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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## Beiträge zur Lösung von Problemen des Feststofftransports: Analyse von Temperatur- und Eisregime

## New solutions of sediment transport problems: analysis of heat and ice regime

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*Dr. M. Mikoš & Dr. A. Stančíková*

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**Keynote paper**

# NEW SOLUTIONS OF SEDIMENT TRANSPORT PROBLEMS : ANALYSIS OF THE HEAT AND ICE REGIME

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ABSTRACT

The contribution submitts an analysis of problems involved in the solution of practical tasks, concerning sediment transport in water courses, the interaction of the fluvial sediment regime with the sea, as well as the thermal and ice regime of water courses and reservoirs. Additionally, each contribution of this thematic group is estimated with regard to the purpose of the conference.

ZUSAMMENFASSUNG

Im vorgelegten Beitrag wird eine Analyse der Probleme, die sowohl die Lösung von praktischen Aufgaben des Sedimenttransports in Flußläufen, der Wechselwirkungen zwischen dem Flußregime und dem Meer, als auch des Temperatur- und Eisregimes der Flußläufe und Staubecken betreffen. Anschliessend sind die einzelnen Beiträge dieser thematischen Gruppe vom Gesichtspunkt der Orientierung der Konferenz diskutiert.

1. New solutions of sediment transport problems

The processes of erosion, transport and deposition of sediment particles in a river basin are rather very complex. The main characteristic of these processes may be a quantitative continuity in time and space. The active factor of the erosion processes are dynamical erosive forces, in the case of water erosion those of running waters, which act against erodible sediment particles.

The starting point of the erosion circle are the processes of weathering and washing away of sediment particles. Investigations on soil erosion demand a comprehensive and interdisciplinary approach, since not only hydraulical parameters of running waters are governing parameters, but also the availability and especially erodibility of sediment particles on the earth surface. The erodibility is governed by geological composition, vegetation cover, slopes, etc., but also by land use or other human activities. The most exact possible knowledge about the time variations of sediment supply from major sediment sources (headwaters and agricultural land) to the river network is of paramount importance.

The second stage in the erosion circle is the transport of sediment particles within the river network. For better understanding of the relevant processes and as a basis for practical solutions, for that part of the erosion circle several groups of activities can be undertaken :

- firstly, the basic research with an aim to improve our knowledge of the physics of sediment transport (incipient of motion, bed forms, sediment loads) is needed,
- secondly, intensive, widespread and accurate monitoring of basic parameters (sediment yield, suspended sediment load, bed load, velocities of bed form movements) is badly needed for broader studies in that field, and
- finally, applied research in the form of comprehensive sediment budget studies :
  - explaining historical changes and the present situation, or
  - forecasting future trends, and
  - include the impacts of any kind of human activities, inclusive possible climate changes, on the response of a river system

  rounds up the proposed groups of activities.

The third stage of the erosion circle is the deposition of transported sediment particles within or at the end of the river network. The deposition can be a kind of :

- temporary storage of :
  - natural origin (bed material storage, alluvial bars and islands, lateral deposits, short-term flood-plain deposits and alluvial fans) and
  - human origin (sediment deposits in reservoirs due to sedimentation and siltation processes), or
- final deposition (long-term flood-plain deposits, river deltas, underwater lacustrine and marine deposits).

Similar groups of activities as for the transportation stage of the erosion circle can be undertaken :

- firstly, the group of basic research comprises the investigation of the depositional processes, leading to :
  - temporary storage (sedimentation conditions, storage duration, reworking of deposits) on one hand, or to
  - final deposition (river deltas evolution, braiding processes and resulting morphology of deltas, interaction between fluvial regime and sea eefects) on the other hand,
- secondly, monitoring of progressive siltation or sedimentation of man made reservoirs, dividing of water discharge and sediment load into several delta branches, protruding of deltas into the sea, or increasing of the underwater fan volume, and
- finally, applied research may then concentrate on the sediment balance studies of progressive reservoir sedimentation and delta evolution.

Above mentioned activities should resulted in an important part of the extensive hydrological basis of water management, part of which are also practical solutions in a form of engineering works and measures.

The XVIIth Conference is dedicated to forecasting of hydrological phenomena and hydrological bases of water management. The field of sediment transport include different practical tasks, among others :

- recognition of main sediment sources, such as water erosion and mass movements in headwaters or agrotechnical soil erosion, their monitoring in situ or by means of photogrammetry and other methods of remote sensing, data analysis, modelling and forecasting of corresponding sediment yields,

- development of improved and new equipment for measurement of suspended and bed load with higher accuracy,
- analysis and forecasting of time variations of suspended and bed load at a chosen location, given as a daily, monthly or annual series,
- analysis and forecasting of suspended load and bed load variations along the Danube under natural conditions due to :
  - fresh sediment supply from tributaries, bed or bank erosion (leading to deggradation), or
  - natural sedimentation (leading to aggradation),

  on one hand, and due to human activities, such as :
  - land use changes in practice and culture, or
  - river engineering works (such as sediment dredging, training schemes for navigation purposes, flood protection schemes, hydropower schemes etc.),

  on the other hand,
- development of new equipment or techniques for monitoring, monitoring itself, analysis and forecasting of sedimentation processes in retention reservoirs along the Danube River and of the Danube delta evolution and protrusion in the Black Sea,
- sediment budget studies, balancing the input and output quantities, mentioned before, performed for one reservoir or river reach, and for bigger catchments or parts of the Danube basin.

Altogether 13 papers were submitted to this Conference theme, 9 of them were dedicated to the solving of sediment transport problems. The first two of them deal with the assessment of suspended sediment supply to the Danube tributaries in Austria and the Czech Republic. Two further paper deal with human impacts on the suspended sediment transport in the Austrian Danube, and the suspended sediment regime in the Danube in Slovakia, respectively. Another paper is dedicated to bed load transport only, namely about the practice of measurement technique for bed load movement in Hungary. Three papers from Russia and Ukraine describe delta processes at the Danube mouth. One of them try to evaluate the dynamics of morphological changes of bed forms, and the other two use changes in the channel and the delta as the basis for the sediment balance study at the Danube mouth. The last paper, dedicated to the problems of sediment transport, belongs to the group of theoretical models of sediment transport.

The paper of Klaghofer and coauthors from Austria deals with soil erosion as the main sediment source for suspended load of the Austrian Danube. The authors used for the evaluation of sediment supply often-used MSLE, corrected by a ratio of sediment delivery. They have got mean values between 10 and 30 t/year,km$^2$. They stated that a change of land use culture or practice may be the main reason for the increasing suspended load in the Danube, which has in the last 30 years increased for more than 30 %. The results obtained by MSLE should be taken into account carefully, since a set of average values have been used. Further improvement of this technique should lead to the use of modern GIS tools, including digital terrain modelling and a set of data banks on relevant parameters of vegetation cover, climate, soils, etc. Since some of the smaller retention basins of the hydro power plants are already filled with sediment, local transport from one basin to the following one also contribute to the suspended load. Though, big retention reservoirs may be big enough only for long-term deposition of coarse bed-load particles. The storage of finer sediment particles in such reservoirs is rather temporare and short-termed, limited by the time of total sedimentation, and therefore a resuspension of such fine deposits may significantly contribute to total suspended load.

The paper of Petrůjová and coauthors from the Czech Republic shows a statistical analysis of measured data on suspended sediment load of the Morava River and some of its tributaries. Specific mean annual loads are as high as 40 t/year,km$^2$ for the site at Kroměříž, calculated from daily data. As a result of a suspended sediment budget study the long-term annual average of suspended sediment load of the Morava River at the border with Austria was estimated to be between 300.000 and 350.000 t/year. When dealing with the problem of missing data in the series of observed suspended sediment load, the authors proposed a kind of regime assessment for monthly and annual series and a kind of regression analysis in the case of daily series.

Summer and Zhang from Austria describe the significant changes in the Austrian Danube within last 120 years due to flood protection and hydropower plant schemes, as well as unthought-out land use. These human impacts have been increasing sediment yield ever since, whereas at the present time the intensity of monitoring decreases. Already under natural non-impound conditions sediment transport processes took place within a very short period of time, which is even shortened by already mentioned human activities. Paralelly, higher sediment concentrations are being measured. After the authors, this effect could be explained by practical unlimited availability of fine sediments in man made reservoirs of hydropower plants, and by increase of sediment yield in the Danube catchments. The authors has developed a new technique to evaluate human impacts on the sediment movement in a fast and accurate way. They stated that the pure statistical technique of the common rating curve for sediment concentration (eq.1 in Summer and Zhang) should be avoided and a physically based Unit Stream Power approach (eq.2 in Summer and Zhang) used instead. At the end, a successful application of this method for the prediction of annual suspended sediment load in the Austrian Danube is shown.

A group from Slovakia, led by Holubová, reports about the investigations at three sites in the Danube reach between Bratislava and Komárno. A detailed statistical analysis is given for the supended load data, measured over twelve months period after the hydropower scheme Gabčíkovo-Čunovo has been put into operation. The obtained results are discussed, but unfortunately, no previous data, measured before the errection of the hydropower scheme, are presented. Anyway, a strong need of permanent monitoring over the whole international section of the Danube River is stressed.

Despite the fact, that in the Danube River bed load transport never exceeds 10 % of the total sediment load, even in the Danube upper reaches, and so the Danube is a typical sand-bed river, unfortunately quite few papers were submitted concerning the practical problems of bed load transport. Devoted to bed load transport only is the paper of Rákóczy and Szekeres from Hungary, being at the same time also the only paper in the category of the development of new and improved monitoring techniques or equipment. The paper reports on the investigation, undertaken to improve the traditional Károlyi-type bed load sampler by means of underwater video. We may conclude, that our monitoring equipment, developed mainly under quite moderate laboratory conditions, should be tested under more complicated or severe natural conditions. To do so, additional modern techniques, such as any kind of electronic devices, may be very helpful or even unavoidable.

A valuable contribution to better understanding of delta changing processes, not only in the Danube delta, but also in other similar deltas, is the paper of Polonsky from the Russian Federation and Kovaliov from Ukraine. They report on dynamics of mouth bars and underwater fans, protruding to the sea in the Danube River delta. From extensive field survey on the mouth bar morphology and morphometry parameters important relationships with their determinig factors have been established. This phenomenological type of investigation is adequate to predict morphometric changes of mouth bars by taking into account water discharge redistribution trends in each delta arm. However, for long-term forecasting purposes more detailed modelling of delta evolution as a dynamical braiding processes should be used instead.

A method, how to evaluate bed load transport from the shift of sand bed forms of different scales, is suggested by Alekseevsky and Granich from Russia. They have applied their method on the Ural and Danube delta. As a result of the analysis of the Danube delta, annual bed load transport to the Lower Danube was estimated to be as high as 8 million tons per year. During flood periods, bed load transport contributes to the total sediment load between 17 and 18 %, and only during low-water periods, this contribution decreases to 1 %. An annual bed load transport equals to 8 to 10 % of suspended sediment yield and therefore may not be neglected. This was found to be in a clear contradiction to many other investigations, which estimated bed load transport to be practically negligible.

This underestimation of the sediment yield for the Lower Danube River was confirmed also by the sediment balance study at the Danube River mouth, carried out by Mikhailova from Russia. She studied the changes of the Chilia (Kiliya) delta, especially the fan volume changes, in the last 240 years. When comparing the fan volume changes and estimated sediment yield, she found out, that the values of the latter were understimated for about 30 %. The reason for that should be at least to some extent due to the fact, that bed load transport has been neglected in other investigations, despite the fact, that, according to the study performed, it contributes to the total sediment load nearly 10 %. When checking the results of this kind of sediment balance study, one should be carefull when converting measured or estimated values of suspended sediment yield, given in mass units, into corresponding volume units. Should we use sediment deposition density of about 1100 kg/m$^3$ or the density of sediment deposits, which increases with time and can reach values around 1600 kg/m$^3$?

The last contribution to problems of sediment transport was submitted by Samoylenko and Koulachinsky from Ukraine. They have developed a stochastic model for wind-generated surface waves in the surf zone of seas, lakes or reservoirs. An important part of the proposed model is the shore dynamics and stability, including litoral sediment transport. The model has been tested on a set of natural and laboratory data,and was found to be suitable for practical purposes, when simulating shore dynamics and litoral sediment transport. Unfortunately, no detailed information is given on the verification of the model.

2. Analysis of the heat and ice regime

Thermal and ice regime of watercourses, lakes, reservoirs, retention reservoirs and water engineering works is an interdisciplinary branch. The regularities of processes, creating those regimes, belong to the realm of hydrology, hydraulics, thermal- and hydrodynamics, meteorology, but even to chemistry and biology. Consequences of those regimes influence in a large extent many human activities, for instance water utilization for hydropower production, in industry, water transport, drinking water supply, fishery, and last but not least flood control, and protection from disturbances of the ecological equilibrium of regions, etc.

Taking into account the solution of practical problems, caused by the regime of heat and ice phenomena, it is important to know the laws of :

- the development of water temperature in time and space in running and stagnant waters,
- the effect of meteorological factors and characteristics of the subsoil of streams and reservoirs on the course of water temperature,
- the development, accumulation, spreading and extinction of various forms of ice phenomena and processes, and
- the effect of hydrological, meteorological, and morphological factors on the ice regime

under natural conditions, when they are exposed only to random cycles - winter, seasonal, annual, or long-term cycle, and under conditions, effected by human activity.

The solution of these problems is taking place on the level of phenomena analysis and studying of regimes, and their influencing factors on one hand, and on the level of their forecasting on the other hand.

The main aim of the XVIIth Conference is forecasting of hydrological phenomena and hydrological bases of the water management. Considering this aspect, following practical tasks may be submitted for the thermal and ice regime, dealing with the analysis and forecasting of :

- time water temperature variations in a concerned place of the stream, or along the stream (longitudinal temperature profile) under natural conditions, which may be expressed also as longitudinal profile of temperature, occuring within the stream (qualified as thermal capacity of the stream),
- water temperature in lakes, reservoirs and retention reservoirs of hydro power plants (the course of temperature on the water surface and stratification of the temperature),
- temperature variations in streams and reservoirs, influenced by the input of warm waters (thermal pollution), occuring in two stages : the first one takes place as intensive mixing of "thermally polluted" water with natural water within the receiving water, and as the second stage as gradual cooling,
- starting ice phenomena and freezing-up,
- development of slush, or frazile ice,
- disintegration of the ice cover and extincton of ice phenomena.

Two essential approaches have been chosen for solution of these tasks :

- statistical methods, based on deduction of physical-statistical empirical relationships between the water temperature and ice occurence on one hand, and chosen influencing factors on the other hand (most frequently air temperature, discharge or water depth), and
- thermal-balance methods, which by means of evaluation of all components of thermal transfer through the water level and river bed, or reservoir bottom, express the water temperature variation, or reaching of certain temperature (e.g. : maximum admissible of 20°C or 25°C, or 0°C, which is one of the preconditions for ice phenomena occurence).

Application of any methods requires, above all, observation of numerous parameters, may it be meteorological and hydrological elements, morphological parameters of the river beds and reservoirs bottoms, parameters of their subsoil, climatic conditions, as well as some astronomic parameters. The monitored parameters should be of long-term characters, homogenous and representative with regard to the place of analysis or forecasting of phenomena.

Monitoring, measuring and processing of data present also currently a time consuming and expensive activity with regard to instrumentation and equipment of monitoring stations, especially as far as ice regime phenomena and processes is concerned. They are influenced more then other hydrological and meteorological elements by the subjective opinion of the observer, thus having various degree of objectivity. Therefore, it is sometimes necessary to use complementary measurements by means of photogrammetry and aerial photography, or using methods of remote Earth survey, or to utilize the relationship between the ice occurence and various meteorological situations.

In addition to representative monitoring of hydrological and meteorological parameters the methods of thermal balance require knowledga of other factors, showing for instance, the conditions of unsteady flow, diffussed heat transfer, etc. Their determination is dependent upon laboratory studies and application of the theory of similitude at thermal-balance processes. Practical application of many theoretical processes details of solution is still connected with difficulties, and therefore, the statistical methods are more frequently used in solving tasks of thermal and ice regime of streams and reservoirs. It is evident also from the selection and contens of the papers, sent as belonging to the group "analysis of thermal and ice regime".

The paper of Dr.Déri from Hungary belongs into the category of problems involved in the relationship of hydrological elements and ice phenomena. It is dealing with the study of the Danube regime influenced by heat input. The course of heat capacity along the stream and its variations, caused either by natural tributaries, or by waste waters, discharged from power plants, industry and sewerage systems into the Danube from the mouth of the Inn, down to the mouth of V.Morava, have been analysed. The extent of thermal capacity increasing over the years 1946 to 1981, in annual average and in summer and winter half-year has been assessed. He has stated, that meanwhile the annual average value is almost constant, the half-year trends show an increase. Comparing the capacity of tributaries and wastewaters (Tab.1 and 2) showed, that the thermal load of the water course, caused by human activity on the Austrian and Hungarian Danube, is equal to the thermal load of the Sava tributary. Thus the total thermal capacity was changed due to these influences in such an extent, that, for instance, its mean winter value in Budapest increased by 16 % and in Mohács by 34 %.

This fact became adequately evident also in the ice regime. Wastewaters from thermal power plants on Hungarian reach of the Danube reduced the ice run by 14 to 18 % and the nuclear power plant Paks by 28 %. They also contributed to the abatement of the hazard of ice lams formation and to freeze up shortening on trained river sections. The paper clearly shows the favourable effect on antrophogenous interventions into the thermal regime of the stream on the potential hazardous manifestations of the ice regime on the Hungarian Danube reach.

While Dr.Déri has been studying the relationship of the heat transported by water, especially its supplemental component ensuing from the antrophogenous activity, to the ice regime and development of ice cover (stagnant ice), Dr.Genev from Bulgaria has dealt with the relationship of air temperature to the ice phenomena on the Bulgarian Danube reach from the right-side tributary Timok, to the city Silistra. His work was based on statistical estimation of this relationship. He has stated, that quantitative characteristics of the ice regime are in a significant correlation with air temperatures at all studied stations. Similarly as in other Danube reaches, the mean winter temperatures show also here an increasing trend. These conclusions have general validity, since in the brief submitted paper their validity for a concerned studied Danube reach is not clearly evidenced.

Previous contributions dealt with the analysis of the thermal and ice regime. The work of the collecive of authors from the Republic Hydrometeorological Institute of Serbia was aimed at an other group of problems, namely the methodology and practical results of ice phenomena forecasting on the Danube. The method of forecasting is based on physical-statistical, or empiric-graphical relationships. The primary relationship shows the dependence of thermal losses (expressed by a sum of negative mean daily air temperatures until the occurence of the first ice phenomena) upon water temperature at the beginning of ice occurence. This relationship was extended by further parameters, i.e. by the discharge, or water stage (water depth). This proceeding requires high-quality forecasting of air temperature, or development of the relationship between the date of the first ice occurence and the date of air temperature drop below 0 °C, on the basis of historical observation series.

In the section between the stations Bezdan and Smederevo the forecasting method has been applied since winter 1971-

72, and monitoring of data has been carried out since 1992, as weel as ice phenomena forecasting and dissemination of information in due time to users, by mens of an automatized system. Obtained results and operational character of this method is considered as satisfactory justification for giving priority to this method, instead of the thermal-balance method.

The last paper by the collective of authors from Austria, lead by W.Summer, had dealt with the analysis of warm wastewaters input into the Danube. Drawing up the plans of thermal load of the Austrian Danube it was assumed, that the warm wastewaters undergo a complete mixing with the Danube water, and then they are changed according to the exponential relationship. Actually, an intense turbulent mixing takes place after the inflow, and being not completely concluded they undergo another variation, namely cooling. The mixing intensity and geometric patterns of the zones of warm and cool water within the receiving water depend largely upon the shape and direction of the plumes of warm wastewater. These problems have been analysed in the paper, while results of mixing were considered for solution of other practical tasks connected with the Danube water utilization.

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# Aspekte zum Sedimenteintrag in die Österreichische Donau und ihrer Zubringer

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Zusammenfassung

Die Hochwässer in der österreichischen Donau werden in ihrer hydrologischen, sedimentologischen Charakteristik wesentlich durch das Geschehen in den Seitenzubringern Inn, Traun, Enns, Ybbs und Melk beeinflußt. Neben einer kraftwerksbedingten Beeinflussung des Feststoffhaushaltes der Donau gewinnt zunehmend als Sedimenteintragsquelle die landwirtschaftlich bedingte Steigerung der Erosion an Bedeutung.
Diese Arbeit quantifiziert die durch geänderte landwirtschaftliche Faktoren verursachte Zunahme des Bodenab- und Bodeneintrages im österreichischen Einzugsgebiet der Donau und ihrer Zubringer. Dabei wird der durchschnittliche mittlere Bodenabtrag mit Hilfe der Allgemeinen Bodenabtragsgleichung errechnet und das in die Flüsse gelangende Sediment mit Hilfe eines Sediment-Austragkoeffizienten abgeschätzt. Die Basis dafür sind vor allem die Nutzungserhebungen des Österreichischen Statistischen Zentralamtes aus den Jahren 1950 und 1990. Es zeigte sich, daß die Anteilsänderungen der landwirtschaftlich genutzten Flächen und die geänderten landwirtschaftlichen Nutzungen (Zunahme des Maisanbaues) zu erhöhten Sedimentationseinträgen führten.

Summary

The hydrological as well as sedimentological characteristics of the floods of the Austrian Danube are controlled by the tributaring rivers Inn, Traun, Enns, Ybbs and Melk. However, the sediment transport experienced a major impact due to the erection of hydropowerplants along the river courses. But an increasing influence of agricultural soil erosion as the major sediment source, which influences significantly the sedimentological behaviour of the Danube, has been recently observed.
This study quantitatively determines the increase of the soil erosion as well as the sediment yield within the catchment of the Austrian Danube and its tributaries. Based on the Modified Soil Erosion Equation average soil erosion rates have been calculated and by the application of sediment delivery ratios the sediment yields for the major sub catchments have been estimated. The study is based on the land use information for the years 1950 and 1990, published by the Austrian Statistical Central Office. The results show an increase in the sediment yield caused by land use changes such as the areal extension of maize.

## 1. Einleitung

Hochwässer der österreichischen Donau werden durch die Seitenzubringer Inn, Traun, Enns, Ybbs und Melk wesentlich in ihrer hydrologischen und sedimentologischen Charakteristik beeinflußt. Hochwässer dieser Zubringer verschärfen nicht nur den Spitzenabfluß der Donau, sondern tragen wesentlich zur Schwebstoffdynamik des Stromes bei. Der in den Teileinzugsgebieten der Donau sowohl erodierte als auch in das Flußsystem eingetragene Boden sedimentiert in den vorhandenen Stauräumen. Bei Hochwässer kommt es dann zu nicht unwesentlichen Umlagerungen der Stauraumsedimente und zum Weitertransport der mobilisierten Schwebstoffe (PRAZAN, 1990). Ausufernde Hochwässer richten dann durch das Ablagern der mitgeführten Schwebstoffe beträchtliche Schäden an landwirtschaftlichen Flächen und Kulturen, Wohnungen, Straßen etc. an.
Obwohl an der Donau durch den Stauraum der Kraftwerksanlage Aschach mit seinem Volumen von mehr als 100 Mio $m^3$ ein enormer Sedimentationsraum vorhanden ist, kann bei kleinen Kraftwerksanlagen wie Jochenstein, Ottensheim-Wilhering, Wallsee-Mitterkirchen, Ybbs-Persenbeug und Melk eine allmähliche Annäherung an den sedimentologischen Gleichgewichtszustand festgestellt werden (RADLER et al., 1993). Demnach gewinnt neben der kraftwerksbedingten Beeinflussung des Feststoffhaushaltes der Donau zunehmend die landwirtschaftlich bedingte Steigerung der Bodenerosion an Bedeutung.

## 2. Untersuchungsumfang

Unter der normalen Bodenerosion versteht man den Abtrag von Bodenbestandteilen durch Wasser oder Wind. Bei der kulturbedingten Bodenerosion wird der Bodenabtrag durch den Menschen dadurch verstärkt, daß die natürliche Vegetation vor allem durch die ackerbauliche Nutzung ersetzt und damit der Bodenabtrag verstärkt wird. Dabei treten unterschiedliche Effekte (CLARK II et al., 1985) auf, die zu

- direkten Schäden auf den betroffenen Flächen (On-Site Schäden) und
- indirekten Schäden (Off-Site Schäden)

führen können. Zu den Off-Site Schäden zählen der Eintrag von Schwebstoffen, Pestiziden, Schwermetallen und organischen Bodensubstanzen in die Gewässer. Damit verbunden ist eine Verlandung von Stauräumen und Seen, eine Einschränkung des Retentionsraumes, des nutzbaren Wasserspeichers und des schiffbaren Strombereiches. Bei Ausuferungen aus Gerinnen kommt es zu Schlammablagerungen in den Hinterländern. Durch eine Verringerung des nutzbaren Wasserspeichervermögens auf den erodierten Böden kann die Hochwasserhäufigkeit steigen.

Zur Quantifizierung des Einflusses veränderter landwirtschaftlicher Bodennutzungsformen auf den Sedimenthaushalt der österreichischen Donau und ihrer Seitenzubringer wurden die Daten der Bodennutzungserhebungen des Österreichischen Statistischen Zentralamtes aus den Jahren 1950 - 1990 (ÖSZ, 1990) verwendet. Primäres Augenmerk wurde dabei auf die Veränderung der Kulturen mit hoher Erosionsgefahr (KLAGHOFER, 1985) wie Mais, Kartoffel, Zuckerrübe und Sommergetreide gelegt. Untersucht wurden die Veränderungen in der landwirtschaftlichen Nutzung sowohl im Gesamteinzugsgebiet der österreichischen Donau als auch in den Hauptzubringern Inn, Traun und Enns. Die Quantifizierung des Bodenabtrages auf den landwirtschaftlich genutzten Flächen erfolgte mit Hilfe der Allgemeinen Bodenabtragsgleichung ABAG (SCHWERTMANN, 1987).

Die Allgemeine Bodenabtragsgleichung (ABAG) lautet:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

A .... langjähriger, mittlerer jährlicher Bodenabtrag
R .... Regen- und Oberflächenabflußfaktor
K .... Bodenerodierbarkeitsfaktor
L .... Hanglängenfaktor
S .... Hangneigungsfaktor
C .... Bedeckungs- und Bearbeitungsfaktor
P .... Erosionsschutzfaktor

Da die Bodenabtragsgleichung nur für gleichförmig bewirtschaftete und bearbeitete Flächen gilt, wurde zur Quantifizierung mittlere Bodenkennwerte, Hangneigungen und Hanglängen für jedes Einzugsgebiet angenommen. Diese Simplifizierung mußte deshalb erfolgen, da einerseits die notwendigen Datensätze für eine exakte Berechnung des Bodenabtrages nicht flächendeckend vorhanden sind, andererseits auch der Erhebungsaufwand dafür zu groß wäre (STRAUSS, 1992). Da mit Hilfe der ABAG nur die Bodenabträge, die bis zum Feldrand gelangen, errechnet werden können, wurde der Transport bis in das Gerinne mit einem Sediment-Austragkoeffizienten (VANONI, 1977) abgeschätzt. In kleineren Einzugsgebieten treten jedoch stark abweichende Sediment-Austragskoeffizienten auf, wie dies KLAGHOFER et al. (1992) zeigten.

## 3. Ergebnisse

Das Ziel der Berechnungen war es, die Bodenabtragsmengen, die bei Starkregenereignissen in die Donau, den Inn, die Enns und die Traun gelangen, zu quantifizieren. Dabei wird, ausgehend von den erwähnten Erhebungsdaten des Österreichischen Statistischen Zentralamtes, die landwirtschaftliche Anbaufläche und Fruchtartenverteilung aus dem Jahre 1950 mit der aus dem Jahre 1990 verglichen und der Bodenabtrag in Verbindung mit typischen geländemorphologischen Daten ermittelt.

