed flows lower than the bankful discharge (3000 m^3/s), the second was activated when the discharges were in the out of bank range. They were calibrated by trial and error on a series of flood waves observed between Bratislava and Medveďov in the last decade. Two sets of selected events with peak flows lower or greater than the bankful discharge were used in the calibration.

Water will be withdrawn from the reservoir and the river by several users (e.g. for irrigation of the flood plains, water for agriculture, industry, fishery etc.). The aquifer connected with the river will be exploited for drinking water supply. Losses due to seepage to deep layers, for evaporation, through navigation locks etc. had to be considered too. The estimated withdrawal rate will exhibit a seasonal variation between 100 and 300 m^3/s. Estimated mean monthly values of the withdrawal rates have been used in the computation of the daily water balance of the system.

The release rules for constant monthly releases from the Čuňovo reservoir were modelled as follows:
(a) the discharges in the Danube were not allowed to decrease below 500, 750, 1000, and 1250 m^3/s respectively, when natural flow conditions allowed for this. Otherwise natural flows have been maintained. The selected threshold values were often used in discussions of the problem,
(b) only discharges in excess of the prescribed releases were used for energy production,
(c) in flood situations only discharges over 4000 m^3/s have been released into the old river bed.

For comparison the original utilization scenario settled in the Slovak-Hungarian intergovernmental agreement, which was signed in 1977, has been considered too. It allowed a release of 50 m^3/s into the old river.

The diversion canal has been modelled by a linear channel. Discharge rating curves derived by uniform unsteady flow computation at the power station and the outlet of the canal were used for the approximation of the mean daily power head.

Eighty-five years of mean daily flows observed in Bratislava in the period from 1901 to 1985 served as model input data for the future behavior of the danubian flows. The natural hydrological regime based on the present flow routing characteristics and on the estimated future water withdrawal rates was modelled for comparison too.

3. SIMULATION RESULTS

The simulated mean annual, monthly, daily discharges and the maximal and minimal mean daily discharges have been statistically analyzed at three sites in the old river. Selected results for a site near to the confluence of the outlet channel and the Danube are listed in tables 2,3,4.

The variability of the predicted mean annual discharges is generally much lower, their skewness far higher than of the corresponding values for natural flow conditions. The behavior of the time series of mean monthly flows exhibits a decrease of variability with increasing releases into the old river. The skewness of the series shows opposite tendency. The autocorrelation properties of natural mean monthly flows of will not be preserved. Flows in wet months are less variable than natural flows in general, but they are extremely skewed with skewness coefficients reaching far beyond the experience in our geographical conditions. Flows in dry months practically stayed on the level of the guaranteed releases with negligible variability, which in turn has increased the skewness to very high values.

Table 2. Predicted mean monthly discharges in m^3/s as a function of the mean monthly release

Vorhersage der mittleren Monatsdurchfluessen im m^3/s als Funktion der mittleren monatlichen Restwassermengen

Release [m^3/s] Month	Natural conditions	500	750	1000	1250
11	1421	501	744	940	1072
12	1460	504	742	936	1071
1	1526	509	746	939	1075
2	1629	514	754	960	1110
3	1953	515	759	991	1194
4	2349	512	925	1057	1247
5	2662	527	770	1014	1259
6	2800	556	797	1040	1282
7	2628	565	802	1041	1276
8	2229	521	766	1011	1245
9	1825	512	757	994	1190
10	1507	500	745	955	1107

Table 3. Predicted coefficients of variation of mean monthly discharges as a function of the mean monthly release

Vorhersage des Variationskoeffizienten der mittleren Monatsdurchfluessen als Funktion der mittleren monatlichen Restwassermengen

Release [m^3/s] Month	Natural conditions	500	750	1000	1250
11	0.34	0.02	0.03	0.1	0.17
12	0.38	0.05	0.05	0.11	0.16
1	0.42	0.09	0.06	0.11	0.17
2	0.39	0.15	0.09	0.11	0.16
3	0.32	0.1	0.05	0.04	0.08
4	0.26	0.16	0.09	0.06	0.04
5	0.27	0.22	0.11	0.07	0.04
6	0.28	0.55	0.35	0.24	0.17
7	0.34	0.34	0.21	0.14	0.1
8	0.28	0.13	0.07	0.04	0.05
9	0.34	0.13	0.08	0.07	0.1
10	0.32	0.01	0.04	0.09	0.15

The simulated energy production in table 4. quantifies the expected production losses with increasing releases into the old river. An analysis of the discharge time series in the power canal showed, that with increasing guaranteed flows in the Danube, the operation of the power plant would exhibit a growing number of random irregular dropouts. The real time control of the system would become difficult and the value of the produced energy would decrease.

Table 4. Predicted percentage of electrical energy production at Gabčíkovo as a function of the mean monthly release.
Vorhersage der Energieproduktion (im Prozenten) als Funktion der mittleren monatlichen Restwassermengen

Release [m^3/s] Month	50	500	750	1000	1250
11	100	64	44	29	19
12	100	65	46	31	21
1	100	66	49	34	24
2	100	68	52	38	27
3	100	75	61	47	36
4	100	80	68	56	45
5	100	83	74	64	54
6	100	84	75	66	56
7	100	82	72	62	52
8	100	79	66	54	42
9	100	72	57	41	29
10	100	66	48	32	21

4. CONCLUSIONS

The analysis has shown, that with increasing mean monthly releases into the Danube at Čuňovo the hydrological regime parameters would not resemble those of the predicted natural flow conditions. The simulated hydrological regime exhibits more extreme behavior resulting from flows concentrated around the guaranteed values with occasional releases of high excess flows in flood situations. Floods would have a shorter duration and sharper peaks, thus the need for periodic flooding of the forests would not be fulfilled. On the other hand, the economic utilization of the system could become difficult because of the irregular and low energy production.

The conflict between the need to restore the ecological conditions and to maintain an economically effective operation of the system remains thus unresolved. The need for different solutions seems to be apparent.

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ABFLUßVORHERSAGE MIT NEURONALEN NETZWERKEN

FLOOD FORECASTING BY NEURAL NETWORKS

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Kurzfassung: Lineare Mehrfachregression is eine bei der Echtzeitabflußvorhersage eingesetzten Methoden. Trotz der nichtlinearen Beziehung zwischen Abflüßen verschiedener Pegelstellen oder zwischen Abfluß und Niederschlag wird ein lineares Model angenommen. In diesem Aufsatz wird die potentielle Anwendbarkeit von neuronalen Netzwerken - eine neue, nichtlineare Modeltechnik - vorgestellt. Die Anwendungsbeispiele beziehen sich auf Hochwasserereignisse in den Rhein und Donau Einzugsgebieten. Für einige Fälle konnten mit Hilfe der neuronalen Netzwerke, im Vergleich zur linearen Regression, verbesserte Ergebnisse erzielt werden. Da sowohl die Eichung als auch der Einsatz von neuronalen Netzwerke eine Vereinfachung darstellt, scheint diese Technik für die operationelle Abflußvorhersage eine attraktive Alternativlösung zu sein.

Summary: Multiple linear regression is one of the methods being used for real-time flow forecasts. Although a linear model is assumed the relationship between discharges or between discharges and precipitation depths are actually nonlinear. The aim of this paper is to present the potentials of neural networks which is a new methodology of nonlinear modelling. The method is applied to flood events in the basins of the river Rhine and Danube. For some cases neural networks indeed show improved results as compared with linear regression techniques. Since a neural network appears easier to calibrate and to operate it presents an attractive alternative to conventional linear and nonlinear regression methods in operational flow forecasting.

1. Introduction

The main objectives of flood forecasting are to predict the peak discharge and the time of occurrence of this peak with sufficiently accuracy. The accuracy of the forecast is dependent on both the type and quality of data available and on the model used. To extend the period of forecast weather forecasts have to be included in the flow prediction procedure. A comprehensive review of models for real time flow forecasting has been presented by Kraijenhoff and Moll (1986).

One of the models being used to forecast daily discharges of the river Rhine at station Lobith situated at the Dutch-German border is based upon multiple linear regression (Model Lobith). This type of models may be appropriate for relatively large river systems in which response times are large. Model Lobith uses rainfall depths and flow data of locations further upstream to predict the discharge at Lobith one or more days ahead.

Although the model generally yields proper results some flood events show evidence of non linearity. Especially discharges forecasted three days ahead are not always calculated properly. It was suggested (Van den Eertwegh, 1992) that neural networks which is a rather new methodology of nonlinear modelling would yield better estimates of the forecasts. This is the subject of a number of hydrological studies in which the potentials of neural networks in hydrological modelling are being examined. Zwamborn (1993) used neural networks in rainfall runoff modelling of the experimental basin of the Hupselse Beek in the Netherlands.

Veldkamp (1993) compared the results of flow forecasts using the Model Lobith and neural networks on the river Rhine. Recently also flow data observed at stations along the river Danube, between Bratislava and Mohacs are involved in this study (Jellema, 1994). This paper presents the main results so far of both these studies on flow forecasting and discusses the promising application of neural networks in real-time flood forecasting.

2. The neural network

A neural network consists of a number of neurons or processing units each of which performs a nonlinear transformation on its inputs. Before transformation inputs are weighted and accumulated. Commonly, the processing units are arranged into distinct layers, i.e. input, hidden and output layers. When the information passes on from input to output without recurrent connections the network is called a feedforward network. To get an idea of how a neural network works a comparison is made with a linear regression model. Figure 1 shows a schematic representation of a typical linear model, in formula:

$$Y = W_1X_1 + W_2X_2 + W_3X_3$$

Y : output,
X_1, X_2, X_3 : input data,
W_1, W_2, W_3 : coefficients

Figure 2 shows a schematic representation of a typical feedforward neural network, in formula:

$$Y = f(W_1 \; f(W_{11}X_1 + W_{12}X_2 + W_{13}X_3) + W_2 \; f(W_{21}X_1 + W_{22}X_2 + W_{23}X_3))$$

Y : output,
X_1, X_2, X_3 : input data,
$W_1, W_2, W_{11}, \ldots$: coefficients,
$f(\,)$: transferfunction

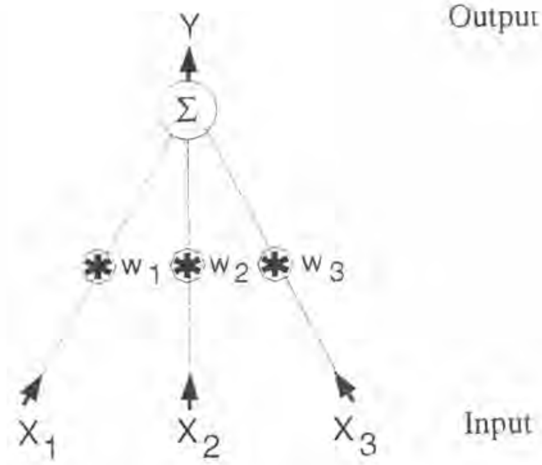

Figure 1: A schematic representation of a linear model.

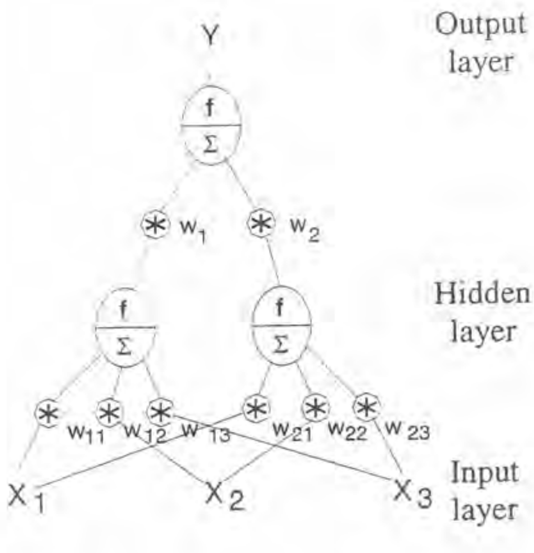

Figure 2: A schematic representation of a neural network

As shown in figure 2 the scheme of the neural network is somewhat more complicated than that of the linear regression model. Most significant is the extra layer known as the "hidden layer". A neural network may consist of a few of such layers. Each layer consists of a number of neurons. In the example of figure 2, the hidden layer has two neurons. A hidden neuron (figure 3) computes a weighted sum ($I_j = \Sigma W_i X_i$) of its inputs ($X_1, X_2 \ldots X_N$) that is transformed by a nonlinear function (f) into the output. Generally a tangent hyperbolic transfer function is applied. Neural networks can in general differ from each other in the number of neurons, number of hidden layers, type of transfer function and in the way that neurons are connected.

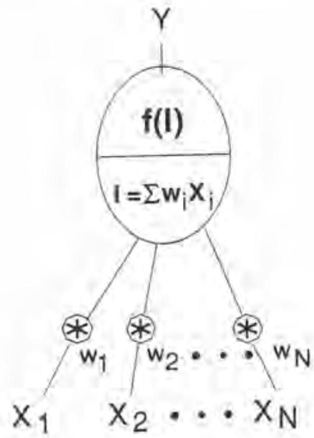

Figure 3: A single neuron.

The weights ($W_1, W_2 \ldots W_N$) have to be calibrated. To determine these parameters neural networks are 'trained' by showing them observed input and output examples. By adjusting the weights the network 'learns' the desired relation between input and output.

In hydrological applications neural networks are trained in an iterative way by a the "backpropagation" procedure. In the first step the weights are randomly generated. Then the output is calculated from a given input. This calculated output is then compared with the desired output. The weights are adjusted so that the deviation between computed and desired output is minimized. The sequence of adjusting the weights is backward from output layer to input layer.

3. Results of flow forecast on the river Rhine.

To forecast the discharge of the river Rhine at station Lobith at the Dutch German border several neural networks have been developed using the software package NeuralWorks Professional II/PLUS of NeuralWare Inc.

As input to the neural networks, discharge and rainfall data are used of stations further upstream in Germany. In this study nine years of daily data have been used, of which one set of data was selected for training and the remaining set for verification of forecasts.

Three groups of neural networks have been made and applied:

1) Neural networks that forecast the whole range of discharges; these networks did not improve the results as were obtained with the linear regression model (Model Lobith).
2) Neural networks that particularly forecast the upper part of the hydrograph and networks to forecast the lower part; only the lower discharges show comparable results as calculated with Model Lobith.
3) Neural networks to forecast the residuals between the discharges forecasted with the linear model and the observed discharges. This network uses the forecast of Model Lobith as a-priori information. The performance of the network in this case is clearly better than that of the linear model especially for the peak discharges. This neural network succeeds in forecasting the systematic nonlinear residuals.

   Since the results of Model Lobith are used as additional input it is shown that neural nets are capable to exploit a-priori knowledge.

4. Results of flow forecast on the Danube

Also in the study of floods on the Danube the software package NeuralWorks has been used. The data provided for this study are mean daily discharges at Bratislava, at Nagymaros and Budapest for the period 1984-1988.

Three groups of neural networks have been made and examined:

1) Neural networks to forecast the discharge at Budapest based upon the discharge observed at Bratislava, i.e. flood routing over a relatively large distance between the gauging stations involved.
2) Neural networks to forecast the discharge at Budapest based upon the discharge at Nagymaros, i.e. flood routing over a rather small distance between the gauging stations.
3) Neural networks to forecast the discharge at Budapest two or three days ahead using the discharge both at Bratislava and Nagymaros. In this case a forecast is being made based upon data collected at stations further upstream.

In most cases the results are promising, but for the examples studied neural networks do not yet significantly improve results of linear models. Especially in the case of forecasts over a small distance i.e. Nagymaros - Budapest the neural network is able to distinct a nonlinear factor. This is shown in the example of figure 4 representing the flood of May 1987.

From this figure it is clear that the neural network approach does fit a little better than the linear model. However not all periods examined show such good results. Since this study uses only discharge data an exhaustive examination of the potential of neural nets to forecast flood discharges at Budapest has not yet done. If more detailed data, e.g. precipitation, evaporation and discharges of tributaries would be used, the nonlinear components in the discharge might be explained better. Therefore continuing research will focus on further exploring the potential application of neural network models in flow forecasting and rainfall-runoff modelling.

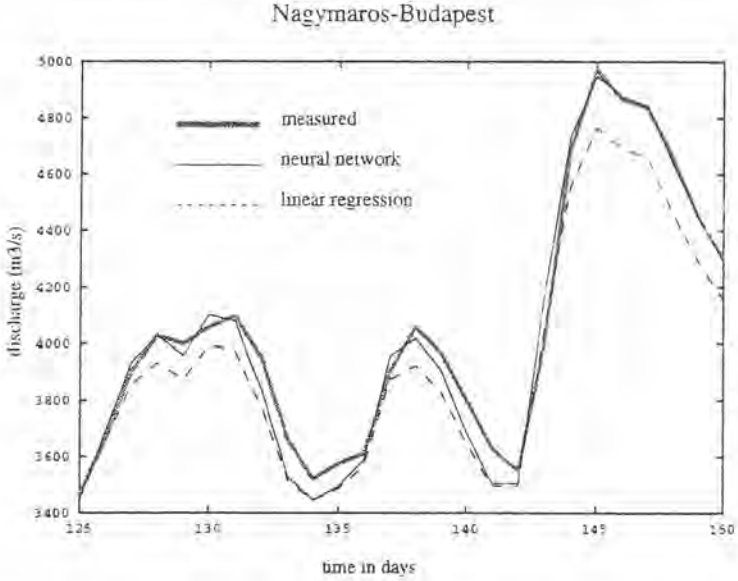

Figure 4: Result of the forecast at Budapest obtained with a neural network model and with a linear regression model. Period Mai 1987.

An advantage of forecasting with neural networks is the adaptive character of the network. If some changes in the river are made e.g. the building of dams and bypass canals it is possible to adapt the model with relatively short time series. This adaptive character is comparable to Kalman-filtering, but in the case of neural networks the approach to the problem is more applied, and only little mathematical knowledge is needed.

5. Conclusions

This paper demonstrates the potential application of neural networks for flow forecasting. It is also demonstrated that a-priori knowledge of the flow forecast can be incorporated in the application of neural nets.

For the Rhine basin some floods are clearly better forecasted by the neural network than by the conventional model Lobith. In those cases the neural network was capable of using the nonlinear information of the input.

In the case of the Danube much less data was available and the capability of neural nets to model nonlinear relations have not yet fully been explored. In the continuing research more data will be included and it is expected that the results of conventional modelling techniques might be improved.

The training of neural networks is relatively easy and the execution of the model is very fast. In case of changing river characteristics neural network models can be easily adapted.

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DEVELOPMENT OF WATER FORECASTING MODEL BASED ON PROBABILITY ANALYSIS OF TRAVEL TIME

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ABSTRACT

Water forecasting model was developed as a result of studying lag time at a river section taken as random value and its distribution curve approximation whose parameters are defined in optimization process. Statistical algorithm of issued forecasts is applied for the purpose of improving forecasts.

As a result of model development numerical and graphic indicators of issued forecasts are presented in this paper for one river flow section

ZUSAMMENFASSUNG

Aufgrund der Erforschung der Zuflußzeit auf der Teilstrecke des Flußlaufs als Zufallsgröße und durch die Verteilungskurve durchgefürhte Annäherung deren Parameter in Optimierungsverfahren bestimmt sind, ist das Modell für die Wasserprognose entwickelt. Zur Verbesserung der Prognose ist der statistische Algorithmus der Anpassung der gestellten Prognosen angewendet.

Als Ergebnis des entwickelten Modells sind in der Arbeit die nummerischen und grapischen Indizes der gestellten Prognosen für eine Teilstrecke des Flußlaufs präsentiert.

1. INTRODUCTION

The computation of water level discharge transformation at the certain section of river flow depending on whether this section is with or without tributaries presents a starting point for the development of the short-term forecasting model. The approach used depends on the availability of hydrological data on the section, travel time and the form of applied transformation functions.

The paper studies the river flow section on the Danube from Budapest to Bogojevo but due to the lack of data on the Drava river at the territory of Yugoslavia which represents a significant tributary on this section, data from gauge station Barch on the Drava river in Hungary were used.

As a result of this study a prognostic model has been developed for the discharge forecasting at the gauge station Bogojevo for the period of 1÷4 days ahead.

2. BASIC ASSUMPTION OF THE MODEL

The discharge computation on the river flow section limited by one output and with several input profiles where water level or discharge observation data exist, can be carried out with the help of linear transformation model with concentrated inflow / *1, 10, 12* /.

$$Q(t) = \sum_{i=1}^{m} k_i \cdot \int_0^t r_i \cdot (t-\tau) \cdot q_i(\tau) \cdot d\tau \qquad (1)$$

where Q (t)-discharge at output profile, q_i (t)-water discharge at i-th input profile, k_i-balance coefficient taking into consideration lateral inflow, corresponding to each input profile, m-number of input profiles, $r(\tau)$-transformation function.

Numerous practical experiences show that transformation function can be very well approximated by two-parameter Gamma distribution / *6, 7* / or by considering it in probability sense - as the density of travel time distribution of elementary water volume at the section / *2, 3* /.

The approximate approach in defining function r (τ) is based on the selection of some of the well-known distribution curves and their parameter assessment at the studied watercourse section.

Numerical experiment as well as the possibility of standardization of the computation / *3* / showed that this curve can be very well approximated by modified Gamma distribution, that is, Brovkovich curve, i.e.,

$$r(\tau) = \frac{\alpha^{\alpha}}{m_1 \Gamma(\alpha)} \left(\frac{\tau}{m_1}\right)^{\alpha-1} \exp\left(-\frac{\tau}{m_1}\right) \cdot B(\tau) \qquad (2)$$

where:

$$B(\tau) = 1 - \frac{C_s - 2C_v}{6\, C_v^{3}} \left[1 - 3\left(\frac{\tau}{m_1}\right) + \frac{3}{\beta_1}\left(\frac{\tau}{m_1}\right)^2 - \frac{1}{\beta_2}\left(\frac{\tau}{m_1}\right)^3 \right]$$

$$\alpha = \frac{1}{C_v^{2}} \; ; \; \beta_1 = 1 + C_v^{2} \; ; \; \beta_2 = \beta_1 \cdot (1 + 2C_v^{2}) \; ; \; C_v = \frac{\sigma}{m_1} \; ; \; C_s = \frac{M_3}{\sigma^3}$$

Parameters of this adopted travel time distribution are defined by the method of moments / 3 / and for the section without tributaries they amount to:

$$m_1 = \bar{\tau} \tag{3}$$

$$\sigma^2 = a^2 \cdot \bar{\tau} \tag{4}$$

$$M_3 = k \cdot a^4 \cdot m_1 \tag{5}$$

where: $\bar{\tau}$ is the average travel time at the section ($\bar{\tau} = \frac{L}{\bar{V}}$, L- the section length, $\bar{V}$ - mean velocity, a-diffusion parameter, k-ratio between coefficient of variation and skewness of travel-time data on considered section.

Necessary values for the assessment of the moments, and with it also distribution parameters assessment are the mean inflow velocity at the section $\bar{V}$,diffusion parameter a and parameter k which are calibrated in the optimization for minimizing of differences between observed and computed discharges at the output section.
Balance coefficients K_i are defined from the conditions of maintaining the water balance at the section and are proportional to the discharge values at input profiles and belonging catchment areas of this profiles. / *1, 10, 12* /, i.e.,

$$K_i = \bar{K}_w \cdot K_{f_i} \tag{6}$$

where K_w is mean unadjustment coefficient of water balance at the section, K_{f_i}- coefficients which are proportional to the ratio of surface areas which are controlled and not controlled by systematic discharge observations.

3. MODEL SCHEME FOR DISCHARGE FORECASTING AT THE SECTION

Above mentioned scheme of runoff computation has served as a basis for development of discharge forecasting model for the river flow section.

Basic Model equation, according to / *8, 1, 10, 12* / is:

$$\bar{Q}_{t+\delta} = \sum_{i=1}^{m} K_i \left[\sum_{j=\delta+1}^{r_i} r_{i,j} \cdot q_{i,t+\delta-j+1} + \sum_{j=1}^{\delta} r_{i,j} \cdot \tilde{q}_{i,t+\delta-j+1} \right] + \phi_t(Q,\delta) \tag{7}$$

where: $Q_{t+\delta}$-forecasted discharge value at the output profile with taking into consideration the initial conditions, δ-forecast lead time, $q_{i,j}$-ordinate of i-th input in j-th moment of time which are known in the time of forecast issuing t, $\tilde{q}_{i,j}$-similar line $q_{i,j}$ but ordinates are not known in the time t, $r_{i,j}$-ordinate of transformation function, $\phi_t(q,\delta)$-correction operator in accordance with literature / *8, 9* / which take into consideration observed discharge data on output profile in the moment of issuing forecast.

As can be seen from the equation (7) in operational short-term water level discharge forecasting it is necessary to solve the problem of taking into consideration the on-line data on output profile as well as the problem of defining of yet not known forecast lead times period.

Introduction of the information on observed discharge on output profile in the moment of issuing forecast can be performed through the operator $\phi_t(Q,\delta)$ whose structure and the mode of application are described in detail in the paper/ *8, 9* /. Here, in developing forecasting discharge model at the section Budapest-Bogojevo correction principle is applied which is based on taking into consideration the forecasted errors in the moment of issuing forecasts / *4, 5, 11* / i.ed.,

$$\phi_t(Q,\delta) = \left(\frac{\Delta Q_t}{r_{1,max}} \right) \cdot r_{1,max+\delta} \tag{8}$$

where: $\Delta Q_t = Q_t - \hat{Q}_t$, $\hat{Q}_t$-forecasted value of discharge without correction, Q_t-observed discharge, $r_{1,max}$-value of maximum ordinate of transformation function.

Also, besides on-line information, the mode of defining input values $\tilde{q}_{i,j}$ for the period of forecast lead time is built in the model. Among several procedures fully described in the papers / *9, 10, 12* / in this paper following expression was applied:

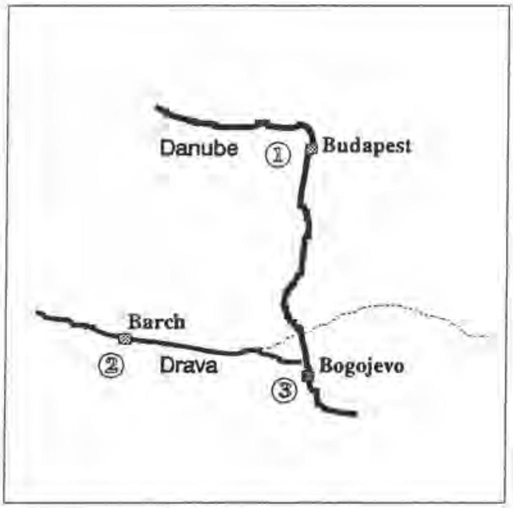
$$\tilde{q}_{t+\delta} = q_{t+\delta-1} + r^{\delta} \cdot (q_t - q_{t-1}) \tag{9}$$

where: r-discharge differences correlation coefficient. This coefficient is defined on the basis of historical data using both data for the rising hydrographs as for the falling ones.

4. MODEL DEVELOPMENT FOR WATER DISCHARGE FORECASTING AT THE DANUBE RIVER AT THE SECTION FROM BUDAPEST TO BOGOJEVO

Studied flow section from Budapest to Bogojevo at the river Danube is typical example for flow section with lateral inflow. (Figure 1.)

Figure 1. River section scheme at the Danube



Budapest at the Danube river and Barch at the Drava river were selected as input profiles and Bogojevo as output profile.

Observation data in the period 1988-1992 were used for parameter calibration of transformation function. The flood waves which appeared at at least one watercourse were selected.

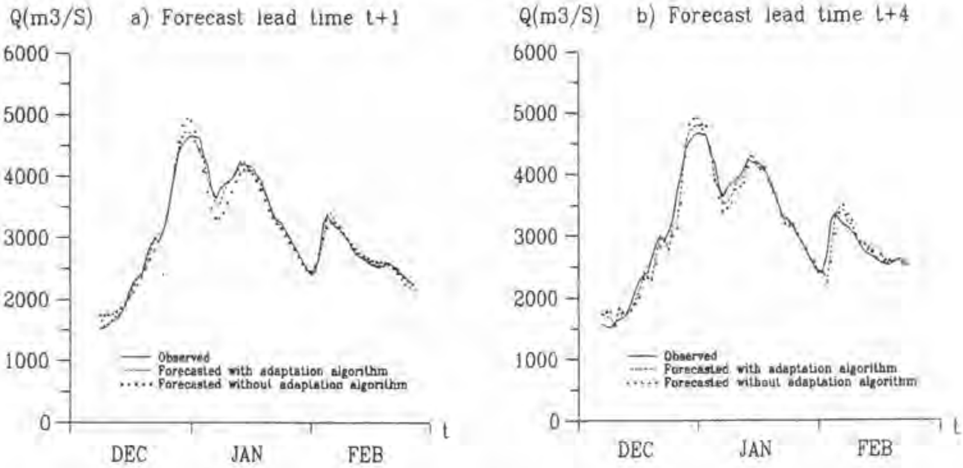
In the optimization procedure parameters of transformation function were defined. Numerical values of these parameters are given in the Table 1.

Optimized parameters were used for development of discharge forecasting model at gauge station Bogojevo for 1÷4 days ahead.

Table 1.Parameters of transformation functions at the section Budapest - Bogojevo

Flow section	L	model parameter			K_1	Optimization period
	km	a day	$\bar{V}$ km/day	k		
Budapest-Bogojevo	279	0.35	52	2.1	0.85	1988-1992
Barch-Bogojevo	167	0.84	31	1.5	1.50	1988-1992

Figure 2. Graphic survey of observed and forecasted discharges at gauge station Bogojevo (a-forecast lead time t+1, b-forecast lead time t+4)



Thus, starting from space distribution i.e. the distances of input profiles from the output ones and initial ordinate characteristics for transformation functions, it was necessary to define only the value of input discharge at the gauge station Barch at the Drava river for t+1 and t+2 days ahead, i.e.,values $\tilde{q}_{2,t+1}$ and $\tilde{q}_{2,t+2}$. For that purpose recurrent expression is used (9).In the Figure 2, for illustration purposes, graphic display was given of observed and forecasted discharges for t+1 and t+4 at gauge station Bogojevo for one characteristic flood wave during 1993.

Table 2 contains the results of issued forecasts during 1993 at the gauge station Bogojevo for t+1 to t+4 days ahead.

Table 2. The assessment of issued forecasts S/σ_δ with the use (numerator) and without use (denominator) of adaptation algorithm

River - profile	Forecasting period (day)			
	1	2	3	4
Danube - Bogojevo	$\frac{0.557}{1.079}$	$\frac{0.323}{0.620}$	$\frac{0.220}{0.452}$	$\frac{0.372}{0.532}$

As can be seen from the Figure 2 and Table 2 developed model for discharge forecast at the gauge station Bogojevo for 1+4 days ahead shows satisfactory results and can be used in operational forecasting issue. Introduction of on-line information improves significantly the accuracy of issued forecasts. That is, taking into consideration the initial conditions is necessary especially for the short-term forecasting.

5. CONCLUSION

Developed model for discharge forecasting at gauge station Bogojevo based on probability principle of defining transformation functions and introduction of current correction of issued forecast showed satisfactory results especially in the high-flow periods. This could have been expected since the model parameters are optimized only on the basis of significant flood waves. Further investigation will be directed to the establishing of the change patterns of model parameters in other river flow regimes as well as introduction of other correction operators pursuant to better research and taking into consideration of initial terms.

Conducive to the increase of forecast lead time at gauge station Bogojevo, the problem will be solved also within the framework of using forecasts issued by Water Resources Research Center "Vituki" in Budapest at input profiles at Barch and Budapest.

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TESTING ROMANIAN AND HUNGARIAN RIVER FLOW MODELS ON THE DATA OF THE LOWER DANUBE

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Summary: In the framework of the hydrological activity of the WMO Regional Association VI (Europe) a special project has been carried out for the past few years. The purpose of the project is to compare the performance of different hydrological models used to forecast the flow in large river systems. As a part of the given project three Hungarian and one Romanian models were tested on the data of the Lower Danube. The results presented in the paper confirmed the applicability of the tested diffusion wave, cascade and Muskingum type models and also pointed out the importance of the real-time updating procedures added as error models.

Erprobung rumänischer und ungarischer Durchflus modelle mit den Daten der Unteren Donau

Kurzfassung

Im Rahmen der hydrologischen Tätigkeit der WMO Regional Association VI (Europe) wurde während der letzten Jahre ein besonderes Projekt durchgeführt. Sein Ziel ist, die für die Durchflusvorhersage grosser Flussysteme verwendeten verschiedenen hydrologischen Modelle miteinander zu vergleichen. Als ein Teil des Projektes wurden drei ungarische Modelle und ein rumänisches Modell mit den Daten der Unteren Donau geprüft. Die im Beitrag mitgeteilten Ergebnisse haben bewiesen, das die untersuchten Modell-Typen (Diffusionswelle, Kaskade und Muskingum) anwendbar sind und haben gleichzeitig auch auf die Wichtigkeit der Anwendung von zusätzlichen real-time Updating-Verfahren, als Fehlermodellen, hingewiesen.

Introduction

The World Meteorological Organization (WMO), of which some 160 States and Territories are Members, is a specialized agency of the United Nations. According to the Convention of WMO, Article 2. one of the purposes of the Organization:

- to promote activities in operational hydrology and to further close co-operation between Meteorológical and Hydrological Services.

The commitment in the field of operational hydrology, as set out in Article 2(e) of the WMO Convention mentioned above, is exercised through the Hydrology and Water Resources Programme (HWRP). This programme assists the Hydrological Services of Members in matters of operational hydrology and in mitigating water-related hazards such as floods and droughts. It also promotes co-operation between countries at regional and sub-regional levels, particularly where shared river basins are concerned, including education and training activities in hydrology.

The scope of the HWRP is basically operational hydrology which, as defined in the WMO General Regulations, comprises:

(a) Measurement of basic hydrological elements from networks of meteorological and hydrological stations: collection, transmission, processing, storage, retrieval, and publication of basic hydrological data
(b) Hydrological forecasting;
(c) Development and improvement of relevant methods, procedures, and techniques.

Working groups on hydrology also are established by the six regional associations (Africa, Asia, South America, North and Central America. South West Pacific and Europe) of WMO to address some topics covered by the HWRP and others relevant to the hydrological problems of their respective Regions, including:

- surveys of the adequacy of networks of hydrological stations, hydrological data-transmission and processing facilities, data banks, hydrological forecasting;

Specific projects are designed to investigate and compare technology such as instruments forecasting models and network-design techniques. Regional aspects of projects covered by the HWRP are implemented principally by the six regional working groups on hydrology in WMO's six regional associations.

According to the resolutions of the Regional Asociation VI. (Europe), one of the tasks of the Hydrological Working Group is to assess the characteristics of the hydrological models used in the Region.

The strategy used by the Hydrological Working Group in order to implement this task comprises two successive phases:

a/ Phase I consists of collecting and analyzing the information on characteristics of the three well-defined types of hydrological models: for hydrological forecasting, extrapolation of hydrological time series and assessment of man's influence on the natural hydrological regime.
This phase had been completed in 1986 by carrying out a Report where the characteristics of 62 hydrological models proposed by 20 countries of the WMO Region VI, have been analyzed.

b/ Phase II includes the testing of the models by their owners on the basis of the data supplied by the interested institutions. This activity allows the model owners to assess the range of applicability of their models and allows the data suppliers to select the adequate model in order to solve some practical problems.

The RA VI countries participating in the second stage of the project have selected the following problems which can be solved by applying the models from the Report:

- daily forecast of historical hydrological data and especially of the flood waves;
- development of historical hydrological data series starting from the usual climatological observation data;
- simulation of the run-off hydrograph in the gauged and un-gauged basins;
- simulation of the fresh - saltwater interface in the coastal areas;
- water balance over basins, especially with reference to infiltration and evapotranspiration;
- study of the man's influences on the hydrological regime.

In order to solve these problems one or several models as well as the necessary data sets for their testing, have been selected.

Five countries expressed intention to test own models with the data sets supplied by some institutions that is: Belgium, Czechoslovakia (former), German Democratic Republic (former), Sweden and Hungary. Up to now, five models from Belgium, Hungary and Romania have been tested using data supplied by Switzerland and Romania.

The purpose of this project is to compare the performance of hydrological and hydraulic models used for forecasting the flows of large river systems. The project was first discussed at Vancouver Workshop (1987).

The the three previous WMO Intercomparison projects dealt with basins which were small enough to demonstrate mainly the characterisation of soil moisture accounting and system type (black-box) models and consequently flow routing was not a predominant factor of these Intercomparisons. This situation is reserved for large rivers, for which many of the well-established forecasting systems have been developed.

It was proposed, therefore, that the project on large rivers would:

a/ Enable hydrologists to compare the relative performance of operational forecasting systems on rivers for which forecasts are really needed and which have not been selected only for the purposes of model comparison.

b/ It would be useful in assessing the relative merits of various flow routing methods for forecasting the flows of large rivers.

Testing Romanian and Hungarian forecasting models

In the midle and the lower Danube the channel flow is the dominant factor to forecast in the operational practice. Not surprisingly the most important component of the operational forecasting models used by the Forecasting Services of the riperian countries is a kind of flood routing procedure which comes from the following classes:

1. Dynamic models based on numerical solutions of the Saint-Venant equations system which describes the usteady motion of the water in the river;
2. Diffusion and kinematic models based on the simplification of the motion equation of the Saint-Venant system;
3. Hydrological models based on replacement of the motion-equation of the Saint-Venant system by the storage equation.

In the framework of the above mentioned WMO project on the data of the lower Danube the following routing models were tested. DIFFU, CLCM and DLCM from Hungary (Bartha, 1993) and DANUBIUS from Romania.

For the purpose of testing forecasting models of flood routing, data were supplied for the period 1977-1981 for Danube river at the hydrometric station Zimnicea and Ceatal Izmail as well as at the station Lungoci on the Siret river which is an important tributary of the Danube.

Zimnicea station lies at 474 kilometres distance from Ceatal Izmail. Lungoci station is 76 km off the confluence of the Danube with the Siret river.

The DIFFU model is based upon the diffusion equation. The basic equation is:

$$\frac{\partial Q}{\partial t}=D\frac{\partial^2 Q}{\partial x^2}-C\frac{\partial Q}{\partial x} \tag{1}$$

where: Q is the discharge;
D - diffusion coefficient;
C - wave celerity.

A solution, suitable for digital computing required the discretisation of the continuous equation both in time and space, which resulted the introduction of an additional (third) parameter, the length unit of the discretisation (ΔX). The parameters of the model (C, D, ΔX) are to be optimized using past observed data and are used afterwards as time invariant values for forecasting.

The CLCM and DLCM hydrological models models are based on the Kalinyin-Miljukov-Nash linear cascade concept, and differ only in the technique of mathematical solution of the basic differential equation system, which can be presented for a single linear reservoir, as follows:

$$\begin{cases} \frac{dW}{dt}=Q-q \\ W=K*Q \end{cases} \tag{2}$$

where: W is the storage, volume;
Q - outflow;
q - inflow;
K - storage (time) coefficient.

The impulse-response function of a single linear reservoir is:

$$h(t)=\frac{1}{K}e^{\frac{-t}{K}} \tag{3}$$

A cascade consists of a number (n) of serially linear reservoirs. The response of such a system to unit impulse is described by the following function:

$$h(t)=\frac{1}{K*\Gamma(n)}\left(\frac{t}{K}\right)^{n-1}e^{\frac{-t}{K}} \tag{4}$$

where $\Gamma(n)$ is the gamma function

The Continous Linear Cascade Model (DL) is based upon the continuous solution of the equation system which is described by the convolution integral:

$$Q(t)=\int_0^t h(t)*q(t-\tau)d\tau \tag{5}$$

where h(t) is defined by equation (4).

The Discrete Liner Cascade Model (M) is based on representing the system of the storage the continuity equations in state space notation (Szöllősi- gy, 1982):

$$\begin{cases} \frac{d}{dt}W(t) = FW(t) + Gq(t) \\ Q(t) = H * W(t) \end{cases} \quad (6)$$

Where: W(t) is the state variable (storage);
q(t) - inflow;
Q(t) - outflow;
F - state transition matrix;
G - input transition vector;
H - output vector.

For discrete time intervals (Δt) the discrete state-space model is described as:

$$\begin{cases} W(t+\Delta t) = \Phi(\Delta t)W(t) + \Gamma(\Delta t)q(t) \\ Q(t) = H * W(t) \end{cases} \quad (7)$$

where:

$$[\phi(\Delta t)]_{i,j} = \begin{cases} \frac{(k\Delta t)^{i-j}}{(i-j)!}e^{-k\Delta t}, \quad k = \frac{1}{K} & \text{if } i \geq j \\ 0 & \text{if } i < j \end{cases} \quad (8)$$

is the state transition matrix, and

$$[\Gamma(\Delta t)]_i = (1 - e^{-k\Delta t}\sum_{j=1}^{i-1}\frac{(k * \Delta t)^j}{j!})/k \quad (9)$$

is the input transition vector.

The forecast updating procedure for the presented models (DIFFU, CLCM and DLCM) is based on an autoregressive model:

$$QF(t+\Delta t) = QS(t+\Delta t) + A_1\varepsilon(t) + A_2\varepsilon(t-\Delta t) + A_3\varepsilon(t-2\Delta t) + A_4\varepsilon(t-3\Delta t) + A_6\varepsilon(t-4\Delta t) \quad (10)$$

Where: QF(t+ t) is the forecasted discharge at the moment $t+\Delta t$;
QS(t+ t) - simulated discharge at the moment $t+\Delta t$;
$\varepsilon(t)$ - forecast error at the moment t;
$A_1, A_2, \ldots A_5$ - coefficients of the autoregressive model.

The DIFFU, CLCM and DLCM models were calibrated for the period 1977-1978 and were checked for the period 1980-1981.

To evaluate model performances, the following numerical criteria were used: the standard deviation, NTD and the first autocorrelation coefficient (Tab.1.)

The NTD criterion gives the magnitude of the error between the observed and the computed hydrographs.

$$NTD = 1 - \frac{\sum_{i=1}^{N}(y_{ci}-y_{oi})^2}{\sum_{i=1}^{N}(y_{oi}-\bar{y}_o)^2} \qquad (11)$$

where: Y_{oi} - observed discharges;
Y_o - mean of the observed discharges;
Y_{ci} - calculated discharges;
N - length of the data series.

The NTD criterion is a dimensionless value which is not dependent on the magnitude of the discharge or the length of the data series.

Analyzing the results obtained by calibrating the DIFFU, CLCM and DLCM models in the Romanian sector of the Danube river between the station Zimnicea and Ceatal Izmail the results presented in Table 1. show that the three models have similar performance.

Testing the forecasting capability of the presented models, while taking into account an one-day lead time, points out the importance of the updating procedure. The same forecast updating procedure was used for all the three models, reducing the magnitude of errors to one third and making the residual error sequences uncorrelated, what was required.

However the difference between the tested models are so negligible, that they are considered so they have the same accuracy. The analysis of computation time required to elaborate hydrological forecasts in real time shows that the DLCM model runs three times faster than the CLCM model and ten times faster than the DIFFU model.

The DANUBIUS model (Serban and Corbus, 1987) is made up out of a simulation model and a forecast updating procedure.

The simulation model is based on the following Muskingum type equations of the which describe the behaviour of a river sector:

$$\begin{cases} \frac{dW}{dt} = Q - q \\ W = K[xq + (1-x)Q] \end{cases} \qquad (12)$$

where: W is storage in the river sector;
q - inflow;
Q - outflow;
x,K - parameters.

The discrete impulse-response function of the equations system (12) is (Serban and Corbus, 1987):

$$h(j\Delta t)=\begin{cases}1-\dfrac{K}{\Delta t}[1-e^{-\Delta t/K(1-x)}], & for\ j=1\\[2ex] \dfrac{K}{\Delta t}[1-e^{-\Delta t/K(1-x)}]^2 e^{-j\Delta t/K(1-x)}, & for\ j=2,3,...\end{cases} \qquad (13)$$

The kernel function has two parameters K and x. Parameter K represents the travel time under steady-state conditions and it is function of the inflow in the river sector and Parameter x represents the attenuation of the floods.

The updating procedure used applies different approaches for the rising and falling limb of the simulated hydrograph.

For the rising limb of the hydrograph, the following relationships are used:

$$QF(t+\Delta t)=QM(t)+[QS(t+\Delta t)-QS(t)]CF(t)$$

$$QF(t+2\Delta t)=QF(t+\Delta t)+[QS(t+2\Delta t)-QS(t+\Delta t)]CF(t+\Delta t)$$

$$CF(t)=[\frac{QM(t)-QM(t-2\Delta t)}{QS(t)-QS(t-2\Delta t)}]^{0.7}$$

$$CF(t+\Delta t)=[CF(t)]^{0.7} \qquad 0.5\le CF\le 2 \qquad (14)$$

For the recession limb of the hydrograph relationships (14) are used, but in that case the CF coefficients are thus calculated:

$$CF(t)=\frac{QM(t)}{QS(t)}$$

$$CF(t+\Delta t)=\frac{QF(t+\Delta t)}{QS(t+\Delta t)} \qquad (15)$$

where: QM(t- t), QM(t) are the flows measured at the moments t-2 t and t respectively;
CF(t), CF*t+ t) - correction factors at the moments t and t+ t respectively;
t - forecasting moment.

The DANUBIUS model was calibrated for the interval 1977-1979 and was checked for the interval 1980-1981 (Table.2).

The numerical criteria used to evaluate the DANUBIUS model performances were: the standard deviation, NTD, the first autocorrelation coefficient and the error frequency curve.

Table 1.

Assessment of the performance for the DIFFU , CLCM, DLCM models

Test Model	Criterion	Calibration 1977-1978	Simulation	Forecasting 1.day ahead
DIFFU	NTD	0.971	0.974	0.998
	R1	0.898	0.955	0.103
	SD	214.6	373.1	105.5
CLCM	NTD	0.964	0.960	0.998
	R1	0.939	0.970	0.146
	SD	309.8	461.9	104.8
DLCM	NTD	0.963	0.964	0.998
	R1	0.929	0.961	0.065
	SD	314.5	440.5	109.5

Table 2.

Assessment of the performance for the DANUBIUS model

Simulation and Forecast	Criteria	Calibration 1977-1979	Forecasting period 1980-1981 1	2	3	4	5	6	7
QS	SD	302	320	341	382	448	552	572	634
	NTD	0.94	0.95	0.91	0.79	0.70	0.64	0.56	0.45
	R1	0.354	0.37	0.38	0.41	0.43	0.45	0.48	0.51
QF	SD	-	68	121	175	268	345	382	440
	NTD	-	0.99	0.98	0.96	0.91	0.85	0.77	0.71
	R1	-	0.09	0.11	0.14	0.17	0.19	0.21	0.22

Analyzing the graphical and numerical criteria to evaluate the DANUBIUS model performances, the following conclusions can be drawn:

- the DANUBIUS model yields very good results when applied in real time. Thus the errors between forecasted and measured levels respectively are smaller than 20 cm in 100 %, 99 %, 98 %, 94 %, 88 %, 68 % and 51 % of the total cases for 1,2,3,4,5,6, and 7 steps/days ahead;
- the forecasting updating procedure leads to a considerable improvement of simulated flows especially for the first 1-4 days of lead time. This is obvious if the SD and NTD criteria are compared in simulation and forecasting regimes respectively;
- The autocorrelation coefficients r_1 for the forecasting intervals are smaller than 0.25, which shows that the model is correctly set, and that the updating procedure is efficient enough to diminish the residual errors degree of dependence.

Conclusions

The application of the DIFFU diffusion model and of the CLCM, DLCM and DANUBIUS hydrological models for the forecasts of daily flows in the Romanian sector of the Danube river leads to similar results.

The forecast updating procedures used by the models tested within the project substantially improved the forecast performance and the residual errors are non-correlated.

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THEMA/THEME

3

Methodische und empirische Erkentnisse bei der Aufstellung von Wasserbilanzen, zugehörige Aspekte von Klimaänderungen und -schwankungen sowie von anthropogenen Einflüssen

Methodological and empirical experiences gained with the compilation of water balances, related aspects of climatic changes and fluctuations and of anthropogenic impacts

Gutachter/Conveners

Professor Dr. V.A. Stănescu & Professor Dr. O. Bonacci

XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
hydrologisch-wasserwirtschaftliche Grundlagen

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Keynote paper

MAN'S AND CLIMATE CHANGE INFLUENCES ON THE WATER RESOURCES

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Abstract

A synthesis on the present problems of the water cycle under the circumstances of the changes in the hydrological balance components due to the human activity and the climate change is presented. The behaviour of the different components of the bio-geochemical and water cycles under the aforementioned conditions depends on the space and time scales, thus: 1. patch scale processes (SVAT models); 2. regional scales models which aggregate the small scale processes to sizes solved by models in real landscapes (10^4km^2); 3. investigations at a scale of 10^5-10^6km^2; 4. global procedures and aggregated models for the translation of the large scale outputs of climate into the scale of ecosystems.
Some types of physically-based as well as the statistical models for trend analysis of hydrological data, used at different range of space are shown.
An overview of the papers concerning the impact of the human activity and/or the climate change upon the water balance components, submitted at the XVII Conference of Danubian Countries in Budapest 1994, is made. The deviations in determining the mean annual runoff using grid maps at different scales are also considered.
The cooperation between Danubian Countries in a sustainable water development constitutes a sound basis for believing that the future of water resources in this region will be optimistic.

Auswirkungen der menschlichen Tätigkeit und der Klimaänderung auf die Wasserresourcen

Kurzfassung

Es wird eine Synthese der Probleme des Wasserkreislaufs geboten, welche sich in den durch menschliche Tätigkeiten und Klimaänderungen herbeige führten Veränderungen der Komponenten der hydrologischen Bilanz manifestieren. Das Verhalten des biochemischen und Wasserkreislaufs-Komponenten hängt unter den erwähnten Verhältnissen vom Raum- und Zeitmabstab ab, undzwar: (1) Prozesse im Parzellen-Mabstab (SVAT-Modelle); (2) Prozesse im regionalen Mabstab, welche die Kleinmabstab-Prozesse zu

Gröbenordnungen integrieren, welche schon durch Modelle im wahrhaftigen Landschaftsmabstab ($10^4 km^2$) gelöst werden können; (3) Untersuchungen im Mabstab von 10^5-$10^6 km^2$; (4) globale Verfahren und Aggregatmodelle für die Übersetzung der grobmabstäblichen Ausgangsdaten von Klimamodellen in den Mabstab des Ökosystems.
Es werden verschiedene Typen von physisch begründten Modellen sowie von statistischen Modellen für die Trendanalyse hydrologischen Daten gezeigt, welche in verschiedenen räumlichen Mabstäben verwendet werden können.
Es wird ein Überblick über die zur XVII. Donauländer-konferenz (Budapest, 1994) eingereichten, sich mit den auf die Wasserbilanz-Komponenten ausgeübten Auswirkungen der menschlichen Tätigkeit und/oder der Klimaänderung befassenden Beiträge geboten. Es werden dabei die bei der zur Feststellung des langjährigen mittleren Abflusses erfolgenden Anwendung von Rasterkarten verschiedener Mabstäbe auftretenden Abweichungen ebenfalls untersucht.
Die Zusammenarbeit der Donauländer für eine erhaltbare wasserwirtschaftliche Entwicklung bildet eine feste Basis für die Annahme, dab die man der Zukunft der Wassersirtschaft in dieser Region optimistisch entgegenblicken kann.

INTRODUCTION

Lots of people, scientists and the others, feel that something is happening to our climate, water resources and environment. There are local problems everywhere and they are different. That is why a large part of scientific community is deeply interested in the perception and the prediction of the water resources problems the humankind is cope with. The main purpose of this short key-note paper is a free and open discussion of the very complex problems related to the impact exerted by antropic and climate changes upon the water balance.

There are a many interesting and valuable conclusions but despite of them the general trend in water resources both concerning the quantity and the quality is not optimistic. Biswas (1991) stated that, like oil some 15-20 years ago, the day when water could be considered to be a cheap and plentiful resource is not virtually over.

On the one hand, the world population is increasing continuously and almost unforseeingly and on the other the amount of fresh water available on a long term basis is limited.

So, the ratio between the needs and water resources is decreasing steadily. Moreover, as the human activity increases, more and more waste products are contaminating available water resources.

Extensive activities have been carried out in water resources development and management during the last 50 years.

Although many of these have had a positive instantaneous impact on the environment, in the long term their influence has proved to be negative. The main issue facing the water related experts is how to ensure a rapid and adequate response to the changing contexts in an unpredictible future and how to prepare the mankind for the water resources future.

A possible representation of the interraction between the water balance components and the human activities is shown on Figure 1.

According to this scheme, the human activity effects may be grouped, thus:

1. Effects of the land cover changes silvicultural and agricultural treatments, deforestation, ploughing, etc.);

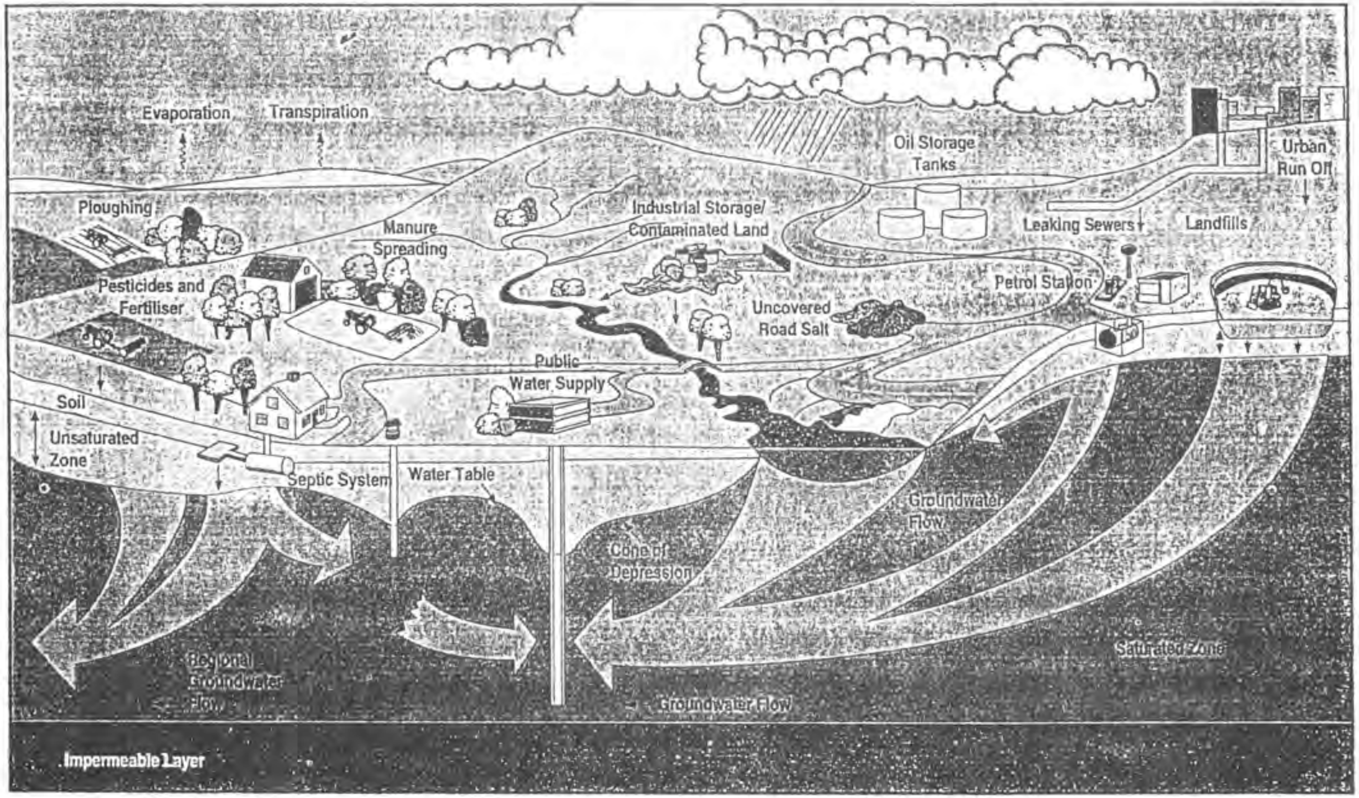

Figure 1. The interraction between the water balance components and human activities (afterPantha Rhei, No. 18, 1984).

Table 1. Enviromental impact of large engineering projects.

TYPE OF PROJECT	ENVIROMENT MEDIA INFLUENCED BY THE PROJECT					
	NATURAL					SOCIAL
	WATER	AIR	SOIL	FLORA	FAUNA	MAN
WATER RESOURCES DEVELOPMENT	2	0	2	1	2	1 - 2
COMUNICATION AND TRANSPORT	2	0	0	1	1	1 - 2
MINING	2	0	0	1	1	1 - 2
INDUSTRY	2	2	0	1	1	1 - 2
URBANIZATION	2	2	0	1	2	1 - 2

Table 2. Change in the hydrologic cycle due to human activities.

TYPE OF PROJECT	The branch of a hydrologic cycle influenced by the project					
	SURFACE		SUBSURFACE		ATMOSPHERE	
	QUANT.	QUAL.	QUANT.	QUAL.	QUANT.	QUAL.
WATER RES. DEVELOP.						
irrigation	2	2	2	2	1	0
water control over catchment	2	2	2	2	1	0
water control in the rivers and lakes	2	2	2	2	1	0
increase of available water resources	2	2	1	0	1	0
COMMUNICAT. AND TRANSP.						
roads	0	1	0	2	0	0
railways	0	0	0	0	0	0
pipelines	0	1	0	1	0	0
airports	1	0	1	0	0	0
MINING						
surface mining	2	1	1	2	0	0
deep mining	1	1	2	2	0	0
exploitation of hydrocarbonic	0	2	2	2	0	0

2. Effects of the engineering works including urbanization (urban runoff, reservoirs, industries, etc.;

3. Effects on the water quality (leaking sewers, oil storage tanks and petrol stations, industrial waste water and storage/contaminated land, septic systems, pesticides and fertilizers, etc.).

Table 1 presents the environmental impacts of large engineering projects (Kovacs, 1980). Therein: 0 - means negligible influence; 1 - means slight and/or indirect impact; 2 - indicates a strong or direct influence.

Table 2 presents large engineering works listed and grouped according to the following three objectives (Kovacs, 1980): 1 - water resources development; 2 - communication and transport; 3 - mining.

In general, the methodology for the assessment of the impact on water resources due to human activity relies upon, either on the comparison of the results from representatives and/or on the modification of each component of the water balance equation, (if such modifications can be predicted).

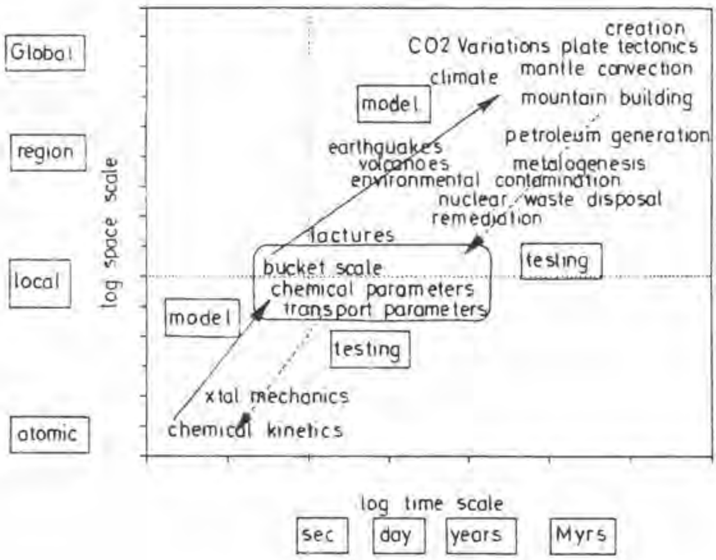

Figure 2. The scale of processes involved in hydrology and water resources (Torgersen, 1994).

The extent and magnitude of the development of water bodies all over the world have not been generally recognized until now. One of the main reasons of this unsatisfactory state is the complexity of the time and space scale of the processes involved in coupled hydrological, hydrogeological and water resources analyses and models. Figure 2 (Torgersen, 1994) shows that the next approach to the water resources analyses and models must involve both a development of grid-scale parametrisation from sound scientific principles at the atomistic level to the lenght scales which are either below and/or beyond the bucket/grid scale of the current engineering approaches (Torgersen, 1994). The water resources problems consist of very small and very fast processes. The causes predominantly appear in a limited area during a short period but the consequences are felt in a large area during a prolonged period. For example the time or the construction of a hydro-power plant or a chemical factory is a few years in an area covering a few square kilometers but the consequenes, predominantly negative, can affect a much larger area (hundreds or thousands of square kilometer), during several decades or even more.

CLIMATE CHANGE/HUMAN ACTIVITY CONSEQUENCES

It has been known since late in the last century that an anthropogenic warming of the earth climate was possible due to the atmospheric emissions and radiative properties of industrial and agricultural "greenhouse gases" (Arrhenius and Waltz, 1990). The problem is to assess the impact of climate change and its variability upon the components of the heat and radiative balance which in its turn exerts a major influence on the water balance.

To answer to this question it should firstly to know what is the real quantity of additional greenhouse effect as comparing with the present one which is beneficial for our planet life, induced by human activity which causes general climate change. Although the answer is not simple, there are a lot of models and scenarios related to the impact of climate change on different items, such as: 1. Sea level rise (WMO-IPCC, 1992) (C.Bondar, 1989); Hydroelectric power generation (Dud, 1993); Precipitations (Bonacci and Denic, 1993); (Koleva, 1994); 4. Water balance (Lobanova, 1994), (Zdenek, 1994), (Miko, 1994), (Niekamp and Hugel, 1994).

The reasons of the climate change exist and some local variations of the climate and hydrological parameters have been noticed.

So, the human activity which directly exerts an impact on the local water balance have caused, cause and will cause a lot of consequences due to the climate change at a regional and global scale.

Finally, there is only one reason for additional greenhouse effect which causes climate change and its variability; i.e. human activities.

Therefore, there is no significant difference between the human activities and climate change on the water balance. The main difference is probably in the space and time scale effects. The effect of the human activites can cover a relatively small area while the consequences of the climate change are more extensive both in the space and time scale.

Even under conditions where the earth's processes are not significantly influenced by the mankind activity the changes in physical parameters of the earth and implicitely the parameters characterizing the water balance componets affect the biochemical cycles which govern the life on the Earth. That is why, during the last two decades a special attention has been paid to the study of the water processes over the land-surface as input elements in global changes models.

Nevertheless the global circulation models (GCMs) do not include sufficiently the role of the biological processes and a profound knowledge of bio-hydrological processes at the land-surfaces is needed to assess the impact which climatic changes and/or Man's activity exerts on the biosphere (Bolle, 1993).

The research of the biosphere processes coupled with the modifications in the water balance components is needed as the former have a feedback impact on the latter.

To explore more closely the relationship between the earth's physical parameters and those of the biochemical cycles, ICSU has decided to initiate the International Geosphere-Biosphere Program (IGBP) which entail, a core project dealing with the Biological Aspects of the Hydroogical Cycle (BAHC). This core project has the following two objectives (IGBP Global Change Report No.28, 1994):

1. To assess the biospheric controls of the hydrological cycle through field measurements in view of developing models of the energy and water fluxes in the soil-vegetation-atmosphere system at temporal and spatial scale ranging from vegetation patches to GCMs grid cells. BAHC project will be interactive at the 10^4 - 10^5 km^2 scales with the project of the integration of the water balance and energy processes at continental scale

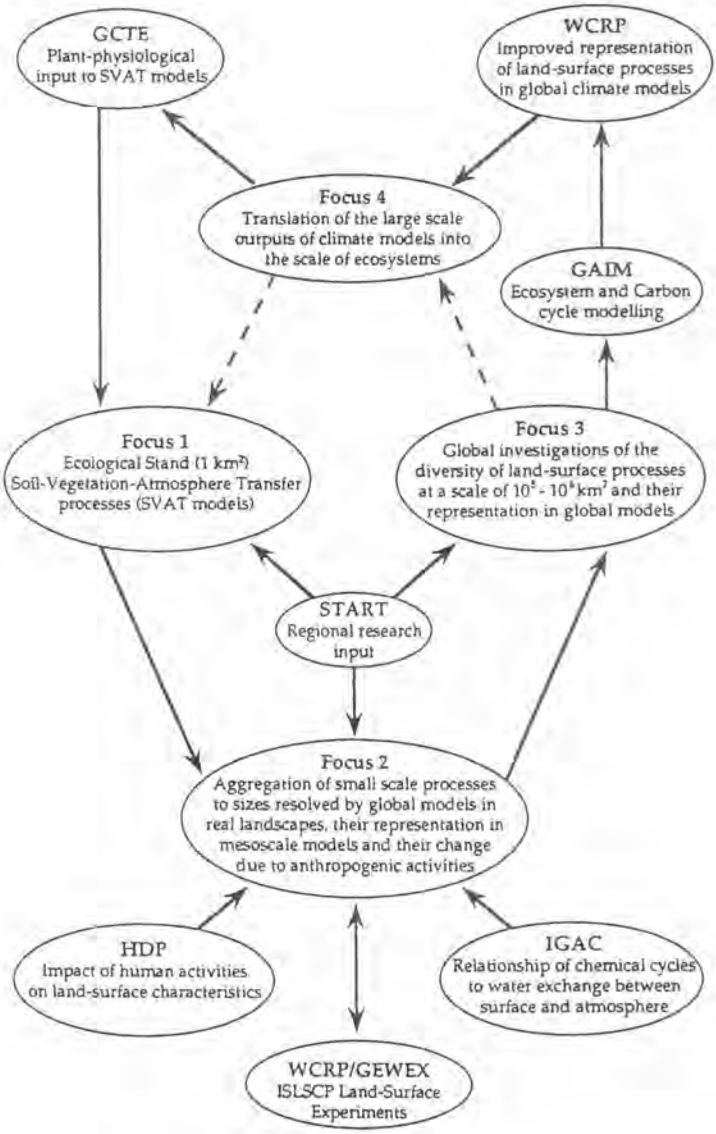

Figure 3. BAHC research in relation to other research activities. (IGBP. Report No. 28)

(Global Energy and Water Flux Experiment project -GEWEX- in the framework of the WMO-World Climate Research Program);

2. To develop appropriate data base that can be used to describe the interactions between the biosphere and the physical Earth System and to test/validate model simulations of such interactions.

The main focuses of the BAHC project (Fig. 3) address to the processes occurring at different scales of spaces and time, thus:

- **Focus 1** is oriented to patch scale processes using model of type SVAT (Soil-vegetation-atmosphere transfer);

- **Focus 2** extends its investigations toward the experiments of regional scales, taking into account the interaction between the water balance components and the land use, type of soils and vegetations under significant heterogeneity conditions, of their distribution;

- **Focus 3** is oriented to the determination of the spatial and temporal variability of the interactions biosphere-hydrosphere over large territories of 10^4-10^5 km^2.

- **Focus 4** is developing procedures, aggregated models to provide climatic variables (precipitation patterns and extreme events) using large scale information.

Thus, for applications in ecology and water balance the output of GCMs should be disaggregated (down scaled) and interpolated at a suitable resolution so as to predict at a spatial scale of 50 km and at a temporal scale less than one day.

For the time being a lot of SVAT models have been developped. The components of a SVAT model, (water balance components included) are shown on Figure 4 (Bolle, 1993).

The water exchange between plants and atmosphere depends on the type and the growth stage of the vegetation, soil humidity, length of the plant roots, CO_2 pressure as well as the meteorological characterstics of the radiation and air humidity at the atmospheric boundary layer.

It can be noticed that in the SVAT models the computation of the actual evapotranspiration as a main component of the water balance is primordial. Presently, there are a lot of models for the evapotranspiration assessment at a small scale and under homogeneous conditions, of the land cover and soil. Among the most used one can be noticed the models based on the eddy correlation (Mizutani and Ikeda, 1993) the micrometeorological method (Bowen ratio method), the modified Penman-Montheith method (1965) where the cannopy and aerodynamic resistences have been introduced.

To test/validate the parameters of these methods special and costly measurements concerning water storage capacity of the soil, the flow velocity of the sap and the water intake ratio should be performed.

As the areas increase, the interconnection of the landscape units result in the very complex ecological processes as shown in Figure 5 (Bolle, 1993).

An evaluation at this scale (10^4 km^2 - 10^5km^2) of the processes governing the coupled biogeochemical and water balance cycles under the human and/or climate change impact becomes much more complicated.

The processes induced by the human intervention at this regional scale have not only a local socio-economical and ecological impact but a sensitive influence on the climate.

Among these distorsions of the fragile equilibrium between the nature and human requirements one can notice the land degradation and desertification which are the result of the over exploitation of water resources forest fires, over grazing, salinization, inadequate replacement of nutrients, climate variability and climate change. The dynamics of these processes have mesoscale impacts on the wind systems and precipitation patterns and aquifers may transport water from distant location (Bolle, 1994).

Thus, the mesoscale processes have an impact not only on the areas of 10^4-10^5km^2 order of magnitudes but due to the interconnexion of the water cycle with the biogeochemical cycle processes the vegetation strongly influences the runoff and the precipitations. Consequently, the sediments and biological debris volumes will increase which results in an impact on the carbon cycle. So the hydrological cycle once more is interrelated to the bio-geochemical cycles.