### 3.1 Das Einzugsgebiet des Inn

Das Gesamteinzugsgebiet des Inn in Österreich beträgt rd. 1,7 Mio ha. Davon sind 43 % landwirtschaftlich und 35 % forstwirtschaftlich genutzt; 22 % sind unproduktive Fläche. Die landwirtschaftlich genutzte Fläche veränderte sich vom Jahre 1950 bis zum Jahre 1990 kaum. Innerhalb der landwirtschaftlich genutzten Fläche kann von 1950 bis 1990 ein Rückgang der Ackerbaufläche beobachtet werden, während der Grünlandanteil steigt. Eine Betrachtung der Entwicklung der Anbaufläche verschiedener Kulturarten des Ackerlandes zeigt, daß die Anteile der Maisanbaufläche im Jahre 1950 2 % betrugen und bis zum Jahre 1990 auf 25 % angestiegen sind. Alle übrigen Veränderungen der erosionsrelevanten Kulturen Rübe, Kartoffel und Sommergetreide beeinflussen das Abtragsgeschehen nur geringfügig. Die Abschätzung der erodierten Bodenmengen mit der ABAG erfolgte mit R = 100 $kJ.mm/m^2.h$

und K = 0,5. Beim Ackerbau wird angenommen, daß 75 % des Getreides und Mais bzw. 25 % von Kartoffel und Rübe in Hanglage angebaut werden. Die typische Hanglänge wird mit 50 m, die typische Hangneigung mit 10 % angenommen. Daraus ergibt sich ein LS mit 1,76. Der C-Wert für Mais ist 0,33, für Kartoffel 0,24, für Rübe 0,21 und für Sommergetreide 0,06.
Im Jahre 1950 wurden unter diesen Annahmen rd. 460.000 t Boden abgetragen. Bei einer durchschnittlichen Einzugsgebietsgröße der Zubringer zum Inn von rd. 13 km² ergibt sich ein Sediment-Austragskoeffizient (SDR) von 0,2. Damit errechnet sich ein Schwebstoffeintrag pro Jahr von 92.000 t.
Unter den gleichen Randbedingungen wie vorher errechnet sich bei geänderten Fruchtartenanteilen im Jahre 1990 ein Schwebstoffeintrag von 128.000 t. Der errechnete Schwebstoffeintrag hat sich somit von 1950 bis 1990 um 39 % erhöht.

## 3.2 Das Einzugsgebiet der Enns

Das gesamte Einzugsgebiet der Enns beträgt rd. 0,90 Mio ha. Davon sind im Jahre 1950 37 % landwirtschaftlich und 46 % forstwirtschaftlich genutzt; 17 % sind unproduktive Fläche. Der Anteil der landwirtschaftlich genutzten Fläche nimmt bis 1990 um ca. 5 % ab, die forstwirtschaftlich genutzte Fläche steigt um diesen Prozentsatz. Im Jahre 1950 wurde kein Mais im Einzugsgebiet angebaut. Im Jahre 1990 stieg der Anteil der Maisanbaufläche auf 23 % der Ackerfläche. Die Anteile von Kartoffel, Rübe und Sommergetreide verringerten sich bis 1990 geringfügig. Die Abtragsberechnung erfolgte unter denselben klimatologischen und geländemorhpologischen Annahmen wie im Einzugsgebiet des Inn. Die Berechnung der Bodenabtragsmengen mit der ABAG ergibt für das Jahr 1950 227.000 t. Mit einem SDR-Wert von 0,2 errechnet sich ein Sedimenteintrag in die Enns von 45.000 t. Im Jahre 1990 errechneten sich bei denselben Randbedingungen, aber einer veränderten Anbausituation, Bodenabtragsmengen von 407.000 t und eine Sedimentfracht von 81.000 t.
Ein Vergleich der errechneten Boden- bzw. Schwebstoffeinträge im Jahre 1950 und 1990 ergibt eine Erhöhung von rd. 80 %. Diese Erhöhung ist auf den starken Anstieg der Maisanbauflächen zurückzuführen.

## 3.3 Das Einzugsgebiet der Traun

Das Gesamteinzugsgebiet der Traun beträgt rd. 0,43 Million Hektar. Davon sind 1950 43 % landwirtschaftlich und 40 % forstwirtschaftlich genutzt; die unproduktive Fläche beträgt 17 %. Der Anteil der landwirtschaftlich genutzten Fläche änderte sich bis zum Jahre 1990 nur wenig. Innerhalb der landwirtschaftlich genutzten Fläche konnte bis zum Jahre 1990 ein deutlicher Anstieg des Ackerlandes und ein Rückgang des Grünlandes festgestellt werden. Die Entwicklung der Anbauanteile verschiedener Kulturarten des Ackerlandes zeigte einen deutlichen Anstieg der Maisanbaufläche von 0 % auf 25 % und eine Abnahme der Kartoffel-, Rübe- und Sommergetreideanbauflächen.
Die Berechnung des Bodenabtrages für das Einzugsgebiet der Traun erfolgte für das Jahr 1950 unter denselben Annahmen wie für das Einzugsgebiet der Enns und ergab für das Jahr 1950 326.000 t. Bei einem SDR-Wert von 0,2 ist der Eintrag in das Gerinne 65.000 t.
Im Jahre 1990 errechnete sich bei der geänderten Anbausituation ein Abtrag von 642.000 t und ein Eintrag in die Traun von 128.000 t. Ein Vergleich der errechneten

Bodenabträge im Einzugsgebiet der Traun bzw. der Schwebstoffeinträge in die Traun im Jahr 1950 und 1990 ergibt eine Erhöhung um fast 100 %. Diese Erhöhung ist auf den starken Anstieg der Maisanbauflächen zurückzuführen.

### 3.4 Das Einzugsgebiet der Donau in Österreich (ohne Enns, Traun und Inn)

Die Gesamteinzugsgebietsfläche der Donau in Österreich beträgt rd. 4,4 Millionen Hektar. Davon sind im Jahre 1950 52 % landwirtschaftlich und 34 % forstwirtschaftlich genutzt; die unproduktive Fläche betrug 14 %. Im Jahr 1990 sank die landwirtschaftliche Nutzfläche an der gesamten erhobenen Fläche auf 49 % und die forstwirtschaftlich genutzte stieg auf 39 %. Die Maisanteilsfläche stieg vom Jahre 1950 von 4 % auf 16 % im Jahre 1990, die Anteile der mit Kartoffel und Rübe bebauten Flächen sanken, wobei sich die Flächen mit Wintergetreide erhöhten. Die Abschätzung der Bodenabträge im Donaueinzugsgebiet ohne den Flüssen Enns, Traun und Inn im Jahre 1950 erfolgte mit der ABAG unter der Annahme eines R-Wertes von 70. Da im Donaueinzugsgebiet in Österreich in der Donauniederung und in weiten Teilen im Osten Österreichs ebene Flächen vorhanden sind, wird angenommen, daß nur 50 % der Flächen, die mit Getreide und Mais bepflanzt sind, sich in Hanglage befinden und bei Kartoffel und Rübe nur 25 %. Als durchschnittliche Hanglänge wird eine mit 75 m angenommen, wobei diese eine Hangneigung von 10 % aufweist. Daraus ergibt sich ein LS-Faktor von 2,15. Der K-Faktor wurde mit 0,5 angenommen. Unter den vorangegangenen pflanzenbaulichen, klimatologischen und geländemorhpologischen Bedingungen wurde ein Bodenabtrag von 1.969.000 t und mit einem SDR-Wert von 0,2 ein Schwebstoffeintrag in die Donau von 349.000 t im Jahre 1950 errechnet. Für das Jahr 1990 errechnete sich mit den vorangegangenen Daten jedoch unter den veränderten Anbaubedingungen ein Bodenabtrag von 2.209.000 t und ein Sedimenteintrag von 442.000 t. Die Erhöhung vom Jahre 1950 auf das Jahr 1990 betrug somit rd. 10 %.
Insgesamt ergaben sich für das gesamte Einzugsgebiet der Donau eine Steigerung des Sedimenteintrages um 31 %, was auf die erhöhten Flächenanteile, die mit Mais bebaut sind, zurückzuführen ist.

## 4. Schlußbemerkungen

Eine ungefähre Abschätzung des Bodenabtrages bzw. Sedimenteintrages in die Donau und ihre Seitenzubringer Inn, Enns und Traun zeigte, daß vor allem die erosionsfördernde Kultur Mais eine Erhöhung des Bodenabtrages verursacht. Da für die Berechnung mit der ABAG - was die Inputdaten betrifft - nur sehr allgemeine Annahmen getroffen werden konnten, können die Rechenergebnisse auch nur ungefähre Anschätzungen der realen Situation sein. Es kann jedoch gezeigt werden, daß durch die veränderte landwirtschaftliche Nutzung ein höherer Sedimenteintrag stattfindet, der die veränderte, erhöhte Schwebstofführung in der Donau (PRAZAN, 1990) teilweise erklärt. Eine exakte Untersuchung des Abtrags- und Eintragsgeschehens kann nur bei einer genauen Kenntnis der geländemorphologischen, klimatologischen und pflanzenbaulichen Gegebenheiten des Gesamteinzugsgebietes erfolgen. Dies setzt, wie bereits erwähnt, die Verwendung von digitalen Höhenmodellen (DHM), geographischen Informationssystemen (GIS), umfangreichen bodenkundlichen, pflanzenbaulichen und klimatologischen Datenbanken voraus.

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XVII. KONFERENZ DER DONAULÄNDER
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# SUSPENDED SEDIMENTS IN THE MORAVA RIVER

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**Summary:** The paper summarizes the first results of a data analysis on suspended sediments content observed in the Morava River basin. Authors present the average annual concentration and, specifically, the load of suspended sediments. Short account is given of results concerning of analyses of relationships between suspended applicability for making predictions.

# SCHWEBSTOFF DER MÄHREN

**Kurzfassung:** Der Beitrag behandelt die erste Ergebnisse der Datenverarbeitung des Schwebstoffgehalts an dem Einzugsgebiet der Mähren. Die Autoren führen Jahrmittelwerte des Schwebstoffgehalts und besonders Schwebstoffabflusses an.

Die Aufmerksamkeit ist nicht nur dem Schwebstoffabfluß aus dem Gebiet der Tschechischen Republik sonder auch aus dem einzelnen Abschnitten der Mähren gewidmet. Im Kürze sind die Ergebnisse der Analyse des Zusammenhangs zwischen Schwebstoffgehalt und Durchfluß genannt, inclusive ihrer eventuellen Ausnutzung für Prognose.

## 1. INTRODUCTION

Daily observation of suspended sediments carried out by the Czech Hydrometeorological Institute in 44 selected water gauging stations since the water year 1985 allowed to initiate an assessment of balance and partially also of regime data on concentration, discharge and loads of suspended sediments within the territory of Czech Republic.

In our paper, some of the results of the analyses of suspended sediments load are given for the Morava River between the Olomouc and Strážnice localities and for its tributaries, namely the Bečva, Dřevnice and Olšava watercourses (Fig. 1.). The analysis is based on data on daily concentration of suspended sediments for seven sites for the period 1990 - 1992. The investigated period was below average in terms of annual water discharge and therefore the resulting average load of suspended sediments reached only 50 per cent of the magnitude for stations with eight-year series of observation, i.e. between 1985 and 1992.

| Station | River | Area [km²] | $Q_a$ [$m^3.s^{-1}$] 1931-80 | c [$mg.l^{-1}$] 1985-92 | c [$mg.l^{-1}$] 1990-92 | $M_s$ [$t.a^{-1}$] # 1985-92 | $M_s$ [$t.a^{-1}$] # 1990-92 |
|---|---|---|---|---|---|---|---|
| Olomouc | Morava | 3.322,07 | 27,146 | | 73,61 | | 135.763 |
| Kroměříž | Morava | 7.014,44 | 51,285 | 112,71 | 90,54 | 491.534 | 288.138 |
| Uherské Hradiště | Morava | 8.113,16 | 55,903 | | 45,28 | | 151.150 |
| Strážnice | Morava | 9.146,92 | 59,605 | | 51,84 | | 135.373 |
| Teplice | Bečva | 1.275,99 | 15,338 | | 39,48 | | 37.574 |
| Zlín x | Dřevnice | 311,99 | 2,212 | | 45,16 | | 8.632 |
| Uherský Brod | Olšava | 401,23 | 2,142 | 62,71 | 63,46 | 16.420 | 8.520 |

x - based on data for 1992 only # - $M_s$ [$t.a^{-1}$] is calculated from daily data

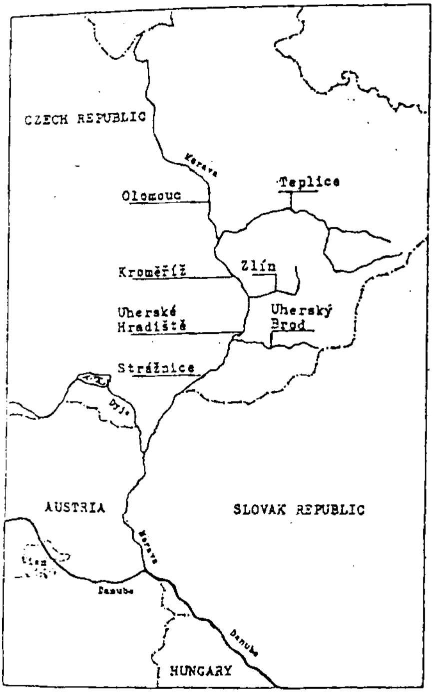
**Tab. 1. List of stations and basic hydrological data**
**Tab. 1. Der Überblick der Stationen und der hydrologisc Grunddaten**

In addition to assessment of loads of suspended sediments for particular subbasins, transport of suspended sediments throughout a stream (of the Morava River) was evaluated and river reaches between the observing sites and the relevant river catchments were characterized in detail.

## 2. BALANCE AND REGIME ASSESSMENT

Load of suspended sediments from the Morava River to Danube is the main balance component. The basic information for its estimation is the average annual load of suspended sediments through the Strážnice site. For the years 1990 - 1992, which showed annual water discharge below average, the average of approximately 135 373 t/year flowed through this site. After corrections on the results of eight-year observation in the Morava Basin, the value was modified and given in the range from 270 000 to 300 000 t/year. In view of a considerable variability of suspended sediments concentrations, the actual annual mean loads range probably between 130 000 t/year (for a dry year) to 650 000 t/year (for a wet year).

However, in order to specify load of suspended sediments from the Morava River to Danube, the load must be given for a site where the Morava River leaves the territory of the Czech Republic, i.e. below the confluence with the Dyje River. The resulting long-term annual average of suspended sediments from the territory of the Czech Republic can then be estimated as 300 000 - 350 000 t/year.



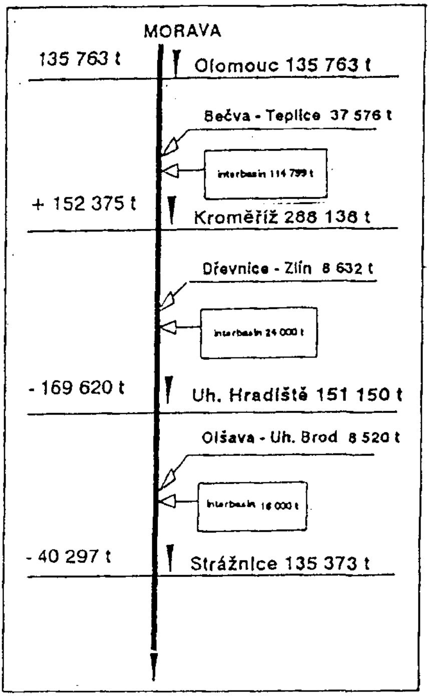




Fig.1. Location of observing sites

Abb.1. Die Situation der beobachteten Profile

Fig.2. Average annual loads of suspended sediments for 1990 - 1992

Abb.2. Jahrmittelwerte des Schwebstoffabflusses 1990 - 1992

Load of suspended sediments to Danube can be estimated by experts of the Slovak Hydrometeorological Institute (Slovak Republic) who have carried out daily observation at the Záhorská Ves site since the water year 1992. It can be assumed that in view of considerable sedimentation along the lover stretches of the Morava River the value vould be lower than loads of suspended sediments from the territory of the Czech Republic.

The assessment of the suspended sediments loads at particular river reaches of the Morava River for 1990 - 1992 identified considerable increases or decreases at the observing sites. This behavior is shovn by a diagram in Fig. 2. The investigated period is too short and atypical (it does not represent the range of hydrological variability) and is therefore difficult to make generally valid conclusions. Some conclusions can, however, be formulated.

Vithin the stretch between the Olomouc and Kroměříž localities, twofold increase of the load of suspended sediments can be noted. The increase is attributed to the Bečva River (flysch region) and mainly to other tributaries from regions vith extensive agriculture. Dovnstream, betveen the Kroměříž and Strážnice localities, decrease of the load of suspended sediments can, on the contrary, be noted (there are seven veirs in this part of the river). The decrease of the load of suspended sediments represents in the three-year average at the city of Uherské Hradiště 57 per cent and at the Strážnice locality 47 per cent of the amount of suspended sediments observed at the Kroměříž site.

Next, ve vere interested in changes of suspended sediments transport along the Morava River for various vater discharge conditions. By assessing the annual values, it vas found that the ratios betveen the loads of suspended sediments at observing sites vere not identical betveen the years and an explanation vas related to the variability of monthly loads (Fig. 3.) and to assessment of ten periods of increased daily vater discharge and suspended sediments concentration. For the assessment, the magnitude of the observed mean and maximum vater flov, and of concentration and loads of the suspended sediments vere taken into account. In order to simplify the characterization of complex natural phenomena, tvo basic types of situations vere determinated, for vhich it vas possible to differentiate other categories (for example, the effects of local rainfall events etc.).

The first type is represented by high vater flov and high load of suspended sediments ($Q_{max}$ of 300 $m^3.s^{-1}$ and over) vhen the loads of suspended sediments along the investigated stretch of the Morava River are nearly identical.

The other type of situation is represented by increased vater flov and suspended sediments loads ($Q_{max}$ mostly betveen 150 and 200 $m^3.s^{-1}$) vhen decrease can be noted in the stretch betveen the Kroměříž and Uherské Hradiště sites of up to 60 per cent, and in the stretch betveen Uherské

Hradiště and Strážnice the loads decrease by further 10 per cent.

At periods of peak flows (Qmax) lower then that of the above two types, effects of the Morava tributaries are clearly apparent, for example, the increase of the load of suspended sediments at the Strážnice site in comparison to the Uherské Hradiště site.

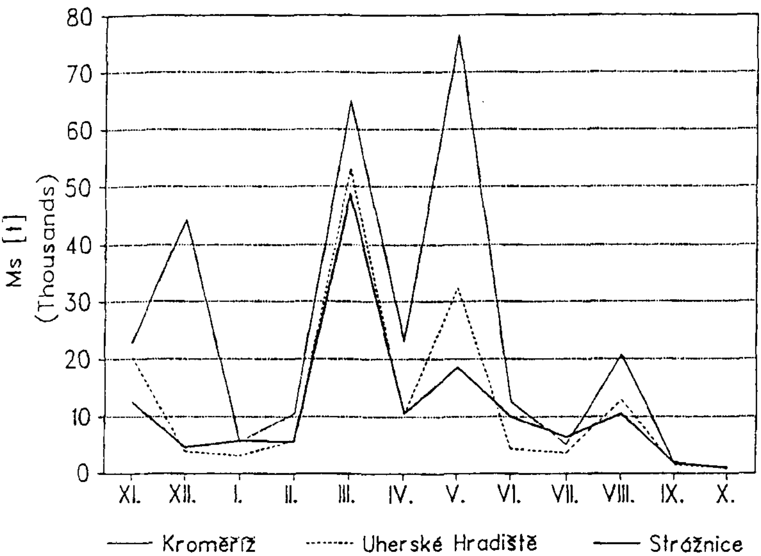



**Fig.3. Mean monthly loads of suspended sediments for 90 - 92**
**Abb.3. Monatsmittelwerte des Schwebstoffabflusses 1990-1992**

The selected types of situations simplify characterization of the investigated river stretches and allow filling-in the gaps in the monthly or annual series of suspended sediment loads when the observation is interrupted at some of the stations.

Evaluation of relationships between the concentration, load of suspended sediments and water flow is subsequent to this assessment. The resulting interrelations depend directly on the quality - representativeness of concentration measurements of suspended sediments in watercourses. Assessment is complicated by high variability and asymmetry of data series of suspended sediments concentration, which increases with a decrease of water flow. The assessment of relationships between water flow and suspended sediments concentration requires, in addition to exact measurements, also knowledge and understanding of complex natural interaction within the basin reflected also in the suspended sediments variability.

Based on the results of previous studies, additional intermediate data series containing daily data for summer and winter periods, or for various flow magnitudes were prepared, apart from the basic daily data series, for the purpose of correlation and regression analyses. In addition, relationship for monthly, annual and "clustered" series were studied. The results allowed to characterize in greater detail particular series of data. For making prediction or for filling-in gaps in daily data series, it is possible, so far, to use only results of regression analyses between water flow and suspended sediments concentration for the so-called "clusters" showing sufficiently high correlation coefficients (daily data series were divided into clusters according to selected magnitudes of water flow and the relevant concentration data were assigned to these values).

In carrying out the observation of the new parameter - concentration of suspended sediments, the Czech Hydrometeorological Institute concentrates its attention mainly on further improvement of measurement precision and application of the relevant results in practice together with an attempt to increase the scope of mechanical and chemical analyses of collected samples.

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# AN IMPACT ANALYSIS OF HYDRAULICAL AND HYDROLOGICAL CHANGES ON THE SUSPENDED SEDIMENT TRANSPORT IN THE AUSTRIAN DANUBE

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Summary: Flood protection schemes as well as hydropower plants have significantly changed the hydraulics of the Austrian Danube. Their impact on the suspended sediment transport is expressed in a faster and increased transport behaviour. Only physically based analysis approaches can predict these increasing human impacts, which have also to consider the major changes in the overall alpine watershed of the Danube.

# DIE ANALYSE DER AUSWIRKUNGEN HYDRAULISCHER UND HYDROLOGISCHER VERÄNDERUNGEN AUF DAS SCHWEBSTOFFREGIME DER ÖSTERREICHISCHEN DONAU

Zusammenfassung: Flußregulierungen und Laufkraftwerke haben die hydraulischen Verhältnisse der österreichischen Donau wesentlich verändert. Ihre Auswirkungen auf den Schwebstofftransport zeigen sich in einem rascheren Prozeßablauf und höheren Konzentrationswerten. Bei der Prozeßbeschreibung können daher nur physikalisch konzipierte Ansätze die vermehrten Einflüsse vorhersagen. Dabei müssen aber auch die wesentlichen Veränderungen im gesamten Einzugsgebiet Berücksichtigung finden.

## INTRODUCTION

The Austrian Danube has experienced significant changes within the last 120 years. They can be traced back to three forms of hydraulical/hydrological impacts on the stream and its tributaring rivers as well as the overall catchment:

1. The meandering and wide flowing stream was channelised and squeezed into a single and straight river bed due to the set up of major flood protection schemes (e.g. the Danube in Vienna). But nowadays they also characterise many of the tributaries of the Danube.
2. The erection of nine hydropower plants along the course of the Austrian Danube has definitely had the most significant impact. The stream was diverted into an almost complete chain of impoundments. Also in this case, similar developments have taken place on the tributaries of the Danube.
3. The introduction of land use management strategies, which were based more on economic considerations than on environmental sustainibility, increased the sediment yield from the intensively used agricultural areas of the alpine watershed.

All these factors have finally increased the amount of suspended sediment that is either washed into the Danube including its trubutaries or transported along the river course during floods. Despite this increasing ecological, morphological and economical importance of erosion, sediment transport and sedimentation processes, the intensity of monitoring programmes decreases and the situation is unlikely to change in the near future, given the current socio-economic climate. Hence, the development of more cost efficient analysis strategies have to be addressed.

## HYDRAULIC CHANGES AND THEIR CONSEQUENCES

Seen as example in the Viennese river training project, which started in the second half of the 18th century, the sediment transport capacity first increased due to the narrowing of the diverted natural river system into a single straight channel (the overall water surface was reduced by 45% as well as the total length of the river), consequently causing increases in the slope from 0.26‰ to 0.45‰, as well as the flow depth and the flow velocity from 1.5 m/s to 2.0 m/s. In the second step these increased transport capacities were then reduced by the river impoundments of run-of-river stations.

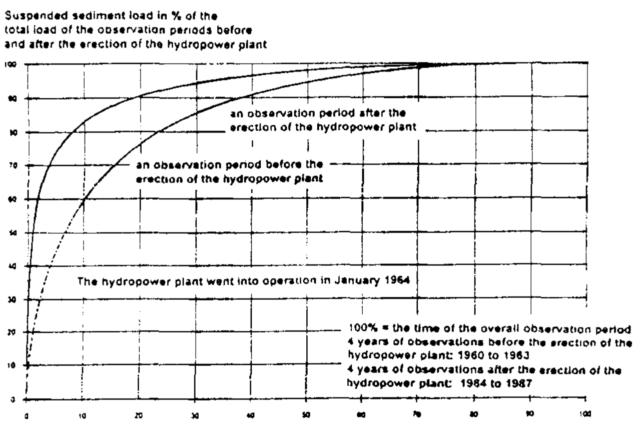


*Fig. 1:* Relative values indicating the discharged sediment load in the Austrian Danube before and after the erection of the hydropower plants.
*Abb. 1:* Relativwerte der transportierten Sedimentfrachten der Donau vor und nach der Errichtung der Kraftwerke.

The average flow velocity near the reservoir head can be estimated with 0.35 m/s. Only during flood periods, the hydraulic condition within certain sections of the impoundments as well as on two several kilometre long non-impounded natural reaches (the Wachau-valley and the Danube between Vienna and the mouth of the tributaring March-river, which discharges into the tail end of impoundment ot the Gabcikovo hydropower plant) are similar to the conditions of the stream without hydropower plants. Referring now to these impounded as well as undisturbed sections, either massive erosion and displacement processes of reservoir sediments during peak flows and/or rapid river bed degradation - leading to a decrease in the surrounding groundwater tables, causing the drainage of the ecological valuable wetlands on both sides of the Danube - are experienced.

Based on an intensive data analysis on the Austrian Danube it can be stated that the sediment transport processes actually take place within a short period of time. Figure 1 indicates now that 50% of the sediment load occurs in only 5% of a 4-year period of daily observations, whereas 90% are discharged in 37% of the time (Radler et. al., 1993).

These monitored data reach back to the fifties when the stream was not impounded by run-of-river-stations. After the erection of the hydropower plants a decrease in the length of the sediment discharge period was experienced. Now 50% of the load is moved in only 2% of an observed 10-year period and the 90% load is discharged in only 25% of the time. But in the same period the sediment concentration monitored during flood peaks has also risen by a factor ranging between >1 and 2.

### A hydraulic, hydrological as well as sedimentological explanation

The erection of hydropower plants has caused impoundment with almost permanent water depths of >10 m (depending on the size/head of the power station) in comparison to an original depth of approximately 3 to 5 m during floods. Flow velocities as well as the energy slopes are reduced. Only during floods are the movable sluice gates opened, once the discharge reaches a certain level. This suddenly causes hydraulic conditions similar to the ones of the natural stream. Although the duration of floods is reduced - now flood waves travel faster in deep impoundment than in shallow rivers (if the Froude-number $Fr < 0{,}5$ then $dc/dh > 0 \Rightarrow$ with increasing water depth h the wave velocity c increases too) - almost the same annual suspended sediment load before and after the erection of hydropower stations is observed. This leads to the faster transport of sediment downstream the Austrian Danube as well as the increase in the concentration peaks. This is possible because:

- there is practically no existence of a limit on erodible river bed sediments in the upstream vicinity of the run-of-river stations.
- there is a significant increase in the sediment yield in the catchments of the major tributaries to the Austrian Danube.

## APPROACHING THE ANALYSIS OF SUSPENDED SEDIMENT TRANSPORT

The phenomenon of suspended sediment transport, as described previously, is a hydrological process that is influenced and controlled by a number of hydraulic parameters. A common relationship between C and a second dominant independent variable - such as the water discharge Q, the average water velocity v, the energy slope S, or the shear stress $\tau$ - is given by the general equation (1) where the coefficient "a" is mostly determined by soil erosion controlling parameters such as soil type, soil condition, climate and other hydrological factors. Hence, it is subject to significant variation, whereas "b", as the second coefficient in equation (1), is relatively constant, because it is a function of the less variable hydraulic conditions of the river/stream.

$$C = a\,(X - X_{cr})^b \qquad (1)$$

X substitutes for Q, v, S, or $\tau$ and $X_{cr}$ denotes the critical values of the second independent variable, describing the incipient motion of the suspended sediment transport.

The cause of the inaccuracy of such an equation for practical purposes, such as the prediction of the suspended sediment load for a single flood (the less common case) as well as over a longer period of time (monthly or annual loads), is associated with the substantial scatter in the rating plot data. In addition, hysteretic effects occur which are characteristic for Q/C-relations. These phenomenon are basically caused by hydraulic and/or hydrologic factors as well as the assumption of the existence of a uniqueness functional relationship between the transported suspended sediment and the water discharge. But rating relationships exist only under special conditions and hence, are not the general rule, except when they are approached on a physical base.

## A physically based approach towards the suspended sediment transport

The dominant factor in the determination of the suspended sediment concentration is the time rate of potential energy expenditure per unit weight of water in an alluvial channel, which gives the Unit Stream Power USP defined by Yang (1972). The relationship between USP and total sediment concentration is expressed by

$$\log C_t = \alpha + \beta \log (vS - vS_{cr}) \qquad (2)$$

in which $C_t$ is the total sediment concentration, vS the USP, $vS_{cr}$ the critical USP required at the incipient motion, $vS-vS_{cr}$ the effective USP and $\alpha$, $\beta$ are coefficients. Due to its importance in the study of sediment transport, the vS product is understood in this concept as a single variable. Considering a slowly rising flood wave (kinematic wave assumption for large rivers - the energy slope is always equal to the bed slope) in a regularly shaped channel, this variable becomes a maximum at the peak of the discharge response during a storm event. Consequently the concentration peak will coincide with the discharge peak, assuming sufficient suspended supply during the flood wave.

In the case of the Austrian Danube with its large catchment the kinematic wave approximation is more or less valid. Therefore the sediment peak appears almost at the same time as the discharge peak. But this neglectable time lag between the highest suspended sediment concentration and the highest discharge already disturbes the derivation of a common rating curve, which is based on a logarithmic correlation between discharge and sediment concentration data. Hence, in this case an approach based on the USP is more suitable.

In comparison to the pure statistical technique of the common rating curve, it can consider the reason for the occurrence of the vS peak shortly before $Q_{max}$ actually occurs, which is due to the fact that the levees have already overflowed by a $Q < Q_{max}$. At this moment, the water discharges into wide flood plains. If the water depth in the flooded area of a channel with a composite cross section does not increase much in relation to the depth of the main channel - a common case -, the flow velocity will decrease, whereas the flood will still increase.These rapid changes lead to a complete different relation between the USP, the hydraulic flow properties and the hydrologic sediment supply (flood plains often represent a source of sandy/silty material), causing a recognisable bend in such a rating curve.

## A physically based rating curve and its assumptions

The build up of a physically based rating curve has to initially consider hydraulic properties and next hydrological impacts, which are difficult to physically describe. When developing such a rating curve, this new approach considers the mentioned hydraulic aspects and therefore the following assumptions can be stated:

1. No time delay between the flood peak and the suspended sediment concentration peak - looking at discharge hydrographs as well as related suspended sediment hydrographs, a similarity in the peak shapes can be recognised, which are displaced by basically the same certain time lag. Hence, it can be stated that
2. the duration of the flood wave as well as the concentration wave is the same. This is also in accordance with equation (2). Aspect (1) and (2) cause the third consequence, that
3. hysteretic effects are neglected. The same discharges at the rising and the falling stage of a flood give the same suspended sediment concentration as well as a sediment yield unaffected by seasonal variations over a hydrological year. As the prediction of the average sediment load over a certain

period (single flood event, hydrological year) is rather of interest than the precise prediction of C at a specific Q, this assumption is also justified.

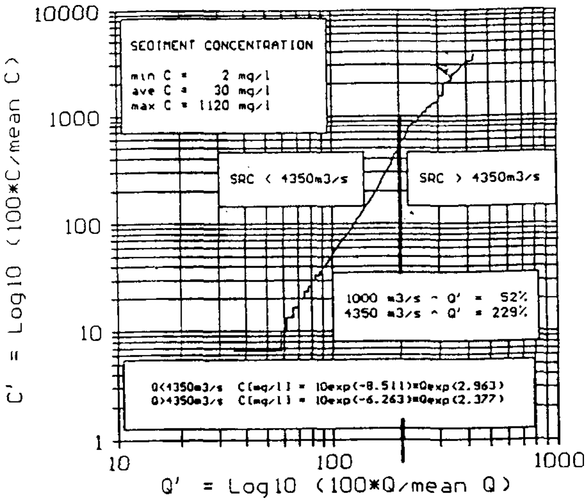


*Fig.2:* Correlation between grouped & ranked values of discharges Q and suspended sediment concentration C for the 12-year period from 1970 tom1981.
*Abb.2:* Beziehung zwischen den klassifizierten und gereihten Durchfluß- (Q) und Schwebstoffkonzentrationswerten (C) für die 12-jährige Periode von 1970 bis 1981.

*Table 1:* Comparison of the observed annual suspended sediment loads (=100%) during the period from 1970 to 1981 with the calculated values based on different sediment rating curves.
*Tabelle 1:* Vergleich der beobachteten Jahresfrachten an Schwebstoff (=100%) während der Periode 1970-1981 mit den berechneten Werten, basierend auf verschiedenen Schwebstoff/Abfluß Beziehungen.

| | ← Long Term Monitoring | →← | | Single Flood Observations | | → |
|---|---|---|---|---|---|---|
| | ← Common SRC | →← | | Grouped SRC | | → |
| Year | Gruber 1973 | 1. 1.'70 to 31.12.'81 | 1. 1.'70 to 31.12.'81 | 8. 8.'70 to 20. 9.'70 | 23. 6.'73 to 28. 7.'73 | 30. 5.'76 to 8. 8.'76 |
| 1970 | 103 | 46 | 94 | 109 | 110 | 120 |
| 1971 | 101 | 47 | 86 | 100 | 95 | 105 |
| 1972 | 98 | 47 | 79 | 93 | 84 | 95 |
| 1973 | 105 | 51 | 82 | 97 | 85 | 97 |
| 1974 | 116 | 56 | 96 | 108 | 96 | 109 |
| 1975 | 119 | 56 | 95 | 112 | 105 | 116 |
| 1976 | 120 | 57 | 94 | 111 | 101 | 113 |
| 1977 | 118 | 57 | 93 | 109 | 98 | 111 |
| 1978 | 117 | 56 | 90 | 107 | 94 | 106 |
| 1979 | 116 | 56 | 90 | 106 | 94 | 106 |
| 1980 | 121 | 58 | 94 | 111 | 97 | 111 |
| 1981 | 121 | 58 | 95 | 112 | 100 | 113 |
| **Mean** | 112 | 54 | 91 | 106 | 97 | 109 |
| **SDev** | 8,6 | 4,6 | 5,5 | 6,3 | 7,3 | 7,3 |

Considering all these aspects in addition to the problematic of drawing a regression line through a set of scattering log(C) and log(Q) data - especially underestimating the most important peak values - a "ranked" relationship between "grouped" values of these two data sets reduces the scatter as well as the error of prediction. The derivation of the new rating curve from a single flood (or from a longer period of observations) is applied as follows:

- The available information on Q and C from detailed measurements during major hydrological occurrences are grouped into a reasonable amount of equally sized classes - the mean values of each class should still represent the actual Q and C hydrograph.
- The mean Q and C-class values of each of the both data sets are ranked according to their size, gaining two new data sets.
- The values of these ranked data sets have now to be assigned e.g. in a xy-diagram (Fig. 2), in such a way that $Q_{max}$ corresponds to $C_{max}$, $Q_{max-1}$ to $C_{max-1}$, $Q_{max-j}$ to $C_{max-j}$ and $Q_{min}$ to $C_{min}$.

This new rating curve basically follows equation (2), stating that a direct relation between C and Q exists and the "ranking" procedure assigns a higher priority to the peak values than to the less important lower C and Q values. Related to this technique is the averaging of the hysteretic effect in terms of a short data base as well as the compensation of seasonal effects when considering a long term data base. The derivation as well as the practical application of the new construction technique was carried out on the Austrian Danube. The available data and the gained results are given in table 1.

## COMPARATIVE RESULTS

Table 1 clearly shows the enormous differences in the results of estimating the annual suspended sediment loads, especially between the Gruber results based on the completely different data from the sixties (good fit) and the common rating curve which was developed from the actual Q and C hydrographs from the seventies (misfit). But Table 1 also contains results calculated on the basis of the new rating curve technique, derived from the relationship between Q and C-values from the period 1970 to 1981 as well as from typical single flood events within this 12-year period. The assumptions so far for the new rating curves seem to be justified by the good correspondence between the results gained by this new procedure and the actual observed annual suspended sediment loads.

## CONCLUSIONS

Strictly assuming that the suspended sediment concentration of a slowly behaving stream - such as the River Danube presents - is basically a function of its hydraulic conditions and negotiates a time delay between the flood peak and the concentration peak of the same storm event, a difference in the duration of both waves as well as denying a hysteretic effect, a logarithmic transformed relation between grouped Q and C-values can be established. Applying this "grouping procedure" to long term hydrographs as well as to single flood observations of a large river (Danube), a high correspondence with the actual measurements can be reached. Such an approach increases the accuracy of the SRC along the Austrian Danube for annual suspended sediment load predictions.
Besides that, the investigation shows that the "grouped" SRC based on single flood observations provides in many cases as good results as the use of the complete 12-year hydrograph (all the results are not shown in this paper). Hence, this technique can be applied to evaluate human impacts on the sediment behaviour in a fast way.

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# IMPACT OF ENGINEERING WORKS ON THE SUSPENDED SEDIMENT REGIME ON THE DANUBE IN THE REACH BRATISLAVA - KOMÁRNO

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Summary: The first results of sediment regime evaluation on the Danube river after the hydropower scheme Gabčíkovo - Čunovo has been put into operation are presented. The analyses based on systematic measurements of suspended sediment concentration were carried out at cross-sections Bratislava, Medveďov and Komárno in the period from September 1992 to August 1993. The relationships for calculation of suspended sediment discharge were obtained and some anomalies in the results are discussed.

# AUSWIRKUNGEN VON INGENIEUREINGRIFFEN AUF DAS SCHWEBSTOFFREGIME DER DONAU IM ABSCHNITT BRATISLAVA - KOMÁRNO

Kurzfassung: In der Arbeit werden erste Resultate der Auswertung des Schwebstoffregimes der Donau nach der Inbetriebnahme des hydraulischen Anlagenkomplexes Gabčíkovo -Čunovo eingeführt. Die auf den systematischen Messungen der Schwebstoffkonzentration beruhenden Analysen vom Schwebstoffregime wurden in den Profilen Bratislava, Medveďov und Komárno im Zeitabschnitt vom September 1992 bis August 1993 durchgeführt. Es wurden die Beziehungen für die Bestimmung vom Schwebstofftransport abgeleitet und einige Anomalien in den gewonnenen Resultaten diskutiert.

## INTRODUCTION

The increasing degree of regulation of the Danube river either for hydro-electric power or gravel-dredging to improve navigation causes significant changes in sediment transport, bed degradation or aggradation, flood control, etc. Impact of engineering works has also been confirmed by present changes in suspended sediment regime on the Danubé river. There is a need to analyse the factors causing these changes on the other aspects of the water system.

As a part of the PHARE project - Danubian Lowland Ground Water Model, (in which the local expenses have been cowered by Ministry of Environment of Slovak Republic) some problems related to measurements and evaluation of suspended sediment regime on the Danube river in the reach Bratislava - Komárno have been investigated.

## THE RIVER DANUBE DOWNSTREAM FROM BRATISLAVA

Standard "Minimum navigable water level" defined by the Danube Commission had been monitored since 1957 ($Q = 948\ m^3s^{-1}$ in Bratislava). The analyses of the water levels have indicated the significant bed level changes. The intensity of the bed degradation process is different and it is caused especially by following reasons:

- about 65.6 mil.$m^3$ of gravel material had been dredged from the Danube channel for industrial purposes over the years 1957-1989.
- river Danube was transformed from multiple channel to essentially single channel for navigation purposes;

the discharges have been concentrated by means of training schemes into the channel of mean and low flow; engineering works caused upstream and downstream bed level degradation which changed river slope; the increase of slope and width reduction have led to the increasing transport capacity;

It may be stated that decreasing of industrial dredging on the Danube (in recent years) limited the impact of this activity on the channel forming processes and lead to the new flow conditions within the channel. Morphological processes influence the river changes in very different ways through the individual section. This conclusion is based on the detailed analyses of 879 cross-sections over years 1972-1989 and 1989-1992 from the river km 1880 to km 1708.

## METHOD AND RESULTS

The systematic measurements of suspended sediment concentration and grain size distribution analyses of suspended load material were carried out on the Danube river in the period from September 1992 to August 1993. Suspended sediment discharge had been assessed by means of laboratory analyses of suspended sediment concentration in the collected samples and by computation from actual water discharge and concentration in the observed cross-section

$$Q_s = Q \cdot C \qquad [kg.s^{-1}] \qquad (1)$$

The water samples had been collected at the locations Bratislava (in three verticals), Medveďov (in one vertical) and Komárno (in one vertical).Sampling procedures were performed by means of the standard type sampler developed by our

Institute. Depth integration method within vertical was used. The sample volume was about 1000 cm³. The relationship for calculation of sediment discharge have been obtained in the following form

$$Q_s = a \cdot Q^b \qquad [kg.s^{-1}] \qquad (2)$$

a, b - constants

Values of suspended sediment concentration (C) or suspended sediment discharge ($Q_s$) at the same discharge (Q) can be very different because suspended sediment concentration and transported amount of suspended sediments are not strictly physically dependent on hydraulic parameters of studied river section. In addition products of erosion are enriched by material and substances which have origin in antropogeneous activity. In spite of considerable scatter of values the presented type of relationship can be applied for prognosis purposes since in the long-term average deviations get smoothed.

Following relationships were obtained in measuring cross-sections:

- Bratislava - for the whole cross-section (Fig.1):

$$Q_s = 1{,}47396 \,.\, 10^{-8}.Q^{2{,}58229} \qquad (3)$$

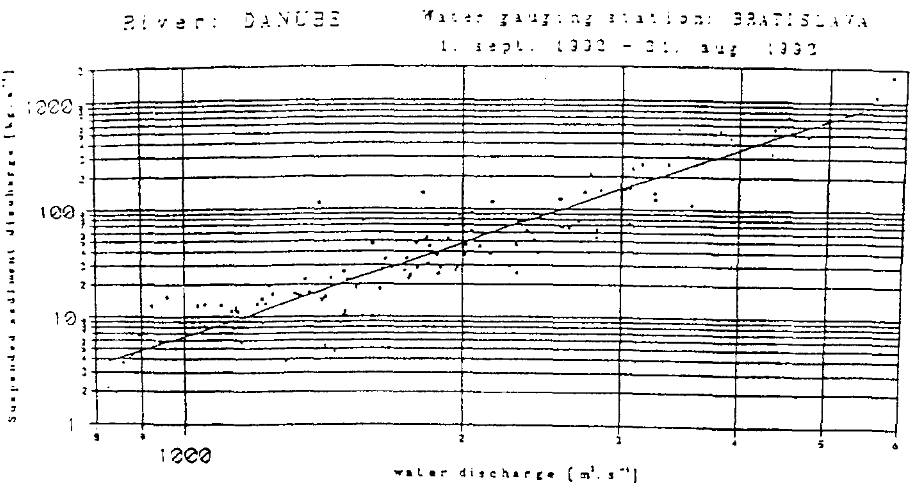


*Fig. 1 Relationship of suspended sediment discharge and water discharge on the Danube in cross-section Bratislava*

Bild 1 Der Zusammenhang des Wasser und Schwebstoffdurchflusses im Profil Bratislava

Nonuniform distribution of the verticals required computation of adequate partial water discharges. The method of Bernadsky was used. The ratio of partial discharges changed with changing discharges.

- Bratislava - separately for each vertical:

$$Q_{s\,left\,vert.} = 1{,}1753.10^{-8}.Q^{2{,}91122} \qquad (3a)$$

$$Q_{s\,centr.\,vert.} = 2{,}1541.10^{-8}.Q^{2{,}8329} \qquad (3b)$$

$$Q_{s\,right\,vert.} = 2{,}7938.10^{-9}.Q^{3{,}0828} \qquad (3c)$$

- Medveďov (Fig.2):

$$Q_s = 3,6884 \,.\, 10^{-6} \,.\, Q^{2.16124} \qquad (4)$$

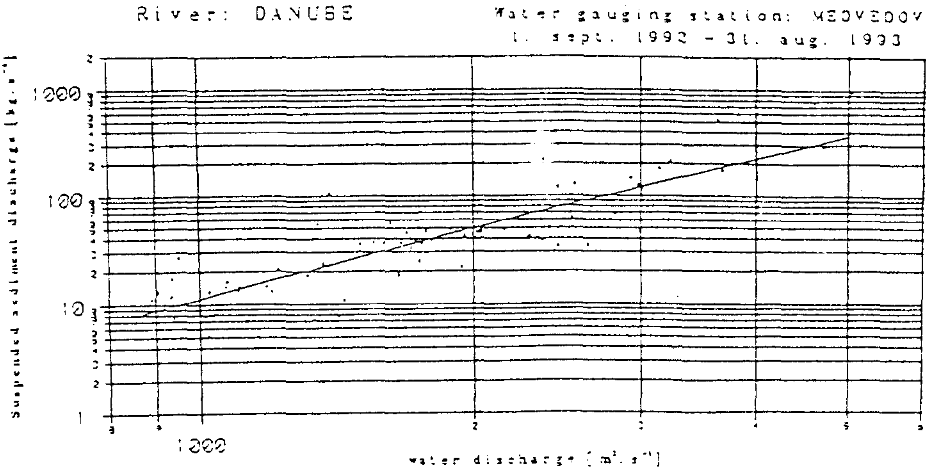


Fig.2 Relationship of suspended sediment discharge and water discharge on the Danube in cross-section Medveďov
Bild 2 Der Zusammenhang des Wasser und Schwebstoffdurchflusses im Profil Medveďov

- Komárno-Komárom (Fig.3):

$$Q_s = 2,7726 \,.\, 10^{-7} \,.\, Q^{2.50856} \qquad (5)$$

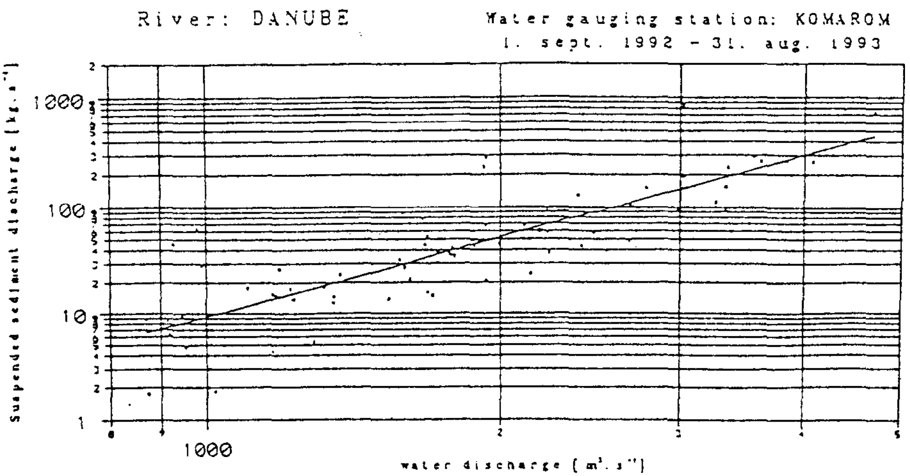


Fig.3 Relationship of suspended sediment discharge and water discharge on the Danube in cross-section Komarom
Bild 3 Der Zusammenhang des Wasser und Schwebstoffdurchflusses im Profil Komárom

Using these relationships based on direct measurements on the Danube the following amounts of suspended sediments were determined: Bratislava 2 167 874 t/12 months, Medved'ov 1 582 044 t/12 months and Komárno 1995 643 t/12 months.

Concentration measurements in three verticals in the cross-section Bratislava were used not only for the definition of relationships C=f(Q) but also for separate definition of the whole-profile suspended sediment discharge $Q_s$ = f(Q). Using the relationships (3a),(3b) and (3c) the following results were obtained: for the left vertical 2 177 221 t/12 months, for the vertical in the streamline 2 137 740 t/months and finally for the right vertical 2 039 767 t/12 months.

Separate definition of discharge amounts obtained for three verticals differ only negligibly (+ 0.43% ,-1.39% and -5.9%) from the discharge amount accepted as representative for the Bratislava cross-section (obtained by using eq.(3)) These data have confirmed that measurements performed in other cross-sections in one vertical provide relatively reliable quantitative information on suspended sediment regime in spite of the specific character of the sediment transport ( C pulsation, stochastic character of the phenomenon, etc.).

## DISCUSSION

Comparison of the results at Bratislava cross-section and Medved'ov cross-section showed that up to Q<2000 $m^3s^{-1}$ the concentrations at Medved'ov are higher then those at Bratislava. Above this value the relation is oposit. Since the results have already been obtained from the period when the reservoir Čunovo was already in operation a more significant influence on sediment concentration values was expected at Medved'ov (reduction of C value due to the sedimentation processes).

The anomaly in suspended sediment concentration conditions may be explained as follows:

- The hydropower scheme Gabčikovo is still under construction; dredging had been carried out in the outlet canal; morphological changes on the alluvial sublayer of the deepend canal have been taking place permanently;
- due to the mouth of the outlet canal into the old Danube channel (downstream of km 1812) especially during low and mean discharges the flow conditions have significantly changed; the river permanently degrades not only the bed but also the channel banks.

The processes of degradation and aggradation over the whole concerned section are in the stage of development. Relatively lower suspended sediment discharges at Bratislava cross-section as compared with the past are consequence of realized measures aimed at river pollution abatement (hydro-power scheme on the upper Danube, waste water treatment technologies and other ecological measures).

Comparison of suspended sediment discharges over selected decades and fifty-year period showed that there are anomalies between annual mean discharges and adequate mean amounts of suspended sediments. They may be explained by lower discharges fluctuation and operation of river projects in Germany and Austria.

Percentage of exceeding of discharges from 3000 to 4000 $m^3s^{-1}$ and higher (which substantially contribute to suspended sediment transport) is lower in the last years.[2]

Increased suspended sediment discharges at Komárno as compared with those at Medveďov may be due to:

- transition of fine-grained fractions from the river bed into the suspension phase since the Danube passes from the outlet canal into the old Danube "without sediments"; the bed material in the section of intensive dredging is different and contains higher percentage of fine grains at present;
- suspended sediment transport from Mosoni-Duna catchment (industrial region);
- intensive local navigation in the Komárno causing whirling of finer bed sediments

## CONCLUSIONS

The results obtained on the basis of direct measurements and analyses carried out over twelve months period do not allow to draw conclusion of general validity due to specific character of morphological processes as well as the suspended sediment regime. In spite of that the results are considered to be very important because they gave the first information of this kind after the hydropower scheme Gabčíkovo - Čunovo has been put into operation.

Knowledge obtained within the scope of the twelve-month target oriented program have explicitly confirmed that the morphological processes, changes in channel material quality, bedload regime and suspended sediment regime should be permanently monitored over the whole international section of the Danube river.

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# OBSERVATION OF BED-LOAD MOVEMENT BY UNDERWATER VIDEO

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ABSTRACT
The movement of stream bed-load can not be observed directly in the nature. Due to the considerable water depths and the bed-load sediment hindering the penetration of light, only highly sensitive video cameras and special halogen lamps can solve the problem of in-situ checking the performance of bed-load samplers.

Recently, the traditional Károlyi-type sampler has been put to use again after some improvements concerning easier handling and submerging. In order to check how the irregularities of the river bed affect the entrance of sediment into the sampler, a video camera and lamps were mounted on the device and successful observations were carried out in the Upper Danube. The existence of bed-load movement was verified by calculation using the method by Stelczer. The field tests will be continued to find the optimum position and entrance shape for the sampler.

## BEOBACHTUNG DER GESCHIEBEBEWEGUNG MIT EINER UNTERWASSER-VIDEOKAMERA

AUSZUG
Die Bewegung des Geschiebes in Flüssen kann in der Natur nich direkt beobachtet werden. Die grösseren Wassertiefen und der Schwebstoff verhindern die Eindringung des Lichtes, so ist die Kontrolle der Leistung von Geschiebefänger am Ort und Stelle nur mit Hilfe einer sehr empfindlichen Videokamera und spezialen Halogenlampen möglich. Der traditioneller Geschiebefäng von Károlyi wurde unlängst wieder in Gebrauch genommen, in einer Form, welche eine leichtere Bedienung und Versenkung des Gerätes ermöglicht. Eine Videokamera und zwei Lampen wurden auf den Vorderteil des Fängers montiert, um zu prüfen, wie die Unebenheiten der Flussohle den Eintritt der Geschiebekörner in den Fänger Beeinflussen. Einige erfolgreiche Beobachtungen wurden schon mit diesen Gerät auf der Oberen Donaustrecke durchgeführt. Das Bestehen einer Geschiebebewegung wurde durch Berechnungen nach der Methode von Stelczer kontrolliert. Die Naturmessungen sind fortzusetzen, um die optimale Lage und Mundgestaltung des Fängers zu finden.

## 1. INTRODUCTION

Hydrologists dealing with the measurement of bed-load transport are very much interested in clearing up the interrelations between the moving sediment particles and the body of the bed-load sampler under natural conditions.

The latter requirement is important, because these interrelations can easily be observed in a laboratory glass-flume. It is well known, however, that the natural conditions can not be modelled in flumes to full extent, thus, laboratory tests are usually applied for the comparison of hydraulic and sediment trapping efficiency of various sampler types.

The phenomenon of bed-load movement can not be directly seen in nature except in very special cases /clear, shallow, swift currents/. In larger rivers, like Danube, the considerable water depths and the suspended sediment content of the stream prevent the direct observation, important though it would be.

Samplers, constructed for coarse gravel, e.g. the Károlyi-type bed-load sampler have a rather bulky steel structure and resting on the be they inevitably disturb the natural flow and sediment transport pattern. Another practical problem is that due to their high hydraulic resistance, in deep rivers the samplers can be drifted far downstream of the measuring vessel until they reach the bottom. At the stage pulling them back, they may easily scrape into the bed material before being lifted, thus, they might take much more material than the amount entering them in natural way. Though this difficulty could be eliminated by using a second cable connecting the sampler with the anchor and preventing the mentioned drifting, regular bed-load sampling programs has been interrupted in several countries or given up totally.

## 2. NEW DEMANDS FOR THE FIELD OBSERVATION OF BED-LOAD MOVEMENT

The construction of the Gabcikovo-Nagymaros Danube hydropower project, the present division of Danube discharges and the control of refilling of pits dredged from the Danube bed have raised several questions for the solution of which the re-start of bed-load sampling recently demanded consideration again. The presently available smaller type of Károlyi sampler /0.3 m wide variant/ was first supplied with wings making the lowering process easier /Fig.1./

After several unsuccessful sampling it was suspected that the device arrives to the bottom with its tail fin first and its mouth might remain a few cm above the river bed making the entrance of sediment grains into the sampler difficult or even impossible. This question was also considered by Károlyi, the inventor of the original sampler /1962/. Though sharp-crested dunes, frequent in sand-bed rivers are not expected to occur on the bottom of a gravel bed river, one bigger grain or object, occasionally protruding from the bed surface might keep the front part of the sampler above the moving grains. Consequently, the empty sampler would indicate a stable bed, while in the reality there is a bed-load movement at the point of measurement. To solve this problem Károlyi has applied a 7 cm high steel support near the hind part of the sampler in order to tilt it forward after touching the bottom. Unfortunately, this "leg" became later forgotten and the copies of the original sampler have been manufactured with a plane bottom plate.

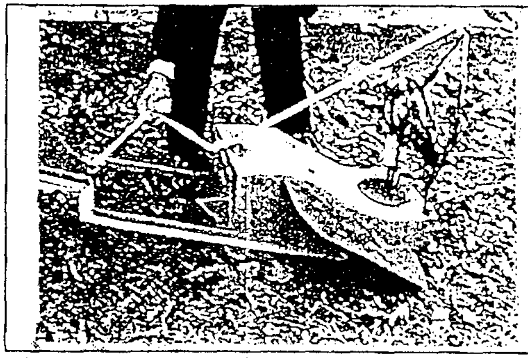

Fig.1.The Hungarian bed-load sampler with wings and video support

Abb.1.Der ungarische Geschiebefang mit Flügel und Videokamera

3. **FIELD TESTS WITH THE UNDERWATER VIDEO**

The history of the technical underwater video applications in Hungary was begun by the pioneering work of Kránitz and Muszkalay. At the end of the sixties, they have mounted an industrial TV camera and two reflectors on a steel frame in order to observe underwater failures of hydrotechnical concrete structures. The picture was visible on the screen of a normal black and white TV set. The equipment proved to be useful for this purpose in a relatively clear water. Unfortunately, in sediment-laden streams, especially in the vicinity of the river bed it could not be successfully applied.

During the past two and half decades electronics made a great leap forward and among others, highly sensitive video cameras and a selection of halogen lamps are available. The Metropolitan Sewage Works of Budapest regularly uses a video system for surveillance of sewage pipe walls. A special bus is carrying and operating the equipment in which the camera is connected to the vehicle by a 200 m long cable. They were placing the bus and staff at our disposal for a field trial in October 1992.

A special hinged console was manufactured and attached to the front of the bed-load sampler, keeping the video camera in the desired position and angle/Figs.1. and 2./. The test was carried out on the Upper Danube, in the vicinity of village Lipót, just before the majority of the discharge has been diverted toward the Gabcikovo power plant. Here the bus could come close to the riverbank. The connecting cable has enabled to lower the sampler in three different verticals. In the first two verticals, i.e. close to the bank; there was no bed-load movement. The resting gravel grains could be well observed under a 2 m deep water even without using the lamps. In the third vertical, 66 m from the bank and with 2.2 m water depth, a measurable bed-load movement was recorded.