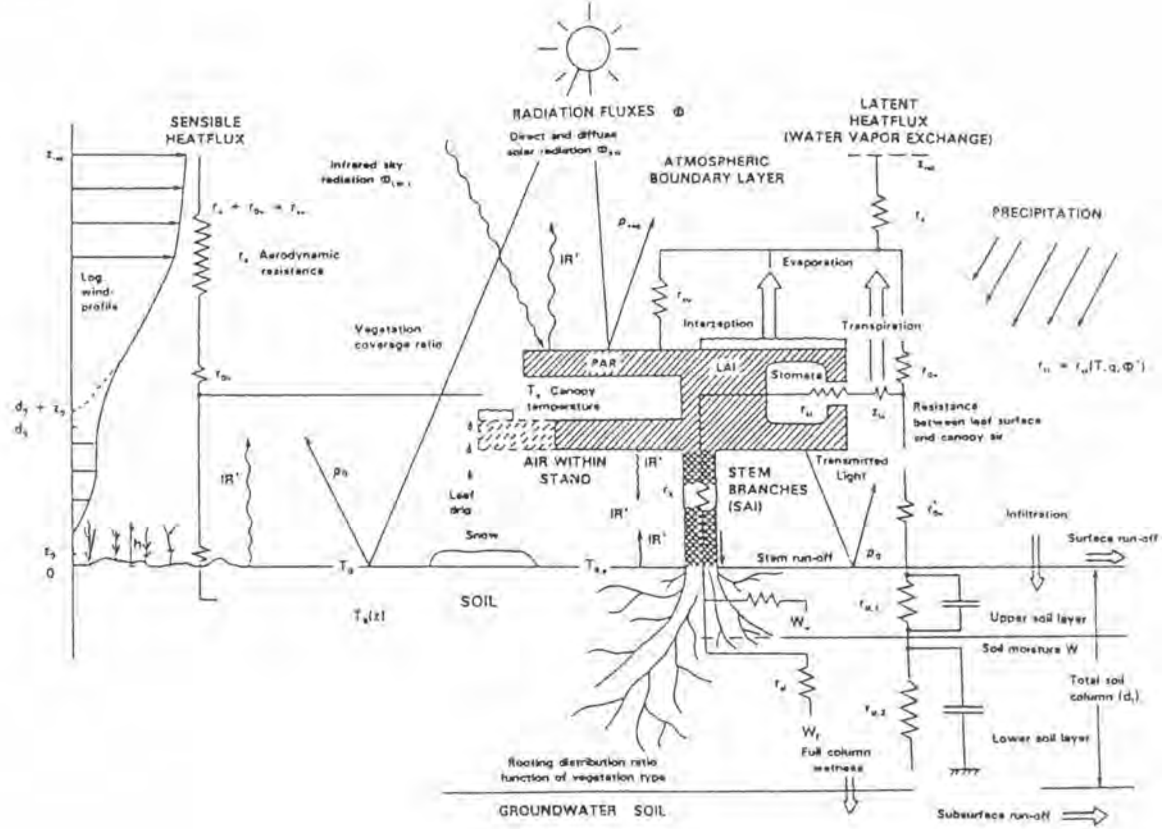

Figure 4. Components of a SVAT model. (Bolle, 1993)

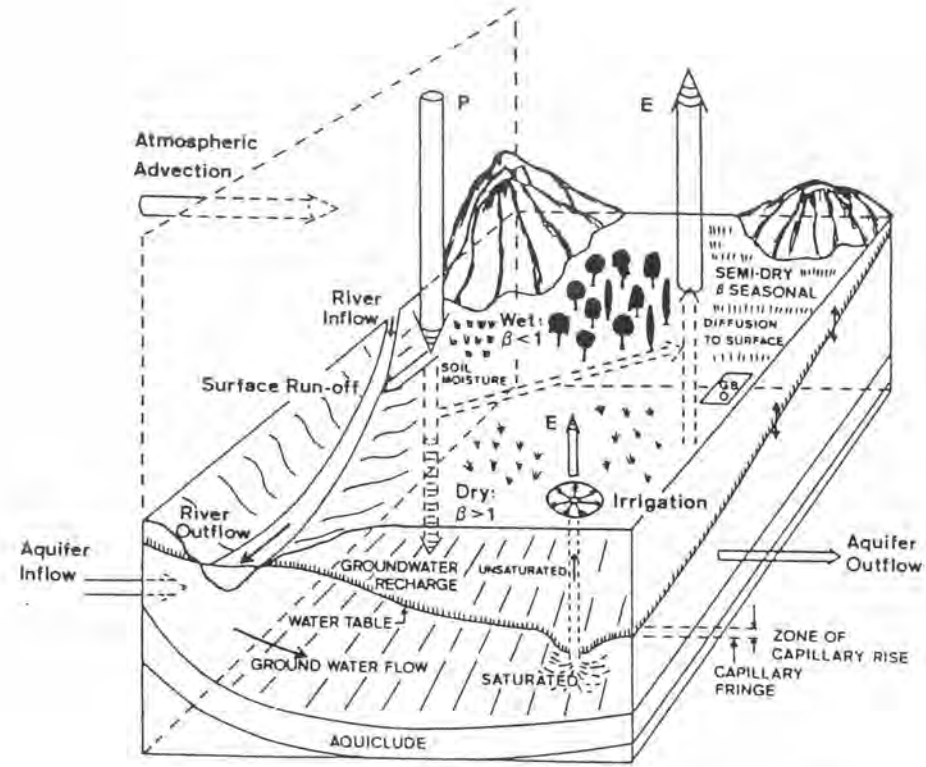

Figure 5. Scheme of a complex landscape and same processes relevant for BAHC.

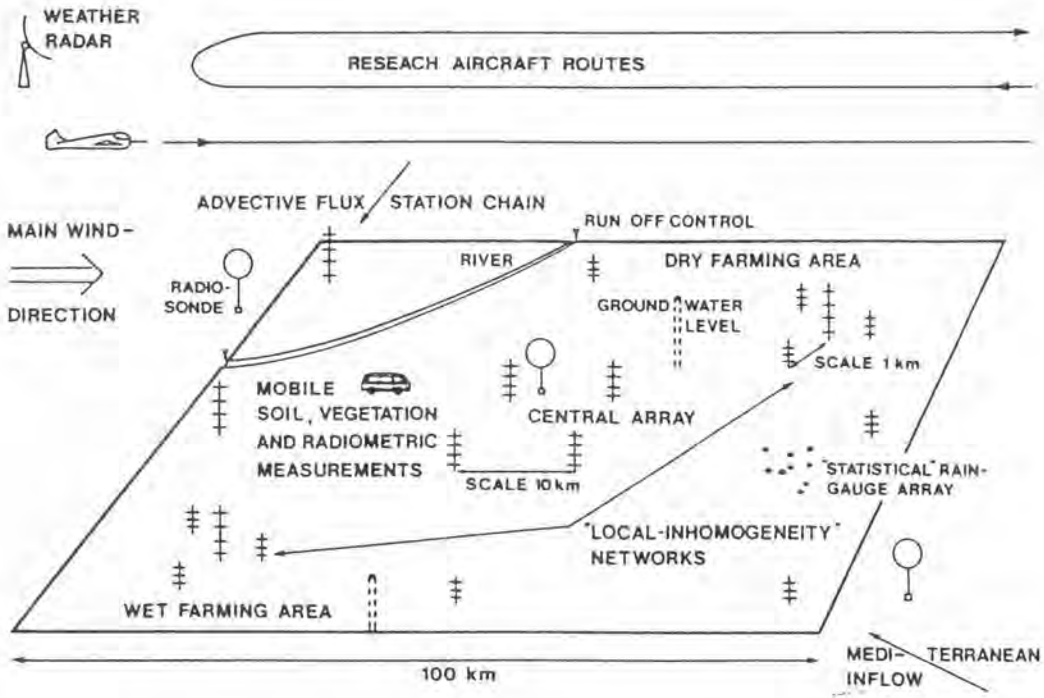

Figure 6. Example for the design of a mesoscale land-surface experiment (Bolle, 1993)

The problem which arises at the mesoscale is to find the aggregation models which should be able to determine both the evapotranspiration estimates averaged over inhomogeneous areas and to study its variability in order to established how conclusive are the mean values.

To build such aggregation models a good knowledge of the land cover is required. Among the main models which have been developped, the SPAC (Soil-Plant-Atmosphere-Continuum) includes some fundamental equations of the atmosphere and underground region (Kuzuha et al., 1993).

In this model the horizontal flows of water and heat are ignored in the underground region.

Another model (Budagovski, 1986) takes into account the leaf area index (LAI) as characterizing the heat and water fluxes. A data convolution on LAI dynamics into a general time-function provides good values for actual evapotranspiration. The model relies upon the assessment of a function Y(LAI) which is determined on plots for different types of vegetation. The evapotranspiration is than computed function of Y(LAI) and the meteorological factors.

The leaf area index as well as the Y(LAI) variability are assessed using remote sensing technics by aircraft and satellite.

An important problem for the aggregation of the hydrological and bio-geochemical cycles over an extended area is the spatial and temporal scaling.

The scaling of the water balance processes from small areas towards extended areas implies the aggregation of the fluxes between atmosphere and the land-surface characteristics to be comparable with the simulations made on the regional and global models.

On the other hand the research of the ecosystem requires inputs from atmosphere (water, snow, atmospheric trace constituents) at spatial resolutions compatible with the ecological units. Therefore, there is a "scaling up" of the ecological zones and a "scaling down" of the meteorological inputs. These implies non-linear relationships and the process parametrization is completly different from that for the patch scale.

In order to study this parametrization a certain number of sites representative for an extended area (say 10^4 km^2) is selected.

These sites are intensively equipped with instruments up to the atmospheric boundary layer.

A system for assessing the inhomogeneity variability at the grid width of mesoscale models and medium resolution of the satellite pixel is shown in Figure 6.

The aircraft observations should be up to dated periodically.

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Another way to study the human/climate change impact is the statistical analysis of the hydrological time series.

In the framework of the WMO - project concerning the climate change program (WCP-WATER) a comparative analysis of hydrological and related data has been launched.

The Working Group of hydrology of the WMO Regional Association VI (Europe) initiated a "Technical Report (Lemmela, Liebscher, Nobilis, 1990) having the following subjects:

- Studies of climate changes and climatic variability using hydrological data (rapporteur: Mr. F.Nobilis, Austria);

- Effects of climate changes on water resources system (rapporteur: Mr. B.Lemmela, Finland);

- Models for evaluating the impact of climate changes on water ressources (rapporteur: Mr. H.Liebscher, Federal Republic of Germany);

This report has described the availability of long hydrological time series (Global Runoff Data Centre-GRDC, Global Precipitation Data Centre-GPCC and FRIEND data base).

Some models for trend analysis of hydrological data series were developped. Also, models for studying the influence of climatic change (based on the future scenarios of studying climate changes) on the hydrological cycle and its components were considered.

Another project directed by Polish Academy of Science in collaboration with the International Institute of Applied System Analysis (IIASA) undertook a statistical analysis on more than 200 sets of data whose span ranged from 30 to 200 years (WMO, 1994).

The test results (published in September 1992) provided statistical evidence of a greater change in the set of time-series than should arise by chance.

The way to study from statistical point of view should continue on a long term basis considering the following goal (WMO, 1994):

- formulating guidelines for water resources managers regarding possible modifications of procedures for deriving design data;

- identifying a global (and regiona) network of benchmark stations;

- exploring procedures for a simulataneous analysis of hydrological and climatological data series.

During the XVIII Conference of Danubian Countries on Hydrological Forecasting and Hydrological Bases of Water Management - Budapest, 1994 a lot of papers are concerned with the trend analysis of hydrological and climatological data series in order to assess human and climate change impact on the water balance components.

An interesting problem is the role of the spatial scale in case of the mean annual runoff representation in form of a grid maps. The advantage of the grid maps for representing the water balance components is evident as they allow to digitize the estimates in a system of cells and thus they facilitate the automatic data processing.

There are several procedures for grid maps producing (Arnell, 1991) of the mean annual runoff:

- Utilization of the runoff estimates recorded in small, representative basins as the mean value of the grid cell. This procedure overestimates the average annual runoff because small catchments are concentrated in head water regions.

- Distribution of the runoff recorded at the outlet of an extended-area basins among the grid-cells within the basin. This procedure is somehow similar with that for producing the isoline maps. Using a larger number of hydrological stations within Danube Basin, the errors of the water balance did not exceed + 5% (Domocos and Sass, 1990). It implies a disaggregation of the average runoff recorded at the outlet by a weighting procedure taking into account the relative contribution of each grid cell.

- Utilization of empirical relationships between runoff and climate and apply the computed runoff to a grided climate date base. This method implies a good knowledge of the climatic data spatial distribution.

- Using the models of monthly water concomitently with climatic grid data. The computation implies the use of the empirical models (Turk-Pike, FREND multiple regression, IIASA Terrestrial Water budget) and therefore the results depend on how the correct are the parameters of these models for monthly evapotranspiration assessment.

The application of this procedures for a grid of $0.5^0 \times 0.5^0$ (35×55 km) in the Danube Basin corresponding to the hydrological station Hofkirchen has lead to computed average annual runoff values which overestimate the real one when using the Turk-Pike and FREND relationships and under estimate the real value of the runoff for the other methods.

In general for a good enough estimation of the annual runoff, using grid maps a much higher resolution grid is needed. For the territory of Romania the utilization of a grid map 30×30 km, results in significant evaluation of the average annual runoff as compared with the results obtained for a grid map having four times more resolution.

INSTEAD OF CONCLUSIONS

Water is our common responsability. The present World water consumption is about 5000 km^3/year and a linear extrapolation results in almost, 10000 km^3 in 2050. To cope with the water needs in the future and with the natural hazards of floods and droughts, the institutions responsibile for water management should be able to have an as correct as possible perception on the regional and global changes due to human activities and/ or climate change.

The prevision of the changes in water balance components corroborated with the inherent interractions with the biogeochemical cycles is prerequisite for a sustainable socio-economical development.

In view to this aim the components of the water balance and the related biogeochemical ones should be continuously measured with a dedicated system of instruments.

On the other hand, a continuous research activity to build models as close as possible to the complex processes of the water cycle at different space and time scales, is required.

To develop these goals a close cooperation between scientists from different regions, is imperative, because the water problems exceed the national boundaries. The main goal of the cooperation between the Danube countries is a sustainable water development in the Danube basin. Great efforts should be made to reach this objective and the present successful cooperation constitutes a sound basis for believing that unpredictable future of water resources in this region will be optimistic.

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XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
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REGIONAL HYDROLOGIC ANALYSIS OF THE UPPER KUPA RIVER CATCHMENT AREA

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ABSTRACT

The upstream stretch of the Kupa River catchment area (within the Danube catchment basin) is the vegetation overgrown karst receiving, due to favorable climatologic and topographic conditions, large quantity of precipitations. The paper presents the results of regional hydrologic analyses based on characteristic parameters of mean, maximum and minimum annual flows for the analyzed period (1950-1989). Based on interrelation of typical hydrologic parameters general expressions are developed for main characteristics and relations governing the surface runoff from the analyzed border karst region of the Danube catchment basin. The results of the analysis are compared to relevant results of other analyses.

REGIONALE WASSERWIRTSEHAFTSANALYSE DES EINZUGSGEBIETES DES OBEREN TEILES VOM FLUSS KUPA

ZUSAMMENFASSUNG

Der obere Teil des Einzugsgebietes der Kupa (im Einzugsgebiet der Donau) gehört zum bewachsenen Karst mit grossen Niederschlagsmengen als Folge günstiger klimatologischen und topografischen Verhältnissen. In der vorliegenden Arbeit sind angegeben die Ergebnisse von regionalen wasseruirtschaftlichen Analysen welche auf Grund Karakteristischer Parameter der mittleren, grössten und kleinsten Jahresabflussmengen durchgeführt wurden für die bearbeitete Zeitperiode (1950-1989). Auf Grund wechselseitiger Verhaltnisse von Karakteristischen hydrologischen Parameter, wurden allgemeine Ausdrücke für die hauptsächichen Verhältnisse entwickelt bezüglich des oberirdisehen Abflusses vom behandelten Karstgebiet des Randteiles vom Donaueinzugsgebiet. Die Ergebnisse dieser Bearbeitung und die entsprechenden Ergebnisse anderer Analysen wurden gegenübergestellt.

1.0 INTRODUCTION

The analyzed region of the upper Kupa River catchment area is located in the western part of the Croatian karst in the Gorski Kotar district. The mild continental mountain climate of this region is characterized by high precipitations - 1900 to 3000 mm per year in average and up to 5000 mm in wet years [5]. The precipitation distribution is typical for particularly low precipitations during the warm season (June-September), with frequent periods of completely deficient rainfall (even for several months), and heavy precipitations during the cold season (October-May).

The major water courses, the Kupa River with its tributaries Čabranka and Kupica, and Rječina River have considerable underground retentions in the back their springs. Only the very small streams of the Crni Lug have practically only surface runoff. The parts of the catchment areas superficially gravitating towards the watercourses are steep and generally overgrown by coniferous and deciduous forests. Regarding high precipitation and vegetation overgrowth, the Gorski Kotar district differs from the other Croatian karst regions where the vegetation reduces going in the eastward direction and the precipitations fall considerably (the most common average annual precipitation from 1300 to 2300 mm).

The intent was to interrelate the characteristic hydrologic parameters of the upper Kupa River catchment area for the period 1950-1989 with the parameters of other catchment areas in the vegetation-overgrown karst of the Gorski Kotar region and the parameters of the complete Croatian karst. (The data obtained from 60 gaging stations in 33 streams in typical karst catchments with the total influence catchment area of 12,600 km^2 have been analyzed for the Croatian karst in the period 1950-1989 [6]).

The analyzed catchments in the upper Kupa River stretch, namely within the complete region of vegetation overgrown karst of the Gorski Kotar are shown in Fig. 1, together with the analyzed gaging stations. It has been determined that the dry period in the overgrown karst region after 1980 did not cause non-homogeneity in the majority of hydrologic series. The former regional analyses have also led to a conclusion that the relations with more than two parameters cannot be applied to karst [6]. This paper covers continuation of the research started in [6].

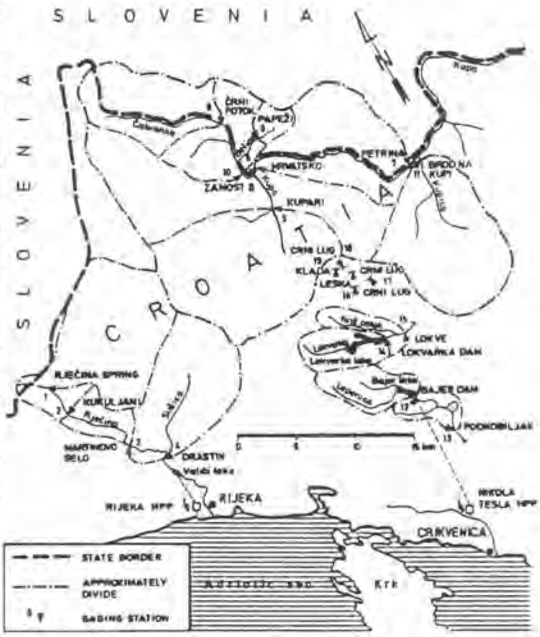

Fig. 1 The Gorski Kotar overgrown karst catchment areas with gaging stations.

2.0 MEAN ANNUAL FLOWS

The conducted analyses have indicated that there are reliable relations between the mean annual flows Q (m^3/s) and influence catchment area A (km^2) for the catchments in karst regions. The Fig. 2, together with calculation data, shows the relations applying to these regions:

(a) the upper stretches of the Kupa and Rječina catchments are affected by underground retentions in the back of their springs:

$$Q = 0.184\ A^{0.8} \qquad \text{correlation coeff.} \quad r = 1.00 \qquad (1)$$

(b) the water courses influenced by the underground retentions and riverbed losses:

$$Q = 0.047\ A - 0.21 \qquad r = 0.99 \qquad (2)$$

(c) very small steep catchments with high precipitation:

$$Q = 0.0614\ A + 0.0028 \qquad r = 1.00 \qquad (3)$$

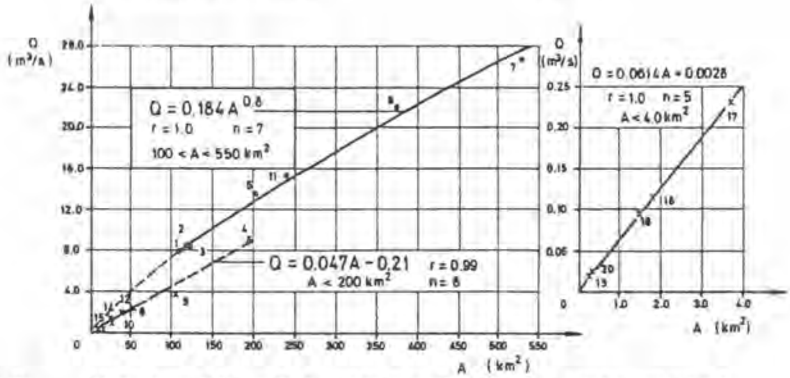

Fig. 2 Mean annual flows Q dependant on the influence catchment area A

The relations (1), (2) and (3) are developed on a small number of data, but since their deviation from the input data is small they are considered sufficiently reliable.

The relation between the effective, P_e (mm), and gross, P (mm), precipitations has been analyzed considering the relations developed for the Croatian karst catchments [6]:

$$P_e = 0.83\ P - 250 \qquad r = 0.98 \qquad (4)$$

The Fig. 3 illustrates the relation (4) which applies for effective runoff in karst for the catchment area with no relevant water losses and mean-water runoff coefficient c > 0.50. In deriving the relation (4) for the Croatian karst 18 paired values (P, P_e) for the overgrown karst with runoff coefficient c > 0.50 have been used in calculation.

In addition to the relation $P_e = 0.83\ P - 250$, the Fig. 3 also shows the limits within which 95% of the values is set (the probable deviation including 95% cases is $\sigma_p = \pm 18\%$). The relation (4) slightly differs from the relation for the Sava River karst region, i.e. $P_e = 0.88\ P - 224$ (mm) [4], and has also been checked against the data on Hellenic karst [2] with very low mean annual precipitations (P = 600 - 800 mm), as shown in Fig. 3.

3.0 MAXIMUM ANNUAL FLOWS

The Fig. 4 shows paired values of influence catchment areas and maximum recorded specific inflows (A, q_M) for all discussed stations in the Croatian karst, with separately presented stations in the overgrown karst. The maximum values envelope for the region of minor catchment areas (up to A = 36 km^2) was defined on the basis of maximum overgrown karst:

$$q_M = 5.74\ A^{-0.093} \qquad (5)$$

and maximum specific inflows of the upper Kupa catchments are
very close to the envelope curve for the catchment areas A = 36 - 4000 km^2

$$q_M = 25.89\ A^{-0.514} \qquad (6)$$

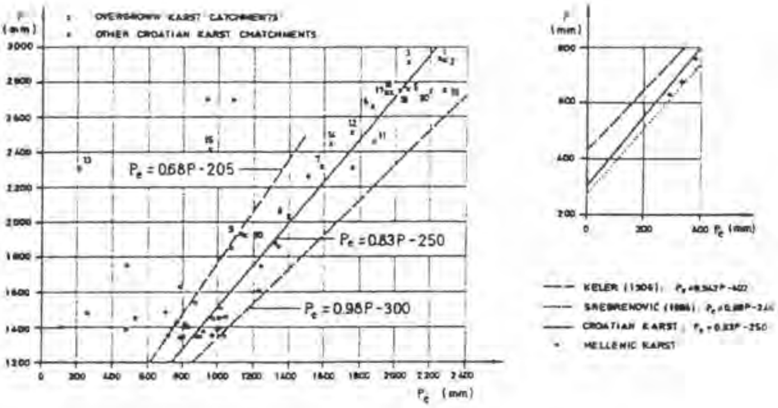

Fig. 3 Effective precipitation P_e dependant on gross precipitation P

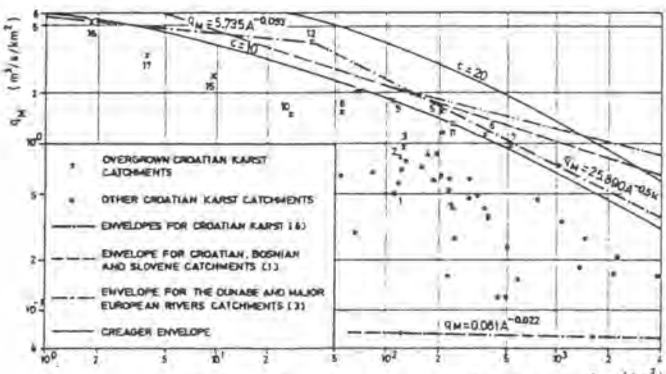

Fig. 4 Maximum recorded specific inflows q_M and Croatian karst influence catchment areas A

The Fig. 4 also shows Creager 10- and 20-year envelope curves, and the maximum envelope curve for the catchment areas of Croatia, Bosnia and Slovenia [1]. The maximum envelope curve, applicable for catchment areas A = 100 - 8000 km^2 [3], has also been presented for catchment areas of the Danube and large European rivers. According to this envelope, the values q_M for the catchments exceeding 150 km^2 in area increase as compared to the envelope for karst catchment areas whose minimum values are explained by the effect of karst underground retentions reducing the flood water.

For modular coefficients of maximum annual flows of 10- and 100-year return period, the relations with the maximum annual flows variation coefficients c_{vM} have been developed (Fig. 5).

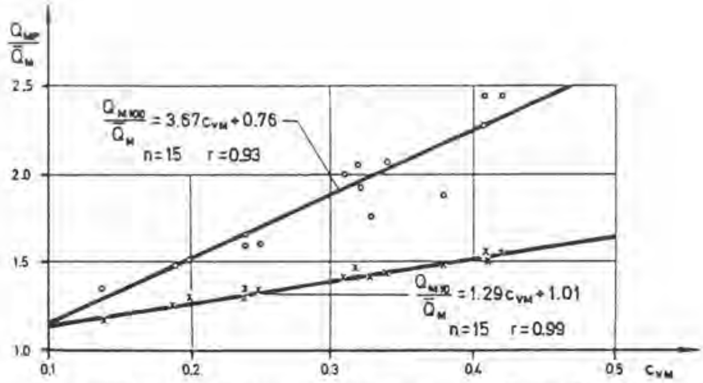

Fig. 5 The modular coefficients of maximum annual flows $Q_{MP}/\bar{Q}_M$ depending on maximum annual flows variation coefficient c_{vM}.

The relations developed for the overgrown Croatian karst

$$\frac{Q_{M10}}{\bar{Q}_M} = 1.29\ c_{vM} + 1.01 \qquad r = 0.99 \qquad (7)$$

$$\frac{Q_{M100}}{\bar{Q}_M} = 3.67\ c_{vM} + 0.76 \qquad r = 0.93 \qquad (8)$$

show little difference from the relations developed for the catchment areas of the Danube and large European rivers [3]:

$$\left(\frac{Q_{M10}}{\bar{Q}_M} = 1.3\ c_{vM} + 1.01, \qquad \textit{respectively}\ \frac{Q_{M100}}{\bar{Q}_M} = 3{,}67\ c_{vM} + 0{,}81 \right)$$

4.0 MINIMUM ANNUAL FLOWS

The typical parameters of minimum annual flows were available for analysis only for the upper Kupa catchment area, including the largest catchment area in the Crni Lug region, since the other catchment areas of the overgrown karst of the Gorski Kotar dry out during the season of low water level. The relations have been developed for average minimum annual flows $\bar{Q}_m$ (m^3/s) dependent on influence catchment area size A (km^2) and mean annual flows Q (m^3/s), as shown in Fig. 6.

$$\bar{Q}_m = 0.004\ A^{1.08} \qquad r = 1.00 \qquad (9)$$

(the relation applies for $A > 3.0\ km^2$)

$$\bar{Q}_m = 0.107\ Q^{1.04} \qquad r = 0.99 \qquad (10)$$

For minimum annual flows in the upper Kupa catchment area of 10- and 100-year return periods, Q_{m10} and Q_{m100} (m^3/s), respectively, the relations have been developed dependant on influence catchment areas A (km^2) and mean annual flows Q(m^3/s) which need not be graphically presented.

$$Q_{m10} = 0.00215\ A^{1.113} \quad r = 0.99 \quad \text{for } A > 3.0\ km^2 \qquad (11)$$
$$Q_{m100} = 0.00074\ A^{1.244} \quad r = 0.99 \quad \text{for } A > 3.0\ km^2 \qquad (12)$$
$$Q_{m10} = 0.064\ Q^{1.07} \quad r = 0.98 \qquad (13)$$
$$Q_{m100} = 0.033\ Q^{1.19} \quad r = 0.97 \qquad (14)$$

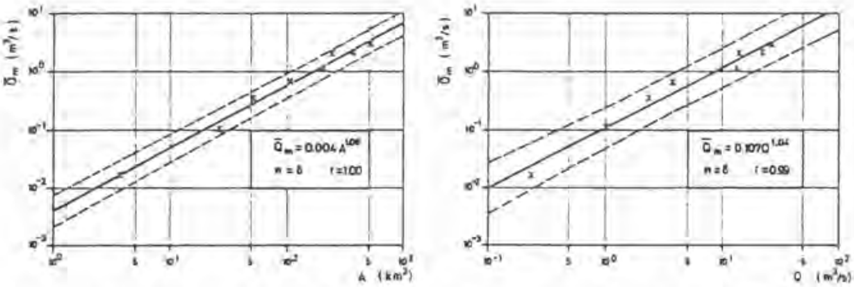

Fig. 6 Relation between average minimum flows $\overline{Q}_m$ with influence catchment area A and mean annual flows Q for the upper Kupa catchment area

5.0 CONCLUSIONS

The relations presented in this paper could be used for similar catchment areas with no or insufficient data available from direct hydrological monitoring. However, it is important that in addition in geological, topographical and biological runoff conditions, the similarity of the precipitation regimes regarding rates and distribution exists.

It should also be said that, compared with the results of the regional analyses conducted for the catchment areas of the Danube and major European rivers [3], the number of relations between the characteristic hydrological parameters obtained for the overgrown karst was considerably smaller. The main cause is the specific karst relief with its specific underground water circulation which differently affects the runoff in the analyzed hydrological profiles.

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TRANSLATION: Sabina Ekinović

XVII. KONFERENZ DER DONAULÄNDER
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DIE DURCH DIE DÜRRE GEFÄHRDETEN REGIONEN DES DONAUEINZUGSGEBIETES

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Kurzfasung

Die Verfasser haben in einer früheren Studie (2) den Dürreindex PAI_0 eingeführt, welcher als prozentmässig ausgedrückte Quotient zwischen der mittleren Temperatur der Periode April-August und dem gewichteten Mittelwert der monatlichen Niederschlagshöhen der Periode Oktober-August definiert wurde.In einer weiteren Studie (3) wurden - unter Verwendung der zur Wahrscheinlichkeit 4% (d.h. zur Wiederkehrsperiode 25 Jahre) gehörenden Werte $PAI_{4\%}$ der PAI_0 Indizes der einzelnen Jahre - die Regionen des Theiss-Einzugsgebietes vom Gesichtspunkt ihrer Gefährdung durch die Dürre qualifiziert (z.B. $PAI_{4\%} < 6$: dürrefreie..., $PAI_{4\%} > 12$: durch die Dürren ausserordentlich gefährdete Region).In der vorliegenden Studie wurde dieselbe Methode zunächst auf das Staatsgebiet Ungarns, und sodann auf das ganze Donaueinzugsgebiet angewandt (Bild 2.)Bei der Lösung letzterer Aufgabe wurden der Donaumonographie (1) entnommene Niederschlags- und Temperaturinformationen sowie eine empirische Beziehung zwischen dem langjährigen Mittelwert des spezifischen Abflusses und der Kennzahl $PAI_{4\%}$ verwendet (Bild 1.).

The drought-endangered regions of the Danube Basin

Abstract

In an earlier paper of the same Authors (2), the drought index PAI_0 was introduced, defined as the in persentage expressed ratio between the mean temperature of the period April-August and the weighted average value of monthly precipitation amounts during the period October-August.In a further study (3), the regions of the Tisza Basin were qualified according to their endangerment by droughts, on the basis of indices $PAI_{4\%}$, i.e. the values of 4% probability (or of return period of 25 year) of the indices PAI_0 of individual years (e.g. $PAI_{4\%} < 6$: no danger of drought,.. $PAI_{4\%} > 12$: region extremely endangered by drought).In the present paper, the same method has been adopted first to the national area of Hungary, and then to the whole Danube Basin(Fig.2.)The latter task has been solved by utilizing precipitation and temperature information taken from the Danube Monograph (1) as well as an empirical relationship between the multi-anual specific runoff and the index $PAI_{4\%}$ (Fig.1.).

1.Ziel und Methode

Die niederschlagsarme Witterung der letzten Jahre sowie die sich entwicklende Klimaänderung (eine globale Aufwärmung der Atmosphäre) lenken die Aufmerksamkeit in zunehmendem Masse auf das Phänomen Dürre, auf die dadurch verursachten Probleme, auf die daraus resultierenden - hauptsächlich die Landwirtschaft treffenden - Schäden.

Eine der Hauptfragen ist die folgende: welche Regionen werden von der Dürre öftesten und härtesten betroffen?

2.Anwendung auf das Theiss-Einzugsgebiet

Diese Frage wurde für das Einzugsgebiet der Theiss mit Hilfe des sog. Dürrenindexes PAI beantwortet, dessen Gebrauch in Ungarn war einigen Jahren eingeführt wurde.

Der Dürreindex PAI_0 wurde folgendermassen definiert:

$$PAI_0 = \frac{t_{IV-VIII}}{P_{X-VIII}} \cdot 100 \qquad (1)$$

wobei: PAI_0 - der Dürreindex (°C/100 mm), $t_{IV-VIII}$ - mittlere Lufttemperatur der Periode April-August (°C), P_{X-VIII} - gewichtete Niederschlagshöhe der Periode Oktober-August (mm) Bei einer durchschnittlichen Saatsstruktur sind die anzuwendenden Wichtungszahlen die folgenden: für Oktober: 0,1; November: 0,4; Dezember bis April: 0,5; Mai: 0,8; Juni: 1,2; Juli: 1,6 und August 0,9 (4).Die nach Gl. (1) errechnete Kennzahl PAI_0 muss, in Abhängigkeit von der Anzahl der Schwületage, der Länge der niederschlagsfreien Periode und der Tiefe des Grundwasserspiegels, noch mit verschiedenen Korrektionsfaktoren modifiziert werden (2).

Die Struktur des Dürreindexes ähnelt derjenigen des Ariditätsfaktors, der als das Verhältnis zwischen den langjährigen Mittelwerten der potentieller Verdunstrung und des Niederschlags definiert wurde und dessen annähernde gebietliche Verteilung für das Karpatenbecken und den mittleren Teil des Donuaraumes durch K. Szesztay (5) ermittelt wurde.

Die Einstufung der Regionen erfolgte auf Grund der Kennzahl $PAI_{4\%}$ d.h. des mit 4% Wahrscheinlichkeit (oder mit 25 Jahre Wiederkehrszeit) zu erwartenden Wertes der Indizes PAI der einzelnen Jahre. Die durch die Dürre in verschiedenen Massen gefährdeten Regionen wurden auf Grund der gebietlichen Verteilung dieser Kennzahl $PAI_{4\%}$ abgegrenzt (3).

3. Anwendung auf das Staatsgebiet Ungarns

Unter Anwendung der oben geschilderten Methode wurden die Berechnungen nun für 72 meteorologische Stationen Ungarns mit den Daten der Periode 1931-1993 durchgeführt, um die durch die Dürren in verschiedenen Massen gefährdeten Regionen des Staatsgebietes abzugrenzen. Dabei wurden, auf Grund des Indexes PAI_{α} , folgenden Qualifizierungen angewendet:

< 6	- dürrefreie Region
6 - 8	- mässig dürregefährdete Region
8 - 10	- mittelmässig dürregefährdete Region
10 - 12	- stark dürregefährdete Region
> 12	- ausserordentlich stark gefährdete Region

4. Anwendung auf das Donaueinzugsgebiet

Aus der Donaumonographie (1) sind die gebietlichen Verteilungen der langjährigen Mittelwerte sowohl der jährlichen Niederschlagshöhe als auch der Temperatur, ja sogar auch die klimazonalen Karten bekannt. Zwar kann man auf Grund dieser Unterlagen die von der Dürre am meisten gefährdete Regionen vermuten, doch können die einzelnen Regionen voneinander exakt, auf numerischer Basis nicht abgegrenzt werden.

So wurde für den ausserhalb Ungarns liegenden Teil des Donaueinzugsgebietes - da hierfür die zur Ermittlung der Dürrekennzahl PAI notwendigen Grunddaten nicht zur Verfügung standen - das folgende indirekte Verfahren verwendet.

Aus den für Ungarn vorliegenden daten wurde - unter Verwendung der Abflusskarte der Donaumonographie - eine empirische Beziehung zwischen dem langjährigen Mittelwert der Abflusses und der Dürrekennzahl $PAI_{4\%}$ ermittelt (Bild 1.). Unter Verwendung der letztgenannten Beziehung konnten dann - mit Hilfe der Abflusskarte des Donaubeckens - die Dürreregionen innerhalb des ganzen Donaueinzugsgebietes abgegrenzt werden (Bild 2.)

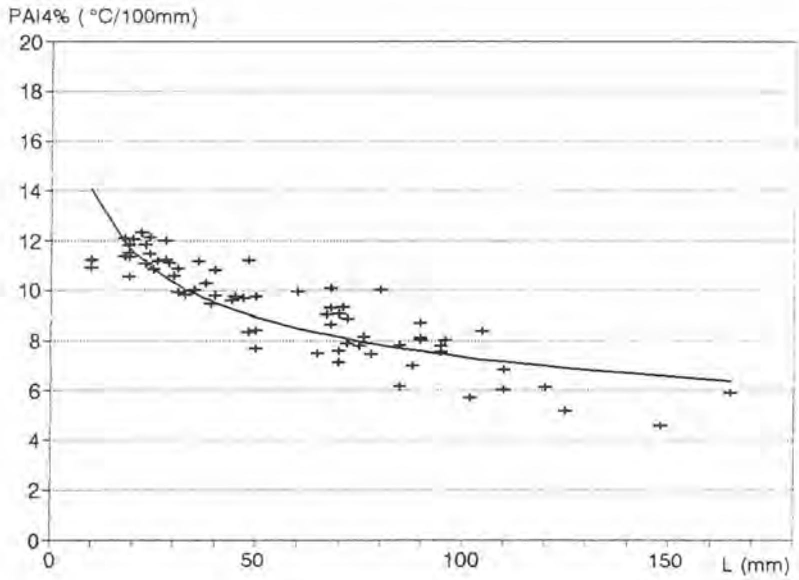

Bild 1. Beziehung zwischen dem langjährigen Mittelwert der Abflusses (L) und der Dürrenkennzahl $PAI_{4\%}$.

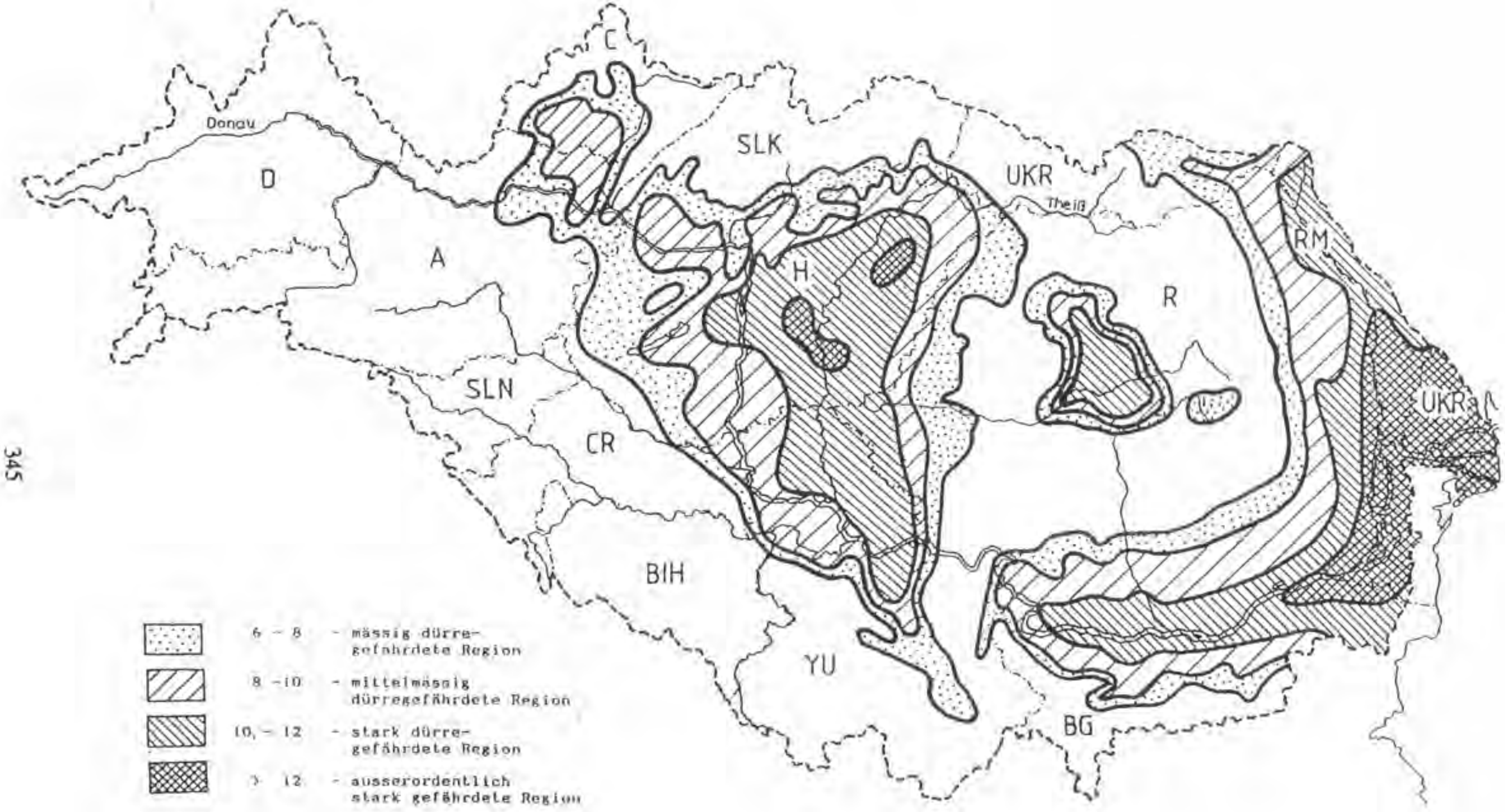

Bild 2. Die Dürreregionen innerhalb des Donaueinzugsgebietes.

Es kann festgestellt werden, dass die mit PAI 4c/c > 6 gekennzeichneten, von der Dürre am meisten gefährdeten Regionen des Donaueinzugsgebietes sich entlang des mittleren Laufes der Donau, in Theiss-Tal, weiters im Tal der Unteren Donau und der Pruth, sowie - in geringeren Masse - im Mährischen und im Siebenbürgischen Becken und in der Region Tara Barsei befinden. Die Dürregefährdung nimmt im Inneren der Tieflandgebiete ständig zu. Stark, ja sogar ausserordentlich stark gefährdete Regionen trifft man im ungarischen und jugoslawischen Teil des Theiss-Tales, am rumänischen und bulgarischen Ufer der Unteren Donau, sowie am unteren Lauf der Pruth, sowohl auf rumänischen als auch moldavischen Staatsgebiet.

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XVII. KONFERENZ DER DONAULÄNDER
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Methods to calculate the water balance of mountain basins

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S u m m a r y

Considered are the methods to calculate the basic elements of water balance of mountain basins (atmospheric precipitation, flow, evaporation, changes in water stock of snow cover, soils and underground layers) during a short (monthlong period of time. Taken into account were the influence of altitude, exposition and slope steepness over the value of water balance elements of the basins. The methods can be made use of when calculating water balances of any mountain area.

Die Methodik der Berechnung von Gebirswasserammlungbilanz

Z u s a m m e n f a s s u n g

Es wird hier betrachtet die Methodik der Grundelemente im Gebirgssamenelgebeit (Niederschlage, AbflieBen, Ausdustung, Wasservorvatswechsel in der Schneedecke, im Boden und in unterirdischen Horizonten) fur einen Kurten (monatigen) Zeitraum. Es wird auch berucksichtigt EinfluB von Hohe, Exposition und Neigung der Gebirgsabhange auf die GroBe der Wasserbilantgrundelemente im Gebirgssammelgebiet. Die Methodik kaun bei der Wasserbilanzrechnung von beliebiger Gebirgsregion verwendet werden.

The theory and calculations, which result from solving the equations of water and thermo- balances of river basins are the bases to hydrologically prognose the flow volume during the flood-time, as well as make short-run prognoses of melted snow losses. The mentioned prognoses, however, are complicated, since not available are the methods to compose the water and heat balances for a short period of time (season, month, etc.), as well as hydrometeorological materials of observations of full value. That was why the author has worked out his own technique which helps calculate the elements of water balance of mountain basins for a short (month, season) period of time for certain years and the long-term period. The methods allow for measuring of the discrepancy of water balance and estimating the observations accuracy. The equation of short-run water balance is composed of six basic elements: atmospheric precipitation (P), summary water flow (Y), summary evaporation from a basin surface (E), water stock changes in: melted snow (Δ Usn) soil layer (Δ Us) and underground horizons (Δ Uu) and can be expressed in a formula:

$$P = V + E \pm \Delta U_{sn} \pm \Delta U_s \pm \Delta U_u , \qquad (1)$$

The right part of the equation is not usually equal to the left one because of not accurate definition of the balance elements and not considering some other balance parameters. Hence, the equation is becoming as follows:

$$P - V - E \pm \Delta U_{sn} \pm \Delta U_s \pm \Delta U_u = N, \qquad (2),$$

where N stands for the balance discrepancy.

The middle layer of atmosheric precipitation for the basin territory (P) is defined by the expression:

$$P_o = \frac{P(z_1)f_1 + P(z_2)f_2 + \cdots + P(z_n)f_n}{F} = \sum_{i=1}^{n} P(z_i)\frac{f_i}{F}, \qquad (3),$$

where f_i is the i-th altitude zone,

$P(Z_i)$ - average precipitation layer zone, which we define by the graph of interconnection between precipitation and altitude and

F - the water collection territory.

The diagrams of connection between the precipitation and observation post altitude are being built for each altitude zone. Three kinds of corrections are introduced into the measured precipitation values: wind, precipitation-measuring bucket and evaporation from it.

The summary water flow is being defined by the materials of hydrometric observations on water posts.

The summary evaporation value we define by the author's method, the basis for which is a method of turbulent diffusion and heat balance (complex method). The calculations are of two stages, where the first one defines evaporation ba-

sed on the complex method equations and the second implies the transition from evaporating to evaporation, depending upon the value of the soil moisture.
Evaporation is defined by Dalton's formula:

$$Eo = 17,5\ (1,15e_s - e)\ \text{mm/month}\ , \qquad (4),$$

where Eo is evaporating,
e_s - absolute atmospheric humidity, being saturated with water steam and calculated for the temperature of the covering surface,
e - absolute atmospheric humidity on the height of 2 meters. There is an unknown value (e_s) in this equation, because of not being observed on the stations.
To define the resiliency of saturated evaporations by the temperature of the covering surface T_n formula (4) we solve the magnus' equation of the heat balance.
Certain transformations in this equation make it look like

$$e_s + 0{,}8T = 0{,}95\,(R - B) + e + 0.8T\ , \qquad (5),$$

whereas the Magnus' formula is

$$e_s = 4{,}58 \cdot 10^{\frac{7{,}45T_n}{235+T_n}}\ , \qquad (6),$$

where R is a radiational balance,
T - atmospheric temperature,
B - the heat flow from a covering surface to the soil.
Thus presented, the method can be made use of for only plain basins. The author has substantially supplemented and improved it with taking into account the influence of the mountain relief on the elements of radiational and heat balances, which determine the regime and the volume of evaporation.
With this the methods to measure the radiational balance (which is the basic factor of evaporation) of river basins is as follows. The river water collecting is dismembered for the slopes of certain exposition, for which the calculation of monthly radiational balance is being conducted. The slope is considered as an inclined surface in the rectangular co-ordinate X,Y system. The X,Y surface coincides with the horizontal one, when its value characterzes the slope marks.
The slope steepness (B) is defined by the equation:

$$B = 90^\circ - \gamma\ , \qquad (7),$$

where γ stands for an angle which comprises the plane of the given mountain slope and the Z axe, them correlating as

$$\sin\gamma = \frac{F_{xy}}{F_o}\ , \qquad (8),$$

where F_{xy} is the projection of Fo on the xy coordinate plane

$$F_o = \sqrt{F_{xz}^2 + F_{yz}^2 + F_{xy}^2} \quad ; \qquad (9),$$

where Fxz stands for projection of Fo on xz, and Fyz - on

$$F_{xz} = 0{,}5\sum_{i=1}^{n}\left[x\left(z_{i+1} - z_{i-1}\right)\right] \quad , \qquad (10),$$

$$F_{yz} = 0{,}5\sum_{i=1}^{n}\left[y\left(z_{i+1} - z_{i-1}\right)\right] \quad ; \qquad (11),$$

where Z are the points for the vertices of a mountain slope rectangle, x and y - the distance of every vertex from the corresponding plane.

Azimuth (a) of the projection normal to the mountain slope on the horizontal plane is defined depending upon quarter of circumference as follows:

$$\begin{array}{lll} a = \lambda & \text{1st quarter} & /+x, +y/, \\ a = 180^\circ - \lambda & \text{2d quarter} & /+x, -y/, \\ a = 180^\circ + \lambda & \text{3d quarter} & /-x, -y/, \\ a = 360^\circ - \lambda & \text{4th quarter} & /-x, +y/, \end{array} \qquad (12),$$

where λ is the angle between the projection normal and the plane and the X vertex. The angle can be defined by cor relation

$$tg\,\lambda = \frac{\sin\beta}{\sin\varepsilon}, \quad \sin\beta = \frac{F_{xz}}{F_o}, \quad \sin\varepsilon = \frac{F_{yz}}{F_o}, \qquad (13),$$

where ε and β are the angles, composed by the plane Fo and vertices X and Y.

The daily solar slope radiation also depends upon the position of the Sun (its altitude and azimuth). The height (h) and the azimuth (A) of any position is known with the astro nomic formulas:

$$\sin h = \sin\varphi \sin\delta + \cos\varphi \cos\delta \cdot \cos t, \qquad (14),$$

$$\sin A = \cos\delta \sec h \cdot \sin t, \qquad (15),$$

where h stands for the height of the Sun over horizon,

A - the azimuth of the Sun

φ - the latitude of observation

δ - the Sun inclination, being defined with astronomic annuals, and

t - the hourly Sun angle, known with

$$\cos t = tg\,\varphi + tg\,\delta - 0{,}0148 \sec\varphi \cdot \sec\delta, \qquad (16).$$

Daily, the Sun radiates the slope as it is shown in the formula:

$$\sum S = \Delta\tau_1 \frac{S_1}{2} + 180\left(\frac{S_1}{2} + S_2 + S_3 + S_4 + \frac{S_5}{2}\right) + \Delta\tau_2 \frac{S_5}{2}, \qquad (17),$$

where τ_{sz}, τ_{ss} is the time of sunrise and sunset, $\Delta\tau_1 = \tau_1 - \tau_{sz}$, $\Delta\tau_2 = \tau_{ss} - \tau_2$
τ_1 and τ_2 - the time of the first and the last observation, and
S_1, S_2, S_3, S_4, S_5 the values of radiation intensivity at the time of observations.

When defining the direct daily radiation for mmountain slopes with (15), we introduce corrections into the values τ_{sz} and τ_{ss}, which consider shadowing of the slope by the mountain ridges. To find the correction values, a cyclic diagram and the graphs of correlation between the sunrise delay and untimely sunset and the orientation and steepness of a slope are used.

The daily volume of the direct and indirect radiation for the whole basin is the average value for separate basin slopes. The measured values are summed up with introducing the coefficient of daily radiation irregularity. Summary basin radiation for a certain period of time (e.g. month) is expressed as a product of average and daily values and the number of days.

When calculating the values of summary radiation, which was absorbed by the earth, we take into account the albedo of the covering surface (α), whose, say, monthly value for the given surface of a mountain slope is defined as average daily value. The albedo of a mountain slope is an average value of radiation in altitude zones, represented by different kinds of covering surface, whereas the albedo of the whole basin comes forward as that of the average mountain slopes.

The intensity of emanation is very important when we measure the radiation balance and is described by Stephen-Bolzman Law:

$$J_n = S'\theta T_s^{4}, \qquad (18).$$

where θ is a constant of Stephen-Bolzman,
S' - emanation capacity, or the coefficient of the difference between the properties of emanating surface and the black body,
T_s - surface temperature.

For small steepness slopes ($a < 30^{o}$), which are characteristic for the Carpathians, the effective emanation is defined by the formula:

$$J_{ef} = J_s \cos a, \qquad (19),$$

where J_{ef} means effective emanation of the horizontal surface.

To define the warmth, flowing into the soil we make use of the materials of soil temperature (for different depths) observations, or tabular monthly data.

To know the average values of atmospheric temperature and humidity on the basin for a certain period of time, we use the graphs of interconnection of these elements with the al titude. The average temperature and humidity on the basin slope for a month can be defined with the formulas:

$$T_0 = \frac{T_1 f_1 + T_2 f_2 + \cdots + T_n f_n}{F}, \qquad (20),$$

$$e_0 = \frac{e_1 f_1 + e_2 f_2 + \cdots + e_n f_n}{F}, \qquad (21),$$

where $T_1, T_2, \ldots T_n$, $e_1, e_2, \ldots e_n$ correspond to the temperature and the humidity in altitude zones, known with the mentioned graphs;

$f_1, f_2, \cdots f_n$ - the altitude zone areas, in per cents to the total slope area, and

F - slope area.

The average temperature and the humidity for the whole basin is nothing but the average temperature and humidity of the separate basin slopes.

Thus, we obtained all necessary data to solve the equation of thermobalance and Magnus' formula, which is needed for estimation of the e_s, a parameter and, when done, for estimation of evaporating by (4).

The transition from evaporating to evaporation is made according to the formula:

$$E = K'P + (E_0 - K'P)\frac{\bar{u}}{u_f}, \qquad (22),$$

where E, E_0 and P correspond to evaporating, evaporation and precipitation,

K - the share of precipitation, evaporated directly from the surface and vegetation,

$\bar{u}$ - average (for the fixed period) value of productive soil moisture stock, and

u_f - the least productive moisture capacity.

Winter evaporation value is usually the value of the daily radiational balance and can be expressed by the formula:

$$E = \frac{R - C'}{L}, \qquad (23),$$

where R stands for the daily radiationaal balance,

C' - daily turbulent heat exchange,

L - specific value of evaporation warmth.

The estimation of the basin radiational balance was carried out according to the mentioned methods.

Suggested methods were tested in Tysa river basin within Ukraine.

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METHODOLOGY FOR THE ASSESSMENT OF THE WATER RESOURCE OF THE SNOW COVER WITHIN A HYDROGRAPHIC BASIN

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Abstract: Snow cover density is generally influenced by the e meteorological parameters. This observation allowed us to establish a relationship between the snow cover density and the air temperature, the depth and the "age" of the snow cover (namely, the number of days elapsed between the appearance of the snow cover and the moment when its density was computed).

The method was then used to estimate the snow cover density and the water equivalent for the raingauge stations where only the snow depth was measured.

These data are useful as the average water equivalent in a river basin constitutes an input element for the forecast models of the spring runoff.

METHODE ZUR SCHÄTZUNG DER WASSERRESERVE DER SCHNEESCHICHT EINES FLUSSBECKENS

Kurzfassung: Die momentane Dichte der Schneeschicht wird von den meteorologischen Parametern beeinflußt. Aufgrund dieser Beobachtung wurde eine Beziehung festgestellt zwischen der Dichte der Schneeschicht und der Lufttemperatur, der Schneedicke und dem "Alter" der Schneeschicht (nämlich, der verlaufenen Tagesanzahl vom Auftreten zur Messungszeit der Schneeschicht).

Die Methode wurde dann zur Schätzung der Schneeschichtdicke verwendet und des entsprechenden Wasseräquivalenten des Flußbeckens, wo nur Messungen der Schneeschichtdicke durchgeführt werden.

Die berechnete Data werden zur Schätzung des Mittelwertes des Wasseräquivalenten verwendet, das als Eintrittsparameter in die Prognosemodellen des Frühlingsabflußes tritt.

1. INTRODUCTION

The spring runoff in a catchment is caused by the melting of the snow cover accumulated on the basin during the cold period of the year, phenomenon caused by the temperature increase during the spring months as well as by the liquid precipitation of that period.

Therefore, one of the necessary elements for the development and use of a spring runoff forecasting model (Stanescu & Simota, 1992) is water amount stored in the snow cover expressed as the mean water equivalent of the snowpack on the catchment, determined at the beginning of the forecasting period.

A major difficulty in a correctly evaluating the mean water equivalent on the catchment is caused by the unevenness of the areal distribution on the catchment, especially when the sampling points have a reduced number and do not cover the entire altitude ecart and the entire variation range of the morphological condition of the basin. The present difficulty in the evaluation of the areal distribution of the snow cover by the means of aerialphotogrammetry or field expedition measurements leads to a determination of the mean equivalent in the catchment based only on snowcover observations in the raingauge network.

The direct measurements for the water equivalent (therefore, density) are carried out only at the meteorological stations at the raingauge stations, only the snow cover depth being measured.

The evaluation of the snow cover density from the snowcover observations at the raingauge station is currently achieved by the comparative assessments with the values obtained at the meteorological stations in the area, according to the evolution in time and altitude of the snow cover. In order to eliminate the subjective factor in these evaluations density correlations of the snow cover can be used with the influencing meteorological parameters.

2. VARIATION OF THE SNOW COVER DENSITY IN TERMS OF THE METEOROLOGICAL FACTORS

The survey of the time evolution, the snow cover density revealed the fact that is influenced by meteorological factors, such as: air temperature, saturation deficit, wind speed, precipitation. The air temperature and the saturation deficit follow rather well this evolution. The wind speed, with rather strong oscillations from one day to another, gives a weaker correlation with the density of the accumulated snow cover (Copaciu & Tibacu, 1993).

The dynamics in time of the snow cover determined the introduction of an additional factor referring to the "age" of the snow cover (B). As the time step was considered in the day time, B stands for the number of days between the appearance of the snow cover and the calculation moment.

Finally, the authors give a calculation relationship of the snow cover density, as it follows:

$$\rho = C_0 + C_1 T + C_2 \left(\frac{B}{h} \right) \tag{1}$$

where ρ is snow density (g/cm^2); C_0, C_1, C_2 - coefficients of the multiple regression; T - daily mean temperature of the air (from the preceding day)(°C); h - snow depth (cm).

It was noticed that during the days with precipitation, the snow cover shows sudden variations (by the occurrence of the "dry" snow or mixed or liquid precipitation). This phenomenon has determined the development of two separate sequences for the days with precipitation and for the days without precipitation, different values being obtained for the coefficients of the multiple regression.

3. APPLICATION OF THE METHODOLOGY AND RESULTS OBTAINED

The above described methodology was applied for the determination of the water content of the snow cover, in Colibiţa catchment. This covers a surface of F = 115 km^2, the mean altitude is H = 1175 m, and an altitude development between 700 and 2000 m. Snowcover data from 5 collecting points have been used (three meteorological stations and two raingauge stations). Out of these 5 points, only one raingauge station is located directly in the catchment.

Because the snow water equivalent is strongly dependent on altitude, the following relationship was used for the calculation of the mean equivalent of the basin:

$$\overline{E} = \int_{H_{\min}}^{H_{\max}} E(H) \frac{\partial p(H)}{\partial H} \mathrm{d}H \tag{2}$$

where $E(H)$ is variation of the snow water equivalent with altitude (mm); $p(H)$ - hypsographic curve, expressed in %; $H_{\min}$, $H_{\max}$ - minimum and maximum altitudes respectively of the river basin (m).

In order to determine $\overline{E}(H)$, it is necessary to entirely use the snowcover information. In the first phase, for the two raingauge stations, densities were evaluated by comparing them with those from the meteorological stations, in terms of the snow cover depth and the altitude distribution trend of the water equivalent.

In order to use type (1) relationships, for the calculation of the snow cover density the multiple regression coefficients were determined on the basis of the data recorded at the meteorological stations, and the following relationships resulted:

$$\rho_1 = 0.18 + 0.02T + 0.04B/h$$
$$\rho_2 = 0.23 + 0.04T + 0.01B/h \quad (3)$$

where ρ_1 and ρ_2 stand for the density of the snow cover calculated for the days with precipitation, and without precipitation, respectively.

For the calculation of the temperature corresponding to the altitude of the raingauge stations, the temperature distribution with altitude was used, by using the daily mean temperature values from the three meteorological stations. In order to average the point temperature variations with altitude, the daily temperatures over the last five days of the month were averaged.

The Tables 1 and 2 present, for comparison, the

Table 1

Raingauge station (H = 1095 m)						
Year	Month	T (°C)	B (days)	h (cm)	ρ_c (g/cm^3)	ρ_e (g/cm^3)
1977	I	-2.6	31	23	0.24	0.20
	II	-2.1	59	5	0.34	0.40
1978	I	-5.6	62	30	0.21	0.25
	II	-3.4	90	32	0.28	0.25
1979	I	-2.4	30	15	0.25	0.20
	II	-8.8	58	4	0.34	0.40
1980	I	-9.5	32	51	0.20	0.20
	II	-7.7	60	35	0.22	0.24
1981	I	-7.0	62	65	0.20	0.25
	II	-7.1	90	68	0.22	0.30
1982	I	-9.5	63	55	0.21	0.25
	II	-6.3	91	70	0.22	0.25
1983	I	-3.7	34	35	0.21	0.25
	II	-3.7	62	26	0.23	0.25
1984	I	-8.0	63	27	0.25	0.25
	II	-4.3	91	34	0.24	0.25
1985	I	-5.3	52	57	0.22	0.25
	II	-13.6	80	65	0.19	0.20
1986	I	-5.1	68	80	0.22	0.20
	II	-10.6	96	85	0.23	0.20
1987	I	-12.2	49	130	0.17	0.20
	II	-7.8	77	60	0.21	0.30
1988	I	-3.9	56	23	0.27	0.20
	II	-6.3	85	40	0.23	0.15
1989	I	-5.7	79	57	0.22	0.20
	II	-0.4	107	34	0.31	0.30

Table 2

Raingauge station (H = 805 m)						
Year	Month	T (°C)	E (days)	h (cm)	ρ_c (g/cm³)	ρ_e (g/cm³)
1977	I	-1.6	30	2	0.37	0.40
	II	-1.0	1	2	0.23	0.40
1978	I	-4.8	69	22	0.24	0.25
	II	-3.2	97	27	0.25	0.25
1979	I	-2.2	30	18	0.24	0.20
	II	-8.1	58	9	0.26	0.40
1980	I	-8.9	32	34	0.20	0.20
	II	-7.0	60	14	0.24	0.30
1981	I	-6.6	30	27	0.21	0.25
	II	-6.9	58	25	0.25	0.30
1982	I	-10.2	62	25	0.26	0.25
	II	-5.6	90	31	0.28	0.20
1983	I	-2.5	35	16	0.26	0.30
	II	-6.8	63	15	0.24	0.20
1984	I	-2.8	31	16	0.25	0.22
	II	-2.8	60	11	0.27	0.27
1985	I	-5.1	52	29	0.24	0.25
	II	-14.2	80	62	0.19	0.20
1986	I	-4.4	47	50	0.21	0.24
	II	-9.0	75	54	0.21	0.20
1987	I	-9.6	49	85	0.18	0.20
	II	-6.3	77	10	0.48	0.40
1988	I	-3.3	56	11	0.38	0.15
	II	-4.8	85	25	0.31	0.30
1989	I	-5.8	137	39	0.31	0.20
	II	1.3	165	27	0.29	0.30

density values evaluated by means of the first method (ρ_e) and the density values calculated by relationships (3), (ρ_c), for the two rainfall stations. Further on, the water equivalent point values were calculated.

On the basis of relationship (2), the mean water equivalent on the catchment was calculated in a first variant (by using ρ_e) E_e and a second variant (by using ρ_c) E_c.

A 13-year period (1977-1989) was considered for the calculation. The values evaluated and calculated correspond to the end of the months of January and February, as the water occurred from the snowmelt influences the runoff in February and March.

From the comparative analysis of the calculated and evaluated densities (Tables 1 and 2), it can be noticed that, generally, there are no great differences. At the same time, the number of the density values calculated by means of formulas (3) having higher values or equal to most of those evaluated, is rather well balanced with the number of those with low values.

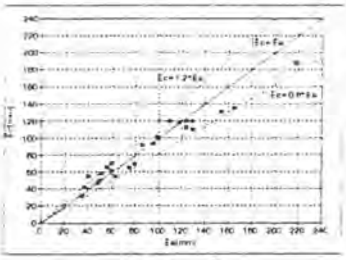

Fig. 1

In the case of the mean water equivalent of the catchment there are no great differences either (Figure 1). The deviation of the calculated values as against the evaluated ones is within a maximum +/- 20% ecart.

4. CONCLUSIONS

The results obtained by using a calculation formula for the snow cover density, in terms of the meteorological parameters, for the determination of the mean water equivalent on the catchment, as compared to the density evaluation method in the points where there are no direct measurements, lead to the conclusion that the advantage of using a calculation relationship does not stand in the "correction" of the evaluated values, but in the fact that it offers to the forecasting hydrologist an assessment "device" for the density, excluding thus the subjectivity of the methodology used until now.

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XVII. KONFERENZ DER DONAULÄNDER
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Conjugated hydrological parameters for water management

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Summary: The conjugated hydrological parameters refer to the hydrological event which is defined by two or even more coupled traditional hydrological synthetic characteristics, one or more of these conditioning the value (values) of the other (others).

An example of computation of the volume components at two reservoir sites while the volume and the maximum discharge of a flood wave (correlated) at the outlet of a catchment is given.

A theoretical computation for n volume components of a reference flood wave at the outlet of a basin is presented.

A procedure for the assessment of the impact of the reservoirs on the maximum discharges of a flood wave at the outlet is presented.

Kurzfassung: Die hydrologische vereinigte Parameter beziehen sieh ouf dos hydrologische Ereignis, das durch zwei oder mehrere hydrologische synthetische und traditionelle (classische) gekupelte Charakteristiken genau beschrieben ist, eine oder mehrere von diesen enthalten das Wert (die Werte) von der undere (die anderen).

Es wird ein Beispiel fur die Rechnung der komponenten der Wassermenge der zwei stauseen gegeben, donn wenn man W max (maximale Abfluss) der Hochwosserwellen in einen underen Abschnitt des Einzugsgebiet kennt.

Es wird eine theoretische Rechnung fur die Komponenten von "n" Wassermenge einen Hochwasserwelle in einer unteren Abschnitt eines Einzugsgebiet gegeben.

Es wird ebenfalls eine Moglichkeit fur die Bestimmung der Oberen Abschnitt stausee Einfluss uber die Hochwasserwellen in einer unteren Alschnitt gegeben

Introduction

The achievement of reservoirs in a hydrographic basin implies a dimensioning calculation of their volumes as well as an impact study for the determination of the reservoir influence upon the flood waves under the natural regime, in any of the points located on the water courses, downstream each of these reservoirs.

If, for instance, we consider the scheme on Fig.1 and an embankment is meant to be achieved over reach O-O on the main river, then the dam dimensioning is done for a maximum discharge resulting from the composition of the deffluent maximum discharges $Q_A^{(d)}$ and $Q_B^{(d)}$ of the affluent floods in reservoirs A and B.

The deffluent discharges $Q_A^{(d)}$ and $Q_B^{(d)}$ depend on the value of the affluent flood waves in the reservoirs and on the planned capacity of these reservoirs. By hypothesis we accept that the value of the flood waves in points A and B is characterised by the volumes of waves W_A and W_B respectively. We also consider that at the outlet of the basin, (point O) the flood wave which has W_A and W_B components is defined by its maximum discharge Q_O and volume W_O.

A flood wave of volume W_O and maximum discharge Q_O can be made but of unlimited number of A and B components. Obviously, the greater the volumes of these W_A and W_B (on condition that $W_A + W_B \le W_O$) the more diminished the aleviation of waves A and B will be and therefore the reservoir efficiency will be smaller.

Method description

The flood occurrence P risk in A and B of equal volumes or larger than certain v_A and v_B values when the wave is in O, is characterized by values Q_O and W_O is defined by the conditioned bidimensional probability relationship:

$$P = P(W_A \geq v_A, W_B \geq v_B \mid W_O, Q_O) \quad (1)$$

More generally, given a series of j variables taking $u_1 ... u_k$ values conditioning a series of $u_{k+1}, ..., u_r$ dependent variables, yields:

$$P = \int ... \int f(u_{k+1}, u_{k+2} ... u_r \mid u_1, u_2 ... u_k)\, du_{k+1}\, du_{k+2} ... du_r \quad (2)$$

where (Ionescu H., 1958):

$$f(u_{k+1}, u_{k+2} ... u_r \mid u_1, u_2 ... u_k) = \frac{1}{2\pi^{(r-k)/2}\sqrt{|M^*|}} \exp\left[-\frac{1}{2|M^*|}\sum_{k+1}^{r} M^*_{ij}(u_i - \bar{u}^*_i)(u_j - \bar{u}^*_j)\right] \quad (3)$$

- is the normal conditioned multidimensional distributed function

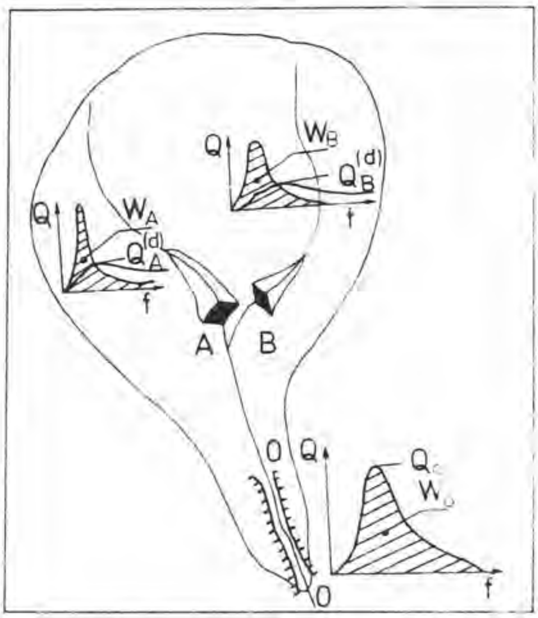

Fig. 1. Scheme of volume components computation
Die Rechnung Schema für die Komponenten der Wassermenge

In relationship (3) there is:

- the matrix of the conditioned mean value

$$\| u_i^* \| = m_2 + M_{21} \| M_{11} \|^{-1} (u_1 - m_1) \quad i = k+1 ... r \quad (4)$$

where:
$u_1 = \| u_i \|$, i = 1...k is the matrix of the conditioning variable values.

$m_1 = || u_i ||$ $i = 1 \ldots k$ is the matrix of the variable conditioning mean values.

$m_2 = || u_j ||$ $j = k+1 \ldots r$ is the matrix of the mean values of the conditioned variables.

- The matrices:

$$M_{11} = || r_{ij} \sigma_i \sigma_j || \quad i,j = 1 \ldots k$$
$$M_{12} = || r_{ij} \sigma_i \sigma_j || \quad i = 1 \ldots k,\ j = k+1 \ldots r \qquad (5)$$
$$M_{21} = || r_{ij} \sigma_i \sigma_j || \quad i = k+1 \ldots r,\ j = 1 \ldots k$$
$$M_{22} = || r_{ij} \sigma_i \sigma_j || \quad i,j = k+1 \ldots r$$

In case the conditioned exceeding probability is calculated for 2 variables the following formula (Owen 1956) can be used:

$$p(u_i, u_j) = 1 - [P(u_i) + P(u_j)]\,0.5 - T(u_i, a_1) - T(u_j, a_2) - C \qquad (6)$$

where

$$a_1 = \frac{u_j - r^*_{ij} u_i}{u_i \sqrt{1 - r^{*2}_{ij}}} \qquad a_2 = \frac{u_i - r^*_{ij} u_j}{u_j \sqrt{1 - r^{*2}_{ij}}} \qquad (7)$$

and

$$C = 0 \quad \text{if } u_i u_j > 0 \qquad (8)$$
$$C = 0.5 \quad \text{if } u_i u_j < 0 \qquad (9)$$

For a_1 or a_2 values higher than 4, generally for $a \geq 4$ there is:

$$T(u, a) = 0.5\,[P(u) + P(ua)] - P(u)\,P(ua) - T(ua, \tfrac{1}{a}) \qquad (10)$$

In relationship (6), $P(u)$ is the probability of value u.

In relationships (6) and (7) values u represent "standardized" values given by relationship:

$$u = \frac{u - \overline{u}^*}{\sigma^*} \qquad (11)$$

where: u^* is the conditioned mean (see relationship (4)).

In relationship (11) σ^* is the conditioned standard deviation, and in relationship (7), r_{ij}^* is the conditioned correlation coefficient. Values σ_i^*, σ_j^* and r_{ij}^* are calculated by means of matrix "variable-covariable" thus:

$$M^*_{ij} = || r^*_{ij} \sigma^*_i \sigma^*_j || = M_{22} - M_{21} M^{-1}_{11} M_{12} \quad i,j = k+1 \ldots r \qquad (12)$$

It must be noticed that, as function (3) is a normal distribution, it is necessary that at least all variables conditioning $U_1 \ldots U_k$ as well as those conditioned $U_{k+1} \ldots U_r$ have a normal distribution. In order to ensure this condition a variable change is performed for any of the U variables, of the form:

$$u = \log U + C \qquad (13)$$

Value C can be determined by successive trials until the points representing the empirical probability curve are placed on a streight line in an axes system when the ordinate has a logarithmic scale, and the abscissa has a Gauss's probability scale. In case we calculate the exceeding probability conditioned for 3 variables, the Steck's data calculation formulas and tables (1958) can be used, and if the probability is determined for more than three variables and these are supposed to be correlated, a Markow scheme can be used, thus:

$$p(u_{k+1} \ldots u_r \mid u_1 \ldots u_k) = p(u_{k+1}, u_{k+2}) \frac{p(u_{k+2}, u_{k+3})}{p(u_{k+2})} \cdots \frac{p(u_{r-1}, u_r)}{p(u_{r-1})} \qquad (14)$$

Application

The application of the above mentioned.
Theoretical bases to the studied case in the present paper is done as it follows.