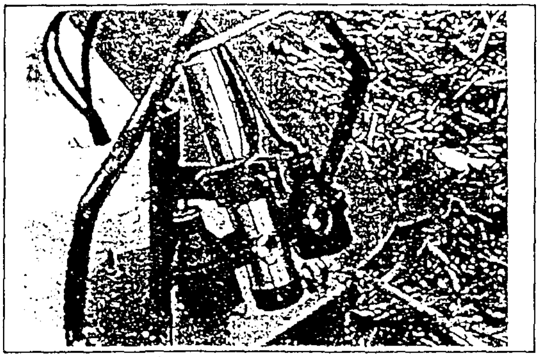

Fig.2. Fixing the video camera onto the sampler

Abb.2. Die auf den Fänger montierte Videokamera

According to the angle of tilting, the camera mounted onto the front of the sampler "sees" a smaller or larger area of the bed surface. One of these positions enables the observation of the foreground of the sampler, together with the entrance edge of it. Thus the intermittent process of sediment movement in the immediate vicinity of the sampler could be monitored /Fig.3./. According to the video recordings the displaced gravel grains either bypassed the sampler, or disappeared beneath it. Only after the space between the entrance part of the sampler and the river bed had become full with sediment, started some grains to roll into the sampler. Even the entering grains have spent a few minutes resting at the entrance previously. This observation indicates that just in front of the sampler a relatively low velocity field arises and at the sides of the entrance vertical vortices are created. Due to the lasters, round scour holes are appearing at the corners. The most surprising result of the underwater video observation was that the sampler tends to catch less bed load than the natural supply, contradicting the former belief according to which the catch is too much.

Fig.3. Video picture of the river bed in front of the sampler

Abb.3. Videobild des Flussbettes im Vordergrund des Geschiebefanges

## 4. COMPARING THE OBSERVATIONS WITH CALCULATION

Knowing the water depth and velocity, as well as the grain size distribution of the obtained bed load, the sediment transport was checked by the method of Stelczer /198o/.

The minimum value of the critical bottom velocity, $v_{fcmin}$:

$$v_{fcmin} = a\ D_{80}^{0.3680}\ h^{0.14} \qquad /1/$$

where: - $D_{80}$ is the grain size by which 8o % of the sample is finer and
- h is the water depth /both in m/.

The values of multiplicative factor a:
- in case of soft /moving/ bed material a = 1.65
- in case of hard bed material a = 1.85.

Equ. /1/ is valid for hydraulically rough alluvial river beds and for the bed-load grain-size range of 0.005 - 0.1 m.

Knowing the critical bottom velocity of 1 % probability and using the normal probability distribution of $\sigma$=0.06 standard deviation, any other values of critical bottom velocity e.g. the mean /5o %/ or the maximum /99 %/ values:

$$v_{fc} = v_{fcmin} + N(h',\ \sigma=0.006). \qquad /2/$$

where: h' is the thickness of the moving bed layer /m/.

From field measurements it is known that the range of fluctuation of $v_{fc}$ between 1 % and 99 % probabilities is 0.28 m/s, thus, the mean value:

$$v_{fcm} = v_{fcmin} + 0.14\ m/s,$$

and the maximum value:

$$v_{fcmax} = v_{fcmin} + 0.28\ m/s.$$

Field data in the case of the video observations:
Soft bed /sediment movement/;
coefficients: a=1.65; b=0.00435; h'=2; $D_{80}$=0.05168 m.

| | I. | II. | III. |
|---|---|---|---|
| Water depth, h, /m/ | 2.40 | 2.000 | 2.200 |
| Bottom velocity, $v_f$, /m $s^{-1}$ / | 0.57 | 0.485 | 0.720 |
| Design grain diameter, $D_{80}$, /m/ | | 0.025 | |
| Critical bottom velocities /m $s^{-1}$/ | | | |
| $v_{fcmin} = a\ h^{0.14}\ D_{80}^{0.36}$ | 0.50 | 0.488 | 0.494 |
| $v_{fc} = v_{fcmin} + 0.14$ | 0.64 | 0.628 | 0.634 |
| $v_{fcmax} = v_{fcmin} + 0.28$ | 0.78 | 0.768 | 0.774 |

Bed-load movement exists if $v_{fc} < v_f$.

Design critical bottom velocity /m $s^{-1}$/

| | I. | II. | III. |
|---|---|---|---|
| $v_{fc} = v_{fcmin} + \frac{v_f - v_{fcmin}}{2}$ | 0.535 | - | 0.6o7 |

According to the above calculation, bed-load movement similar to results of our experience exists in vertical III. only.

## 5. TASKS FOR THE NEAR FUTURE

5.1. Improvement on the Károlyi-type bed-load sampler by re-installing the steel support to the hind part similar to the original device in order to tilt the sampler forwards.

5.2. Supplementing the entrance edge of sampler by a protruding flexible plate in order to hinder the passage of oncoming sediment grains below the sampler body and facilitate their entry into the sampler.

5.3. Possible change of angle or size of the steel wings on both sides of the sampler to improve of submergence procedure.

5.4. Purchase of a high sensibility underwater video-camera with all the connected units placed on the board of the measuring vessel. Only in this case would be possible to carry out bed-load observations in any desired vertical of a cross-section.

5.5. Reproducing an electronically improved version of the bed-load noise detector, developed in 1965 by Bedeus and Ivicsics. It could facilitate and accelerate to select the optimal verticals for a detailed observation.

5.6. Laboratory studies of flow conditions around the winged sampler in order to optimize of size and shape of wings.

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XVII. KONFERENZ DER DONAULÄNDER
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# DYNAMICS OF MOUTH BARS IN DANUBE RIVER DELTA

# DYNAMIK DER MTNDUNGSBARREN IM DELTA DER DONAU

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W.F. Polonskij und W.A. Kowaljowe

Summary: Mouth bars in Danube River delta have been investigated long by Danube River Hydrometeorological Observatory (Izmail) and the State Oceanography Institute (Moscow). Their morphology and morphometric parameters are very different in both various delta streams and in time. Changes in such parameters as: shape in plane, bar length, and depth over it depend, primarily, on the relative role of water discharge from river and sediments on the one hand, and offshore depths and sea wave energy in a particular delta stream mouth on the other. Research findings provide quantitative dependences describing morphometric parameters of various types of mouth bars as function of their determining factors. This permits to predict their changes depending on water discharge redistribution in the delta braiding system.

Kurzfassung: Mtndungsbarren im Delta der Donau werden im Laufe einer langen Periode von der Wetterwarte (Izmail) und vom staatlichen ozeangraphischen Institut (Moskau) erforscht. Ihre Morphologie und morphometrische Kennzeichnungen sind sowohl ftr unterschiedliche Deltawasserstrome, als auch der Zeit nach sehr unterschiedlich. Die Anderung solcher Kennzeichnungen als: Forme im Plan, Barrenlfnge und Tiefe darauf -- hfngt hauptsfchlich vom Wasserabflub und Geschieben einerseits und Wellenschlagskraft in der Mtndung eines bestimmten Deltawasserstroms andererseits ab. Im Folge der Erforschung wurden quantitative Abhfngigkeiten morphometrischer Werte unerschiedlicher Deltabarrenarten von bestimmenden Faktoren festgestellt. Das ermpglicht eine Prognose ihrer Anderungen unter Bertcksichtigung der Abflubneuverteilung im Deltawasserstrpmesystem.1

Mouth bars forming in Danube River delta experience combined influence of both river (water discharge and sediments) and sea factors (offshore depths, sea wave and currents). Classification developed earlier [1, 3] refers them to river-and-sea biased type (Type II with various sub-types).

About 30 morphology surveys have been carried out in Danube delta to establish quantitative relations between mouth bar morphometric parameters and their determining factors.

Following parameters are being considered when assessing quantitatively mouth bar morphology and morphometry (Fig. 1):

$l_b$ = length of bar riverward slope (bar length, for short) measured from mouth section to bar crest along the main flow axis; $h_b$ = depth over hollow at bar crest; $F_f = \frac{2S_b}{\pi l_b^2}$ is bar full shape coefficient representing a ratio of area $S_b$ of the mouth bar to the area of semicircle with radius equal to $l_b$; $F_s = \frac{S_1}{S_2}$ is bar asymmetry coefficient representing a ratio of area $S_1$ of the bar leeward portion as regards prevailing side winds to $S_2$ area of the windward part; $H_b$ = height of the front slope of the river fan from bar base to crest; $I_b$ = bar front slope gradient; $I_m$ = initial offshore bottom gradient; $\Delta l_b$ = mouth bar advance into the sea per year.

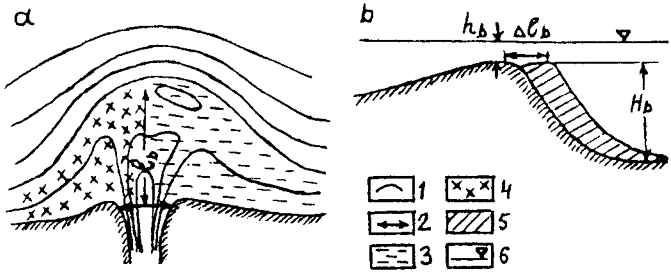


Fig. 1. Mouth bar scheme. a - plane; b - longitudinal section.

1 - isobaths; 2 - mouth section; 3 - area of bar leeward part ($S_1$); 4 - area of bar windward part ($S_2$); 5 - river fan advance during dt time; 6 - level. See text for other notation.

Length of mouth bars in Danube delta varies from 30-50 m to 2-3 km for various delta arms. Depth over bar crest in natural settings varies from 0.5 to 2.5 m. For bars dredged artificially for navigational purposes, the depth may reach from 4-5 m (Prorva arm) to 7-8 m (Sulina arm).

When assessing quantitatively bar forming conditions, mouth bar morphology and morphometry for this or that time period, one can establish relation between regime specific to bar forming factors and bar reshaping regime.

Three criteria have been identified for quantitative assessment of mouth bar forming conditions using equation describing sediment balance at frontal (seaward) slope of the river fan [3][1]:

---

[1]All physical properties are given in SI units.

1. Criteria for river and sea relative influence on mouth bar formation:

$$T = \frac{r_Y}{EY} \quad . \qquad (1)$$

where: $r_y$ = specific sediment discharge from river in the stream mouth; E = specific wave energy at bar front slope base depending on wave height and combined velocity; $Y = \frac{I_b}{I_m}$.

2. Criteria for mouth bar advance intensity:

$$A = \frac{r_Y (T - 2.5 \cdot 10^{-4})}{T \cdot H_b} \quad . \qquad (2)$$

3. Criteria for variance in side wave influence on the bar:

$$D = \frac{\Delta E}{r_Y} \quad , \qquad (3)$$

where: $\Delta E = E_1 - E_2$ = difference between period-average shore-longitudinal component of energy flows for prevailing side wave $E_1$ and its opposite side wave $E_2$.

With river influence prevailing, hypothetical dependences of length and depth at mouth bar crest as function of water discharge Q and flow sediment concentration r have the form [4, 9]:

$$l_b = K'_l Q^{0.47} \rho^{-0.56} \quad , \qquad (4)$$

$$h_b = K'_h Q^{0.36} \rho^{0.15} \quad , \qquad (5)$$

where: $K'_l$ and $K'_h$ = dimensional proportionality coefficients; Q = maximum water discharge in stream mouth at flooding; $\rho$ = average annual sediment concentration.

Evaluation of mouth bar morphometry and bar forming factors in deltas of Danube, Amu-Darya, Sulaka, Don, Pechiora, Yana rivers permitted to obtain generalized dependences $K'_l = f_1(T)$; $K'_h = f_2(T)$; $F_\rho = f_3(T)$.

Investigation of $K'_l = f_1(T)$ dependence showed that with relatively high sea influence on mouth bar formation, insignificant increase in T value results in significant increase in $K'_l$, and with river influence dominating bar formation, $K'_l$ coefficient does not change much with changes in T value.

Dependence $K'_l = f_1(T)$ for Danube delta mouth bars, with T value ranging between $2 \cdot 10^{-4}$ and $7 \cdot 10^{-4}$ kg/J, may be approximated by power function:

$$K'_l = 1.2 \cdot 10^{8} T^2 \quad . \qquad (6)$$

Thus, the length of mouth bar according to (4)-(6) depends complexly on water discharge and flow sediments, wave energy, and extent of offshore bottom distortion by stream fan. On the whole, with increased water discharges Q for Danube delta arms, bar length increases greater than can be assumed from formula (4).

With low river influence, depth changes are stipulated mostly be sea wave activity. The greater this activity is, the greater are the depths over the bar, and the more evenly they are distributed at various bar portions. If river role in bar forming is significant, depth changes are associated mostly with bar forming cycles coming as a result of the river flow dynamics (bar shallowing, forming of pit in the bar center, discharge redistribution in bar hollows, discharge concentration) [1]. The depths in different bar portions may vary significantly (the bar may even dry up or form deep hollows).

Dependence $K'_h = f_2(T)$ for mouth bars in Danube delta, with T ranging between $2\cdot10^{-4}$ to $7\cdot10^{-4}$ kg/J, may be approximated by power function:

$$K'_h = 3\cdot10^{-8}\, T^{-2} \quad . \qquad (7)$$

The nature of full-shape coefficient $F_f$ variations as function of T value changes is similar to $K'_h$ changes. This proves that bar shape changes with varied balance of river and sea roles in the stream mouth are significant if influence of sea and river on the mouth bar is relatively equal. With river factors dominating significantly, the mouth bar acquires a relatively protruded shape, extending sharply into the sea, which does not change much with further intensification of river-induced bar forming factors.

The following approximated relationship is true for Danube mouth bars in their main range of variations:

$$F_f = 4.5\cdot10^{-4}T^{-1} \quad . \qquad (8)$$

There is also the following relation between bar asymmetry coefficient and side wave variance criteria, with D > 0:

$$F_s = 6\cdot10^{-3}\, D + 1 \quad . \qquad (9)$$

Findings showed that river fans are in equilibrium (not advancing or receding) when $T = 2.5\cdot10^{-4}$ kg/J.

A generalized relationship between river fan advance value per year and mouth bar advance intensity criteria for various Danube delta streams has been found:

$$\Delta l_b = 4000\cdot A \quad . \qquad (10)$$

By calculating bar trend criteria T using formula (1), and knowing bar type or subtype correspondence to given criteria intervals, one can determine mouth bar subtype and qualitative nature of its morphological changes, respectively, as well as assess quantitatively bar morphometry. (Table 1.) By using dependences (4)-(10) and assigning water discharge and sediment values in a stream mouth, one can obtain their respective bar lengths, depths over hollow at bar crest, its shape coefficients, and also fan advance into the sea.

When predicting bar length changes with time in stages, one should take into account possible lag in bar length $l_b$ changes with respective Q, $\rho$, and $K'_l$ values. When stream fan becomes

Table 1. Description of Mouth Bars of Various Genetic Types and Subtypes

| Type | Type description | Subtype | Bar description | Morphologic feature: Central pit | Morphologic feature: Mouth spits | $T \cdot 10^4$ | $K'_l$ | $K'_h$ | $F_f$ | Possible formation in Danube delta |
|---|---|---|---|---|---|---|---|---|---|---|
| I River-dominant | | | | | | | | | | |
| | River factors prevailing | Ia | Bar constantly advancing into the water body | Available | Long | | | | | Impossible |
| | | Ib | Intensive advance at flooding and slow advance in dry weather | - " - | - " - | >10 | >70 | <0.06 | <0.7 | Hardly probable |
| II River-and-sea biased | | | | | | | | | | |
| | Notable influence of sea factors | IIa | Advance at flooding and partial destruction in dry weather | - " - | Average | 10-5 | 35-70 | 0.06-0.09 | 0.7-1 | Typical for large and developing arms |
| | | IIb | Advance at flooding and equal destruction in dry weather | Not always | Short | 5-[illegible] | 10-35 | 0.09-0.3 | 1-2 | Typical for stable medium arms |
| | | IIc | Insignificant advance at flooding and prevailing destruction in dry weather | Absent | Short | <2.5 | <10 | >0.3 | >2 | Typical for decreasing medium and minor arms |

shorter (recedes) -- if mouth bar length $l_{be}$ for the end of investigated period determined from formula (4) appears smaller than the difference between length $l_{bb}$ at the beginning of the period and fan reduction value $\Delta l_b$ -- $l_{be}$ value should be calculated using the formula:

$$l_{be} = l_{bb} + \Delta l_b \qquad (11)$$

where: $\Delta l_b$ = a negative value.

If, when stream fan is advancing, mouth bar length $l_{be}$ for the end of investigated period determined from formula (4) appears greater than the sum of initial length $l_{bb}$ plus fan increase value $\Delta l_b$, $l_{be}$ value should also be calculated from formula (11). However, in this case, $\Delta l_b$ is a positive value. In other cases, $l_{be}$ shall be calculated using formula (4).

Independent testing of mouth bar reshaping at Potapovsky, Bystry, Vostochny, and Starostambulsky arms in recent years confirmed practicability of applying suggested set of estimation dependences to predict changes in morphometric parameters of mouth bars taking into account water discharge redistribution trends in delta streams. However, long-term forecasting of such trends, in turn, should be based on modelling delta braiding evolution, taking into account both bed deformation, mouth protruding, and bar reshaping processes [4]. Hence, water discharge redistribution in delta and mouth bar reshaping should be estimated jointly as a single system.

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# Special Features of Bed Load Transport Calculation in the Danube and the Ural Deltas

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SUMMARY: To estimate the bed load transport the method taking into account the shift of bed form hierarchical system is suggested. This method is applicated for delta branch system on example of the Danube and the Ural mouth areas. The analysis of bed load transport spatial-temporary changeability in this deltas is performed.

KURZFASSUNG: Für die Berechnung des Triebgeschiebabflusses wurde die Methode vorgeschlagen, die die Verschiebung des Hierarchiesystems der Schwemmketten (Riffe, Dünen, Sandwellen und s.w.) berücksichtigt. Die Methode wurde für die Systeme der Delta Wasserläufe auf dem Beispiel von Donau- und Uralmündungsgebiete verwendet. Die Analyse der räumlich-zeitlichen Variabilität des Triebgeschiebabflusse in diesen Deltas wurde durchgeführt.

Mouth areas are the specific natural objects which are forming in zone of river and sea interaction. River sediment load is one of main factors of mouth area dynamics. Mineral particles moving both as suspension and on bottom surface take part in delta formation. Suspended sediments are of great significance for mouth processes since they are predominant part in total load of mineral particles. The bed load transport (G) is a few percents only of suspended sediment load. Nevertheless, the significance of coarse-grained material entering into a delta is great enough. During recent years a bed load transport estimation method is applying more often for flat river sections which have sand channel deposits. This method takes into account the shift of a hierarchical system of alluvial bed forms (ripples, dunes, sand waves, bars etc.) [2-5 etc.].The techniques of their application for river deltas require special analysis.

Traditionally, the value G is defined from equation

$$G = kB_* \sigma_* h_{bf} C_{bf}, \tag{1}$$

where $B_*$ - is the width of bed load moving zone; $\sigma_*$ is the density of deposits; $k$ equal to 0.6, $h_{bf}$ and $C_{bf}$ are a form coefficient, height and velocity of bed form moving. This equation describes bed load transport with active along-flow shift of one bed form only. In the presence of developed bottom relief structure, several types of bed forms can move actively [3,5 etc.]. In this case, the total bed load discharge is sum of partial bed load discharges $G_i$ and $G = \sum G_i$, where i is ordinate number of bed form type. Bed form structure data generalization for rivers of various size shows there are 5 or less bed form types [1,2]. They are named A, B, C, D, E to prevent inadequate interpretation. The largest bed forms A have a proportional length to channel width. Bed form E are the least ones and their length is proportional to flow depth. The bed forms (B, C, D) occupy intermediate position. Microforms of bottom relief (D and E) move actively during the low-water period. The bed load transport is the result of their along-flow shift and depends on duration of low-water phase (365 - $T_f$):

$$W_{Glw} = (365-T_f) \sum_{i=E}^{i=D} G_i = k\, B_* \sigma_* (365-T_f) \sum_{i=E}^{i=D} (\beta h_{bf} C_{bf})_i, \tag{2}$$

where $\beta$ is reducing coefficient according i-type bed form total height to deposit layer; $T_f$ is flood period duration in days. During the flood period a bed load transport can be estimated by the equation:

$$W_{Gf} = T_f \sum_{i=E}^{i=A} G_i = T_f k\, \sigma_* B_* \sum_{i=E}^{i=A} (\beta h_{bf} C_{bf})_i. \tag{3}$$

Partial bed load discharges G are defined is response to the equation (1) where are taken into consideration geometric and dynamic characteristics of all the bed form types during both high and low water regime phases (see Table 1).

Table 1

The dependenc es' parameters for owner height ($h_{bfi} = \beta_i a_i N^{b_i}$) and shift velocity ($C_{bfi} = n_i v N^{p_i}$) of different bed forms in active phase.

| Dependenc. parameter | Type of bed forms | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | D | E |
| | Flood period | | | | | Low-water period | |
| a | 0.046 | 0.018 | 0.032 | 0.023 | 0.005 | 0.005 | 0.003 |
| b | 1.95 | 2.00 | 1.50 | 1.4 | 1.9 | 2.0 | 2.0 |
| $\beta$ | 0.55 | 0.31 | 0.39 | 1.0 | 1.0 | 1.0 | 1.0 |
| n | $1.1 \times 10^{-6}$ | $3.1 \times 10^{2}$ | $3.5 \times 10^{-4}$ | $2.2 \times 10^{4}$ | $2.16 \times 10^{4}$ | 600 | 600 |
| p | 5.4 | -2.6 | 4.6 | -3.5 | -3.5 | -2.0 | -2.0 |

$v$ is average flow velocity during the low-water period or the flood one; estimate values of bed form shift velocity ($C_{bfi}$) are represented in m/days; heights of bed forms ($h_{bfi}$) are in meters.

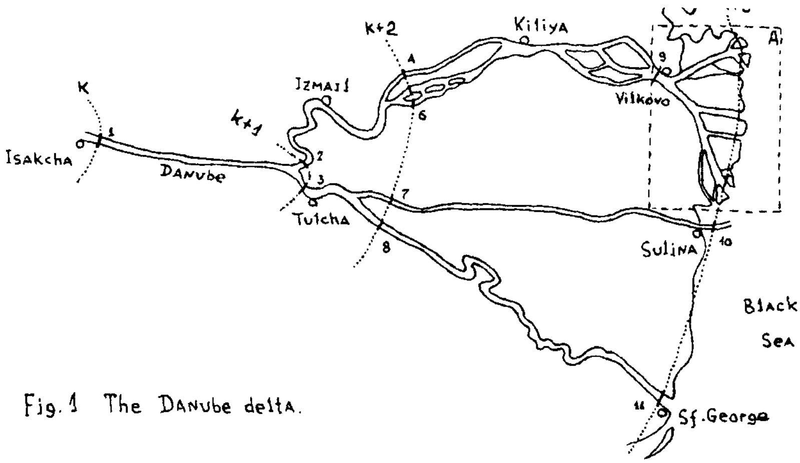


Fig.1 The Danube delta.

Analysis of Table 1 shows these characteristics are functions of river order (size) N [1] in terms of Horton suggestion [6]. Since river order relates to water flow scale, the average water discharge of long standing can be independent variable of functions $h_{bfi} = \phi\ (N)$ and $C_{bfi} = \psi\ (N)$. In all the cases, total bed load transport is

$$W_G = W_{Glw} + W_{Gf} \ . \tag{4}$$

The verification of this method for the Dnestr showed capacity to find G and $W_G$ values and result fluctuation is no more than 30 percents.

The aim of this investigation is to the possibilities and peculiarities of mentioned above method in large river deltas such as the Danube and Ural.

The overall space of Danube mouth area is equal to 5640 $km^2$ . The delta head is located of 115 km from Black Sea. The average water discharge of long standing (flow rate) comprises 6450 $m^3/s$, and the same suspended sediment yield is equal to 67.5 million tons per annual [7]. The mean duration of flood period approximated 150 days. The water flow velocities during the flood period are 2.5 - 3 time more high than low-water ones and they range from 0.5 to 1.1 m/s for different delta streams. Channel deposits in delta branches are formed by sandy and dust-silty fractions. Sand deposits prevails in channel width of main delta branches throughout. As the main channel divides and near the sea, the zone width of sand deposits in delta branches is reduced gradually to fairway width. It is equal to zero in the mouth of vanish delta streams. The field experiments show that the five bed form types in bottom relief structure are represented in the majority of delta branches.

In the Danube delta there is a multibranchial network in which may be calculated about 60 branches (see Fig.1). They vary in water flow discharges noticeably. Water flow discharge ratio between the largest and smallest branches is equal to 93. Water flow discharges of delta branches are consistent with some orders of rivers. Conventional orders of these branches can be obtained from the existing relationship between flow rates and orders (sizes) of intrazonal rivers [2]. In the Danube mouth area the conventional orders of delta branches range from 3 (the Belgorodsky) to 15 (the Danube). Delta branches may be classified under some types varying in intensity of degradation and aggradation. Bed load moving such as bed form shift is most typically for active and stable branches. Structure of bottom relief is simplified, and the suspended sediment load contribution grows in vanishing branches. The last hundred years the Danube delta formation has been going in conditions when background level of Black Sea remained practically constant.

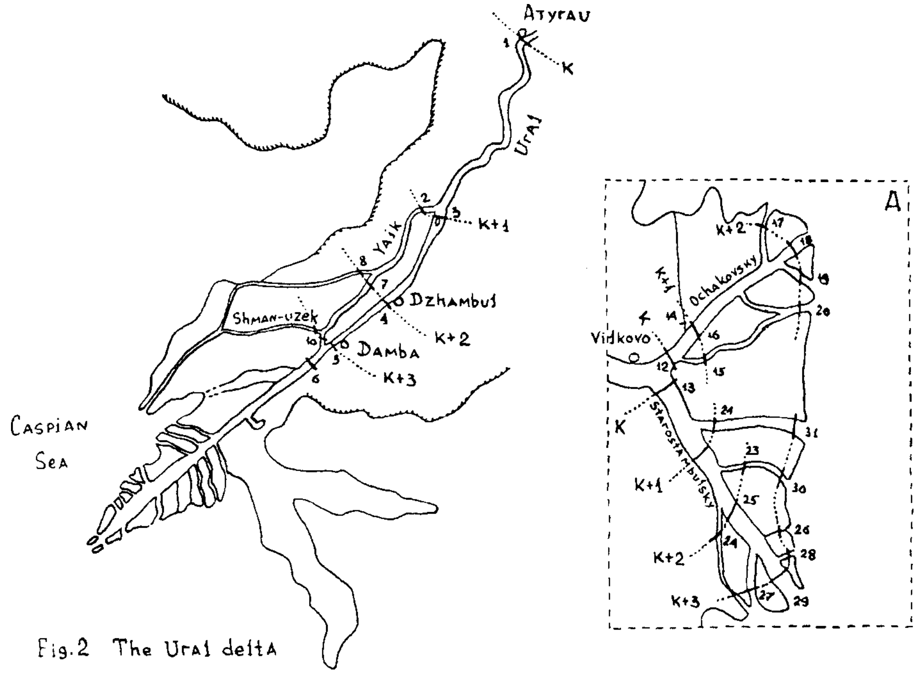


Fig.2 The Ural delta

The Ural delta occupies a floor space of 250 $km^2$. The delta head is sited approximately of 40 km from the Caspian Sea. The Ural flow rate comprises 230 $m^3/s$, and the same suspended sediment yield contribute 2.8 million tons per annual [8]. The water flow velocities during the flood period are 5-14 time more rapid than low-water ones and they range from 0.5 to 1.5 m/s. The duration of flood period averages about 80 days. Channel deposits in delta are largely formed by sandy fractions. They prevail in the largest delta branches. The sand deposit layer in small branches is often remained under silty layer during the low-water period. Bottom relief of the Ural River and delta streams includes a five bed form types.

A channel network of the Ural mouth area is the less branchial in comparison with the Danube delta. In the Ural delta there are about 25 streams of which 15 ones are the manmade fishway-canals (see Fig.2). Water discharge of the Ural River discharge is a twenty time as much as the smallest natural delta stream. Conventional order of the Ural is equal to 8. The Ural delta branches range orders from 4 to 7. During the long time this delta formed in conditions when the Caspian Sea level is slowly decreased, but from 1979 sea level began to raise abruptly (more than 2 m). Nowadays in the Ural delta there is a changing of tendency in hydrological and morphological processes.

Considering the hydrological peculiarities of the Danube and the Ural deltas, the consequence of bed load transport calculations by relationships (1) - (3) and data from Table 1 it can to estimate the bed load transport characteristics (see Table 2). The analysis of obtained results of bed load transport shows that an average in a year more than 8 million ton of sand enters to the Lower Danube. This yield contribute from 8 to 10 percents of suspended sediment yield. Basically, these results lend support to the validity of different hypotheses about bed load portion in the total sediment yield. The bed load transport in the Ural delta head is equal to 0.32 million ton per annual. Just as in the Danube delta, the Ural bed load transport contribute from 8 to 10 percents of suspended sediment yield (W). As the main channel divides and water discharges (or orders) of delta branches reduce, the bed load transport decrease gradually. In some vanish branches, the bed load transfer is absent.

Table 2.

Bed load transport characteristics in the Danube and Ural deltas

| Number on Figure | Streams | Flow rate $m^3/s$ | Conventional orders | Bed load transport, thous. tons | | |
|---|---|---|---|---|---|---|
| | | | | Annual | During the flood period | During the low-water period |
| | **The Danube delta** | | | | | |
| 1 | Danube River(54 mile) | 6450 | 14.7 | 8440 | 8140 | 299 |
| 2 | Kiliya br., outlet | 3740 | 13.7 | 3650 | 3460 | 191 |
| 3 | Tulcha br., outlet | 2710 | 13 | 1845 | 1720 | 125 |
| 4 | Kislitsky br., outlet | 193 | 7.7 | 18 | 14 | 4 |
| 5 | Kiliya(Sredny) br. | 2390 | 12.8 | 1530 | 1410 | 123 |
| 6 | Ivanest' br., outlet | 774 | 10.5 | 294 | 259 | 35 |
| 7 | Sulina br., outlet | 1250 | 11.4 | 315 | 275 | 40 |
| 8 | Sf.George br., outlet | 1460 | 11.8 | 345 | 306 | 39 |
| 9 | Kiliya br.(near Vilkovo) | 3540 | 13.7 | 2750 | 2610 | 140 |
| 10 | Sulina br., mouth | 1250 | 11.4 | 189 | 165 | 24 |
| 11 | Sf.George br., mouth | 1460 | 11.8 | 207 | 184 | 23 |
| 12 | Ochakovsky br., outl. | 1050 | 11.1 | 698 | 612 | 86 |
| 13 | Starostambulsky br., outl. | 2490 | 12.8 | 1650 | 1540 | 110 |
| 14 | Belgorodsky br., outl. | 7 | 3.5 | - | - | - |
| 15 | Ankudinov br., outl. | 74 | 6.2 | 17 | 15 | 2 |
| 16 | Ochakovsky br.(below Belgorodsky br.) | 967 | 11 | 197 | 172 | 25 |
| 17 | Prorva br. | 496 | 9.6 | 108 | 91 | 17 |
| 18 | Potapovsky br. | 219 | 8 | 10 | 10 | - |
| 19 | Gneushev br. | 128 | 7.2 | 6 | 6 | - |
| 20 | Poludenny br., mouth | 198 | 7.8 | 19 | 16 | 3 |
| 21 | Bystry br., outlet | 984 | 11 | 233 | 203 | 30 |
| 22 | Starostambulsky br.(below Bystry br.) | 1510 | 11.8 | 540 | 488 | 52 |
| 23 | Vostochny br., outlet | 173 | 7.5 | 36 | 30 | 6 |
| 24 | Limba br. | 94 | 6.5 | 15 | 14 | 1 |
| 25 | Starostambulsky br.(below Limba br. | 1340 | 11.5 | 296 | 266 | 30 |
| 26 | Zavodninsky br., outl. | 7 | 3.5 | - | - | - |
| 27 | Kurilsky br. | 46 | 5.6 | 4 | 4 | - |
| 28 | Tsygansky br., outlet | 113 | 6.9 | 11 | 10 | 1 |
| 29 | Starostambulsky br.(below Tsygansky br.) | 1080 | 11.2 | 244 | 210 | 34 |
| 30 | Bystry br., mouth | 984 | 11 | 140 | 122 | 18 |
| 31 | Vostochny br., mouth | 173 | 7.5 | 22 | 18 | 4 |
| | **The Ural delta** | | | | | |
| 1 | Ural River (near Atyrau) | 230 | 8 | 324 | 289 | 35 |
| 2 | Yaik br., outlet | 61 | 5.9 | 56 | 51 | 5 |
| 3 | Zolotoy br., outlet | 169 | 7.5 | 239 | 215 | 24 |
| 4 | Zolotoy br.(near Dzhambul) | 169 | 7.5 | 235 | 212 | 23 |
| 5 | Zolotoy br. (near Damba) | 169 | 7.5 | 180 | 162 | 18 |
| 6 | Ural br. (near Damba) | 205 | 7.9 | 154 | 138 | 16 |
| 7 | Yaik-left br., outlet | 47 | 5.6 | 42 | 38 | 4 |
| 8 | Yaik-right br., outlet | 14 | 4.1 | 3 | 3 | - |
| 9 | Shman-uzek br., outlet | 11 | 3.85 | 2 | 2 | - |
| 10 | Damba br. | 36 | 5.3 | 24 | 22 | 2 |

The bed load transfer is uneven during of the year. During the flood period, abou 96 percent of total annual bed load transport enter to the Danube delta, about 90 percents of the same one enter to the Ural delta. The sizes of delta branches exert some influence on bed load distribution during the year. During the flood period, from 94 to 96 percents of $W_G$ extend through the most large branches of the Danube delta. In the event, that the branch water flow discharges are equal to 0.2 $Q_0$ (where $Q_0$ is flow rate at the delta head), the value of $W_{Gf}$ decreases and ranges from 83 to 88 percents. To a lesser degree the bed load transport distribution during the year depends on the Ural delta branch sizes. These facts are connected with peculiarities of structure changing of bed load transfer such as bed form shift in relatively small and large streams. Now, the bed load transfer is associated with dynamics of bed forms such as C, D and E. For the delta streams $Q_0$ > 600 $m^3/s$, more than 50 percents of $W_G$ are associated with C - bed form dynamics. If the water flow discharges of delta branches are less than 600 $m^3/s$, that the contribution of D and E microforms to formation of W increases (by comparison with other bed form types). In the Ural delta D and E bottom microforms supply more than 83 percents of $W_G$.

During the different water regime phases, the ratio $W_G/W$ is changing. In the Danube delta (during the flood period), this ratio is equal from 17 to 18 percents. During the low-water period a bed load transport portion decreases to 1 percent. In the Ural delta, the bed load transport forms about 10 percents of W during the flood period and 20 percents of W during the low-water one.

The spatial transformation of bed load transport is observed as the main channel divides to streams. The change of $W_G$ is common to both separate streams and all delta as a whole. If at the upper margin of the mouth area there is $W = W_1$, and in delta branch sectors spaced at $L_2,..,L_n$ from the delta head the bed load transport is accordingly equal to $\sum_j^2 W_{2j},...,\sum_j^n W_{nj}$ (where j is quantity of streams) then the coefficient r equal to $W_{k+1}/W_k$ is a measure of $W_G$ spatial transformation. In this case $k = 1,2,...n$. If $r < 1$, that spatial diminution of bed load transport takes place, and for $r > 1$ then bed load transport increases. In a event, $r = 1$ then $W_{k+1} \cong W_k \cong$ const. The change of $W_G$ is attended with corresponding change of delta deposit thickness. The coefficient $r_*$ is equal to $(1-r)/\Delta L$ (where $\Delta L = L_{k-1} - L_k$) would be appropriate for use so that to characterize this process. The greater is coefficient $r_*$, the greater quantity of bed load transport arrived from upper sectors remain at the delta flat sector (in segment) with the width of ΔL.

Table 3

Spatial changing of bed load transport in the Danube and Ural deltas

| Channel systems | Number of segment | Total bed load transport in segment $W_G$, million tons | Coefficient r | Distance between segments ΔL, km | Coefficient $r_*$, $km^{-1}$ |
|---|---|---|---|---|---|
| The Danube delta | k | 8.44 | | | |
| | k+1 | 5.49 | 0.650 | 20.5 | 0.017 |
| | k+2 | 2.50 | 0.455 | 42.0 | 0.013 |
| | k+3 | 0.97 | 0.387 | 72.0 | 0.009 |
| Ochakovsky system | k | 0.70 | | | |
| | k+1 | 0.21 | 0.306 | 5.0 | 0.139 |
| | k+2 | 0.14 | 0.667 | 10.0 | 0.042 |
| Starostambulsky system | k | 1.65 | | | |
| | k+1 | 0.77 | 0.468 | 7.0 | 0.076 |
| | k+2 | 0.35 | 0.449 | 5.0 | 0.110 |
| | k+3 | 0.26 | 0.743 | 7.0 | 0.037 |
| The Ural delta | k | 0.32 | | | |
| | k+1 | 0.30 | 0.910 | 13.0 | 0.007 |
| | k+2 | 0.30 | 1.020 | 7.5 | -0.003 |
| | k+3 | 0.21 | 0.700 | 7.5 | 0.040 |

The mean r is equal to 0.5 for the Danube delta. Near the coastline of delta the total bed load transport decreases of 10 (Table 3). The coefficient $r_*$ changes from 0.009 to 0.139 $km^{-1}$. To a lesser degree the spatial transformation is expressed in the Lower Ural. The coefficients r and $r_*$ change within from 0.70 to 1.02 and from -0.003 to 0.035 $km^{-1}$. There is characterized that $r > 1$ and $r_* < 0$ in upper sector of delta. This peculiarity is associated with intensive water flow redistribution in favour of the Yaik channel system because of Caspian Sea level increasing.

## CONCLUSION

1. At the river mouth areas it can be use the method permit to evaluate the bed load transport.This method is based on estimation of sand bed forms' dynamics. For using it is necessary to specify the conventional orders (sizes) of delta branches. They are set for a known water discharge portion of branches with the using of correlation relationship between orders and flow rates of intrazonal rivers. In the estimations it is important to take into account that zone width of sand particle shift depends on delta stream tendency. In the stable and active branches, the $B_*$ value is proportioned to low-water channel width. In a vanish branches it is true that $B_* \to 0$ and the sand transport on the bottom surface may be decreased to zero.

2. Estimate data from proposal method provide a means to analyze the bed load transport spatial-temporary changeability of separate branches, delta branch systems and discrete mouth regions. The knowledge about the bed load transport and suspended sediment yield transformation permit to recognize the evolution tendencies of different channel network elements, to forecast deltaic hydrological and morphological processes.

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# SEDIMENT BALANCE AT THE DANUBE RIVER MOUTH

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River sediments play a dominant role in the Danube delta formation. In the last 250 years the most intensive deposition of the Danube sediments occurred at the Chilia branch mouth. Here so called the Chilia delta rapidly protruded into the sea. The paper presents the results of new investigations of the hydrographic, morphologic and morphometric changes of the Chilia delta, sediment balance at the Chilia branch mouth. The relation of the sediment balance with the sediment regime of the Danube River and the Chilia branch and the fan volume changes was studied. The sediment balance equation analysis for the Chilia delta showed that the data on the sediment yield for the Danube and the Chilia branch are underestimated.

## DIE FESTSTOFFBILANZ IN DER DONAUMÜNDUNG

Die Flußfeststoffe spielen die führende Rolle in der Formierung des Donaudeltas. In den letzten 250 Jahren geschieht die intensivste Ablagerung des Feststoffes auf der Mündung des Kilija-Flußarms. Hier entstand schnell das sogenannte Kilija-Delta. In dem Vortrag sind die Resultaten der neuen Untersuchungen der hydrographischen, morphologischen und morphometrischen Änderungen des Kilija-Flußarms vorgewiesen. Es ist die Verbindung der Feststoffbilanz mit dem Feststoffregime der Donau und des Kilija-Flußarms und mit der Änderung des Deltavolums ausgerechnet. Die Analyse der Gleichungen der Feststoffbilanz für das Kilija-Flußarm hat gezeigt, daß die Angaben in dem Feststoffabfluß der Donau und des Kilija-Flußarms zu niedrig gemessen sind.

## 1. Introduction

The Danube delta was formed mainly by river sediments. In the last 250 years the most intensive deposition of the Danube sediments took place at the mouth of the Chilia branch. Here so called the Chilia delta was formed. This delta presents an example of the active protruding delta, formed by a large sediment yield and at an open nearshore of the nontidal sea with a relatively stable level and a moderate sea wave action. The relation between the sediment yield and the delta formation process and the sediment balance as a physical basis of this process are of a great interest.

## 2. Sediment yield of the Danube River and the Chilia branch

The literature on the suspended sediment yield of the Danube River is contradictive. According to different data the suspended sediment yield at the delta head equals 83,0 mln tn/yr (1864-1894) [4]; 65,7 mln tn/yr (1861-1922) [3]; 66,5 mln tn/yr (1921-1962) [1].

The modern observation data of the Danube Hydrometeorological Observatory (DHO) in Izmail (the Ukraine) allowed us to establish that the suspended sediment yield of the Danube River at the delta head sharply decreased after 1960 (Figure 1). Over the period from 1921 to 1960 it was 67,4 mln tn/yr (2140 kg/s) and since 1961 it decreased to 42,5 mln tn/yr (1350 kg/s).

The decrease of the suspended sediment yield was noted by many researchers and was explained by the reservoir cascade construction in the Danube basin [5].

The ratio between the water flow at the head of the Chilia branch and in the Danube itself periodically changed (Figure 2). This ratio increased as the Chilia branch was formed [2,3]. It reached nearly 70 % in 1890. Then it became to decrease to 58,5 % in 1992.

The investigations during the last 30 years showed that the suspended sediment yield distributed between the Danube delta branches nearly in the proportion to the river water flow.

The suspended sediment yield along the Chilia branch practically does not change.

For the following correlation between the branch sediment yield and the changes in the Chilia delta volume and the analysis of the sediment balance, the calculations of the suspended sediment yield were carried out for some periods (Table 1). These periods were fixed between the dates of the topographic surveys of the Chilia delta.

These calculations were carried out in the following manner: 1) over the period from 1921 to 1962 the values of the Danube suspended sediment yield were accepted on the observation data [1]; 2) over the earlier period, when the data of water flow were available (1838-1920), the values of the Danube suspended sediment yield

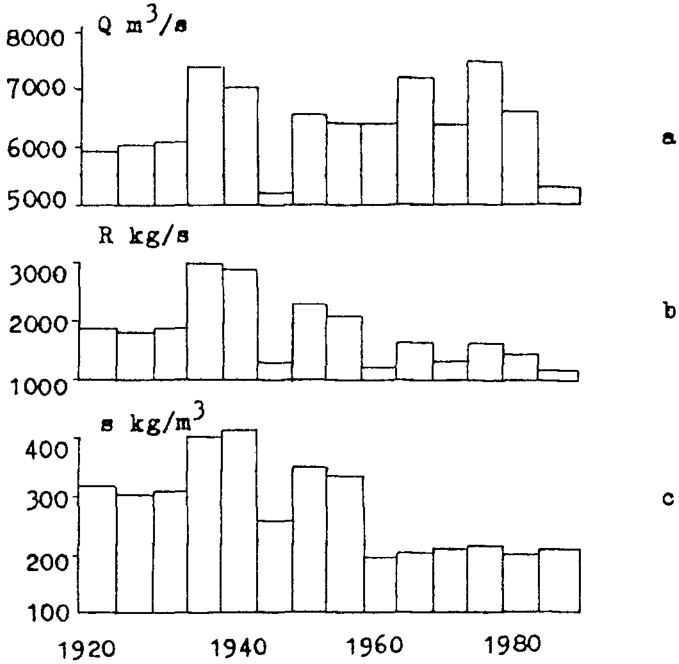

Figure 1. Changes in water (a) and suspended sediment (b) discharges and suspended sediment concentration (c) of the Danube River (at the delta head)

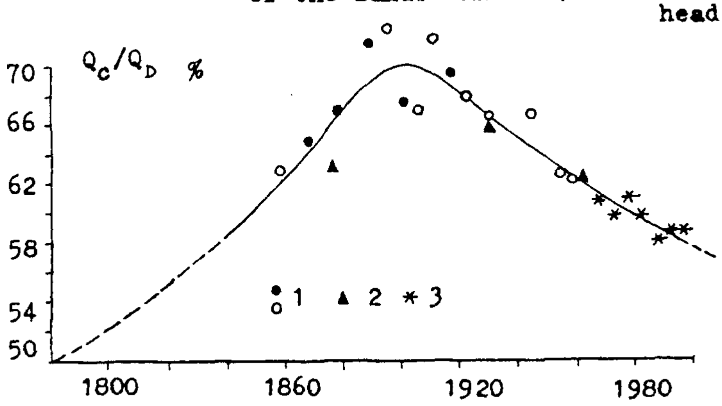

Figure 2. Changes in ratio between water discharges of the Chilia branch ($Q_c$) and the Danube River ($Q_D$)
1 - after [3], 2 - after [2],
3 - data of DHO

Table 1

Morphometrical characteristics of the Chilia delta and integrated values of sediment yield

| Year | Delta area F (sq km) | Fan volume $W_f$ (cu km) | Integrated river sediment yield $W_r$ (cu km) | Ratio between fan volume and integrated river sediment yield $W_f/W_r$ (%) |
|---|---|---|---|---|
| 1740 | 0 | 0 | 0 | 0 |
| 1830 | 80 | 2,26 | 2,816 | 80,2 |
| 1856 | 111 | 2,89 | 3,821 | 75,6 |
| 1871 | 122 | 3,45 | 4,246 | 81,2 |
| 1883 | 174 | 4,05 | 4,744 | 85,4 |
| 1894 | 214 | 4,64 | 5,079 | 91,3 |
| 1922 | 285 | 5,66 | 6,349 | 89,1 |
| 1930 | 291 | 6,02 | 6,647 | 90,6 |
| 1943 | 308 | 6,55 | 7,285 | 89,9 |
| 1948 | 309 | 7,01 | 7,461 | 94,0 |
| 1957 | 328 | 7,54 | 7,789 | 96,8 |
| 1980 | 348 | 8,26 | 8,363 | 98,8 |

were determined from the relationship between an average annual suspended sediment and the water disharges, based on the data from 1921 to 1960 (after 1960 under the anthropogenic influence, the relationship was broken); 3) over the period before 1838 it was accepted that an average annual suspended sediment discharge of the Danube was equal to 2144 kg/s (as well as over the period from 1921 to 1960); 4) over the period since 1963 we used the data of immediate observations at the Danube and the Chilia branch carried out by DHO; 5) over the period before 1963 the suspended sediment yield of the Chilia branch was determined on the basis of data of the Danube sediment yield and with regard to a changing fraction of this branch water flow (Figure 2); 6) the values of the suspended sediment yield were converted from mass units (mln tn) to volumes units (cu km) with regard to a prevailing particle-size distribution in the deposition of the Chilia branch fan; for the above mentioned distribution, the sediment deposition density is equal to 1100 kg/cu m; 7) after many investigations [1,2,5] the bed sediment load of the Danube equals 1 % of the suspended sediment yield [5], so it was not taken into account.

### 3. Changes of the Chilia delta

The formation of the Chilia delta began in the middle of XYIII century (nearly in 1740). The hystory of its evolution is illustrated by 12 charts of the topographic surveys from 1830 to 1980. Over this period the Chilia delta protruded into the sea, holding its asymmetry.

In this evolution the Chilia delta passed over the four phases: without bifurcations and branches (1740-1800); with few branches, when their number did not exceed 20 (1800-1856); with a great number of branches, when their number was 40-60 (1856-1956) and again with few branches. There were only 14 branches' mouths in September 1993.

The analysis of the changes in the delta morphometric characteristics (Table 1) allowed us to determine with the help of the reverse extrapolation the probable date of the delta formation beginning (1740). The most intensive delta protruding was over the period from 1871 to 1922. This period was characterized by a large water flow and the sediment yield. In the last years the delta growth has been slowed down due to the decrease in the Danube sediment yield and in the fraction of the Chilia branch sediment yield.

4. Sediment balance at the Chilia branch mouth

The sediment balance equation at the Chilia branch mouth during time interval $\Delta t$ is as follows:

$$\Delta W_f = W_r + W_{ln} - W_{ls} - W_d ,$$

where $\Delta W_f$ is the change in the fan volume; $W_r$ is the river sediment yield; $W_{ln}$ and $W_{ls}$ are the volumes of longshore sediment drift from the north and to the south accordingly; $W_d$ is the sediment volume carried away to the large marine depths outside the fan.

The fan volumes $W_f$ were calculated by the charts of the topographic surveys of the Chilia delta and its nearshore, and the values of $\Delta W_f$ were determined as the difference in these volumes (Table 1).

The sediment yield was defined in the manner shown above.

Thus the main components of the sediment balance equation, calculated throughout the Chilia delta formation (from 1741 to 1980) are the following: $\Delta W_f$ = 8,26 cu km, $W_r$ = 8,363 cu km. It was considered that the value of the longshore sediment drift from the north ($W_{ln}$) was equal to $0,12 \cdot 10^{-3}$ cu km/yr [6] and was constant over the period of 240 years. Now the sediment longshore drift to the south ($W_{ls}$) is equal to $0,85 \cdot 10^{-3}$ cu km/yr [6]. It was assumed that over the period of 240 years it was half of the value, because in the past the delta was weakly protruded into the sea and it slightly feeded the longshore sediment drift, directed to the south.

Thus the volume of the sediments carried away to the large marine depths outside the fan equals only -0,03 cu km.

The analysis of the sediment balance equation over the period of the Chilia delta existance shows the following (Table 2):

1. Nearly all river sediments deposited in the fan. The role of the sea sediments in the delta formation was small. The amount of sediments, carried away outside the

Table 2

Components of sediment balance at the Chilia branch mouth (averaged over 240 years)

| *Component* | *cu km/yr, $10^{-3}$* | *cu km* | *percent of $W_r$* |
|---|---|---|---|
| $W_f$ | 34,42** | 8,26 | 98,8 |
| $W_r$ | 34,84** | 8,363 | 100 |
| $W_{ln}$ | 0,12 | 0,029* | 0,3 |
| $W_{ls}$ | -0,425 | -0,102* | -1,2 |
| $W_d$ | -0,125 | -0,03 | -0,3 |

* Obtained by dividing of integrated value by 240 years

** Obtained by multiplying of average annual value by 240 years

fan was also small.

2. The fraction of the river sediments remaining in the fan increased with the delta growth.

3. It is found that if the sediment balance equation is composed for shorter periods, the fan increase is more than the river sediment yield over the corresponded time intrval. For examole, the ratio between the fan change and the sediment yield in 1922-1957, 1957-1980 and 1922-1980 equals 130,0; 125,4; 129,1 % correspondingly.

Thus the sediment yield is underestimated by nearly 30 %. The available data on sediment yield evidently did not consider sediment transport in the nearbottom layer and in the form of the sand waves. The new experiments, carried out by DHO shows that the bed sediments move in the form of the sand waves (ripples and dunes). Their fraction consists about 9-12 % of the suspended load. Therefore the bed load of the Lower Danube is much more than 1 % of the suspended load (as it is usually accepted [1,2,5]).

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# THE STOCHASTIC SCHEME/MODEL FOR FIRST-BREAKING WAWES IN THE SURF ZONE COORDINATED WITH SPECTRAL REGULARITIES AND SUPERPOSITION PRINCIPLE OF BEACH/SHORE DEFORMATION AGENT & RESULTS

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ABSTRACT. The use of own experimental result permits to base, work out and verify both the new stohastic theory and adequate scheme/model for first-breaking waves, wave systems, corresponding depths, breaking indexes and other special proposed characteristics distributions and their combinations in the surf zone of seas, great natural & manmade lakes with taking into account the shore peculiarities coordinated with joint spektral regularities and fundamental superposition principle of nonconhesive beach/shore deformation agents & results including sediment transport.

## DIE STATISTICH SCHEMA/MODELL ZU DER ERSTE-BRECHEN WELLEN IN DER WELLENSCHLAG ZONE MIT ETWAS ÜBEREINSTIMMEN DER SPEKTRAL GESETZMÄßIGKEITEN UND DAS SUPERPOSITION PRINZIP DEN FACTOREN UND RESULTATEN DEN STRANDEN DEFORMIETION

RESÜMEE. Der neu Theorie und die Schema/Modell zu den Verteilung das Wellen Elementen, das Wellen Systemen, der Entsprechen Tiefen, die brechen Indexen und der anderer Gradmesseren in der Wellenschlag Zone die Seen und die Stauseen bringen sich mit der Verwertung das superposition Prinzip und der spektral Gesetzmäßigkeiten den stranden Deformietion die sediment Transport.

## 1. INTRODUCTION

Evolution purposes of statisticai and spectral theory for wind-generated surfase waves and stochastic sediment transport theory determine the prinsipal long-term objective of this research directed towards increasing of knowledge about energy dissipating wave flow interaction with deformating inshore (beach/shore) surface with recent notions about shore dynamics. Such principal objective was to base, work out and nature verify the theoretic stochastic scheme/model for first-breaking waves, wave systems and corresponding depths distribution in the surf zone on nonconhesive shore beaches of seas, great natural and manmade lakes with taking into account the sediment transport forming conditions. The focused evaluation [*Samoylenko,1988*] of up-to-date researches showes that the existing theory of wave deformation in the surf zone [*e.g.,Gluckovsky,1966; Callins and Wier,1969; Jwata and Sowaragi,1982, ets.*] iterprets and takes into account no one from our confirmed working hypotheses (q.v. this paper part 2). Practical experience testifes that recent methods for wave characteristics probablities definition in two temporal dimensions (system or group and regime) are not complete for adequate explanation of surf zone waves variability and joint combination probabilities of wave and beach fluctuations.The lack of theoretic explanations for beach deformation agents & results stochastic structure in conditions of their similary joint interaction doesn't permit to investigate the four-dimensional temporal/spatial system "water-sediments- shore" and to be useful for better understanding of shore dynamics and stability. Solution of such problems have defined this paper subject.

## 2. BASIC PRELIMINARY RESEARCH ACCOMPLISHMENTS

Our preliminary research accomplishments [*Samoylenko 1986, 1988*] devoted for deeper understanding of natural particular shore zone processed and phenomena appearing due to interaction of water/beach sediment particles fluctuations and movements permit to formulate, obtain and prove the following main working hypotheses and basic conclusions for present investigation:

1)the existense in the surf zone special three-dimentional, differ to direction and period, oscillations of dynamic homohenuos beach part surface called "stochastic deformations" or "S-deformations". Such deformations appear according to the relationships of beach form and size spatial and seasonal fluctuations with short and long-term cyclic and unregular random fields of waves and nearshore currents for each water or sediment transport;

2)the presence of their own stochastic laws and spectral regularities in beach parametrs dynamics and S-deformations coordinated with waves phenomena and usually registered during field-work instrumental observations;

3)the feasibility of fundamental physical superposition principle of beach/shore agents (hydromorphodynamic & sediment processes) and their action results (beach surface form variability);

4)the existense of the first - breaking wave subzone (FBrS) (as compartment of the surf zone), not a point or line, for calculating waves depth characteristics at beach part profile during calculating or real storm (Figure 1) even under quazihomogenous hydrodynamic pressure.

As a result of marked four conclutions appeared the possibility and necessity to describe the wind waves energy transition across the nearshore zone by stochastic evalution of new first-breaking subzone parameters with taking into account the whole wave-systems set in storm at full width of this subzone $W_{fbr}$ (Fig.1) and different characteristics combinations. We have awarded for corresponding scheme/model parameters the following additional symboles: "c" (calculating) - for changing absolute and relative FBrS-parameters which are described by stochastic distribution laws ("c" de-

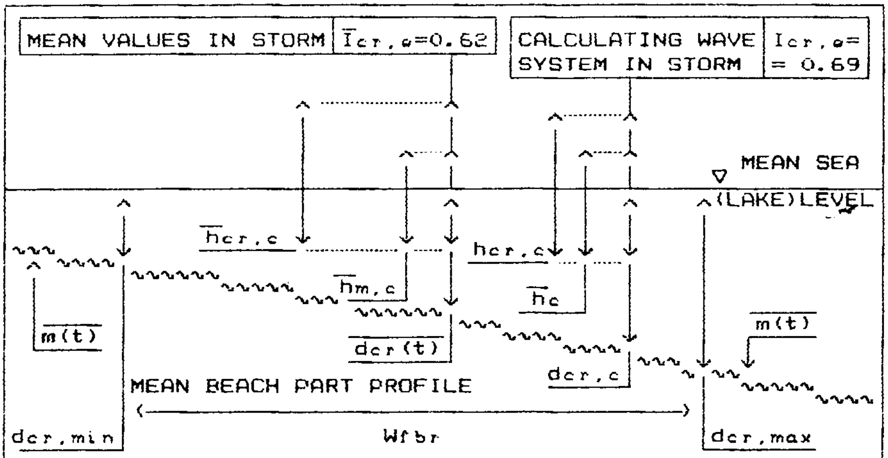


Fig.1.Calculating wave&depth characteristics in the first-breaking wave subzone (Wfbr) (legend in paper part 3)
Zeich.1.Der ausrechen Gradmesseren der Wellen und den Tiefen in der erstebrechen wellen Subzone (Wfbr)

notes the definite for hindcast or forecast probability sets, meaning probability of exceeding, symbol "P",%); "e" (equivalent) - for fixed values, including group with symbol "c", which are interpreted as energy equivalent for spectra of wave elements distributions in different dimentions. That is why the problem is to be solved by finding the numeral of model parameters for definition of wave-breaking criteria and "typical" [*Collins et.,1969*] wave height depths which are mostly energy adequate for the whole wave spectra interaction with mobile beach surface in the surf zone and permit to search the profiledone wave elements according to their seasonal and spatial nearshore storminside distributions.