1. The probability distribution of W_A and W_B conditioned variables as well as of W_O and Q_O conditioning ones is brought to a normal distribution by using the relationship (13).
As an example, the following were chosen:
W_A - the volumes of the annual flood waves at the Broşteni station (F=646 km²) on the Motru River.
W_B - the volumes of the annual flood waves at the Corcova station (F=420 km²) on the Coşuştea River.
W_O and Q_O - volumes of the annual flood waves and annual peak discharges respectively at the Fata Motrului station (F=1703 km²) o
At these stations, there are available annual series of maximum discharges and volumes with a 40 year lenght each.
By applying relationship (13) following standardized variables result:

$$u_1 + \log W_0 ; u_2 = \log Q_0 ; u_3 = \log W_A ; u_4 = \log W_B \quad (15)$$

2. The mean square deviations $\sigma_1, \sigma_2, \sigma_3, \sigma_4$ are calculated as well as the correlation coefficients $r_{12}, r_{13}, r_{14}, r_{23}, r_{34}$ between variables, yielding:

Table 1

Variable	Mean	Mean square deviation	Correlation coefficients		
			u2	u3	u4
u1	1.6	0.231	0.83	0.82	0.68
u2	2.4	0.267		0.65	0.50
u3	1.3	0.230			0.64
u4	1.0	0.314			

3. The following matrices are formed:

$$m_1 = \left\| \begin{matrix} 1.6 \\ 2.4 \end{matrix} \right\| \qquad m_2 = \left\| \begin{matrix} 1.3 \\ 1.0 \end{matrix} \right\| \quad (16)$$

4. The following matrices are determined according to the relationships (5)

M_{11}		M_{12}	
60.505	-43.515	0.044	0.049
-43.515	45.372	0.040	0.041
0.044	0.040	0.053	0.046
0.049	0.041	0.042	0.099
M_{21}		M_{22}	

(17)

5. Matrix M^*_{ij} is calculated according to the relationship (12) and then the values $r^*_{ij}, \sigma^*_i, \sigma^*_j$

6. The correlation between the annual volumes of the floods is made at Broşteni and Corcova stations ($W_A = f(W_B)$).

7. The flood wave at the outlet of the basin (the hydrometric station of Fata Motrului) is considered as having a peak discharge with 1% probability of Q_0=950 m^3/s.

Considering a mean total duration of the flood wave T_T=120 h, a mean coefficient of the form γ = 0.37, it yields $W_0 = Q_0 \cdot T_T \cdot \gamma$ =152.10^6 m^3.

8. It is considered that over the rest of the basin with a surface of 637 km^2, the maximum volumes represent ratios R of 10%,20%,30% and 50% of the total volume of 152 .10^6 m^3 occurred with a 1% probability at Fata Motrului.

Any of the R value alternatives (for example R=10%) leads to the determination of the total volumes runoff on the two A and B subbasins and then, from the correlation between these, determined at item 6, the pair of values $W_A^{(R1)}$ and $W_B^{(R1)}$ yields.

9. Relationship (13) is applied for each of the pairs $W_A^{(R1)}$ and $W_B^{(R1)}$ yielding a pair of variable values $u_{3Ri} = \log W_A^{(Ri)}$ and $u_{4Ri} = \log W_B^{(Ri)}$ for a accepted R_i ratio. The following matrix is carried out:

$$u_i = \begin{Vmatrix} \log W_0 \\ \log Q_0 \end{Vmatrix} = \begin{Vmatrix} \log 152 \cdot 10^6 \\ \log 950 \end{Vmatrix} \qquad (18)$$

and from the relationship (4) u^*_i is calculated.

10. With values σ^*_i, σ^*_j, r^*_{ij} resulted from item (5) and the values of the conditioned means resulted from item (9), according to relationship (11) the standardized values of the conditioned variables u_{3Ri} and u_{4Ri} are

$$u'_{3Ri} = \frac{u_{3Ri} - u^*_3}{\sigma^*_3} \qquad \text{and} \qquad u'_{4Ri} = \frac{u_{4Ri} - u^*_4}{\sigma^*_4} \qquad (19)$$

11. Further on, Owen's calculation scheme is applied through the relationships (6)-(10) and, for a given pair of volume values at the Broşteni (W_A) and Corcova (W_B) stations, the simulated exceeding probability is calculated under the conditions when the annual maximum discharge and maximum volume values are given with a 1% exceeding probability at the Faţa Motrului station.

12. By adopting another R percentage ratio for the participation of the rest of the basin in the occurrence of the flood wave with a 1% exceeding probability at the outlet of the basin, another pair of values $W_A^{(R2)}$ and $W_B^{(R2)}$ result according to item 8.

Table 2 gives the exceeding probabilities according to relationship (1) for various pairs of values of the variables W^A and W^B determined following the adoption of a certain R ratio.

Table 2

R(%)	$W_A(10^6m^3)$	$W_B(10^6m^3)$	$W_0(10^6m^3)$	$Q_0(m^3/s)$	P(%)
10	91.5	45.3	152	950	4.5
20	79.0	42.6	152	950	10.2
30	70.3	36.1	152	950	20
50	50.1	25.9	152	950	57.5

Conclusions

The R ratio is noticed to express in fact the way in which the rainfall is spatially distributed on the basin when at its outlet it forms a flood wave with a given p exceeding probability.

It can be noticed from Table 2 that the P exceeding probability of the pairs W_A and W_B conditioned by the flood wave at the outlet with a 1% exceeding probability of the peak discharge is very low when the rainfall is considered as practically concentrated only in the upstream area of the basin and the contribution of the rest of the basin to the wave volume at the outlet is only 10% of the total.

In 57.5% of the total of combinations, a combination where $W_A \geq 50.1.10^6$ m^3 and $W_B \geq 25.9.10^6 m^3$ occurs.

This happens in a situation when the rest of the basin, although with only a 637 km^2 surface (as against the total area of the two subbasins of 1066 km^2) participates with 50% of the total volume of the wave at the outlet.

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HYDROLOGICAL CHANGES OF THE DRAVA RIVER AT THE DONJI MIHOLJAC STATION (CROATIA)

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ABSTRACT

A great number of hydrotechnical structures have been built along the Drava River and throughout its catchment area during the last fifty years. The construction of these structures had a great influence on the water regime of the Drava River. The paper presents the analysis of the time series of the water levels and discharges at the Donji Miholjac station from 1890 (1926) to 1992. The analysis includes the occurences of ice regime and the water temperature measurements covering the period from 1946-1992. The paper deals with the intensity of these changes, the time of their occurence and trends. The discriminant analysis method was used for defining the period when significant changes in the hydrological regime occured.

HYDROLOGISCHE VERÄNDERUNGEN DER DRAU AN DER MEβTELLE DONJI MIHOLJAC

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KURZFASSUNG

Im Laufe der letzten 50 Jahre wurden die Drau entlang und im Flußgebiet der Drau zahlreiche umfangreiche hydrotechnische und auch andere Arbeiten ausgeführt. Alle Arbeiten übten einen großen Einfluß auf das Wasserregime der Drau aus. In dieser Arbeit wurden eine Reihe von Wasserstands-und Durchflußmessungen and der Meßstelle Donji Miholjac im Zeitraum von 1890 (1926) bis 1992 analysiert. Eiserscheinungen wie auch die gemessenen Wassertemperaturen im Zeitraum von 1946 bis 1992 wurden analysiert. Intensität der hydrologischen Veränderungen, die Zeit ihrer Erscheinungen und deren Trends wurden durchstudiert. Diskriminationsanalyse wurde zur Feststellung der genauen Zeit der bemerkenswerten Veränderungen im hydrologischen Regime angewendet.

INTRODUCTION

The Donji Miholjac gauging station is located on the right bank of the Drava river in Croatia. It is 77.81 km distant from the Drava confluence into the Danube (System of water dams Đurđevac and Barč, 1977) or 74.6 km (Die Donau und ihr Engzugsegebiet, 1986). The performed studies were used as a basis of hydrological data dealt with in this paper. The Drava catchment area on that profile amounts to 37142 km^2. The total catchment area of the Drava River to its confluence with the Danube is 41238 km^2. Consequently the Donji Miholjac station controls an area of 90% of the Drava River catchment area. Datum plane is 88.39 m above the Adriatic sea level. This cross-section is relatively stable and the hydrological measurements performed there are reliable and long-lasting. The Donji Miholjac station is at the farthest downstream measurement point along the Drava streamflow where the back water influence of the Danube is felt. Considering the mentioned characteristics it can be assumed that the profile at Donji Miholjac sums up the influence of all natural and artificial changes which occurred along the Drava streamflow and in its catchment during the last hundred years. The main objective of this paper is to study the hydrological changes caused by man's activity. The analyses and results presented herein can be considered a continuation and correction of the analysis of the results performed by Bonacci et al. (1992). They should be used as a basis for better understanding and predicting the process development in the future.

1. ANALYSIS OF DISCHARGES AND WATER LEVELS

Table 1 presents the main statistic characteristics of monthly and yearly discharges measured at Donji Miholjac station in the period from 1926-1992. The minimum measured discharge which was measured on 13 January 1987 was 152 m^3/s, whereas the maximum discharge was measured on 9 February 1972 and it amounted to 2288 m^3/s.

TABLE 1 Donji Miholjac - Drava: Monthly discharges statistics in m^3/s (1926-1992)

Month	Mean	St. dev.	Min	Max.
Jan.	380	104	209	644
Feb.	382	104	211	657
Mar.	463	150	196	990
Apr.	563	152	246	1032
May	732	184	369	1234
Jun.	801	233	454	1598
Jul.	691	228	361	1422
Aug.	569	188	302	1228
Sep.	483	165	257	1088
Oct.	472	181	222	1038
Nov.	528	216	209	1225
Dec.	439	152	232	821
Year	542	97	363	821

Figure 1 presents the mass curve of the transformed monthly discharges in Donji Miholjac. The transformation of the measured mean monthly discharges from January 1926 to December 1992 (804 months) was performed using the truncation level T.L. = 542.17 m^3/s. This was the mean monthly discharge during the above mentioned period. Bonacci (1993) concluded that the selection of different truncation levels does not yield great differences in the interpretation of time series. Significant data on drought and wet periods identification can be obtained from Figure 1. It presents an artificial but real picture of the occurrence of drought periods (-) and their exchange with wet periods (+) and neutral periods (0). The beginning and end of each period are presented in Figure 1. This is the first actual step in the identification of dry, wet and neutral periods.

Table 2 presents the average and standard deviations of discharges and water levels in three different time periods: 1) 1926-1992 or 1890-1967; 2) 1926-1967 or 1890-1967; 3) 1968-1992. By using these values and the statistical tests (t and F tests) it was possible to establish a significant difference between the average values of minimum annual water level in the following two periods: 1890-1967 and 1968-

1992. A lower but statistically still significant difference was established for the series of mean yearly water levels for the following two periods: 1926-1967 and 1968-1992. Identical conclusions can be drawn for the yearly minimum discharges in these two periods. For the maximum yearly discharges and water levels and for the mean discharges only a few differences can be explained by random influence since the difference is not statistically significant. It can be generally stated that the following values were significantly decreased after 1967, i.e. in 1968-1992 period : 1) Minimum yearly water level H_m from -15 cm to -98 cm, i.e. for 83 cm; 2) Average yearly water levels $\overline{H}$ from 102 to 54 cm, i.e. for 48 cm; 3) Minimum yearly discharges Q_m from 253 m³/s to 205 m³/s, i.e. for 48 m³/s.

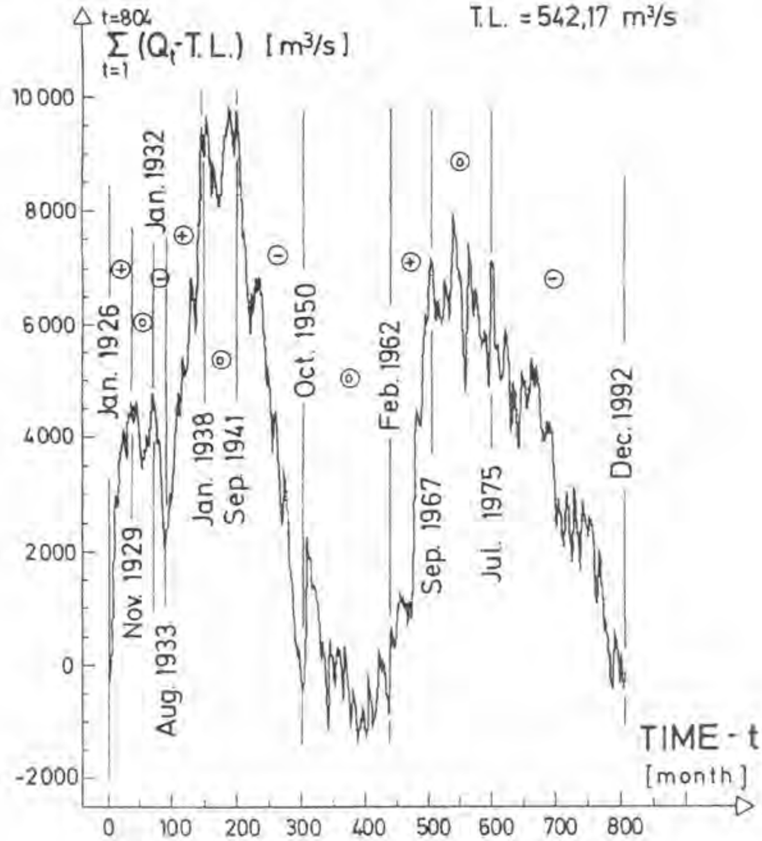

Figure 1

Figure 2 presents a series of yearly minimum water levels in the period 1890-1992, whereas Figure 3 presents a series of yearly minimum discharge in the period from 1926-1992. The Figures show the trends for the entire period under study from 1890-1992 for H_m or for 1926-1992 for Q_m, and for two sub-periods 1890-1967 for H_m or 1926-1967 for Q_m and for 1968-1992. According to graphical presentation and equation of linear trends and the coefficients of linear correlation presented in Figure 2 and 3 it can be concluded that there was a continuous trend of decrease in the yearly minimum discharges and water levels during the entire period. However, after more careful observation it becomes evident that the process of sudden decrease in the yearly minimum discharge and water levels started after 1967. The reasons for this phenomenon were explained by Bonacci et al. (1992) by the construction of dams and reservoirs on the Drava River. The construction of several small dams and reservoir with a volume of 1 to $11x10^6$ m^3 in Slovenia and Croatia caused a sudden decrease in the quantity of suspended sediment for even 60% on the Drava profile at Donji Miholjac. The bed load sediment from the upstream section of the Drava was mainly stopped which caused more intensive erosion of the bottom and the banks of the Drava River at the section downstream from the Mura confluence with the Drava. i.e. at the section more than 160 km long.

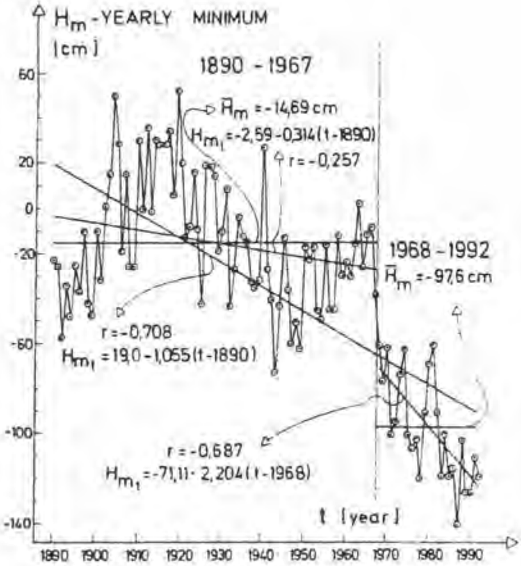

Figure 2

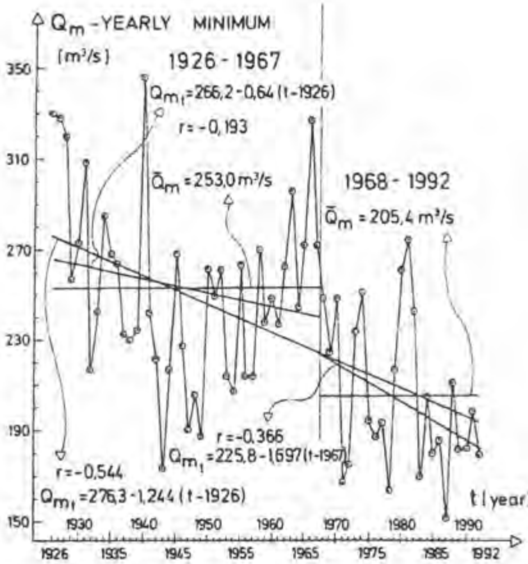

Figure 3

TABLE 2 Donji Miholjac-Drava; Average and standard deviations of discharges and water levels at different time periods

PARAMETER Q - DISCHARGE H - WATER LEVEL		TIME PERIOD	AVERAGE IN TIME PERIOD	STANDARD DEVIATION IN TIME PERIOD
Q_m	YEARLY	1926-1992	235.3	44.59
	MINIMUM	1926-1967	253.0	40.65
	[m^3/s]	1968-1992	205.4	34.09
$\overline{Q}$	MEAN	1926-1992	542.2	96.51
	[m^3/s]	1926-1967	559.6	109.60
		1968-1992	521.8	73.40
Q_M	YEARLY	1926-1992	1349.0	319.20
	MAXIMUM	1926-1967	1367.0	305.80
	[m^3/s]	1968-1992	1318.0	344.80
H_m	YEARLY	1890-1992	-34.8	44.55
	MINIMUM	1890-1967	-14.7	27.70
	[cm]	1968-1992	-97.6	23.61
$\overline{H}$	MEAN	1926-1992	84.3	41.91
	[cm]	1926-1967	102.3	36.86
		1968-1992	54.2	31.54
H_M	YEARLY	1890-1992	323.8	62.06
	MAXIMUM	1890-1967	327.8	57.18
	[cm]	1968-1992	311.4	75.27

The erosion and transportation of alluvial material from the Drava riverbed led to the lowering of the riverbed bottom and hence to the decrease in the minimum and mean yearly water levels. These factors should not directly influence the decrease in the minimum, and partly in the average yearly discharges of the Drava at Donji Miholjac. The reason is evident from Figure 1. It can be noted that since September 1967 (July 1975) a long-lasting period of drought started, i.e. of discharge decrease which did not finish until December 1992. This process was intensified by increased exploitation of the Drava River for irrigation as this increased the water losses in the Drava catchment (Bonacci, 1993).

This study also includes the analyses of redistribution of discharges during the year. It was noted that during the period 1968-1992 the discharges were most decreased from July to September and from January to March, whereas the discharges were increased in December. According to these analyses it cannot be stated that a significant redistribution of discharges has occurred during the year on the Drava River at Donji Miholjac. However, the analyses showed that such a possibility exists and that the process should be carefully monitored.

2. WATER TEMPERATURE AND ICE REGIME

The mean yearly water temperature at the Drava profile at Donji Miholjac in the period 1946-1992 was 11°C, the minimum measured temperature was 0°C, while the maximum was 25.6°C. Table 3 presents the mean minimum, average and maximum yearly water temperatures and the average number of days with the occurrence of ice in three different time periods: 1) 1946-1992 or 1948-1992; 2) 1946-1967 or 1948-1967; 3) 1968- 1992. The analysis of data presented in Table 3 points to a possible change in the temperature regime, particularly referring to the minimum yearly temperatures T_m. In the period 1946-1967 the average minimum yearly water temperature was higher than 0.01°C, whereas in the period 1968-1992 it was raised to 0.35°C. The mentioned data are neither statistically significantly different. The conclusion reached on the change in the temperature regime should be considered absolutely reliable. The occurrence of the change in the temperature regime of the Drava River in the cold period of the year confirmed by the fact that there were on the average 20.9 days with ice in the period from 1948-1967 and that the average day of days with ice during the year was decreased to 8.52 days in the period 1968-1992. In the first of these two mentioned periods there were only five years without ice at Donji Miholjac, which covers only 25% of the period. During the last 25 years there were eleven without ice, which represents 44% of the analyzed period. It should also be noted that significant change in the temperature regime has been noted since 1973. These changes can be caused by a great number of factors. Bonacci and Trninić 1991) stated an almost identical change in the temperature regime of the Sava River near Zagreb which has been observed since 1965 and has continued to the present day.

TABLE 3 Donji Miholjac-Drava; Average values of water temperature and number of days with ice per year during different time periods.

PARAMETER T-WATER TEMPER. N-ICE REGIME		TIME PERIOD	AVERAGE IN TIME PERIOD
T_m	YEARLY	1946-1992	0.19
	MINIMUM	1946-1967	0.01
	[°C]	1968-1992	0.35
$\bar{T}$	MEAN	1946-1992	11.20
	[°C]	1946-1967	11.40
		1968-1992	11.10
T_M	YEARLY	1946-1992	23.30
	MAXIMUM	1946-1967	23.60
	[°C]	1968-1992	23.10
N	ICE REGIME	1948-1992	14.00
	[days/year]	1948-1967	20.90
		1968-1992	8.52

They believe that main reason of water warming during the cold period is the man's influence upon the hydrological and particularly chemical characteristics of the water. This influence includes the effect of large urban aglomerations and industrial plants. The analysis shows that the minimum yearly water temperatures are gradually increasing, which is statistically insignificant, whereas the maximum yearly water temperatures are gradually decreasing.

3. DISCRIMINANT ANALYSIS

In this Chapter a method of discriminant analysis (Bonacci 1972, Bonacci et al. 1992) was used in order to accomplish the following tasks: 1) To study hydrological parameters causing discrimination; 2) To study the time when the sets were separated according to the analyzed hydrological parameters. Since this statistical methodology is specific and numerous computations are included only the main results will be presented subsequently.

The analysis covered the period from 1890-1992 for the following two hydrological parameters: 1) Yearly minimum water levels H_m ; 2) Yearly maximum water levels H_M. In the period 1926-1992 the following four hydrological parameters were available (employed,used): 1) Mean yearly water levels $\bar{H}$; 2) Yearly minimum discharges Q_m; 3) Mean yearly discharges $\bar{Q}$; 4) Yearly maximum discharges Q_M. In the period 1946-1992 the following parameters were employed: 1) Yearly minimum water temperature T_m ; 2) Mean yearly water temperature $\bar{T}$; 3) Yearly maximum water temperature T_M. Data on the ice regime N in a day/year were available in the period 1948-1992.

It was stated that the separation of sets is mainly influenced by the minimum yearly water levels H_m, average yearly water levels and the minimum yearly discharges Q_m. The other studied parameters do not influence the discrimination process significantly. The ice regime plays a less significant role. The procedure of defining the discriminant function Z was used. This can be illustrated by the following expression of the discriminant function Z defined according to parameters H_m and Q_m.

$$Z=0.836 \cdot H_m-0.00396 \cdot Q_m$$

wherein H_m is expressed in m and Q_m in m^3/s. The expression was defined for the separation into the following two time periods: 1) 1926-1967; 2) 1968-1992. By taking the average values from Table 2 for the period 1968-1992, which are H_m=0.9756 m and Q_m=205.4 m^3/s, and by introducing them into the above expression, the following values for the discriminant function Z will be obtained:

$$Z=0.836 \cdot (-0.9756)-0.00396 \cdot 205.4=-0.8156-0.8133=-1.6289$$

The presented simple computation shows that the significance of parameters H_m and Q_m was almost the same for the separation process. The discrimination analysis confirmed the previous conclusions related to the time changes of separation and pointed to 1968 as the year when the statistically significant separation of the hydrological Drava regime at Donji Miholjac started.

CONCLUSION

The analyses performed in this study confirmed that significant changes in the hydrological regime of the Drava River at Donji Miholjac started approximately at the beginning of 1968. These changes were reflected by a sudden and continuous lowering of the river bottom which was noted from a series of the yearly minimum water levels H_m. In addition, mean yearly water levels $\bar{H}$ and the yearly minimum discharges Q_m were also decreased. The reasons for the above mentioned facts should be explained primarily by the construction of dams and reservoirs along the upstream part of the Drava River. These changes also led to the retention of a large amount of bed load sediment and also of suspended sediment in the storage basins. Thus, the river sections downstream from the dams degrade and this is accompanied by a lowering of the yearly minimum water levels. There exists a real possibility of a systematic decrease in the yearly minimum discharges due to an increased water consumption, especially for irrigation. The analyses of the water temperature regime prove there has been an increase in the minimum water temperatures were increased during the cold period of the year which resulted in less frequent occurrence of ice on the Drava profile at Donji Miholjac. Since it is located in the downstream section of the Drava the profile at Donji Miholjac integrated all influences resulting from man's activities in the upstream regions. Consequently, a similar trend (or even more intensive one) can be expected in the future and it might be even intensified.

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XVII. KONFERENZ DER DONAULÄNDER
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Die neu Methode der hidrologischen Berechnung in Verhältnisse der intensiv Wirtschafttädigkeit

New method of hydrological calculation during intensive economic activity

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Kurzfassung: Die Autoren vorschlagen den originalen Weg ausfindig machen die statistischen Charakteristik fur die Ausnutzung in hidrologischen Berechnung. Seine Grundlage ist die nächst Bestätigung: der mittel Quadrat der Abweichungen die zufällig Größe von einige Zahl minimum wurdet, wenn diese Zahl mit mathematische Erwartung der zufällig Größ zusammenfallen. Die Ausnutzung der neu Methoden an einen Beispiel der hidrologischen Berechnung für Bassinen zwei groberes Flußes des Mittelasiens - Syr-Darja und Amu-Darja gezeigt.

Summary: The authors suggest original way for using in hydrological computations. It is based on the following statement: mean square of the random value deviation from some value is minimum if this value coincides with mathematical expectation of the random value. The application of new method in the hydrological calculations for two basins ol large water economy ways in the Central Asia - Surdarya and Amudarya rivers gives interesting results presented in the report.

1. Introduction.

Hydrological calculations are necessary for definition of optimum parameters and exploitation regime of hydrotechnical constructions during their designing. Calculation methods, which are applicable both in our country and abroad describe river flow statistical characteristics when the regime of the rivers is natural or slightly distorted. But the number of such rivers is decreasing owing to intensive use of their flow for economic needs(irrigation, hydropower generation). This specifically concerns the lower reaches of Central Asian rivers and the rivers of the Republic of Uzbekistan , where all water resources are utilized in the economic cycle. The existing methods of hydrological calculations are already non fit and there is an urgent necessity in developing new generation of hydrological calculations , which would be able to take into account the changing economic situation. Scientists in the USA, Western Europe, Russia and in Uzbekistan's SANIGMI are involved with the search of new calculation methods.

The authors of this paper on the basis of the theory of nonstationary random processes and sequences developed the basis of new generation of hydrological calculations which allow to determine the probability and other statistical characteristics of mean annual and extreme water discharge.

2. The method of calculation of distribution moments and function of hydrological sequence distribution.

As a rule the description of random process is made on the basis of its multiple realization (essemble), obtained under the same set of conditions. But it is impossible to get multiple realizations in hydrology, so the scientists have to estimate statistical characteristics of nonstationary hydrological data series by its one sample. Now the estimation is made by the method of moving averaning. There are two conflicting requirements for obtaining reliable estimations: for statistical characteristics to be more stable it is necessary that the period of averaging would be longer, but for the revealing trend not to be smoothed by it it is necessary that the period of averaging would be as short as possible. V.S. Pugachev proposed the solution of the task of choosing the optimum averanging period. /1/

There is another way to find statistical characteristics of random nonstationary processes. The following is the basis of this method: mean square of random value Y deviation from some value A will be minimum, if A agrees with an expected value Y, i.e. expected value $m_y(t)$ is determined from the condition:

$$M\,[Y(t)-m_y(t)]^2 = S(t) \text{ --- min} \qquad (1)$$

It's easy to see that $S_{min}(t)$ is a variance of the random processD(t).

Let's prescribe individual realization of the random sequence $Y_i = Y(t)$, where i changes from 0 to N. Let's represent $\overline{Y}_i = m_y(t_i)$ as a sum of functions(the function may be orthogonal) in the form $a_j * g_j(t_i)$, i.e.

$$\overline{Y}_i = \sum_{j=0}^{j=P} a_j * \varphi_j(t_i) \qquad (2)$$

Let's write down (1) taking into account (2) and the mentioned above statements:

$$S_p(\overline{a}) = \frac{1}{N}\sum_{i=0}^{i=N} \left[Y_i - \sum_{j=0}^{j=P} a_j * \varphi_j(t_i) \right]^2 \to \min \qquad (3)$$

The function φ_i having been prescribed the coefficient a_j can be found from the system of (p+1) equations

$$\frac{\partial S_p}{\partial a_j} = 0 \qquad j = \overline{0,p} \qquad (4)$$

To solve the problem completely it's necessary to find a value of P,i.e. the required number of terms in the series used in equations (2) and (3). As one can see, instead of finding the optimum period during moving averanging, it's necessary to define the value of P in new version of the problem.

But if the expression (2) is really a mathematical expactation of random sequence Y_i then in (3) the value of $S_p(a)$ must equal the value of D as in the trend variance which was calculated using the structural and correlation functions:

$$\frac{1}{2*[1 - r_y(1)]} \left[B_y(1) - \frac{1}{N} \sum_{i=0}^{i=N-1} (\overline{Y}_{i+1} - \overline{Y}_i)^2 + \right.$$

$$\left. + \frac{1}{N} \{ [(Y_0 - \overline{Y}_0)^2 + (Y_N - \overline{Y}_N)^2] \} \right] =$$

$$= \frac{1}{N}\sum_{i=0}^{i=N} \left[Y_i - \sum_{j=0}^{j=p} a_j * \varphi_j(t_i) \right]^2 \qquad (5)$$

The equation (4) having been realized, the equation (5) will allow to find the values of P by selective search beginning from zero and finishing by the value not more than N/2.

To calculate the value of P it's useful to introduce $\Phi(p)$ function which is determined by the equality

$$\Phi(p) = S_{p\,min} - D\ (p) \qquad (6)$$

Here S_{pmin} is the expression (3) with the given p and the values of a_j when $S_p(a)$ reaches it's minimum. D(p) value is the left part of the expression (5) for the given value p on which Y_i and other values depend.

Let's choose from the multiple of values of P $0 < p < p_{N/2}$ the value $p=p_m$ which presets the minimum to the absolute value or to the square of $\Phi(p)$. This chosen value will be desired one. If calculation has resulted in $P_m=0$ the trend is insignificant. When $p_m > 1$ the trend is significant.

As a basis expansion functions Chebyshev's polynomials have been selected from the class of orthogonal functions; the approximation by these polynomials gives the minimum of maximum error and smooth approximation.

After we have found the distribution of the moments of random sequence it is necessary to determine an unconditional function of distribution for the moment i or frequency of $P(y_i, i) = 1 - F(y_i, i)$. There is a multiple of density types and the functions of distribution which are applicable to them. For the limited random values (with the lower limit preset) where Y_{min} is the minimum possible discharge (discharge of the continious stream is always larger then zero), distribution density can be presented as:

$$f(y) = \begin{cases} 0 & \text{if } y \le y_{min} \\ C\,(y - y_{min})^p\, e^{-ay^2 + by} & \text{if } y > y_{min} \end{cases} \qquad (7)$$

when $Y_{min} = 0$ and $P(y_{min}) = 0$ the equation (7) can be writen as

$$f(y) = \begin{cases} 0 & \text{if } y \le 0 \\ C\, y^p\, e^{-ay^2 + by} & \text{if } y > 0 \end{cases}$$

This density of probability, short of normalizing multiplier is three parametric one and is quite flexible in terms of its practical applicability for statistic parameters estimation in hydrological calculations (mean, variation coefficient and asymmetry coefficient).

3. The results of the method application.

The results of the measurements of monthly average and extreme water discharge on the main gauges of the basins of Amudarja and Syrdarja rivers were taken as initial information for calculation. On the Figure 1,2 the revealed trends and the curves of frequency of the corresponding discharges for particular year are presented.

The advantage of the revealed regularities is that in every particular case we can get not "some general variation tendency of temporal data series "/2/, not " slow, gradual variation of the random variable during the time period at issue /3/, but mathematical expectation of random hydrological process constructed from its certain realization.

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Fig. 1

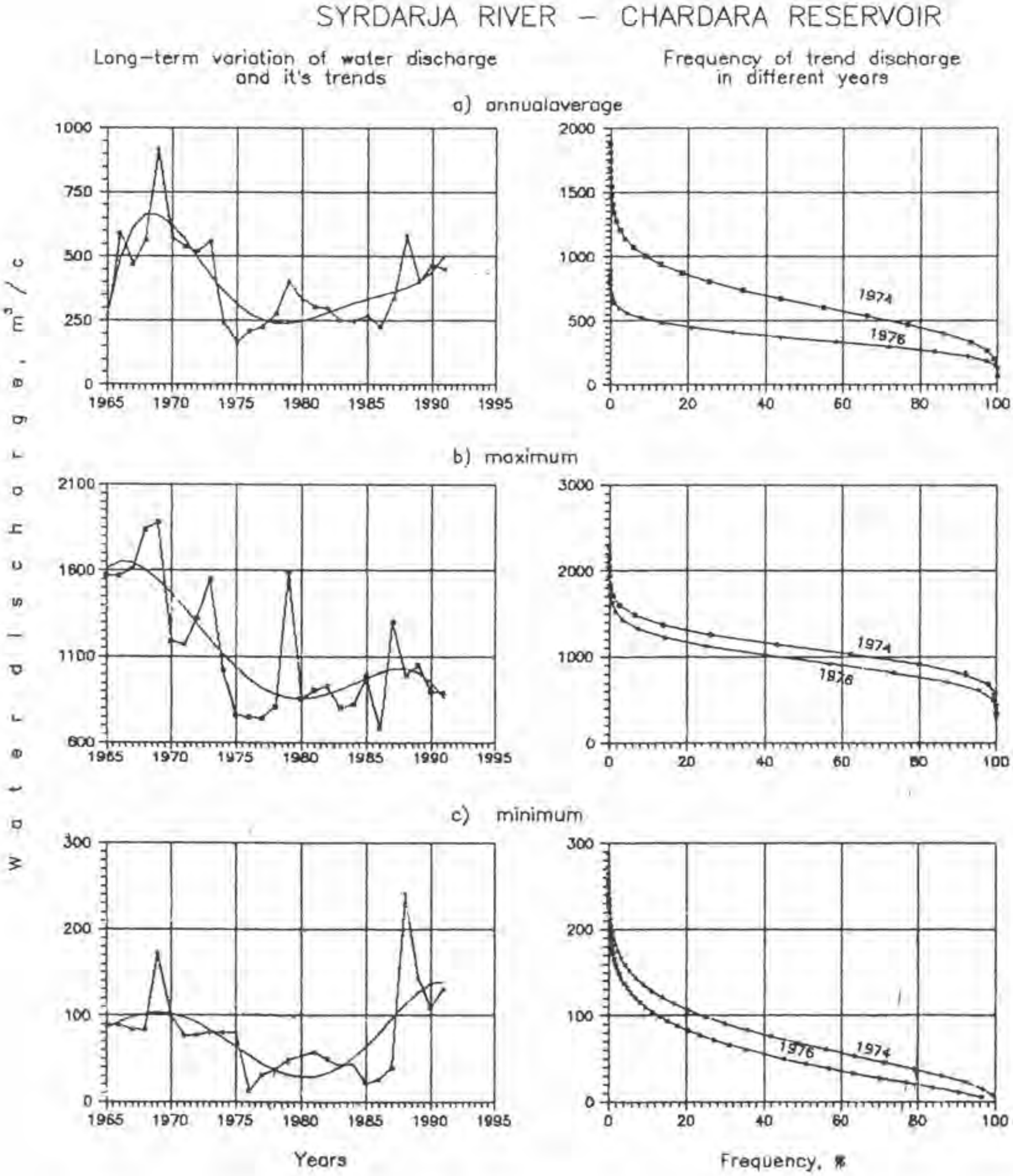
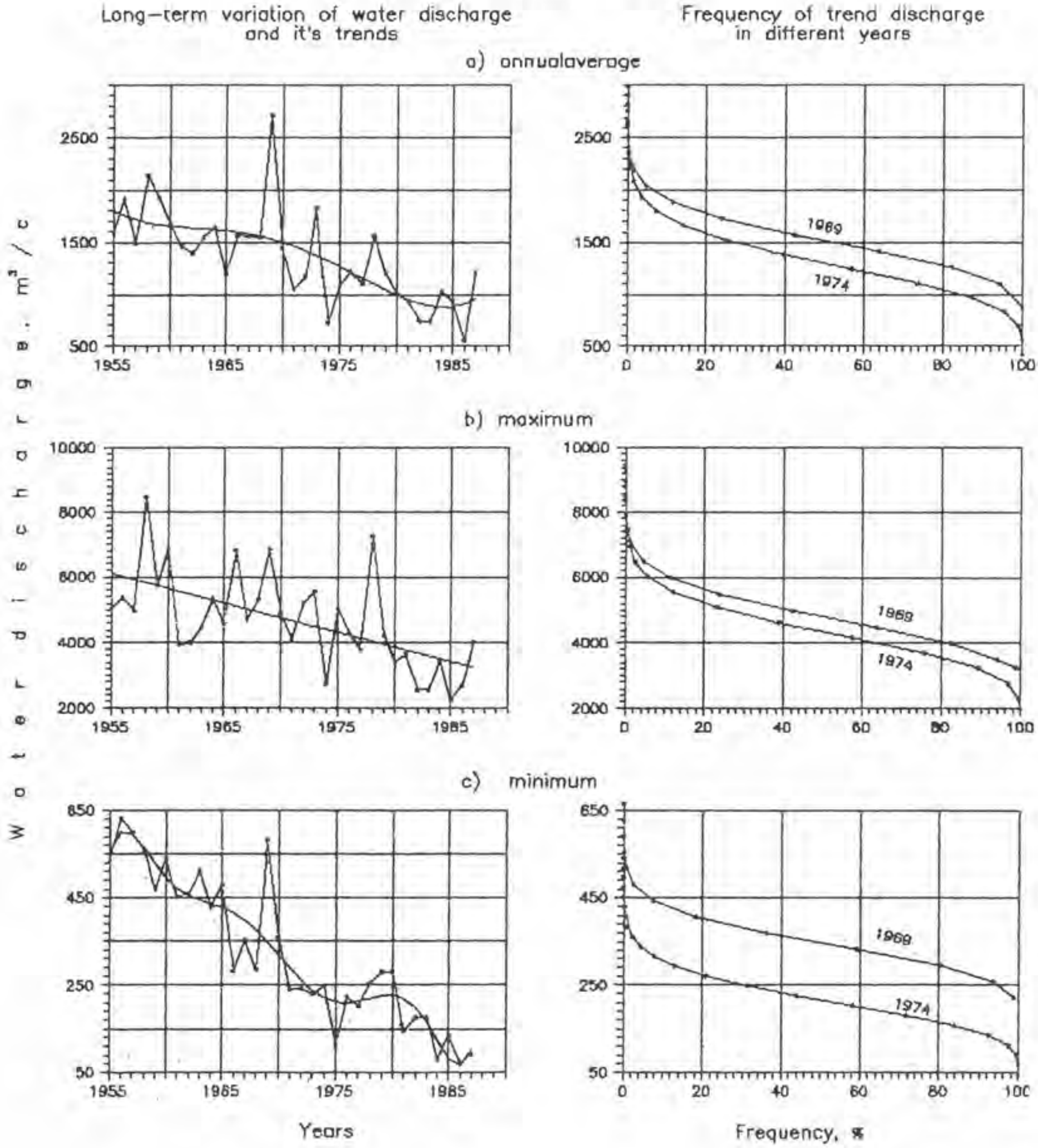

SYRDARJA RIVER – CHARDARA RESERVOIR
Long-term variation of water discharge and it's trends
Frequency of trend discharge in different years
a) annualaverage
b) maximum
c) minimum
Water discharge, m³/c
Years
Frequency, %
1974
1976

Fig.2

AMUDARJA RIVER – KERKY



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Trend analysis of the runoff data in the Nagymaros section of River Danube

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Summary

The paper is a contribution to the WMO project entitled "Analysing long-time series of runoff data" (1987). The gauging station with the longest reliable time series in Hungary, the section Nagymaros on River Danube was selected for the analysis. The investigated period was : 1883-1985.

Using several methods for homogenity tests and trend analysis, the time series of annual minimum, mean and maximum discharges were analysed. All of the time series were found homogeneous by all methods. After dividing the year into four seasons, the time series of monthly minima ,means and maxima were examined. A significant decreasing tendency in the autumn series and a less definite increasing tendency in the summer time series was found.

A regression analysis between the monthly mean water temperatures and discharges was carried out. A significant correlation was found only between the summer data pairs. Due to the known physical reasons, this is a negative correlation.

Trendanalyse der Abflußdaten der Donau bei Nagymaros

Kurzfassung

Die Studie ist ein Beitrag zum WMO-Projekt "Analyse langjähriger Abflußdaten" (1987). Die Analyse basiert auf die längste Abflußzeitreihe Ungarns, die für den Q[illegible]schnitt Nagymaros der Donau vorliegt. Die Untersuchung bezog sich auf die Pe[illegible]de von 1883 bis 1985.

Die Zeitreichen der jährlichen Mindest-, Mittel- und Höchstabflüsse wurden unter Anwendung verschiedener Methoden der Homogenitäts- und Trendanalyse untersucht. Sämtliche Zeitreichen ergaben sich, nach sämtlichen Methoden, als homogen. Danach wurde das Jahr in vier Jahreszeiten aufgeteilt und es wurden dieselben Trenduntersuchungen für jede Jahreszeit einzeln durchgeführt. Eine signifikante abfallende Tendenz konnte in den Herbstserien und eine weniger ausgeprägte abfallende Tendenz in den Sommerserien nachgewissen werden.

Zwissen den monatlichen Mittelwasserabflüssen und mittleren Wassertemperaturen wurde eine Regressionanalyse durchgeführt. Eine signifikante (undzwar, aus den bekannten physikalischen Gründen, negative) Korrelation zwischen den beiden Variablen konnte nur für die Sommerperiode nachgewiesen werden.

1.) Introduction

VITUKI contributed to the project entitled "Analysing long-time series of hydrological data" in 1987 by the request of WMO. The aim of the project to recover the tendencies in the available longest reliable hydrological data series and to search for a connection among these tendencies and the climathical changes.

The gauging station with the longest reliable time series in Hungary, the section Nagymaros on River Danube was selected for the analysis. The investigated period was 1883-1985, because the measured data are not quite reliable from 1986 due to the construction work of the barrage .

At the begining we run the time series analysing software package supplyed by WMO using our data series, after that we started an individual research.

2.) Statistical analysis of yearly data

During 1992 some basic research - concerning the analysis of long hydrological time series - was initiated involving Prof. J. Reimann into the work. Software was written for the realization of eight methods for analysis : one for them for testing independence, six for testing homogenity and two for trend analysis.

The following technics were used :

1.) Test of independence :
- Wald-Wolfowitz test, to analyse the independence of data and wether those are identically distributed

2.) Homogenity tests :
Non parametric methods
- Wilcoxon test, based on rank-statistics
- Kolmogorov-Smirnov test, based on order-statistics

- Combinatorical method, based on order-statistics
- Khi-square method

Parametric methods

- Student T-test, where normal distribution is assumed and it is capable to check, whether mean values of the two parts of time series are identical
- Welch-test, where normal distribution is assumed and it is capable to check, whether standard deviations of the two parts of time series are independent

3.) Trend analysis (non parametric tests)
- Spearman-test, based on rank-statistics
- trend-analysis, based on the least square method

We used for our computations discharge data series of River Danube at Nagymaros. The investigated period was : 1883-1985. To eliminate the annual periodicity, only annual values were used, namely five :

1.) time series of annual mean discharges
2.) time series of annual minimum discharges
3.) time series of annual maximum discharges
4.) time series of annual averages of monthly minima of daily discharges
5.) time series of annual averages of monthly maxima of daily discharges

All of the executed statistical tests with the time series gave the following results:

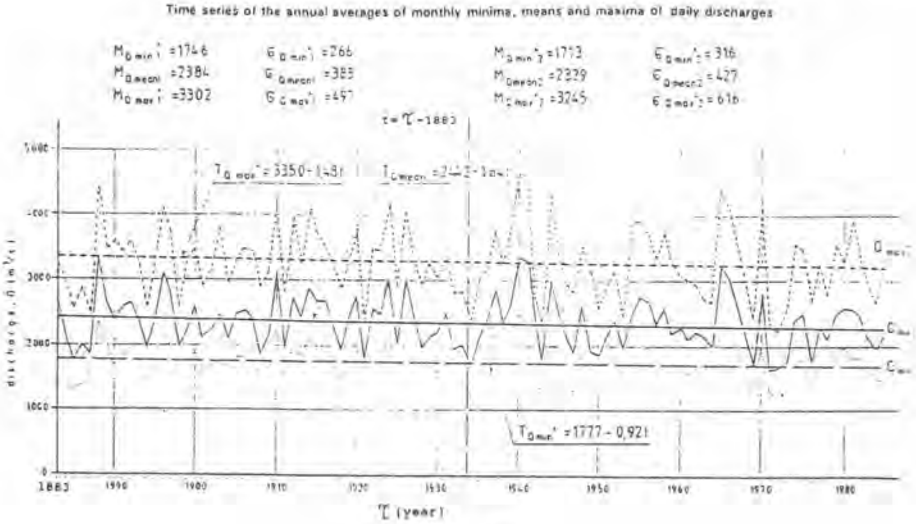
1.) Elements of time series are independent
2.) The time series are homogeneous
3.) There is no significant trend in the time series

Nevertheless a slight tendency towards decrease was detected in each time series, however these trends were not significant.

Figure 1

DANUBE - NAGYMAROS

Time series of the annual averages of monthly minima, means and maxima of daily discharges



We presented on Figure 1. the time series of the annual averages of monthly minima, mean and maxima of daily discharges.
Cutting into two parts the time series and analysing both of them, it is evident, that from one hand multi annual averages show a tendency to decrease ,on the other hand multi annual variances show a tendency to increase.
The decrease of averages - as we see - could be connected to long term climatic changes. The increase of variances can be explained by antropogenious impact, particularly by the operation of different kind of reservoirs, serving different purposes, constructed on river systems.

3.)Seasonal analysis of monthly discharge data series

During 1993, dividing the year by four qarters (spring : III-IV-V, summer : VI-VII-VIII, outumn : IX-X-XI, winter XII-I-II), we repeated the above investigations using the time series of monthly minimum, mean and maximum discharges. The results are summarized in Table 1.

Table 1.

Results of seasonal analysis of the data series of monthly minimum, mean and maximum discharges

statistical test		test of independence (Wald-Wolfowitz test)	trend analysis		homogenity-test					
data series	quarter		least square method	Spearman-test	Wilcoxon-test	Kolmogorov-Smirnov test	Combinatorical method	Khi-square method	Student T-test	Welch-test
monthly mean discharges	spring	+	-	-	+	+	+	+	+	+
	summer	+	-	-	+	+	+	+	+	+
	outumn	+	+	+	-	+	-	+	-	-
	winter	+	-	-	+	+	+	+	+	+
monthly minimum discharges	spring	+	-	-	+	+	+	+	+	+
	summer	+	+	+	+	+	+	+	+	+
	outumn	+	+	+	+	+	-	-	-	-
	winter	+	-	+	+	+	+	+	+	+
monthly maximum discharges	spring	+	-	-	+	+	+	+	+	+
	summer	+	-	-	+	+	+	+	+	+
	outumn	+	-	-	+	+	+	+	+	+
	winter	+	-	-	+	+	+	+	+	+

Concerning to the results of test the data series were found homogeneous in general. Excepcion are the monthly mean discharges and the monthly minimum discharges both in the outumn qarter. The trends are decreasing in both cases. Even in the monthly minimum discharge data of the summer qarter the trend analysis found a decreasing tendency, but the homogenity tests didn't supported that assumption.

4.) Seasonal analysis of the monthly maximum discharges exceeding 85 and 90% quantile levels

We determined the 85 and 90% quantile levels for the whole (103 year long) data series for all the four quarters of year. After that we took into consideration only the discharge data series exceeding these quantile-levels.

We concluded from the results that the number of exceedances well approximatable by poisson distribution function in the majority of cases. The magnitude of exceedances fit to exponential distribution function in every cases.

Concerning the magnitude of exceedance significant difference between the two parts of the time series was not detectable.

As regards the number of exceedances a definite decreasing tendency is observable during the outumn quarter. During the summer quarter the number of exceedances above 90% quantile level show a considerable increase (Table 2.).

Table 2.

The paramethers of the Poisson distribution function belonging to the different quantile levels (we recorded in brackets the number of cases of exceeding the given level)

time series / quantile-level	spring			summer			outumn			winter		
	whole time series	first half of time series	second half of time series	whole time series	first half of time series	second half of time series	whole time series	first half of time series	second half of time series	whole time series	first half of time series	second half of time series
85%	0.45 (46)	0.42 (22)	0.46 (24)	0.45 (46)	0.40 (21)	0.49 (25)	0.45 (46)	0.56 (29)	0.33 (17)	0.45 (46)	0.48 (25)	0.41 (21)
90%	0.30 (31)	0.29 (15)	0.31 (16)	0.30 (31)	0.21 (11)	0.39 (20)	0.30 (31)	0.38 (20)	0.22 (11)	0.30 (31)	0.29 (15)	0.31 (16)

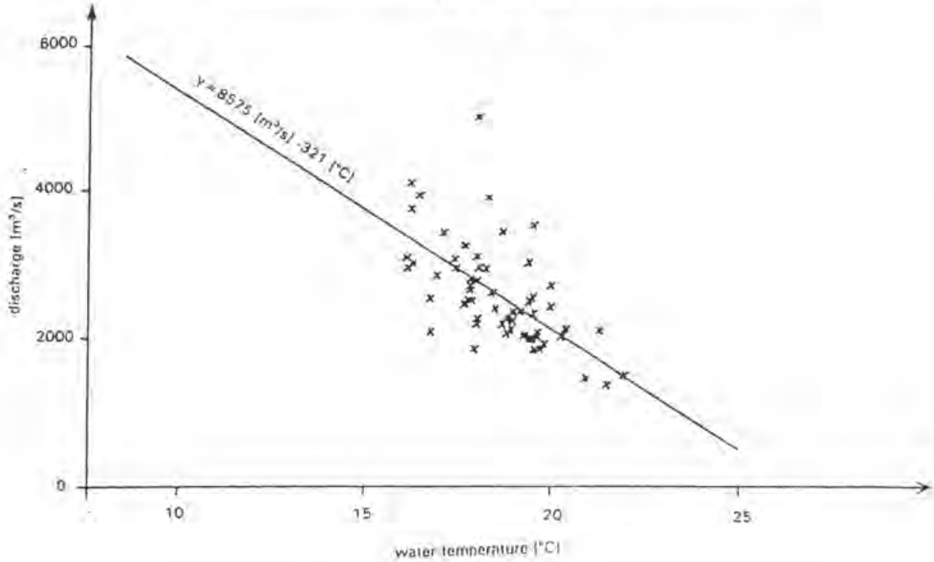
5.) Homogenity test for the monthly mean water temperature and regression analysis between the water temperature- and discharge data series

The monthly mean water temperature data at the section Nagymaros on River Danube were available for us from 1967. We performed the homogenity- and trend analysis for the whole data series and for the data series for the four quarters as well. All of the analysis found the data series homogeneous, in which significant trend was not detectable.

We computed the paramethers of the crosscorrelation connection between the monthly mean water temperature and discharge data series. There was found a considerable correlation function only in the summer quarter (-0.63), which means a negative correlation between the two variables in the given season (Figure 2.)

Figure 2.

Correlation connection between the monthly mean water temperature and monthly mean discharge at the section Nagymaros on River Danube, summer quarter (1967-1985)



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TRENDS AND CYCLICITIES OF THE RIVER RUNOFF ON ROMANIA'S TERRITORY

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Abstract: In order to reveal certain trends and cyclicities of the river runoff on Romania's territory, the discharges recorded at hydrometric stations with long and continuous series of observations were analysed, characteristic to the main geographic areas of the country.

The main statistical parameters were determined for the series of mean monthly and annual discharges as well as the statistic tests for the description of the time series behaviour.

In order to emphasise certain cyclicities within the time series the autocorrelation function was used as well as the Whittaker-Robinson test and the spectral analysis.

A linear trend resulted for the discharge time series from the analysis of the general tendency.

The statistical analysis carried out revealed common runoff trends and cyclicities for certain large geographical areas of the country, depending on the regional phisico-geographical characteristics of the hydrografic basins and being directly influenced by the characteristics of the general climatic factors.

TENDENZEN UND ZYKLIZITÄTEN IM FLIEßEN DER FLÜSSE AUF DEM GEBIET RUMÄNIENS

Kurzfassung: Um Tendenzen und Zyklizitäten des Fließens der Flüsse auf dem Gebiet Rumäniens festzulegen, wurden die von 18, für die wichtigsten geographischen Zonen des Landes charakteristischen hydrometrischen Warten mit langzeitigen und ununterbrochenen Beobachtungsreihen registrierten Wassermengen analysiert.

Für die betreffenden Meßreihen von monatlichen und jährlichen mittleren Wassermengen wurden die wichtigsten statistischen Parameter bestimmt, sowie statistische Teste zur Beschreibung des zeitlichen Verhaltens ausgearbeitet.

Zwecks Hervorhebung von Zyklizitäten im Rahmen der Zeitreihen wurden die Autokorrelationsfunktio, der Whittaker-Robinson-Test sowie die Spektralanalyse angewandt.

Aus der Analyse der allgemeinen Tendenz ergab sich die Mengenreihen eine lineare Tendenz.

Die durchgeführten statistischen Analysen stellen Tendenzen und Zyklizitäten heraus, die für große geographische Zonen des Landes gemeinsam sind, von den regionalen physisch-geographischen Merkmalen der Einzugsgebiete abhängen und durch die charakteristischen Klimafaktoreen unmittelbar beeinflußt werden.

INTRODUCTION

Climate and water resources system are in close relationship, the water resources recording in time a series of quantitative changes in accordance with the variation of the climatic factors.

Within this context, the assessment of the rivers runoff trends and cyclicities have been made by analysing the time series of monthly and annual mean discharges from 18 hydrometric stations with long and continuous series of observations. These stations are located in different physico-geographic regions of the country (Figure 1) and their recording length is higher than 35 years.

In Figure 1, $\bar{Q}$ represents the multiannual mean discharge for the stations selected.

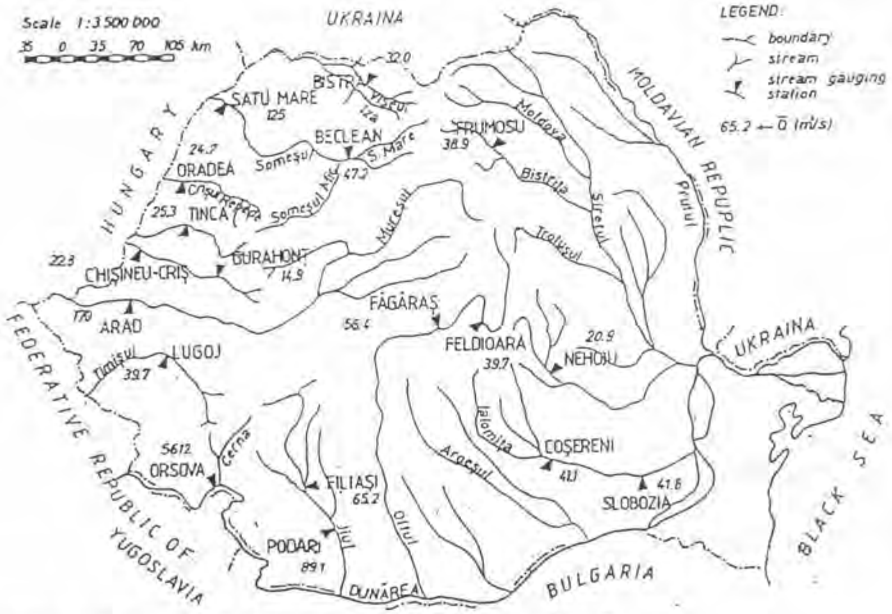

Figure 1. Location of Stream Gauging Stations, including $\bar{Q}$

Due to the fact that it is difficult to obtain homogeneous and consistent time series of discharges, those quasiconsistent time series for which adequate corrections have been made (as the reconstruction of the natural flow regime) have been considered acceptable.

Basic statistics were calculated for the time series of monthly and annual mean discharges and for the individual monthly time series (WMO, 1988).

The main statistical parameters calculated are: the multiannual mean discharges along with the standard deviation, the multiannual mean specific discharge, the variation coefficient, the skewness coefficient, the coefficient of Kurtosis.

TRENDS AND CYCLICITIES

The main component of a time series is represented by the general trend due to the factors with permanent action.

The general trend of the hydrologic series can be determined by the modification of the climatic factors as well as by human influence.

The most frequently methods used in the analysis of the general trend are those of analytical adjustment by applying the least square method (Iosifescu et al., 1985).

For the long-term variations it can be stated that the trend is in certain cases linear and in other cases parabolic. The conclusive was the linear tendency. Thus, Table 1 contains the equation of the straight line determined for each of the annual mean discharge series considered.

***Table 1.** Linear trends of the series of annual mean discharges*

Station	Linear trend $x(i) = a + b\,i$	
	a	b
Bistra	28.1436	0.1864
Satu Mare	124.7400	-0.0180
Beclean	44.7400	0.1230
Gurahonț	14.6620	0.0060
Chişineu Criş	23.1540	-0.0250
Oradea	24.1230	0.0176
Tinca	25.0640	0.0131
Arad	154.1430	0.2560
Lugoj	34.9780	0.2270
Filiaşi	74.0520	-0.5318
Podari	95.1410	-0.3040
Feldioara	32.6256	0.3360
Făgăraş	56.1590	0.2310
Coşereni	38.2510	0.1490
Slobozia	38.0000	0.1138
Nehoiu	20.2610	0.0320
Frumosu	38.4400	0.2730
Orşova	5587.4090	0.1183

A slightly increasing linear trend results for most of the discharge series. The region of Oltenia is an exception, showing a decreasing trend of the discharge series.

The study of the river runoff cyclicities was carried out by the analysis of the autocorrelation function by applying the Whittaker-Robinson test and by means of the spectral analysis.

For the selected hydrometric stations, the autocorrelation functions and the confidence limits were represented, corresponding to a 95% significance level (WMO, 1988).

The Whittaker-Robinson diagrams were also graphically represented (Tertisco et al., 1985). It for the studied series has been calculated the variance estimation of the residuals, the minimum of which can provide the estimation of the periodicities:

$$\hat{\lambda}^2(n)=\frac{1}{N}\sum_{t=1}^{N}x^2(t)-k\sum_{t=1}^{n}y_s^2(t) \tag{1}$$

where N is the number of data in the series; $x(t)$ are the residuals, obtained by the elimination of the trend from the initial series; $y_s(t)$ is the seasonal component; $k=N/n$, $n=2,3,\ldots,N$. The Whittaker-Robinson test gives the advantage that it estimates simultaneously the seasonal component as well as its period.

Often, periodicities within time series can be better determined by the analysis of the series in the domain of frequencies, by using the spectral analysis.

The periodogram for the series $x_1,\ldots,x_N$ is defined as:

$$I(p)=\frac{2}{N}\left[\left(\sum_{i=1}^{N}x_i\cos\frac{2\pi ip}{N}\right)^2+\left(\sum_{i=1}^{N}x_i\sin\frac{2\pi ip}{N}\right)^2\right] \tag{2}$$

where N is the number of data in the series; x_i are the mean discharges; $p=1, 2, \ldots [(n/2)-1]$ where [ ] denotes "the integer part of" (WMO, 1988). Then the Fischer test (Davis, 1976) was used for the existence of a dominant periodical component of a periodogram.

Figure 2 represents the periodograms for the hydrometric stations of Slobozia, Nehoiu and Coşereni located in Muntenia. They reveal common periods for the three hydrometric stations located in the same phisico-geographic area.

But, the most useful for the identification of the periodicities within a time series is the spectral density, showing the existence of a cycle and its frequency.

The spectral density function was computed based on the autocorrelation coefficients (Haan, 1977):

$$S(f)=\Delta t\left[r(0)+2\sum_{k=1}^{m-1}r(k)\cos(2\pi f\Delta t)+r(m)\cos(2\pi mf\Delta t)\right] \tag{3}$$

where Δt is the length of the time interval (1 month, 1 year); f is the frequency ($f=kf_N/m$, where $f_N=1/2\Delta t$ is the highest frequency for which any information can be obtained); $r(k)$ are the autocorrelation coefficients and m is the maximum number of correlation lags.

By the analysis of the cyclic component of the considered series, common periods resulted for certain large geographic areas of the country: for Muntenia 8, 15-16 and 12 year periods; for Transylvania 10, 13-15 and 20

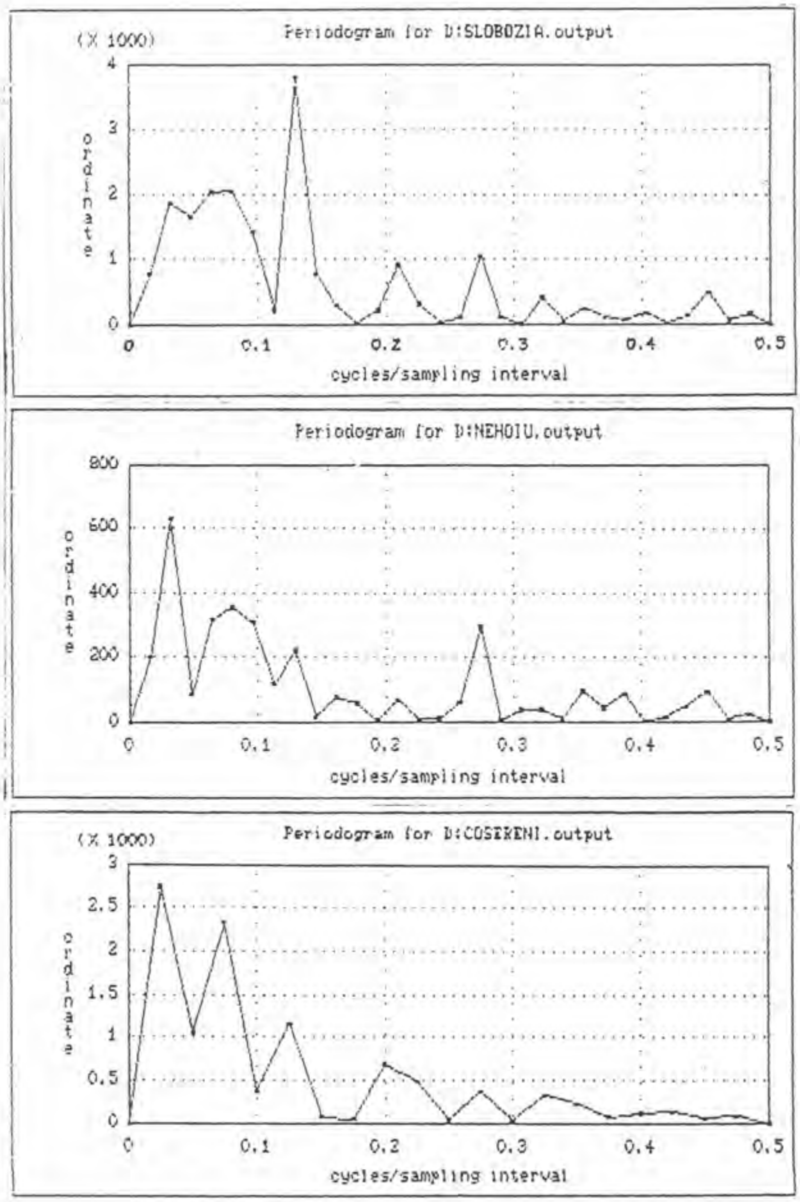

FIG. 2

year periods; for Oltenia 8 and 15 year periods; for Crişana 8, 13-15 year periods.

It can be noticed that certain periodicities are characteristic for several areas. Also 3-6 year periods were obtained which are not common to large areas, but for Orsova periods of 30, 21 years were obtained, reflecting the general climatic characteristics of the Danube basin.

The variation of all these periods depends on the phisico-geographic regional peculiarities of the hydrographic basins, being directly influenced by the characteristics of the general climatic factors.

CONCLUSIONS

The analysis of the 18 series of monthly and annual mean discharges for the territory of the country, revealed the following conclusions:

- The dependency of the altitude of the specific mean discharge; it is higher with the increase of the altitude;
- The maximum values of the multiannual monthly mean discharge resulted for the months of April, May and minimum ones for the months X-III;
- High values of the variation coefficient resulted for the months of July, September, October and low ones for the spring months;
- The asymmetry is positive for all the time series;
- The general trend is slightly increasing;
- Common periods of certain large geographic areas of the country resulted, determined by the influence of the general climatic factors and of the regional phisico-geographic peculiarities of the hydrographic basins.

The results obtained from the analysis of the time series of mean discharges can provide certain information for the long-term prediction of the rivers runoff evolution on Romania's territory.

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ANTHROPOGENIC IMPACT ON THE FLOOD DISCHARGE INCREASE – CASES AND REQUIRED MEASURES

M. Breznik

Anthropogenic impact on the flood discharge increase is in the construction of flood protection embankments, river regulations and erection of river barrages. These measures result in the reduction of retention volume and in the capacity increase of the water outflow as well as in the greater danger of coincidence of river and affluents flood waves. Cases confirm the above statements. The former flood areas should be activated by embankment spillways. During the time of the greatest danger the water level in river storages should be reduced and embankments made higher in downstream areas. Mathematical models should determine the impact of artificially changed conditions for known catastrophic floods.

ANTHROPOGENER EINFLUSS AUF DEN HOCHWASSERABFLUSS – BEISPIELE UND NOTWENDIGE MASSNAHMEN

Kurzfassung. Der anthropogene Einfluß auf den Hochwasserabfluß sind der Bau von Hochwasserdeichen, die Flußregulierung und der Ausbau von Flußstaustufen. Deswegen verkleinert sich der Retentionsraum, vergrößern sich die Abflußfähigkeit und die Gefahr einer Koinzidenz der Hochwasserwellen des Flußes und der Zuflüsse. Die bearbeiteten Beispiele bestätigen die obigen Feststellungen. Die früheren Überschwemmungsgebiete sollten wieder mit seitlichen Überläufen aktiviert werden, in der Zeit der höchsten Gefahr sollten der Wasserspiegel im Staubecken vorläufig versenkt und die Hochwasserdeiche flußabwärts erhöht werden. Mit mathematischen Modellen ist der Einfluß der künstlich veränderten Umstände auf die bekannten katastrophalen Hochwasser festzustellen.

THEORETICAL BASICS

With catastrophic floods the discharge is the function of ratio between water volume in the river and time of the outflow of that water, which in return is again the function of hydraulic conditions

$$Q = f\left(\frac{V_R}{T}\right) \quad T = f\ (HY)$$

Q = discharge at floods, V_R = river water volume, T = water outflow time, HY - hydraulic conditions

In normal conditions the volume of water in the river was reduced by the water retention between previous level and flood level in river and by retention in the flood area

$$V_{R\ NAT} = V_R - V_{RR} - V_{RF}$$

V_R- volume of water in the river, V_{RR} - retention in river, V_{RF} = retention in flood areas, $_{NAT}$ - natural conditions

In artificial conditions the flood areas with highwater flood embankments are being cut off the river, the river retention is mainly filled by high level of hydropower plant, with lifting of gates some storage water is being discharged.

$$V_{R\ ART} = V_R + V_{AC}$$

V_{AC} - discharge of some storage water behind the gates, $_{ART}$ - artificial conditions upon the construction of embankments, regulations and river barrages.

$$V_{R\ ART} >> V_{R\ NAT}$$

Artificial conditions result in greater water quantity of the river, which is discharged faster than in natural conditions.
Capacity of outflow in artificial conditions is much greater as that of natural conditions due to the reduced roughness, increased cross section in the storage basins of hydro power plants and due to the increased water surface slope caused by regulations or lifting of gates.

$$C_{Q\ ART} >> C_{Q\ NAT}$$

C_Q - capacity of outflow

Due to greater outflow capacity, the outflow time is to be shorter in artificial conditions

$$T_{Q\ ART} < T_{Q\ NAT}$$

and the flood outflow much greater

$$Q_{ART} >> Q_{NAT}$$

CASES

With very heavy floods in 1954 the greatest discharge of the Danube in Obernzell was 9600 m³/s (Hans 1956) and that in Vienna of 9160 m³/s (Embacher 1956). Volume of that flood wave in Obernzell was V = 3870 hm³ (Fig. 1) above the mean flood discharge 2700 m³/s.

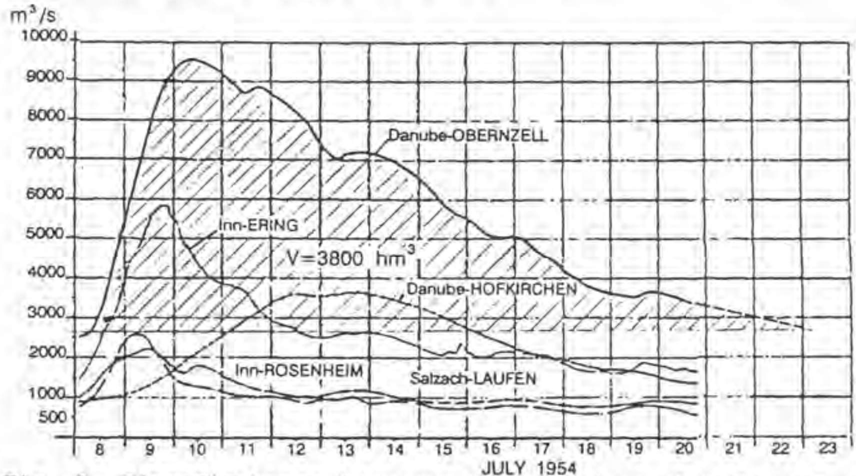

Fig. 1 Time-discharge hydrograph of Danube and tributaries in July 1954 (hydrograph after Hans 1956)

Abb. 1 Ganglinie des Abflusses der Donau und der Zuflüssen im Juli 1954 (Ganglinie nach Hans 1956)

Flood discharge of the Danube in August 1991 was 9600 m³/s in Kienstok and the same in Vienna (Fig. 2, Heilig 1992) and in Bratislava 9300 m³/s (Svoboda et al. 1992). Volume of the flood wave above the mean flood discharge of 2700 m³/s was in Kienstock 2150 hm³ and in Bratislava 1100 hm³. With considerably lesser precipitations in 1991 as those in 1954 and substantially smaller volume of flood waves in 1991, the Danube discharge was nearly the same to that in 1954. How to explain this disproportion? It was partly influenced by great discharges of the Austrian affluents in 1991 and by the smaller one of the German Danube. The main impact should be the greater water discharge capacity and consequently the shorter outflow time of the flood wave. Volume of the flood wave in Bratislava was reduced by the retention in the Austrian and Czech part of the Danube below Vienna.

The course of the Danube flood wave in 1954 was examined by Embacher (1956) who determined in all flood areas the reduction of velocity of flood wave propagation (Fig. 3) and the reduction of the flood wave volume due to the retention in flood areas. Then flooded area are at present cut off from the river by means of embankment of hydro power stations and flood protection embankments. The average velocity of the flood wave propagation on the Danube in Austria was 2,7 km/h and the mean water velocity was 2,9 m/s in the deep part of the Danube river bed in Vienna on July 15, 1954.

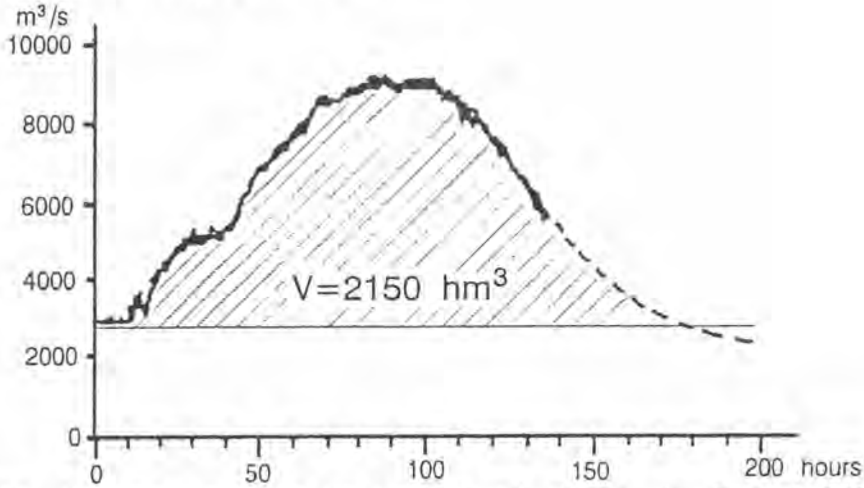

Fig. 2 Time-discharge hydrograph of Danube in August 1991 (hydrograph after Heilig 1992)

Abb. 2 Ganglinie des Abflusses der Donau im August 1991 (Ganglinie nach Heilig 1992)

Mundt (1980) in his study on floods dangers and the relevant protection in the lower Inn states (quote): "Inflow time at great high water is some hours....difference of levels between the mean and high water is approx. 9 m...From the beginning of this century the discharge time of high water has been reduced from the edge of the Alps to the Passau for about a half...The acceleration of the flood waves is partly due to the erection of hydro power plants and partly due to the deepening of the river bed as the result of regulation...." (unquote).

Peak of the flood wave in 1991 caused the inundation of Salzburg in late afternoon on August 2, and reached Vienna on August 4. Velocity of the propagation peak was around 9,8 km/h.

Greater velocity of flood waves propagation will result in greater probability of summing up of the peaks of waves of the main river and affluents. Also, there will be greater danger of coincidence for the flood wave flowing to the East and towards East moving cold fronts with the biggest precipitations.

Bauch (1968) studied the influence of the construction of the river barrages on the 59 km long section of the

Danube between Regensburg and Straubing. A 590 m long physical model in the scale of lengths 1:100 and heights 1:25 was made. Also, a mathematical model with equation of unsteady flow in open channels and their solution in a difference scheme was done. The most important results of the study: two thirds shorter discharge time of highwater wave, velocity of propagation peak of flood wave increased by 3,3:1 ratio of time, attenuation of the peak wave is smaller and the retention volume for the takeover of the highwater wave considerably smaller.

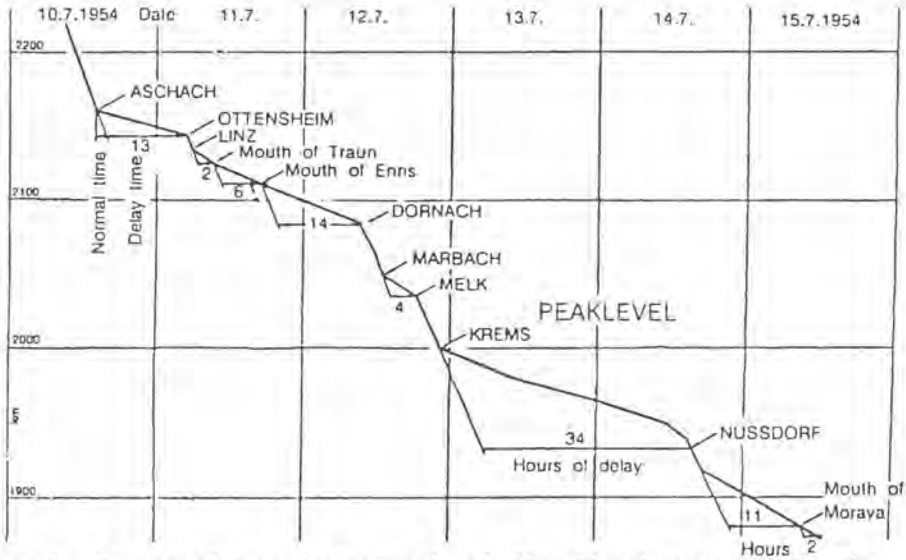

Fig. 3 Time-distance hydrograph of the flood wave of Danube in July 1954 (after Embacher 1956)

Abb. 3 Zeitfolgelinie der Fluwelle der Donau im Juli 1954 (nach Embacher 1956)

Cižova (1992) analyzed the impact of antropogenic activity on 82 flood waves of the Danube in years 1923-1988 and 40 in years 1975-1988 and found out the acceleration of the water discharge and the shortening of the propagation time of highwater wave and faster lifting of the river level prior to the highest level. In December 1991 the water level of the Danube in Bratislava increased by 380 cm in 24 hours. Between Linz and Bratislava in 1968 propagation time was from 20 hours to up the normal 24 hours and more, at present the propagation time with mean discharges is, however, 10 to 20 hours. With all discharges the propagation time is shortened for approx. 10 hours and between Vienna and Bratislava for approx. 5 hours. Therefore, now it is more difficult to forecast the flood waves.

In Carinthia in Austria in September 1965, 200 km² were inundated (Wurzer 1966). Upstream the Annabruecke profile with the discharge of 2223 m^3/s there were no river barrages on the Drava, and no flood protection embankments along the river Gail. Downstream there were three river barrages in Austria and in Slovenia 6 river barrages with head of 8 to 17 m. In the Drava canyon in Slovenia there were no flood areas. From the then lowest constructed barrage Mariborski otok there is, up to 30 km distant profile of Ptuj with discharge of 2280 m^3/s, mainly plane with smaller flood areas along the Drava. The distance from Annabruecke to Ptuj is 180 km and the velocity of

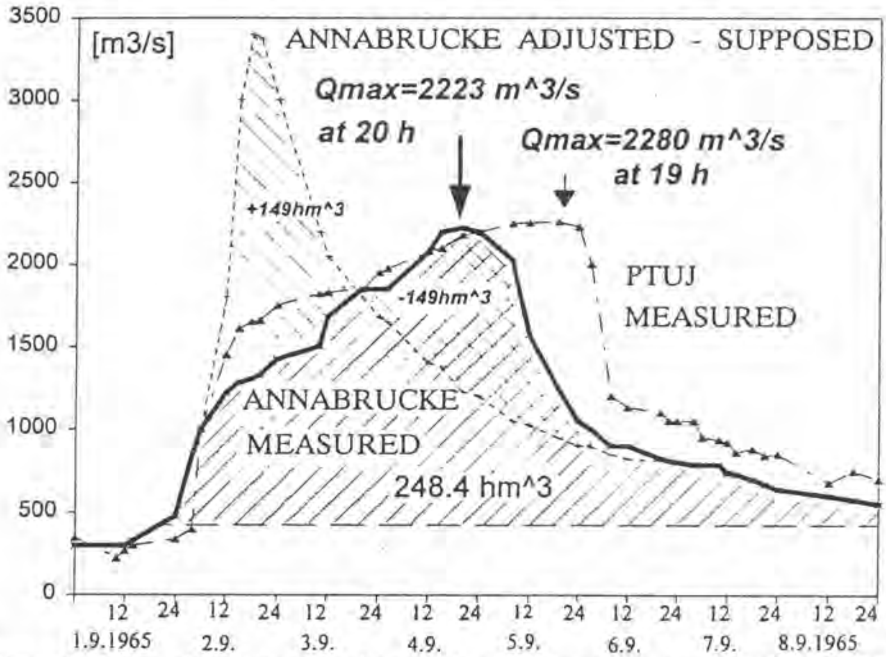

Fig. 4 Time-discharge hydrographs of Drava river in September 1965 -- measured, -- supposed due to the loss of retention volume

Abb. 4 Ganglinien des Abflusses der Drau im September 1965 -- gemessen, -- supponiert wegen Verlust des Retentionvolumes

propagation peak of flood wave was 7,8 km/h. It was most probably increased due to the outflow through 9 storage reservoirs. At present there are in the 90 km area upstream of the Annabruecke profile 7 new river barrages with head of 10 to 26 m. Along the river Gail and many others, flood protection embankments were constructed. Greater majority of 200 km² inundated ground in 1966 is presently protected against floods. Hydrograph Annabruecke 1966 (Fig. 4) has an untypical curve of discharge increase due to great retention. Typical hydrograph of the river with no flood areas has a steep curve of discharge increase and a flat curve of discharge decrease (Bergman 1992). Figure 4 shows a hypothetical hydrograph for present conditions. Discharge will increase mainly due to the retention loss in the river and flood areas, increase of the river outflow capacity, increase of the specific precipitations intensity caused by shorter outflow time of flood wave and will be reduced due to the retention in storage basin in high mountains. In the Drau basin in Austria high in the Alps there are 10 big storage basins with entire total volume of approx. 460 hm^3. Surfaces of their catchment areas are Mooser 87, Koralpe 67, Koelbrein 58, Fragant 56, Freibach 44, Bockhartsee 15, Reisseck 8 km^2 and some minor, total of around 400 km^2. Their significance for the reduction of floods is minor. In comparison to 11000 km^2 of the Drau basin in Austria the influence of reduction remains unsubstantial, around 5%, even with the increase of the precipitations intensity in mountains.

For the river Vah basin in Slovakia Benicky (1992) made an estimate with mathematical model showing the increase of flood outflow from 2000 up to 2400 m^3 and the shortening of the peak wave propagation time from 42 to 19 hours due to the construction of a chain of river barrages and flood protection embankments.

ACTIVE AND PASSIVE PROTECTION MEASURES

At very high flood outflows with return period of 50 years or 100 years all former flood areas are to be activated by the construction of overflow spillways on the embankments. During the period of greatest possible discharge e.g. on the Danube from middle of June till mid September the levels in all basins of river barrages should be lowered for 2 to 3 m, thus creating partial retention for the takeover of the highwater wave and prevent the total outflow of the storage water at gates lifting.

Flood forecast service will be enabled to request on time the partial outflow of storage basins on shorter rivers only, there assuring beneficial effect. On the Danube partial storage basin outflow requests time, one week at least, a period for which catastrophic precipitations can never be forecast in advance. In flood areas the housing and industrial constructions are to be prevented. Flood damages of 9 million German marks value in Slovenia in November 1990 concerned newly built structures in known flood areas. Along most of the rivers by towns and industrial complexes the flood protection embankments are to be made higher, valuable machinery in industrial structures are to put on higher level.

Iron-gate dam on the Danube has the spillway dimensioned at 16.800 m^3/s, at the outflow of 22.000 m^3/s there are transformer platform and the engine room roof 2,2 m above the tail water. Small protection wall at the edge of the transformer platform could easily protect engine room against higher water than anticipated.

RECOMMENDATION

An evaluation is to be elaborated on impact of all those rivers where natural conditions have changed due to river barrages, flood protection embankments or regulations. It is to be done by mathematical models for high waters from the years 1954 and 1501 on the Danube, from years 1966 and 1851 on the Drava and for known high waters on other rivers. Also, the outflow of water stored behind gates of river barrages is to be taken into account. Pečinova (1988) reports that in 1954 in the upstream of Bolgaria the storage in 50 reservoirs was 4% and in 1980 in 600 reservoirs 25%, that is about 45000 hm^3 (!) of annual flow of the Danube in Bolgaria.

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THE CHANGE OF CONSTITUTIVE EQUATIONS OF WATER BALANCE SURFACE DRAIN IN THE CONDITION OF ARTIFICIAL IRRIGATION

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The report conserns a results of researches of irrigation influence on surface flow caracteristics.

DIE VERÄNDERUNG DER WASSERHAUSHALTGLEICHUNGSKOMPONENTEN DES OBERFLÄCHENABFLUSSES UNTER BEWÄSSERUNGSVERHÄLTNISSEN

Im Bericht werden die Forschungsergebnisse von Bewässerungseinflüssen auf die Kennwerte der Oberflächenabflüsse dargestellt.

The objekt of reaserch is a territory of the south Ukraine and Moldova. It is an arid region. One can resieve a large crops here, only with a help of irrigation. Moisture rise,after irrigation brings an increase of water flow from slops to channel network.The ways of estimation of irrigation influence on the flood flow as a rule, examines a separate territories, or reserved basins. Conditions of flow forming on the small grounds and on the large basins are very different. This difference is caused by different soil-botanic conditions and by presipitation irregularity in time and in space. Irrigation increases moisture, essentially and, that is why the influence of many other factors of flow becomes not so important. And the main - a type of flood flow may be changed on the irrigating lands. Because of aeration zone saturation and small absorbtion into the impervious bed, surface flow formes under the influence of subsurface flow.

All greate rains were researched in this region. Watergeneration layer was calculated for this rains both for natural condition of moistening,and for condition of irrigation.Mean values of watergeneration layer with probability of exeeding 1% for different soil types are changing insignifically. That is why it can be means only for land's agricultural using.

Irrigation influence on the affluent layer one can estimate on the base of balance equation

$$Y_{1\%_{op}} = Y_{1\%}(1 - f_{op}) + Y'_{1\%_{op}} f_{op} \qquad (1)$$

from which

$$\gamma_y = 1 + \left[\left(Y_{1\%_{op}} / Y_{1\%}\right) - 1\right] f_{op} \qquad (2)$$

where, γ_y - coefficient of irrigation influence on affluent leyer; $Y_{1\%}$ - affluent layer for natural condition of moistening; $Y'_{1\%_{op}}$ - affluent layer from irrigating parts of basin; $Y_{1\%_{op}}$ - affluent layer from basin with partial irrigation; f_{op} - square of irrigation.

Equation (2) permits to estimate the irrigation influence on the maximum flood fiow for different values of f_{op} by the way of imitation models.

Results of calculations for different values of f_{op} and for different agricultural using of lands showed, that γ_y depends on square of irrigation, more then on soil types. Moreover, coefficient γ_y almost does not depends on the agricultural using of the territory.

$k_{y_{op}}$ - is a coefficient of reduction of affluent layer on the irrigating lands. This coefficient problem was connected with a lack of observation. For the basin with partial irrigation

$$k_{y_{op}} = k_y + f_{op}(k_s - k_y) \qquad (3)$$

where, k_y - reduction coefficient of affluent layer on unirrigating lands; k_s - reduction coefficient of watergeneration.

$$k_y = 1 - 0.30\ \lg F/10;\ \text{when } F \leqslant 10 km^2 - k_y = 1.0 \qquad (4)$$

where, F - basin square.
From (3)

$$\gamma_{k_y} = 1 + [k_s/k_y - 1]\, f_{op} \qquad (5)$$

where, γ_{k_y} - coefficient of precipittation space irregularity influence on affluent layer in the condition of irrigation.

The imitation model with γ_{k_y} was created for different f_{op} and F - up to 1000 km^2, such as for γ_y.

Analysis of calculation showed, that in the result of reduction coefficient changes under the influence of irrigation, the values of γ_{k_y} are not largest then corresponding values of γ_y and even for $F > 1000\ km^2$, values of γ_{k_y} are considerably largest, then values of γ_y. That is why both γ_y and γ_{k_y} must be account, when irrigation influence on the flood flow researches.

Coefficient of summary influence onthe flood flow is

$$\gamma_{op} = \gamma_y\ \gamma_{k_y} \qquad (6)$$

The table №1 was done for different combinations of F and f_{op} (soil – ordinary black earth) on the base of (6).

VALUES OF COEFFICIENT γ_{op}.

Table № 1

f_{op} % \ F_{km^2}	≤ 10	20	50	100	200	500	1000
25	1.10	1.14	1.17	1.20	1.23	1.28	1.32
50	1.24	1.31	1.40	1.47	1.54	1.63	1.70
75	1.40	1.52	1.68	1.80	–	–	–
100	1.55	1.69	–	–	–	–	–

The same table may be done for another soil types.

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INFLUENCE OF MARINE FACTORS ON HYDROLOGICAL REGIME OF DANUBE DELTA

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Hydrological regime, morphology and ecology of the Danube delta are formed as a result of interaction between riverine and marine factors. In the Danube delta the main hydrological processes associated with the influence of marine factors are the following: 1) backwater events, caused by eustatic rise of the Black Sea mean level; 2) storm surges; 3) salt sea water intrusion into the delta branches; 4) delta sea coast erosion under the wave action. In the paper the main peculiarities of marine factors impact on the hydrological regime of the Danube delta were considered and some their quantative charactaristics were evaluated.

DER EINFLUβ DER MEERFAKTOREN AUF DEM HYDROLOGISCHEN REGIME DES DONAUDELTAS

Das hydrologische Regime, die Morphologie und die Ökologie des Donaudeltas formieren sich als Ergebnis der Wechselwirkung der Flüβ-und der Meerfaktoren. Die hauptsächlichen hydrologischen Prozessen in Verbindung gesetzte mit dem Einfluβ der Meerfaktoren sind folgende: 1) die Staüerscheinungen hervorgerufene der eustatischen Erhöhung des Wasserstandes des Swarzes Meeres; 2) die Windstauen; 3) die Intrusion der salzigen Meerwasser in die Deltafluβarmen; 4) die Unterspülung des Standes des Deltas unter der Einwirkung der Meerwellen. In dem Vortrag sind die hauptsächtlichen Gesetzmäβigkeiten der Einwirkung der Meerfaktoren auf das hydrologische Regime des Donaudeltas betrachten und ihre einigen zahlenmäβigen Charakteristiken festgestellt.

1. Introduction

One of the largest European delta was formed at the mouth of the Danube River. Its area is more than 5600 km^2. Principal features of its hydrographic network are presented by three main delta branches (the Chilia, Sulina, Gheorghe), numerous distributaries, lakes, lagoons and swamps.

Hydrological regime, morphology and ecology of the Danube delta were formed as a result of interaction between riverine and marine factors. The impact of riverine factors (water flow and sediment load) on the regime and structure of the Danube delta has been already studied [5-8].

The impact of the marine factors on the Danube delta is also of great importance but has not been adequately studied yet.

Tides in the Black Sea are absent. Therefore in the Danube delta the main processes associated with the influence of marine factors are the following: 1) backwater events, caused by eustatic rise of the Black Sea level; 2) storm surges; 3) salt water intrusion into the delta branches; 4) delta coastline erosion under the wave action.

2. Impact of the Black Sea level rise

The Black Sea level is subjected to a slow eustatic rise with the mean rate of 4-6 mm per year. In the 100--year period (1880-1980) mean annual water level near Odessa (NW part of the Black Sea) rose by 45 mm (average 4,5 mm/yr).

The length of penetration of the backwater zone into the delta because of sea level rise can be evaluated by analysis of the gauge data in the Chilia branch within 1953-1992 (40 years) (Figure 1). In this period the mean annual water levels at Primorskoe (nearshore) rose by 23 cm (5,7 mm/yr). At Vilkovo (18 km from the sea) this rise was equal to 17 cm (4,2 mm/yr). At Chilia station (47 km from the sea) water level rise was not more 4 cm (less 1 cm/yr). Thus over the period of 40 years induced by sea level rise backwater zone penetrated into the Chilia branch only by 45-50 km.

3. Storm surges

Induced by strong NE, E or SE winds the highest storm surges at the nearshore zone reached 1m. Extending of the storm surges upstream along the delta branches (L_S) depends on the rate of the storm surge at nearshore (H_S) and water discharge of the Danube or delta branch (Q). The calculations [6] based on hydraulic methods [3] permitted to obtain the relation of the value of L_S on H_S and Q (see Table).

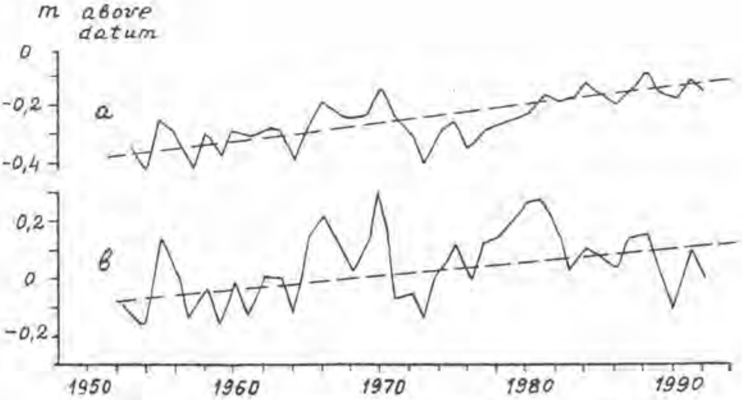

Figure 1. Variations in the mean annual water levels at Primorskoye (nearshore) (a) and Vilkovo (the Chilia branch, 18,0 km from the sea) (b)

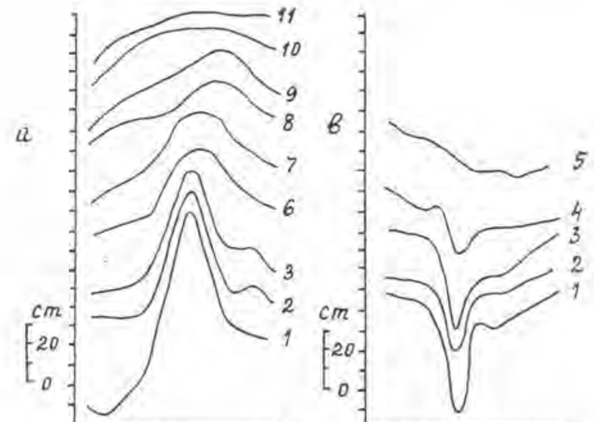

Figure 2. Water level variations: a - storm surge, 26.01.1962; b - negative surge, 25.09-4.10.1959
1 - Primorskoye (nearshore), 2 - Prorva (3,6 km from the sea), 3 - Vilkovo (18,0 km), 4 - Chilia (47,0 km), 5 - Kislitsa(68,0 km), 6 - Izmail (93,6 km), 7 - Isaccea(136,4 km), 8 - Reni (163,3 km), Braila (206,1 km), 10 - Hirsova (288,7 km), 11 - Cernovoda (336,4km)

Table. Lengths of storm surge extending

Q m^3/s (the Danube)	H_S m		
	0,2	0,5	1,0
2000	320	540	700
3000	160	270	350
4000	130	210	280
5000	100	170	230
6000	70	130	190
7000	50	90	160

Actual lengths of storm surge extending (L_S) can be examined by observation data. For example in Figure 2a water level variations in the period of strong storm surge in 1962 is showen. This storm surge reached 1,0 m at the nearshore. Water discharges of the Danube in this period were 3000–3500 m^3/s. In this case the value of L_S was more than 350 km. At mean water discharges storm surges of 0,5–0,6 m at the nearshore extend by 120–160 km. These examples showed that data in the table are realistic.

The negative surges in the nearshore zone reach 0,5–0,6 m. The extending of water level fall in the periods of strong negative surges reached 50–70 km (Figure 2b).

4. Salt water intrusion

Salt water penetrates usually into the Sulina and Prorva branches that were gredged for navigation in their bar parts to 8 and 4,5 m correspondingly. Intrusion of sea water into these branches occures in the form of salt water wedge [1,2, 4] (Figure 3). The factors favourable for salt water intrusion are the following: low water discharges, difference in density of marine and riverine waters, large depths of the branches and mouth bars, landward winds and storm surges. Salt water wedges over the periods of low water flow contineusly are present near bar parts of the Sulina and Prorva branches. Maximum observed lengths of salt water intrusion reached 16,5 km in the Sulina branch on 22 November 1963 [2] and 16,8 km in the Prorva and Ochakov branches on 20 September 1990.

The theory of salt water wedges at river mouths [4] permits to evaluate a critical value of the water discharge for initiation of salt water intrusion Q_{cr} and formulas for length of this intrusion L_S. Value of Q_{cr} can be determined by formula

$$Q_{cr}=BhV_{\rho} \quad , \qquad (1)$$

where B and h are width and depth of the channel, V_{ρ} is so called densimetric velocity equaled to $\sqrt{(\Delta\rho/\rho_m)\, g h}$, where $\Delta\rho = \rho_s - \rho_r$, $\rho_m = 0{,}5(\rho_s + \rho_r)$, ρ_s and ρ_r are densities of marine and riverine waters. Critical water discharges for the Sulina and Prorva branches are equal to 1320 and 567m^3/s correspondingly.

Semi-empirical equations for calculation of lengths of

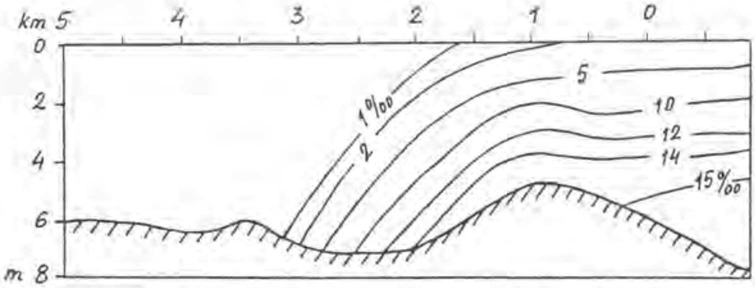

Figure 3. Salt water wedge in the Prorva branch on 14 September 1989

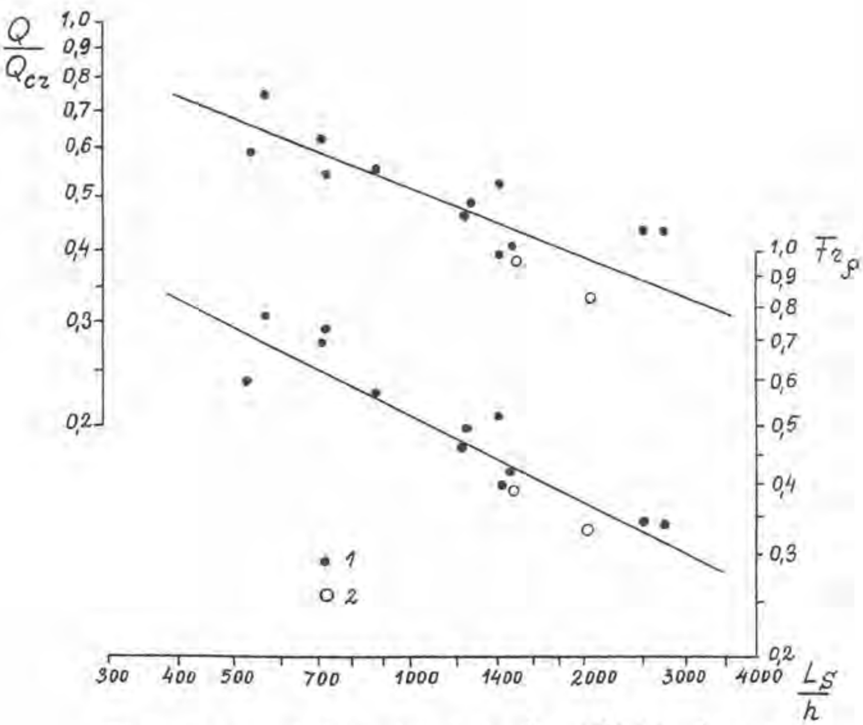

Figure 4. Relationships $L_S/h = f(Q/Q_{cr})$ (a) and $L_S/h = \varphi(Fr_\rho)$ (b) for the Prorva (1) and Sulina (2) branches

salt water wedge are the following (Figure 4):

$$L_s/h = 180(Q/Q_{cr})^{-2,63} \quad , \quad (2)$$

$$L_s/h = 270\,Fr_\rho^{-2,04} \quad , \quad (3)$$

where Fr_ρ is densimetric Froude number, which is equal to V/V_ρ or $V/\sqrt{(\Delta\rho/\rho_m)\,g\,h}$, V is water velocity averaged over cross-section upstream the top of the salt water wedge.

Equation (2) for the Prorva branch at Q_{cr}=567 m^3/s and h=4,5m lead to simple formula

$$L_s = 14,1\cdot10^9\,Q^{-2,63} \quad . \quad (4)$$

Results of the calculation by this equation are the following:

Q m^3/s	500	400	300	200
L_s m	1120	2020	4300	12500

These results are close to the observed data.

5. Delta sea coast erosion

Induced by the sea wave action scours occured in some sites of the delta coastline far from the outlets of the large delta branches. The main sites of erosion are located on shores between outlets of the Sulina and Gheorghe branches and between the outlets of the Bystryi and Starostambul branches. Local retreat of the delta coastline can reach 10-15 m/yr. Coastal erosion was accelerated because of the mean sea level rise and authropogenic decrease of the Danube sediment load in the last 20-30 years.

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TOWARDS NARROWING UNCERTAINTIES OF REGIONAL CLIMATE CHANGE PREDICTIONS BY GENERAL CIRCULATION MODELS AND EMPIRICAL METHODS

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Abstract
During the 80s and early 90s the conviction was growing within the international scientific community that the climate system is changing at such a rate that global ecosystems and human society are being threatened. The demand to estimate the regional impact of future global climate changes become very important. The tools of regional climate simulations and forecasts will be classified and discussed first in this study. Two main groups of regional climate simulations can be defined: 1./ coupled or nested modelling methods, where a limited area model (LAM) is nested into a general circulation model (GCM), in which the mezoscale atmospheric forcings are taking into consideration by higher model resolution over the region; 2./ semiempirical and empirical methods, where climate scenarios are defined using historical data records and statistical models; and the atmospheric forcings are not at all explicitly defined, or if they are taking account than only through the atmospheric response to large-scale forcings by GCMs. The advantages, limitations and the validity of those methods will be discussed. Also the results of a case study for doubled carbon-dioxide climate scenario will be presented on a precipitation network over the drainage basin of the Lake Balaton (which belongs to the above mentioned second method). A methodology is developed and applied to estimate the space-time distribution of daily precipitation under climate change for the western part of Hungary. The estimation technique is based on the analysis of the semi-Markov properties of atmospheric macrocirculation pattern (MCP) types, and a stochastic linkage between daily macrocirculation types and daily precipitation events. Historical data and GCM outputs of daily MCP corresponding to $1xCO_2$ and $2xCO_2$ are considered. Most of the local average precipitation reflect, under $2xCO_2$, a somewhat dryer precipitation regime in western Hungary.

1. Introduction
In the Earth climate history we can find several natural variations, but just recently get able mankind to influence the climate through his activities. Those changes are happening on the local, regional and global scale and the main cause of this is the increasing concentration of CO_2 (and other greenhouse) gases in the atmosphere due to the combustion of fossil fuels and the destruction of forest and soils. A chain reaction were inducted, which effects the earth's radiative balance and leads to the global warming of the atmosphere. The real aim of climate investigations and modeling is to provide a reasonable good forecast for climate variables on spatial detailed scale for the future. In the absence of perfect models of the temporal evolution of the climate, several methods for projecting future climate states have been developed over the past few decades (Giorgi et al., 1991 and 1992). These were: a./ deriving estimates of future climate change by extrapolating from the instrumental record of climate fluctuations over the past century; b./ drawing analogues from climate states during historical or paleoclimatic periods; c./ interpolating from simulations by General Circulation Models (GCMs) of the equilibrium change in the climate system that would be induced by a doubling of the CO_2 concentration to about 600 ppm; d./ using coupled or nested mesoscale models within a GCM to obtain a higher spatial resolution to the stimulations of the

GCM; e./ coupling the use of various statistical submodels to GCMs to generate estimates of regional-scale distributions of climate variables from coarse-grid GCM outputs. These methods can divide mainly into two groups: coupled or nested modelling methods (section 2.) and semiempirical, empirical methods (section 3.). In this study first we discuss some aspects of the methodology of climate change predictions, than their advantages and limitations. Finally we would like to present some of our results we get in a case study was carried out for the territory of western Hungary, in particularly the region of Lake Balaton and its drainage basin. In which we developed a stochastic space-time model to estimate the effects of climate change scenarios on regional/local precipitation. The proposed approach is an extension of the usual analysis of regional hydrological impacts of climate change. Often, the quite uncertain hydrological outputs of atmospheric global circulation models (GCMs) are desegregated to estimate regional hydrological events. This study proposes to examine the time series of daily GCM-produced atmospheric macrocirculation patterns (MCPs) to estimate regional and local precipitation. The approach is based on a classification of daily MCP's of the Atlantic European region, where each distinct pattern is mainly defined using the 700 Hpa geopotential pressure field. The classification is a reduced version of the Hess-Brezowsky macrosynoptic system (HBms). The classification analysis and the trend forecast were made for the drainage basin of the Lake Balaton, and the 2xCO_2 climate change scenario results are presented.

2. Nested modelling approach

In the recent years the need to gain a better understanding of regional impacts of possible global climate change has lead to research activities aimed at improving the simulation of regional climates. One of these efforts consists of using a limited area model (LAM) nested in a general circulation model (GCM) to carry out high-resolution regional climate simulation. In the one-way nesting procedure the output of GCM global climate simulation is used to drive a high resolution LAM over a selected areas of interest. The basic strategy for this approach is to use the GCM to simulate the response of general circulation to large scale forcing and nested LAM to modelling, in psychically based way, for local processes arising under the GCM grid-scale. The nested LAM-GCM modeling technique can be especially useful in areas where forcing due to complex topographic features or coastlines influence the regional distribution of climate variables (Marinucci et al., 1992). Such area are the western United States, middle-south Europe.

2.1. General circulation models

The aim of GCMs is the simulation of the full three-dimensional character of Earth's climate: in these models an attempt is made to represent most physical processes believed to be important. Since the accuracy of the model is partly depends on the spatial resolution of the grid points and the length of the time step, a compromise must be made between the resolution desired and the computational facilities available. At present the grid points are typically spaced between 300-500 km. Vertical resolution is obtained by dividing the atmosphere into between six and fifteen layers. Computational constraints lead to problems of a more theoretical nature. With a coarse of grid spacing small-scale atmospheric motions (such as thundercloud formation, boundary layer processes) can not be modelled, however they may be reality for atmospheric dynamics. Moreover, several hydrological and agroecological impact applications of GCM model simulations would also require a fine space resolution of 30-70 km, at least over some selected areas.

2.2. Limited area models

LAMs have been mostly used for short-term weather forecasting and for study of the behavior atmospheric phenomena such as fronts, severe storms, extratropical and tropical cyclones, topographically induced circulation over a selected area. The operation domain of the LAMs are usually 1-10 million km^2 in size to achieve realistic simulations of the evolution of synoptic-scale weather systems over the region. The LAMs grid-point spacing is around 50 km, including 14-20 vertical layers. Usually many LAMs do not include accurate representation of physical processes important climate processes; for example radiative transfer or soil hydrology. For this reason, the LAMs developed for nested application are provided with relatively sophisticated physical package including radiative transfer, cloud and precipitation processes and biosphere-atmosphere transport scheme, as well. It is important to identify the very different aims of these developing and using GCMs as compared to the designers of LAMs. The latter are prediction tools while GCMs can represent only probable conditions.

2.3. Preliminary results

An important phase of the development of a nested GCM-LAM regional climate model is the validation of the LAM climatology over the selected region, so that model biases and uncertainties can be identified and, if possible, corrected. The preliminary experiments clearly illustrated how the use of a nested LAM leads to a much improved simulation of regional climatic detail compared to the GCMs alone. A typical construction is the Mesoscale Meteorological Model (MM4) developed by Pennsylvania State University nested into the Community Climate Model (CCM1) of National Center for Atmospheric Research. In this analysis it was shown that the CCM1 simulated a realistic large scale climatology over the region, but did not capture the regional detail induced by local topography. Conversely, the nested MM4 simulated realistic storm systems and produced a much more accurate regional distribution of climatic variables which compared well with the high resolution observations. The experiments showed a realistic pictures and in particular illustrated the capability of nested MM4 to simulate cyclogenesis from the large scale fields provided by the driving CCM1 and correct in this way the climatological underprediction of storm by CCM1.

2.4. Regional climate simulation for the Central European region

The nested modeling approach is presently being adapted by the climate modeling group of the Department of Geography at ETH-Zurich. Improvements in the National Center for Atmospheric Research (NCAR) version are essentially linked to higher spatial resolution of both the GCM and the MM4 models. By increasing the spatial definitions of both sets of models, it is expected that a significant improvement in the simulation of regional climate features, especially precipitation patterns will be observed. In Central Europe, global warming may be accompanied by changes in precipitation amount, intensity and annual distribution; this would in turn have considerable impacts on hydro-power and agriculture sectors. In order to achieve progress in the development of the coupled modeling approach for the region of Central Europe, a research project involved hungarian and polish scientists and organized by swiss partners has been established. Experience gained in handling of coupled GCMs and regional-scale models will allow studies undertaken the better understanding of fundamental climate processes and, the interactions and feedbacks between different elements of climate systems, and how these may impact on different regions of Europe in the future.

3. Empirical and semiempirical approaches

The semiempirical and empirical models are commonly used, while their computer demand are much less. The approach, where we deriving estimates for the future by extrapolating from historical records of climate fluctuations over the past century, have strong limitations. On one hand this method is usually using the land-based surface-air temperature record, which is impacted in part, by the process of urbanization happened in the last few decades. On the other hand, the projections of regional climate change in average surface temperature is much smaller, than it would be associated with the doubled CO_2 level (GCM simulations). The semiempirical models are usually statistical submodels, which are coupled to GCMs (Wigley et al., 1990). Recently many notable experiment happened in the statistical coupling of GCM outputs to water-balance models and precipitation models. The limitations of this methods include the possibility that the statistical relationships established for the current climatic state may not hold in the $2CO_2$ world.

3.1. Precipitation model with space-time approach:

For meteorological application, precipitation is usually modelled as a stochastic process. These point-process models describe precipitation occurrence, amount (Chang et al., 1984, Bogardi et al., 1988) at selected locations. Spatial characteristics of precipitation are usually analyzed for selected events (Chua and Bras, 1982). Space-time models for the spatial and time distribution of precipitation over a region are usually models for single events, based on some general physical considerations and several stochastic assumptions (Rodriguez-Iturbe and Eagleson, 1987). A model for simultaneous multisite generation of daily precipitation was developed in Binark et al. (1976).

In this work a modified version of the space-time precipitation model developed in Bardossy and Plate (1990) was used. The main difficulty of modeling the precipitation as an univariate autoregressive process is its space-time intermittence. The precipitation occurrence at a given location must be conditioned on precipitation at other locations; then the precipitation amount is conditioned on occurrence and amount at other locations. This approach requires the estimation of a lot of parameters. Another difficulty is that time series models have been developed principally for Gaussian processes but conditional probability distributions of precipitation are far from normality. Therefore, there is a need to develop a transformation that establishes a relationship between precipitation and the normal distribution (Bogardi et al. (1992) and Matyasovszky et al. (1993)). The difficulty in using the above mentioned stochastic model is that the process cannot be observed. As a consequence, the correlation matrices must be estimated indirectly from the observed precipitation time series. Specifically, indicator series defined by precipitation quantiles are used to estimate the correlations among the indicator series. Then the required correlations can be calculated from the indicator series correlations.

3.2. Circulation pattern - precipitation - climate change scenarios

Daily circulation patterns for the Atlantic-European region are characterized by the daily spatial distribution of sea level pressure (Hess-Brezowsky microcirculation system (1969)) and middle tropospheric pressure height. The regional/local hydrological variables at a given time and location are strongly influenced by atmospheric circulation patterns, hence climatic variability may be related to changes in atmospheric circulation (Lamb, 1977). The task here is to extend the mathematical model described in the previous section by conditioning on daily CP types. As proposed in Bardossy and Plate (1992) this can be done by considering each circulation type separately and define the multivariate normal process. Three types of daily CP data are used. The historical data are represented by the National Meteorological Center (NMC) grid point analyses of the height of 700 hPa pressure fields available from NCAR. The analysis is based on daily values (12^{00}) at 51 points on a diamond grid covering the Atlantic European region for the period January 1950 - June

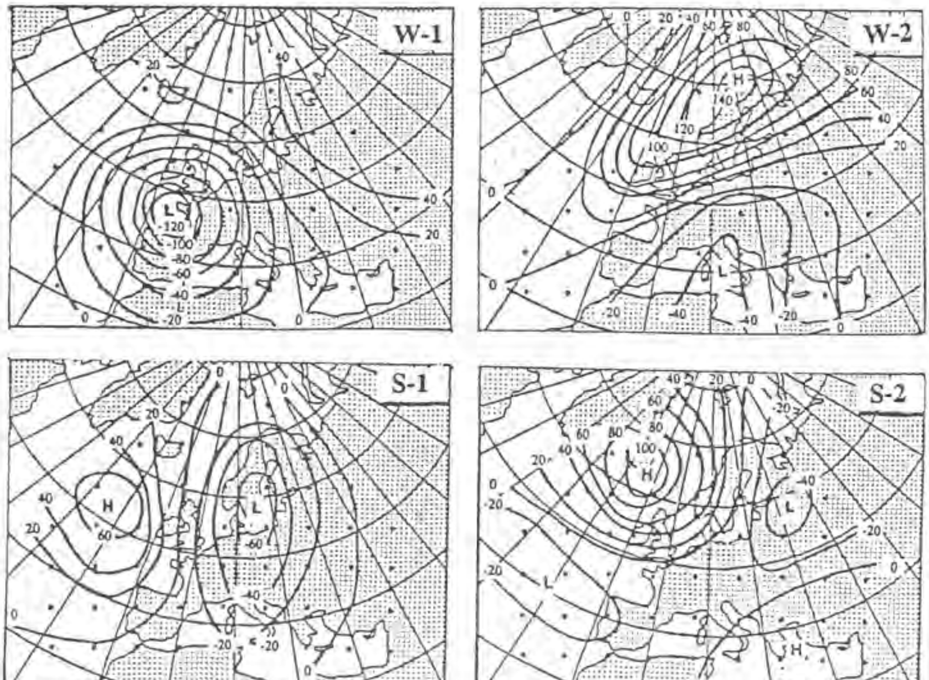

Figure 1. Characteristic MCP types for the Winter (W-1, W-2 maps) and for the Summer (S-1, S-2 maps) seasons

1989. Two 10-year long data series for the same pressure level has been obtained from the outputs of the Max Planck Institute corresponding to the $1xCO_2$ and $2xCO_2$ scenario. There are several possibilities combined with considerable experience for classifying daily CPs. A brief review of classification techniques for precipitation modeling purpose can be found in Bartholy (1992). In the present work the three data sets are classified with the 3 MCP systems. The periods from April to September 30 (Summer half year) and from October to March 31 (Winter half year) have been examined separately. Defining 10 types for both periods seems to be a good compromise between the increasing number of types and decreasing distances of pressure fields within types. Two - two MC pattern examples are given for the winter and summer seasons, respectively (**Figure 1**), which demonstrate the generally weaker zonal airflow in summer and the much stronger winds in winter. Given the set of CP types, the next step is to develop a stochastic model in order to describe the sequence of these patterns, which is done here by using Markov chains. This Markov model is used to calculate the distribution of CP type duration as well as to develop simulated time series of space-time local climatological quantities conditioned on CP types (Bogardi et al., 1992). In order to eliminate the difference between the frequencies of the $1xCO_2$ and $2xCO_2$ cases, we included the spatially averaged 700 hPa pressure height into the analysis; and the annual cycle of the pressure height as an analogy of the difference between present and the $2xCO_2$ climates. The relationship between the two quantities can then be used to estimate the effect of climate change on regional/local precipitation (Matyasovszky et al. 1992).

3.3. The results of a case study for western Hungary

The geographical region to be investigated locates in western Hungary (the drainage basin of the Lake Balaton) and is represented by 28 precipitation stations. Daily precipitation data at 28 stations in western Hungary between 1950 and 1989 are used. The precipitation model was checked using a split sampling approach, that is, parameters are estimated from the first 20 years of data (model calibration) and the simulated precipitation series is compared to the second 20 years of data (model validation). Regional precipitation climate reflecting $2xCO_2$ scenario is estimated by the same simulation technique, but using parameters (Fourier coefficients) corresponding to the $2xCO_2$ case. The winter and summer half years are analyzed separately. Probability distribution functions estimated from the historical data and simulated data corresponding to the historical and $2xCO_2$ cases are calculated. We get as a result, that in case of $2xCO_2$ on the whole area the precipitation probability will be lower and the average daily precipitation amount will be definitely less, then in the last 50 years. In the winter season the area is divided into two parts: subregions with decreasing and increasing precipitation amounts. We can find on the **Figure 2** the spatial distribution of the mean daily precipitation anomalies in case of CO_2 doubling for both seasons. The southern part will be slightly more wet, while the other area somewhat dryer then it was recently.

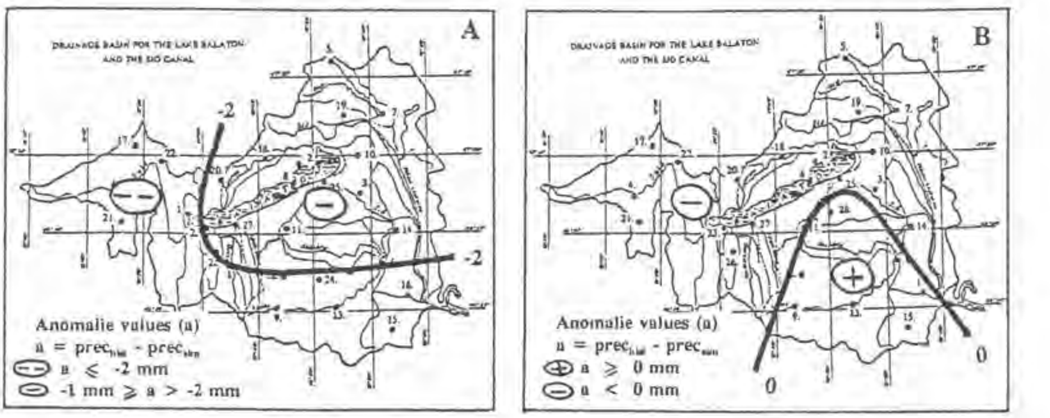

Figure 2. Spatial distribution of meaan daily precipitation anomalies in case of CO_2 doubling: A./ Summer season; B./ Winter season

Summarized: A space-time precipitation model has been coupled with the stochastic simulation of daily CPs in order to generate time series of point or areal daily precipitation reflecting regional/local effect of a global climate change. To this end, in addition to historical data daily large-scale atmospheric pressure output of the GCM model for the $1xCO_2$ and $2xCO_2$ cases has been used. The approach is based on the statistical relationship between daily CP types and daily precipitation. Classification methods of daily CPs cannot be used alone to measure changing spatial distribution of pressure heights obtained from GCMs and related to climate change. For this reason an additional variable, the average pressure height, is introduced into the analysis.

4. Acknowledgements

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XVII. KONFERENZ DER DONAULÄNDER
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Langjährige Trends im Niederschlagsgeschehen und ihre Abhängigkeit von Orographie und Wetterlage

J.Guttenberger

Kurzfassung: In Mitteleuropa werden regional unterschiedliche säkulare Niederschlagstrends festgestellt. Im Bergland ist eine größere Zunahme der mittleren jährlichen Niederschlagshöhen festzustellen als im Flachland. Diese Unterschiede lassen sich auf Veränderungen in der Zirkulation zurückführen. Das Niederschlagsgeschehen an einem festen Ort wird dann durch die jahreszeitliche unterschiedliche Reaktion der Großwetterlage mit der Orographie beeinflußt.

Long Range Precipitation Trends and their Dependence on Orography and Atmospheric Circulation.

Summary: In Central Europe an increase in precipitation amounts has been observed since the last hundred years. The trend is more significant in hilly regions than in the lowlands. It is due to the response of circulation patterns to landscape conditions. The effect of orography is stronger in winter as it is in summer.

1. Einleitung

Langfristige Variationen des Niederschlagsdargebotes sind Gegenstand einer Reihe von Untersuchungen, die zu regional unterschiedlichen Ergebnissen führen (/1/, /2/, /3/). Verschiedentlich hat man sich auch mit der Wasserbilanz unter dem Aspekt von Klimaänderungen auseinandergesetzt (/4/). Dem Niederschlagsgeschehen als einem wichtigen Teil des Landschaftswasserhaushalts stehen zeitlich konstante und variable Einflußgrößen gegenüber. Zu den variablen Faktoren zählen die großräumigen atmosphärischen Vorgänge, während die Geländebeschaffenheit als ein im menschlichen Zeitrahmen konstanter Einflußfaktor gelten kann. Im folgenden werden deshalb festgestellte langjährige Trends im Niederschlagsgeschehen eines Ortes mit seiner orographischen Umgebung und den die lokalen Witterungsabläufe prägenden Großwetterlagen in Beziehung gesetzt.

2. Säkulare Niederschlagstrends in Bayern

In Bayern wurden langjährige Niederschlagsreihen von 43 Stationen auf ihre zeitlichen Veränderungen hin untersucht (/5/, /4/). Stellvertretend seien hier die Niederschlagsverhältnisse an den Stationen Rosenheim und Pressig-Rothenkirchen vorgestellt. Nähere Angaben zu diesen und den übrigen Stationen sind der angegebenen Literatur zu entnehmen. Einen Überblick über die geographische Situation gibt Abbildung 1. Rosenheim ist ein typischer Vertreter des südbayerischen Sommerregentyps mit einem ausgeprägten Niederschlagsmaximum im Sommer und dem Minimum im Winter. Pressig-Rothenkirchen ist dagegen ein typischer Vertreter der höheren Lagen der nordbayerischen Mittelgebirge mit zwei Maxima, davon eines im Sommer und das andere im Winter. Letzteres kann gebietsweise zum Hauptmaximum werden.

Die jährlichen Niederschlagshöhen an den beiden Vergleichsstationen schwanken von Jahr zu Jahr stark. Der Schwankungsbereich der Extreme beträgt in Rosenheim 856 mm und in Pressig-Rothenkirchen 832 mm. Die geringsten jährlichen Niederschlagshöhen wurden in Rosenheim im Jahr 1947 mit 655 mm gemessen, in Pressig-Rothenkirchen ebenfalls im Jahr 1947 mit 560 mm. Dies hebt die überregionale Auswirkung dieses Jahres als trockenstes der gesamten Zeitreihe hervor. Das demgegenüber nasseste Jahr trat in Rosenheim 1912 mit 1511 mm und in Pressig-Rothenkirchen 1980 mit 1392 mm auf. Einen Vergleich der 30jährig gleitenden Mittelwerte der jährlichen Niederschlagshöhen von Rosenheim und Pressig-Rothenkirchen zwischen 1891 und 1990 ermöglicht die Abbildung 2. Die dem Anschein nach konträre Entwicklung beruht auf dem mit 0,26 mm/a geringeren Trend von Rosenheim, im Vergleich zu 2,94 mm/a in Pressig-Rothenkirchen.

Teilt man den Jahrestrend in den der beiden Halbjahre auf, so zeigen in der Gesamtschau die Trends der Sommerniederschlagshöhen ein wenig regelmäßiges Bild. Es treten überwiegend positive, an 14 Stationen auch negative lineare Trends auf. Im Winterhalbjahr ist der Aufwärtstrend verstärkt und an allen Stationen feststellbar. Räumliche Schwerpunkte der Stationen mit starkem positiven Trend sind Gebiete mit vorwiegend orographisch beeinflußtem Niederschlagsverhalten. Dazu gehören Stationen am Alpennordrand und in den Mittelgebirgsregionen Bayerns, wo Stau- und Steigungsniederschläge dominieren.

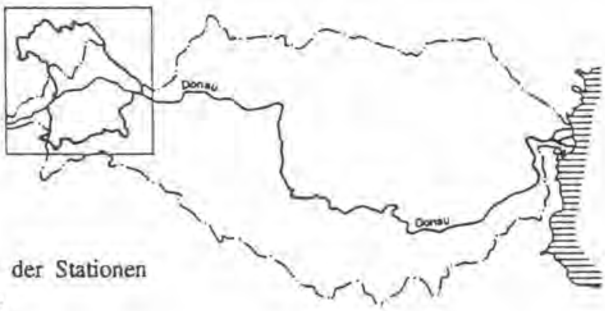

Abb. 1 Übersichtskarte der Stationen
Fig. 1 Map of locations

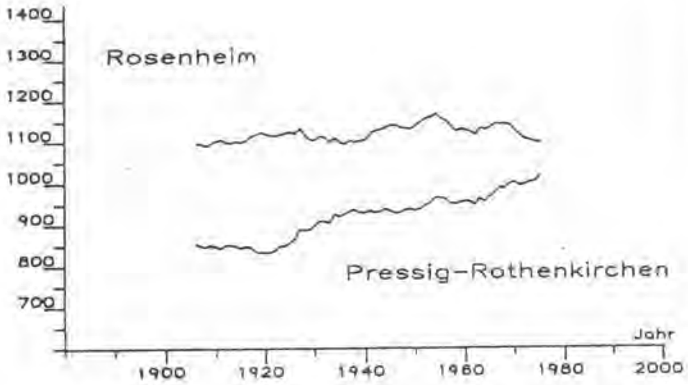

Abb. 2

30jährig gleitende Mittel der jährlichen Niederschlagshöhen in mm von Rosenheim und Pressig-Rothenkirchen 1891 - 1990.

Fig. 2

30year moving average of precipitation heights in mm of Rosenheim and Pressig-Rothenkirchen 1891 -1990.

3. Einfluß von Orographie und Jahreszeit

Dieses Erscheinungsbild läßt einen jahreszeitlich veränderlichen Einfluß der Orographie auf die Niederschlagsbildung vermuten. Dies umso mehr, als an manchen Stationen der Trend von Sommer- und Winterniederschlagshöhen gegenläufig ist.

Dynamische Vorgänge, die niederschlagsauslösend wirken, lassen sich vereinfacht in Advektion und Konvektion unterteilen. Konvektiver Niederschlag kann sich bei Vertikalbewegungen in labil geschichteten Luftmassen bilden. Labilität ist hier als Eigenschaft der gesamten zum Niederschlag beitragenden Atmosphärensäule zu verstehen. Im Sommer werden die konvektiven Umlagerungen durch thermische Labilisierung über erwärmten Untergründen vom Boden her verstärkt. Der Einfluß des Reliefs wird abgeschwächt. Insbesondere bei intensiven konvektiven Niederschlagsereignissen stehen die Niederschlagshöhen, die dann über den Ebenen abregnen können, denen der gebirgigen Regionen in nichts nach (/6/).

Im Winter ist die inhärente Labilität von Kaltluftmassen in geringerem Maße niederschlagsfördernd. Größere Niederschlagshöhen liefern Aufgleitvorgänge vor allem an der Frontalzone, wie beim Hochwasser in Südwestdeutschland an Weihnachten 1993, von dem auch der nördliche Teil des oberen Donaueinzugsgebietes betroffen war.

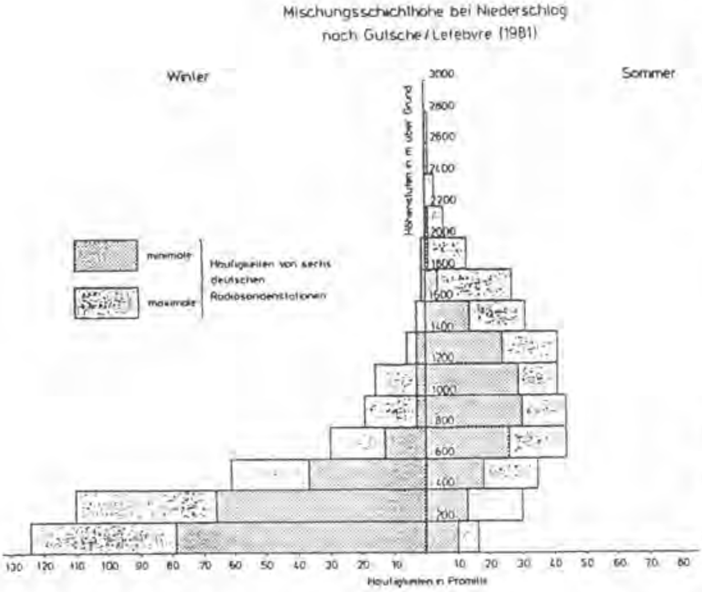

Abb. 3

Minimale und maximale Häufigkeiten der Mischungsschichthöhen bei Niederschlag im Winter und im Sommer (Daten nach /7/.

Fig. 3

Minimum and maximum frequencies of mixing heights in winter an summer season (Dates after /7/.

Neben dem Temperaturniveau ist in den beiden Hauptjahreszeiten auch der Aufbau der bodennahen Atmosphäre unterschiedlich. Eine Auswertung von Radiosondenmessungen macht diese Unterschiede am Beispiel der Mischungsschichthöhe bei Niederschlag im Winter (Dezember - Februar) und im Sommer (Juni - August) deutlich (/7/). Der graphischen Darstellung (Abb. 3) ist jeweils die größte und die kleinste relative Häufigkeit der Mischungsschichthöhe aller untersuchten Stationen zu entnehmen. Die Häufigkeitsschwerpunkte der Höhen liegen im Sommer bei 600 m bis 1400 m ü.Grund, im Winter unterhalb 400 m ü. Grund. Da die Höhe der Mischungsschicht mit dem Kondensationsniveau gleichgesetzt werden kann, ist der deutliche Zuwachs der Niederschlagshöhen im Winterhalbjahr selbst bei geringen Höhenanstiegen verständlich. Diese Tatsache gab auch Anlaß zur Einteilung von Niederschlagslandschaften nach dem Jahresgang. Deren gegensätzliche Ausprägungen sind in Kapitel 2 bereits beschrieben (/8/, /9/).

Analog dazu zeigen die Stationen in den Mittelgebirgen (Plech: 1,11 mm/a) und am Alpenrand (Kreuth: 1,29 mm/a) einen überdurchschnittlichen positiven Trend der winterlichen Niederschlagshöhen. Am wenigsten davon betroffen sind die Gebiete im Flachland südlich der Donau (Ludmannsdorf: 0,00 mm/a) und im nördlichen Alpenvorland (Eggenfelden: 0,23 mm/a) (/5/).

4. Abhängigkeit von der Großwetterlage

Eine weitere Ursache für das beobachtete räumliche Verteilungsmuster der Trends ist in dem Zusammenspiel von Großwetterlagen und der Streichrichtung der Gebirge zu sehen. Je nach Anströmrichtung ergibt sich dabei eine Niederschlagsverstärkung oder -abschwächung. In kleinerem Maße als in den Alpen treten an den Mittelgebirgen Föhn- und Stauerscheinungen auf, die im Winter durch das niedrigere Kondensationsniveau verstärkt werden. Sind im Winter zyklonale Westlagen häufiger, produzieren sie im Bergland Niederschlag im Überfluß, während das Flachland weniger davon profitiert. Im Gegenzug werden im Sommer bei häufigeren gewitterträchtigen Wetterlagen Bergland und Ebene gleichmäßiger überregnet.

Die in Deutschland gebräuchliche Wetterlagenklassifikation geht auf Hess/Brezowsky zurück. Vom Deutschen Wetterdienst werden die Goßwetterlagen routinemäßig täglich bestimmt und veröffentlicht. Es gibt 29 verschiedene Großwetterlagen, die sich nach der Hauptströmungsrichtung und der Zirkulation unterscheiden. In den Abbildungen 4 und 5 sind die mittleren täglichen Niederschlagshöhen im hydrologischen Winterhalbjahr bei zwei unterschiedlichen Wetterlagen dargestellt. Die angegebenen Niederschlagsstationen des Deutschen Wetterdienstes liegen in den Kerngebieten der in Kapitel 2 beschriebenen Niederschlagslandschaften, nämlich im Frankenwald in Nordostbayern und im südostbayerischen Alpenvorland. Es sind dies Kronach (305 m ü.NN) im Luv, Helmbrechts (618 m ü. NN) auf der Höhe und Hof (450 m ü.NN) im Lee, bzw. Maria Eck (882 m ü. NN) direkt am Alpenrand und Mühldorf (401 m ü.NN) weiter nördlich im Inntal gelegen.

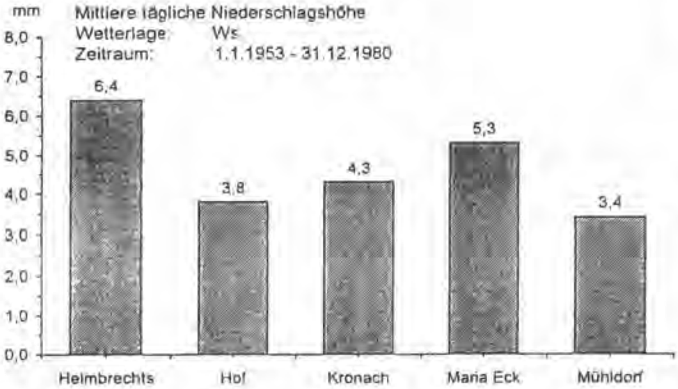

Abb. 4

Mittlere tägliche Niederschlagshöhe in Nordost- und Südostbayern bei Großwetterlage Ws im Winterhalbjahr.

Fig. 4

Mean daily precipitation heights in northeast- and southeast Bavaria at circulation pattern Ws in the winter season.

Die südliche Westlage (Ws) (Abb. 4) führt im Alpenvorland an der Warmfront und vor der Kaltfront zu föhnigen Aufheiterungen. Die Niederschläge setzen erst mit Durchgang der Kaltfront ein. Im Mittelgebirge wechselt sich Aufgleitniederschlag an der Warmfront mit Schauerniederschlag in der Kaltluft ab.

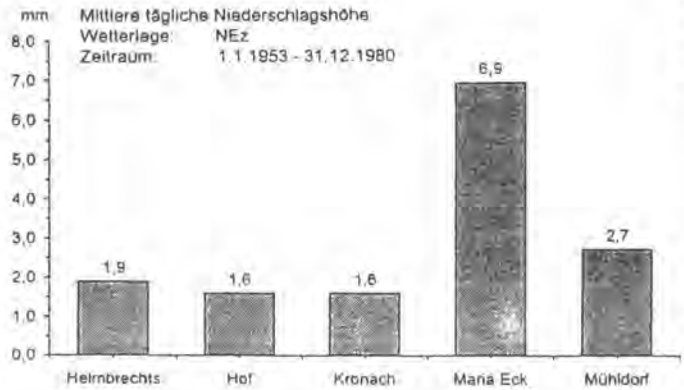

Abb. 5

Mittlere tägliche Niederschlagshöhe in Nordost- und in Südostbayern bei Großwetterlage NEz im Winterhalbjahr.

Fig. 5

Mean daily precipitation heights in northeast- and southeast Bavaria at circulation pattern NEz in the winter season.

Die mittleren täglichen Niederschlagshöhen sind an den hochgelegenen Stationen (Helmbrechts: 6,4 mm; Maria Eck: 5,3 mm) deutlich höher als an den Talstationen (Mühldorf: 3,4 mm). Im Luv des Frankenwaldes (Kronach: 4,3 mm) sind sie höher als in seinem Lee (Hof: 3,8 mm) und im Norden insgesamt höher als im Süden (/10/).

Bei der zyklonalen Nordostlage (NEz) (Abb. 5), einer klassischen Stauwetterlage, fallen die meisten Niederschläge am Alpenrand (Maria Eck: 6,9 mm). Nach Norden hin nehmen die Niederschlagshöhen deutlich ab. Die Unterschiede der jeweiligen Lage in Nordbayern sind unerheblich. Je nach Häufigkeit der beteiligten Wetterlagen ist deshalb die jährliche Niederschlagshöhe von Jahr zu Jahr verschieden. Aus dieser Abhängigkeit läßt sich der Einfluß von Klimaänderungen auf das Niederschlagsgeschehen an einem Ort beurteilen. Verschiedene Untersuchungen belegen die zeitliche Variabilität der Großwetterlagenhäufigkeiten. Seit 1930 hat im Winter die Häufigkeit von ozeanischen Wetterlagen, wie die Westwetterlagen zusammenfassend bezeichnet werden zugenommen (Abb. 6) (/11/). Dies korrespondiert mit der in Bayern festgestellten, im Bergland besonders auffälligen Zunahme der mittleren jährlichen Niederschlagshöhen.

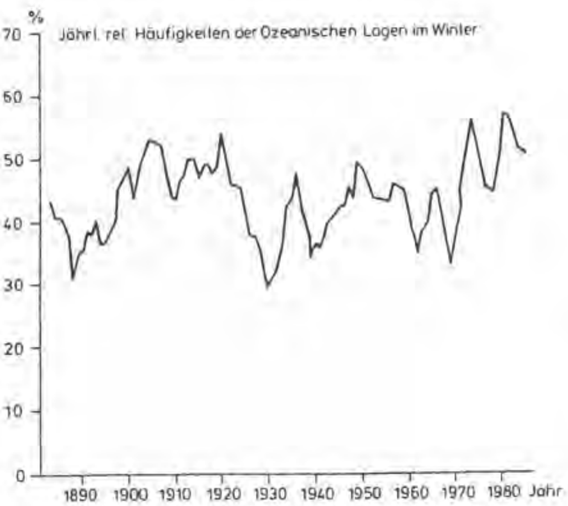

Abb. 6

Jährliche relative Häufigkeiten der ozeanischen Lagen im Winter seit 1880 (nach /11/).

Fig. 6

Mean yearly relative frequencies of Oceanic circulation patterns in Central Europe in winter since 1880 (after /11/).

5. Schluß

Global errechnete Klimaprognosen lassen sich nicht ohne weiteres lokal verifizieren. Insbesondere der Niederschlag zeigt eine deutliche kleinräumige Variabilität. Berücksichtigt man örtliche Gegebenheiten, die die Niederschlagsbereitschaft im Witterungsablauf einer Großwetterlage verändern, gewinnt man ein besseres Verständnis der Vorgänge und kann externe Einflüsse realistischer abschätzen.

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VARIABILITY OF PRECIPITATION IN THE DANUBE BASIN

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The aim of the present study is to reveal long-term change in precipitation in Danube basin and to determine their tendency and rate. Variability in the annual, summer and winter precipitation time series during the last 100 years are analysed. The presence of some form of trend in data were examined by the Spearman and Mann-Kendal rank statistics. The power spectrum analysis has been applied, too. A generally decreasing, not statistically significant trend is present over the entire time interval in summer and annual precipitation.

NIEDERSCHLAGVARIABILITAT IM DONAUGEBIET

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Das Ziel der iUntersuchung ist die Erorterung der Niederschlagvariabilitat im Donaugebiet und deren Tendenz und Grad. Analysiert sind die Daten der Niederschlagvariabilitat der Jahres-, Sommer- und Winterniederschlagen in den letzten 100 Jahren. Das Vorhandensein einer bestimmten Form der Tendenz in den Daten war aufgrund der Spearman- und Mann-Kendal Kriterien. Spectralanalyse wurde auch angewendet. Eine allgemein abnehmende, nicht statistisch geltende Tendenz kommt zum Ausdruck in ganzen Zeitabschnitt in den Sommer- und Jahresniederschlagen.

Introduction

Precipitation is one of the most significant of all climatic variables. It has the most immediate effect on human comfort. It plays an important part in determining the composition of ecosystems and is strongly related to other atmospheric processes such as evaporation and runoff. Changes in monthly and annual precipitation are of interest also for their importance in different fields such as agriculture, hydrology, water resources, atmospheric pollution etc.

Methods and Results

Because precipitation can vary substantially from one year to another at a given location it is extremely difficult to distinguish an important emerging trend from a mere short-term irregularity in the climatic pattern. In this study the emphasis will be on existence of trend and periodicities in precipitation amounts from 1901 to 1992. The data base used for this purpose consists of summer, winter and annual precipitation for five stations located in lower course Danube.

To examine the homogeneity of studied time series a non - parametric run test has been used. This test is sensitive to slippage of the mean, trend or some form of oscillation. Some of the series are tested by Alexandersson's test, too. According to tests the used series may be concluded to be homogeneous.

The precipitation series are smoothed by 10-years weighed moving average. In the new time series the short (rapid) variations are smoothed away so the longer (slower) ones are revealed more clearly. These series showed a generally oscillatory character with increases and decreases. Winter precipitation fluctuates around the mean showing general trend to increasing (15mm/100 years). In summer precipitation shows an downward tendency (15 mm/100 years) characterized by many fluctuations. The outstanding feature of annual precipitation is below average amount in the late 1940-s. Annual precipitation shows scarcely perceivable trend of decreasing.

Because the visual examination of the smoothed curves is very subjective, an objective statistical method was used to investigate precipitation trends. The presence of some form of trend in data is examined by the Spearman rank statistic, r and Mann-Kendal rank statistic r1 (WMO. 1966, 1990). The r and r1 are given in Table 1. For comparison in the table are given r and r1 for Budapest, Vienna and Bratislava. The values with 95 per cent significance are marked by *.

Table 1 Spearman r and Mann-Kendal r1 rank statistics for winter (W), summer (S) and annual (A) precipitation

Station	Spearman r (W)	Spearman r (S)	Spearman r (A)	Mann-Kendal r1 (W)	Mann-Kendal r1 (S)	Mann-Kendal r1 (A)
Vidin	1,01	-0,38	-0,48	0,067	-0,079	-0,013
Lom	1,23	-1,33	-0,11	0,073	-0,085	-0,016
Orahovo	1,58	-0,13	-1,35	0,113	-0,012	-0,090
Nicopol	0,85	-0,29	0,04	0,064	-0,019	-0,001
Svistov	2,05*	-0,64	-0,99	0,139*	-0,099	-0,077
Budapest	-	-0,78	-2,96*	-	-0,018	-0,199*
Vienna	-	-	-0,26	-	-	-0,036
Bratislava	-	-	0,50	-	-	0,067

The trend in summer and annual precipitation is negative while in winter it is positive. But these trends are not statistically significant for most of the stations. These results agree with previous author's results (Koleva, 1993). Annual precipitation in Budapest and Vienna as well show a decreasing trend. Annual precipitation shows a different pattern in Bratislava. It is worth noting that the analysed period for Bratislava and Vienna is 1951-1990.

To reveal some hidden periodicities the method of spectral analysis is used. It indicate that there are some oscillation of 2-3, 4 and 14 years.

Conclusion

The majority of the analysed stations presents a small decreasing trend in annual precipitation with a significance under the value corresponding to the 5 per cent level.

A general trend in summer is negative, while this one in winter is positive.

In annual precipitation the quasibiennial, 4 and 14 year oscillations are found.

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XVII. KONFERENZ DER DONAULÄNDER
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REGIONAL CLIMATE SCENARIOS BY ENERGY AND WATER BALANCE MODELLING

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ABSTRACT Statistical investigations on the connections between hemispherical and regional climate variations to establish regional climate scenarios are first presented for Hungary. Then, a regional energy- and water-balance model is presented, which calculates soil moisture content of the upper 0.5 m layer, water vapour pressure and temperature of air at the surface, regulated by the external climatic forcings. Effects of changes in the atmospheric carbon dioxide broadly correspond to the previous results.

ZUSAMMENFASSUNG Statistische Untersuchung Über den Zusammenhang zwischen Hemispherische und Regionale Klimaschwankungen sind zuerst vorlegen, den Grund zu legen für Regionale Klimascenarien für Ungarn. Dann, ein Regionales Energie- und Wasser-Bilanz Modell ist einführt, das berechnet die Feuchtigkeit in der obener 0.5 m von der Schicht den Boden, die Feuchtigkeit und die Temperatur der Luft bei der Oberfläche. Wirkung der Änderungen in atmospherisches CO_2 ist im grossen angemessen zu vorige Resultate.

1. INTRODUCTION

Estimating regional features of the expected global warming is one of the actual problems in the greenhouse-gas issue. In long-term perspective, application of coupled atmosphere-ocean General Circulation Models (GCM) is the most promising way, however, the spatial resolution of GCMs is constrained for practical reasons by the capacity of present computers. Coarsely resolved GCM-outputs, cannot be directly used for this goal. The problem is not only the lack of information with necessary spatial resolution, but the gridpoint-values themselves are consequently distorted, due to the physical objects, not resolved by the model, but significantly contributing to the spatial development of meteorological, especially cloudiness and precipitation fields.