## 3. RESULTS AND COMMENTS

By analitic-stochastic solutions [*Samoylenko,1988*] with the attraction of own experimental investigation results upon hydromorphodynamic data was created the simulation scheme/model (SM) for first-breaking wave depth parameters in FBrS during calculating storm using the spectral perculiarities of beach surface S-deformations under different period hydrodinamic agent affection,superposition principle of these agents interaction and stohastic regularities. Model includes both the generalized and modificated more detailed following levels (basic symbol "K" denotes the definite SM-parameter normalized by its mean value):

*The I-st(generalized) SM-level*

$$d_{cr,c} = 1.45\overline{d_{cr}(t)} = 1.45h_{cr,c} = 2\overline{h}_c = 2.35\overline{h}_{cr,c} = 2.9\overline{h}_{m,c}, \quad (1)$$

$$I_{cr,e} = h_{cr,c}/d_{cr,c} = 0.69; \quad \overline{I}_{cr,e} = I_{cr,e}/K(I_{cr,e}) = 0.62, \quad (2)$$

where $h_{cr,c}$ is the critical height of calculating wave along its first-breaking line,$d_{cr,c}$-the critical depth along the first-breaking line of wave with $h_{cr,c}$, which in (1) is energy equivalent for the whole waves and their system distributions spectra in definite probability storm; $\overline{d_{cr}(t)}$ - the average in storm wave breaking depth $d_{cr}$; $I_{cr,\circ}$ - the breaking index of $h_{cr,c}$ wave; $\overline{I_{cr,\circ}}$ - mean breaking index; $\overline{h_c}$ - the mean wave height in calculating system with $h_{cr,c}$; $\overline{h_{cr,c}}$ - $h_{cr}$ averaged during the whole storm; $\overline{h_{m,c}}$ - the mean from average in system $\overline{h}$ waves storminside.

*The II-nd SM-level*

This level estimates the stormininside hydromorphodynamic FBrS-parameters variability which reflects (Fig. 1) the $W_{fbr}$-fluctuations numerally identificated by $d_{cr}$-variation and beach surface oscilations (S-deformations) as the indicator of this surface "complication". It can be written as

$$d_{cr,c}=[\Phi(d_{cr,5\%})\times Cv(d_{cr})(1)_{max}\times Cv(m)(t)/\overline{Cv(m)(t)}+1]\overline{d_{cr}(t)}, \quad (3)$$

$$I_{cr,\circ}=\overline{d_{cr}(t)}/d_{cr,c}; \overline{K}(h_\circ)=\overline{h_c}/h_{mc}=K(d_{cr,\circ})=\overline{d_{cr,c}/d_{cr}(t)}=1/I_{cr,\circ}, \quad (4)$$

$$K'(h_{cr,\circ})=h_{cr,c}/\overline{h_{cr,c}}=\{\{\Phi\{K[K(h_{cr,29\%})]\}Cv[K(I_{cr})]+1\}\}K(d_{cr,\circ}), \quad (5)$$

where symbol "$\Phi$" denotes the definite probability deviations from the mean normalized by standard and estimatad from special parameter temporal (t) random functions; "Cv"- the variance coefficient function of FBrS- parameters along the shoreline in storm (temporal storminside symbol "1"); straight line above the symbol denotes the mean parameter value; m - submarine beach slope coefficient, $m=d(W_{fbr})/d(d_{cr})$; others are explained by table 1.

Table 1. The function (6) coefficients
Tabelle 1. Die Koffizienten den Funktion (6)

| K(FBr) | K(FBr)$_\circ$ | $A_{br}$ | Z |
|---|---|---|---|
| 1. Distribution of $h_{cr}$ set to the storm mean $h_{cr}$ value ratio: | | | |
| $K'(h_{cr})=h_{cr}/\overline{h_{cr}}$ | $K'(h_{cr,\circ})=K'(h_{cr,10\%})=1.62$ | 1.62 | 2. (6) |
| 2. Distribution of $d_{cr}$ to their storm average ratio and the systems mean wave height set to their average storminside ratio: | | | |
| $K(d_{cr})=d_{cr,c}/\overline{d_{cr}(t)}=$ $=K(\overline{h})=\overline{h}/\overline{h_m}$ | $K(d_{cr,\circ})=K(\overline{h_\circ})=K(d_{cr,5\%})=$ $=K(\overline{h_{5\%}})=1.45$ | 1.38 | 4 |
| 3. Distribution of $h_{cr}$ to its mean value in calculating system ratio: | | | |
| $K(h_{cr})=h_{cr}/\overline{h}$ | $K(h_{cr,\circ})=K(h_{cr,10\%})=1.38$ | 1.38 | 4 |
| 4. Distribution of the mean $h_{cr}$ set to the storm mean from system average ratio: | | | |
| $K(\overline{h_{cr}})=\overline{h_{cr}}/\overline{h_m}=$ $=K(h_{cr})/K[K(h_{cr})]$ | $K(\overline{h_{cr,\circ}})=\overline{K}(h_{cr,5\%})=1.23$ | 1,18 | 8 |
| 5. Distributions of K[K($h_{cr}$)]set to their storm average ratio and the breaking indexes set to the storm mean index ratio: | | | |
| $K[(h_{cr})]=$ $=K(h_{cr})/K(\overline{h_{cr}})]=$ $=K(I_{cr})=I_{cr}/\overline{I_{cr}}$ | $K[K(h_{cr,\circ})]=K(I_{cr,\circ})=$ $=K[K(h_{cr,29\%})]=$ $=K(I_{cr,29\%})]=1.12$ | 1.18 | 8 |

As necessary addition to (1)...(5) where obtained the all main charachteristics of normalized FBrs-parameters [K(FBr)] stochastic distributions for SM which generally can be represented, taking into account the *B.Gluckovsky* [1966] function by

$$K(FBr)=A_{br}\{-\lg[K(FBr)]\}^{1/z} , \qquad (6)$$

where $A_{br}$ and z are the function (6) coefficients placed in table 1. Simultaneously we've determined the probabilities of normalized FBrS-parameter values $[K(FBr)_{\omega}]$, which are energy eqvivalent for the whole their spectrum sets interaction with beach surface.

Due to the mentioned superposition prinsiple, for the $K(FBr)_{\omega}$ determination were used our new theoretic stochastic distribution schemes for S-deformations and joint combination probabilities of water and sediment environment dynamic characteristics in FBrS [*Samoylenko,1986,1988*]. So as initial were used the normalized spectrum density functions of wave-breaking depths and surf zone width which maximums is adequate for probability values 0.039 (3.9%) and 0.228 (22.8%).

*The III-d SM-level*

This level which estimates the all main FBrS-parametres was obtained coordinated with hidromorphostochastic wave-breaking depths model [*Samoylenko,1986*] and taking into account (4),(5) can be integral represented by

$$I_{cr,\omega}=\frac{h_{cr,c}(\overline{\lambda}_{d\omega}/s_m)^{Cv(h_{d\omega})}\cos\theta^{o}_{cr}}{[\Phi(d_{cr},5\%)Cv(d_{cr})(1)+1]s_m}\,[\overline{m(t)}m_nCv(m/h_{d\omega})]^{-U(d_{cr})} , \qquad (7)$$

$$U(d_{cr})=\frac{Cv(h_{d\omega})d_{cr}(M_o)}{\overline{Cv(d_{cr})(t)}\;\overline{d_{cr}(t)}}=\frac{1}{\overline{Cv(m)(t)}}=\frac{\overline{h}_{m,c}}{\sigma(d_{cr})(t)}=$$

$$=\frac{\overline{h}_c}{\sigma(d_{cr})(t)K(d_{cr,\omega})} , \qquad (8)$$

where $\lambda_{d\omega}$ denotes the calculating length of deep-sea wave $(h_{d\omega})$; $\cos\theta^{o}_{cr}$-cosine of $h_{d\omega}$ approach angle to its first-breaking depths isoline; $m_n$-natural slope coefficient for beach consisting of particles with mean weighted diameter $s_m$ in non - oscillated water; $d_{cr}(M_o)$-the modal $d_{cr}$ value; $Cv(h_{d\omega})$- the system $h_{d\omega}$ variance coefficient; $\sigma(d_{cr})(t)$-the temporal $d_{cr}$-standard function; $Cv(m/h_{d\omega})$ - proposed by us the hydromorphometry variability coefficient defined according to hydromorphometry criterion, which can be written as

$$V_{m,h} = (h_{cr,c}/\overline{\lambda}_{d\omega})^{Cv(h_{d\omega})Cv(m)(t)} , \qquad (9)$$

In case of $V_{m,h} \geq Cv(h_{d\omega})$ variability of beach surface parameters and wave characteristics is adequate and $Cv(m/h_{d\omega}) = Cv(m)(t)/Cv(h_{d\omega})$; when $V_{m,h} < Cv(h_{d\omega})$ S-deformations dominate and $Cv(m/h_{d\omega})=Cv(m)(t)$.

## 4. VERIFICATION

The created scheme/model have been tested on the data collected from natural and laboratory research sites. Verification procedures intended the attraction of own experimental investigation results which were conducted in the surf zone of Black Sea, Azov Sea and Ukrainian natural and manmade lakes at 21 observing stations used as a basic natural experimental models for hydromorpholythodynamic processes. Also the existing information in field-work and laboratory model observation results in the paper scope were used for SM verification, which showed the sufficient for practical purposes similarity between the SM all level component solutions and real data [*Samoylenko, 1988*]. These solution with simulation modeling means applying are feasible for the surf zones with mean bottom gradients (i=1/m) from 0.070 to 0.010, beach sediments with mean weighed diameter from 0.15 to 1.00 mm with any angel of wave approaching the shore and dynamic bottom profiles existense.

## 5. CONCLUTIONS

The new stochastic theory and adequate scheme/model (SM) for first-breaking waves, wave systems, corresponding depths, breaking indexes and other special proposed characteristics distributions and their combination in the first-breaking surf zone subzone (FBrS) of seas, great natural and manmade lakes were based, worked out and verified for generalized and more detailed levels to give the possibility for increacing of knowlege about temporal-spatial transformation nearshore effect under waves energy dissipation.

According to the first scheme/model level the calculating wave height $h_{cr,c}$, which is energy equivalent for the whole waves and their systems distributions spectra in definite probability storm is $h_{cr,c}$ along its first breaking line with 10% probability of exceeding in wave system, which in its turn has 5% probability in storminside wave-systems set. Correspondent to $h_{cr,c}$ and its system criteial depth $d_{cr,c}$ has 5% probability in the $d_{cr}$-set of all wave systems storm-inside, and first-breaking index $I_{cr,c}=h_{cr,c}/d_{cr,c}$ has 23% probability in set of indexes during the calculating storm.

Were obtained all the main characteristics of normalized first-breaking subzone parameters stochastic distributions for SM which permit to estimate any definite FBrS-element of needful probability.

Revealed results proved the possibility and necessity to describe the wind waves energy transition and dissipation across the mobile nearshore surface by stochastic evaluation of new first-breaking zone parameters using their own joint spectral and superposition bottom fluctuations & wave breaking storminside peculiarities for better fundamental understanding of natural surfzone/sediment phenomena and shore deformation mechanism including the practical solutions of sediment transport problems applying mathematic and simulation modeling by the computer technology.

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# ASSESSING THE IMPACT OF THERMAL LOAD INCREASE ON THE ICE CONDITIONS OF THE RIVER DANUBE

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## ABSTRACT

Concentrated anthropogenic sources of thermal input load to the River Danube also play a role in the changes of the ice regime of the Hungarian part of Danube. Among these sources tributary water courses of warmer water than Danube and cooling water discharges of thermal power plants are the most significant ones.

The thermal capacity of Danube has significantly increased upon the effect of Hungarian and foreign warm water discharges. The probability of occurrence and duration of standing ice had substantially decreased over the regulated river reaches. Over non-regulated river reaches thermal inputs reduced, but did not eliminate, the hazards of ice-floods.

# WIRKUNGSANALYSE DER WÄRMELEISTUNGERSTEIGERUNG DER DONAU

## ZUSAMMENFASSUNG

Auch die mit menschlicher Tätigkeit verbindenden konzentrierten Wärmebelastungen spielen in der Veränderung der Eisregimen der ungarischen Donaustrecke bedeutungsvolle Rolle. Zwischen den Wärmebelastungen haben die Nebenflüsse von grossem Durchfluss -deren Wasser wärmer ist als das Donauwasser- und die Warmwasserabflüsse der Kraftwerke beachtliche Bedeutung.

Unter dem Einfluss der Warmwasserbelastungen von ungarischer un ausländischer Herkunft is die Wärmeleistung der Donau sehr bedeutend erhöcht, und die Entstehungwahrscheinlichkeit der Eisscholle un sein Lebensdauer wurden geringer. Die winterliche Wärmeleistungssteigerung der Donau hat das Risiko des Eishochwassers entlang der unregulierten Stromstrecke vermindert aber nincht behebt

## 1. INTRODUCTION

The ice regime of the River Danube is affected by both natural and anthropogenic thermal discharges. Natural ones are those of the tributary rivers of warmer water than that of Danube. Downstream of the confluence with these warmer tributary water courses the water of Danube warms up and this might contribute to the melting of ice. There are tributaries which exercise cooling effects on Danube too. The natural thermal capacity of Danube is increased by the warmer tributaries and anthropogenic warm water discharges and this can affect local ice conditions and induce changes in the longitudinal profile of the ice regime.

## 2. NATURAL AND ANTHROPOGENIC THERMAL CAPACITY OF THE RIVER DANUBE

Warm water discharges increase the temperature of the river and alter the ice regime. Ice conditions of the Hungarian reach of the River Danube have been altered by the local and foreign (upstream) concentrated thermal discharges to an appreciable extent.

The thermal capacity of the river is expressed in terms of the heat flux across the wetted cross-section area, as:

$$M_s = Y_b \cdot C_b \cdot t_b \cdot Q_b \qquad (2\text{-}1)$$

where

$M_s$ = the thermal capacity, Mcal/s
$Y_b$ = specific weight of water, 1000 kg/m$^3$
$C_b$ = specific heat of water, kcal/kg °C
$t_b$ = temperature of water, °C
$Q_b$ = rate of water flow, m$^3$/s

Simplifying Eq. 2.1 one obtains that

$$M_s = 4.19\, t_b\, Q_b\,,\ \ \text{MW} \qquad (2\text{-}2)$$

The multi-annual average thermal capacity of Danube is 104 GW in the river reach between Budapest an the country border. It is 163 GW and 34 GW in the average of the summer and winter half year, respectively, while drops to 11 GW in January (the month of the minimum air temperature).

Analyzing the tendencies of the changes of the thermal capacity of the river reach in concern one finds that in the period of 1946-1981 the rate of thermal capacity increase was +0.02 GW/yr in annual average and +0.12 GW/yr in the winter-, while -0.09 GW/yr and summer half year, respectively. It is worthwhile to mention that although the annual average thermal capacity of the river is nearly stagnant considerable trends can be identified in the winter and summer half years, indicating a tendency of increasing extremes.

The thermal capacity introduced by inflowing tributary streams and point -source spent or waste water discharges can be calculated by the following expression:

$$M_m = 4.19\ (t_m - t_b)\ Q_m \tag{2-3}$$

where

$M_m$ = thermal capacity introduced, (MW)
$t_m$ = temperature of inflowing water, (°C)
$t_b$ = water temperature of the recipient, (°C),
$Q_m$ = rate of inflow, ($m^3/s$)

The winter-time (January, February, March) thermal capacities of the more important tributary rivers of Danube are summarized in Table 1., along with the capacities introduced by them to Danube. On the basis of Table 1. the following conclusions can be drawn:

- Most of the smaller tributary streams represent cooling effect for Danube

- The southern right-bank side tributaries contribute substantial thermal capacities to Danube, representing thus significant ice-melting effects,

- The winter heat budget of rivers Dráva and Száva plays important role in the ice regime of Danube and thus in the formation of ice-jams (Horváth, 1960).

The thermal capacity data of larger concentrated anthropogenic warm water discharges are summarized in Table 2.. Comparing the data of tables 1. and 2. it can be stated that the total man-introduced thermal load along the Austrian and Hungarian Danube reaches equals that of the relatively warm River Száva (Sava). Anthropogenic thermal discharges represent appreciable modifying effect upon the ice regime of the River Danube.

The thermal capacity of Danube has been considerably increased upon the effects of global warming of the atmosphere and of the concentrated warm water discharges (Figure 1). The average winter-time thermal capacity of Danube has been increased by 16% and 34% at Budapest and Mohács (southern country border), respectively.

## 3. EFFECTS MODIFYING THE ICE-REGIME

The ice-melting capacity introduced by concentrated warm water discharges can be calculated by the following expression (Kretschmer, 1979):

$$E = 1000.\ Q_m \cdot t_m \tag{3.1}$$

where:

- $E$ - is the melted ice flux, $m^3$/day,
- $Q_m$ - is the rate of warm water inflow
- $t_m$ - is the temperature difference between the warm water discharge and the recipient stream

Ice-melting capacities, as calculated by Eq. 3.1, are summarized in Table 2.. In column 6. of Table 2 the "ice-drift-density decreasing effect" of the heat input is shown, as calculated in function of the width of the river in winter, the size of drifting ice floe, and of the calculated ice-melting capacities.On the basis of these data it is found that the thermal power stations along the Hungarian reach of the river reduce the density of drifting ice by 14-18%, while the effect of the Nuclear Power Plant of Paks amounts to 28%. These together represent significant changes in the ice regime of the River Danube.

The increased thermal load of concentrated inputs had significantly contributed to the intermittent character of the longitudinal profile of standing ice, which is experienced in the past decades (Figure 2.). Namely, below the confluence with thermal discharges, within the full mixing length, ice is being melted by the thermal plumes. For example; the excess heat capacity introduced by the spent and waste water discharges of Budapest, via treatment plants and directly from the sewers, to Danube is sufficient -in function of the water regime- for the melting of 10 cm thick standing ice cover over 1-2 km length of the river.

Thermal discharges along the River Danube had appreciably contributed to the steadying of the intermittent character of the longitudinal profile of standing ice, and to the decreasing of the rate of ice-jam formation.

Cooling water discharges of thermal power plants had contributed to the decreasing of the hazard of ice-jam generation, to varying extent along different reaches of the river. Experiences indicate that the intermittent character of standing ice does not increase the risk of ice-jam formation, as it delays the formation of standing ice cover and reduces its duration.

Summarizing the above considerations one may state that the increasing thermal capacity of the river decreases the probability of the occurrence of standing ice cover, thus improving the effects of river training activities in controlling the ice regime.

Figure 3. shows ice-regime profiles corresponding to three different periods of time. Comparison of the characteristic data of periods 1. and 2. reveals the ice-regime improving effects of river training activities that had been carried out in the end of the 19th and in the first half of the 20th century. Comparison of the corresponding characteristics of periods 2. and 3. allows the quantification of the ice-regime modifying effects of anthropogenic thermal loads of the past decades as well as those of ice-destruction (breaking, blasting) activities. On the basis of Figure 3. it may be stated that favourable changes have occurred over a considerable part of the Hungarian Danube. Nevertheless, in order to reduce the risk of ice-flood further ice-defence activities are

needed in the southern part of the Hungarian reach as well as along the foreign Danube reaches further downstream.

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Table 1.

Cooling and heating heat output from tributary of river Danube in winter period (I - III months)

| Tributary | | | | Danube, the receiving water | | |
|---|---|---|---|---|---|---|
| name | $t_v$ °C | heat output MW own | heat output MW passed | gauging station | $t_v$ °C | heat output GW |
| Inn | 2.9 | 5413 | - 9013 | Regensburg | 7.8 | 15.6 |
| Enns | 2.9 | 3810 | - 364 | Mauthausen | 3.1 | 16.3 |
| Morva | 2.4 | 1428 | - 273 | Wien | 2.8 | 18.8 |
| Rába | 2.4 | 463 | - 57 | Rajka | 2.7 | 19.4 |
| Vág | 1.6 | 1026 | - 577 | Komárom | 2.7 | 23.3 |
| Garam | 1.0 | 230 | - 415 | Dunaalmás | 2.8 | 24.7 |
| Ipoly | 1.9 | 295 | - 140 | Dunaalmás | 2.8 | 24.7 |
| Sió | 3.0 | 365 | - 0 | Dunaujváros | 3.0 | 28.5 |
| Dráva | 3.2 | 5639 | + 880 | Bezdán | 2.7 | 24.9 |
| Tisza | 2.3 | 9266 | - 1642 | Bogojevo | 2.7 | 26.6 |
| Száva | 4.2 | 35057 | +12664 | Bogojevo | 2.7 | 26.6 |
| V. Morava | 3.8 | 5630 | - 297 | Smederovo | 3.6 | 87.1 |

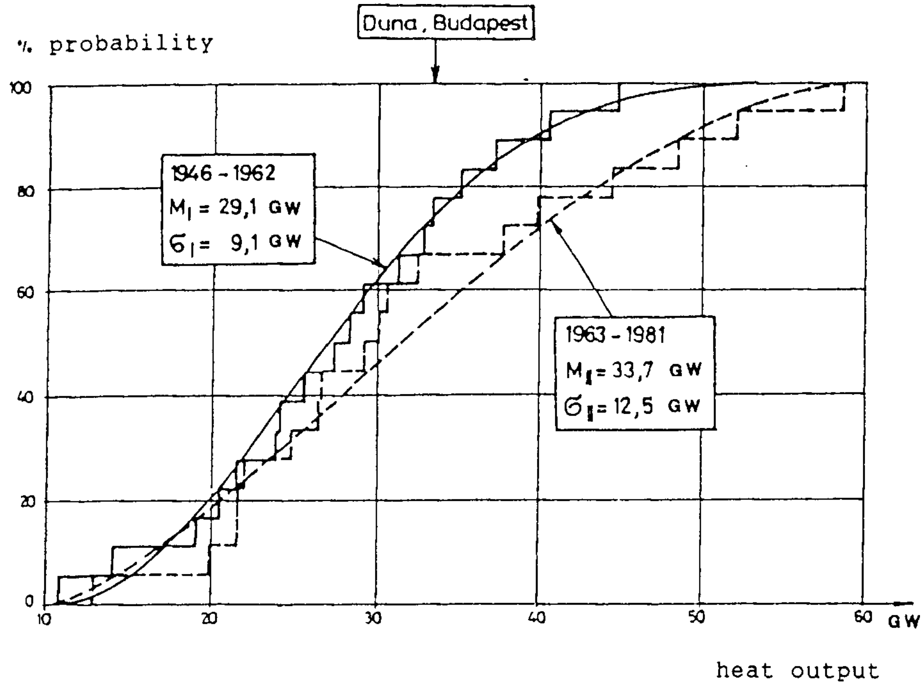
(*) in the case of passed heat output
+ heating
- cooling effect
$t_v$ = average water temperature °C (january - march)

Table 2.

Characteristics and ice melting effects of inflow heat output on the austrian and hungarian reach of river Danube

| Concentrated hot-water input | | | | Ice melting power | $-\Delta P$ (**) | source of data |
|---|---|---|---|---|---|---|
| place | Temperature | discharge | heat output | $1000 m^3$ | % | |
| | °C | $m^3/s$ | MW | ice/day | | |
| Pleiting thermal power-st. | 11 | 28 | 1291 | 308 | -18 | /1/ |
| Linz canals | 12 | 0.75 | 38 | 9 | - 2 | /1/ |
| Manure works | 12 | 4 | 201 | 48 | - 3 | /1/ |
| Linz remote heating | 18 | 2 | 151 | 36 | - 2 | /1/ |
| Industr. cooling water | 12 | 13 | 654 | 156 | - 9 | /1/ |
| Traun canal | 3 | 40 | 503 | 120 | - 7 | /1/ |
| Area of Wien | 12 | 3 | 151 | 36 | - 2 | /*/ |
| Budapest | 12 | 3.5 | 176 | 42 | - 2 | /2/ |
| Dunamenti thermal power-st. | 8 | 60 | 2011 | 480 | -14 | /3/ |
| Paks atomic power-st. | 15 | 65 | 4085 | 975 | -28 | /*/ |
| Indus. w. (Hungary) | 11 | 46 | 2020 | 484 | -14 | /2/ |
| Total | --- | --- | 9,274.00 | 2,694.00 | --- | ---- |

Source of data: /1/ Kretschmer /1979/
/2/ Annual of Water Resources Management /1986/
/3/ Szolnoky /1980/
/*/ estimated /1988/
(**)Decrease in density of ice drift



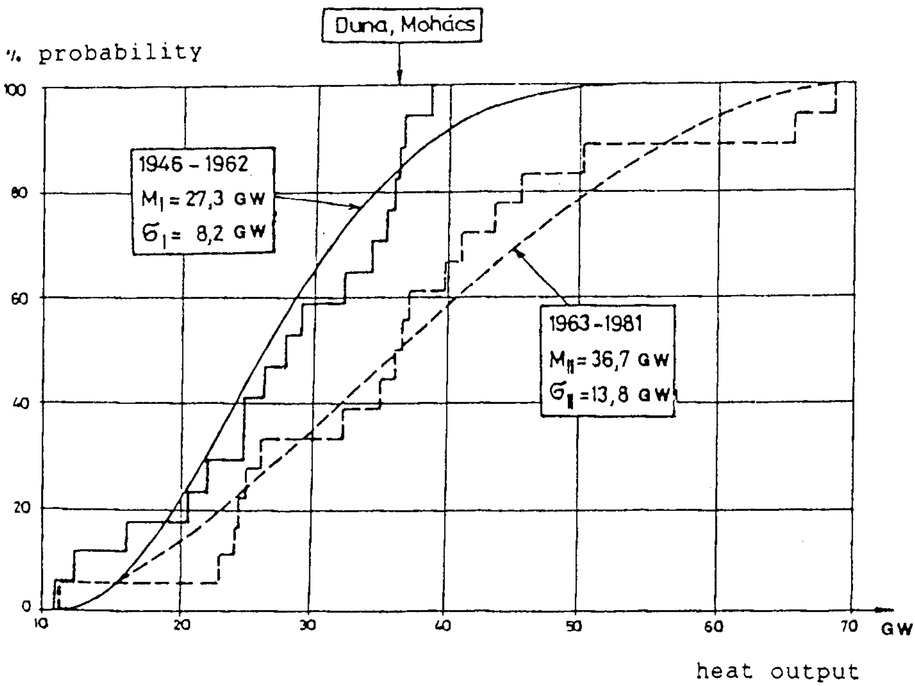




Fig. 1. Distributon function of Danubian heat output in winter half year

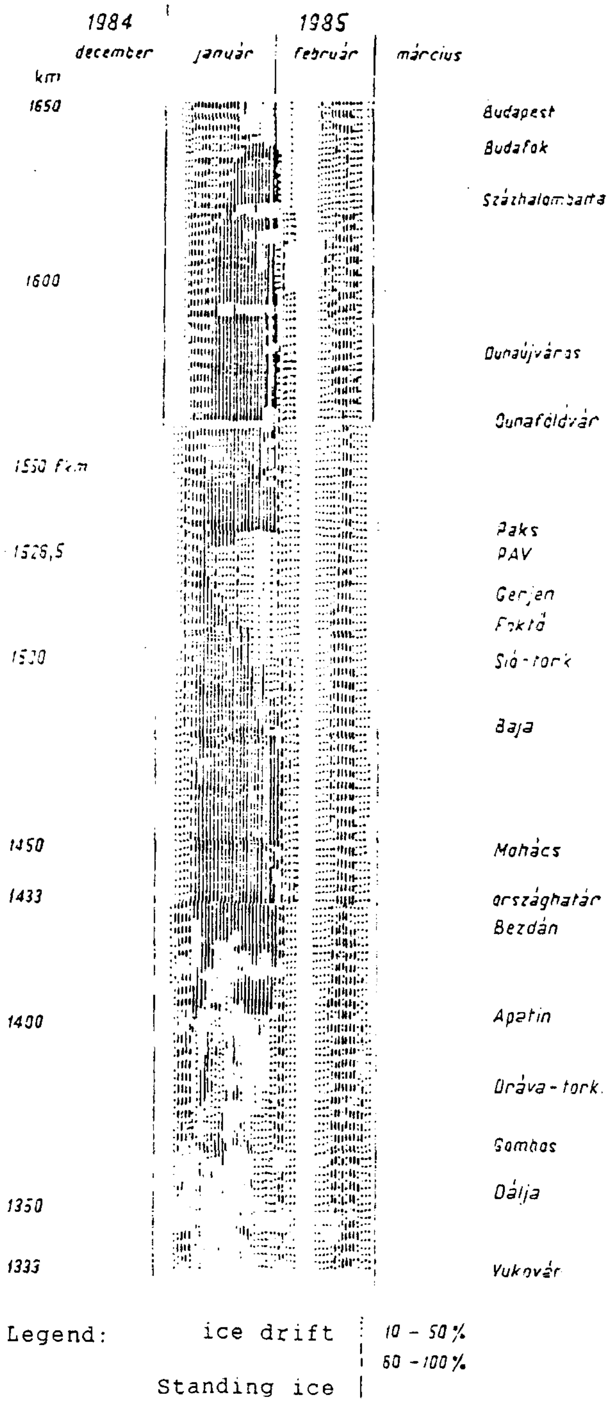



Fig. 2. Longitudinal section on regime of ice of river Danube

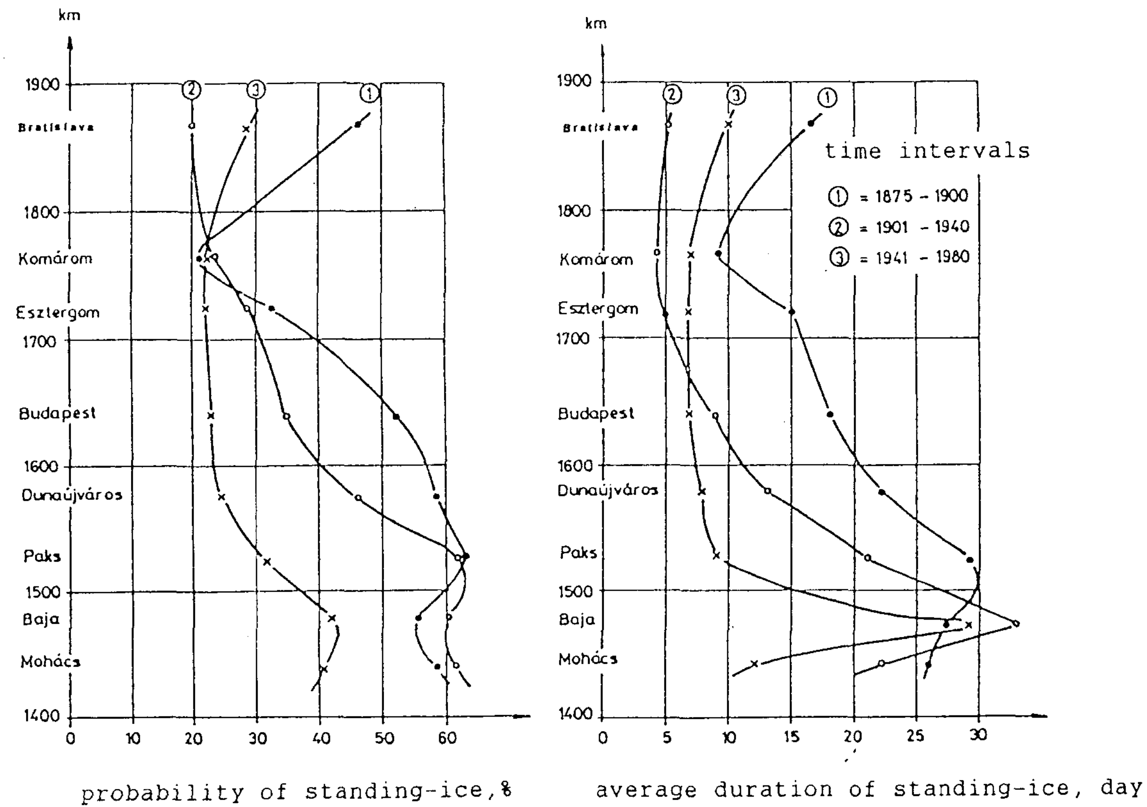



Fig. 3. Longitudinal section of characteristic of Danubian standing-ice

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# TEMPERATURE FLUCTUATIONS AND ICE PHENOMENON REGIME IN THE LOWER DANUBE

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SUMMARY: For the investigation of the Lower Danube ice regime, the temperature time series of 5 Bulgarian stations, along the Lower Danube are analyzed. Their homogeneity and trends are scrutinized. Correlation between the air temperature and ice regime of the river is looked for. The analysis is accompanied with filtration of the initial data. Statistical evaluations and illustrations are given. It is supposed that the ice regime is influenced by climate and anthropogenic changes.