Thus, to construct a regional climate scenarios the problem of "downscaling" should be solved. This means a transformation of useful (i.e. consistently forecasted and differing from noise of internal variations) large-scale information, produced by the GCMs into climate elements of the region in question. Statistical methods of this transformation may involve global or continental-scale averages (patterns) as independent variables. Smaller scales are not feasible, as the characteristic dimension of predictor patterns should be larger than the minimum resolved wavelength of the GCM, which is at least 4 times longer than the distance between the grid-points (500 km for the coupled models).

If relying on global (hemispheric) independent variables, their future trends can be estimated with a higher confidence in the GCMs, but the connections to regional anomalies are probably less direct. In case of continental patterns, the connections with regional anomalies might be more definite, but these patterns can only be used under the assumption that they are predicted by the GCM correctly. This "perfect prognosis" approach is at present acceptable only at very large scales, which is a limitation to the use of more straightforward regional relations.

Another problem with continental-scale predictors is the assumption that the response of the regional climate to a changing flow, due either to the longer-time forcings or to inter-annual climate variability is the same. This assumption is not very likely (e.g. [8]), therefore it is recommended to combine the statistical approach with a regional (i.e. energy- and water-balance type) climate model. Before presenting a prototype of this idea, however, first we describe a set of statistical methods.

2. STATISTICAL DOWNSCALING FROM HEMISPHERIC AVERAGES FOR HUNGARY

This approach has been developed in the recent years ([3]-[7]). Results for small (<1 K) changes in the hemispherical mean temperature were based on time series of instrumental measurements. Method of "slices" was introduced to investigate the connections between regional climatic elements and two hemispherical temperature characteristics, ie. average temperature and air temperature difference between continents and oceans. Generality of these connections was then demonstrated by using historical proxy data and paleoclimatic information of the Holocene. Regional features of larger (1-4 K) global warming were estimated from the annual cycle, from paleoclimatic reconstructions and GCM outputs.

During the last 100 year, a 0.5 K hemispherical warming had been accompanied with a 0.5-0.8 K temperature increase, a 7-14 percent decrease of precipitation, a 20 percent increase in sunshine duration in the Summer half-year. In the Winter half-year temperature in Hungary demonstrates a connection with the continent-ocean temperature contrast, while the sign of changes in precipitation and sunshine duration is not unambiguous. These changes correspond to about 60 % increase in frequency of dry months (with soil moisture content less than 30 % of available potential values) and 8-10 % increase in global radiation at the surface.

According to the equilibrium estimations concerning 1-4 K hemispherical warming, the proportion of the temperature increases in Hungary vs. those in the Hemisphere is going to be less than one in Summer, while in Winter it remains about one and a half. Summer precipitation and also its annual sum is expected to be substantially less than today at a 1 K hemispherical warming, while at about 2 K the change of the annual sum would be zero or slightly positive. Summer precipitation, however is not expected to be substantially more than today, even at 4 K.

3. MODEL OF THE ENERGY- AND WATER BALANCE

Equation of energy-balance applied for half-yearly averages is:

$$a \frac{dT}{dt} = R(T,n) + A(n,T) + l(n,T) + \delta R(c_i) \quad (1)$$

where a is heat capacity of the soil-atmosphere system, T - air temperature at the surface, t - time, R - radiative balance, n - relative sunshine duration, A - sensible heat balance, l - latent heat balance, c_i - the concentration of the i-th atmospheric component (or other external climate forcings), δR - the primary change in the radiation balance, following a change of c_i.

Eq. (1) is being solved for T, while n is a coupling parameter, providing the connection of regional physical processes to the global ones. Linear connections are established in all terms, while primary changes in the local radiative balance have been calculated in a radiative-convective model [10], adjusted for Budapest. Details of parameterization of the energy-balance equation are published in [5]. The energy-balance equation has also been coupled to a model of the water-balance for a smaller region within the area of the energy-balance model (Fig. 1).

Initial forms of water balance equations for the effective layer of the soil, and the vertical air column, separately are :

$$\frac{dw_s}{dt} = P - ET - f \quad (2)$$

$$\frac{dw_p}{dt} = ET - P + \frac{1}{L} , \quad (3)$$

where w_s and w_p are the moisture contents of the soil and air column, P - precipitation, ET - the evapotransspiration, f - the outflow, l - latent energy income from atmospheric humidity divergence and L heat of evaporation for unit mass (2470 J/g).

Eqs (2), (3) and (1) form a closed model, if relations of terms at the right sides are parameterized in terms of prognostic variables on the left sides and in relative sunshine duration (n) connecting local terms to the global ones through the relation :

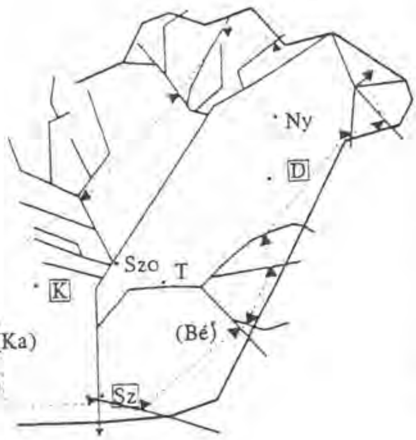

Fig. 1 Part of water catchment area of river Theiss (within the dotted line) excluding hilly regions, with 13 water level observing points, 8 surface climate observing stations. Three of the latter, indicated by s are used in soil-moisture calculations. The area of the model is 35.7 km^2.

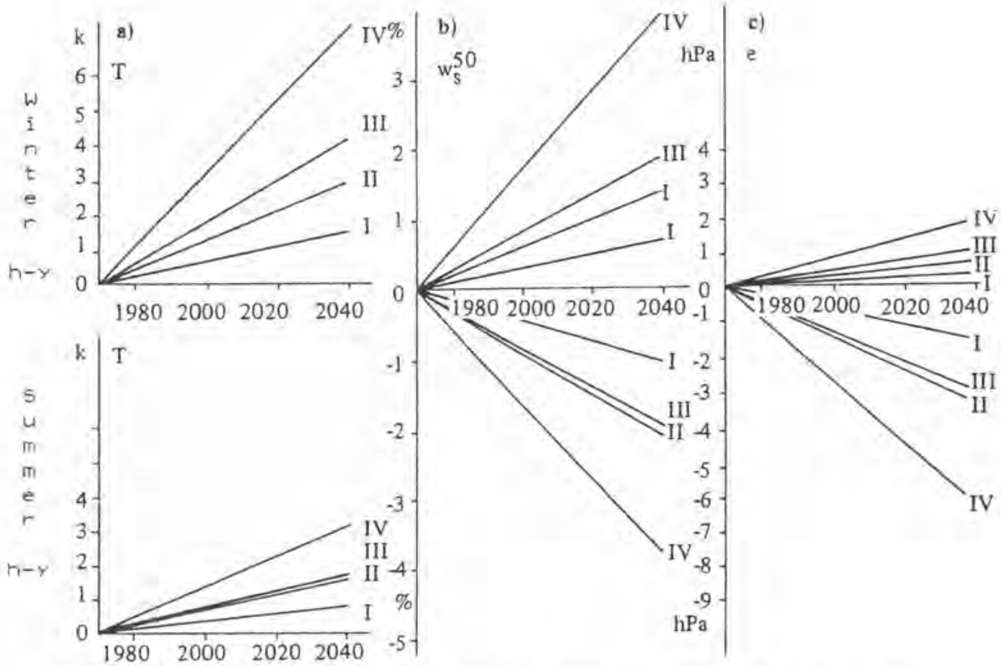

Fig. 2 Changes in temperature at the standard 2 m observation level in K (part a/), soil moisture content in % of the disposable water content (part b/) and atmospheric water vapour (part c/) according to CO_2-increase scenarios I-IV. Upper series of figures correspond to the Winter half-year and lower series to the Summer half-year.

$$n = n(\langle T\rangle, \Delta T) \qquad (4)$$

where $\langle T\rangle$ is the hemispherical mean temperature and ΔT the continent-ocean contrast over the Northern Hemisphere. Linear regression coefficients of (4) are determined from [3].

Left sides of (2)-(3) are expressed as linear formulae of soil moisture in the upper 0.5 m layer ($w_s = k_s w_s^{50}$) and of near surface water vapour pressure ($w_p = k_p e$) from additional calculations. So the prognostic variables of the model are T, w_s^{50} and e.

Monthly mean soil moisture content of the upper 0.5 m is reconstructed for 8 stations of Hungary [2]. First, original connections are established between potential evaporation and characteristics of the air, and also between potential and actual evaporations as a function of the previous soil moisture. Then soil moisture content is derived by water-balance method for 1951-1980. The third step is a multiregression fitting of the calculated soil moisture against retarded temperature and precipitation values. These connections are applied for the rest of the 1881-1990 period.

Parameterization of water balance terms is fulfilled from time series of observed meteorological elements and calculated soil moisture data for 59 years (1931-89). Outflow data [12] (see triangles in Fig. 1) are used for 26 years (1961-86). More details on the water-balance parameterization can be found in [9].

For external forcings an exponential growth of equivalent CO_2-concentration is assumed together with a logarithmic law between concentrations and changes in the radiation balance and a linear response of the global temperature to the linearly increasing radiative forcing ([11]). So the hemispherical mean temperature and continent-ocean temperature contrast can be expressed as $\langle T\rangle(t) = \Theta k_c t$ and $\Delta T(t) = D\langle T\rangle(t)$, respectively. The local radiative balance is $\delta R(t) = k_R k_c t$, where k_R is determined from [5].

After these parameterizations, the system of three linear ordinary differential equations is solved numerically by a fourth order Runge-Kutta method. The time step is one month.

4. EXPERIMENTS WITH THE COUPLED MODEL

The model was run assuming four alternative scenarios:

I. Long (200 years) equivalent CO_2-doubling time, medium global sensitivity (Θ = 2.078 K - [1]) and medium connection between $\langle T\rangle$ and ΔT (D=0.12) according to a quasi-equilibrium response realized in periods 1891-1920 and 1951-80 (no trends in $\langle T\rangle$)

II. Medium (100 yrs) equiv. CO_2-doubling time, no other changes.

III. Stronger connection between $\langle T\rangle$ and ΔT (D=0.32) according to the transient response, practically realized in the definite warming-up period between 1917 and 1942, no other changes.

IV. Large sensitivity (Θ =4.75 K - [11]), no other changes.

The results of experiments with these forcing scenarios are demonstrated in Fig. 2. The main conclusions are the followings:

1. The decrease in the summer half-year cloudiness plays an equivalent role in the local warming as compared to the direct radiational forcing due to the increase in CO_2-concentration according to our calculations in the regional climate model.
2. Changes in regional temperature are larger than those in the hemispheric mean for both half-years. Warming-up in the winter half-year is especially strong in scenarios with higher D values.
3. Soil moisture content of the summer half-year decreases considerably following all scenarios. Increase in the winter half-year is not so high from scenarios I. and II. In annual mean, however, there is a compensation, according to the other two versions.
4. Behaviour of water vapour pressure is similar to that of soil moisture content, but increases in the winter half-year do not fully compensate the summer half-year dry-out in any scenario.

5. DISCUSSION

Present form of the regional energy- and water-balance model is a prototype, to a combined approach of the regional climate scenario problem. A more sophisticated version can be coupled to GCM output fields in the future, with the intention to use them in parameterization of the advective terms and cloudiness. Regional variables would than be calculated by the regional model. itself.

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SOIL WATER BALANCE UNDER CLIMATE CHANGE

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Resume
Model of soil water balance (SWB) was assembled on the same physical principles as the model of irrigation water requirements, i.e. in relation to the meteorological factors. Based on this model the increase of deficits in SWB is estimated related to temperature increase in climate change. The results have shown that these deficits can be doubled. The change of streamflows was estimated on the basis of the correlation analysis of the logarithmic transformation of monthly flows in the vegetation period and SWB. In other months the correlation analysis of the temperature and SWB was used.

Bodenwasserbilanz und Klimaänderung
Kurzfassung
Das Modell der Bodenwasserbilanz wurde auf dengleichen physikalischen Prinzipen als Modell den Bewässerungs-ansprüche zusammengestellt, d.h. in Beziehung zu den meteorologischen Faktoren. Aufgrund dieses Modelles schätzt man den Aufschwung von Defiziten der Boden-wasserbilanz bei der Temperaturerhöhung in der Klimaänderung ab. Die Ergebnise haben gezeigh dass diese Defiziten bis verdoppelt werden kann. Veränderung des Durchflusses schätzt man durch die Korrelationsanalyse der logarithmischen Transformation der monatlichen Durchflusse in der Vegetationsperiode und Bodenwasserbilanz. In anderen Monaten wurde die Korrelationsanalyse der Temperaturen und Bodenwasserbilanz verwandt.

1. Introduction

Soil water balance (SWB) is an important factor of hydrological regime in many regions. Soil water balance deficits (SWBD) indicate the water stress of plants or the supplementary irrigation requirements on the water resources. However, SWB seems to be also an important hydrological factor in rainfall - runoff relations, factor that is correlated to flows in the basin. This factor can be used as a robust index that can represent the impact of climate change on the hydrological regime.

2. Climate Change

As a result of increased atmospheric concentrations of CO_2 and other trace gases a global change - greenhouse effect, global warming might be anticipated. Atmospheric concentrations of CO_2 have increased by more than 25% since the Industrial Revolution began in the nineteenth century causing with high probability the global warming by about 0.5 ^{o}C (Cohen,1990).

According to the rising concentrations of CO_2 at the beginning of the next century doubling of CO_2 concentrations is expected. The attempts to model the earth's atmospheric change used the general circulation models (GCM). Based on these models most scenarios indicate that the global mean-annual temperature would increase by 1.5^{o} to 4.5 ^{o}C at the beginning of the twenty first century (WMO,1986) Some GCMs estimates (Mitchell,1989) indicate the increase 3.5°. to 5.0 ^{o}C. On regional and seasonal scales much greater warming may occur in high latitudes. However, there is much uncertainty in these predictions.

The consensus regarding global warming which may occur has lead to scientific and political concern regarding the possible impacts of this change on natural and social systems, on global and regional scales (WMO,1988).

3. Soil WAter Balance Determination

Soil water balance can be expressed in a simplified form as

$$S = EP - AE \qquad (1)$$

where: S is the change of soil water storage in the effective root zone, EP is effective precipitation (surface runoff, subsurface runoff and seepage into lower soil layers have been expressed as unused part of precipitation), and AE is actual evapotranspiration.

Effective precipitation is derived from the values of precipitation that is measured directly. Actual evapotranspiration is often calculated based on the different formulas as the measurement of evapotranspiration in field conditions is neither technically nor economically acceptable. The extrapolation of evapotranspiration from lysimeters to areal evapotranspiration results in great errors and does not reflect the relation to temperature and other meteorological data. Therefore the computation was based on the Penman's formula (Penman,1954), modified by FAO, for potential evapotranspiration, corrected by the model of Morton, (1983) and reduced to the actual evapotranspiration.

The Penman's formula was derived for the semi-humid zone and it has been recommended by international organizations like WMO,1966 and FAO. This formula is discussed in details by Kos,1982. In this paragraph only the main parts of it that are important for the derivation of the basic idea of the model of SWBD are presented.

The formulas for actual evapotranspiration relate often the potential evapotranspiration and the soil moisture. Therefore at first the formula for potential evapotranspiration is presented. Potential evapotranspiration PE can be expressed as a part of the potential evaporation E0 and a conversion factor f:

$$PE = f\ E0 \qquad (2)$$

Potential evaporation is defined as

$$E0 = D\ R + G\ E \qquad (3)$$

where G is the function of the psychrometric constant,
D is the function of the slope of the dependence of the saturated water vapor pressure on air temperature,
R is energy budget (net radiation),
R = f(temperature,sunshine,albedo,dewpoint),
E is flow of water vapor,
E = f(temperature, dewpoint, wind speed).

4. Soil Water Balance Deficit

A series of theoretical works (e.g. Brutsaert, Sticker, 1979) aimed at the relationship between the actual and potential evapotranspiration. The resulting relations involve, however a lot of parameters that are hardly to be determined for the present state. A more difficult task is to estimate these parameters for the future and not in a point but for a large area. Therefore in this paper a different approach was used that is based on the concept of relation of SWBD to irrigation water requirements (IWR) and acceptable irrigation deficits. The model of IWR derived by Kos, 1982 was based on the soil water balance of the root zone and Penman's formula of the potential evapotranspiration and assumption that actual areal evapo- transpiration is a linear function of the potential evapotranspiration. This model used as the time interval one month. The model was calibrated on the basis of observed monthly values of IWR from the routine irrigation of the irrigation projects. Using the relation between IWR and SWBD the IWR model can be transformed into relation

$$W_j = k_1\ f_j\ D_j\ R_j + k_2\ f_j\ G_j\ E_j + k_3\ P_j + k_4\ W_{j-1} + k_5 \qquad (4)$$

where W_j and W_{j-1} are monthly SWBD in periods j and j-1 respectively,
$k_1, \ldots, k_5$ are regression coefficients.
R ,D ,G ,E, and f were described in eq. (2) and (3),
P_j is precipitation

4.1. SWBD Model and Climate Change

A relatively simple model of climatic change was designed that assumed that the present relation of temperature to the other meteorological factors will be maintained and linear regression of all these factors to temperature was tested. The transformation of meteorological factors was estimated by the following relation.

$$Z = Y + B\ .\ dT \qquad (5)$$

where : Z - transformed value of the meteorological factor (e.g.sunshine in %),
Y - measured value of this meteorological factor
B - regression coefficient of the relation of Y to temperature (e.g. in sunshine % / ^{o}C);
dT - expected change in mean temperature ^{o}C.

Using this relation the monthly time series in the period 1931-1960 (resp. 1930-1970) were analyzed in ten meteorological stations in Czech Republic. The value of the change of temperature dT= 1.5 ^{o}C resulted in an average increase of SWBD to 120-135 % (i.e. increase by 20 - 35 %) and the value dT=4.5 ^{o}C resulted in increase to approx. 200 % i.e. doubling the values derived under past and present conditions (Kos1992).

4.2. Probability Distribution of SWBD

The probability distribution of monthly SWBD is normal. As an example the c.d.f. (cumulative distribution function) for the SWBD in June are presented in Fig. 1. Not only for this months but also for other months of vegetation period and increased transformed values due to the rise of temperature the test of the goodness-of-fit proved the normal distribution. The SWBD c.d.f. change with the increased temperature is represented in June in Fig. 1.

In this paper the computation of SWBD increase was performed on the assumption of change of temperature and statistically significantly related meteorological variables, precipitation included. In some localities and months this regression was not statistically significant, and therefore precipitation remained unchanged.

5. Estimation of the Hydrological Impact of Climate Change

The impact of global and regional warming on hydrological regime can be studied on the relation of temperature increase to streamflow pattern change. In this paper the method of statistical analysis and cross - correlation between monthly SWBD and streamflows was used in the vegetation period and temperature and streamflows in non - vegetation period.

Determination of the marginal distribution of flows in each month was the first step of the analysis . As neither the normal nor the two- parameter log-normal distribution provided an adequate model of the flows in some months, the three-parameter log-normal distribution has been used. The normal transform of the observed and adjusted flows is then $y = \ln (Q - Qo)$.

The second step of analysis was the transformation of flows according to the change of temperature. The aim of this study was not to develope a general purpose hydrological model simulating the impact of temperature change on the rainfall-runoff relations on the basis of a comprehensive structure of the hydrologic cycle and representing a broad variety of regimes. For this study a special-purpose black-box synthetic approach was used, considering the fact that the data for the detailed retrospective analysis of the rainfall-runoff relations are not available.

Kos,1992 has observed a statistically significant relation of monthly SWBD and monthly flows. This simple special-purpose hydrological black- box model uses the coefficients calibrated by use of regression and correlation techniques.

In the non-vegetation period the hydrological model was even further simplified and a direct relation to the temperature was tested and in several months it was statically significant. It is based on the fact that in these months the temperature increase is related to the increase rate of melting of the accumulated snow.

6. Numerical Example: The Jizera River Catchment

The Jizera River is a tributary of the Labe River in the central Part of the Czech Republic. The area of the Jizera River catchment is 2193 km2. The results of the computation the impact of temperature increase on c.d.f. of SWBD in June are presented in Fig. 1. and the c.d.f. of flows in June in Fig.2. (for further details see Kos,1993).

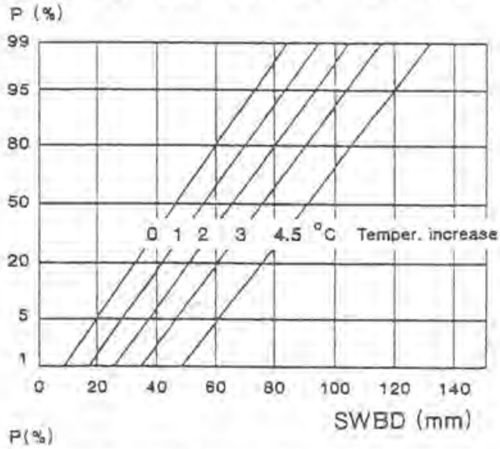

Fig.1. Cumulative distribution function of SWBD in June with temperature increase 0 to 4.5°C; P-probability [%]; SWBD - soil water balance deficit [mm]

Verteilungsfunktion des Defizits der Bodenwasserbilanz in Juni mit Temperaturerhöhung

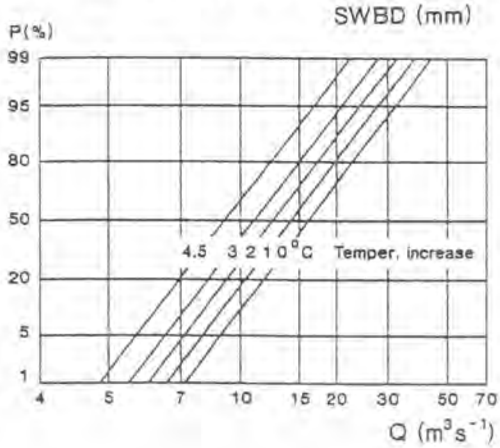

Fig.2. Cumulative distribution function of transformed flows in June with temperature increase 0 to 4.5°C; P-probability [%]; Q - flows in site Turice on the River Jizera [$m^3\ s^{-1}$]

Verteilungsfunktion der transformierten Durchflusse in Juli mit Tempreatur-erhöhung

7. Conclusions

The impact of climate change on hydrological regime and namely streamflows in relation to global and regional warming is often discussed. However, few attempt has been made to quantify these relations. This is a very difficult task as many hydrological factors may be influenced.

In this paper the simple mathematical statistical approach to this issue was used. The relations were statisticaly significant and the quantitative results can be used as the comparison of various models. The results seem to be relevant for climatic scenarios with small temperature increase (e.g. 1.5 ^oC - 2^oC). For higher temperate increase the results can be used as the indicators of possible hydrological risk that the water management planners should be aware of.

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INVESTIGATION OF CLIMATIC VARIABILITY INFLUENCE ON SOIL MOISTURE IN HUNGARY

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Summary: A simple statistical method developed for the upper one meter layer soil moisture calculation was used to generate long soil moisture data series. To test the method the calculated values based on monthly data were compared with *in situ* measured soil moisture data collected in Keszthely (western part of the country) and Szarvas (eastern part of the country). Long climatic data series of precipitation, temperature and water vapor deficit for 16 Hungarian stations, can be found everywhere in the country, going back to 1881 have been used. From these data one can determine month by month the soil moisture deficit. The data were calculated for a hypothetical 'average' plant stand which behaves like maize. The generated soil moisture indices have been investigated in order to find out about any signal of global warming on subgrid scale. The statistical analysis showed that presence of consecutive dry seasons is not an abnormal situation under Hungarian climate but up till now no systematic change has been found in the constructed data series.

UNTERSUCHUNG DER WIRKUNG AUF DIE KLIMAVERÄNDERUNG DES BODENFEUCHTIGKEITS INHALTS IN UNGARN

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Kurzfassung: Eine einfache statistik Methode entwickelte sich durch die Ausrechnung der oberen 1 Meter dicken Bodenschichts Feuchtigkeitinhalts, um lange Bodenfeuchtigkeitsinhalts Datenserie zustande zu bringen. Um die Methode auszuprobieren mußte man, die durch die monatlich errechneten Daten mit den Daten, die man auf verschiedenen Plätzen gemessen hat, z.B.: in Keszthely (im westlichen Teil des Landes) und Szarvas (im östlichem Teil des Landes) vergleichen. Die Datenserie des langem klimatischem Mangel an Niederschlag, Temperatur und Wasserdampf, die man in ganz Ungarn auf 16 Stationen misst, werden schon seit 1881 verwendet. Von diesem Daten kann einer, von Monat zu Monat den Bodenfeuchtigkeitsinhalt rechnen. Mit der Hilfe dieser Daten wurde eine "durchschnitliche" Pflanze die sich wie Mais verhält entwickelt. Der zustande gebrachte Bodenfeuchtigkeits-Index wurde untersucht, ob man irgendein Anzeichen im zusammenhang mit der Globalen Aufwärmung findet. Die Statistikanalyse deutete darauf hin, daß die sich wintereinander kommende trockene Jahreszeiten, nicht eine ungewöhnliche Erscheinungen im Klima von Ungarn sind, aber bischer fand man noch keine regemäßigen Veränderungen in der zusammenstelung der Datenserie.

Introduction

Drought is one of the major climatic hazards of the Hungarian agriculture beside the hail and frost damages. It seems droughts have occurred much more frequently in the last decade then previously. In 1992 and 1993 the summer was warm and dry and the soil moisture content reached the wilting point (WP). The recent higher frequency of droughts in Hungary has emphasized the need of more detailed information about the climate of the past. Without such knowledge it is not possible to make meaningful statistical statements about the future occurrence of extreme events. We would like to answer the question if the climate have begun to change towards drier one or the high frequency of droughts is a normal situation under Hungarian climate. Looking for local signal of climatic change mostly temperature and precipitation are examined. In our paper to answer the question a combined meteorological variable, the upper one meter available soil moisture content, was chosen for that purpose. No special drought index was used only the frequency of the low soil moisture content was examined. Using long data series evaporation of bare soil has been discussed in Hungary (*Bussay et al.*, 1993, *Lambert et al.*,1993). Our paper tries to approach the problem from the vegetated surface. The territorial distribution of used meteorological stations is shown in *Fig.1.*

Fig. 1.
The location of stations used for the soil moisture calculation

For our calculation monthly mean and sum of temperature, water vapor pressure and precipitation were used respectively. If we would like to find any signal of climatic change in the case of temperature it is enough to take into consideration only few stations because there is close correlation between stations. There is drawn in *Fig.2* Szarvas monthly temperature mean versus Keszthely for the period 1881-1990 where 1320 data are shown. In the case of precipitation monthly sum we can found less good connection (*Fig.3*) and in the case of calculated soil moisture content (*Fig.4*) a total independence. The last two figures indicate that the territorial change could be higher than temporal.

Calculation method

The basis of the calculation is the water balance equation. The composite loss of water to the air from all surfaces is called evapotranspiration (ET). If there is no lack of water and the rate of evapotranspiration determined only by the atmospheric conditions we speak about potential evapotranspiration (PE). Under favorable conditions the cloud droplets fall to the Earth as precipitation (P). Over land areas where P is greater than ET and the excess, called runoff (R) is transported on the surface as streamflow to rivers, lakes and finally to the sees and ocean. Under certain circumstances one part of the excess water infiltrates into deeper soil layer. Infiltration (F) is not easily determined so for practical purposes it is better to consider a column which extends from the surface to a depth where significant vertical exchanges are absent. In general form of the water balance is given by:

$$P = ET + R + F + \Delta S$$

where Δ S the net change in soil moisture content.

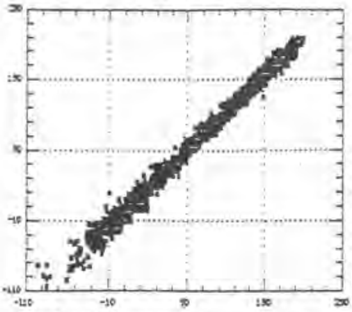


Fig.2.

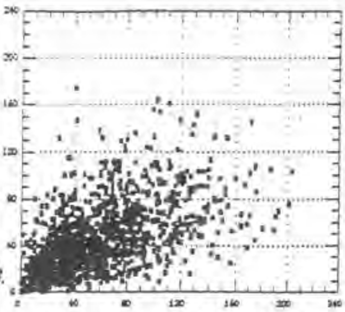


Fig.3.

Monthly mean temperature Monthly sum of precipitation

for Keszthely versus Szarvas (1881–1990)

Evaluation of available soil water content

For the calculation of the available soil moisture content, expressed in precipitation unit, *mm*, the simplified form of the water balance equation was used. The greater part of the Hungary is flat and mostly during the vegetation period the percent of the runoff is very small so the runoff was taken equal zero and its value for the whole time series was neglected. We calculated only the upper one meter layer soil moisture content. According to the results of the field soil moisture measurements done on bare soil and under vegetated surface to is was found that the rate of infiltration could be considerable in the end of the winter during the thawing. Taking into consideration that we make a mistake the infiltration was neglected too. After the simplification for the

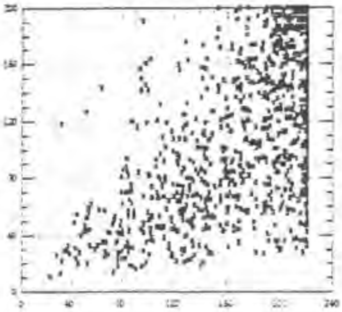


Fig.4.

Monthly value of calculated AWC for Keszthely versus Szarvas (1881–1990)

calculation a reduced form of the equation was used. The upper one meter layer soil moisture content on the next time step will be expressed as

$$WC_i = WC_{i-1} + P - ET$$

where *i* is the number of the next time step. For the most part of the examined period only monthly data available. It is necessary in order to obtain a homogeneous series to use monthly data throughout. It is however, preferable to use daily precipitation and evaporation data. The use of monthly data alone can produce systematic errors in estimating monthly-end soil moisture water content. We have found that these errors can be reduced by dividing each month into three or six segments, distributing monthly precipitation and calculated evapotranspiration values even by these segments and then calculating soil moisture content accumulated over successive segments. The total amount of water can be stored in a soil column is field capacity (FC). The certain part of the field capacity is not available by plants. The maximum value of available water content of the examined soil layer can be expressed as

$$WC_{max} = FC - WP.$$

The value of the field capacity depends on the type of soil. The wilting point is not only the function of soil type and previously used agrotechnics but of the kind of vegetation too. In the case of clay the field capacity is taken equal with 320 mm and the wilting point with 100 mm, in case of sandy soil there are 210 and 40 respectively. The used soil type for every stations changes between the given values according to the soil type. For the calculation of evapotranspiration the Budyko-Posza method was used. The steps of calculation are very simple. If the calculated soil moisture content on the next time unit exceeds the field capacity its value is taken equal with field capacity, namely if

$$WC_{i+1} > FC, \text{ then } WC_{i+1} = FC.$$

The evapotranspiration is expressed as a simple linear function of the potential evapotranspiration, ET = *k.w.*PE, where *k* is the so called plant constant,. *w* is an empirical variable depends on the soil moisture content. If the water content higher than 50 % the evapotranspiration is taken potential, namely

$$w = \begin{cases} 1 \text{ if } & \dfrac{WC - WP}{FC - WP} > 0.5 \\ & \dfrac{WC - WP}{FC - WP} \text{ else.} \end{cases}$$

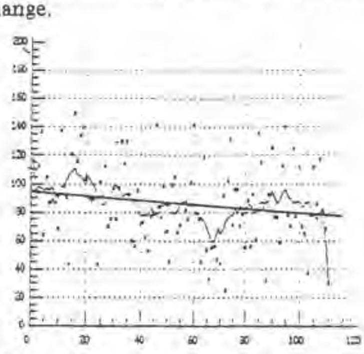
The *k* plant constant is determined by lysimeter measurements. Plant constants used by Penman for the grass transpiration calculation. In our case the plant constants for the calculation of transpiration evaluated by several years' field experiments using Thorthhwaite type compensation lysimeter. Using lysimeter measurements have done since late sixties at Agrometeorological Observatories in Hungary for 19 species a five-day-averages of plant constants were calculated (*Posza* and *Stollár* 1983). In our case, for the climatological type examination, monthly average plant constants were used. For the calculation of potential evaporation a simple empirical regression form was used (*Antal* 1968). The measured *A pan* evaporation was taken equal the potential evaporation and some modification was introduced before the regression function calculation. The potential evaporation expressed as

$$PE = a.[e_s(1-r)]b.(1 + \alpha.t).c$$

where *a*, *b* and *c* are the empirical constants, e_s saturation water vapor pressure, *r* relative humidity, *t* mean air temperature. Under Hungarian climatic conditions the equation works well (*Antal* and *Kozmáné Tóth* 1980).

Reliability of model results

A doubled hypothesis was used in the calculation. We supposed that the upper one meter layer soil moisture content could be calculated acceptable neglecting runoff and infiltration simultaneously. The other assumption was the existence of an average plant.. If we would like to control our calculation there is real object to compare with. If the calculated values behave as a measured values we can except that the produced values are suitable for further examination. The annual course of the soil moisture content can be described very simply. It has a maximum values at the end of the winter when the melting snow saturates the soil. The minimum water content occurs in July or August at the end of typical continental dry spell characterizing Hungarian climate. The actual soil moisture values changes between the possible maximum, the field capacity, and the possible minimum values. The minimum soil moisture content in some years reaches the wilting point but very rarely decreases below its value. The actual course of the soil moisture depends on temporal distribution of the precipitation and the grown species. The statistical behavior of the calculated hypothetical soil moisture data are similar to the expected. Comparison of calculated data with measured shows good temporal change.



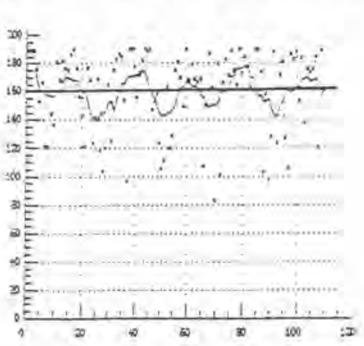


Fig.5. *Fig.6.*

Eleven-year moving averages of available soil moisture content and the linear regression for Zalaegerszeg station for Kecskemét station

Using the outlined method, we have reconstructed a hypothetical monthly available water content back to 1881 for 16 meteorological station. The tendency within the growing season correlated well but the absolute value was over the calculation used daily data. The trend towards drier summer soil moisture conditions which was detected in east part of Hungary was not found in the west part of country. If the assumption that climatic change would have caused generally increased atmospheric water demands is correct the trend would be enlarged however it must be emphasized that a trend detected from soil moisture simulations using a single climatic record 'in itself' gives no information about climatic change.

Drought conditions are not determined only by lack of precipitation. The precise evaluation of drought severity is difficult because different people perceive drought in different ways. We can distinguish between at least four different types of drought - meteorological, hydrological, physiological and agricultural drought. We have to notice that agricultural, hydrological and physiological drought conditions are determined not only by precipitation but also by transpiration and by timing of precipitation events. For our examination from the calculated monthly available soil moisture content three types of 'indices' were chosen. In Hungary the maximal soil moisture content occurs in the end of the winter in February or in March. In our data series the minimal values occurred in end of summer in August or in September. Supposing that the February values is not far from the maximum available water content the difference of its and the August value was chosen as a drought index. The second chose was soil moisture content in August alone as the absolute minimum. If its values approaches the wilting point that year can expect as year of drought. Last choose was the average available soil moisture content over the four-month period May to August.

Results of simple regression analysis

Firstly a simple linear regression was fitted on the data. The chosen annual minimum and the four-month (May-August) average showed the same tendency. In case of 4 stations we found a non significant increasing and in the other 12 cases decreasing tendency. The result is ambiguous. The variance is very high. Examining the data series we can choose both drying as wetting periods too. To separate the dry and wet periods a 11-years moving average was fitted. A linear regression and the moving average for Kecskemét and Zalaegerszeg stations are shown in *Fig.5* and *6.* respectively. Examining the 4-month soil moisture average we could find as dry period as the last decade was. For example in case of Keszthely station the forties were more drier then recent ten years. But the linear regression shows mostly decreasing tendency we can not accept this results comparing with moving averages as a signal an unambiguously drying climate.

Conclusions.

The used method for soil moisture trend analysis has its own strength and weakness. Actually it says more then the simple temperature or precipitation time series. Its weakness that it does not give any definite results but we suppose we can conclude the follows:

(1) There is important difference between AWC within a short distance.

(2) Decreasing tendency similar to the last decade occurred during the last century but there was not global warming.

(3) The presence of consecutive dry seasons is not an abnormal situation under Hungarian climate. Examining the soil moisture data as drought indices we have not found systematic change among them only drier and wetter periods. The present decade in the east part of the country is a drier one.

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Der Einfluß von Klimaänderungen auf Schneedeckenentwicklung und Schneeschmelze in den bayerischen Mittelgebirgen

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Kurzfassung

Im nachfolgenden Beitrag wird die prognostische Simulation des Einflusses klimatischer Änderungen auf die Schneedeckenentwicklung und das Abflußregime eines nordbayerischen Einzugsgebietes im Winter beschrieben. Für die Simulationen ist ein DHM-gestütztes, physikalisch basiertes Schneemodell entwickelt und mit einem Niederschlag-Abfluß-Modell gekoppelt worden. Die Untersuchungen zeigen, daß unter bestimmten klimatischen Bedingungen die Dauern einer geschlossenen Schneedecke zwar abnehmen, die Schneehöhe und der Wassergeahlt aber durchaus höhere Maxima aufweisen können. Dies wiederum kann die Wahrscheinlichkeit maßgebender Taufluten durch Überlagerung von Schneeschmelze und Regen bei einer Änderung des regionalen Klimas stark erhöhen.

The Impact of Climate Change on Snowcover and Snowmelt in Northern Bavaria

Abstract

The following paper deals with the prognostic simulation of the impacts of climate change on snowcover and winter runoff in a catchment area in northern Bavaria. For the simulations a DTM- and physically based snowcover-model has been developed and coupled with an rainfall-runoff-model. The investigations show, that the duration of the snowcover will decrease and its maximum height and water contents will increase. This may lead to higher snowmelt and rainfall depending flood events in winter caused by regional climatic change.

West für Windverfrachtung, auf den mittleren Grauwert normierte Koeffizienten berechnet, die die aus der Geländehöhe berechneten Schneehöhen aus dem ersten Bearbeitungsschritt noch modifizieren. Für den Wassergehalt wird in ähnlicher Weise verfahren.

Aus den gewonnenen raumbezogenen Werten werden für jedes, im Niederschlags-Abfluß-Modell definiertes Teilgebiet sogenannte Schneedeckenparameter bestimmt, mit denen die im Teilgebietsschwerpunkt mit dem physikalischen Schneemodell ermittelten Schneehöhen und Wassergehalte korrigiert werden. Diese Parameter erlauben somit die räumliche Extrapolation der Schneehöhe und des Wassergehaltes über das gesamte Gebiet. Die räumliche Auflösung beträgt entsprechend dem digitalen Höhenmodell ca. 28m x 28m, jeder Grauwert in Abbildung 1 entspricht der Schneehöhe für dieses Rasterelement.

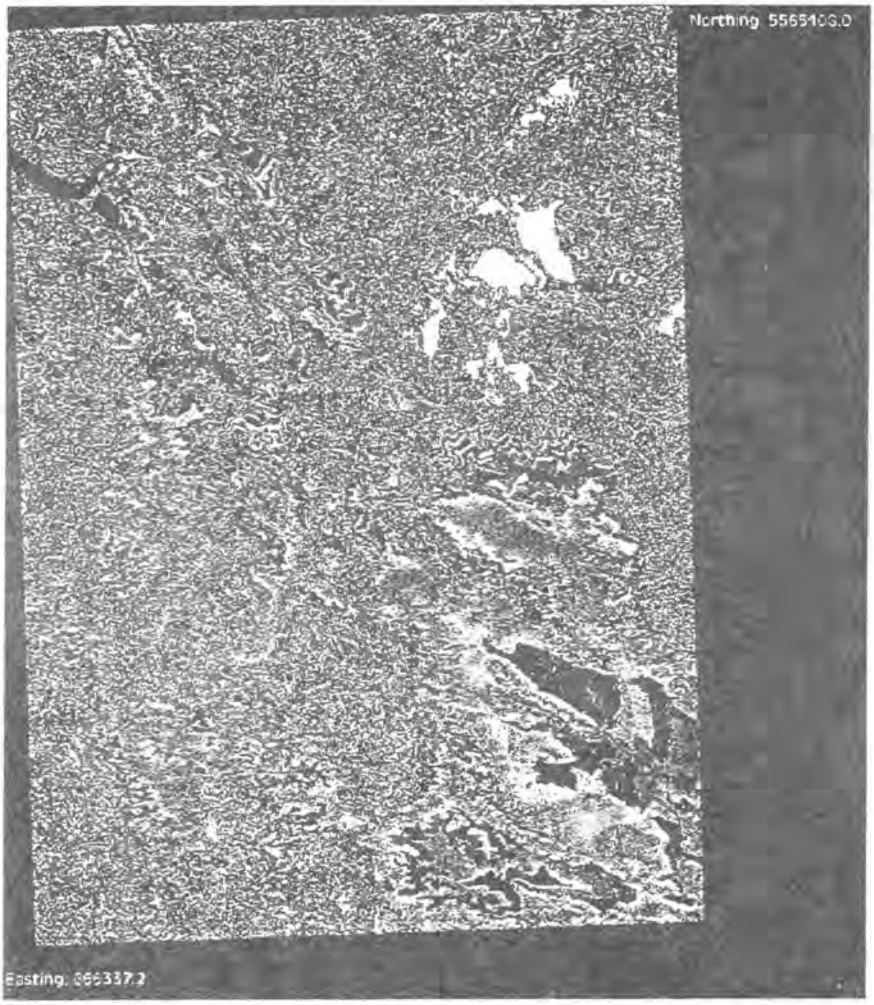

Abb. 1: Anhand eines digitalen Höhenmodells räumlich verteilte Schneehöhen (jeder Grauwert entspricht einer bestimmten Schneehöhe)

3. Szenarien und Modellrechnungen

Für die stochastischen Szenarien sind zunächst Niederschläge und Temperaturen generiert und als Grundlage für die Berechnung der Abflüsse mit einem Niederschlag-Abfluß-Modell verwendet worden. Auch wenn das zugrundeliegende Modell mit Ausnahme des Schneeschmelzteiles und der Evapotranspiration noch immer konzeptionelle Ansätze verwendet und daher an den Prozeß angepaßt werden muß, so sind doch aus den statistischen Untersuchungen Trends erkennbar, die Rückschlüsse auf die Sensibilität des Abflußregimes bezüglich klimatischer Veränderungen zulassen. Dabei sind unter anderem folgende stochastische Szenarien definiert worden:

Szenario 3:
- *Verminderung* der Niederschlagssumme im Sommer um 70 mm,
- *Erhöhung* der Niederschlagssumme im Winter um 70 mm,
- *Erhöhung* der Niederschlagsvariabilität um 15%,
- *Erhöhung* der Temperatur um durchschnittlich 2 K,
- *Zunahme* der Temperaturschwankungen um 10%

Szenario 4:
- *Verminderung* der Niederschlagssumme im Sommer um 70 mm,
- *Erhöhung* der Niederschlagssumme im Winter um 120 mm,
- *Erhöhung* der Niederschlagsvariablilität um 15%,
- *Erhöhung* der Temperatur um durchschnittlich 2 K,
- *Zunahme* der Temperaturschwankungen um 10%

Szenario 5:
- *Verminderung* der Niederschlagssumme im Sommer um 70 mm,
- *Erhöhung* der Niederschlagssumme im Winter um 70 mm,
- *Erhöhung* der Niederschlagsvariabilität um 15%,
- *Erhöhung* der Temperatur um durchschnittlich 2 K,
- *Zunahme* der Temperaturschwankungen um 15%

Szenario 6:
- *Verminderung* der Niederschlagssumme im Sommer um 70 mm,
- *Erhöhung* der Niederschlagssumme im Winter um 120 mm,
- *Erhöhung* der Niederschlagsvariabilität um 15%,
- *Erhöhung* der Temperatur um durchschnittlich 2 K,
- *Zunahme* der Temperaturschwankungen um 15%

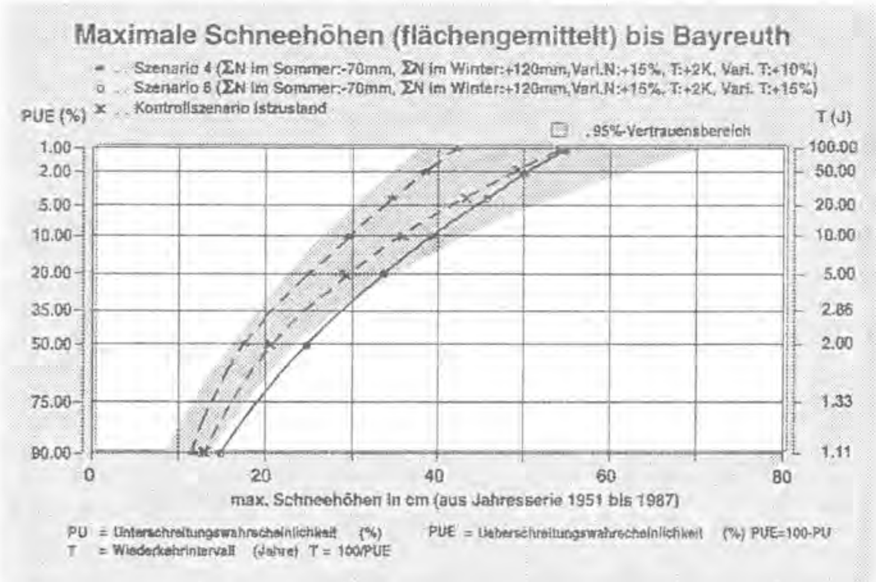

Abb. 2: Verteilungen der maximalen täglichen Schneehöhen für zwei Szenarien und den Istzustand (aus Simulationsrechnungen abgeleitet)

Mit den modifizierten Niederschlags- und Temperaturreihen ist das Schnee- und das Niederschlag-Abfluß-Modell belastet worden. Statistisch ausgewertet wurden neben den Abflüssen auch die Dauer der Schneebedeckung und die zugehörigen maximalen Schneehöhen und Wassergehalte. Stellvertretend für alle anderen Ergebnisse sind jeweils für die Szenarien 4 und 6 sowie den Istzustand in Abbildung 2 die Verteilungen der maximalen Schneehöhen aufgetragen. Die Szenarien 4 und 6 unterscheiden sich ausschließlich in der Zunahme der Temperaturschwankungen um 10 bzw. 15%. Die Schneedichte, das Verhältnis von Schneehöhe und Wassergehalt, ist temperaturabhängig. Je häufiger tiefere Temperaturen herrschen, desto weniger verdichtet sich der Schnee. Dies führt zusammen mit höheren Niederschlägen zu größeren Schneehöhen bei gleichzeitiger Verkürzung der Dauern der Schneebedeckung. Damit können sich aber auch die Wasserabgaben aus Schneeschmelze und Regen und damit die maximalen tägliche Winterabflüsse vergrößern (Abbildung 3).

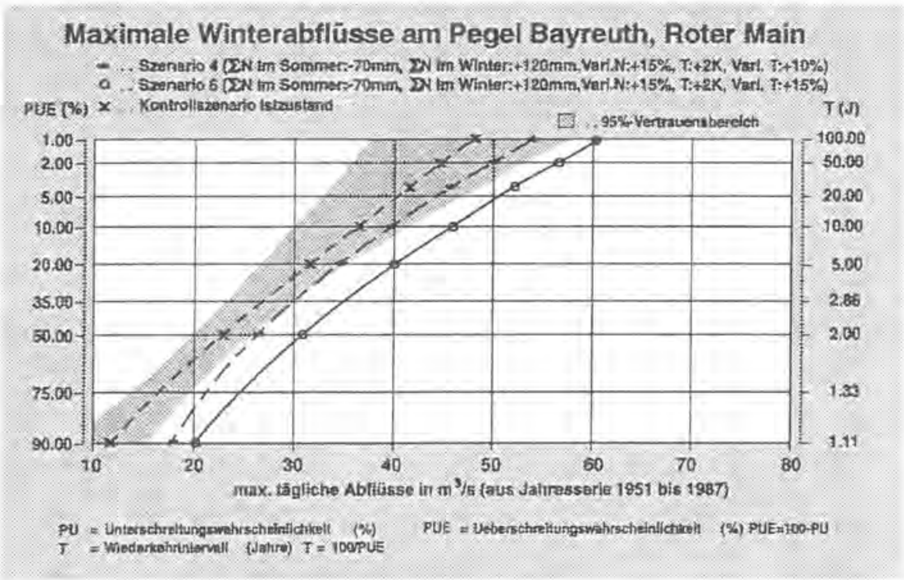

Abb. 3: Verteilungen der maximalen tägliche Winterabflüsse am Pegel Bayreuth für zwei Szenarien und den Istzustand (aus Simulationsrechnungen abgeleitet)

4. Zusammenfassung

Es wird wohl nicht damit zu rechnen sein, daß der Boden eine Erhöhung der Niederschlagsintensitäten auffängt. Die Abflußspitzen werden im Gegenteil prozentual stärker zunehmen als die Maximalniederschläge, weil bei Wassersättigung nicht mehr in den Boden infiltriert werden kann. Dies gilt natürlich besonders für den gefrorenen Boden. Im Winter kann durch häufigere Überlagerungen von Schneeschmelze und Regen die Gefahr von Taufluten zunehmen. Somit können sich auch die Bemessungswerte (z.B. das HQ_{100}) für Einzugsgebiete in Mittelgebirgen, in denen die maßgebenden Ereignisse durch Taufluten hervorgerufen werden, ändern. Danach bemessene bauliche Hochwasserschutzmaßnahmen müßten dann hinsichtlich ihrer Sicherheit im Hochwasserfall überprüft werden.

Die Arbeiten zeigen, daß das betrachtete Einzugsgebiet, und dies ist sicherlich auf andere Gebiete in ähnlicher Weise übertragbar, sensibel auf Änderungen im Niederschlagsdargebot und der Temperaturen reagiert, da beide Größen zusammen die Schneedeckenentwicklung und damit auch den im Tauwetterfall verfügbaren Wasservorrat in der Schneedecke maßgebend bestimmen. Die ansonsten naheliegende Vermutung, daß eine Erwärmung grundsätzlich zu einer Verminderung der Taufluten führen muß, kann somit nicht bestätigt werden.

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Modeling of floods at mountain rivers under different scenarios of climate changes

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Summari: Variations in the mountain river flow under different meterological scenarios simulating probable climate changes are computed. The method is based on a mathematical model of forming the mountain river flow. As input data simulated variants of the annual cycle of meteorological elements are used.

Die Modellierien des Hochwassers auf den Bergfusses bei der verschiedene Scenaria der Klima Veraenderungn

Kurzfassung: Die Veraenderundgen des Abflusses einer / Bergfusses bei verschiedene "meteorologische Scenaria" die wahrscheinliche Klimaveraenderungen simulieren ist untersucht. Der Methode liegt die Vereinigung des Modell der Schmelzabfluss bilding auf der Berggebiete mit dem Bauen der obengenannte Scenaria zugrunde.

Climatologists persistently study the problem of probable climate changes. The knolage of influence degree of these changes on disastrous situations on mountain rivers regime is not less important. One of the most suitable approaches to study such kind of impact may be a combination of reliable model of flow formation in mountains and imitation of meteorological element time fluctuations. Further on simulated meteorological element functions will be called "meteorological scenario".

One of the popular versions of climate changes is

its warming. The scale of warming is not definitely estimated yet. That is why we proceeded from a priori supposition: precipitation quantity and their characteristics remain permanent, and air temperature changes within $\pm$ 2°C range. Meteorological scenarios were modeled in different ways, but as the main scenarios, the following ones can be distinguished:
- mean perennial air temperatures of each ten days increase by 2°C during the whole year;
- mean perennial ten days air temperatures only of the warm half of a year - vegetation period, increase by 2°C (from April until September);
- on the same situation for the cold half of a year from october until march;
- mean air temperatures decrease during the cold half of a year, and they increase by 2°C during the warm one;
- extreme air temperatures increase or decrease by 2°C (maximal and minimal ones - during 25 years observation period of each ten days during the seasons mentioned above).

The study was conducted on the base of observation data in the Naryn river catchment. Water inflow in the Kamparata reservoir, 350 km^2 catchment area, was taken as example.

The main hydrological processes in the Naryn catchment are also typical for many other mountain river catchments, in the Middle Asia, where water run off is formed mainly as a result of seasonal snow and glacier melting with unessential influence of rain waters. The developed model was described in details in literature [1,2], that is why we shall briefly enumerate the main intermediate problems, solved with the help of the model: 1) precipitation and air temperature values calculation as a function of a catchment altitude; 2) accumulation and snow cover and glacier melting as a function 9of a catchment and over its area; 3) calculation of water run off losses; 4) calculation of transformation of inflow on a catchment surface in the down stream cross section run off hydrgraph.

Income data are the sums of the days precipitation values and mean ten days air temperatures at hydometeorological stations. Time interval of calculation is ten days, height interval is from 200 to 500 m. The problem of accuracy of calculated inflow hydrogrphs into reservoirs during vegetation period and especially the dates of flood maximum occurrence and their values is important one. This fact determines to considerable degree the reliability of obtained conclusions while solving the given problem. The methods of hydrgraphs calculation and also the methods of hydrographs calculation and also the methods of short-term and long-term hydrological forecasts for several rivers in the middle Asia were developed on the base of the model. The catchment areas of these rivers are from 1000 to 5000 km^2.

Comparison of calculated and observed water inflow hydrographs to a number of reservoirs reveals close relation between them, s/σ=0.2-0.5 (s - mean square error, σ - mean square deviation of a phenomenon). Coincidence of the dates, when maximal discharges were observed was 85-90%. Mean calculation error of the maximal discharge values during the vegetation period is 10-15%; estimation of long -term forecast reliability (s/σ), depending on prediction period (from 1 to 6 months), changes within 0.40-0.75 range. Accuracy of mean perennial water inflow hydrograph into Kamparata reservoir calculation, based only on mean perennial values of precipitation and air temperature are characterized by the following parameters: calculation error of the maximal discharge of the mean perennial water inflow hydrograph from the observed value during vegetation period it was about 3%. The question of choosing the method of meteorological scenario construction is not less important for solving the given problem. It consists of two main features: to define the value of possible maximal precipitation and value of possible maximal precipitation and to define air temperature time fluctuations. Several methods were used for calculation of maximal possible precipitation. We shall adduce one of them here: water storage in snow cover and precipitation value during vegetation period calculations are based on the model, using determined before for each station, extreme sums of precipitation for each ten days within warm and cold parts of a year during all observation period.

Comparisons, made for water inflow into Toktogul reservoir have shown, that the maximal ten days discharge, depending of the way, how "maximal possible" value of precipitation was chosen (with other equal condition), changes from 3890 to 7050 $m^3 sec^{-1}$. The last value corresponds to described above method. Of cause, the probability that precipitation will occur during each ten days all through the whole year at the same time over the whole catchment, with precipitation sums equal to extreme ones is very low. But there is no evidence of the fact, that it is absolutely impossible.

The analysis of calculation of water inflow hydrgraphs into Toktogul reservoir [2] has shown, that time distributions of precipitation and air temperature have the most considerable influence on the flood maximal discharge formation at the same equal conditions. The largest values are in the situation when maximal possible duration of the cold period is followed by extremely warm period. Successive modeling of these period durations made it possible to reveal definite time intervals for several reservoirs. The cold period appeared to be 24 ten days (from the first ten days of October until the third ten days of May - i=1-24), and the warm period - 12 ten days - from the first ten days of June until the end of September - i=25-36) (i - a number of ten days period, beginning from the first ten days of October). the study off value of the mountain rivers and maximal discharges formation included first of all calculation of hydrogrph based on meteorological scenario, when mean perennial air temperature during each ten days (from October of the previous year until September of the following one) increased by 2°C, and the value of precipitation was assumed to be equal to mean perennial one in each ten days. The results of calculation have shown the following (fig. 1,a,b): the values of

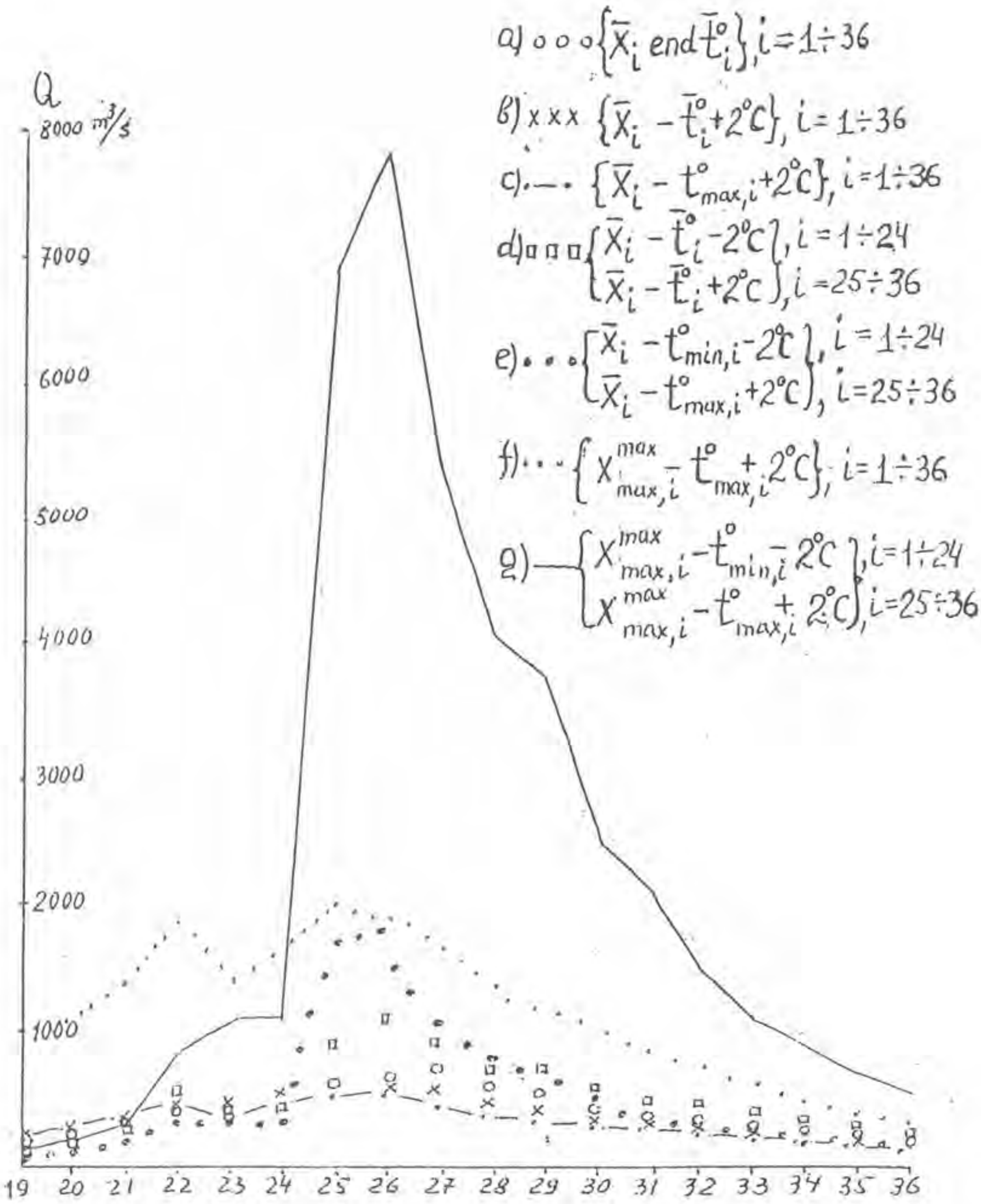

Fig. 1. Hydrographs of inflow into the Kamparata reservoir at different meteorological scenario (a-g).

maximal (Q_{max}) and mean ($\overline{Q}_{veg}$) water discharges during vegetation period decreased comparing with thus mean perennial values, but to a different extent: if the first one decreased by 18% (Q_{max} from 770 m^3sec^{-1} to 650 m^3sec^{-1}), the second one only by 6% ($\overline{Q}_{veg}$ from 430 m^3sec^{-1} to 410 m^3sec^{-1}. Climate "warming" or "cooling of only winter by 2^0C as on Q_{max} value, and also on $\overline{Q}_{veg}$ value had not essential influence.

Climate "warming " of only spring-summer period (from April until September) by 2^0 leads also to reduction of the main run off characteristics, what is determined by decrease of snow cover storage in the mean altitude zones in April-May and run off redistribution in time. Including in meteorological scenarios of maximal air temperatures, increased by 2^0C during the whole year led to more reduction of the values of maximal discharges and the volume of run off during vegetation period: Q_{max} became equal to 500 m^3sec^{-1}, $\overline{Q}_{veg}$ – 300 m^3sec^{-1} (fig. 1,c). Thus climate "warming" that can be characterized by increase of mean and maximal ten days temperatures during the whole year (at other equal conditions) must lead to reduction of maximal discharges and run off volume of the mountain rivers during vegetation period.

Uneven distribution of temperature within the seasons (at mean values of perennial precipitation) abruptly changes the picture of run off formation. For example, meteorological scenario, constructed taking into consideration the hypotheses about climate "cooling" from october until May (t_i^o -2^0C, where i=1-24 ten days) and "warming" from June until September (t_i^o $+2^0C$, where i=25-36 ten days) led to noticeable increase of maximal discharge value from 770 to 1025 m^3sec^{-1} (by 33%). The mean value of discharge during vegetation period increased from 430 to480 m^3sec^{-1} (by 10%) (fig. 1,d). The scenario that includes reduction on observed minimal air temperatures during the cold period ($t^o_{min,i}$ -2^0C, when i=1-24 ten days), and increase of observed maximal temperatures during warm period ($t^o_{min,i}$ $+2^0C$, when i=25-36 Ten days) has shown that maximal discharge value equals in this case to 1800 m^3sec^{-1} (it is 2.5 times as much as mean perennial discharge, and at that time mean discharge during vegetation period increased only by 30% – from 430 m^3sec^{-1} to 550 m^3sec^{-1}) (fig.1,e).

After the values of maximum possible ten days precipitation had been included in meteorological scenario (X^{max}_{max}), calculated on the base of described above methods, abrupt increase of run off volume during vegetation period occurred. For example after increase of observed, maximal air temperature in each ten days during the whole year by 2^0C ($t^o_{max,i}$ $+2^0C$, when i=1-36 ten days), the mean discharge $\overline{Q}_{veg}$

became equal to 1170 $m^3 sec^{-1}$, and its value at the most unfavorable conditions ($t^o_{min,i}$ -2^oC, where i=1-24 ten days and

$t^o_{max,i}$ $+2^oC$, where i=25-36 ten days reached
$\bar{Q}_{veg}$ = 2200m^3 sec^{-1} (fig.1,f),

remaining in all other types of scenarios within 1900-2200 $m^3 sec^{-1}$ range. The values of inflow water volumes into Kamparata reservoir corresponding to those adduced above, are able to create disastrous situation, if the necessary measures have not been made before. Forecasting methods, described in [3] allow to predict probability of such disastrous situation in a particular year.

Changes of temperature characteristics have much more influence on the values of maximal discharges. Thus using the first scenario discussed above ($t^o_{max,i}$ $+2^oC$, when i=1-36ten days), Q_{max} appeared to be about 2000 $m^3 sec^{-1}$, and using the scenario including the most unfavorable conditions ($t^o_{min,i}$ -2^oC, when i=1-24 ten days and $t^o_{max,i}$ $+2^oC$, when i=25-36 ten days) the maximal discharge reaches nearly 7000$m^3 sec^{-1}$. if the last situation will happen, it will create conditions for inevitable catastrophe(fig.1,g).

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ESTIMATING THE IMPACT OF CLIMATIC CHANGE ON UTILIZATION OF SURFACE WATER RESOURCES

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ABSTRACT

This paper focuses on the assessment of possible impacts of present and future climatic variability on riverflow characteristics and consequently on water supply from chosen reservoirs in the Czech Republic. Hydrological inputs are represented by hypothetical scenarios constructed on the basis of a statistical-hydrological analysis of instrumentally observed air temperature and riverflow time series. Results of the investigation indicate a risk of possible negative consequences of climatic change on future water reservoir management. Hence new approaches to water reservoir operation in real time are discussed.

BEWERTUNG DER FOLGEN DER KLIMATISCHEN VERÄNDERUNGEN AUF DIE AUSNUTZUNG DER WASSERRESOURCEN

ZUSAMMENFASSUNG

In dem Beitrag werden die Folgen der heutigen und zukünftigen klimatischen Variabilität auf die mit der Wasserversorgung verbundenen Durchflusscharakteristiken einiger Reservoiren in der Tschechischen Republik diskutiert. Die hydrologischen Eingaben für die Auswertung sind mittels hypothetischer Szenarien representiert. Diese wurden auf der Basis einer statistisch-hydrologischen Analyse der historischen Temperatur- und Durchflusszeitreihen zusammengesetzt. Die Ergebnisse machen die möglichen Riziken der negativen Einflüße der klimatischen Veränderungen auf das Wirtschaften mit Wasser sichtbar. Aus diesem Grund werden in dem Beitrag auch die neuen Methoden für die Regelung der Reservoiren in realer Zeit diskutiert.

1. INTRODUCTION

Stationariness of physical processes is often assumed concerning problems of water reservoir planning and operation. Studies are usually based on the assumption of stationariness of hydrological conditions represented by short-term instrumental riverflow series. This assumption makes solution easier, but is it justifiable?

Following the problem from the geological period point of view there are certain clear long-term climatic and hydrological periodical fluctuations. However, taking into account water reservoir lifetime, these periodical fluctuations represent rising or falling parts of the long-term periods in which allowances should be made for water reservoir planning and operation (Fig.1).

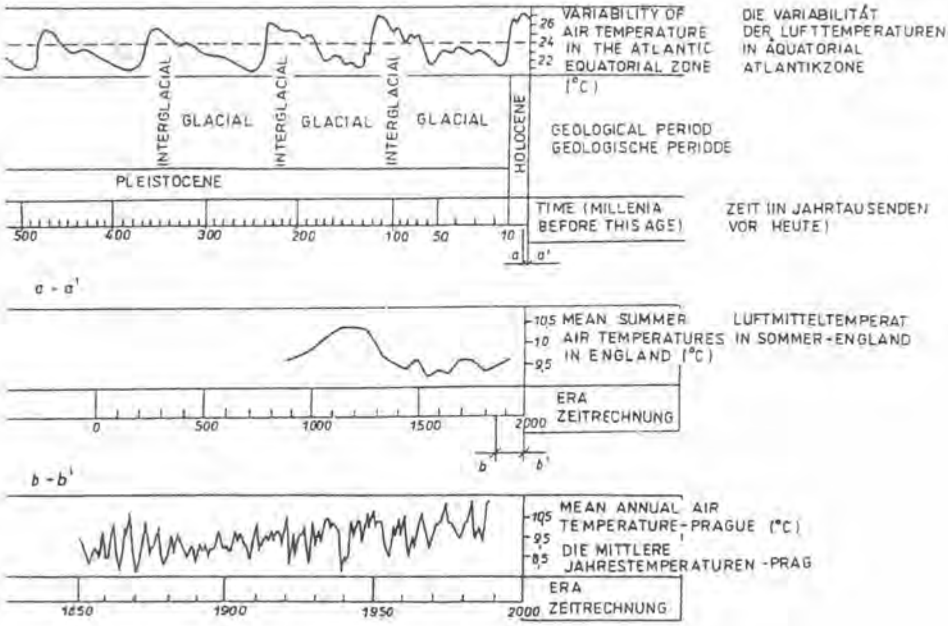

Fig.1 Variability of paleohistorical, historical and instrumental air temperature time series

Abb.1 Die Variabilität der paleohistorischen, historischen und instrumental gemessenen Temperaturzeitreihen

Furthermore, stationariness of hydrological processes can also be discussed from the point of view of an increase in the concentration of greenhouse gases in the atmosphere correlated with an increase in global mean temperature. Changes in global and regional climatic conditions, whether linked to anthropogenic forcing or through natural variability, can lead to a wide range of hydrological impacts.

In the Czech Republic water reservoirs are the main sources of drinking water, and trustworthy hydrological information for their future planning and operation is required. For that reason sensitivity of water reservoirs to changes in hydrological conditions has been evaluated and possibilities for mitigation of negative impacts on water supply have been investigated.

Hydrological inputs were simulated through hypothetical scenarios taking into account both long-term variability of hydrological processes and influence of global warming on riverflow regimes. Impacts of direct human activities in river basins (urbanization, changes in land use, etc.) have not been taken into account.

2. SCENARIOS OF CHANGES IN RIVERFLOW REGIMES

Hypothetical scenarios were constructed for target quasi-stationary hydrological conditions at the beginning of the 21st century due to the absence of a tight-fitting prediction of the development of hydrological conditions. Use was made of statistical-hydrological analysis of historical air temperature and riverflow series. Regarding the aforementioned long-term periodocity of mean annual flows, 70-year historical time series were analysed in 7 Czech and Moravian catchments. Moreover the 140-year flow series in Děčín, on the river Elbe, Czech Republic, was investigated and, in addition historical riverflow series in Orsova on the Danube, Smalininkai on the Neman and Locmanska Kamjanka on the Dnepr were also compared. On the basis of this analysis long-term, more than 100-year periodicity of mean annual flows was hypothesized. Consequently interval estimation of future statistical characteristics of mean annual flow series was carried out following the characteristics of the critical dry period in the middle of the last century. Changes in mean flows represent a decrease of 6 - 16 % in comparison with an instrumentally observed period reflecting so called "stationary" hydrological conditions.

With respect to global warming, estimating the impact on mean annual riverflows is still difficult and is affected by regional conditions. More hopeful results were obtained for the streamflow distribution within a year. In this case correlation between air temperatures and discharges is significant, particularly in winter and spring months [e.g.1,2,3,4,5]. Therefore the problem was investigated on the assumption that the changes in mean annual flows caused by global warming have the same character as long-term variability and only the changes in seasonal distribution of flows were taken into account.

Seasonal timing scenarios have flowed from the analysis of the warm reference period 1943-1952. In this decade the mean air temperature went up sharply by nearly 1°C and the decrease in the mean flow was of 6 - 19 % in comparison with the long-term discharge in the instrumentally observed period. Fig.2 shows 5 types of scenarios of monthly flow distribution and distribution reflecting stationary conditions in 1921-1988.

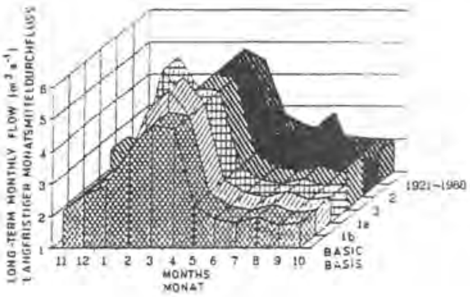

Fig.2 Types of hypothetical scenarios of mean flow distribution within a year

Abb.2 Typen der hypothetischen Szenarien der Verteilung der Monatsmitteldurchflüsse

3. IMPACT OF HYDROLOGICAL CHANGES ON RESERVOIR STORAGE CAPACITY

The sensitivity of the yield-storage relationship to a change in climate was tested. The solution to this problem involves both the influence of long-term variability of flows and the impact of changes in seasonal distribution on direct supply reservoirs. Synthetic 900-year series of mean monthly flows were generated for stationary and quasi-stationary (predicted) hydrological conditions making use of the statistical characteristics of observed historical flow series and historical scenarios. Some of the results are presented in Fig.3 and Tab.1.

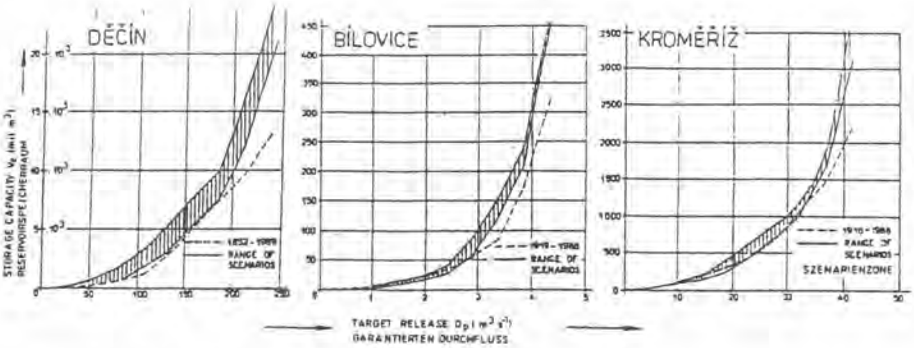

Fig.3 Yield-storage relations
Abb.3 Regimekurven des Reservoires (das Verhältnis zwischen dem garantierten Durchfluss und dem Reservoirspeicherraum)

Fig.3. shows a family of lines relating a target release from the direct supply reservoir and a storage capacity for the instrumentally observed period reflecting stationary conditions and for the predicted hydrological conditions at the beginning of the next century. Three reservoir sites are demonstrated. It is assumed that the reliability of water delivery is 100 % during the analysed period.

In Table 1 percentage differences between reservoir storage capacities in predicted and stationary conditions are mentioned. Particular values of the target release O_p correspond to the level of regulation of mean flow in stationary conditions (from 10 % to 90 %).

Tab.1 Reservoir storage change ΔV_z due to hydrological regime changes relating to target release O_p - in %

Tab.1 Die durch die Veränderung des hydrologischen Regimes verursachte Veränderung des Reservoirspeicherräumes ΔV_z für den garantierten Durchfluss O_p - in %

Děčín		Bílovice		Kroměříž	
O_p $[m^3s^{-1}]$	ΔV_z [%]	O_p $[m^3s^{-1}]$	ΔV_z [%]	O_p $[m^3s^{-1}]$	ΔV_z [%]
26.52	-59 ÷ +894	0.48	0	4.59	+2 ÷ +32
53.03	+36 ÷ +259	0.96	-72 ÷ -53	9.18	+2 ÷ +27
79.55	-1 ÷ 190	1.44	-38 ÷ -20	13.78	-23 ÷ +8
106.06	+58 ÷ +190	1.92	-26 ÷ 0	18.37	-20 ÷ +26
132.58	+13 ÷ +91	2.40	-27 ÷ +18	22.96	-2 ÷ +42
159.09	+5 ÷ +53	2.88	+3 ÷ +60	27.55	-5 ÷ +30
185.61	+1 ÷ +37	3.36	+42 ÷ +81	32.14	-4 ÷ +11
212.12	+24 ÷ +68	3.85	+20 ÷ +41	36.74	+10 ÷ +23
238.64	+52 ÷ +87	4.33	+39 ÷ +49	41.33	+38 ÷ +75

The results clearly vary over a wide range. Differences range, in average, from -40 to +80 %. However a certain pattern has appeared. Even though the results of the investigation of a small number of reservoirs are not representative, most of those reservoirs with an over-year working cycle, i.e. where the target release is more than 50-60 % of long-term mean flow, signal increase in effective storages and negative consequences on water supply under changing hydrological conditions. The impact on reservoirs with a seasonal working cycle is not unambiguous. If the storage capacity of a reservoir benefits from the hydrological changes, then increased target release could cover a rise in water demand or improve the environment downstream from the reservoir. In other cases, there is a question how insufficient supply yields should be covered.

4. WATER RESOURCE SYSTEM OPERATION UNDER CHANGING CLIMATE

To mitigate possible unfavourable consequences of climatic changes several courses of action might be taken, eg.building new water resources, using economic stimuli to reduce demand for water, developing modern technologies of water resource operation in real time. Taking into account existing uncertainties in hydrological predictions the two latter approaches seem to be adequate for Czech conditions.

For this reason, in the framework of this research project, one of the methods of water reservoir operation in real time was tested to reveal its ability to reduce failures in reservoir function caused by changes in hydrological inputs. Although only a limited number of hydrological situation was investigated the results have proved that a method based on the principle of adaptability [6] could be successful in solving water supply problems in the near future. For this reason subsequent investigation should also be focused on other water resource system operation methods to test their capability in the wide range of possible hydrological impacts of climatic change. However a qualified prediction of hydrological inputs should have been made regarding interval estimation of future statistical characteristics of riverflows instead of a search for representative recurrent intervals, which is not reasonable in non-stationary conditions.

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METHODOLOGY OF HYDROLOGICAL COMPUTATIONS AND SUPER-LONG FORECASTS IN CONDITIONS OF CLIMATIC CHANGE AND MAN'S IMPACTS

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ABSTRACT: New methods of hydrological computations are proposed for the conditions of the present climate change and man's impact on watersheds and in river channels. These methods include: selection of dynamic characteristics, mathematical modelling of long-term time series, hydrological computations of heterogeneous time series in case of different information available on hydrological data and hydrological factors, as well as evaluation of the possibility of a super-long-range forecasts. Some a case studies are given.

METHODOLOGEN FÜR DIE HYDROLOGISCHEN BERECHNUNGEN UND SUPER-LANGE VORHERSAGEN FÜR DIE VORAUSSETZUNGEN DER ÄNDERUNGEN DEN ZEITGEMÄSSIGEN KLIMA UND DER EINFLUSS DEN MENSCH

AUFZEICHNUNG: Die neuen Methoden sind für die hydrologischen Berechnungen für die Voraussetzungen der Änderungen den zeitgemässigen Klima und der Einfluss den Mensch auf Abflussgebiet und ins Strombett vorgelegten. Diese Methoden aufnehmen die Wahl der dynamischen Charakteristic, die mathematischen Modellierungen den Zeit-lange Serien, die hydrologischen Berechnungen den verschiedenartig Zeitserien bei Vorhandensein von verschiedanen Information auf hydrologischen Daten und hydrologischen Faktoren, und auch die Bewertung der Möglichkeit der super-lange Vorhersagen. Einigen Beispielen sind angefuhrten.

MAIN FEATURES OF HYDROLOGICAL PROCESSES

A main feature of hydrological computations in modern period is an increase of anthropogenic impact on all generalized parameters using in the computer process and as a result, they become non-stationary. Non-stationarity and non-homogeneity of historical fluctuations are proved in many investigations, even in those, which are based on statistical methods. For example, maximum index of nonhomogeneity for regions of European part of Russia is 50-70% and mean value of index is fluctuating from 15 to 35% for different regions, for Danube basin maximum index is 47%, mean value is 21%.Therefore there is a contradiction between existent methods of runoff description in the form of a distribution functions or generalized parameters, which are transfered from present to future, and changing external conditions (anthropogenic climate change and impact of man's activity factors) as well as demands of a practice for using the dynamic properties of river runoff such as: series and periods of water raising and water decreasing, an extraordinary events, etc.

Another contradiction takes place in modern hydrological computations between conceptions of computations and super-long range forecasts. Methods for hydrological computations are based on the concept of a random autocorrelation sample, while the methods of super-long-range forecasts are based on the deterministic and deterministic-stochastic laws of long-term runoff series dependent on time. At the same time, the hydrological computation is a probabilistic forecast of extreme events appearance in given time interval in the future (return period). Furthermore, hydrological computations and forecasts are based on the same information, therefore they have to use the same model of the time series.

METHODOLOGY

New methodology in hydrology allows to consider a runoff as a dynamic multi-components system. It's based on two main properties of natural processes: cyclicity and compositionality.

1. The cyclicity is a sequence time series of phases of raising and decreasing of water with different periods:

$$Y_i < Y_{i+1} < \ldots < Y_m > Y_{m+1} > \ldots > Y_{m+k} < Y_{m+k+1} < \ldots, \quad (1)$$

where m - period of water raising, k -period of water decreasing, m+k - period of the cycle.

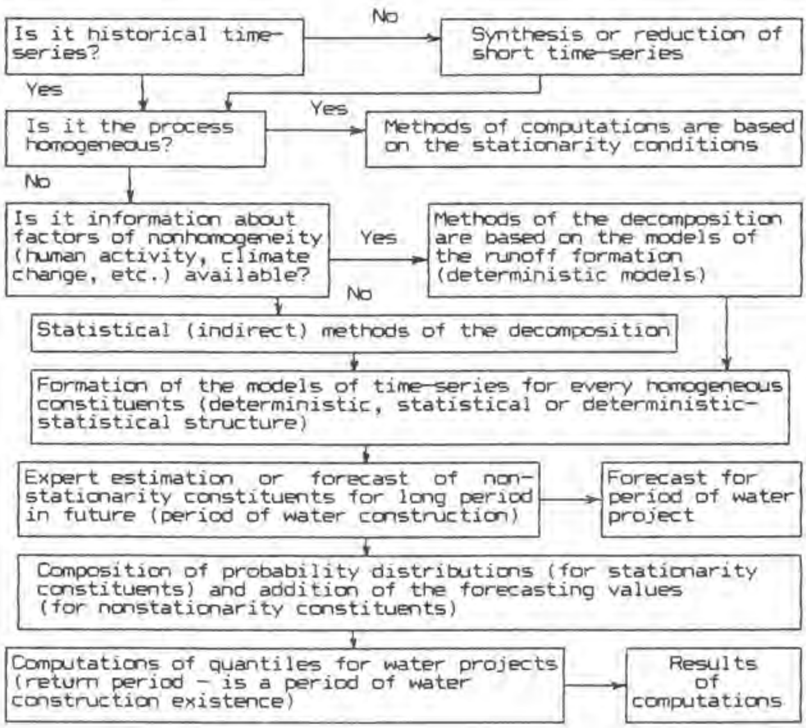
The cyclic nature and repeatability of earthly processes are related with the rotational movement inherent to all objects in the Universe (the Galaxy, the Solar system, the Earth, the atmosphere, etc.). Periodicity (the constancy of cycle periods in time) of the dynamics of space objects is refracted to the cyclicity and rhythmic (non-constancy of cycle periods in time) for hydrometeorological processes on the Earth. Another reason of cyclicity is a property of inertia and entropy of the system, when after an influence of external factor, the system speeds in former state with minimum of internal energy.

2. The second basic property of complex natural processes, and runoff too, is a composite nature of their structure, that is conditioned by influence of different scales factors, forming the runoff process as a whole.

In modern conditions considered historical time series of runoff may consist of three components at least, such as: natural component, the component that connected with direct man's activity and the component connected with climate change.

SCHEME OF RUNOFF COMPUTATIONS-FORECASTS AND METHODS

Offering scheme of hydrological computations and forecasts for conditions of the climate change and human activity is shown on the figure:



The particular cycle of the methods are used on every stage of the application. So there are very many methods, we'll give a short setting and main their ideas only. The following methods are applied in conformity with stages of the algorithm.

1. For filling of data absence and for reduction of time series are applied methods, based on the methodology of space relationship for hydrological historical data as the meteorological processes, generalised for long period, are homogeneous over large area. Methods of data reconstruction are based on the regressional relationships with more longer historical time series at analogue-sites (long-term synchronous), based on the relationships with analogues for particular years (yearly synchronous) and based on methods of synthesis (models of runoff formation, methods of the regional analysis, etc) if data are absent at all.

2. Complex of the statistical methods and methods of runoff genesis are applied depending on the informational availability. The methods of runoff genesis have more priority, than statistical ones. Statistical methods include in themselfs a different mathematical criteria, corrected for the peculiarities of hydrological information and methods of complex process estimation are based on signal/noise ratio, value of the trend-component in time series and on verification of the justifiability of generalized parameters.In fact all methods give a qualitative conclusion only, but we do not know how many different-scale quasi-homogeneous components represent the time series.

3. Decomposition of the complex process, if we have an information about factors of non-homogeneity (climate change, human activity, etc.) over the historical period, is based on the building of the runoff formation models of balance structure and their coefficients are determined by LSM (least square method).

4. There are many situations, as a rule, when information about factors of non-homogeneity is absent for historical period, but is known we have a compositional process and have to do a decompositon. The existing decomposition methods (spectral and correlation analysis, different methods of smothing, etc) have a great restrictions to the kind of the cycles function and their parameters. Hence, there have been developed a new decomposition methods such as: a truncation method and method of the poli-linear decomposition, which assume a priori only the assembly of the composition structure according to superposition principle. It means, that any interaction of two adjacent scales is reflected in the coefficients of the additive structure. The algorithm of the truncation method is given in [1] and of poli-linear decomposition in other our paper in those proceedings.

5. There are two ways to make a model of a process or an event. In the first case the model structure is specified a priori from theoretical assumptions and coefficients are determined from experimental data. Despite of the merits available, this approach may lead to great errors if the specified model structure does not correspond to a reality. The other approach, which we use, is based on the methodology of the theory of an experiment and it is based on the fact that both the model structure and model coefficients are determined only from the properties of the data observed. The model is made according to the principle of a successive sophistication at the transfer from simple one-factor dependences under homogeneous conditions to multi-factor and composite structures. Finally, the empirical analysis results in the determined laws of informative factors in time and, depending on the obtained results, a deterministic part of the model is formed (if factors depend on time) or statistic one (if no dependences on time are established). During the final stage, all the parts of the model with the account of informative indices interaction, are combined into one model.

6. The prediction is possible if: there is a dependens of cycle characteristics upon time or the process is compositional (with different scales). If even the first requirement is not met, mean trends may be applied to predict large-scale components of the compositional process, which also makes the general uncertainty lower. The main postulate of this approach is: a large-scale process (or processes) originating today, cannot be over tomorrow. The main criterion of possibility and efficiency of forecasting is the correct verification of forecasts results.

7. Probability or return period (pt) in hydrological computations is interpreted as period of water project. For traditional way, hydrological computations in changing natural conditions are based on the following equation:

$$Ypt = \underset{i=1}{\overset{k}{f}} (E(Pi)) + Ycl / t=pt + Yhu /t=tp , \qquad (2)$$

where f(E(Pi)) - a composition of distributions of k stoshastic components;

Ycl - forecast of runoff component, connected with climate change on period pt-years in future;

Yhu - forecast of runoff component, connected with human activaty on period pt-years in future;

Ypt - computed hydrological value for pt-return period.

CASE STUDIES

Historical time series of annual runoff have been considered for 25 sites in Danube basin, including 21 sites on Danube river and 4 sites on its main tributaries: Tisza, Sava and Morava for 1941-1991 and for one long time series from 1840 for site Orsova. The truncation method was used to separate a compositional processes of annual runoff into homogeneous components for every site with error of process is 5% and two simple homogeneous components were determined for every case. Analysis of characteristics of the cycles, such as period of cycle (T), length of phase of raise (Tup) and fall (Td), mean speed of raise (Vup) and fall (Vd), volume of runoff of the cycle (W) and amplitude of cycle (A) was realized and results are shown in table for mean indexes of first (small) scale process:

Site	Period (years)	T (years)			Tup (years)			Td(years)			Number of cycles
		mean	max	min	mean	max	min	mean	max	min	
Regensburg	61	4	9	2	2	5	1	2	4	1	13
Hofkirchen	48	3	5	2	1	3	1	2	4	1	11
Linz	48	4	8	2	1	5	1	2	4	1	10
Stein-Krems	48	4	8	3	1	5	1	2	5	1	9
Wien	48	4	8	3	1	5	1	2	5	1	9
Bratislava	48	3	6	2	1	3	1	2	5	1	11
Nagymaros	48	3	6	2	1	4	1	2	4	1	12
Orsova	48	3	7	2	1	4	1	1	3	1	12
Novo Selo	48	3	7	2	1	4	1	1	3	1	12
Lom	48	3	7	2	1	4	1	1	3	1	12
Svislov	48	3	7	2	1	4	1	1	3	1	12
Oltenita	48	3	7	2	1	4	1	1	3	1	13
Silistra	48	3	7	2	1	4	1	1	3	1	12
Tulcea	48	3	7	2	1	4	1	1	3	1	12
Scharding	48	3	6	2	1	3	1	1	5	1	11
Szeged	48	3	8	2	1	4	1	2	4	1	12
Sremska M.	47	3	8	2	1	5	1	1	3	1	12
Orsova	149	3	7	2	1	4	1	1	4	1	40

The results of super-long forecasting of indexes of the last cycle when the last year before forecast (Tbeg): 1986 and 1988 are following:

Tbeg	T	sign	Tup	sign	Td	sign	A	sign	Vup	sign	Vd	sign	W	sign
1986	4-6	+	1-2	0 +	2-4	+ 0	500-1000	+	500-1200	+	200-400	+	800-2000	+
1988	3-5	+	1	0	2-4	+	700-1000	+	780	+	200-400	+	1500-2000	+
Real	4	+	1	0	3	+	800	+	780	+	287	+	1740	+

The forecast on 1987 when Tbeg=1986 is R=3050-2250 m3/s with errors: +8,2% and -20,2%.

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A RAINFALL RUNOFF MODEL AS A TOOL TO INVESTIGATE THE IMPACT OF CLIMATE CHANGE

EIN NIEDERSCHLAGE-ABFLUSSMODELL ALS WERKZEUG ZUR UNTERSUCHUNG DER AUSWIRKUNGEN EINER KLIMAÄNDERUNG

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Abstract A complex model with modular structure used in operational forecasting was utilized in the simulation of possible climate change scenarios. The core of the model is the GAPI rainfall-runoff model extended with a snowmelt module. In the first attempt flow conditions of River Danube at Nagymaros station were analyzed in connection with the changing of daily temperatures in the drainage basin, with a special emphasis on snowmelt induced runoff. Three scenarios for the daily temperatures had been investigated: observed, $+ 1\ ^{\circ}C$ and $+ 3\ ^{\circ}C$ temperature rise. The second attempt was carried out for Rába river at Szentgotthárd, where observed temperature and precipitation series were replaced by an analog representing warmer and drier climate. The analysis of results had shown that the rise of temperature is followed by increasing peak discharge for the first flood wave in the spring - summer period, while consecutive flood waves pass on the river with decreasing peak discharges.

Kurzfassung Ein bei der operativen Vorhersage genutztes komplexes Modell mit Modul-Struktur wurde für die Simulation möglicher Klimaanderungs-Szenarios verwendet. Den Kern des Modells bildet das mit einem Schneeschmelze-Modul ergänzte Niederschlags-Abflußmodell GAPI. Im ersten Schritt wurden die Abflußverhältnisse der Donau am Pegel Nagymaros im Zusammenhang mit den veränderten Tagestemperaturen des Einzugsgebietes, unter besonderer Berücksichtigung des durch die Schneeschmelze ausgelösten Abfusses, unter Annahme einer Temperaturerhöhung um jeweils $0\ ^{\circ}C$, $1\ ^{\circ}C$, $3\ ^{\circ}C$, analysiert. Der zweite Schritt wurde für den Raab-Pegel Szentgotthárd durchgeführt, wobei die beobachteten Temperatur- und Niederschlagsreihen mit analogen Reihen ersetzt wurden, die für ein wärmeres und trockneres Klima kennzeichnend wären. Eine Analyse der Ergebnisse ergab, daß während bei der ersten Hochwasserwelle im Früjahr oder Sommer eine Verschärfung des Spitzenabflusses eintritt, die späteren Hochwasserwellen mit abnehmenden Spitzenwerten abfließen würden.

1. INTRODUCTION

Most of the attempts to investigate the impact of climate variation on flow regime are based on statistical relationships between meteorological and hydrological elements. A good example for the territory of Hungary was given by Nováky (1989). As the interest towards the analyzis of consequences of changing climat had grown, the usefulness of more complex catchment models soon became evident (Lettenmeier et al., 1989). The present work follows that second track and utilizes a complex model with modular structure used in operational forecasting at the National Hydrological Forecasting Service (NHFS), Hydrological Institute, VITUKI. Beside the evident convenience of readily available software and easy access to operational data base the choice of the model was proved by a number of intercomparison studies (WMO, 1991; Harkányi & Bálint, 1985). Two types of approaches were made to test the applicability of the given modelling system for the investigation of hydrological consequences of climate variation. The first attempt was carried out in the form of a sensitivity study, where the observed temperature series, input for the model, were replaced by series, where each value had been raised by 1 and 3 centigrade, consequently. Results of these artificial temperature "scenarios" with observed precipitation series as they modified model output, i.e. flow of River Danube at Nagymaros station. The second attempt was carried out for the Upper-Rába/Raab river drainage basin upstream of Szentgotthárd station. The observed temperature and precipitation series were replaced by an analog, observations at Baja meteorological station, representing warmer and drier conditions, close to the estimated $2CO_2$ climate (Mika, 1990).

2. DESCRIPTION OF THE APPLIED MODEL

A computer based operational runoff forecasting system at NHFS was first introduced in the early eighties (Szöllősi-Nagy et al.,1986). The complexity of the system was limited by the capacity of the available computers. Recently the the previous model has been extended by a snowmelt module (Gauzer, 1990) and the complexity of the system has been raised.

The system has a modular structure to describe the different hydrological processes of the catchment. The general set-up of the system used for climate change impact study is shown in Fig. 1. The operational forecasting version includes a module, to utilize quantitative precipitation forecast issued by the Hungarian Meteorological Service and a final stochastic corrector module which are not reported here.

Each module obviously is somehow physically based. Inherent uncertainties associated with any model are partly handled in the forecasting procedure. These uncertainties originate from:

- limitations in selecting the numbers and types of modules;
- imperfect model structure;
- observational errors;
- approximation of distributed variables by lumped variables;
- inefficiency and bias in parameter estimations;
- sampling variations, etc.

In simulation mode there is no way to correct them, however part of the errors are compensated on the long run with averiging.

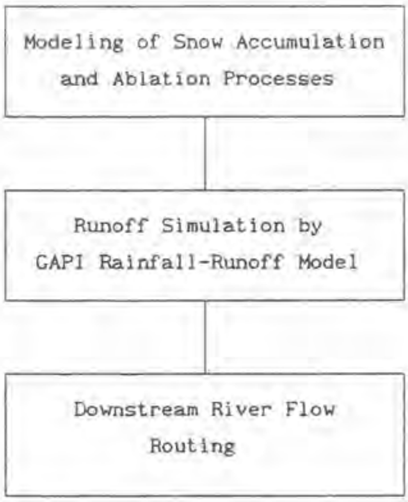

Fig. 1. Modular set up of the modelling system

2.1. THE SNOWMELT PART OF THE MODEL

The first module of the system optionally consists a degree-day type and an extended, more complex swowmelt model. In the cold period of the year the values of effective precipitation - appearing on the ground surface in the form of liquid water - are calculated by the given module.(Gauzer, 1991)

$$M = (C_o - C_p)(T - T_o) \tag{1}$$

where:

- M - snowmelt [mm]
- C_o - degree-day melt factor [mm/°C]
- C_p - correction factor for taking into account the effect of precipitation falling during the melt
- T - air temperature [°C]
- T_o - threshold value of the air temperature [°C]

If additional data types are available (cloudiness, wind speed, dew-point, etc.) the snowmelt process is calculated by computing of energy-budget of the snowcover.

$$\Delta E = E_{sw} + E_{lw} + E_l + E_s + E_p + E_g \tag{2}$$

where:

- Δe – changing of the energy of the snowcover
- E_{sw} – absorbed short wave radiation
- E_{lw} – net long wave radiation
- E_l – latent energy flux (condensation or evaporation)
- E_s – sensible heat flux
- E_p – contribution of energy from precipitation
- E_g – energy flux from the ground

– factor for correction of observed solid precipitation values;

2.2. THE "GAPI" RAINFALL RUNOFF MODEL

The second module of the developed forecasting system is a rainfall-runoff model "GAPI" (Bartha & Harkányi, 1985). Its name indicates the type of moisture accounting procedure used in the model, which is an implicit one and based upon the Antecedent Precipitation Index (API) The runoff conditions are related in the GAPI model to the exceedance probability of the current API which distribution is assumed to be Gamma. The GAPI model itself consists of two modules:

Module 1. estimates the rainfall losses and separates surface, subsurface and basic runoff

Module 2. performs the routing of surface, subsurface and basic flow, while taking into account the effect of surface and underground storage capacity

For a given period part of rainfall forming surface and subsurface runoff can be expressed through volumetric runoff coefficient

$$\alpha = \frac{\sum_{i=1+t}^{i=T+t} Q_i - MQ_o}{\sum_{i=1}^{i=T} P_i}$$

where:

- α – volumetric runoff coefficient
- Q_o – baseflow rate
- t – time lag of runoff to rainfall
- T – period of rainfall and runoff integration
- Q – discharge at the downstream river station
- P – precipitation

For the sake of simplicity in operational models baseflow rate $[Q_o]$ is taken as unchanged and estimated using data of lowflow season, while in simulation mode a simple relationship between annual precipitation and annual low flow is applied. The rate of effective rainfall largely depends on seasonal changes of catchment humidity conditions, i.e. indirectly on characteristics of antecedent effective rainfall. The GAPI model applies an exponential form of antecedent precipitation index such as:

$$API_i = \sum_{t=0}^{t=N} P_{i-t} e^{-ta}$$

where N is the length of API window i.e. the period within API reaches a value 0.05 or less.

The API is calculated on the basis of effective rainfall value. Using the results of some earlier studies instead of seeking a direct relationship between the volume of surface runoff and API, the ratio of surface runoff is expressed through the probability of API. The distribution of API of different length was investigated on more than ten river basins and the results showed that the following form served with the most suitable expression for the density function

$$f_k(API) = \frac{\lambda^k API^{k-1}}{\Gamma(k)} e^{-\lambda API}$$

Assuming that there is dependence of effective catchment area on the probability of API, the ratio of surface runoff can be estimated if the probability of API is known.

$$A_{f,i} = f[P(API_i)]$$

and the interflow ratio

$$A_{a,i} = 1-A_{f,i}$$

That is Modul 1. separates the total volume of runoff into three parts

Surface flow

$$u_{1,t} = u_t A_{f,t} \alpha_t$$

Interflow

$$u_{2,t} = u_t (1-A_{f,t}) \alpha_t$$

Baseflow

$$u_{3,t} = Q_o = \text{const.} = Q_{min}.$$

After the determination of surface, subsurface and baseflow volumes for each time sequence Δt the routing of these volumes follows as it effected by the surface and subsurface storage capacities. This operation is performed by Modul 2. which consists of two parallel cascades. The first cascade with parameters (n_1, K_1) routes surface flow and the second with parameters (n_2, K_2) routes subsurface (inter) flow. The baseflow is kept constant. The routing procedure is similar to the one is used in channel routing and in details described in the next chapter. Model GAPI produces the resulting flow (discharge rate for downstream station) for each discrete time step as the sum of the routed values of surface, subsurface and base flow.

2.3. ROUTING MODULE (DLCM)

The developed models for on-line (Real-time) operational hydrological forecasting models are usually based upon some simplifications of the Saint-Venant equations was given by Kalinyin and Milyukov (1958) who introduced the notion of "characteristics reach". The "characteristics reach" technique replaces the equation of moments by a linear relationship between channel storage and outflow from the "characteristics reach". The solution is formally identical with that of the Nash-cascade (1957) used for rainfall/runoff modeling. Both continuous models are linear lumped time-invariant representations and can uniquely be described by the state and output equations.

The continuous model cannot be directly applied in practice since measurement data are obtained at discrete time epochs and, data processing is done on digital computers, therefore, a discrete model is required indeed. However, the discretization of a continuous model is not straight forward. A discretization scheme should be adequate in the sense that it should -be discretely coincident (with the continuous model), -preserve the continuity and transitivity. This is solved in the Discrete Linear Cascade Model (DLCM) developed by Szöllősi-Nagy (1982) utilizing an approach similar to the one reported by Szolgay (1984), Szolgay & Minarik (1990).

3. SIMULATION THE IMPACT OF CHANGING INPUT

The actual simulation tackled the system of river Danube and its nine tributaries all together including 28 cross-sections. Observations of discharge at 12-hour time steps have been used. To estimate snowmelt and rainfall-runoff processes data from 32 meteorological stations have been used, namely observations of precipitation and air temperature at 12-hour time steps including daily minima and maxima of air temperatures. As a first step time series of active precipitation and soil frost are estimated for each meteorological observation site. Consequently areal means of active precipitation and soil frost are calculated for each of the drainage basins belonging to individual cross-sections, serving as input for the GAPI model. Runoff time series produced by GAPI are routed with the use of DLCM. The above procedure has been carried out with the set of optimized parameters used in the operational forecasting practice.

Three scenarios for the daily temperatures have been analyzed:

(1) Temperatures are distributed according to the observed values;

(2) Temperatures are 1 °C higher than the observed ones for the stated period;

(3) Temperatures are 3 °C higher than the observed ones for the stated period.

The second attempt was carried out for the Upper-Rába/Raab river drainage basin upstream of Szentgotthárd station. The observed temperature and precipitation series were replaced by an analog, observations at Baja meteorological station, representing warmer and drier conditions, close to the estimated $2CO_2$ climate.

The simulation of runoff was carried out for the above scenarios, and the results received have been analyzed. The following questions have been tackled:

- seasonal and monthly distribution of runoff;
- changes in the winter low-flow period;
- changes in the peak discharges of floods during the winter;
- changes in the peak discharges of the spring snowmelt induced floods.

4. CONCLUSIONS

Flow conditions of River Danube at Nagymaros, and Rába/Raab at Szentgotthárd station were analyzed in connection with the changing distribution of temperatures in the drainage basin with a special emphasis on snowmelt induced runoff.

The following experiences have been gained: Since maximum discharges generally appear during spring, the effect of rise of temperatures remained insignificant. The higher snowmelt induced winter flood wave occurs, the larger increase in the ratio of the volume of winter runoff to the annual volume can be expected. If no winter flood wave passes on the river, the changes remain unsignificant (i.e. under 1-2 %).

Changes of a winter flood wave depend on the role of snowmelt. If a winter flood wave induced by liquid precipitation passes on the river increase of peak discharge remains unsignificant (see December flood wave in the wet period). In case of mostly snowmelt induced winter flood waves peak discharges rise significantly (15-30 %, see December flood wave in the average period). (**Fig. 2**)

In case of several spring and early summer snowmelt induced flood waves the rise of temperature results increasing peak discharge for the first flood wave, while consecutive flood waves in such a period pass on the river with decreasing peak discharges (see flood waves in the dry and average period). Peak discharge of a single major snowmelt induced flood wave shows increasing tendency (see spring flood in the wet period).

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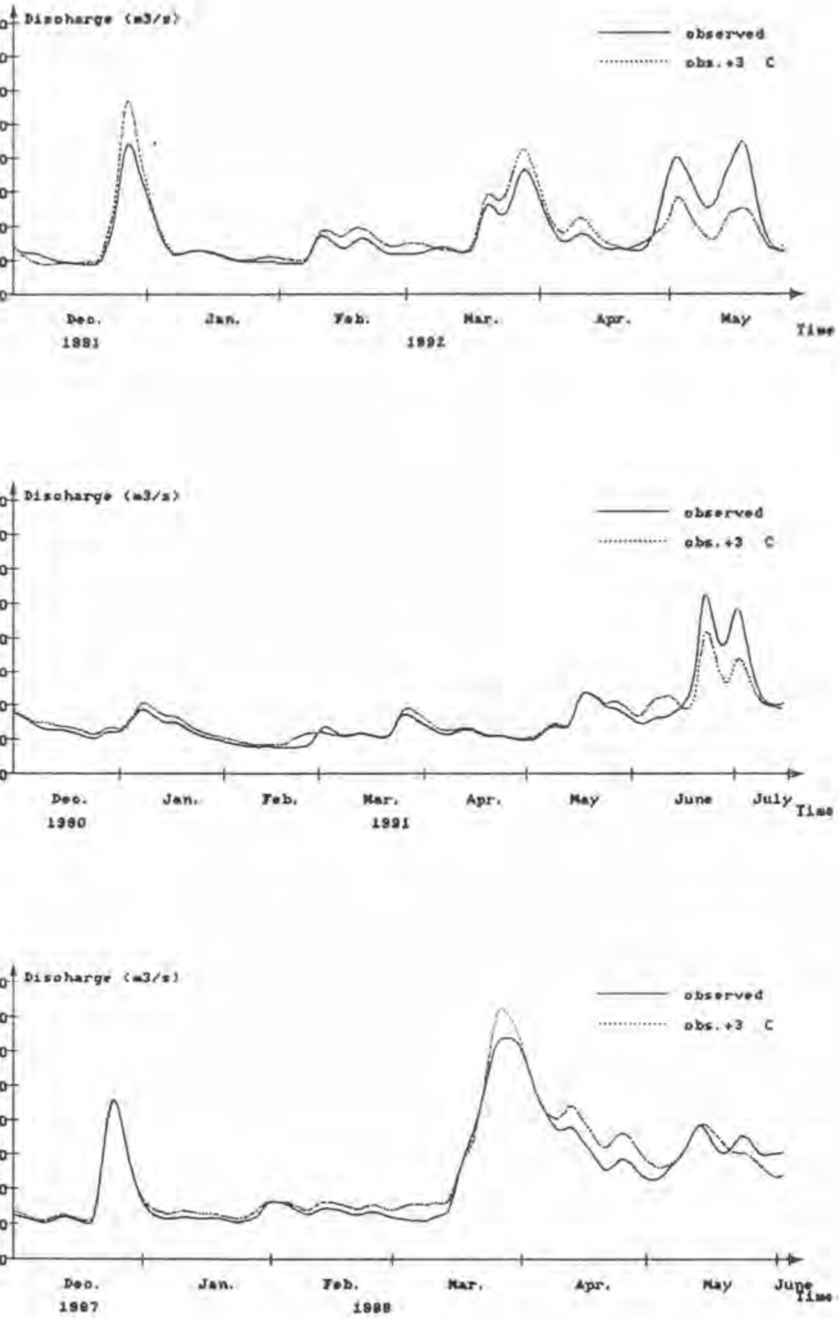

Fig. 2 SIMULATED RUNOFF FOR DANUBE - NAGYMAROS
Observed and 3 °C higher air temperatures

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APPLICATIONS OF EQUATIONS OF WATER BALANCE STRUCTURE FOR ASSESSMENT OF CLIMATIC CHANGES AND MAN'S IMPACTS

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ABSTRACT:Two trends in research are suggested for estimating the influence of climate change and man's impact on runoff. These trends are: multi-purpose analysis of runoff and of runoff-producing factors in time and runoff formation modelling with a balance structure. New methods for selection of climate component for hydrometeorological series and fields have been developed. A number of case-studies on the analysis of long-term series of hydrometeorological characteristics of annual and intra-annual discreteness are given for the Danube basin.

DIE ANWENDUNG DER GLEICHUNGEN DER WASSERBILANZSTRUKTUR FUR BEWERTUNG DER KLIMATISCHE ANDERUNGEN UND DES EINFLUSSES DER WIRTSCHAFTLICHE AKTIVITAT

AUFZEICHNUNG: Die zwei Richtungen sind fur Bewertung des Einflusses der klimatische Anderungen und der wirtschaftliche Aktivitat auf den Abfluss vorgelegt: die komplexmassig Analyse des Abfluss und der Faktoren die den Abfluss hervorrufen in Zeit und Modellierungen des Abfluss mit der Bilanzstruktur. Die neue Methoden sind fur Aussonderung der klimatische Komponente fur hydrometeorogischen Reihen und Feldes ergearbeiten. Es gibt eine Analyse den vieljahrigen Reihen der hydrometeorologischen Charakteriken der jahrliche und intra-jahrliche Diskretisierung fur des Donau-Abflussgebiet.

BACKGROUND

It has been accepted that climate is subject to changes, therefore, those climate characteristics which have been observed during the recent 100-200 years should be studied and explained. The review made on the state-of-art of this problem and on interrelations in the hydroclimatic system shows that long-range variations in the climate may be explained both by natural and anthropogenic reasons. Since climate models are far from being perfect, the results of estimating probable changes in runoff may be variable and may differ by an order. In majority of studies it is noted that the most realistic changes in runoff in future should not exceed 20-30%. The problem of assessment of man's impact is more difficult so the numerical information about factors is absent at all for long-term period. In those conditions the principal consideration should be given of empirical models with more simple structure and data analysis, particularly, joint analysis of runoff and its factors.

THEORY

Two main ways may be used for assessment of climatic changes and man's impact when the empirical information is widely adopted:

- analysis of long-term series of runoff and its factors to find the regular properties during the time in every component of every hydrometeorological characteristics;
- formation of the models to connect as well hydrometeorological characteristics each to other themselves, as separated quasi-homogeneous components of the same scale for different characteristics.

Specifical feature of hydrometeorological time series is that they are a composition of the processes (components) of different scales. The way of analysis of every component and time series modeling is based on the decomposition of complex process into simple and homogeneous constituents. The existed methods require many a priori information of the model structure, which is usually unknown. Therefore new decomposition methods have been developed, such as: truncation method and method of poli-linear decomposition. The first of them is presented in [1].Method of poli-linear decomposition allows to separate complex fields of hydrometeorological characteristics and its main idea is - a factoral decomposition. The basis realization in this method is obtained as a mean field over the historical period. The common model of hydrometeorological characteristics Y will be:

$$Y(X1,X2,X3,X4)=C0(X4)+C1(X4)*Yp(X1,X2,X3)+E(X1,X2,X3,X4) \quad (1)$$

where X1,X2 - geographical co-ordinates, X3 - number of the month, X4 - number of the year, C0,C1 - coefficients are obtained by LSM.

Expression (1) for particular year could be rewritten in form of exceptions from means values to eliminate an influence of areal and annual gradients:

$$Y-Yp = (Yc-Ypc) + By*(Yp-Ypc) + Ey, \quad (2)$$

where Y - field of the hydrometeorological characteristic over the area in j year, Yp -the middle field of hydrometeorological characteristic for historical period, Yc -the mean value of hydrometeorological characteristic over the area in j year,Ypc -mean value of hydrometeorological characteristic over the area and for historical period, By=C1-1, A=Yc-Ypc.

Offered structure of the model includes three components. The first component defines the variability of mean areal magnitude for long-term period, the second component is bound up with mean spatial nonhomogeneity of hydrometeorological field and the third component reflects the fluctuations of individual peculiarities.

Established regularities of informational indices over the time may be used for forecasting. At the same time, the determination of the intercommunication between hydrometeorological characteristics is the second important problem to estimate of quantitative impact on runoff and to increase the reliability of established laws in time. The more simple relationship between runoff and runoff-producing factors is expressed by the water-balance equation.However, the balance equation is a particular case of regression equation when all its factors are took into account and they have the same units of measurements. In this case, the coefficients of equation are equal 1. There are many real situations, as has been obtained in [2,3], when regression equation is more efficient for determination of coefficients by least square method (LSM), for example. In case of regression equation we can use the factors with different units of measurement, eliminate the systematic errors and determine the minimum errors of balance equation.

The application of proposed methodology and methods are given in following case-studies.

ANALYSIS OF LONG-TERM VARIATIONS FOR ANNUAL DATA.

Long-term series have been considered for annual runoff along Danube river and its main tributaries,for total annual precipitation in the centre of Danube basin and for mean annual temperature over the whole basin. The truncation method was used for decomposition and long-time analysis of water balance components. As it has been determined, all hydrometeorological characteristics consist of two different scale constituents. Mean period of cycles of the least-scale component is 3 years with variations from 2 to 8 years or runoff, 3 years with variations from 2 to 6 years for pre pitation and 3-4 years with variations from 2 to 11 for long-term series of temperature. Period of cycles for constituent of next scale varies from 8 to 30 years and mean value is equal 15 years.

Interestingly to note that new truncation method can be used only for such separation when periods of two neighbouring scales are crossed, while others statistical method of decomposition require a constant period of cycles. Third secular constituent has weak negative trend for temperature in last time, which is observed in south-east part of the basin, weak positive trend in precipitation from the beginning of 60th and long-term runoff rise from the middle of 19th century. Annual runoff has a sharp fall from the middle of 70th at the delta of the Danube and this result connects with man's activity. Some regular properties were determined for amplitudes of cycles of least-scale constituent for all hydrometeorological characteristics. The amplitudes have a cyclic laws with period of fluctuations 15-20 years. Number of cycles during observation period have trend of rise for runoff from hight sites to the Black sea.

Analysis of differences of runoff at two neighbouring sites along Danube, as errors of channels balance equation, was executed and is shown a complexity of man's influence. Therefore, joint analysis shown the conjugate properties for all water balance component for long-term period.

ANALYSIS OF LONG-TERM VARIATIONS FOR INTRA-ANNUAL DATA.

Analysis of intra-annual properties of hydrometeorological characteristics has a great importance for practice and for understanding of dynamics of climatic changes. Five runoff sites, seven temperature stations and one precipitation poit with monthly time series have been chosen for this analysis by truncation method.In the capacity of intra-annual indexes were given such as: an annual range (Ra) for all characteristics, a number of floods or fluctuations in every year (Nf), type of the season when the highest flood takes plase (W -winter, S - spring, A - autumn, Sm -summer), the duration of flood season in months (Tr). The results of analysis for runoff sites are following:

T(Ra) in year		Tr		Nf		Season	
mean	var.	mean	var.	mean	var.	mean	var.
3	2-5	5.1	2-8	2.1	1-4	S	W-A

Two scale processes are found in the time-series of annual range of runoff. Mean period for least-scale component is 3 years (2-5) and for second-scale -is 11 years (8-14). As for annual data, the cyclic laws were obtained for annual range with periods of fluctuations in 15-20 years.Number of floods per year have a cycles with periods 2-3 years and cycles of amplitudes for them have period from 12 to 18 years. Mean number of fluctuations per year for precipitation is 3.2 with small variations from 2 to 4 and they have a cyclic structure in time.The season of maximum is autumn, as usually. The amplitude of annual variations for temperature have a cyclic law in time too, but not homogeneous over Danube basin. The regular properties of cycles of annual ranges are more stable in northern part of the basin, then in southern one.Periods of Ra for first (small) scale process is 3 (2-7) years, for second-scale Ra=14 (10-15) if we look at northern part and Ra=4-5 (2-13) for 1st scale and Ra=22 for 2nd scale process in another part. Such situation connects with different global synoptic processes, whose come into collision over Danube basin.

ANALYSIS OF FIELDS OF HYDROMETEOROLOGICAL DATA

Historical time series of monthly hydrometeorological characteristics have been used for decomposition by polilinear method. Parameters Ar, Br, Ap, Bp, At and Bt for runoff, precipitation and temperature, as have been established, have some cyclic trends in amplitudes with periods about 15 years. Models of intercommunication between coefficients of separation for different characteristics have been built on the base of following common equation:

$$F\ (Ar,Br,Sr,Ap,Bp,Sp,At,Bt,St) = 0 \qquad (3)$$

and for particular case,for example Ar:

$$Ar = g\ (Br,Sr,Ap,Bp,Sp,At,Bt,St) \qquad (4)$$

The results of regression modelling are following:

```
Ar= 8.49Br-2.91Sr*Bt+2.76St-0.70Bp*At+0.22Br*Ap-4.06    ( 5 )
    (73.0)  (13.7)  (5.0)     (4.3)     (2.4)  R=0.93
Ap= 14.37Ar-5.25Bp*St+0.26Sp*St-9.02St*Ar-8.60          ( 6 )
    (43.6)  (32.7)     (15.0)     (8.7)         R=0.84
At= -0.0039Ar*Sp-21.63Bt*Br+0.32Bt*Ap-0.074             ( 7 )
       (34.1)     (33.7)     (32.2)             R=0.61
Br= 0.080Ar+0.72Bt*Sr+0.0076Bp*Ap-1.974Bt+0.036         ( 8 )
    (76.9)  (12.1)     (7.7)     (3.3)          R=0.90
Bp= 0.046Sp+0.17Ap*Br-0.003Ap*Sp+0.046Ar*Sr-1.282       ( 9 )
    (30.8)   (27.4)    (22.6)     (19.2)        R=0.78
Bt= -0.39At*Br+0.005At*Ap-0.001Bp*Sp+0.13St-0.002Ap-0.2 (10)
      (35.5)     (24.6)     (15.1)  (13.1)  (11.7)
                                                R=0.67
Sr= 0.008Ar*Sp+32.95Br*Bt+0.0014Ap*Sp+3.78             ( 11 )
      (56.9)     (24.1)      (19.0)             R=0.64
Sp= -2.72Ar*At-0.15Ap*Ar-24.77Ar*Bt-3.05At*St+24.0     ( 12 )
      (30.9)     (24.3)     (23.7)    (21.1)    R=0.64,
```

where: R - correlation coefficient, (...) under equation - explained part of variance, in %.

Climatic component in those equations is expressed by coefficients of separation B_j and A_j and joint effects, which expressed by multiplication of coefficients, take place widely.

EQUATIONS OF WATER BALANCE STRUCTURE

Application of regression equation of water balance structure is shown for modelling in [4,5] and for assesment of climatic changes in [6]. In this research the equation of runoff formation has been built for one watershed: Tisza - Szeged. It was obtained the following equation for data of annual discreteness:

$$R = 1.756P - 125.1T + 1664 + E \quad \text{with } R=0.79, \qquad (13)$$

where explained part of variance for P is equal 90.7%, for T -9.3% and E -errors of equation which characterize all other factors and man's impact too. The peculiarity of the model that annual runoff has nonhomogeneous conditions of formation during an year and consists of some seasonal components, which connect with spring, summer-autumn and winter floods. In this case common structure of model is following:

$$R = \sum(F_j\ (P_j,\ T_j,\ P_{j-1}) + E_j), \qquad (14)$$

where P_j - precipitation of jth flood, P_{j-1} - index of soil moisture before jth flood, T_j - index of evaporation.

Equations of such structure have R=0.84-0.88, more than for annual discreteness.Analysis of balance errors (E) shows that they have cyclic trend in amplitudes and it's explained one of the case of man's activity: long-term dam's regulation. Equations (12), (13) have been used for assessment of climatic changes upon given scenarios for the future.

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XVII. KONFERENZ DER DONAULÄNDER
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HYDROLOGICAL EFFECT EVALUATION UNDER CLIMATIC AND ANTHROPOGENIC IMPACT

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Abstract: The paper deals with the water balance component modifications induced by the climatic and anthropic impact.
The considered components are: the input rainfall affected by a long term trend, the one accepted by the WMO, and the infiltration parameters under the assumption of a corn or wheat cover at the level of the entire river basin.
For the rainfall sequence over a 18 year period, the second order variability is considered, by means of relationships between different stochastic variables describing an intermittent process, The most significant one is given for the relation between the event mean and its standard deviation, characterized by a correlation coefficient of 0,85.
For the infiltration process, its parameter transformation is achieved in connection with the obtained results in the experimental field. Thus, the agricultural land use introduces a long period during the first half (corn), or of the second one (wheat) in a year, without vegetal cover, that is with lower infiltration rates.
The hydrological effects are estimated by means of the HIDROZ rainfall-runoff model of the daily water balance.
The resulting scenarios lead to the conclusion of a higher arid regime in both cases of the mentioned impacts.

AUSWERTUNG DER UNTER KLIMATISCHEM UND ANTHROPISCHEM IMPAKT STETTFINDENDEN HYDROLOGISCHEN WIRKUNGEN

Kurzfassung: Der Beitrag beschäftigt sich mit den durch klimatischen und anthropischen Impakt eingeleiteten Anderungen von Komponenten des Wasserhaushalts.
Die betrachteten Komponenten sind der durch eine langzeitige, von der DMM angenommene Tendenz beeinträdhtigte Niederschlag und die Infiltrationsparameter, unter Voraussetzung einer Bedeckung mit Mais und Weizen im Maßstab des ganzen hydrographischen Einzuggebiets.Für die Niederschlagsequenz auf eine Zeit von 18 Jahren wird die Veränderlichkeit zweiter Ordnung mittels der Beziehungen zwischen verschiedenen stochastischen variablen betrachtet, die einen intermittierenden Vorgang beschreiben. Die größte Bedeutung kommt der Beziehung zwischen Mittelwert und Standardabweichung per Ereignis zu, gekennzeichnet durch einen Korrelationskoeffizienten von 0,85.
Für den Infiltrationsvorgang erfolgt die Umwandlung seiner Parameter abhängig von den experimentell erhaltenen Ergebnissen. Dergestalt fügt die landwirtschaftliche Nutzung des Geländes während der ersten Jahresh*lfte (Mais) oder während der zweiten Jahreshälfte (Weizen) eine lange Zeitspanne ohne Pflanzenbedeckung, das heißt mit einer niedregeren Infoltrationsrate ein.

Die hydrologischen Wirkungen für den täglichen Wasserhaushalt werden mittels des HIDROZ-Modells für Regen-Abfluß abgeschätzt. Die sich ergebenden Drehbücher führen zur Schlußfolgerung eines verstärkt dürren Haushalts, in beiden der erwähnten Impaktfälle.

INTRODUCTION

The human activity has induced a lot of changes in the hydrological cycle with direct effects on it as well as indirect ones determining climatic changes.

These effects have been very important for the hydrological research for many years, being a main source of non-stationarity in the measured time series. The analysing methods may be of the stochastic type or imply mathematical modelling of the rainfall-runoff process. Which of them is to be used depends on the problem and on the available data.

In the paper, those types of anthropic impact were chosen which act to the entire watershed scale, affecting the initial water balance. In this case, the hydrological approaches are of the second type and depend on the actual experimental results of a given problem, as well as on the time and space requirement for the available data.

It is not an easy matter to choose data for the investigation of a certain problem. In the present case, the option was for a water basin in the mountain area for the simple reason of having more rainfall events during a year. But this option does not correspond very well to the specific precipitation of the agricultural areas.

The available experimental results are limiting the analysis to a linearised one, that is the estimated effects are referring only to the induced modification of a certain component in the modelled water balance. Their additional effects derived from the internal relationships between the considered components are neglected in the model. This approach has a limited confidence level, but a more complex analysis under non-linear assumptions is not possible for the moment, due to the lack of specific data for it. A non-linear approach needs more experimental results, which would be possible to be obtained during an existing phenomena under a certain impact, acting at a large scale.

The paper deals only with some numerical experiments on the impact problems under reasonable assumptions for the climatic and anthropic impact.

The meaning of the climatic impact is a reasonable change of a rainfall or temperature sequence derived from the WMO (Bach, 1989; Budyko, 1989) approaches on global changes, compatible with the hydrologic model.

The anthropic impact is considered in the case of land use change, that is the whole water basin is turned into an agricultural area with wheat or corn cover. The reason for choosing such study cases is to have different combinations between the natural variability of the input rainfall in the hydrologic system and the estimated modification of the infiltration parameters.

CLIMATIC IMPACT EFFECTS

The climatic impact considered in the mentioned linearised manner means the rainfall sequence modification of the second order variability in order to have adequate input into the hydrological model.

This change is tailored on the assumed WMO trend and monthly distribution for the rainfall sequence, whereas for the temperature sequence any additional modification was made.

In order to tailor the rainfall sequence to the model requirements one considers its time series as an intermittent process (Yevjevich, 1972).

A simpler way for the estimation of the input rainfall for the model is the use of the WMO modifying rapport of the monthly mean values to the daily values. This does not take into account at all the second order variability of the process.

In fact, it is not possible to consider a real second order variability due to the shortness of the historical period in the non-stationary case, but a reasonable approach can be made. This aspect means to transfer the long-term variability to the model time scale.

A manner of achieving this is to search different relationships between the defining variables of the intermittent process.

The process variables taken in account were: the event mean, the event standard deviation, the event duration, its maximum intensity, its mass rainfall, the length between events, the event skewness.

One has investigated the searched relationship through their correlation coefficients. The analysing sample refers to one minute intensities over a historical period of 30 years.

Significant values of correlation coefficients were obtained only for the event mean - event standard deviation, that is of 0.85. The next significance is of 0.56 for the event duration - its mass rainfall and the poorest one is for the dry period - the next event mass rainfall - of 0.02.

In such a case, the estimated second order variability corresponds to the most significant identified relationship. That means that the new rainfall sequence supposes only modified event time distributions superposed on the long-term variability of the monthly mean rainfalls. These time distributions will be more spreaded for higher rainfalls and more smoothened for the lower ones. The separation between high and low rainfall is around the 18 year general mean.

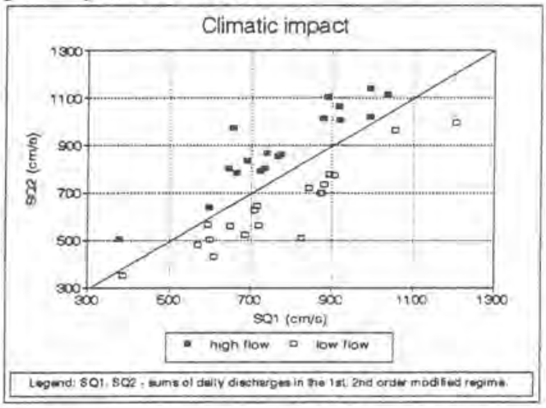


Fig. 1. Estimated effects for the climatic impact, as sums of daily discharges higher (lower) than the general mean value.

The modification of the sequence is transposed into a hydrological effect by means of the HIDROZ model (Şerban et al., 1992). The simulated results for the second order variability of rainfalls are compared with those corresponding to the scenarios obtained under the assumption of the first order modification, on Fig.1.

THE ANTHROPIC IMPACT EFFECTS

The long-term hydrological effect in the case of an anthropic impact is investigated by the infiltration component in the same linearised manner.

The analysis is limited only to the aspects covered by the experimental results.

The basic experiment concerns synchronised rainfall-runoff events observed on two homogeneous plots from all points of view, except for the vegetal cover, which, in one of the cases, is missing. The analysis is achieved by means of the runoff coefficients.

The comparison of the corresponding runoff coefficients for the same event, on the mentioned plots, has led to the conclusion that systematic deviations from the normal status, that is with vegetal cover, occur for each month of the year (Zlate & Grămadă, 1990).

One can see the obtained conclusion on Fig. 2, 3.

As concerning the agricultural land use, a laboured area is in fact an area without vegetal cover for a few months of the year, that is the global infiltration must be corrected according to the mentioned graph regarding the assumed vegetation status.

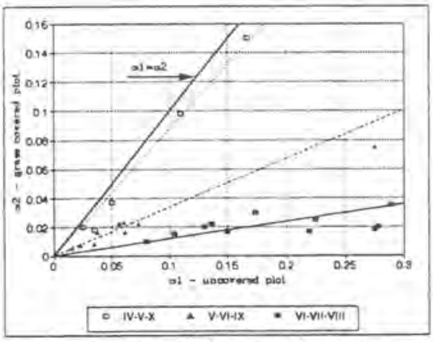


Fig. 2. Experimental results regarding the α runoff coefficient change, relied to the vegetal cover.

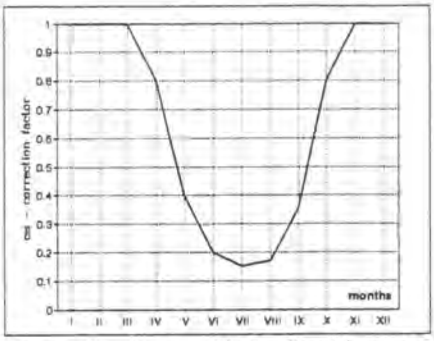
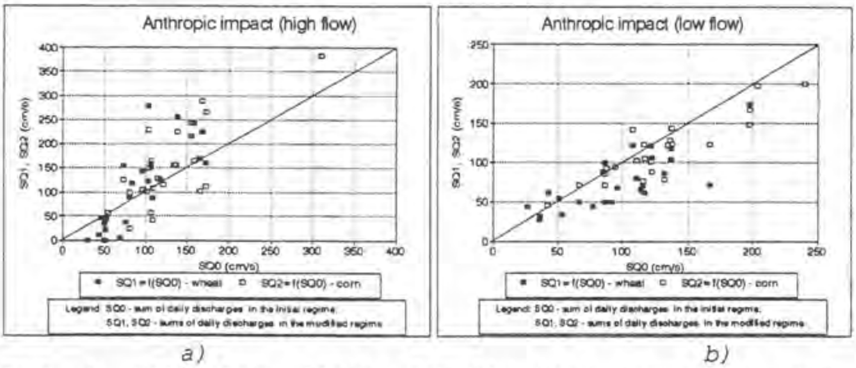


Fig. 3. Mean distribution of the α deviations as a correction factor, C_{α} , for the uncovered plot.

The wheat and corn having different vegetation periods during the year, a useful result would be to realize what is the most unfavourable hydrological effect of the two cases.

Such a conclusion was not possible as the numerical experiments were achieved in a mountain area, where, the rainy day distribution during a year is relatively even.

The general effect obtained implies a high increase of the pick flow and the decrease of the low flow. The statistics made over a 5 year period is presented on Fig. 4 corresponding to a whole water basin change for the land cover.



a) *b)*

Fig. 4. Estimated effects for the land cover, as sums of daily discharges higher (lower) than the general mean value

The scaling effect of transferring the results obtained on an experimental plot to a watershed of medium range was neglected.

More accurate estimations from the scaling viewpoint are possible by means of special experiments and of physically based modelling.

CONCLUSION

The long-term effect for both types of the considered impact is the increase of the arid character of the hydrologic regime.

The simulated hydrological effects are obvious for the daily values, but a more general view on a longer period may be achieved with a global statistical approach. This statistics implies sums of daily values, higher or lower than the general mean of the considered period. Thus, the high flow corresponds to the values above the general mean and the low flow, to the lower ones. Also, in the case of the antropic impact, the sums imply only the months with modified infiltration rates, whereas in the case of climatic impact, the sums are achieved for the entire year.

More obvious effects are those of the anthropic impact, due to the considered one-crop land cover of the whole watershed. Taking into account that the long-term effect refers to a large-space scale, the numerical experiment for reasonable assumptions seems to be a rapid estimation in a complex problem. The basic assumptions correspond to interpretations of the specific experimental data. These data used for impact problems may lead to a better understanding of these matters. Thus, the complexity of a problem can be reduced to a simple, very accessible aspect.

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SUSTAINABLE GROUNDWATER USE

ERHALTBARE AUSNUTZUNG DER GRUNDWASSER

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ABSTRACT:

Sustainable development and use of groundwater resources start to be imperative in the future. Priorities of public water supply in groundwater extraction increase the conflict of interest with industry, agriculture, and other consumers. The concept of sustainable operation and management of groundwater budget will be shown on the area of Osijek (925 km^2) through effective rainfall and percolation process analysis. Effective rainfall recharges aquitard and in the long term insure groundwater extraction from leaky aquifer in the amount of 27.000.000 m^3 per annum. Results of measurement and mathematical models are briefly given.

ZUSAMMENFASSUNG:

Erhaltbare Entwicklung und Ausnutzung der Grundwasserressourcen ist imperativ in der Zukunft. Die Prioritaten von Wasserversorgung in Grundwasserausnutzung geraten immer haufiger in Konflikt mit anderen Benutzern - z. b. Industrie, Landwirtschaft usw, deren Bedurfnisse und Anspruche steigen. Die Konzeption von erhaltbaren Ausnutzung und Verwaltung der Grundwasserbilanz wird am Beispiel von Osijek-Gebiet (925 km2) dargestellt, mittels Analyse von effektiven Niederschlagen und Infiltrationprozessen. Effektive Niederschlage bilanzieren langfristig die Ersetzung in halborosen Schichten und sichern das Schlopfen aus porosem Aquifer in Mengen von etwa 27.000.000 m3 Wasser pro Jahr. Die Resultate von Messungen und Analysen werden in mathematischen Modellen kurz dargestellt.

INTRODUCTION

Groundwater exploration has great progress in lower Drava river basin in Croatia. Due to topographic conditions main source of groundwater recharge is precipitation. Several dry years and highly developed infrastructure (canals, drainage, regulated rivers,...) insure quick runoff from the area reducing potential for use.

Area discussed in this paper is flat agricultural alluvial plain close to river Drava, 20 km upstream of its mouth to river Danube. Average altitude is 85 - 95 m.a.s.l. with average rainfall of 640 mm/annum. This rainfall characteristic represents last 30 years while measurements from 1882. show slight decrease in amount of precipitation (trend of -.65 mm/year from 1882 to 1989.) Ground water exploration raised significantly by developing of new water supply system based on wellfield Vinogradi in 1984. with average extraction quantities of $12*10^6$ m^3/annum with additional industrial groundwater use.

Diagnostic groundwater management is being supported more recently with the help of physical based computer models simulating effective rainfall as the basis for groundwater budget. The power of simulation models is to provide the possibility to study the effect of groundwater recharge and limits for sustainable groundwater exploration. Main basis for a model should be measurements of both subsurface and deep groundwater. Some results of such studies are given.

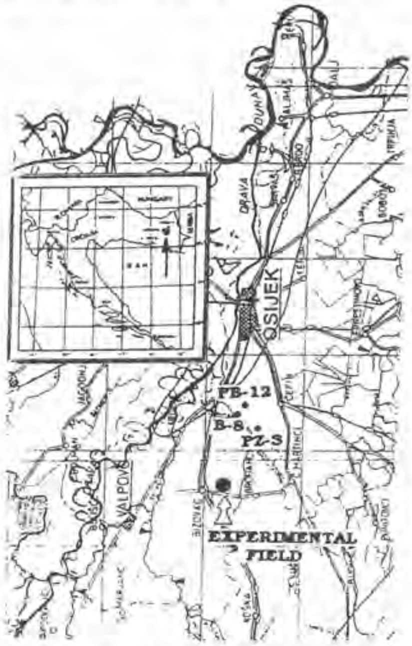

Fig 1. Situation of the area
Situation der Region

INFILTRATION - PERCOLATION

Theory of infiltration is well known and mutual role appears from water balance. The water balance in the unsaturated/saturated soil profile accounts for the incoming and outgoing water fluxes and includ following terms:

$$\Delta V = R + IR - (I + Q + ET + DP)$$

where:

- ΔV - the change of soil water storage (mm)
- R - rainfall (mm)
- IR - irrigation amount (mm)
- Q - runoff (mm)
- I - the interception losses (mm)
- ET - evapotranspiration (mm)
- DP - deep percolation (mm)

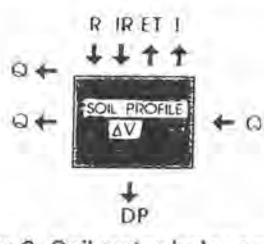

Fig 2. Soil water balance
Bodenwasserbilanz

Deep percolation is defined after neglecting irrigation (poor or no irrigation) and including effective rainfall ER (portion of total rainfall which infiltrate and do not effect deep percolation) :

$$DP = R - (I + Q + ER) \qquad (1)$$

GROUNDWATER MODEL FOR WELLFIELD VINOGRADI

For the purpose of developing new wellfield Vinogradi and for later operating and maintenance, groundwater model (Urumović 1984,) was developed and calibrated during period 1984 - 87. Model covers area of 925 km^2. Pumping wells drains semiprevious aquifer from 40 to 170 m depth. The aquifer is constituted from fine to medium graded sand with hydraulic conductivity from 10 to 20 m/day. Aquifer recharge is leakage from cover layers which the model substitute as aquitard. By activity of wellfield Vinogradi starts process of desaturation of first waterbearing layers. In subsurface region it stays perched water. Movement of ground water table are transferred to deeper level to develop long therm regional balance of recharge of pumped aquifer. During the period when aquifer recharge doesn't cover pumping quantities there is use of ground water reserves from cover layers.

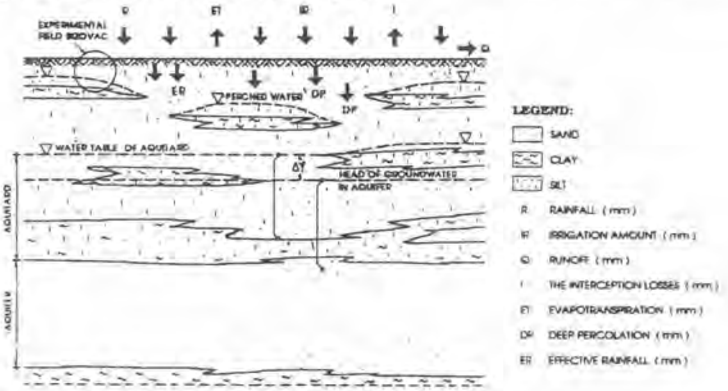

Fig. 3. Schematic cross section of the aquifer

From the model calibration it appears that in period 1984 - 87. approximately 10 - 17 % of total rainfall recharge groundwater on modeled area. Average pumping amount during that period was 480 l/s or 27 % of recharge of covering layer. Maximum infiltration was under the area of the wells.

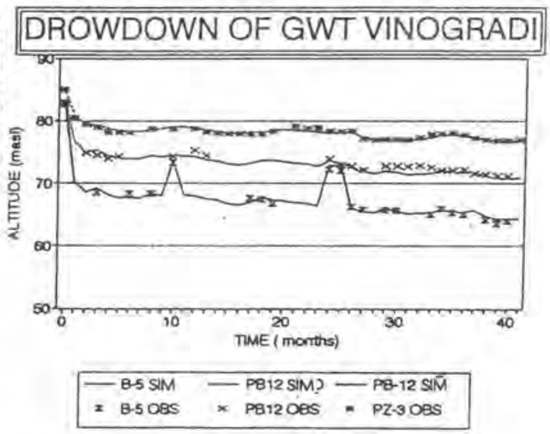

Fig 4. Results from period of exploration
Resultate von Untersuchungsperiode

EXPERIMENTAL FIELD BIZOVAC

Measurements at experimental field Bizovac are part of wide agricultural investigations governed by Mr. V. Puvača, Belje. This field is close to location Vinogradi.

On the basis of the measurement 10 - 20 % of rainfall R feed groundwater budget with various quantities during a year. It appears that most significant period for groundwater recharge is last three months when occurs app. 65 % of total yearly recharge. Speaking in quantities, these % are :

- first quarter 2 - 5 %
- second quarter 2 - 2.5 %
- third quarter 0 - 1 %
- forth quarter 5 - 15 %

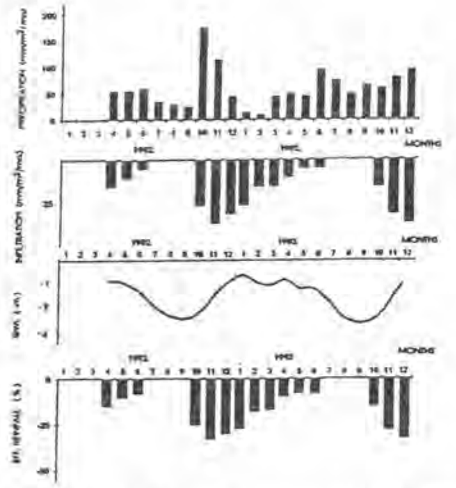

Fig 5. Water balance measured at Bizovac
Wasserbilanz gemessen in Bizovac

EFFECTIVE RAINFALL MODELS

Some well known procedures for effective rainfall calculations are given by USBR (Stam), Budget procedure, USDA (SCS method) , FAO&AGLW, Chow, Stahn, and other empirical methods. Some of them are calculated (period 1987 - 90) to obtain results for ER (Effective rainfall) for different soil types and cover to calculate equation 1 for deep percolation on the bottom of the first layer.

Method	R (mm)	I (%)	Q (%)	ER (%)	DP %
SCS	640	2-3	11 - 22	50 - 72	15 - 25
FAO&AGLW	640	2-3	15 - 18	60 - 65	16 - 23

According to CROPWAT model (FAO 1992.), computer model for simulation of crop water requirement for agricultural land which cover 85 % of the area, and dry conditions as are one in last few years, available water which remain after crop use recharging groundwater are for main crops at the area during growing season:

Crop	R (mm)	Period for water use (days)	Deep Percolation - max % of R
Maize	188	135 - 150	9
Wheat	126	85 - 95	11
Sugar beet	205	155 - 165	6

SUSTAINABLE WATER USE

Sustainable water use is necessity due to limits in amount of groundwater extraction for region of Osijek. Region of Osijek is the greatest consumer of groundwater at the lower Drava basin. Available recharge quantities are approximately 46.1 $*10^6$ m^3/annum what can vary due to long therm drought or rainy periods. Analyzing available recharge quantities versus groundwater exploration, it can be shown that there are approximately 27 $*10^6$ m^3/annum (59 % of total available quantities) of extracted groundwater from the region. Additional 19 $*10^6$ m^3/annum can be extracted to keep groundwater balance under control. With plan of extracting additional 20 $*10^6$ m^3/annum for public water supply limits are reached. Monitoring and analyzing with real time forecasts should be basis for further groundwater exploration. As an increase in groundwater exploration in the region is expected, water authorities should keep the level of extraction under control.

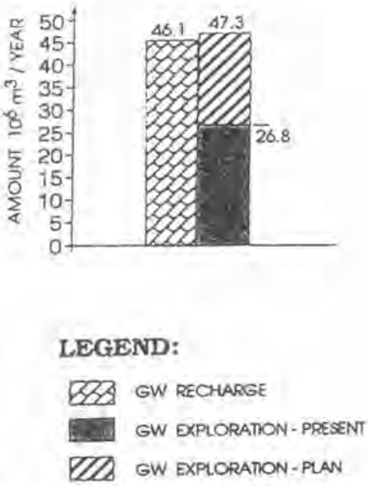

Fig 5. Water budget of Osijek region
Wasserbilanz vom Osijek-Gebiet

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GROUNDWATER BUDGET OF QUARTERNARY DEPOSITS IN DRAVA VALLEY IN CROATIA

GRUNDWASSERZUSTAND VON QUARTAR - SEDIMENTE IM DRAVA - FLUSSGEBIET IN KROATIEN

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ABSTRACT:

The groundwater exploration within the drainage basin of Drava river in Croatia is considerably increased. The main source for public water supply is the aquifer formatted in heterogeneous quaternary deposits up to 300 m thick. This is spread over the whole area of wide Drava valley with gently sloping toward east. The western parts consist of gravel and send with high permeability in contrast to eastern parts made up predominantly of uniform sands alternated with clay and silt layers. The infiltration from precipitation is the main source of natural recharge. However, in condition of intensive groundwater extraction the inducing recharge from Drava river flow could be realizable. Because of great groundwater reservoir potential the aquifer has overall regional significance. Nevertheless, there are some locations within the region where consumer demands exceed local groundwater resources.

The paper presents groundwater analysis experience in Croatian part of Drava valley with main characteristics of aqufer.

ZUSAMMENFASSUNG:

Die Grundwasserausnutzung im Drava-Flussgebiet in Kroatien ist wesentlich angestiegen. Die Grundquelle fur Wasserversorgung ist das Quartar-Aquifer, formiert in heterogenen Sedimenten, die bis 300 m stark sind. Es streckt sich in ganzen Gebiet des breiten Drava-Tals, mit saufter Neigung vom West zu Ost. In der Westregion handelt essich um Kies und Sand von grosser Durchlossigkeit, und in der Ostregion um einformigen Sande, abwechselnd mit Ton und Schluffschichten. Da der Fluss Drava global betrachtet der Hauptwasserlauf ist, gilt die Niederschlageinfiltration als Hauptquelle der naturlichen Ersetzung in der Grundwasser-Regionalbilanz. Wegen der grossen Wasserreserven ist das Aquifer von Bedeutung fur die ganze Region. Trotzdem gibt es auch in dieser Region Gebiet, wo der Bedarf die naturlichen Quellen ubertrifft. In dieser Arbeit werden die Erfahrungen in Grundwasseranalyse von Drava-Tal in Kroatien dargestellt, mit Haupteigenschaften.