## TEMPERATURAENDERUNGEN UND FLUSSEISGANG-REGIME IN UNTEREN tEIL dONAU

KURZFASSUNG: Fuer die Forschung des Flusseisgang-Regimes des unteren Donau werden die Temperaturedaten aller Haupt-hydrometeorologischen Stationen analysiert. Es wird deren Homogenitaet und das Existieren von Trnd festgelegt. Es wird eine Korrelation zwischen der Lufttemperatur und dem Flusseisgang-Regime gesucht. Es wird angenommen, dass die Entstehung und Verbreitung des Flusseisgang-Regimes einen komlexen Charakter hat und wird vom Klima - und Antropogaenaenderungen verursacht.

## 1. INTRODUCTION

The *Danube* is a *natural frontier* between Bulgaria (southward) and Rumania (northward) from the outflow of the Thimok river (km 845) till Silistra (km 375.5). The Danube, have in this section, in general east direction. In this part the river runs between 22 41 E and 27 16 E and 43 38 N and 44 12 N . As it can be seen it is speaking of a comparatively short length (470 km) in a narrow geographical belt.

The Danube froze over near Ruse for 96 days in winter 1840 - 1841, for 101 days in 1887 -1888. During the winter 1897 - 1898 the Danube froze down 3 times. The ice run lasted to March 30 in 1876. In 20-th century, up to 1994, the Danube frizzed down at Ruse 14 times.

The aim of this paper is to reveal the peculiarities of the ice regime in this part of the river and its trend in the second half of the 20-th century.

Temperature time series for five Bulgarian ports from 1951 - 1990 are used.

The time series for this period was chosen with regard that since 1950 on the Danube and its feeders have been constructed a lot of barrages.

## 2. ANALYSIS AND RESULTS.

The homogeneity of the time series were tested by non-parametric methods. At 95 % significance level the homogeneity of the time series used was accepted.

The simple correlation coefficients of the mean winter temperatures are above 0.90 and significant for all pairs (Table 1).

Table 1. Three angular Matrix of Pearson product moment Correlations.

| Station | Orjahovo | Svistov | Ruse | Silistra |
|---|---|---|---|---|
| Lom | 0.99 | 0.98 | 0.96 | 0.90 |
| Orjahovo | | 0.99 | 0.97 | 0.91 |
| Svistov | | | 0.99 | 0.94 |
| Ruse | | | | 0.96 |

The mean winter temperature (December - February) in

Silistra is normally higher than in the other considered stations and the coldest in most cases is Lom (Fig. 1). The *difference of the mean winter temperatures in different* stations do not exceeds 1.5 C°

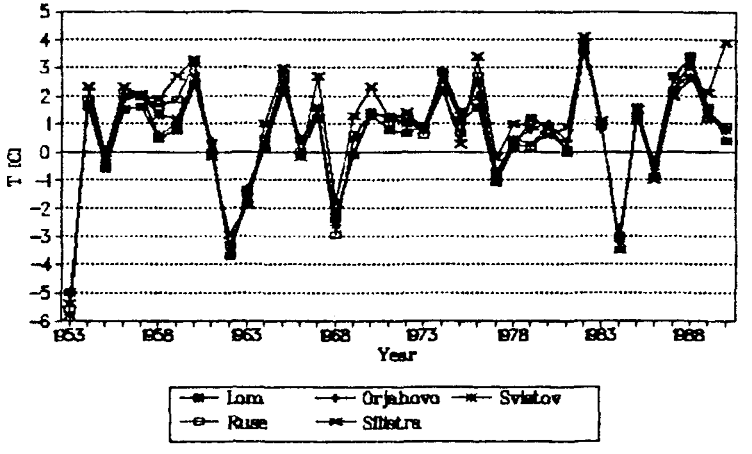


Figure 1. Mean winter Temperatures.

The factor analysis reveals only one factor with significant weights for all stations (Table. 2)

Table 2. Factor Matrix.

| Station/Factor | 1 | 2 |
|---|---|---|
| Lom | 0.982 | -0.159 |
| Orjahovo | 0.992 | -0.114 |
| Svistov | 0.997 | 0.005 |
| Ruse | 0.992 | 0.092 |
| Silistra | 0.943 | 0.183 |

Days with ice run were given weight -0.1 and days, when the river is frozen over - -0.2. The weights sum for most winters is the biggest in Silistra (Fig. 2).

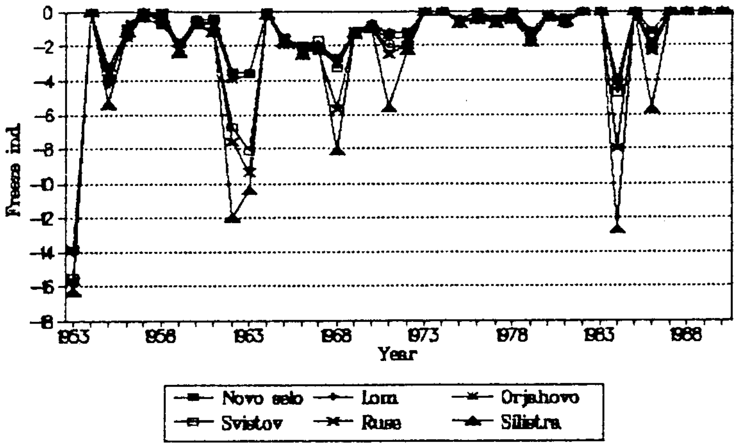


Figure 2. Sums of winter freeze Indexes

The obtained quantitative characteristics of the ice regime is in significant correlations with mean winter temperatures for all stations (Table 2).

Table 3. Sample Correlations of the mean winter Temperatures with the Ice event Weights.

| Station | Novo selo | Lom | Orjahovo | Svistov | Ruse | Silistra |
|---|---|---|---|---|---|---|
| Corr. coif. | 0.76 | 0.77 | 0.76 | 0.80 | 0.85 | 0.87 |

Five days Mean moving average of the daily minimum temperatures were calculated. This value, as a rule, in the first day with ice run is below - 5 C°. In the first day when the river freeze down the five days moving average of the minimum temperatures are normally below - 10 C°.

The mean winter temperature of this part of the Danube is presented by 3-term smoothed polynomial (Fig. 3) It shows a trend of increasing.

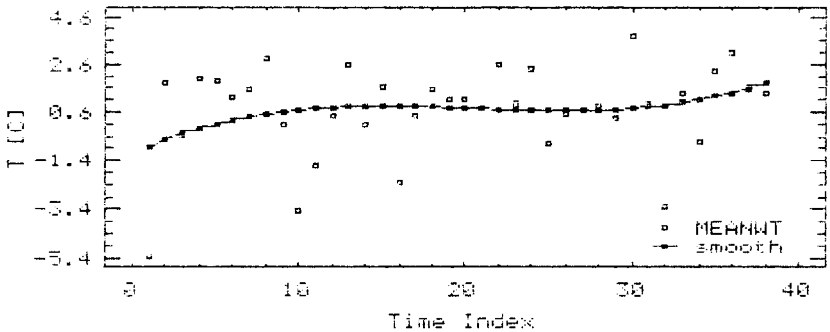


Figure 3. Polinomial smoothed mean winter temperature.

## 3. CONCLUSIONS

- The ice events in this part of the Danube are influenced by the Iron gate barrage;
- The ice events downstream increase because quantitative accumulation.
- The appearance of some ice phenomena may be forecasted if a seasonal air temperature forecast is available;
- The ice events up to the end of this decade should be expected to be less than in the previous.

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# ICE FORECASTING AT THE DANUBE APPLIED IN THE REPUBLIC HYDROMETEOROLOGICAL INSTITUTE OF SERBIA

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## ABSTRACT

Forecasts of the first ice events and ice-bridge at the river Danube, from Bezdan to Djerdap accumulation has been made in the Water Forecast Division of the RHMI of Serbia since winter 1971/72.

Forecasts of ice events are based on physico-statistical or empirical graphical dependencies between the amount of total heat loss necessary for the ice and ice-bridge occurrence and certain hydrological elements. For the elaboration of forecasts, it is necessary to monitor permanently all the parameters of the waterway winter regime (water level, flow, water temperature, mean daily air temperature) and a reliable meteorological forecast as well.

Since 1992, monitoring of hydrological and meteorological parameters, forecasting of ice events and dissemination to the users in due time have been automatized.

## INTRODUCTION

Ice condition monitoring on the rivers and ice event forecasting are significant in various aspects, such as:

- river traffic (cargo transportation on waterways)
- prompt engagement of icebreakers at critical parts (in river mouth zones and sharp river bands) and endangered structures (bridges, dams)
- flood protection in case of ice barrier forming at the time of spring ice floating

making a decision on taking the corresponding steps for ice breaking, due to the special working regime of hydropower plants, in case they are endangered.

The problem of forecasting the time of ice and ice-bridge events has become more prominent when the hydro-power plant Djerdap at the Danube was installed.

The method of mathematical and statistical dependence has become operational in the Republic Hydrometeorogical Institute of Serbia since winter 1971/72. This method is operationally more usable and is proven to be justified in relation to the balance method.

## DESCRIPTION OF APPLIED METHOD

The method of mathematical and statistical or empirical dependencies analyzes the amount of the total heat loss necessary for the ice event depending on various elements.

Corresponding dependencies are obtained in statistical way on the basis of the observational data of a certain watergage profile.

The amount of the mean daily negative air temperatures is taken as an approximate characteristic of the total heat loss, starting from the day when temperature was below 0°C till the day of the first ice event.

For the forecast of the first ice event we use a graph defining the dependence, **$(\sum - T)_{min} = f(T_w)$**, the necessary amount of the negative mean daily air temperatures for the ice occurrence depending on the water temperature the day before the mean daily air temperatures were below 0°C (Figure 1).

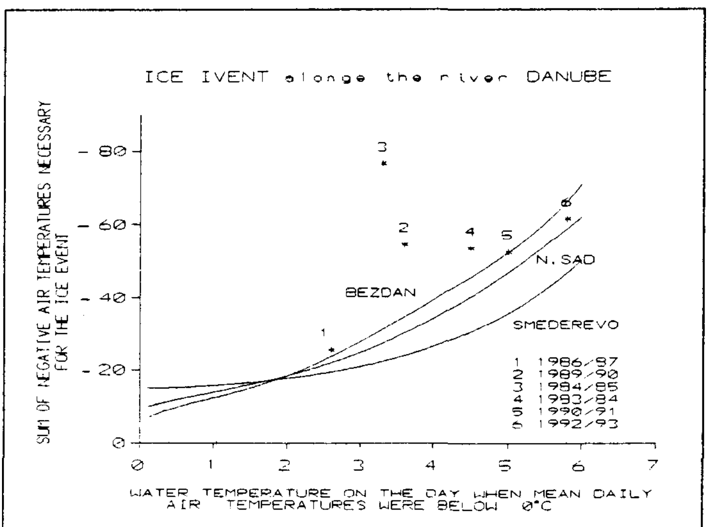


**Figure 1**

The same method can be spread taking a third variable, the water level (applied in RHMZ), flow or water depth.

The date of fulfilling the necessary negative amount is determined on the basis of predicted air temperatures.

However, even without forecasting the air temperature, the date of the ice occurrence can be determined also by using the graphical relation between the date of occurrence and the date when the mean daily air temperature fell below $0^0$C, depending on water temperature or the amount of negative air temperatures necessary for the ice forming (Figure 4).

On the first day of ice occurrence, the forecast of the ice-bridge occurrence is made. For the forecast of the ice-bridge event, the graphs defining the dependencies are used :

a) **($\sum$ - T)min = f (Hp1)** necessary amount of the mean daily air temperatures (from the day of ice occurrence) for the ice-bridge forming, depending on water level or flow on the day of ice event (Figure 2) and

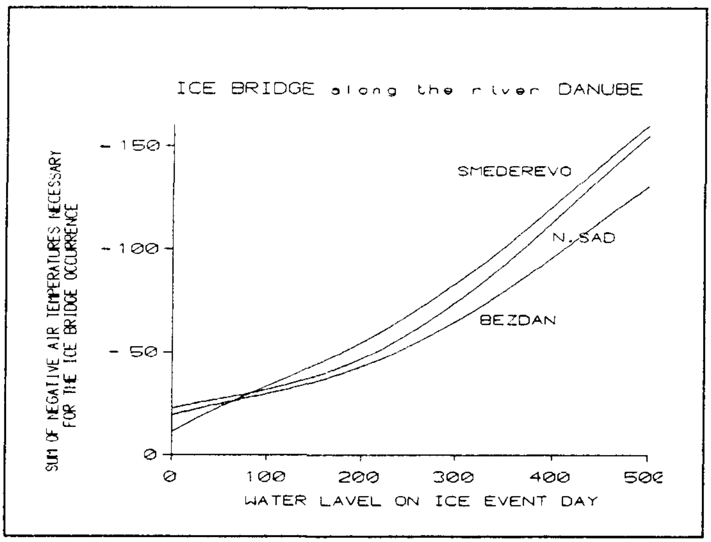


**Figure 2**

b) **Tkr = f (Hpl)** critical mean daily air temperature depending on water level or flow on the day of ice occurrence (Figure 3)

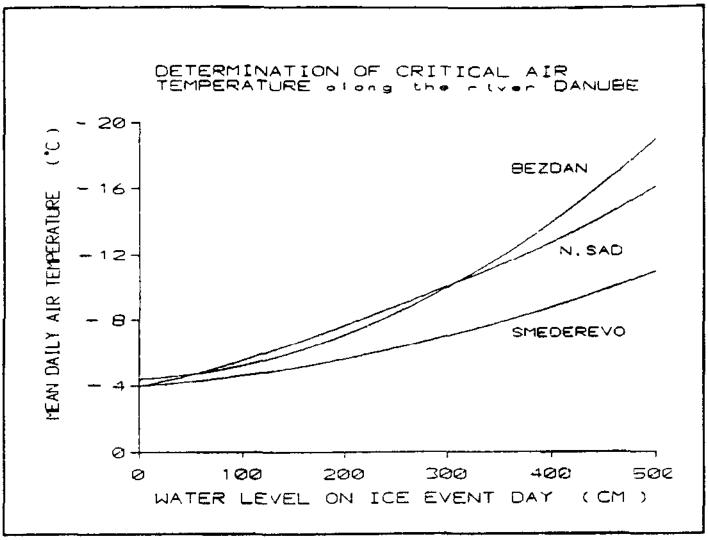


**Figure 3**

For the forecast of the date of ice-bridge occurrence, the existence of the amount of negative temperatures is not enough. The ice-bridge occurrence is possible also in the case when the mean daily temperature is lower then some critical value.

In order to be able to forecast the ice events on the Danube, the necessary graphical dependencies for the water gage stations Bezdan, Novi Sad and Smederevo were made, with available data for the period 1948/1971.

## AUTOMATION OF FORECASTING SYSTEM

Since 1992, monitoring of hydrological and meteorological parameters, forecasting of ice events and dissemination to the users have been automatized.

Choosing the corresponding station, a daily table with hydrological and meteorological parameters from the data base of the operational system is made, enabling the observation of the changes and its intensities.

A necessary amount of the negative mean daily air temperatures for the ice or ice-bridge events is determined and then is compared to the current situation. Introducing the forecast air temperature, the date of ice-bridge event is determined.

For a short time period, it is possible to make a forecast and prepare the information, and then send it to the users.

Ice event forecasts are issued for the period of seven, fifteen or thirty days ahead by using the short-or long range numerical weather forecast made by the meteorologists of the Republic Hydrometeorological Institute of Serbia.

For the needs of long range ice forecasts, the analogous hydrological situations are used from the standpoint of ice events, obtained by automatic search of certain elements from the base of the historical data, specially made for this purpose.

## CONCLUSION

The ice regime analysis on the Danube indicated that ice events start with the autumn falling limb and end with the spring rising limb of high waters. The average sum of the mean daily negative temperatures necessary to form the ice event is -39°C with average realization within 9 days, and for the ice-bridge occurrence from -74°C to -130°C.

In the period of the application of the forecast method, there were no severe winters with intense and long-term ice events on the Danube, with the exception of the winters 1984/85 and 1986/87. The
Figure 1 represents realized sums of mean daily negative air temperatures in the last 10 years of Bezdan. In winter 1984/85 there was a significant variation. For the same period (water gage station Bezdan), the Figure 4 shows a prolonged time from the mean daily air temperature falling below 0°C up to the time of the ice occurrence. In this period the water temperatures were slightly higher when the air temperature were below 0°C.

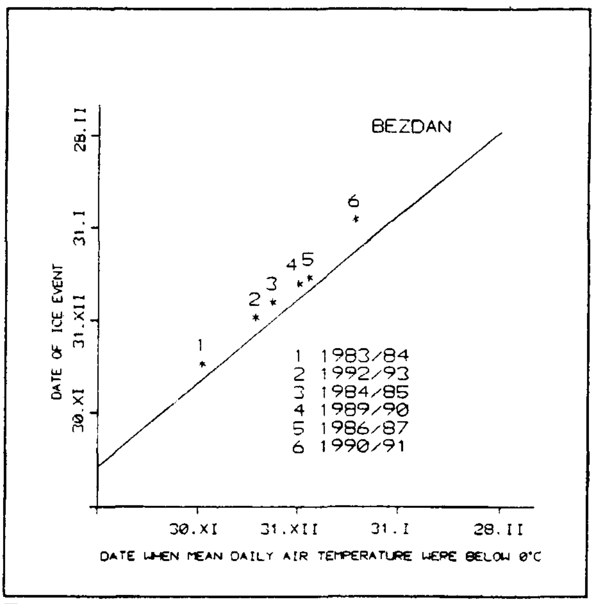


**Figure 4**

In case of change of meteorological conditions, and in the lower part of the Danube there is the influence of the Djerdap accumulation, a longer time period and higher number of ice events is needed to make the corresponding analysis and conclusions.

In the last years, the ice event forecast in Serbia was important for the ice protection in winter 1984/85, while in other years, beside river traffic, its significance might be considered from the economical aspect only. On the basis of the ice event forecasts, the water management organizations made their decision whether to engage the icebreakers, saving thus a noticeable financial means.

Concerning the before said problems, it is necessary to emphasize the necessity of permanent and careful monitoring of all the parameters of the waterway winter regime, elaboration of the ice event forecasts and supply the information to the users in due time where the realized automation plays an important role. The significance of reliable meteorological forecast should be especially emphasized.

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# ANALYSE VON THERMISCHEN ABWASSEREINLEITUNGEN IN DIE ÖSTERREICHISCHE DONAU

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**Zusammenfassung:** Einleitungen von thermischen Abwässern in ein Oberflächengewässer wie die Österreichische Donau weisen sehr unterschiedliche Ausbreitungsformen auf. Diese hängen von geometrischen und dynamischen Parametern der Einleitung und des Vorfluters ab. Daher kann nicht von einer vollkommenen Durchmischung unmittelbar nach der Einleitung, wie es bei den Wärmelastrechnungen der Österreichischen Donau angenommen wird, ausgegangen werden.

# ANALYSIS OF THERMAL DISCHARGES INTO THE AUSTRIAN DANUBE

Summary: Thermal discharges into ambient water bodies such as the Austrian Danube exhibit a great divesity of flow patterns. These depend on the influence of geometric and dynamic conditions of the discharge (effluent) and the ambient receiving water Therefore a complete mixing over the entire cross-section can't be assumed.

## 1. EINLEITUNG

Industrielle und kommunale Ansprüche entziehen dem natürlichen Wasserkreislauf eine beachtliche Wassermenge, die nach der Nutzung als belastetes Abwasser wieder rückgeführt wird. Am Beispiel des Österreichischen Donauabschnittes wird nachstehend die Ausbreitung von eingeleitetem Kühlwasser aufgezeigt. Tabelle 1 zeigt deutlich, daß der Wärmeeintrag in die Donau aufgrund der zahlreichen kalorischen Kraftwerke und anderer großer Industrieunternehmen eine deutliche Veränderung des natürlichen Wärmeregimes erfährt und die Donau auf weite Strecken nachhaltig belastet.

Aus diesem Grund müssen technische Entwürfe und Entscheidungen über das Verhalten und über die Auswirkungen von Einleitungen in eine turbulente Strömung, wie sie die Donau aufweist, getroffen und optimiert weden (z.B. rasche Durchmischung, Vermeidung örtlicher Belastungsspitzen, etc.). Entsprechende Vorhersagen können auf Vergleichsmessungen, Modellversuchen und/oder Berechnungen basieren. Naturmessungen sind teuer, wenn nicht unmöglich, und bei zeitraubenden Modelluntersuchungen lassen sich die Ähnlichkeitsverhältnisse zur wirklichen Strömung oft nicht in jeder Hinsicht zufriedenstellend verwirklichen. Mathematisch fundierte Berechnungsmodelle dagegen bieten eine Vorhersagemöglichkeit, die meist schneller und billiger als das Experiment ist.

*Tabelle 1:* Bescheidmäßig zulässige Einträge der größten thermischer Einleiter in die Österreichische Donau.
*Table 1:* Largest legal discharges into the Austrian Danube.

| Objekt | Entnahme $m^3$ / s | Entn. Temp. ° C | Einleittemp. ° C | ΔT ° C | Wärmeeintrag MJ / s |
|---|---|---|---|---|---|
| VOEST Alpine-Linz | 15<br>max. 23,5 | - | 40 | - | 2378 |
| Chemie Linz AG | 10 | - | 30 | 13 | 1172 |
| FHW Linz | 3,84 | - | 30 | 10 | 452 |
| DKW Dürnrohr | 29 | 20 | 30 | 8 | 972 |
| DKW Bergern | 44 | - | 30 | 8 | 1465 |
| KKW Tullnerfeld | 35 | - | - | 13 | 1905 |
| DKW Theiss | 15,5 | - | - | - | 649 |
| DKW Korneuburg | 10 | - | - | 15 | 628 |
| DKW Donaustadt | 8,6 | - | 30 | 10,7 | 385 |
| | 15 | | 30 | 8 | 502 |
| DKW Simmering | 24 | - | - | 16 | 1607 |
| | 7 | | 30 | | 469 |
| | | | $t_{max}$ Donau: 25° | | |

## 2. DERZEIT VERWENDETES RECHENVERFAHREN FÜR DIE ERSTELLUNG VON WÄRMELASTPLÄNEN AN DER ÖSTERREICHISCHEN DONAU

Für die Wärmelastrechnung der Österreichischen Donau wird ein Rechenverfahren verwendet, das die Temperatur eines Gewässers mit Hilfe der Exponentionalmethode ermittelt. Dabei wird davon ausgegangen, daß sich das eingeleitete thermische Abwasser unmittelbar nach der Einleitung vollkommen mit dem Wasserkörper durchmischt - bei Vernachlässigung kleinräumiger Fahnenbildung unterhalb von Wärmeeinleitungsstellen - und die so entstandene Mischtemperatur einem Gleichgewicht zustrebt. Die Berechnung der Flußtemperatur im Längsprofil erfolgt abschnittsweise, wobei die Abschnittsgrenzen jeweils an Stellen maßgeblicher natürlicher oder künstlicher Wärmeeinträge gelegt werden, wie z. B. an Flußmündungen oder an Ausleitungen von kalorischen Kraftwerken. Unterhalb einer Wärmeeinleitung wird das Längsprofil der Flußtemperatur, soferne im betrachteten Abschnitt annähernd gleiche orographische, meteorologische und hydrologische Verhältnisse herrschen, durch eine negative e-Potenz dargestellt (Eckel, 1986). Die Ergebnisse der Wärmelastrechnung wird in Form eines Wärmelastplanes dargestellt (Abb. 1).

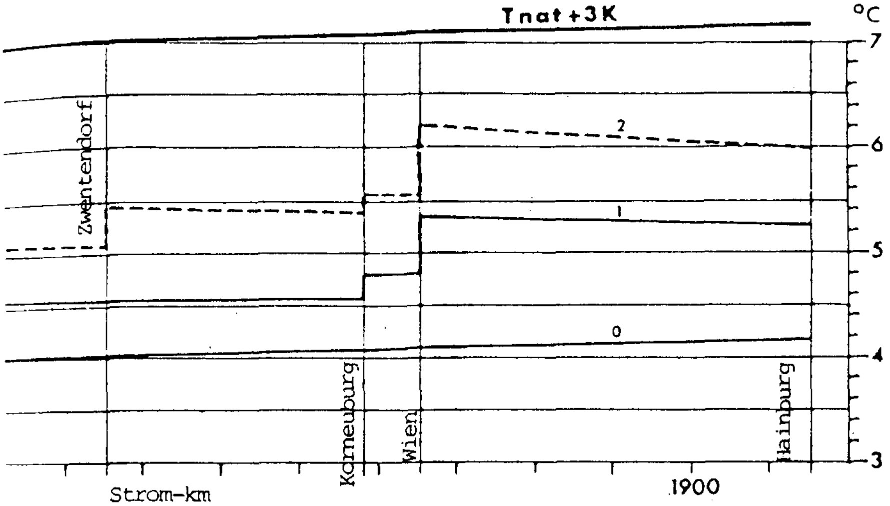


*Abb. 1:* Ausschnitt aus dem Wärmelastplan der Österreichischen Donau (Eckel, 1986).
*Fig. 1:* Section of the heat load map for the Austrian Danube (Eckel, 1986).