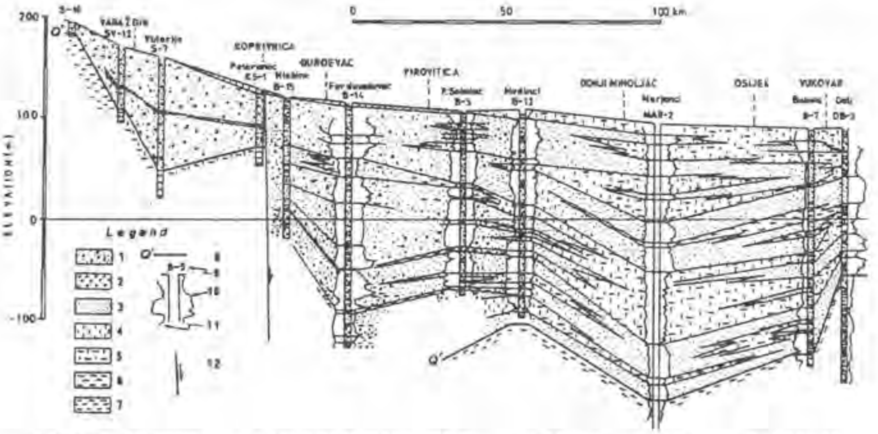
1. INTRODUCTION

River Drava in Republic of Croatia runs into the territory of Panonian basin. During the history, there were good conditions for the forming of wide, long river valley. The alluvial deposits of Drava valley are represented by fluvial and swamp sediments which came at the end of sedimentation cycle in the boundary of Panonian basin, called depressions of rivers Mura and Drava. The lower boundary of the aquifer was found on Q` horizon (Urumovic et al, 1976, 1978) which represents the regional discontinuity of sedimentation.

Below that level, in this part of Panonian basin, fine clastic deposits (silt, clay, marl) with intrusions of sand and clay are dominant. Deposits are more homogeneous and thin (Fig. 1 and Fig. 2) in the depression of Mura river, situated more upstream of the mouth of Mura into the river Drava. On the connection of the depressions of these two rivers is structural shelf, where is the thickness of quaternary deposits reduced. The boundary of Legrad shelf and the depression of Drava river is marked by geological fault (Fig. 1) in which lowered down block the quaternary deposits suddenly become thicker.

In the depression of river Drava the deposits are more heterogeneous due to thicker layers of clay and silt in downstream regions (Babic et al, 1978). A formation of fine and heavy coarse deposits is connected with neotectonic activities after the sedimentation of marked Q` horizon (Prelogovic et al, 1992)

In the surface parts, the deposits are covered by loess, and swamp formations very good for agricultural exploitation. Groundwater in alluvial aquifer is interesting for the public water supply and for the irrigation purposes during the period of vegetation when the droughts occur very often.



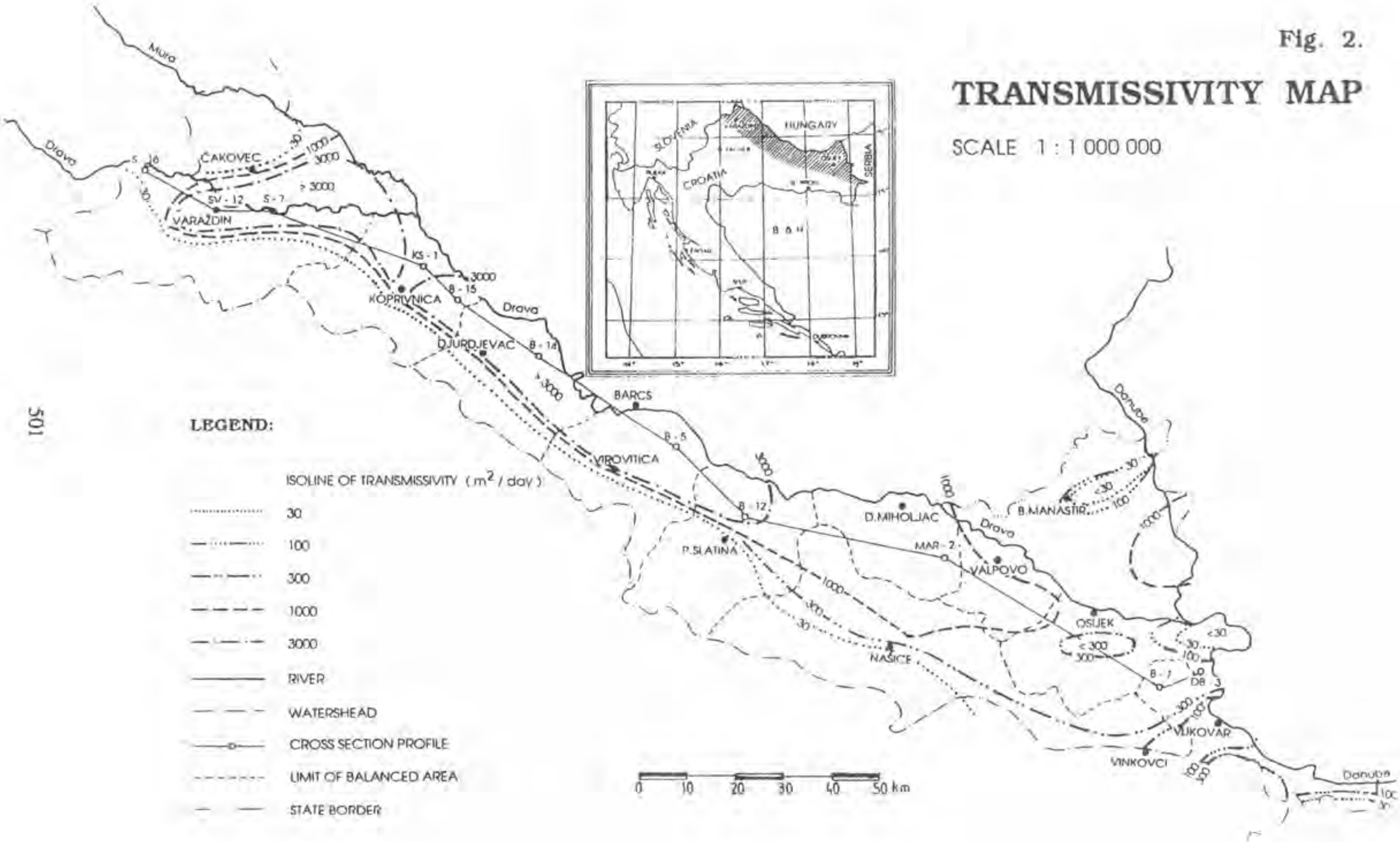
1. GRAVEL AND SAND 2. CONGLOMERATE GRAVEL 3. SAND 4. SILT 5. SILTY CLAY
6. CLAY 7. MARL 8. MARKER Q' - SUBSTRATUM OF THE AQUIFER 9. BOREHOLE
10. RESISTIVITY LOG 11. SPONTANEUS POTENTIONAL LOG 12. FAULT

Fig. 1. Cross section profile along Drava valley

Fig. 2.

TRANSMISSIVITY MAP

SCALE 1 : 1 000 000



2. HYDROGEOLOGICAL CONDITIONS

In lithological development of the deposits there are some general conclusions. There is increasing of average diameter of the grains going from the west to the east. In the western part, there is domination of gravel mixed with sand and in eastern parts, there are the layers of homogeneous fine and medium coarse sand with the intrusions of silt and clay of different thickness.

The large thickness of permeable layers, the natural recharge of groundwater due to infiltration of precipitation and the possibilities of induced recharge from surface flows make this complex aquifer basis of public water supply (regional and local) not only in the basin of Drava and partially in the basin of Danube, but also in the adjacent basin of Sava river.

In the western part of the valley there are deposits of gravel with various percentage of sand. In the extremely western parts they are leaned to the Miocene sandstone and marly soil and there thickness is the smallest, only about 10 m. Going to the west, the thickness of the gravel layer increases up to about 150 m. In its basis, the Pliocene clay, marl sandstone and sand were found. Approaching to the structure of Legrad shelf , the thickness of the gravel layer gradually decreases and the intrusions of clay and sand show up in the lower parts of the deposits.

The aquifer is covered with thin silty, sandy and clay layer along the whole western part of the valley. Its thickness is regularly less than 1m. It is often just covering of organic materials (humus), though in boundary parts it can reach the thickness of few meters. The existing wells cough hold of deposits up to 40 m. The aquifer is unconfined. The values of hydraulic conductivity's are from 100 to 250 m/day. Rivers Drava and Mura are cut into the aquifer, so the water power station have very strong influence to the regime of groundwater (Urumovic et al, 1990). The groundwater has calcium hydrocarbonate facies. The hardness of the water is from 15 to 20 dh. The processes of reduction are dominant, so the content of iron dissolved in groundwater is almost always less than 0.3 mgFe/l. The aquifer is brought into the danger of pollution very much. The content of nitrites in the groundwater increased from the initial 2-3 mgN/l to the more than 15 mgN/l.

In the middle parts of the area (Fig. 1 and 2) the gravel layers are spread. There thickness is more than 300 m. Sporadically, there are conglomerations, alternating vertically and laterally with sand. There are some significant appearances of silt and clay in the form of admixture to the heavy coarse deposits or as a locally and vertically spread layers. The aquifer is mostly covered by silt and clay of different thickness. It can be even 30 m. The existing wells caught hold of deposits up to 80 m. The aquifer is heterogeneous with well marked anisotropy. The shallowest waterbearing layers are unconfined and semi-confined. The average hydraulic conductivity is 50-150 m/day. The groundwater has calcium hydrocarbonate facies with sporadically higher presence of ions of manganese. The hardness is from 11 to 20 dh, although in some boundary parts it can overcome 35 dh. There is exchanging of conditions of oxidation and reduction, so we have appearance of low iron content (below 0.3 mgFe/l in the western parts) and high iron content (over 3 mgFe/l). The danger of pollution is medium to high depending on adjustment of the hold to the structure of deposit or, in other words, on usage of autopurificational properties of deposits.

In the eastern parts of the area the layers of medium and fine coarse sand are dominant exchanging with layers of clay and silt. The appearance of gravel is significant only in some boundary parts. The thickness of the aquifer is a little bit smaller than in the middle parts of the area, but it is still more than 150 m. The aquifer is covered with the layer of silt and clay. Its thickness is regularly bigger than 10 m, in some places it is over 50 m.

The aquifer is extremely heterogeneous with expressive anisotropy, especially in some layers of sand with tiny intrusions of silt. The shallowest waterbeard layers are regularly semi-confined with exemption of some parts of Baranja and the inundations. The average values of hydraulic conductivity is 10-20 m/day.

The groundwater has mostly calcium-hydrocarbonatum and manganese-hydrocarbonatum facies with sporadically higher content of sulphate ions. The hardness of water, in the layers of exploitation (in the natural conditions) is from 14 to 35 dh. Very high hardness (over 50 dh) has been recorded in some locations of poor permeability in covering deposits. There are conditions of reduction and high content of iron dissolved in groundwater, regularly between 1 and 2 mgFe/l. There are also some limited locations with very low content of iron, less than 0.3 mgFe/l and some inside depressions with the iron content higher than 10 mgFe/l. The danger of pollution of the groundwater is medium, very much dependable on adjustment of the hilt to the structure of deposits or usage it autopurificational properties of deposits.

3. GROUNDWATER RESOURCES AND CONSUMPTION

The natural recharge of groundwater occurs due to infiltration of precipitation. Quantity of infiltrated waters has very wide range, depending on the regime of precipitation, type of crops and quality of covering deposits. The estimated average values of infiltration in some area are 5-25 % of annual precipitation. Higher values can be met in the western parts, and lower values in the eastern parts. The total budget of groundwater is very large thanks to the thick aquifer, so the natural recharge of groundwater gives only 0.1 % of totally stored water. The induced recharge of groundwater is significant only in Varazdin region where is the natural regime of groundwater disturbed by building of water power station.

The groundwater is mostly used for the public water supply and rarely for irrigation. In the last period, available resources did not limited the consumption of water in the water supply system. The biggest consumers of the groundwater are in the extremely western parts (Koprivnica, Varazdin), and extremely eastern parts (Osijek and Vukovar with large industrial capacities). The estimation of long-term needs in water supply has the similar distribution in the space as nowadays. The needs overcomes restorable quantity of the groundwater in the region of Osijek and Vukovar, in the east. The main factories of these towns are situated near the rivers Drava and Danube respectively, what is the good circumstance.

In the middle parts of Drava valley the long-term needs represent only the small percent of the natural recharge of the groundwater. So, Drava valley can be a significant resource of groundwater for adjacent regions of Sava basin which have a deficit of water.

4. CONCLUSIONS

Alluvial aquifer of lower Drava river basin is basic resource for public water supply. Natural recharge from precipitation in the whole region is higher than exploration quantities and in the most of the parts higher than estimated future needs. This aquifer is potential resource for adjacent area with deficit in groundwater resources, like western parts with significant hydraulic conductivity, so it is significant induced groundwater recharge from river Drava. Surplus of groundwater resources can be useful for some other needs so it represents multifunctional basis of water management.

The specific situation is in the lower eastern parts where the rechargeable resources are still sufficient for present exploration, but in the future, consumption higher than natural recharge is expected. Therefore, sustainable development and management of groundwater resources will require dynamic comprehension of other water resources and redistribution in groundwater use.

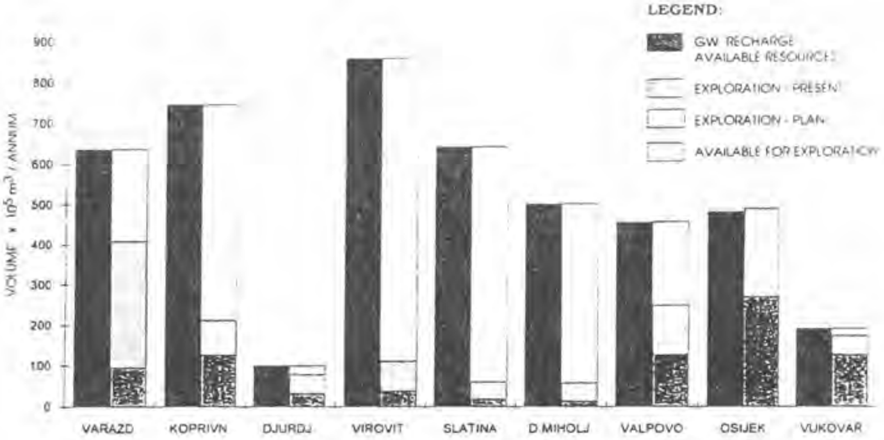


Fig. 3. Groundwater balance potential

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XVII. KONFERENZ DER DONAULÄNDER
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RELATIONSHIP BETWEEN THE RIVER AND THE BANK-FILTERED GROUNDWATER RESOURCES ALONG THE HUNGARIAN DANUBE

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ABSTRACT

The 400 km long Hungarian reach of the River Danube is characterized by valleys of 5-30 km width. Along the right- and left river banks there are bank-filtered drinking water resources available in the total of 211 km length. Additional bank-filtration capacities are offered by the three large islands in the vicinity of Budapest over a total length of 93 km. The total drinking water production capacity from these resources is 4.2 million m^3/day. Presently waterworks utilize bank-wells along appr. 100 km long bankline with the total drinking water production capacity of 1.6 million m^3/day.

Over the western upstream reaches of Danube, in the Szigetköz, the river feeds the groundwater with 163,000 m^3/day recharge rate in multi-annual average. Along the rest of 360 km bankline groundwaters of the area feed the river with a multiannual average inflow rate of 944,000 m^3/day. Natural groundwater recharge/discharge conditions have been substantially modified by hydraulic structures and by the water withdrawal of the waterworks.

Operation of bank-wells along the bank-line zone is at pollution risk due to accidental pollution events of the parent river and to toxic pollutants leached out from hazardous wastes into the groundwater of the background (off-river) zone. Accidentally introduced contaminants of the parent river will reach the production wells during less than a day, for most of the 1000 water abstraction units of the Danube reach in concern. Protection of bank-filtered drinking water resources needs the urgent establishment of respective international cooperative agreements.

ZUSAMMENHANG ZWISCHEN DER UNGARISCHEN STROMSTRECKE DER DONAU UND DEN UFER-FILTRIERTEN WÄSSERN

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ZUSAMMENFASSUNG

Die 410 km lange Ungarische Stromstrecke der Donau ist durch eine kette der 5 - 30 m breiten Täler charakteriziert. Zur uferfiltrierten Wassergewinnung sind die entleng des linken und rechten Ufers befindliche 211 km lange Landzone und ein 93 km langes Küstengebiet der drei in der Nähe von Budapest liegenden Donau-Inseln geeignet. Die schöpfbare uferfiltrierte Wasservorräte machen 4,2 Millionen m^3/Tag aus.

An einer 100 m langen benützten Uferstrecke is ein Drinkwasserschöpfungsystem in Betrieb, dessen Kapazität 1,6 Millionen m^3/Tag ist.

Entlang der 50 km langen Stromstrecke in Szigetköz speist die Donau das umliegenden Grundwasser mit einer Durchflussmenge von 163 000 m^3/Tag. Aber die 360 Reststrecke der Dunau in Ungarn ist durch die Grundwässer gespeist wessen Wassermenge 944 000 m^3/Tag ist. Das natürliche Grundwasser-Regime wird durch die hydreulischen Bauten und Entnahme-bauwerken entleng der Donau wesentlich geändert.

Die am küstengebiet der Dunau inbetriebhaltende unerfiltrierte Brunnen werden durch wegen der Havarie entstehende Flussbettverschmutzungen und die vom Hintergrund stammende gefärliche Abfälle gefährdelt. Beim bedautenden Anteil der mehr als 1000 Entnahmebauwerken werden die Burnnen durch die Flussbettverschmutzung in kürzer Zeit als ein Tag verschmutzt. Dei Notwendigkeit des Schutzes der uferfiltrierten Wässer drängt auf die Entwicklung der internationalen Zusammenarbeit.

1. Hydrogeological environment of the Hungarian Danube reach

The River Danube, forming the northern border of the western part of the country and flowing across it from the north towards the south, had cut its channel into a chain of various geological formations, that differ from each other significantly.

It is worthwhile to note that:

- The particle size of the bed material of the channel of Danube decreases towards the south (from rough gravelly particles to fine sand);
- Along two river reaches of particular importance (in the vicinities of Esztergom and Budapest) the river channel was cut into the foot of the Dunántuli Középhegység (the Transdanubian Middle Mountain Ranges)

The 410 km long Hungarian river reach is characterized by a chain of valleys of 5-30 km width. The larger part of these valleys consists of alluvial gravel terraces of excellent hydraulic conductivity.

Water bearing formations along the river consist of the following strata:

The water-bearing gravel complex is the deepest at the North-western part of the river, near to the country border, consisting of Pleistocene formations of 50 - 400 m depth. The seepage coefficient of the aquifer varies in the range of 50 - 200 m/day. Along the eastern and southern parts of the Hungarian Danube the thickness of the water bearing layers is considerable smaller. In the case of the three large islands (Szentendre, Margit and Csepel islands), which play a decisive role in the water supply of Budapest and its agglomeration, the thickness of the gravel aquifer is about 10 - 18 m.

The upper cover layer consist mostly of clayey-sandy meadow soils of 0.5-5.0 m depth, reaching down to 20 m at certain locations. This means that bank-filtered drinking water resources are rather vulnerable, open (not protected against diffuse pollution).

2. Natural water budget of the groundwater zone along the river bank

Regional groundwater budget studies aimed, among others, at the determination of the hydrogeological protection zones of the waterworks, are focussed on the assessment of multiannual water budget elements. The rate of exchange of water between the groundwater resources and the parent river is characterized, accordingly, with the multi-annual slope of the groundwater table (Székely and Major, 1980).

On the basis of the water budget analysis of the near-bank zones it was found that in the NW-ern part of the River Danube, in the vicinity of the country border, Danube feeds the adjacent groundwater resources at a rate of 163,000 m^3/d, in multi-annual average. from Gönyü down to the southern country border there is an inflow of 944,000 m^3/d from the groundwater resources to the river, in terms of multiannual average values. The net budget is thus 781,000 m^3/d supply from the river towards the aquifers.

3. Utilization of bank-filtered drinking water resources

48% of the piped drinking water supply of Hungary relies on bank-filtered drinking water resources. 905 of the drinking water production of the Budapest Waterworks is based on the bank-filtered resources of the Szentendre- and Csepel islands. As it was mentioned before these water resources are hydrogeologically unprotected and thus they are prone to local pollution hazards. Groundwater resources of the islands become more and more polluted and the contaminants also appear in the water abstracted by the bank-wells. The protection of bank-filtered drinking water resources requires an urgent action. In certain areas these drinking water resources represent a strategically important reserve.

Figure 1. gives an overview of the utilizable and free bank-filtered drinking water

resources along the Hungarian section of the River Danube (Déri, 1992).

4. Contamination of bank-filtered drinking water resources by accidental pollution events and counter measures to be taken.

Waterworks, utilizing bank-filtered drinking water resources, are facing pollution problems from two basic sources: from the direction of the off-river shallow groundwaters, on one hand, where high nitrate content and toxic contaminants originating from solid waste disposal sites represent pollution hazards. On the other hand pollutants enter the bank-filtered resources via the Danube water withdrawn by the wells. Increasing problems are associated with the contaminants accumulating in the bottom sediment of the river, among which oil derivatives and heavy metals are of the main concern. Contaminants buried in the infiltration (recharge) zone of the background aquifers and in the sediments of the channel bed can be remobilized and reaches the water which is being abstracted by the bank-wells. For example; in the water abstracted by the wells of the southern part of Budapest heavy metals and ammonia, originating from the untreated waste waters of Budapest via the bottom deposits of the channel bed, reached such levels which require the treatment of the water before discharging it into the distribution network.

4.1. Effects of accidental pollution of the off-river background aquifers on the bank-filtered drinking water resources.

An example of the cases of catastrophic groundwater pollution in the off-river zone is the case of the Southern Waterworks of Vác, where toxic water pollutants were detected in February 1981 in the water abstracted by the bank-wells. This pollution event had a regional impact and was thus of paramount significance.

On the 14-th of February, 1981 citizens of Vác were complaining about nuisance odor and taste of the drinking water supplied. This was the first case in the history of drinking water supply of Hungary when waterworks faced such difficulties which resulted in serious disturbances to the water supply of a larger city. In this case a part of the production wells had to be closed down for a longer period of time. Efforts made for minimizing the harmful effects of the thus created water shortage required substantial expenditures.

Due to the effects of toxic contaminants leached out from solid waste disposal sites in the area of the hydrogeological protection zone of the Southern Waterworks of Vác the waterworks had to be closed down on the 29th of March 1981 entirely, thus loosing a production capacity of 20,000 m^3/d. Lessons reaching far beyond the boundaries of the Vác Waterworks could be drawn on the basis of the two months history of this pollution event (Déri, 1991, 1992).

4.2 Effects of accidental river pollution on the bank-filtered drinking water resources

The impacts of accidental river pollution events on the bank-filtered drinking water resources can be assessed by the numerical groundwater model of pollutant transport and transformation. The model has been developed at the Institute of Hydrology of the Water Resources Research Centre VITUKI. The model can be used for assessing the expectable effects of contemplated well-operation changes on the groundwater flow regime (on the depression surfaces) as well as for the estimation of the changes of the concentration distributions and profiles. The model is also being used for the design of hydrogeological protection zones.

Figure 2. shows the results of the impact analysis of an accidental river pollution event on the conditions of the aquifer utilized by a series of radial wells along the Szentendre Danube-arm of the River Danube. Effects of pollutant loads lasting for selected periods of time (12 and 8 hours) were analyzed. Concentration fronts of a conservative contaminant, moving with the water towards the wells, are shown in the figure in function of the time of seepage. It is worthwhile to note that the pollution "cloud" reaches some of the wells already during the pollution event. Dilution effects and the movement of the front are well demonstrated by the figure. An important conclusion was that a relatively short (8h and 12h) river pollution event could contaminate all wells in 14.4 days.

Considering the findings of Sujbert (1991), Varga (1991) and Hegedűs (1991) that the genotoxic baseline conditions of the raw river water feeding the production wells in concern are already objectionable more, attention should be paid to the related impact assessment of accidental pollution events. In order to decrease the health risk of the population concerned genotoxicity screening studies would be highly required for this area on a regular basis (Varga, 1991)

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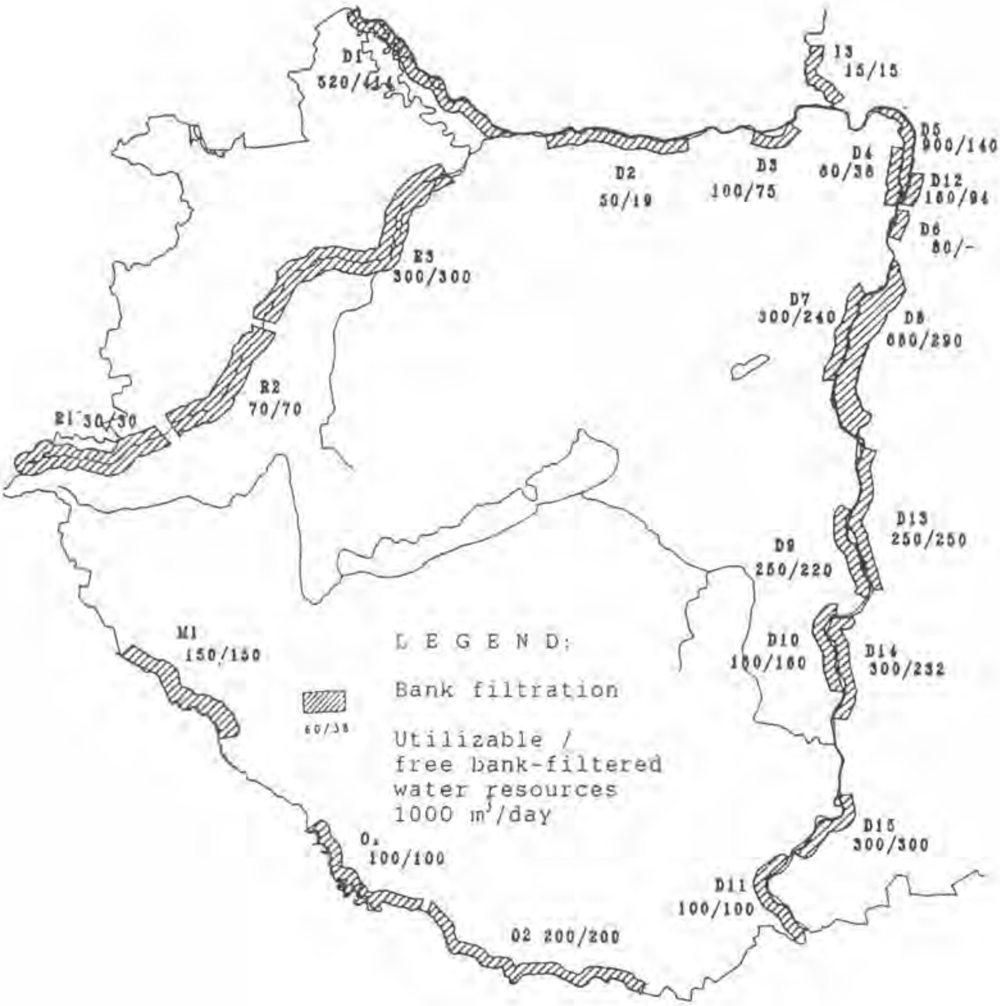
Fig.1. Utilizable and free bank filtered water resources along the hungarian reach of river Danube



Concentration of contamination, moving with the water, after 4.27 day, in case of 12.8 hour duration.

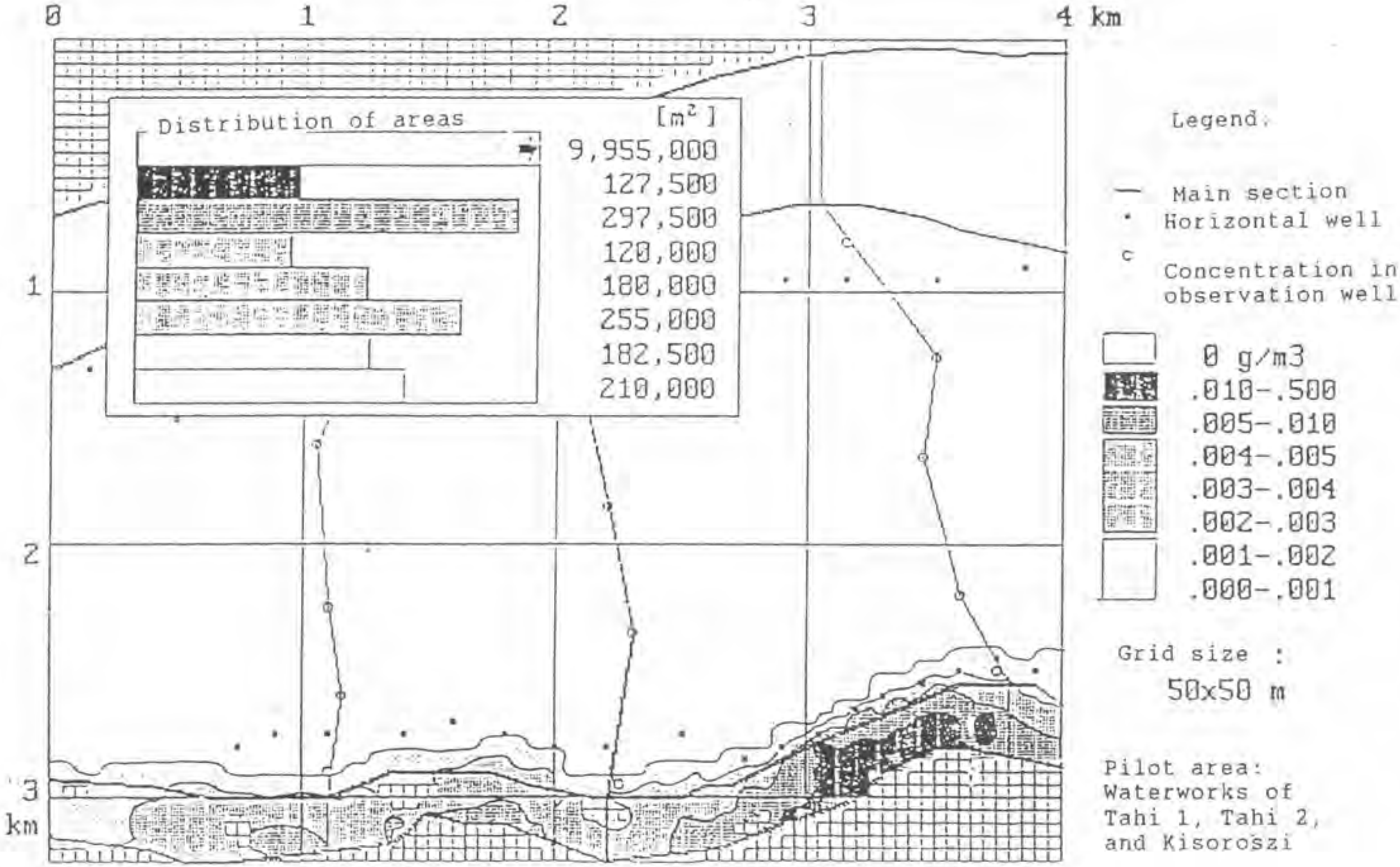


Fig.2. Distributon of contamination-concentration, moving from the river-bed to the operating wells

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DER VON DER DONAU GESPEISTE GRUNDWASSERKÖRPER UNTER DER KLEINEN SCHÜTTINSEL

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Kurzfassung

Unter der Kleinen Schüttinsel (ung.:Szigetköz), entlang einer 50 km langen Donaustrecke, welche einen - aus Donausedimenten bestehenden, - mächtigen Schuttkegel fliesst, werden die Grundwässer vom Donauwasser gespeist. Die unterirdisch strömende Wassermenge wird mit etwa 7-10 m^3/s angegeben. Die Wasserqualität ist - abgesehen von den lokalen Verschmutzungen der Seichten Schichten - für Trinkwasserversorgung geeignet. Der Grundwasservorrat ist derzeitig nur in geringem Mass genutzt, aber soll für die Zukunft vor schädlichen Eingreifen verschont werden. Die Umleitung der Donau nach Gabčíkovo hat - ausser den für die Pflanzen schädlichen Grundwasserspiegelsenkungen - auch in dieser Hinsicht schwer lösbare Probleme verursacht, die auch die Qualität des Grundwassers gefährden.

SUBSURFACE WATER RESOURCES, FED BY THE RIVER DANUBE, IN THE SZIGETKÖZ AREA

Abstract

In the Szigetköz, along a 50 km long section of the River Danube, the river flows over her own very deep alluvial cone and recharges the subsurface water resources, continuosly refreshing them. The rate of subsurface "recharge" flow is estimated in the range of 7-10 m^3/s. Apart from the effects of local pollution sources of the

shallow groundwater zone this vast groundwater resources is of drinking water quality. This resource is being utilized partially only, but it should be definitely preserved for future generations, and thus must be protected against harmful interventions. The diversion of Danube to the Gabcikovó hydropower station resulted in substantial subsidence of the groundwater table which is detrimental to the vegetation and it causes very difficult problems in respect to both the quality and quantity of this important subsurface water resource.

1. Die wasserführende Formation

Die bedeutendste wasserführende Formation - die unmittelbar hydraulisch mit der Donau im Kontakt steht der ungarische Donaustrecke entlang - ist die von der Donau abgelagerte mehrere Hundert m mächtige Kiessandschicht in der Kleinen Schütt. (Bild 1)

Die Durchlässigkeitsbeiwerte dieser Formation bewegen sich zwischen 5 und 300 m/Tag, im Mittel um 150 m/Tag.

Das alluviale Kiessandgeschiebe ist anisotropisch abgelagert, der regionale Anisotropiegrad (Ujfaludi - Maginecz, 1991) ist etwa $\lambda=10$ zu schätzen.

Die vertikale Durchlässigkeit der 0-5 m starken, feinkörnigen, oberen Deckschicht lässt sich mit 0.025-1.0 m/Tag angeben (Maginecz, 1993.).

Der Eintrittswiderstand im Hauptarm der Donau ist vernachlässigbar gering. In den Nebenarmen ist das Flussbet normalerweise in einer 0.2 m mächtigen Schicht kolmatiert. Für diese Schicht ist 0.2-1 m/Tag wertikale Durchlässigkeit charakteristisch.

2. Der Grundwasserspiegel

Im mittleren und östlichen Teil der Kleinen Schütt steigt der Grundwasserspiegel normalerweise bis in die Deckschicht.

Der Grundwasserspiegel folgt rasch den Schwankungen der Donauwasserstände mit einem durchschnittlichen Gefälle von 0,3-0,5 m/km nach SSO. (Bild 2.)

Der Grundwasserspiegel liegt im Westen 4-6, in der Mitte und im Osten 1-3 m unter Geländeoberkante. Die Lage des Grundwasserspiegels im Verhältnis zur unteren Ebene der feinkörnigen Deckschicht ist für die Landwirtschaft, bzw. für die Feuchtezufuhr der Pflanzen von ausschlaggebender Bedeutung. Die Deckschicht ist im westlichen Teil allgemein nicht, in der Mitte teilwese, im östlichen Teil überall von unten durchfeuchtet. (Bild 3.)

Der Grundwasserspiegel fällt seit den fünziger Jahren trendartig unter einigen Teilen des Schüttgebietes (Bilder 4a-c). Die Senkung von 0,5-1,0 um Rajka ist der ähnlichen Vertiefung des Mittel - und Niedrigwasserbettes der Donau, der gesunkene Spiegel um Győr der Entnahme der städtischen Wasserwerke zuzuschreiben. In der Höhe von Dunaremete lassen sich trendartige Senkungen weder in den Donauwasserständen, noch im Grundwasserspiegel feststellen. (Bild 4.)

Die Spiegelschwankungen weisen eine enge (60-80 %) Korrelation mit den Donauwasserständen auf. (Bild 5.) Für die Korrelation mit dem Niederschlag, der Lufttemperatur, Verdunstung ergaben sich niedrige (20-50 %) Werte. Die Schwankungen der Donauwasserstände machen sich in den Beobachtungsbrunnen entfernungsabhängend in 1 bis 8 Tagen bemerkbar (VIZITERV, 1987.), aber eine volle Entwicklung der Auswirkungen erfolgt erst nach mehreren Monaten (Maginecz, 1993.).

3. Grundwasserströmungen

Neueren Untersuchungen nach speiste die Donau den Kieskörper vor der Umleitung mit einer Wassermenge von 7-10 m^3/s. Das vor Kürze entwickelte mathematische Modell ergab den Wert von 8,6 m^3/s (Maginecz, 1993.).

Es ist mit grosser Wahrscheinlichkeit anzunehmen, das der bedeutendere Teil dieses Wassers über die "gespülte" Bettoberfläche des Hauptarmes in den Kies eintritt.

Die Werte der δO^{18} Isotopenkonzentration - die in der Donau eindeutig von jenen in den nicht aus der Donau stammenden Grundwässern abweichen - beweisen das die Kiesschicht unter der Kleinen Schütt vollständig (bis zu 70-100 %) mit Donauwasser gefüllt ist. Südlich des Moson-Donauarmes jedoch sinkt der Anteil des Donauwassers auf unter 20 %. Nach den C^{14} Altersbestimmungen stammt ein geringer Teil dieses Wassers aus den Oberpliozän-Sandscichten (Deseő, 1993.).

Die Fliessgeschwindigkeit der Grundwasserströmung konnte durch Verfolgen der in der Donau in 1963 entstammendenen Tritiumspitze ermittelt werden Die höchsten Geschwindigkeiten (400 m/Jahr) ergaben sich in der Tiefenspanne 70-90 m, als Beweis für die Bedeutung der Speisung aus der Donau in den tieferen Schichten (Deseő, 1993.).

Die Einsickerung aus dem Niederschlag wurde im Mittel auf 60 mm/Jahr geschätzt (Major, 1985.) und ist somit im Vergleich zum Zufluss aus der Donau vernachlässigbar in der Kleinen Schütt.

Die Moson Donau speisst das Grundwasser entlang einer kurzen Strecke, der längere Unterlauf wirkt jedoch als ein Entwässerungskanal.

In den Monaten September und Oktober, 1992 wurden bis zum Wehr unterhalb des Leithauptzuflusses 2,0-2,2 m^3/s Versickerungsverluste in das Grundwasser gemessen. Der Entzug aus dem Grundwasser war jedoch 6,8-9,3 m^3/s über der darunterliegenden Strecke (Rakoczi, L.-Szekeres,J., 1993.).

4. Grundwasserqualität

Abgesehen von lokalen Verschmutzungen in der oberen, 12-15 m tiefen Wasserschicht deuten die Gütewerte im Allgemeinen auf ein für Zwecke der Trinkwasserversorgung geignetes Wasser hin.

Die lokalen Nitratverschmutzungen in der Bodennahen Grundwasserschicht sind zum grössten Teil dem Mangel an Kanalisation in den Ortschaften und den Chemikalien der Landwirtschaft zuzuschreiben. Die Ergebnisse der Untersuchungen an stabilen N^{15} Isotopen wiesen ebenfalls auf Schmutzstoffe tierischer, bzw. kommunaler herkunft (Deseő, E., 1993.).

5. Grundwasservorräte und ihre Nutzung

Das reine und laufend angereicherte Grundwasser in der Kiesformation unter der Kleinen Schütt ist auch im Nationalen Rahmenplan der Wasserwirtschaft (1984) als eine mögliche Quelle der Versorgung mit einer Kapazität von 750 Tausend m^3/Tag angeführt.

Die tatsächliche Entmahme ist weniger als 100 Tausend m^3/Tag. Bedeutendere Wasserwerke sind bei Győr (Raab) und Mosonmagyaróvár im Betrieb.

Die - auf 5,5 km^3 geschätzte quaternären Kiesablagerungen (Erdélyi, 1979.) können nur in der ferneren Zukunft, als Reserve zur Deckung eventuell auch nicht ungarischer

Wasserbedarfe in Betracht gezogen werden, sofern es gelingt den Zufluss erwünschter Menge und Güte zu bewahren.

Die Summe der gegenwärtigen und zukünftigen Entnahmekapazitäten ist ungefähr gleich der natürlichen Zuflusses, dessen überwiegender Teil als Uferfiltrat über die Kiesschichten im Hauptarm der Donau in die wasserführende Formation eintritt. Der Zustand dieser Flächen, die Dauer der Bettfüllung und die Güte des eintretenden Wassers dürften daher keine wesentlichen Änderungen erleiden.

6. Veränderungen seit der Umleitung der Donau

Seit der Umleitung der Donau zum Kraftwerk Gabcikovo bei Cunovo (Dunacsuny) in 1992 oktober fliessen im bisherigen Hauptarm der 40 km lange Donaustrecke ausserhalb den Hochwasserperioden - die nur ein bis zwei Tage lang anhalten - nur 200 bis 350 m^3/s, statt des Mittelwertes um 2000 m^3/s. Der Wasserstand - der in den Niederwasserperioden um 2 m weniger betrug als der mittlere Wasserstand - ist im Vergleich dazu noch um weitere 1.5-2 m zurückgegangen. Die Nebenarme sind völlig ausgetrocknet.

Der Grundwasserspiegel neben der Donau ist nach der Umleitung im Vergleich zu den früheren Mittelwerten um etwa 2-3 m abgesunken, (Bild 6.) in einer Entfernung von 5 bis 10 km von der Donau aber nur um 0-1 m. In der Nähe des Stausees ist ein Ansteigen des Grundwasserspiegels zu beobachten.Die Strömungsrichtungen haben sich stark verändert. Die Grundwasserspiegelabsenkung im mittleren Teil und entlang der Donau wirkt sich dort schädlich aus, wo der feinkörnige Boden früher von unten durchfeuchtet wurde. Die künstliche Infiltration durch die Wassereinleitung in den Nebenarmen und die geplanten Unterwasser-Staustufen in Hauptarm kann man nicht als endgültige, Sanierungsmassnahme betrachten.

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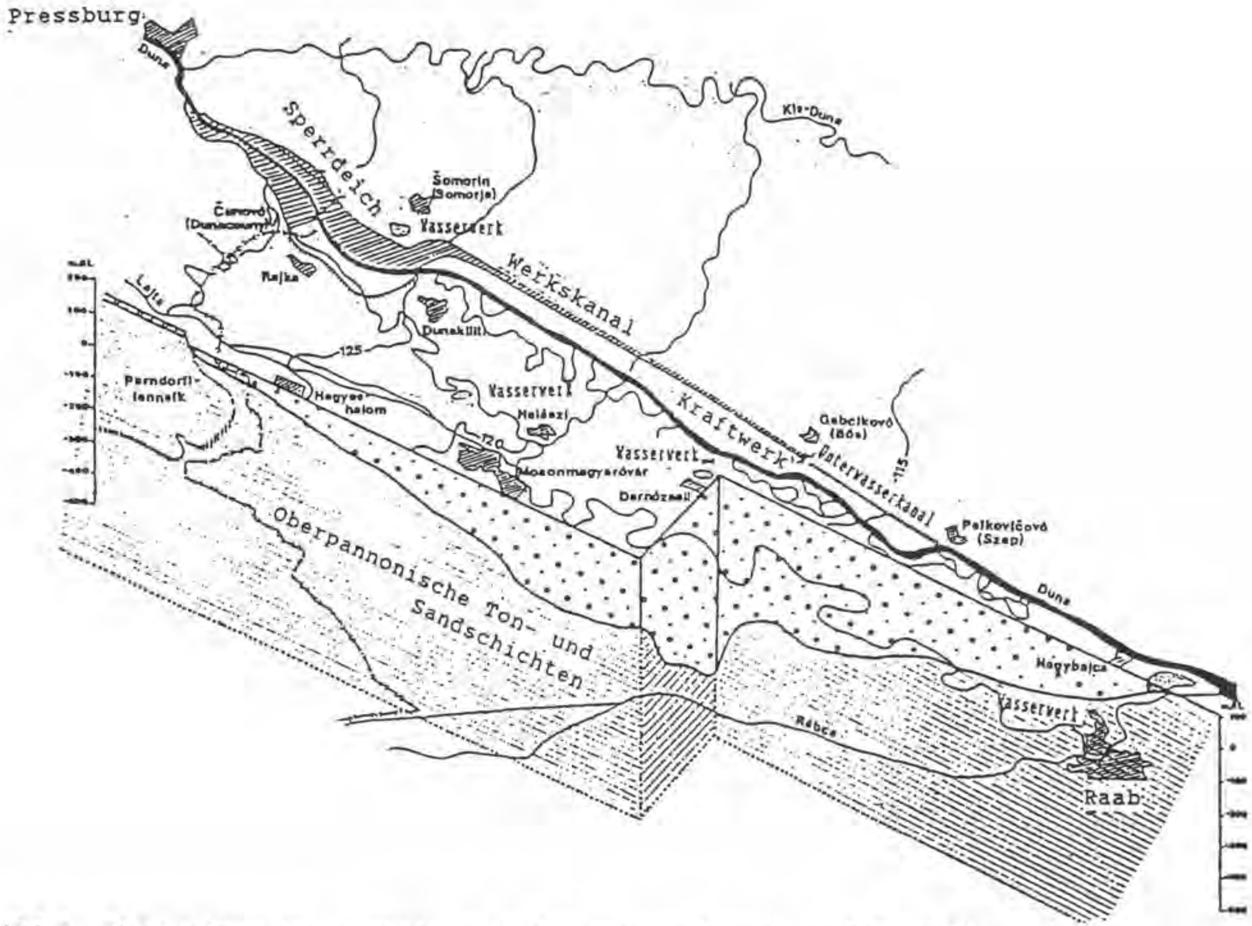

Bild 1. Blockschema des schüttkegels der Oberen-Donau (nach Neppel)

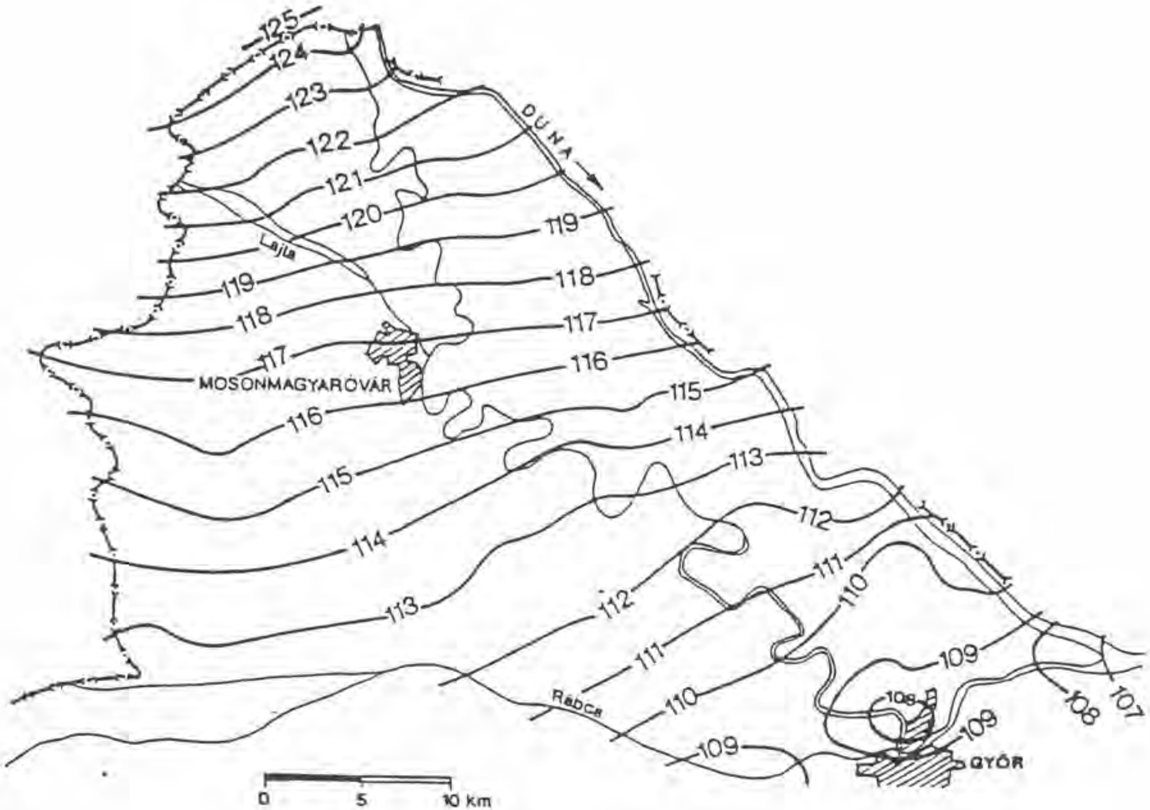

Bild 2. Grundwasser-Höhenlinien, Originalzustand (nach Maginecz)

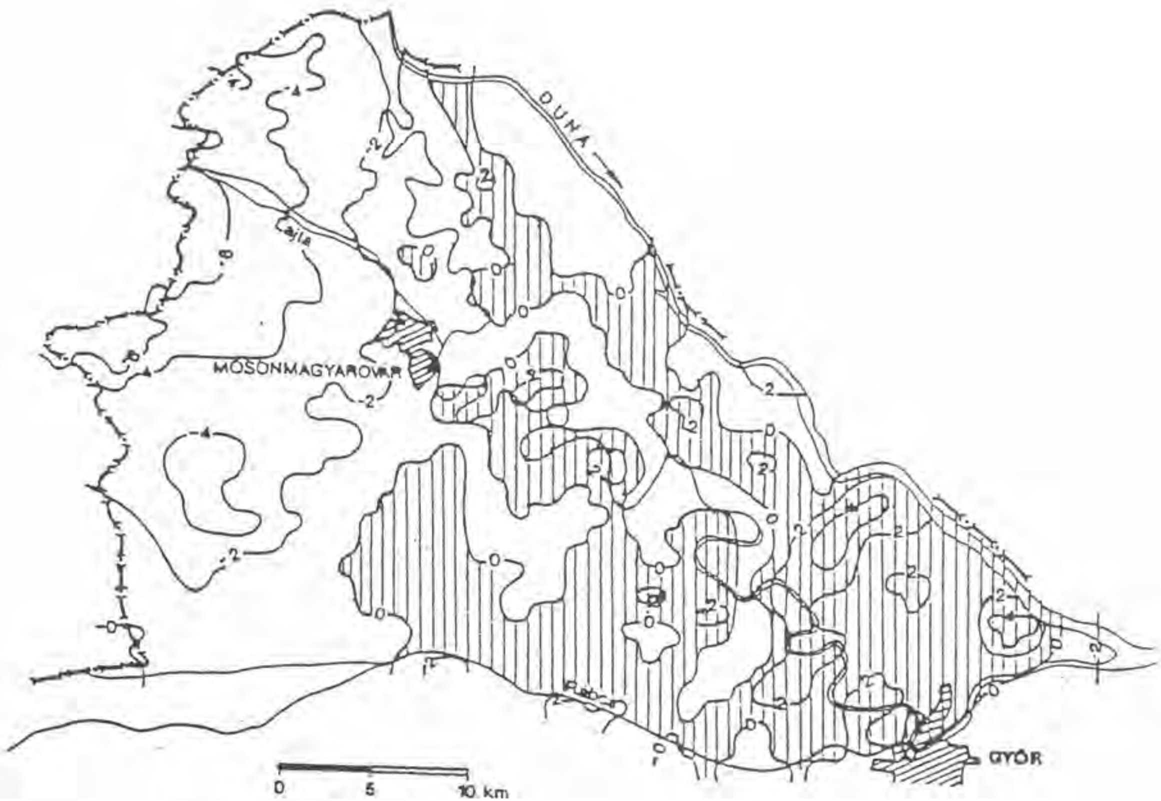

Bild 3. Tiefe des Grundwasserspiegels unter Unterkante der Deckschicht [m], Originalzustand (nach Maginecz)

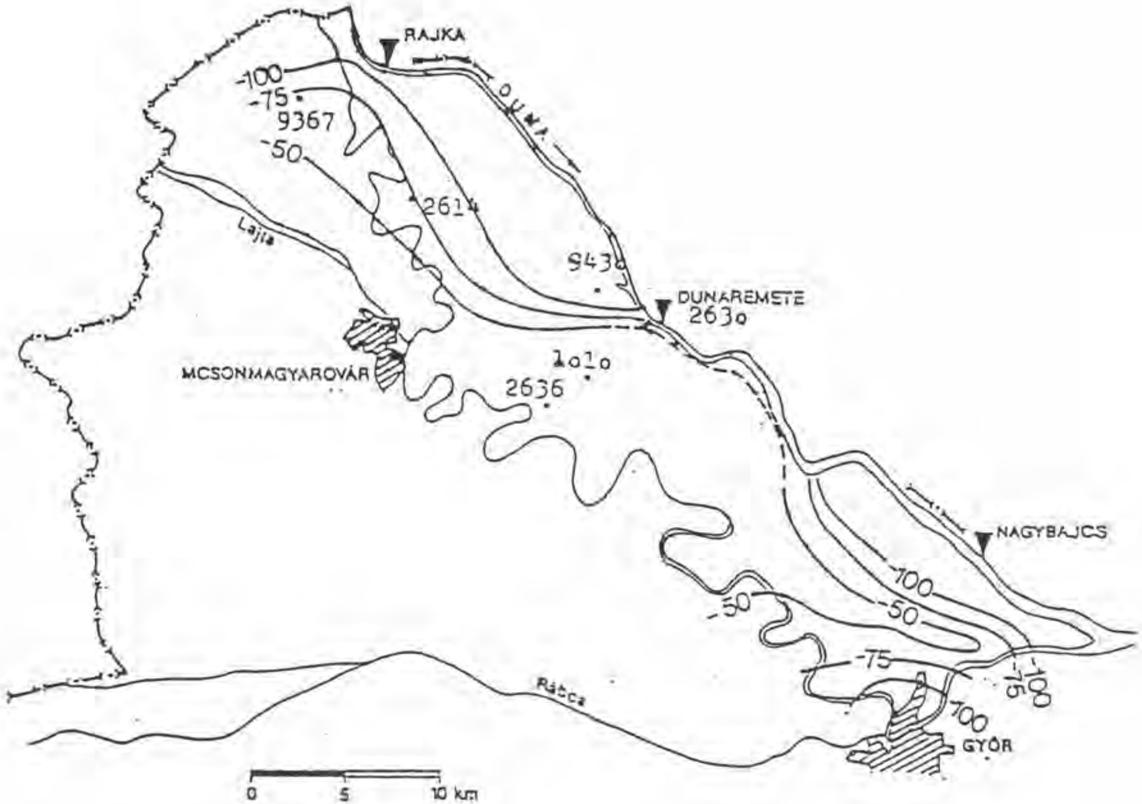

Bild 4. Unterschied der mittleren Grundwasserstand in den Perioden 1956-60 und 1986-90 (nach Szalai)

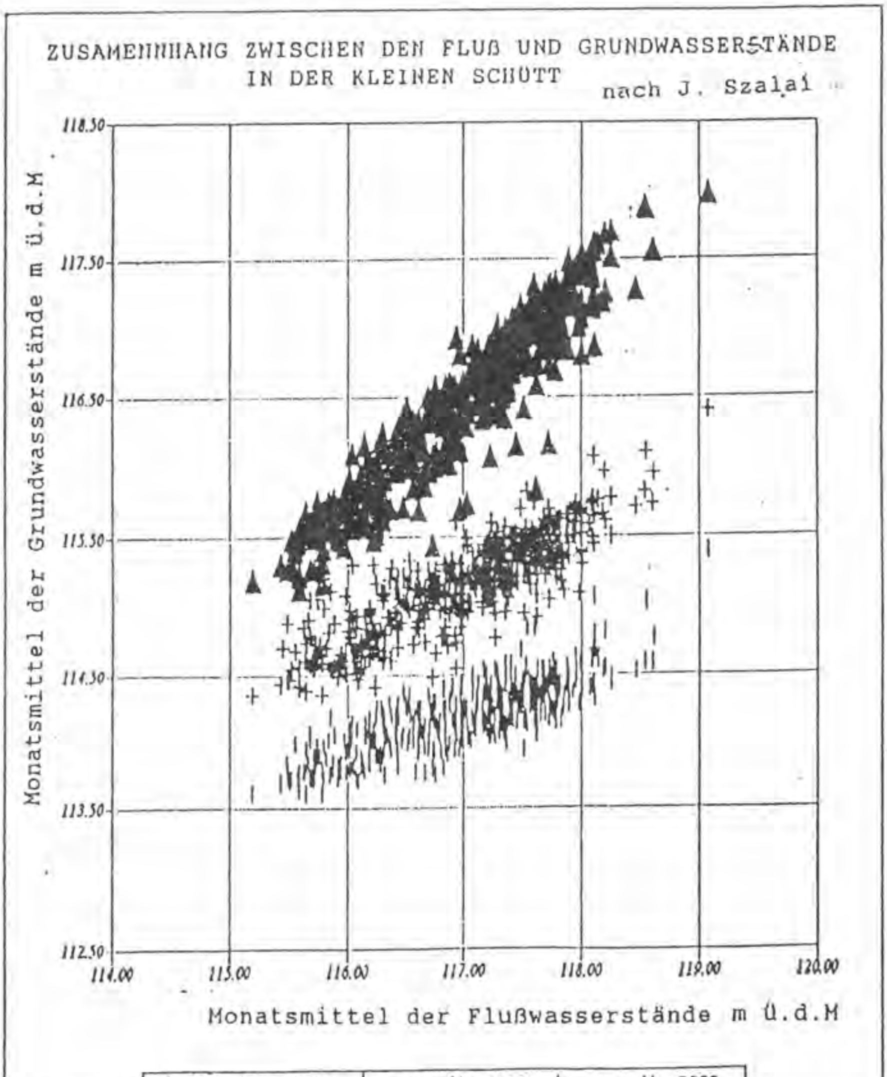
ZUSAMENHHANG ZWISCHEN DEN FLUß UND GRUNDWASSERSTÄNDE
IN DER KLEINEN SCHÜTT
nach J. Szalai
Monatsmittel der Grundwasserstände m ü.d.M
118.50
117.50
116.50
115.50
114.50
113.50
112.50
114.00
115.00
116.00
117.00
118.00
119.00
120.00
Monatsmittel der Flußwasserstände m ü.d.M
g.w.p Nr.: 1010.
g.w.p.Nr.: 2630.
g.w.p.Nr.: 2636.

Bild 5

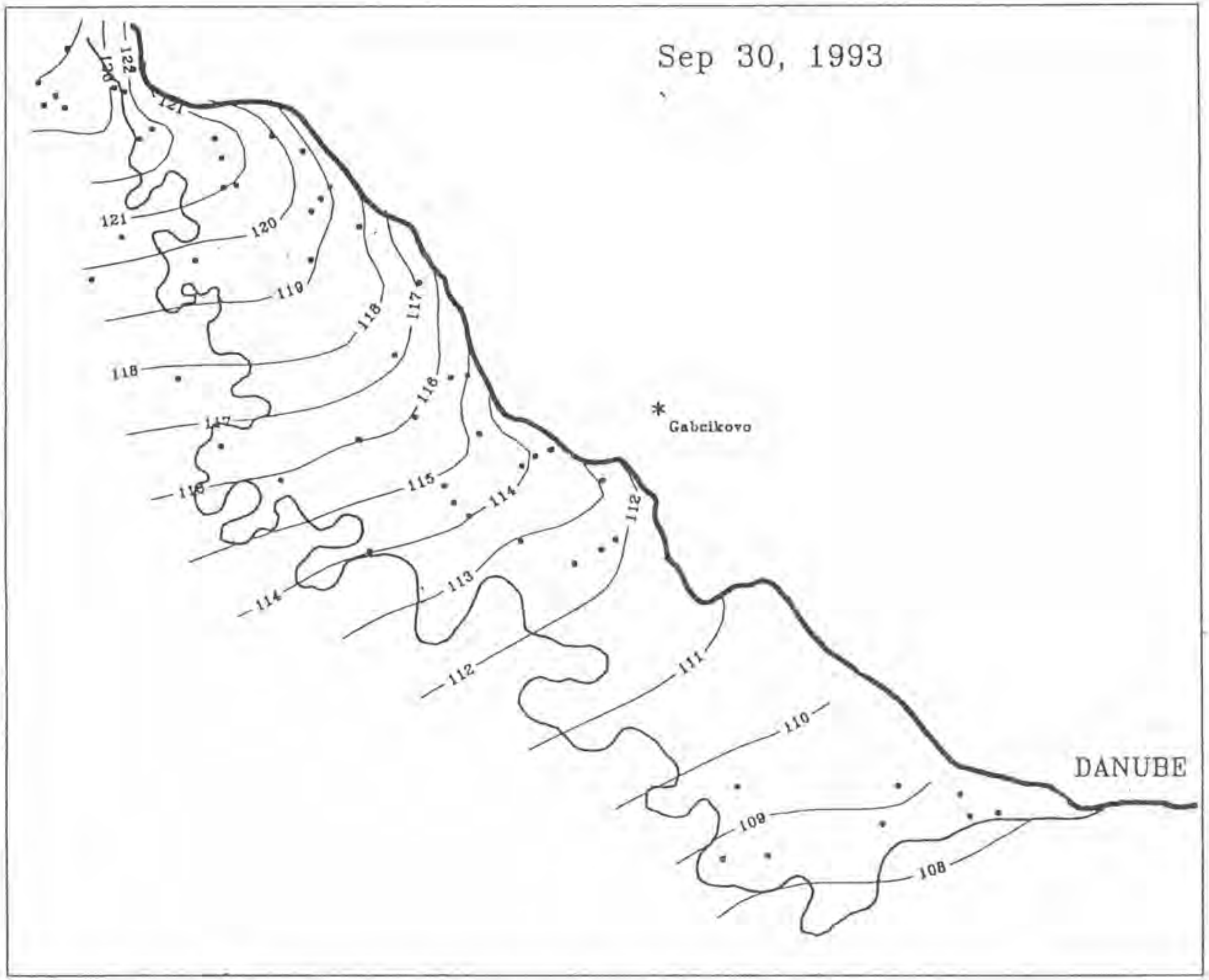

Bild 6. Grundwasser-Höhenlinien nach der Umleitung der Donau

XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
hydrologisch-wasserwirtschaftliche Grundlagen

XVIIth CONFERENCE OF THE DANUBE COUNTRIES
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Hoch-, Mittel- und Niedrigwasserabflußverhalten im oberen Donau-Einzugsgebiet bis Ulm

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Kurzfassung

Um extreme Envicklungen im Abflußverhalten des oberen Donau-Einzugsgebietes zu erkennen, hat die Landesanstalt für Umweltschutz Baden-Württemberg eine erste Zustandsaufnahme gemacht. Untersucht wurden die höchsten mittleren und niedrigsten monatlichen und jährlichen Abflüsse an Pegeln der oberen Donau bis Ulm und an mündungsnahen Pegeln der Nebenflüsse, deren Zeitreihen i.d.R. eine Länge von 60 bis 70 Jahren aufweisen. Zusätzlich einbezogen wurden 100jährige Zeitreihen mit monatlichen Niederschlagshöhen von Stationen des Deutschen Wetterdienstes im oberen Donau-Einzugsgebiet. Die Ergebnisse der Regime-, Homogenitäts- und Trendanalyse belegen in den letzten 20 bis 30 Jahren einen Anstieg der Hoch- und mittleren Abflüsse sowie ein nur geringfügiges Fallen der Niedrigwasserabflüsse während der Trockenwetter-Zeiten von September bis November. In dieser Zeitspanne sind die jährlichen Niederschläge angestiegen und haben sich im Jahresgang verändert. Die Niedrigwasser-Abflußverhältnisse sind als noch weitgehend natürlich anzusehen. Die Veränderungen im Hoch- und mittleren Abflußverhalten können durch ein sich in den letzten 3 Jahrzehnten veränderndes Niederschlags-Verhalten erklärt werden.

Summary

The characteristics of peak, mean and low-flow discharges in the upper Danube cathment area

To recognize extreme changes in the run-off regime of the upper Danube a first inventory was carried out by the Landesamt für Umweltschutz Baden-Württemberg. The time series of peak, mean an low-flow discharges at the gauging stations of upper Danube as for as Ulm and of the tributary rivers were investigated on a monthly and yearly scale; the time series had to be as long a 60 to 70 years. In addition, 100 years - time series of monthly precipitaion data, delivered by Deutscher Wetterdienst, were analyzed. The results of the analysis of regime, of homogeneity tests and trend analysis show a rise of the peak and mean discharges as well as slight drop of low-flow during dry periods (August to November) within the last 2-3 decades. During this time period the annual precipitation depths are increased and altered in its yearly regime. The low-flow characteristics are considered to be almost naturally. The changes in the peak and mean run-off regime may be largely explained by a precipitation regime which is changing since the last 3 decades.

Einführung und Untersuchungsgang

Vorauswertungen im oberen Donau-Einzugsgebiet zeigen in den letzten 25 Jahren eine deutliche Zunahme der Hochwasserabflußscheitel und an einigen Donau-Pegeln auch steigende mittlere Abflüsse. In den letzten 10 Jahren treten öfter extreme Niedrigwasser-Zeiten auf. Um extreme Entwicklungen zu erkennen, hat die Landesanstalt für Umweltschutz Baden-Württemberg an 60- bis 70jährigen Abfluß-Zeitreihen im oberen Donau-Einzugsgebiet (Abb. 1) sowie in benachbarten Einzugsgebieten des Rheins und des Neckars umfangreiche Konsistenzprüfungen und Zeitreihenuntersuchungen durchgeführt und eine Zustandsaufnahme zum Abflußverhalten gemacht. Bisher wurden die Ursachen für Veränderungen im Abflußverhalten vorwiegend nur auf menschliche Tätigkeiten wie Landnutzungsänderung, Urbanisierung, wasserwirtschaftliche Regelungen (Flußbau, Hochwasserschutz, Wasser-Fernversorgung etc.) und als Folge der immer intensiver werdenden gewerblich-industriellen Nutzung von Regionen zurückgeführt. Mit Ausnahme von einigen Schwerpunkten im Untersuchungsgebiet, wie die Räume um Donaueschingen, Tuttlingen, Ulm, Kempten, Memmingen werden die o.a. Einflüsse auf das Abflußverhalten als gering eingeschätzt, weil im übrigen oberen Donau-Einzugsgebiet die Siedlungsdichte relativ gering ist.

Veränderungen im Abflußverhalten können auch bedingt sein durch ein sich veränderndes Niederschlagsverhalten. Daher wurden auch 100jährige Zeitreihen (1892-1992) mit monatlichen und jährlichen Niederschlagshöhen von 10 Stationen des Deutschen Wetterdienstes (Offenbach a.M.) einbezogen (Abb. 1 u. Tab. 1). Auf die Ableitung von Gebietsniederschlägen wurde bewußt verzichtet, weil das zur Verfügung stehende Stationsnetz zu weiträumig ist. Daher werden Zeitreihen an Einzelstationen beurteilt. Das Problem der Stationsrepräsentanz und Schluß auf räumliche Verteilung bleibt offen, weil Inseleffekte, lokale Ereignisse und Größe des Niederschlagsgebietes i.d.R. nicht erkannt werden können.

An 13 Pegeln des oberen Donaueinzugsgebietes einschließlich der bayerischen Pegel Neu-Ulm-Bad Held/Donau und Wiblingen/Iller wurden zunächst 60- bis 70jährige Zeitreihen mit monatlichen und jährlichen höchsten Scheitelabflüssen HQ, mittleren Abflüssen MQ und niedrigsten Abflüssen NM_7Q untersucht (Abb. 1 u. Tab. 2). Für die Stationsauswahl maßgebende Gesichtspunkte waren weitgehend gesicherte Erfassung der Hoch- und Niedrigwasserabflüsse und keine intensiven Einflüsse von wasserwirtschaftlichen Regelungen, wie z.B. in den Einzugsgebieten der Donau-Nebenflüsse Brenz und Eger im Nordwesten sowie der Rot im Südosten des Untersuchungsgebietes vorhanden. Mit Ausnahme des Pegels Beuron/Donau zeigen die Zuflüsse zu den Pegeln keine direkten karsthydrologischen Beeinflussungen. Die Auswertungen erfolgen jeweils ab Beginn der Pegel-Beobachtungen bis zum Stichjahr 1992.

Die Zeitreihen für Niederschlag, Hoch- und mittleren Abfluß werden gemäß dem hydrologischen Jahr (jeweils von November bis Oktober) und der Niedrigwasserabfluß gemäß dem Niedrigwasser-Jahr (jeweils von April bis März) untersucht. Die Zeitreihen werden bewußt nicht auf eine einheitliche Zeitspanne bezogen, weil dadurch ein wesentlicher Verlust von Informationen verloren gegangen wäre, insbesondere zu Zeitabschnitten, in denen innerhalb der Zeitreihen Inkonsistenzen und Inhomogenitäten nachweisbar sind.

Um Inhomogenitäten in den Abfluß- und in den Niederschlags-Zeitreihen zu erkennen, wurden statistische Verfahren zum Erkennen von signifikanten Veränderungen (Bruchpunkttest, Summen- und Doppelsummenlinienverfahren), die eigentliche Trendanalyse (Beurteilung der Trend-Signifikanz gemäß dem Mann-Kendall-Test [7], [2]; parameterfreier Test, unabhängig von Häufigkeitsver-

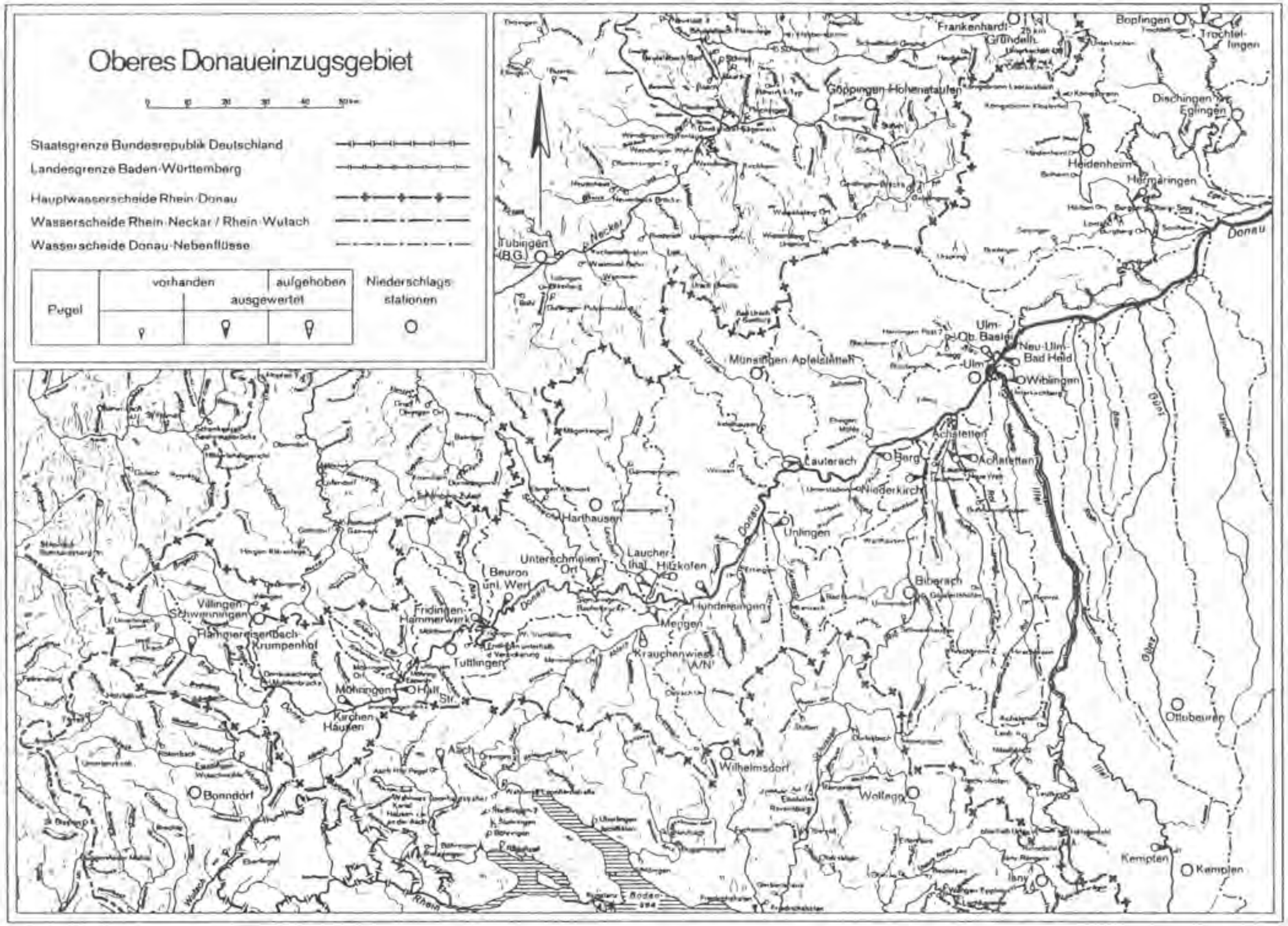

Abb. 1: Abflußpegel und Niederschlagsstationen im oberen Donau-Einzugsgebiet

Tab. 1: Trenduntersuchung von 100jährigen Niederschlagszeitreihen im oberen Donau-Einzugsgebiet. Jährliche und wintersaisonale Niederschlagshöhen.

Region Niederschlagsmesser (Einzugsgebiet) (Zeitspanne 1892-1992)[1]	Höhe [m üNN]	hN(J) Hydrolog. Jahr (Nov.-Okt.) Mittel [mm]	Trend [mm/Jahr]	Signif. [%]	Änderung ab	hN(Wi) Wintersaison (Dez., Jan., Febr.)[2] Mittel [mm]	Trend [mm/Jahr]	Signif. [%]	Änderung ab
Schwarzwald-Einzugsgebiet									
1. Villingen-Schwenningen (Brigach)	720	861	+ 1,54	99,5	1955	207	+ 0,77	99	1955
2. Bonndorf/Schwarzw. (Wutach)[3]	876	971	+ 0,79	80	(1935)	240	+ 0,72	90	1935
Schwäbische Alb									
3. Tuttlingen (Donau)	648	856	+ 1,08	98	1964	165	+ 0,61	99	1956
4. Harthausen (Lauchert)[4]	737	773	+ 0,27	-	1952	145	+ 0,46	99	(1935)
5. Münsingen-Apfelstetten (Große Lauter)	750	890	+ 1,56	99,5	1960	181	+ 0,60	99,9	(1944)
6. Heidenheim (Brenz)	500	821	+ 1,70	99,9	1924	189	+ 0,80	99,9	1949
Alpenvorland									
7. Biberach (Riß)	581	807	+ 0,29	-	1964	125	+ 0,22	90	1954
9. Kempten (Iller)	705	1.204	+ 1,13	90	1952	235	+ 0,23	-	1963
9. Ottobeuren (Günz)	665	1.045	+ 1,86	99,5	1962	170	+ 0,45	98	1948
10. Ulm (Donau)	522	733	+ 0,72	90	1952	130	+ 0,35	99	1954

1) Hydrologisches Jahr, jeweils von November bis Oktober
2) Summe über 3 Monate
3) Stationsverlegung 1985
4) Station endet 1984

Tab. 2: Trend- und Homogenitätsuntersuchung von Hoch-, Mittel- u. Niedrigwasserabflüssen an Pegeln im oberen Donau-Einzugsgebiet

Region Pegel/Gewässer	A_{Eo} [km²]	Untersuchte Zeitspanne[1]	Höchster jährlicher Abfluß HQ(J) Mittel [m³/s]	Trend [m³/s Jahr]	Signifik. [%]	Änderung ab
Östlicher Schwarzwald						
1. Hammereisenbach-Krh./Breg	158	1927-1992[2]	49,5	+ 0,67	99,9	1976
Schwäbische Alb						
2. Kirchen-Hausen/Donau	767	1923-1992[2]	129	+ 1,04	98	1977
3. Beuron unter Wert/Donau	1.320	1927-1992[2]	133	+ 1,42	99	1976
4. Hundersingen/Donau	2.629	1930-1992	173	+ 1,75	98	1976
5. Berg/Donau	4.037	1930-1992	202	+ 1,19	80	1976
6. Neu-Ulm-Bad Held/Donau	7.578	1926-1992[2]	575	- 0,18	-	1963
7. Fridingen-Hammerwerk/Bära	133	1938-1992[2]	18,5	+ 0,15	70	1975
8. Unterschmeien-Ort/Schmiecha	150	1932-1992[2]	9,08	+ 0,016	-	1976
9. Laucherthal/Lauchert	452	1933-1992[2]	13,0	+ 0,075	80	1976
10. Lauterach/Große Lauter	299	1930-1992	4,43	+ 0,015	90	1972
Alpenvorland						
11. Niederkirch/Riß	405	1932-1992[2]	26,7	+ 0,11	95	1956
12. Achstetten/Westernach	250	1933-1992	20,6	+ 0,16	98	1979
13. Wiblingen/Iller	2.115	1921-1992	462	- 1,44	90	1940-1950

1) HQ- und MQ-Zeitreihen jeweils von November bis Oktober, NM_7Q-Zeitreihen jeweils von April bis März
2) Folgepegel mit Vorgängerpegel

Region Pegel/Gewässer	Mittlerer jährlicher Abfluß MQ(J) Mittel [m³/s]	Trend [l/s Jahr]	Signifik. [%]	Änderung ab	Niedrigster jährlicher Abfluß $NM_7Q(J)$ Mittel [m³/s]	Trend [l/s Jahr]	Signifik. [%]	Änderung ab
Östlicher Schwarzwald								
1. Hammereisenbach-Krh.Breg	4,68	+ 12	80	1964	0,92	- 2	-	1946-1952
Schwäbische Alb								
2. Kirchen-Hausen/Donau	12,7	+ 11	-	1964,1976	2,79	- 7	-	1946-1952, [illegible]
3. Beuron unter Wert/Donau	10,9	+ 78	98	1964	0,95	- 7	90	1944-1953
4. Hundersingen/Donau	24,6	+ 83	80	1965	6,45	- 18	-	1942-1953
5. Berg/Donau	38,0	+ 110	80	1964	14,1	+ 9	-	1942-1953
6. Neu-Ulm-Bad Held/Donau	119	+ 188	-	1964	48,6	+ 18	-	1946-1953
7. Fridingen-Hammerwerk/Bära	1,75	+ 3	-	1964	0,30	+ 2	80	1947-1953
8. Unterschmeien-Ort/Schmiecha	1,57	+ 1	-	1964	0,34	+ 3	99,5	1949-1953
9. Laucherthal/Lauchert	4,28	+ 3	-	1965	1,69	- 2	-	1947-1953
10. Lauterach-Große Lauter	1,43	+ 5	-	1973	0,48	+ 5	99,9	1942-1952, 1976
Alpenvorland								
11. Niederkirch/Riß	4,44	- 6	-	1942,1964	2,38	+ 7	80	1945-1952
12. Achstetten/Westernach	2,24	+ 6	95	1964	1,02	+ 2	-	1944-1953
13. Wiblingen/Iller	69,4	+ 59	-	1964	23,4	+ 1	-	1944-1952

teilungen) sowie die Analyse von zyklischen Veränderungen auf die Zeitreihen angewendet; methodische Grundlagen siehe [4], [5]. Weiterhin wurden Regimeänderungen im jährlichen Gang von Niederschlag und Abfluß vermutet und untersucht.

Ergebnisse und Folgerungen

1. Niederschlag

- Die 100jährige Zeitreihen der an den DWD-Stationen erfaßten monatlichen und jährlichen Niederschlagshöhen zeigen überall steigende Trends; mit Ausnahme an den Stationen Bonndorf, Harthausen und Biberach sind die Trends signifikant (Tab. 1).
- Überall im Untersuchungsgebiet sind stark signifikant steigende Trends bei den Niederschlagssummen über die Wintermonate Dezember bis Februar, außer bei der Station Kempten (Iller-Gebiet) erkennbar (Tab. 1).
- Inhomogenitäten, insbesondere Zunahme der jährlichen Niederschlagshöhen sind bei fast allen Zeitreihen ab den 50er und 60er Jahren zu erkennen, außer an den Stationen Bonndorf am westlichen Rand und Heidenheim im Nordosten des Untersuchungsgebietes.
- Vergleichende Auswertungen zu den Jahresgängen der monatlichen Mittelwerte zeigen bei allen Stationen in den letzten 30 Jahren (Teilzeitspanne 1962 bis 1992) gegenüber der davorliegenden Teilzeitspanne 1892 bis 1962 generell höherliegende Monatsmittel in den Monaten November bis Juni; in den Monaten November bis April liegen die Monatsmittel der Stationen im westlichen Untersuchungsgebiet wesentlich höher als im östlichen Beeich. Mit Ausnahme der Stationen Kempten und Ottobeuren am Ostrand des Untersuchungsgebietes zeigen die Monatsmittel der letzten 30 Jahre in den Monaten Juli bis Oktober i.d.R. geringfügig niedrigere Werte gegenüber der davorliegenden Vergleichszeitspanne.

Damit ergeben sich Veränderungen und Verschiebungen im Jahresgang der Niederschläge, die sich auf das Abflußverhalten auswirken können. Hier besteht weiterer Untersuchungsbedarf, insbesondere auch, weil Zusammenhänge mit - evtl. anthropogen beeinflußten klimatischen - Veränderungen vermutet werden [7], [8].

2. Hochwasserabfluß

- Im oberen Donau-Einzugsgebiet bis Ulm steigen die jährlichen Scheitelabflüsse signifikant an 10 untersuchten Pegeln (Tab. 2). An fast allen Pegel-Zeitreihen läßt sich ein deutlicher Anstieg, etwa ab Mitte der 70er Jahre erkennen.
- Vergleichsuntersuchungen der Jahresgänge der mittleren monatlichen Höchstabflüsse zeigen, ähnlich wie bei den u.ä. mittleren Abflüssen für die 30jährige Teilzeitspanne 1962 bis 1992 gegenüber der davorliegenden Teilzeitspanne in fast allen Monaten generell höhere und in den Monaten November bis Juni/Juli wesentlich höhere mittlere Hochwasserabflüsse.

Mit Ausnahme des alpin beeinflußten Iller-Einzugsgebietes und am unterhalb der Iller-Mündung liegenden Donaupegel Neu-Ulm treten die jährlich höchsten Scheitelabflüsse vornehmlich in den Winterhalbjahren auf (vornehmlich von Dezember bis April). Es besteht die Vermutung, daß die winterlichen Höchstabflüsse zunehmend beeinflußt werden durch ein sich in den letzten Jahrzehnten veränderndes Niederschlagsverhalten (s.o.); ein häufigeres Zusammentreffen von Schneeschmelze und Niederschlagstätigkeit wird vermutet. Hier besteht noch weiterer Untersuchungsbedarf.

3. Mittlerer Abfluß

- Mit Ausnahme des Riß-Einzugsgebietes (Pegel Niederkirch) zeigen alle untersuchten Pegel-Einzugsgebiete mehr oder minder steigende Trends in den mittleren jährlichen Abflußreihen (Tab. 2). In den Einzugsgebieten der Donaupegel oberhalb von Ulm bis zu den Quellflüssen im Schwarzwald und an der Westernach (Pegel Achstetten) ergeben sich signifikant steigende Trends.

- Die Erhöhung der mittleren Abflüsse ist etwa ab Mitte der 60er Jahre nachweisbar und kann mit den Erhöhungen der Niederschläge ab den 50er und 60er Jahren in Zusammenhang gebracht werden.

- Vergleichsuntersuchungen der Jahresgänge der mittleren monatlichen Abflüsse zeigen generell gleiches Verhalten wie oben bei den Hochwasserabflüssen beschrieben.

Der in den letzten Jahrzehnten beobachtete erhöhte mittlere Abfluß und dessen Abhängigkeit von steigenden Niederschlägen im oberen Donau-Einzugsgebiet sollte durch weitere Untersuchungen zur Wasserbilanz und zu möglichen Veränderungen der Verdunstung ergänzt werden; vgl. [9].

4. Niedrigwasserabfluß NM_7Q

- Von den im oberen Donau-Einzugsgebiet untersuchten 13 Pegel-Zeitreihen (Tab. 2) haben nur 2 stark signifikant positive Trends (Unterschmeien/Schmiecha und Lauterach/Große Lauter) und 2 schwach signifikant steigende Trends (Pegel Friedingen/Bära und Niederkirch/Riß). Die steigenden Trends könnten bedingt sein durch Einleitungen der Trinkwasserversorgung oder aber auch durch mangelnde Präzision in der Niedrigwasser-Meßtechnik. Der schwach signifikant fallende Trend am Donaupegel Beuron ist wahrscheinlich bedingt durch karsthydrologische Einflüsse im Bereich der oberhalb liegenden Versinkungsstellen.

- Deutlich erkennbar werden bei allen Pegelzeitreihen die starken Trockenwetter-Abflußperioden zwischen 1942 und 1953 (Tab. 2). Die sprunghafte Erniedrigung der NM_7Q-Abflüsse nach 1971 am Pegel Kirchen-Hausen/Donau ist wahrscheinlich bedingt durch den zum gleichen Zeitpunkt erfolgten Pegel-Neubau und einer genaueren Erfassung der Niedrigwasser-Verhältnisse ab diesem Zeitpunkt.

- Die Jahresgänge der mittleren monatlichen NM_7Q-Abflüsse ergeben beim Vergleich der neuerlichen Teilzeitspanne 1962 bis 1993 gegenüber der jeweils davorliegenden Teilzeitspanne niedrigere NM_7Q-Abflüsse für das westliche Untersuchungsgebiet in den Monaten Juli bis November und für das östliche Untersuchungsgebiet in den Monaten September bis November; dies ist als Hinweis auf extremere Trockenperioden in den Spätsommer- und Herbstmonaten zu deuten.

Wie die Trenduntersuchungen ergeben, muß das derzeitige Niedrigwasser-Verhalten aufgrund der Meßungenauigkeiten des Niedrigwassers, der nur geringfügigen Trinkwasserüberleitungen aus Fremdeinzugsgebieten und der Karsterscheinungen oberhalb von Beuron noch als weitgehend natürlich angesehen werden. Dennoch ergeben sich Tendenzen zu erniedrigten Niedrigwasserabflüssen gerade in den Spätsommer- und Herbstmonaten. Weitergehende Untersuchungen zum Auftreten von Niedrigwasser im Zusammenhang mit Trockenwetterperioden und (zusammenhängenden) Niedrigwasserdauern stehen noch aus.

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XVII. KONFERENZ DER DONAULÄNDER
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Variations of the river runoff in the Danube river basin as a result of climate changes

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Abstract: Regional peculiar features of the mean annual and seasonal runoff of the Danube basin rivers were stated, using the results of complex statistic analysis of 35-year and 60-year series of hydrological observations. In the upper part of the basin the directed runoff variations are slight, negative during the warm period of the year and positive during the winter period. In the lower part of the basin (rivers in the East Carpathians) the variations of the annual, spring, summer and autumn runoff are characterized by positive trends. The most significant climatic river runoff variations have been observed in 70-s and also in 30-s, 60-s and 80-s in the middle and lower parts of the Danube river basin

I. Introduction

The current changes of the Global climate, characterized by 0.5°C increase of the mean global air temperature for 100 years /1/, cause interest among hydrologists as these changes can affect the variations in the character of water resources formation. Studies, made by the authors /2,3/ on the rivers of Russia and former USSR territory, suggest, that the current regional differences are observed in the direction of the mean annual and mainly seasonal and monthly river runoff variations both for 100-year period and for the years of the second half of the XXth century.

A considerable extent of the Danube river basin, a variety of runoff formation conditions and the availability of the reliable long-term observations for hydrological regime at its inflows, allow to estimate the regional peculiar features of river runoff variations in the basin.

2. Methods of studies and used materials

In accordance with the Recommendations of the World Meteorological Organization /4,5/ it is wise to apply complex statistic analysis of hydrological observation series for the similar calculated periods to study time and space regularities in water resources changes. Analysis of the long-term properties of the averages in time series allows to estimate climatic variations of annual, seasonal and monthly river runoff.

Considering the additions, proposed by the authors /2,3/, the following complex of statistic criteria has been used: ranked criteria of special test for trend, Mann's criterion, Kruskel-Wallice criteria to perform samplings (basing on two periods with three subperiods) within one statistic population and Buishand-Worsly test for the outlier (change) in the series /5/.

Calculations by the complex methods have been performed by 5 observation sites, located in different parts of the basin, and by the Danube river stations - Bratislava. The calculations were made for two calculated periods - 1926-1985 and 1951-1985.

To estimate space regularities in the direction and intensity of runoff variations, the calculation results were used only for 35-year (1951-1985) period of observations, using a slightly simplified methods of the WMO and authors /2-4/, which is based on a special test for trend. The selection of a trend and its analysis have been performed via the method of least squares. Statistic parameters, necessary for analysis, were obtained after preliminary functional smoothing of time series. With a final decision about the existence of a trend or a tendency within time series an expert estimation is made with reference to the derived statistic parameters: statistic significance or probability of detected trends and tendencies - γ , a coefficient of the first oder polynom or trend parameter - b_2 ,errors of the parameter calculation- σ_ℓ , the considered variance $-\frac{\sigma_t^2}{\sigma_{est}^2}$ ρ. The mandatory condition for trend existence is $\gamma \geq 95\%$ and $\ell < 2\sigma_\ell$, and the condition for tendency existence is $75\% \leq \gamma < 95\%$ and $\ell > \sigma_\ell$ .When the signs (specifying an ascending and descending trend) of the criterion γ and trend parameter ℓ do not coincide, it is considered that a trend or tendency is absent as in the case when $\gamma < 75\%$ and $\ell < \sigma_\ell$.

Such calculations are made for 15 observation sites at the Danube basin rivers (Table 1) over the territory of Germany, Czechia, Slovakia, Roumania, Ukraine. While analyzing space distribution of runoff variations at the Danube river basin the calculation results were also used for the observations at the rivers in the adjacent basins over the territory of the above mentioned states and Poland.

3. Probability and direction of the mean annual seasonal and monthly river runoff variations.

The trend probability estimation by the methods of the WMO and authors /2-4/ for 35-year period (1951-1985) testifies to the probability growth of the directed water runoff variations from the upper west to the east regions of the basin (Table 1).

In the upper Alpine area of the Danube river basin the variations of the mean annual river runoff (Inn, Zaltzakh rivers) are characterized by the absence of a trend or slight negative tendencies (trend probability is about 75%). The probability of the negative variations is increased during spring-summer months and the positive tendencies (Saltzakh river) and even trends (Inn river) are observed during low water winter period.

The mean annual basin runoff, formed in the west Carpathians (Vag, Gron, Morava rivers), is characterized by the absence of significant variations. The variations of the mean annual runoff are characterized by a positive tendency only at individual small rivers (Kisuka river).

No substantial annual runoff variations are observed for 35-year and 60-year periods at the observation line at the Danube river near Bratislava. But positive tendencies in runoff of the Danube river and its inflows are observed at this part of the basin during spring (March-April) and autumn (October-November) months. At individual months of the summer period the negative tendencies (Table 1) are observed along with the predominance of significant variation absence.

In the lower left-bank part of the basin, where the river runoff is formed mainly in the east Carpathians, the character of the mean annual, seasonal and monthly runoff variations substantially differs from the variations in the upper part. The tests for trend of data on the mean annual runoff on 8 rivers over the territory of Slovakia, Roumania and Ukraine testify to the fact, that positive variations for 1951-1985 are observed on all rivers, and on 6 rivers the probability of variations is more than 95%. Only runoff variations on Toplev and Uzh rivers are characterized by the trend probability of 86-90%.

In seasonal runoff the positive variations are clearly defined during summer months (July) as well as during spring and autumn seasons. Runoff on the rivers of the lower part of the Danube river basin changes slightly during winter months.

The detected regularities of the mean annual, seasonal and monthly runoff variations on the rivers of the lower part of the Danube river basin are confirmed by the predominant positive trends in the variations of the mean annual and seasonal runoff on the rivers of the adjacent territories of Poland, Ukraine and Moldova, which runoff is also fermed at the east Carpathians.

4. Analysis of hydrological series stationarity

Calculation analysis via the WMO complex methods for 35-year and 60-year periods, made by the mean monthly and annual data, allowed to state, that runoff on Vag river to Liptovsky, Morava river to Moravtzani and Danube river to Bratislava is substantially regulated. It does not allow to find out the direction and periods of runoff climatic variations for the selected calculated periods. Thus, observations for Zaltzag-Burgkhauzen river for the upper part of the basin, Inzera-Turitza river for the middle part and Muresh-Arad river for the lower part of the Danube river basin are used to analyze hydrological series stationarity and to specify the periods of the directed variations.

Analysis of the mean annual runoff for Zaltzakh-Burgkhauzen river basin, using Mann's criterion, indicates the absence of a monotonic trend in the series for 1926-1985 and the existence of the negative tendency for 1951-1985 that confirms the results of a special test for trend via the methods of authors (Table 1). The absence of a trend for 60-year period is explained by the fact that variations of water content at the beginning and end of this period are of an unequally directed character and cause a compensation of the positive and negative deviations.

Kruskel-Wallice criteria, calculated for different subperiods of a specified series according to the accepted alternative hypothesis indicate a violation of uniformity in the mean annual runoff values for 1951-1985 and Buishand-Worsley criteria specify the periods of sharp variations in the mean annual values of the series - 1979 and 1980. The calculations for the monthly mean runoff values showed a more distributed character of outliers in river water content in 35-year series: by Buishand - in 1970 - April and August, in 1975 - July, in 1976 - January, in 1977 - February, in 1979 - March, May, June and December, in 1980 - September and December; by Worsley - in 1979 - February, May, June, December, in 1980 - January, March, April, July-October.

Thus, the most significant outlier in runoff values for the upper part of the Danube river basin has occured at interface of 70s and 80s and was most pronounced in summer and winter runoff.

No monotonic trend of the mean annual runoff variations is observed in the middle part of the Danube basin for observation data at Inzer-Turitza river for the period from 1926 to 1985 and a slight tendency (78% probability) is observed for 1951-1985. The calculations by Kruskel-Wallice criteria confirm the violation of series uniformity for 60-year period. Buishand-Worsley criteria define more exactly that a sharp water content change also occured at the end of 70s but some changes were observed at the beginning of a calculated 60-year period.

The results of complex statistic analysis of observation data on Muresh river in the lower left-bank part of the Danube basin confirm the substantial positive variations for 35-year period and the existence of a monotonic positive trend for 60-year period. Analysis via Kruskel-Wallice criteria verifies the existence of substantial outliers in the series for 35-year and 60-year periods and analysis via Buishand-Worsley criteria indicates the existence of significant outliers at the beginning of the series (1936, 1939) during 60s and 80s. The great changes in 30s occured due to the variations of the monthly mean values of winter and summer runoff and in 60s and 80s - during spring-summer months.

Thus, the most significant climatic variations of river runoff in the Danube basin in the XXth century occured in 70s, but in the middle and especially in the lower part of the basin these variations were observed in 30s, 60s and 80s.

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Table 1

Variations of the monthly mean runoff on the rivers of the Danube for 1951-1985

	Probability and trend sign by months and for the year, %												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
			Germany										
Zaltzakh-Burgkhauzen	79,4	94,1	abs.	-89,4	abs.	abs.	-84,6	abs.	abs.	abs.	abs.	abs.	abs.
Inn-Vasserburg	99,9	99,9	81,1	abs.	-92,6	-93,4	-90,0	abs.	abs.	abs.	abs.	95,1	abs.
			Czechia										
Morava-Moravitzani	abs.	abs.	94,7	abs.	abs.	abs.	-75,2	abs.	abs.	88,9	abs.	abs.	abs.
			Slovakia										
Gron-Brezna	abs.	abs.	abs.	abs.	abs.	abs.	abs.	abs.	-83,4	abs.	90,0	74,2	abs.
Vag-Liptovsky Mikulash	abs.	abs.	abs.	abs.	abs.	abs.	abs.	abs.	abs.	abs.	98,2	abs.	abs.
Kisuka-Chadtza	abs.	abs.	81,9	abs.	86,0	-80,2	abs.	abs.	abs.	95,8	94,1	abs.	76,1
Toplev-Ganusovtze	abs.	abs.	abs.	abs.	93,8	abs.	97,0	abs.	88,9	abs.	98,6	89,4	86,7
Danube-Bratislava	abs.	abs.	81,9	97,2	abs.	abs.	abs.	abs.	-84,1	abs.	86,7	abs.	abs.
			Roumania										
Muresh-Arad	abs.	abs.	92,6	92,2	95,6	87,9	98,8	96,6	99,7	99,3	95,1	abs.	99,9
Samesh-Satu-Mare	abs.	abs.	abs.	abs.	90,0	78,8	98,2	94,4	98,2	93,8	98,7	abs.	91,0
			Ukraine										
Prut-Jarechma	abs.	abs.	86,0	abs.	93,8	96,8	99,9	abs.	abs.	abs.	abs.	abs.	99,9
Tereblya-Kolochava	87,7	abs.	97,5	abs.	95,6	99,1	99,6	96,9	98,9	95,5	95,5	94,5	99,8
Rika-Mezhgorje	abs.	abs.	87,9	abs.	99,4	81,1	99,4		abs.	abs.		abs.	97,7
Borzhava-Dolgoe	abs.	abs.	94,1	abs.	93,6	96,1	99,6	99,8	99,9	99,2	99,0	abs.	99,6
Uzh-Zarechevo	abs.	abs.	abs.	abs.	abs.	78,2	98,5	abs.	97,2	abs.	94,7	abs.	90,0

XVII. Konferenz der Donauländer
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AKTUALISIERUNG DER WASSERBILANZ DES DONAUBECKENS UND ERFASSUNG ANTHROPOGENER EINFLÜSSE

ARBEITEN UND PLANUNGEN DER REGIONALEN IHP - ARBEITSGRUPPE FÜR HYDROLOGIE DER DONAULÄNDER

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KURZFASSUNG

Im Anschluß an frühere Arbeiten der Donauländer, publiziert in der "Hydrologischen Monographie der Donau", wurde im Rahmen der "Regionalen IHP-Zusammenarbeit der Donauländer" eine Aktualisierung der seinerzeitigen Auswertungen beschlossen und in Angriff genommen. Dabei wird die Wasserbilanz der gesamten, nunmehr verfügbaren Periode von 1931-1990 neu bearbeitet sowie der aktuelle Stand der wichtigsten wasserwirtschaftlichen Nutzungen erfaßt. An diesem Projekt sind alle - nunmehr 13 - Donauländer beteiligt.

UPDATING THE WATER BALANCE OF THE DANUBE BASIN AND MONITORING OF ANTHROPOGENIC INFLUENCES

PROJECTS AND DRAFTS OF THE REGIONAL IHP - WORKING GROUP ON HYDROLOGY OF THE DANUBE COUNTRIES

ABSTRACT

In continuation of former works of the Danube countries, published in the 'Hydrology of the River Danube', the 'Regional Working Group on Hydrology of the Danube Countries within IHP' decided to develop an up-to-date version of the water balance of the Danube basin. The water balance this time will cover the now available period of 1931-1990. Additionally, the present state of the main water management structures is assessed. This project is supported by all - now 13 - Danube countries.

1. Einleitung

Die "Regionale Zusammenarbeit der Donauländer im Rahmen des Internationalen Hydrologischen Programmes der UNESCO" hat sich in der Vergangenheit als nützliches Instrument erwiesen, um trans- und übernationale Aspekte der Hydologie und Wasserwirtschaft im Donauraum gemeinsam zu behandeln. Nach nunmehr kleiner gewordenen Ländereinheiten erscheint eine solche Zusammenarbeit umso notwendiger.

Die gesamten, in verschiedenen Projekten laufenden Aktivitäten der "Regionalen IHP - Zusammenarbeit der Donauländer" können in dem vorliegenden Rahmen nicht umfassend dargestellt werden. Deshalb erfolgt hier eine Beschränkung auf das Projekt "Aktualisierung der Hydrologischen Monographie der Donau".

Im Anschluß an frühere Arbeiten im Rahmen der genannten Zusammenarbeit, publiziert in der "Hydrologischen Monographie der Donau", wurde eine Aktualisierung der seinerzeitigen Auswertungen beschlossen und in Angriff genommen. An diesem Projekt sind alle - nunmehr 13 - Donauländer beteiligt. Im Anschluß an frühere Arbeiten wird der Zeitabschnitt 1971-1990 zusätzlich berücksichtigt. Auch diese Initiative kann in dem vorliegenden Beitrag kaum umfassend dargestellt werden. Es erfolgt deshalb eine weitere Beschränkung auf den Themenkreis "Aktualisierung der Wasserbilanz des Donaubeckens". Weitere Aktivitäten im Zusammenhang mit der "Aktualisierung der Hydrologischen Monographie der Donau" werden in einem abschließenden Kapitel dargestellt. Dazu soll betont werden, daß sich dies im Sinne der Schwerpunktsetzung dieses Beitrags ergibt und damit *keine Wertigkeit dieser Arbeiten im Zusammenhang mit dem Gesamtprojekt* zum Ausdruck gebracht werden soll.

Im Rahmen der "Aktualisierung der Wasserbilanz des Donaubeckens" werden die Daten der gesamten, nunmehr verfügbaren Periode 1931-1990 neu bearbeitet. Ergänzend dazu wird der aktuelle Stand der wasserwirtschaftlichen Nutzungen erfaßt. Die Notwendigkeit und der aktuelle Bezug dieser Arbeiten ergibt sich nicht nur aus der gegebenen und möglichen künftigen Klimavariabilität, vielmehr erfordert auch die stetig zunehmende anthropogene Beanspruchung der Wasserresourcen ein höheres Maß an gemeinsamer, überregionaler Zusammenschau der Entwicklung.

Die Arbeiten zur Wasserbilanz wurden mit einem österreichischen Teilprojekt, betreffend die Ermittlung von Niederschlagsverteilungen und Gebietsniederschlägen, begonnen. Das Ziel sind gerasterte Verteilungen, die als Eingabegrößen für die weiteren Auswertungen dienen. Diese werden zur Gänze mit GIS-Methoden durchgeführt werden. Parallel dazu wird - im 'Global Runoff Data Center' in Koblenz/Deutschland - eine Abflußdatenbank aufgebaut. Damit wird die Grundlage für umfassende Abflußauswertungen geschaffen, gleichzeitig aber auch eine weitere wichtige Eingangsgröße zur Wasserbilanz erfaßt. Die früher durchgeführten Abflußauswertungen bedürfen wesentlicher methodischer Ergänzungen und Erweiterungen, die derzeit erarbeitet werden. Als vertiefende Arbeit hiezu ist das Teilprojekt "Raumzeitliche Analyse von maximalen Projekthochwässern im Donauraum", durchgeführt von Rumänien, anzusehen.

2. Methodik der Wasserhaushaltserfassung

2.1 Bearbeitungsansätze

Die vielfach in der Vergangenheit vorhandenen und auch heute noch nicht völlig abgebauten Zweifel an der Notwendigkeit und praktischen Verwertbarkeit eines 'Monitoring' des Wasserkreislaufes halten einer kritischen Betrachtung nicht stand. Vor allem ist hier anzuführen, daß mit zunehmender Länge der Beobachtungsreihen die Erkenntnis wächst, daß die Variabilität der Prozesse viel größer ist, als man ursprünglich annehmen konnte. Auch über längere Zeitabschnitte und größere Regionen können Auspendelungen auftreten, die beträchtliche sozio-ökonomische Folgen nach sich ziehen. Als besonders verletzbar erweisen sich Gebiete, in denen der Niederschlag nicht wesentlich größer als die Verdunstung ist. Die Veränderungen des Wasserdargebots als relativ kleines "Restglied" können dort existenzbedrohende Ausmaße annehmen.

Ziel einer sachgerechten dynamischen Erfassung des Wasserkreislaufes muß es sein, eine zeitliche und örtliche Auflösung zu verwenden, die den praktischen Erfordernissen in Hydrologie und Wasserwirtschaft gerecht wird. Damit werden solche Auswertungen über eine eher "geographisch" orientierte Darstellung hinaus zu einem brauchbaren, ja unverzichtbaren Werkzeug wasserwirtschaftlicher Planung. Erst in jüngster Zeit jedoch sind die technologischen Voraussetzungen gegeben, eine solche Aufgabenstellung auch für Großregionen, wie etwa das Donaubecken, mit einiger Aussicht auf Erfolg in Angriff nehmen zu können.

Bei der räumlichen Aufgliederung in *Bilanzgebiete*, ebenso wie bei der Erarbeitung detaillierter *örtlicher Verteilungen* (Wasserbilanzkarten) konnte früher der Zeitschritt des "vieljährigen Mittelwertes" kaum reduziert werden. Nicht nur, daß heute der Begriff des "vieljährigen Mittelwertes" an sich nicht mehr aufrechterhalten werden kann (sofern er als "Grenzwert" einer möglichst langen Beobachtungsreihe angesehen wird), der Zeitschritt ist für praktische Erfordernisse über hydrologische Jahre - vermutlich bis zu Monatsabschnitten - schrittweise zu reduzieren. Der Weg von längeren zu kürzeren Zeitabschnitten bei gleichzeitiger Erhöhung der örtlichen Auflösung ist dabei durchaus zweckmäßig.

Eine wesentliche Verbesserung der Behandlung der Aufgabenstellung stellen die großen Forschritte in der rechnerischen Handhabung *gerasterter Verteilungen* dar. Damit wird auch ein enger Zusammenhang zwischen örtlicher Verteilung und Bilanzierungs - Gebietsmittelwerten hergestellt, die direkt rechnerisch ineinander übergeführt werden können.

Bei der Neubearbeitung des Wasserhaushalts des Donaubeckens kann mit großem Vorteil auf frühere Ausarbeitungen, die Wasserbilanz im Rahmen der "Hydrologischen Monographie der Donau" zurückgegriffen werden. Sie sind - auf breiter Basis entstanden - als hochrangige "Expertenmeinung" zu berücksichtigen. Um sie einbringen zu können, sind sie allerdings zunächst in eine digital verarbeitbare Form zu bringen. Diese Arbeiten und die dabei erzielten Ergebnisse werden nachfolgend beschrieben.

Im Falle der Niederschlagsverteilung wird nach der Rasterung zunächst eine Adaptierung an die Beobachtungsdaten vorgenommen. Sodann erfolgt eine Ausdehnung auf andere Zeitabschnitte sowie schließlich eine schrittweise Reduzierung des Zeitschrittes. Diese Arbeiten werden in einem eigenen Teilprojekt von Österreich behandelt und befinden sich bereits in fortgeschrittenem Stadium.

Für die - in einem weiteren Teilprojekt zu behandelnde - rechnerische Analyse des Wasserhaushalts wurde als Pilotversuch die aus der Monographie vorhandene Abfluß- und Verdunstungsverteilung gerastert und die Bilanzrechnung auf dieser Grundlage nochmals durchgeführt. Die sich daraus ergebenden Schlüsse für die weitere Bearbeitung werden anschließend dargestellt.

2.2 Gebietseinteilung

Da in der rechnerischen Analyse zunächst Gebietsniederschläge für Flußeinzugsgebiete zu ermitteln sind, müssen auch *Einzugsgebietsgrenzen* digital erfaßt werden.

Um als Pilotversuch zunächst die Wasserbilanz entsprechend der "Hydrologischen Monographie der Donau" nachvollziehen zu können (siehe Abschnitt 5.1), wurden die gemäß dem damaligen Entwurf gewählten 47 Teilgebiete digital erfaßt. Die Einteilung ist nach heutigen Gesichtspunkten nicht besonders zweckmäßig, da teilweise sehr große Gebietsteile (etwa das gesamte Theiß - bzw. auch das gesamte Save - Einzugsgebiet) als ein einziges Gebiet erfaßt wurden. Auch ist die Generalisierung der Grenzen - selbst für den verwendeten Maßstab 1 : 2 000 000 - etwas zu großzügig ausgefallen. Die Grenzen werden jedoch benötigt, um einen direkten Vergleich mit den früher ermittelten Gebietsniederschlägen zu ermöglichen. Ein verbesserter Entwurf mit größerer Genauigkeit und weiterer Gebietsunterteilung ist im Rahmen des Gesamtprojekts vorgesehen. Es wird eine Einteilung in etwa 100 bis 150 Teilgebiete erfolgen.

Die *Staatsgrenzen* für nationale Bilanzierungen wurden aus der Karte 1 : 2 000 000 des "Österreichischen Ost- und Südosteuropainstituts", die auch als topographische Karte für die "Hydrologische Monographie der Donau" diente, digital erfaßt.

2.3 Gebietskenngrößen und weitere Beobachtungselemente

Als wichtige Elemente zur Analyse des Wasserhaushalts sind Geländehöhe und Vegetationsbedeckung anzusehen. Beide Elemente sind mit den heutigen Mitteln günstig aus Satellitenbildern zu erarbeiten. Die Geländehöhe könnte technisch etwa gleichwertig auch aus Isolinienkarten entnommen werden. Nationale - allerdings in Koordinatensystem und Rasterung nicht kompatible - Geländemodelle sind für den Ober- und Mittellauf der Donau vorhanden. Arbeiten zu den genannten Gebietsgrößen konnten bisher noch nicht in Angriff genommen werden.

3. Erfassung von Referenz - Niederschlagsverteilung und Gebietsniederschlag

Die Niederschlagsverteilung der *Hydrologischen Monographie der Donau* für den Zeitabschnitt 1931-1970 entstand durch Zusammenfassung der einzelnen nationalen Auswertungen für die jeweiligen Staatsgebiete. Dabei wurden die Auswertungen an den Staatsgrenzen wechselseitig abgestimmt. Es ist dies die einzige existierende Niederschlagskarte des Donaugebiets, die auf Länderauswertungen beruht und muß daher wohl auch als die zutreffendste erachtet werden. Der Maßstab beträgt 1 : 2 000 000, wobei aber die Länderentwürfe teilweise wesentlich größermaßstäblich waren. Sie deckt das Donaugebiet lückenlos, umfaßt also auch die in manchen Karten fehlenden Gebiete am Oberlauf des Inn in Italien und der Schweiz sowie den vollständigen Oberlauf der Donau in Bayern.

Diese Isolinien wurden im Rahmen des Graphik-Systems AutoCAD digitalisiert und in das Arbeitskoordinatensystem (Lambert'sche konforme Kegelkoordinaten) transformiert. Es ergeben sich insgesamt etwa 57 000 Stützstellen (Isolinienpunkte). Diese müssen nun in eine Organisationsform gebracht werden, die einen raschen Zugriff auf die Stützstellen für die Umgebungsbereiche der planquadratsweise durchzuführenden Interpolation gestattet. Die Daten werden in einem zweistufigen Verfahren zunächst in Spaltenbereiche, sodann in quadratische Recheneinheiten sortiert. Das Endprodukt sind die in etwa 400 Planquadratseinheiten abgelegten Massenpunkte. Im Durchschnitt sind je Recheneinheit etwa 120 Stützpunkte gespeichert. Die Belegung ist jedoch sehr unterschiedlich und kann von Null bis in die Größenordnung von 1000 reichen.

Um aus den unregelmäßig in der Fläche verteilten digitalisierten Isolinienpunkten zu einer gerasterten Darstellung zu gelangen, muß für jeden Rasterpunkt ein Wert der Niederschlagshöhe aus den Umgebungspunkten interpoliert werden.

Die Ergebnisse müssen für die weitere Auswertung zwischengespeichert werden. Für die Verwaltung der gerasterten Daten werden Speichereinheiten von 50x50 Elementen ("Planquadrate") verwendet. Es ergaben sich insgesamt 405 Planquadrate (Rasterung mit 1 km Maschenweite). Das Planquadratsmodell umfaßt etwa 1.01 Mio Einzelpunkte (ca. 5 MB Daten). Üblicherweise wird die Rasterweite so gewählt, daß die Anzahl der Rasterpunkte ungefähr jener der Stützpunkte entspricht. Dies würde im vorliegenden Fall eine Rasterweite von 4-5 km ergeben. Es ist aber zu bedenken, daß die Punktdichte regional sehr unterschiedlich ist. In den Alpen und Karpaten ist das genannte Kriterium durchaus erfüllt. Ein gröberes Raster ist - auch im Hinblick auf spätere Arbeiten - daher nicht zweckmäßig.

Für die Interpolation des Rasters stehen verschiedene Verfahrensvarianten zur Verfügung:

- Interpolation mit dem reziproken Abstandsquadrat als Gewichtung
- Interpolation mittels "gleitender Schrägebene"
- Interpolation mittels "gleitender Polynome"

Alle Verfahren sind strikt interpolierend, d.h. die Stützpunkte werden eingehalten.

Für die vorliegende Aufgabenstellung wird die Interpolation mittels "gleitender Polynome" herangezogen. Dies hauptsächlich deshalb, weil größere Gebiete (vereinzelt sogar ganze Planquadrate) ohne Stützpunkte (d.h. Isolinienpunkte) gegeben sind und dieses Verfahren am besten solche Gebiete berücksichtigt. Da das Verfahren den Einfluß der Stützwerte auf das Ergebnis mit dem Quadrat der Entfernung ausdämpft, kann auf eine - in der Regel rechenaufwendige - Auswahl zunächst gelegener Stützpunkte verzichtet werden. Es werden jeweils alle Stützpunkte einer 150x150 km Umgebung herangezogen. Für jeden Netzpunkt des Rasters ist im Anschluß an die Koeffizientenermittlung ein lineares Gleichungssystem mit 6 Unbekannten zu lösen. Als Lösungsalgorithmus wird die Gauß -Elimination herangezogen.

Etwas nachteilig für die Rasterung ist die Tatsache, daß die verwendete Isolinienkarte strikt nur bis zur Berandung des Donaueinzugsgebiets ausgeführt wurde. Da das Rechenraster aus technischen Gründen einen Übergriff über die Berandung haben muß, sind in den Randbereichen Extrapolationen notwendig, die nicht immer sinnvolle Werte ergeben. Diese störenden Erscheinungen können durch Adaptierung an die Beobachtungsdaten beseitigt werden. In diesem Schritt kann eine ausreichende Anzahl von Beobachtungsdaten außerhalb der Einzugsgebietsgrenze des Donaubeckens vorgegeben werden.

Der Gebietsniederschlag jedes Teilgebiets ergibt sich durch Verschnitt des Rasters mit der polygonalen Gebietsgrenze. Auf technische Details dieser klar definierten Aufgabenstellung braucht in diesem Zusammenhang nicht eingegangen werden.

4. Erfassung der Referenzverteilungen von Abfluß und Verdunstung

Um als Pilotversuch die Auswertungen der "Hydrologischen Monographie der Donau" auf digitalem Wege nachvollziehen zu können, erfolgte auch eine Rasterung der damals erarbeiteten Isolinienkarten der Abfluß- und Verdunstungshöhe.

Die Erfassung der Referenzverteilungen von Abfluß und Verdunstung erfolgte nach durchwegs den gleichen Methoden, die auch bei der Rasterung der Niederschlagsverteilung verwendet wurden. Eine weitere Beschreibung ist daher in diesem Zusammenhang nicht erforderlich.

5. Auswertung des Wasserhaushalts

5.1 Digitaler Nachvollzug der Monographieauswertungen

Mit den gerasterten Verteilungen von Niederschlag, Abfluß und Verdunstung wurden die seinerzeitigen Auswertungen der "Hydrologischen Monographie der Donau" nachvollzogen. Dabei wurden die auch dort verwendeten Teileinzugsgebiete herangezogen. Die Ergebnisse sind kurz zusammengefaßt die folgenden:

- Die Fläche des Donaueinzugsgebiets muß auf etwa 800 000 km^2 reduziert werden. Dies ergibt sich aus einer geodätisch-analytischen Auswertung der Kartenunterlagen.
- Die Gebietsniederschläge zeigen außerordentlich gute Übereinstimmung mit den früheren Ergebnissen. Die Unterschiede sind zum überwiegenden Teil kleiner 1% und betragen im flächengewichteten Gesamtmittel nur 0.25%. Es sind keine systematischen Unterschiede erkennbar.
- Die Abflußhöhen der Wasserbilanzgebiete sind durchwegs etwas (aber nur sehr geringfügig) kleiner als die früheren Werte. Das flächengewichtete Gesamtmittel ist um 0.76% kleiner als der damalige Wert.
- Die Verdunstungshöhen der Gebiete sind praktisch identisch mit den früheren Werten. Die Unterschiede liegen im Rundungsbereich und verschwinden im Gesamtmittel völlig.
- Die Zusammenstellung der Wasserbilanz für jene 47 Bilanzgebiete, die früher verwendet wurden, ergibt ebenfalls durchwegs sehr ähnliche Resultate. Die Tendenz zu negativen Bilanzabweichungen im Oberlauf, positiven hingegen im Unterlauf bleibt erhalten. Der flächengewichtete Gesamtbilanzfehler ist mit +1.10 % geringfügig größer als das damalige Ergebnis (+0.60%).
- Die Einhaltung der Abflußbilanz an den Meßquerschnitten der Donau verbessert sich. Der summierte Gesamtfehler beträgt 1.10% gegenüber 4.66 % seinerzeit. Die Abflußhöhe ist jedoch im Donauoberlauf systematisch zu klein, im Unterlauf hingegen zu groß.

Insgesamt zeigt sich die vorgenommene Rasterung als ausgesprochen tauglich für die Behandlung der Fragestellung. Vor der weiteren Verwendung dieser "Referenzverteilungen" sollte bei Niederschlag und Abfluß eine Adaptierung an die Meßergebnisse erfolgen. Bei der Abflußhöhe sollten dabei unbedingt zusätzliche Meßquerschnitte herangezogen werden.

5.2 Weiterführende Ansätze

Nachdem sich die frühreren Auswertungen der "Hydrologischen Monographie" sowohl als weitgehend konsistent zu den Beobachtungswerten, als auch in sich sehr kohärent erwiesen haben, können sie als Ausgangspunkt weiterer Bearbeitungen herangezogen werden.

Aus den gerasterten Darstellungen von Niederschlag und Abfluß läßt sich eine gerastere Repräsentation des *Abflußbeiwerts* erzeugen. Dadurch könnten sich nochmals Verbesserungen in der Abflußverteilung ergeben, die aus Gründen der Stetigkeit und Plausibilität vorzunehmen wären.

Eine Übertragung der Niederschlagsverteilung auf beliebige vieljährige Zeitabschnitte sowie eine zeitliche Disaggregation bis zu Monatswerten erscheint auf Grund des relativ dichten Beobachtungsnetzes möglich. Es ist anzunehmen, daß dies während des derzeit laufenden Teilprojekts gelöst wird.

Bezüglich der Abflußverteilung kann derzeit nur das Erreichen von hydrologischen Jahren in der zeitlichen Disaggregation als einigermaßen gesichert angenommen werden. Eine weitere Unterteilung setzt u.a. die Kenntnis des aktuellen Verlaufs von anthropogenen Speicherungen im Einzugsgebiet voraus. Dies ist derzeit kaum auf nationaler Ebene befriedigend gelöst. Erschwerend kommen weiters die übrigen Glieder des Wasserrückhalts, vor allem der Speicherung im Schnee, hinzu.

Um nicht eine kaum kurzfristig bewältigbare Fülle zusätzlicher Daten zu benötigen, scheint daher in der analytischen Behandlung des Wasserhaushalts derzeit eine *Beschränkung auf hydrologische Jahre erforderlich*. Auch dies würde bereits einen großen Fortschritt gegenüber früheren Bearbeitungen bedeuten. Besonderer Wert sollte dabei auf die Behandlung der Zusammenhänge Niederschlag - Abfluß - Verdunstung - Lufttemperatur - Gelände - Vegetation gelegt werden.

Dennoch ist es derzeit schon möglich, unter gewissen Einschränkungen einige Zukunftsszenarien für die Entwicklung des Wasserhaushalts des Donaubeckens zu entwerfen. Dies hauptsächlich deshalb, weil sich auf Grund bisheriger Untersuchungen ein dominierender Zusammenhang zwischen Niederschlags- und Abflußentwicklung zeigen läßt.

6. Aktualisierung der Hydrologischen Monographie der Donau

Das eingangs erwähnte Gesamtprojekt "Aktualisierung der Hydrologischen Monographie der Donau" umfaßt neben der hier beschriebenen "Aktualisierung der Wasserbilanz" noch weitere Aktivitäten:

- Es erfolgt eine *Neuerfassung der wichtigsten wasserbaulichen Anlagen im Donaueinzugsgebiet*. In diesem von Rumänien koordinierten Teilprojekt werden Kraftwerke, Dammbauten, Regulierungsarbeiten und sonstige größere Eingriffe einheitlich erfaßt und dokumentiert. Auch größere Maßnahmen an Nebenflüssen und im gesamten Einzugsgebiet, insbesonders auch Speicherungen, werden einbezogen. Die Ergebnisse werden eine qualitative Beurteilung der Beeinflußung des Abflußregimes gestatten und auch eine erste größenordnungsmäßige Abschätzung in quantitativer Hinsicht ermöglichen. Eine genauere quantitative Analyse sollte zu einem späteren Zeitpunkt auf dieser Arbeit aufbauen.
- Das Abflußregime der Donau wird an Hand der bis 1990 ergänzten Datenreihen für nunmehr die Gesamtperiode 1931-1990 neu bearbeitet. Neben der Ergänzung des Zeitabschnitts erfolgt dabei eine Erweiterung und Vertiefung der Auswertemethoden. Grundlage hiefür sind die Reihen täglicher Abflußwerte. Die Datensammlung und die Zusammenstellung der Datensätze erfolgt im "Global Runoff Data Center" bei der Bundesanstalt für Gewässerkunde in Koblenz/Deutschland. An die Datensammlung wird zunächst eine statistische Grundauswertung der Datenreihen angeschlossen. Vertiefende Analysen sind für die Hoch- und Niederwasserbereiche vorgesehen.

XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
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Mathematische Modellierung des Ablaufes von Schneewassergehalten in den Gebirgseinzugsgebieten der Karpaten unter Berücksichtigung der Orographie

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Kurzfassung

Die Untersuchungen der Schneedeckenzustände an Hand der Aufnahmedaten und Absflüsse von kleinen Einzugsgebieten des dichten Beobachtungsnetzes in der Karpaten haben ermöglicht, ein Verfahren zur Berechnung der Schneeschmelzintensität zu erarbeiten. Dieses Verfahren zieht auf indirekte Weise eine Differenz der Wärmeeinträge an Einzelflachen eines Einzugsgebietes in Betracht, die sich durch Hangrichtungen unterscheiden. Dabei wird die Schneeschmelzintensität durch zwei Parameter ausgerechnet - ein Schmelzfaktor und ein Temperaturberichtigungsglied.

Mathematical modelling the course of snow pack water equivalent over mountain catchments in the Karpathians takes into account of orography

Abstract

The researches of snow cover dynamics on grounds of survey data and runoff from small catchments by dense network in the Carpathians give a possibility to devise of method for snowmelt intensity estimating. This method takes indirectly, into account the difference of heat in-ut at particular areas with different valley slopes orientation. By that a snowmelt intensity is calculated through two parameters - snow melting index and corrective for temperature.

1.Einleitung

Verhältnisse der Schneeschmelzwasserbildung in den Gebirgseinzugsgebieten in den Karpaten sind sehr kompliziert, dass es sich durch unbeständige Wetterereignisse im Winter, die zur häufige Tauwetter bringen, erklärt. Dabei ändern sich die Schneeansammlungs- und Schmelzprozesse nicht nur zeitlich, sondern auch räumlich, weil sie von den Wärmeeinträgen zu einer oder anderer Fläche abhängig sind, die sich durch vertikale Veränderlichkeit der meteorologischen Grössen, Flächenrichtungen und Hangneigungen unterscheiden. Darum verteilt sich die Scheedecke als ein Hauptfaktor, dass für Schmelzwasser im Frühling und während Tauwetter im Winter bestimmend ist, in einem Einzugsgebiet ungleichmassig. Aber meteorologische Standardbeobachtungen, und sogar Linienmessungen, sind nicht fähig, die Eingangsdaten vom Wassergehalt der Schneedecke und Schneeschmelzintensität in einem Einzugsgebiete mit möglich für die Praxiszwecke notwendige landesweite Detaillierung vorzustellen.

Um die Möglichkeit für die Schätzung räumlicher Verteilung des Schneewassergehalts und Verlauf des Abschmelzens zu haben, wurde ein Verfahren der Schmelzintensität erarbeitet, das auf indirekte Weise Differenzen in Wärmeeinträgen an Einzelflächen eines Einzugsgebietes durch Flächenrichtungen in Betracht ziehen kann.

2.Ausgenützte Daten

Für die Erarbeitung des Schätzungsverfahrens der Schneeschmelzintensität sind die langjährige meteorologische Bemessungsergebnisse auf dem Gebiet von Wasserbilanzstation in den Transkarpaten ausgenutzt. Hier auf der Fläche von 550 km^2 befinden sich 3 meteorologische Stationen und 28 Niederschlagsmessstellen, die auf der Seehöhen 440-1330 m liegen. An 19 Stellen werden regular Abflussmessungen erfüllt.

Die Linienschneemessungen werden jede 5 Tage an 22 Stellen durchgeführt. Die bedeutende Zahl von Schneemessungen und ihre Regelmässigkeit während 40-45 Jahre haben erlaubt, die Schneedeckenzustände bei verschiedenen Bedingungen und an der Flachen mit verschiedenen Richtungen zu untersuchen.

Für die Anpassungsprüfung des ausarbeitenden Verfahrens wurden die Daten aus Flusseinzugsgebiete Ush, Latoryzja, Borshawa und Opir herangezogen. Diese Einzugsgebiete mit den Flächen von 800-1300 km^2 sind bei der Abflussmodellierung auf 2-3 Einzelflächen und 5 Höhenzonen geteilt.

3. Die Verfahrensbegründung

Die Schneeschmelzprozesse sind von Gebietsgrössen und meteorologischen Werten beeinflusst, die Wärmehaushalt der Schneedecke bestimmen. Dazu gehören, ausser Wetterbedingungen, auch Höhenlage, Exposition, Hangneigung, Bewaldung und Horizonteinengung durch Bergen. Diese Einflussgrössen wurden in mehreren Veröffentlichungen besprochen (z.B.[1,2]).

Für einzelne geringe Teilflächen kann man die vorgeschlagenen Methoden der Wärmebilanzberechnungen der Schneedecke bei Vorhandensein der nötigen meteorologischen Grossen verwenden. Wenn man noch Flussgebiete mit ihrer Veränderlichkeit von landschaftlichen und thermischen Bedingungen beschreiben muss, entstehen dann manche Schwierigkeiten aus Mangel an entsprechenden Kenngrossen.

Darum muss man, wie in vielen ähnlichen Fällen, solche Schematisierung gewehrleisten, um die Einflüsse der mehreren Grössen zu einfacher für die Praxis Lösung zusammenzufassen.

In dem vorschlagenden Verfahren wird der Unterschied der Warmeeinträgen an einzelne Flächen eines Einzugsgebietes durch Temperaturberichtungen geschätzt. Entsprechende Korrekturgrössen haben Bezug auf Lufttemperaturen, die an meteorologischen Stationen gemessen. Dabei beachtet man, dass Stationen befinden sich gewöhnlich an Talsohlen und registrieren darum mittlere Temperaturregime der nahegelegene Gegend. Folglich gehen wir von der Voraussetzung aus, dass der Einfluss der Hangneigung sich für die Flächen mit ähnlichen Reliefformen und Schneeverteilungsbedingungen ausgeglichen wird.

Also wird die Schneelschmelzintensität durch Verwendung zweier Parameter berechnet - Schneeschmelzfaktoren und Korrekturgrössen zur Temperaturen, die an einer Station gemessen oder für eine Höhenzone geschätzt sind.

4. Die Bewertung der Verfahrensparameter

Die Schätzwerte der Verfahrensparameter wurden mittels Vergleichung der Wassergehalts messwerte der Schneedecke und Modellberechnungen für die entsprechenden Perioden auf den Flächen verschiedener Richtungen.

Dafür wurde das mathematische Modell der Schneedecken bildung SDB verwendet, das eine Komponente des Mehrniveausystemes der Schmelzwasser-und Regenabflussbildung ist [3, 4]. Die Struktur des Modells SDB erlaubt räumliche Ungleichartigkeit der Schneedecke und der Schmelzintensität wegen Höhenlage abzuschätzen. Mit diesem Zweck wird dieses Modell zu jedem getrennten Höhenstreifen mit seinem meteorologischen Bedingungen angewendet. Die Schneeschmelzintensität wird mittels Schneeschmelzfaktor nach Lufttemperaturen ausgerechnet.

Solcherweise kann man ein Wassergehatswert S zu jeder Zeit t durch Lösung der Wasserbilanzgleichung bekommen (in mm) :

$$S_t = \sum_{i=1}^{t} (P_i - E_i - H_i) \qquad (1)$$

Hierbei bedeuten

t - Tageanzahl seit dem Winteranfang;
P,E,H - Niedeschlag-, Verdunstung- und Schneewasserabgabe-Tagesmengen (einsch.Tauwetter).

Schneewasserabgaben H werden zur Berücksichtigung des Schmelz - und Regenwassers sowie anhand von Grössen der schneebedeckten Flächen berechnet:

$$H_i = 1{,}15\ FH\ [\ T_i\, K_S - A\ (S_{i-1} + P_i'\ )] + P_i'' , \qquad (2)$$

wo FH - Anteil der Fläche, der mit Schnee bedeckt;
T - Lufttemperatur;
K_S - Schneeschmelzfaktor;
A= 0.25 - Retentionsfaktor;
S - Wassergehalt in der Schnee;
P' u. P'' - feste und flüssige Niederschläge.

Für die Schätzung der Schmelzflächendynamik (d.i. FH) wird die Gammaverteilungsfunktion des Wassergehaltes benutzt [4] .

Die Werte des Schmelzfaktors verändern sich während des Winters, dadurch ziehen die Verlängerung der Sonnenstrahlung und die Vergrösserung der Sonnenintensität bis zum Frühling in Betracht (Tab. 1).

Tabelle 1

Die Werte des Schneeschmelzfaktors K_S

The valeus of snow melting index K_S

Die Perioden	K_S , mm (Tag. °C)	
	Waldlose Flächen	Waldige Flächen
(1) Dezember - Januar	2.5	1.5
(2) erste u. zweite Februardekaden	3.5	2.0
(3) ab dritte Februardekade	4.4	2.5

Simulationsberechnungen mit Hilfe des Modells SDB wurden gewöhnlich bei Lufttemperaturkorrekturen zwischen -3.0 und +3.0 °C anhand der Daten von Schneemessstellen durchgeführt. Diese Stellen befinden sich in der Nahe der meteorologischen Stationen und haben verschiedene Expositionen.

Auf vergleichbarer Grundlage der Modellrechnungen und der Ergebnisse der Schneeaufnahmen wurden die Lufttemperaturunterschiede für die Flächen mit verschiedenen Richtungen bezüglich der Stations messwerte erhalten, die gewöhnlich an Talsohlen liegen (Tab.2). Der Unterschied der Tagesmittellufttemperaturen beträgt zwischen Flächen, die nördliche und südliche Richtungen haben, durchschnittlich etwa 2 °C.

Tabelle 2

Die Schätzwerte der Lufttemeraturunterschiede auf den Flächen mit verschiedenen Richtungen

The estimates of air temperature difference over different orientation areas

Die Flächenrichtungen	Die Schätzwerte der Unterschiede der Tagesmitteltemperaturen, C
Meteorologische Station	0.0
nördliche (N)	-1.0
nordwestlichte (NW)	-1.0
nordöstlichte (NO)	-1.0
östliche(O)	-0.5
südöstliche (SO)	0.0
südliche (S)	+1.0
südwestliche (SW)	+0.5
westliche (W)	0.0

Um ein Wassergehalt in der Schnee oder eine Wasserabgabe in allgemeinen in einem Einzugsgebiete abschätzen zu können, muss man Einzelflächen bestimmen, für die sich entsprechende Temperaturkorrekturen anpassen. Es ist sich erwiesen, dass solche Angaben für drei Gruppen von Einzugsgebieten bezüglich der Flusstalrichtung vorzustellen ermöglicht sind (Tab.3). Diese relative Flächenwerte werden nach orographischen Angaben mit nächstlichen Optimisierung ermittelt.

Tabelle 3

Verteilung der Flächen mit Verschiedenen Richtungen

Areas distribution about different orientation

Die Flächen-richtungen	Korrektur-grössen, °C	Relative Flächengrössen im Falle der Flusstalrichtung		
		N → S	S → N	O → W, W → O
N,NW,NO	-1.0	0.15	0.35	0.40
O	-0.5	0.20	0.20	0.10
SO,W	0.0	0.35	0.30	0.20
S	+1.0	0.15	0.05	0.15
SW	+0.5	0.15	0.10	0.15

5. Anpassung des Verfahrens

Vorgeschlagenes Verfahren wird als eine Prozedur des mathematischen Schneeschmelz- und Regenwasserbildung - Modells verwendet. Da die Korrekturwerte nur mittlere Bedindungen der Warmeeinträge bestimmen, kann man dieses Verfahren nur für die Einzugsgebiete (ihre Anteile oder Höhenstreifen) mit den Flächen nicht kleiner als 100-150 km^2 genutzt werden.

Aus durchgeführten Modellrechnungen der Abflussgänge in den Einzugsgebieten von Tyssa und Dnister wird abgeleitet, dass die Anwendung des Verfahrens genauere Ergebnisse liefert, insbesondere während der Anfangsperiode der Schneeschmelze.

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PREDICTION OF THE PROBABLE ACCUMULATION TIME OF RUNOFF BASED ON THE CHARACTERISTICS OF A BASIN

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ABSTRACT

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The paper presents the calculation of this parameter in case no hydrometric data are available for the involved basin. The method is based on the use of the climatic and phisyographic characteristics of the basin in order to determine the value and evolution of the mean accumulation time, as well as on the zonal determination of a set of non-dimensioned frequency curves corresponding to each starting month of the accumulation of a water volume at a point of a river.

KURZFASSUNG

Die Bestimmung der Vorhersage, bedarf einer Wasserspeicherung in einer Wasserbecken bedingt von einem gewissen Anfangs speicherungs datum gewissen Anfangs speicherungs datum, ist von großem Interesse für die Bewirtschaftung der Wasserressourcen.

Die Arbeit zeigt die Rechnung der Parameters, im Falle man nicht über die hydrometrische Daten im gewünschten Wasserbecken, verfügt. Diese Methode begründet sich auf die Benützung der klimatischen und hydrogologischen Charakteren des Beckens für die Bestimmung der Größe und Erstwicklung der Durchschnittszeit der Ansammlung, sowie die Zonenbestimmung eines undimensionierte Kurven-frequenz. Setes, entsprechend jeden Monates, am Anfang der Wasseransammlung, welches durch die gewünschten Sektionen fließt.

1. INTRODUCTION

The time required to accumulate a volume of water at a point on a river is of interest in water resources planning problems. The operating rule for water resources systems e.g. the conjuctive use of surface and groundwater supplies are based principally upon the probabilities of specified volumes of water being available at different time of year.

It was found convenient to express runoff volume in terms of the annual average runoff volume (VMM). For example the expected time to accumulate the annual runoff volume (100% VMM) is one year but in a dry year it will take longer than 365 days wilst in wet years this volume will be accumulated in a shorter time. The prediction of frequency of exceeding or not exceeding some threshold accumulation time in various zones of Romania is, in essence, the object of this paper.

2. DESCRIPTION OF THE METHOD

First of all, the method implies the calculation of the annual average runoff volume (VMM), the seasonal pattern of behaviour of the mean accumulation time and the frequency distribution of accumulation times about its mean. The first computation step is to evaluate the runoff accumulation time for each month of record to obtain the seasonal variation in average filling times. This standardisation permits intercatchments comparison for obtaining the average behaviour for catchments in the same climatic and hydrological zone. The second computation step is to derive the runoff accumulation time frequency diagram to enable rather accumulation times for a given start month to be estimated. The diagrams are used to establish a set of dimensionless frequency curves determined by runoff volume and start month. The final stage is to construct the runoff accumulation time frequency diagram by combining the results from all start months for all regions of Romania.

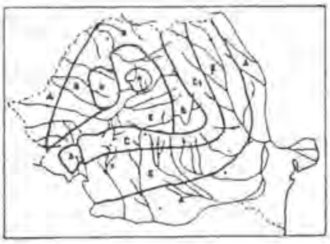
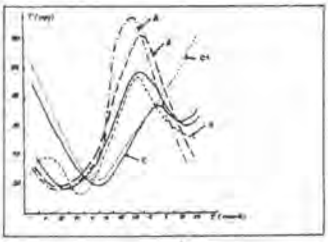


Figure 1. Location of the gauge stations used and regions with characteristic curves of the mean accumulation time



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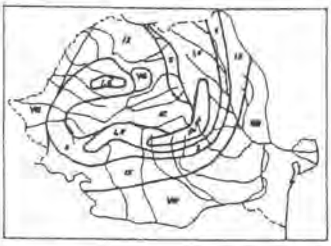
The 60 representative gauged basins (Figure 1) were used to derive the annual variation of the runoff accumulation time versus start month wich appears sinusoidal (e.g. Figure 2). The resultant seasonal curves from analized catchments were compared by first aligning them so that the months of maximum and minimum accumulation times were matched and then by simple graphical overlaying. The details of the curve i.e. the position of its maximum (Figure 3), its amplitude (Figure 4), asymmetry and variation from



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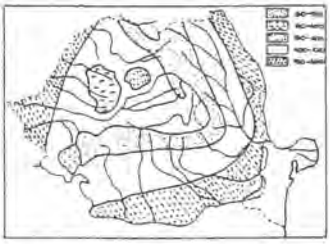

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The month of maximum runoff accumulation time was regionalized for Romania (Figure 3). In general the greater the base flow support in the catchment, the later is the month of longest runoff accumulation time. Conversely the wetter the climate of the catchment is the earlier the month. However both effects are relatively small in comparison with the runoff volume itself. This varies from august to february. The month of longest runoff accumulation time is given by the equation:

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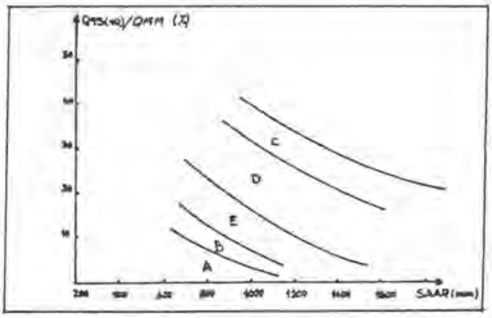

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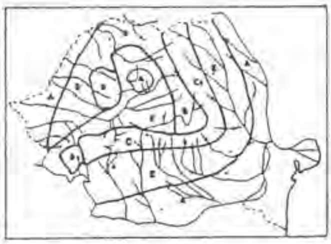

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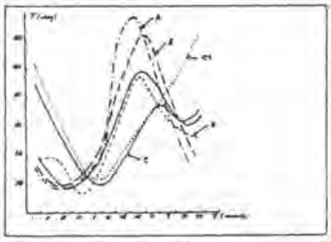

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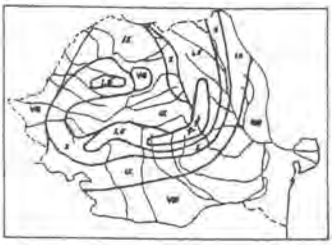

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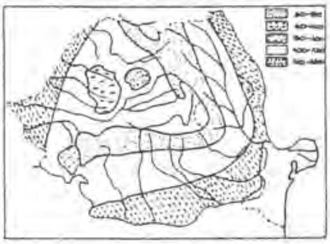

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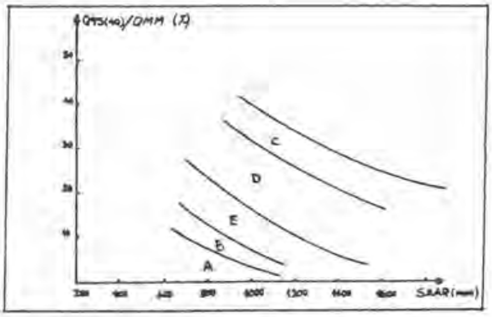

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From table 1 it is seen that the frequency curve nuber for a combination of July start with 25%VMM runoff volume can be interpolated as 14. The factors from Figure 6

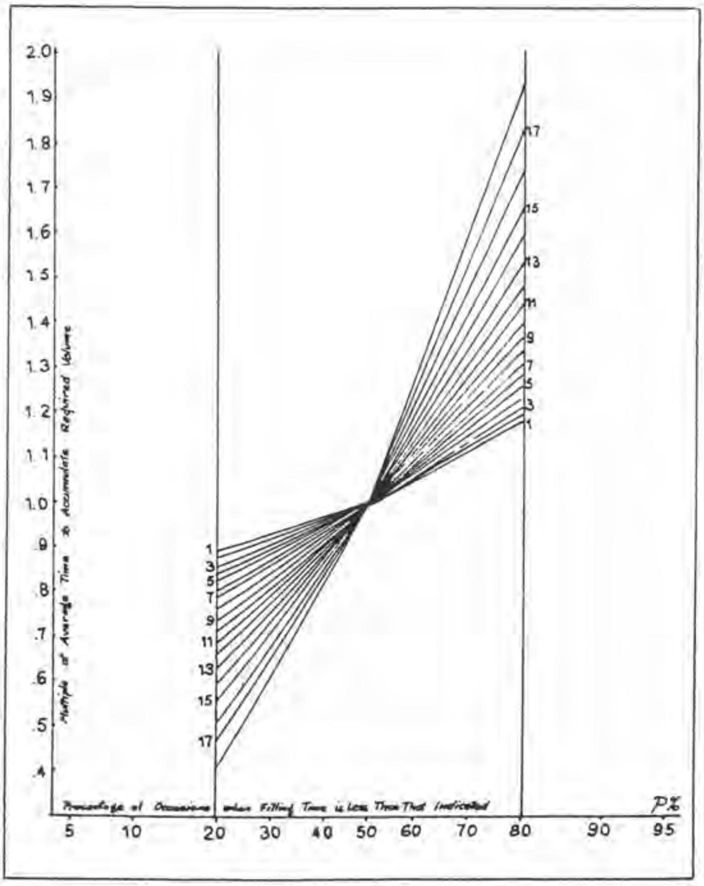

Figure 6.Dimensionless frequency curves for runoff accumulation time

are then used to scale the average accumulation time previously obtained and to interpolate or extend to other frequencies. The same analysis is necessary to carry out for each month in turn.Resultant values are shown in figure 7.

The frequency of July 1st starts accumulating the re quisite volume by december 1st is found to be about 90%. Thus the frequency of non-accumulation - i. e. the risk of having to maintain the alternative supplies is only 10%.

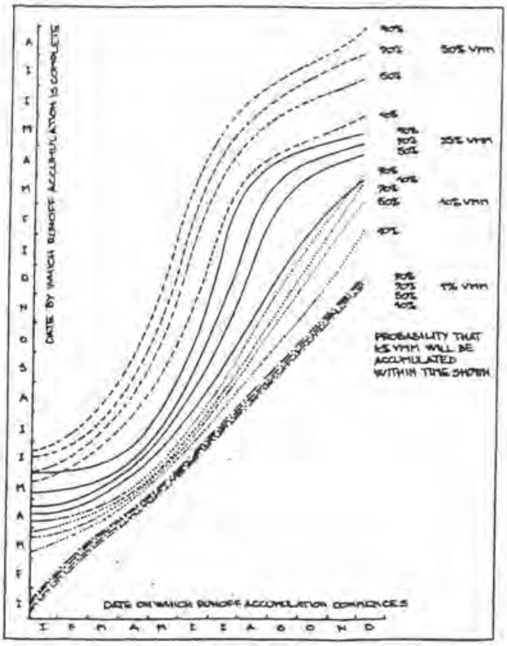

Figure 7.Runoff accumulation time frequency diagram for Bicaz Reservoire

5.CONCLUSION

The frequency curves of the time taken to accumulate a runoff volume permits the prediction of the finish dates associated with given levels of probability.

In case when it is proposed to use an aquifer conjunctively with a surface supply (when the aquifer is normally depleted), or in case of an accumulation, the diagram constructed offers the possibility of the prediction of the time need to accumulate the needed volume with the risk of non-availability; this value is the basis of management decisions on the suitability of the surface supply.

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