## 3. HYDRODYNAMISCHE DURCHMISCHUNGSVORGÄNGE UND BERECHNUNGSMETHODEN

Der Durchmischungsvorgang, wie ihn in der Ingenieurpraxis kommunale- und/oder industrielle Emissionseinleitungen darstellen, ist eine mischungsintensive turbulente, drehbehaftete Strömung, die aus Wirbelelementen verschiedenster Größe aufgebaut ist; an den kleinsten Elementen mit der größten Frequenz wirken viskose Kräfte, welche die kinetische Energie der Turbulenzbewegung in Wärmeenegie überleiten. Der hohe Impuls-, Stoff- und Wärmeaustausch erfolgt durch turbulente Schwankungen, welche die Ausbreitung von Strahlen verursachen.

Ein dreidimensionaler Strahl, der in einen ruhenden oder strömenden Vorfluter an dessen Oberfläche eingeleitet wird, breitet sich durch das Zusammenwirken von Impuls- und Auftriebskräften aus. Dabei haben in verschiedenen Abschnitten der Strahlausbreitung die treibenden Kräfte unterschiedliche Bedeutung. Der Einfluß dieser Kräfte auf ein betrachtetes Flüssigkeitselement. das sich auf der Strahltrajektorie in einer Entfernung x von der Einleitstelle befindet, wird durch die örtliche densimetrische Froude-Zahl $Fr_l(x)=u/(g'h)^{0,5}$ charakterisiert. Dann ist u die Strahlgeschwindigkeit, $g'=(\rho_a-\rho)g\rho_a$ ist die reduzierte Erdbeschleunigung mit $\rho$ die Dichte des Strahlmediums, $\rho_a$ der Dichte des Umgebungsfluids im Vorfluter und g die Erdbeschleunigung, h ist die charakteristische Tiefe des Strahls an der Einleitstelle.

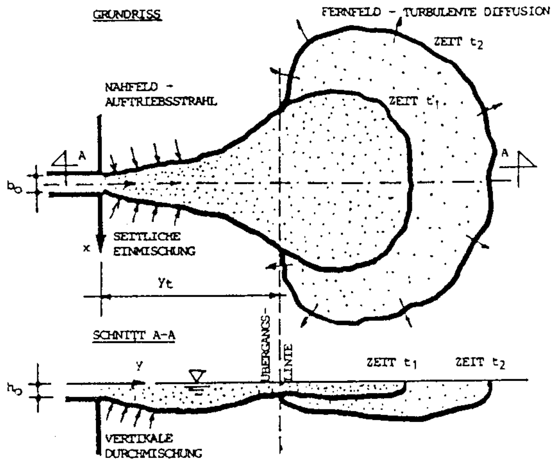


*Abb.2:* Auftriebstrahls, der in ein ruhendes Gewässer eingeleitet wird.
*Fig.2:* Typical bouyant surface jet discharging into a stagnant environment.

Durch das Einleiten eines konstanten Zuflusses bildet sich ein Auftriebsstrahl aus, der sowohl durch Impuls als auch durch nach oben gerichteten Auftrieb (positiver Auftrieb) charakterisiert ist (Abb. 2). Der unmittelbar nach der Einleitstelle liegende Nahbereich des Strahls (Nahfeld der turbulenten Mischzone) wird durch das Wirken der Impulskräfte ($Fr_l(x) >> 1$) dominiert. Der Diffusionsvorgang im Strahlnahbereich ist durch zwei Phänomene gekennzeichnet:

1. Lineare Strahlausbreitung sowohl in laterale als auch in vertikale Richtung.
2. Einmischen des Umgebungsfluids in den turbulent strömenden Strahl.

In einer größeren Entfernung von der Einleitstelle (Fernfeld der turbulenten Mischzone) reduziert sich der Einfluß des Strahlimpulses und die Auftriebskomponente gewinnt im weiteren Strahlverhalten an Bedeutung.

Im Fall von mehr oder weniger stark ausgeprägten Geschwindigkeits- und Konzentrationsgradienten zwischen Strahl- und Umgebungsfluid erfolgt der Durchmischungsvorgang nur noch durch turbulente Diffusion/Dispersion bzw. durch Grundturbulenz solange, bis ein vollständiger Ausgleich mit dem Umgebungsfluid stattgefunden hat. Der diese beiden Ausbreitungsformen trennende Übergangsbereich kann durch zwei heuristische Ansätze interpretiert werden (Jirka et al., 1981):

1. <u>Mikroskopische Betrachtungsweise:</u> Das Strahlwachstum wird im Nahfeldbereich durch die in diesem Bereich größten auftretenden Wirbeln bzw. Wirkelkräfte bestimmt, die ihre Wirbelenergie von den Schubkräften im Randbereich erhalten und diese an die kleineren Wirbel weiterleiten. In steigender Longitudinalentfernung von der Einleitstelle beginnt eine zunehmende Strahlstabilisierung die turbulente Vertikalbewegung im Strahl zu dämpfen. In der Folge steigt die Zahl der großen horizontalen Wirbel und es ergibt sich daraus eine zweidimensionale Strahlausbreitung im Fernfeld. Versuche zeigten, daß $Fr_l(x) \approx 1$ als Kriterium für den Übergang zwischen Nah- und Fernfeld herangezogen werden kann.
2. <u>Makroskopische Betrachtungsweise:</u>.Die, durch die Dichtedifferenz zwischen Strahlfluid und Umgebungsfluid hervorgerufene , nach oben gerichtete Auftriebswirkung bewirkt an der freien Wasseroberfläche mit steigender Entfernung von der Emissionsstelle eine kontinuierlich zunehmende Strahldeformation. Die vertikale Strahlausdehnung wird immer geringer, die horizontale Ausbreitung der Mischzone hingegen erhöht sich solange, bis das strahlartige Nahfeldferhalten abgeklungen ist. Im Übergangsbereich zwischen Nah- und Fernfeld entspricht die in Strahlrichtung wirkende advektive Ausbreitungsgeschwindigkeit ungefähr der auftriebsbedingten longitudinal und lateral gerichteten

Ausbreitungsgeschwindigkeit. Das bedeutet wiederum, daß $Fr_{l}(x) \approx 1$ ist.
Im Falle der Einleitungsbedingungen an der Donau werden jedoch die Strahltypen und Formen der Mischzonen auch ganz wesentlich von der geometrischen Gestaltung und Lage der Einleitstelle in Bezug auf das Vorflutgewässer und den hydraulischen Verhältnissen im Vorfluter geprägt. In den angesprochenen Situationen bewirkt der Querimpuls die Ablenkung des Strahls. Es ist der Impuls groß genug, um direkt unterhalb der Einleitung ein ausgeprägtes Rezirkulationsgebiet entstehen zu lassen, vor allem dann, wenn die Emission über die gesamte Wassertiefe erfolgt. Mit zunehmender Entfernung vom Rückgabebauwerk legt sich die Emissionsfahne an das Einleitungsufer an, wo sie sich kilometerweit flußab zieht (Abb. 3). In Abhängigkeit des Einleitungsimpulses und/oder des Strahlauftriebes in Relation zur Tiefe des Vorflutgewässer kann weiters die Stabilität des Strahls abgeschätzt werden. Generell kann gesagt werden, daß die Kühlwassereinleitungen stark auftriebsbehaftete Strahlen darstellen, die mit mehr oder weniger starkem Impuls in die unterschiedlich Tiefe Donau eingeleitet werden. Aufgrund dessen liegen stabile Einleitungsbedingungen vor.

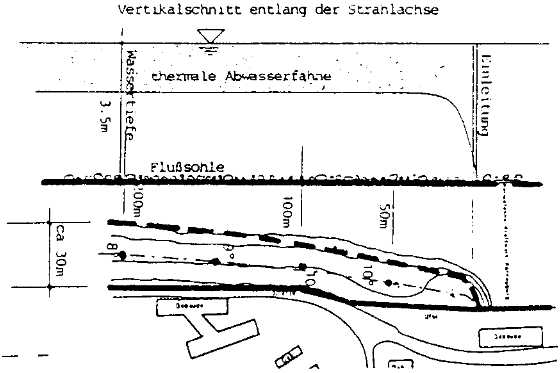


*Abb.3:* Abwasserfahne der Kühlwassereinleitung des Kraftwerkes Korneuburg (K. Zirm et al., 1982).
*Fig.3:* Mixing Zone of the thermal discharge of the Korneuburg power plant (K. Zirm et al., 1982).

## 2. VERFAHREN ZUR BESCHREIBUNG VON MISCHVORGÄNGEN

Die soeben aufgezeigte Komplexivität und Vielfältigkeit der Strahlausbreitung erschwerte die Entwicklung relativ einfacher analytischer Lösungsansätze. Der dreidimensionale turbulente Stömungsvorgang kann durch die exakten Navier-Stokes-Gleichungen (Impuls) und die Kontinuitätsgleichung dargestellt werden. Dieses System nicht-linearer, partieller Differentialgleichungen ist prinzipiell mit Hilfe numerischer Verfahren lösbar, doch lassen sich die bereits erwähnten kleinen Wirbel aufgrund des begrenzten rechnerischen Auflösungsvermögens schwer erfassen. Allerdings sind in der praktischen Anwendung solche Einzelheiten nicht von Interesse. Die zahlreichen entwickelten Modelle sind nur dann anwendbar, wenn eine einfache geometrische Situation vorliegt und der Strahl durch keine Uferberührung in seinem Verlauf beeinflußt wird.

Das an der Österreichischen Donau angewandte Expertensystem CORMIX (Jirka, 1993) beruht aber auf dem Ansatz der Längenmaßstabsmodelle. Das sind Modelle, die das Verhalten der Einleitungsstrahlen durch charakteristische Längenmaßstäbe typischer Strahleigenschaften beschreiben. Das Prinzip dieses Ansatzes geht davon aus, daß eine Einleitungssituation durch voneinander in charakteristischer Weise unterscheidbare Zonen beschrieben werden kann. Jede dieser Zonen wiederum zeichnet sich durch typische hydrodynamische Eigenschaften aus, sodaß für sie verschiedene Größen wie Einleitungsimpuls, Querimpuls, Auftrieb, Querstömungsgeschwindigkeit etc. definierbar sind. Somit kann der Fließzustand eines jeden Abschnittes mit Hilfe wesentlicher hydraulisch-hydrodynamischer, physikalischer und geometrischer Parametern approximiert und durch Störterme der Einfluß von nicht berücksichtigter Parametern in den Gleichungen korrigiert werden. Die Ausdehnung dieser typischen Zonen und der Gültigkeitsbereich der entsprechenden Gleichungen wird durch charakteristische Längenmaßstäbe abgegrenzt. Das wiederum führt zu einer Klassifizierung typischer Ausbreitungsformen (Abb. 4). An der Donau sind vor allem jene Formen vorzufinden, die durch ein rasche Strahlumlenkung und ein wandnahes Ausbreitungsverhalten gekennzeichnet sind. Wie bereits erwähnt, ist die vollständige Durchmischung über den gesamten Abflußquerschnitt nicht gegeben.

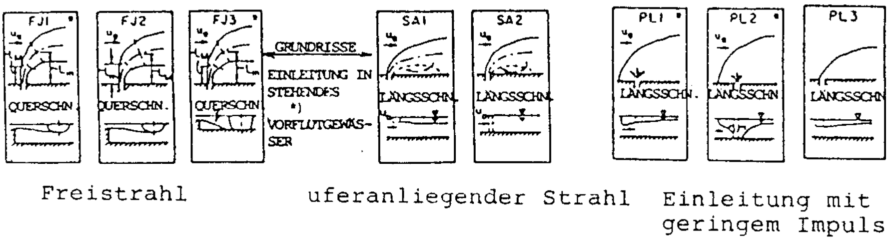


*Abb.4:* Typische Strahlformen bei Oberflächeneinleitungen.
*Fig.4:* Typical surface buoyant jets.

## 5. SCHLUSSFOLGERUNGEN

Die Ausbreitung und Durchmischung von Kühlwassereinleitungen an der Österreichischen Donau ist durch die Einleitungsgeometrie bzw. -hydraulik gekennzeichnet. Aufgrund der Querströmung erfolgt eine Ablenkung des auftriebsbehafteten Freistrahls zum Einleitungsufer hin, verbunden mit einer Rezirkulationszone nahe der Einleitstelle, die durch die vertikale Durchmischung des Strahls über die gesamte Wassertiefe noch verstärkt wird. Folglich zieht sich die Emissionsfahne über eine lange Strecke entlang des Ufers ohne sich in horizontaler Richtung quer zur Hauptströmung auszudehnen. Die vollständige Durchmischung, wie sie in den Wärmelastrechnungen angenommen wird, ist nicht vorhanden.

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# VARIATION AND TREND OF THE WATER, SEDIMENT AND SALT RUNOFF FOR THE DANUBE RIVER, AT THE INLET IN OUR COUNTRY, DURING THE PERIOD 1840 - 1992

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ABSTRACT

By numerical analysis and data processing of the direct measurements of water discharges, sediment discharges and water mineralization at Orşova, the authors succeeded to create long series of annual mean data of the 3 hydrological regime elements of the Danube. In this issue, the temporal variation as well as the tendency regressions over 1840 - 1992 of the mean annual values of the water discharges, sediment discharges, mineralization and salt discharges, flown on the Danube bed through the hydrometric section Orsova (km 955), are presented.

The results of the processings and calculations permit the knowledge of the evolution and tendency of the hydrological regime elements under the circumstances of the anthropic influences, emphasizing the observed changes.

1. - During the last century, to the natural process of the sediment formation and water mineralization in the Danube basin, the influence of the human activity was added resulting in a decreasing trend, with time, of the concentration of the disolved salts in the Danube water. This phenomenon is emphasized by the observations made in the past, on the Danube, within the limits of our country borders, as well as on other reaches of the Danube. This authors, bringing their contribution to the research of the Danube hydrological regime within the Romanian border reach, have performed large investigations in order to turn to good account and to process the entire old data background for the reconstruction and development of new long data series over large time periods of the past concerning the annual water, sediment and salt runoff on the Danube over the period 1840 - 1992.

The numerical analysis of the respective data allowed to obtain information on the secular variation and trend of the four components of the Danube hydrological regime over the hydrometric section of Orşova (km 955). The results of the variation and trend numerical analysis of the respective data are presented.

2. - The annual mean <u>water discharges</u> show significant time oscillations with various evolution trends over various time intervals (Fig.1a).

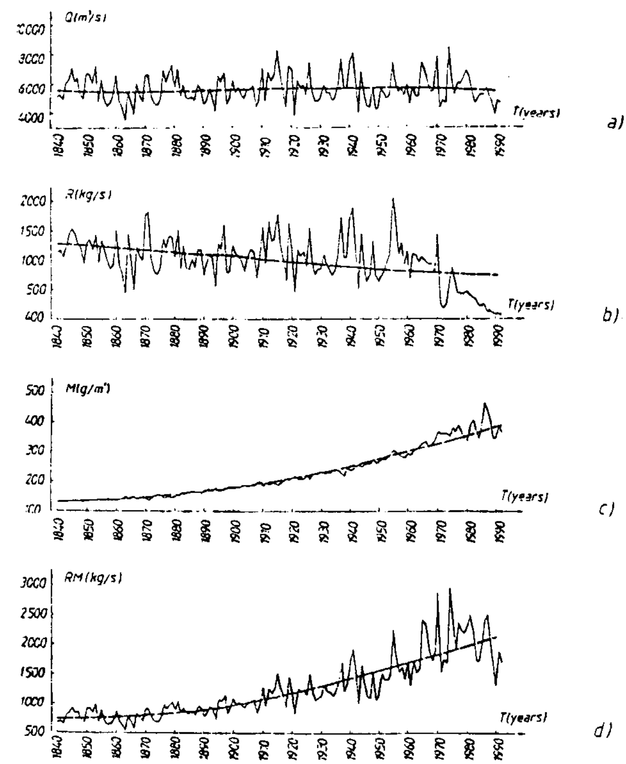

**Fig. 1.** Chronological graphics of the annual mean water discharges (a), of the annual mean sediment discharges (b), of the annual mean mineralization (c) and of the annual mean salts discharges (d) of the Danube river at the inlet in our country, over the years 1840-1992.

Table 1 represents the main statistical parameters of the annual mean discharges over various time intervals.

Table 1.

| Item | Time interval | Statistical parameters of the discharges | | | | | |
|---|---|---|---|---|---|---|---|
| | | Qmax $m^3 s^{-1}$ | Qmean $m^3 s^{-1}$ | Qmin $m^3 s^{-1}$ | $\sigma$ Q $m^3 s^{-1}$ | CVQ | CSQ |
| 1 | 1840-1992 | 8265 | 5590.7 | 3469 | 951.2 | 0.1701 | 0.4218 |
| 2 | 1840-1945 | 8265 | 5645.8 | 3469 | 965.7 | 0.1710 | 0.3485 |
| 3 | 1946-1992 | 7810 | 5463.3 | 3774 | 896.2 | 0.1640 | 0.6016 |
| 4 | 1971-1992 | 6880 | 5374.3 | 3774 | 804.2 | 0.1496 | 0.1360 |

where: - Qmax is the maximum value of the annual mean water discharges;
- Qmean- the multiannual mean of the mean annual water discharges;
- Qmin - the minimum value of the annual mean water discharges;
- $\sigma$ Q - the mean square standard deviation of the annual mean water discharges;
- CVQ - variation coefficient of the annual mean water discharges;
- CSQ - asymmetry coefficient of the annual mean discharges.

Out of the numerical attempts for a linear or curve simulation of the evolution trends with time of the annual mean water discharges, for the period 1840-1992, the periodical trend with a trigonometric function form (1), represented on Figure1 by dotted line, proved to be optimum.

$$Q(t) = 5590.7 + 114.5 \sin\left[ \frac{2\pi}{153} (t - 1840) + 3.895 \right] \quad (1)$$

where: - t is time, in years;
- Q(t) - mean water discharges of the trend, expressed in $m^3 s^{-1}$.

Function (1) allows a minimum in 1860, followed by a maximum in 1936.

Thus, for 1936-2013, the evolution trend with time of the annual mean water discharges for the Danube at Orsova, is decreasing with an annual mean rate of about 3 $m^3 s^{-1}$.

Over the entire analized interval (1840 -1992) the water runoff of the Danube at Orşova ( km 955 ), was characterized by a multiannual mean discharges, of 5590.7 $m^3 s^{-1}$. The extreme values of the annual mean water discharges, had a maximum value of 8265 $m^3 s^{-1}$ in 1915 and a minimum value of 3469 $m^3 s^{-1}$ in 1863. Over various time intervals, the variation coefficient of the annual mean water discharges oscillated between 0.17 and 0.15 with a decreasing tendency with time.

3. - The annual mean sediment discharges showed significant time oscillations with a continuous decreasing trend with time, over various time intervals (Fig. 1 b). Table 2 gives the basic statistical parameters of the sediment discharges, over various time intervals.

Table 2

| Item | Time interval | Statistical parameters of the discharges | | | | | |
|---|---|---|---|---|---|---|---|
| | | Rmax kg $s^{-1}$ | Rmean kg $s^{-1}$ | Rmin kg $s^{-1}$ | $\sigma$ R kg $s^{-1}$ | CVR | CSR |
| 1 | 1840-1992 | 2044 | 982.6 | 64.4 | 413.2 | 0.4205 | -0.1726 |
| 2 | 1840-1945 | 1893 | 1115.9 | 438 | 311.3 | 0.2790 | 0.2751 |
| 3 | 1946-1992 | 2044 | 686.9 | 64.4 | 451.1 | 0.6567 | 0.6367 |
| 4 | 1971-1992 | 889 | 300.7 | 64.4 | 202.0 | 0.6718 | 1.031 |

where the descriptions of the statistical parameters are synonimous with those on Table 1.

The linear simulations of the time evolution trends of the sediment annual mean discharges, carried out at various time intervals, showed a significant accentuation of the decrease with time of the sediment runoff on the Danube at Orşova (km 955) during period following the second World War. If, over the entire analyzed period (1840-1992), the annual decreasing rate of the annual sediment mean was of about 0.39 kg/s, it increased to values of about 0.61 kg $s^{-1}$ during 1840 -1945 and to about 23.1 kg $s^{-1}$ during 1946-1992.

The empirical function of the tendency for 1840-1992 of the annual mean sediment discharges of the Danube at Orşova is given by the expression:

$$R(t) = 462.8 + 799.3 \exp \left[ -2.293 \frac{(t-1840)^2}{153^2 + (t-1840)^2} \right] \tag{2}$$

where: - t is the time, in years;

- R(t) - mean sediment discharges of the trend, expressed in kg $s^{-1}$.

With the decrease of the sediment runoff with time, the sediment concentration decreased also considerably, from a multiannual mean of 172.2 g $m^{-3}$ during 1840-1992 to a mean value of 53.6 g $m^{-3}$, during 1971-1992.

The evolution trend mean with time, during 1840 -1992, of the Danube sediment concentration at Orşova is expressed by the empirical function (3):

$$\rho(t) = 75.46 + 148.33 \exp \left[ -2.2766 \frac{(t-1840)^2}{153^2 + (t-1840)^2} \right] \tag{3}$$

where: - t is time, in years;

- ρ(t) - trend mean concentration of the sediments, expressed in g $m^{-3}$.

The decrease with time of the sediment runoff and concentration was mainly due to the influence of the human activities, by the hydraulic structures built in the hydrographic basins of the water courses, by the dams on the beds and the forestry works for stopping torrents.

The phenomenon was especially present on the Danube, due to the great hydropower station and the navigation structures built at Iron Gates (km 942.8) which entered into exploitation in 1971. The dam built on The Danube at Iron Gates changes completely the sediment runoff regime through the reservoir and downstream along the Danube up to its outlet in to the Black Sea.

If over the interval 1840 -1945, the multiannual mean value of the sediment runoff on the Danube at Orşova was of about 1115.9 kg $s^{-1}$, this was diminished to a half (about 686.9 kg $s^{-1}$) during 1946 -1992 and reached a mean value of about 300.7 kg $s^{-1}$ during 1971 -1992 after the building of the hydropower station and navigation system of Iron Gates.

4. - The concentration of the salts dissolved into the Danube water increased significantly with time following the industrial development, the agriculture chemification and urbanization (Fig. 1 c). Table 3 gives the statistical parameters of the Danube water mineralization over various time intervals.

Table 3

| Item | Time interval | Statistical parameters of the dissolved salt concentration | | | | | |
|---|---|---|---|---|---|---|---|
| | | Mmax g $m^{-3}$ | Mmean g $m^{-3}$ | Mmin g $m^{-3}$ | σ M g $m^{-3}$ | CVM | CSM |
| 1 | 1840-1992 | 463 | 223.1 | 129.7 | 82.86 | 0.3714 | 0.8275 |
| 2 | 1840-1945 | 252.7 | 175.0 | 129.7 | 35.00 | 0.2000 | 0.5074 |
| 3 | 1946-1992 | 463 | 329.9 | 252.0 | 51.04 | 0.1547 | 0.3398 |
| 4 | 1971-1992 | 463 | 374.5 | 334.5 | 31.46 | 0.0840 | 1.1500 |

The analysis of the Danube water mineralization data shows that at Orşova (km 955), at the middle of 19th c., the dissolved salt concentration is about 130 g $m^{-3}$. Due to the development of the economic activities in the Danube basin the waste water drained into the Danube increased significantly leading to a continuous increase of the water mineralization.

The dissolved salt concentration increased from about 329.9 g $m^{-3}$ in 1840 -1945, to about 329.9 g $m^{-3}$ in 1946 -1992 and to about 374.5 g $m^{-3}$ during the last 20 years (1971-1992).

The empirical function (4) expresses the evolution mean trend with time of the Danube water mineralization, at Orşova, during 1840-1992.

$$M(t) = -7.134 + 135.907 \exp\left[\frac{2.1565\,(t-1840)^2}{153^2 + (t-1840)^2}\right] \qquad (4)$$

where: - t is the time, in years;

- M(t) - water mineralization, expressed in g $m^{-3}$.

5. - The salt discharges on the Danube increased as significantly as the water mineralization (Fig. 1 d). The evolution mean trend of the salt discharges is immediately obtained by the product of the empirical functions (1) and (4), in the following form:

$$RM(t) = \left\{5590.7 + 114.5 \sin\left[\frac{2\pi}{153}(t-1840) + 3.895\right]\right\} \times$$

$$\times \left\{-7.134 + 135.91 \exp\left[\frac{2.1565\,(t-1840)^2}{153^2 + (t-1840)^2}\right]\right\} / 1000 \qquad (5)$$

where: - t is time, in years;

- RM(t) - mean trend discharges of the salts, expressed in kg $s^{-1}$.

Graph (c) of Figure 1 shows that the annual mean discharges on the Danube at Orşova oscillated between 700 and 2880 kg $s^{-1}$, with a continuous increasing tendency, expressed by function (5) and the dotted line of the respective graph.

As the industry development, the agriculture chemification and the urbanization of the human settlements have not stopped, the Danube water mineralization as well as the salt discharges are expected to increase further on.

6. - The following conclusions results from the paper:

6.1. - The water runoff on the Danube, at Orşova (km 955) during 1840-1992 is a relatively balanced natural system, evaluated at an annual mean volume of about 176.429 $km^3$.

6.2. - The sediment runoff on the Danube, on the same hydrometric section and over the same time interval, continuously decreased from annual amounts of about 39.83 mil.tons, at the middle of the 19th c. to about 22.8 mil.tons, at the end of the 20th c. Presently, the continuous decreasing process of the sediment runoff on the Danube, with unfavourable influences upon the littoral morphological processes at the outlet into the Black Sea.

The Danube sediment concentration shows the same decreasing trend as the sediment runoff. The causes of the decreasing of the sediment runoff and concentration are the anthropic influences of the structures built in the hydrographic basins of the Danube (dams on the beds and forestry protection works).

6.3. - The dissolved salt runoff in the Danube waters has constantly increased from annual amounts of about 22.4 mil.tons at the middle of the 19th c. to amount 66.92 mil.tons towards the end of the 20th c. The increase of the salt runoff and concentration on the Danube (from about 130 g $m^{-3}$ to about 390 g $m^{-3}$) was due to the development of the industrial activities, the agriculture chemification activities and urbanization. These processes did not stop, representing some of the most severe anthropic risks adversely affecting the ecological system of the Danube and of the Black Sea. The effects already obvious of the increase of the inferior Danube water mineralization led to deep modifications of the fish population structure in the Danube water, other ecological consequences being imprevisible.

From the above conclusions it can be stated that the riverian states located in the upstream* reaches of the Danube should act strongly on taking technological measures for the purification of the waste waters drained into the Danube bed from the industrial and domestic users.

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# THEMA/THEME

# 5

## Grundlegende Aspekte der Wasserqualität und Gewässergüte: Aspekte des Umweltschutzes und der Nutzung des Lebensraumes der Donau

## Basic aspects of water quality and the state of water bodies: aspects of environment protection and utilization of the biotopes of the Danube

Gutachter/Convener

*Dr. G. Jolánkai*

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# SYSTEMS APPROACH TO MANAGING THE AQUATIC ENVIRONMENT IN THE LIGHT OF PAPERS SUBMITTED TO SESSION 5 OF THE CONFERENCE

Keynote paper by Géza Jolánkai
Water Resources Research Centre, VITUKI, Budapest, Hungary

## Abstract

In this keynote paper various activities of the management of the aquatic environment as the components of a systems approach are described, starting with the setting of objectives, through monitoring, data evaluation and modelling until the selection and implementation of strategies. The papers of the conference (in subject area 5) were grouped according to such system components. Eventually, the papers submitted and reviewed did not provide a full and complex picture of the relevant activities of the Danube basin. Nevertheless, they clearly demonstrated the multiplicity of problems the aquatic environment of the Danube river system is facing. There seem to be especially serious problems in some parts of the former socialist countries, where preventive or remedial measures of environmental protection and water pollution control have not been introduced yet, or with low efficiency and at low percentage of the sources of pollution only. Several papers were modelling oriented, although the scale of the basin (and that of the problems) does not seem to allow (yet?) the elaboration of integrated basin scale modelling concepts. However, basin scale research coordination and emergency warning efforts were also reported. To the Convenor the time seems to be ripe for launching actual basin wide integrated water and environmental management projects. As international cooperative efforts, bi- and multi-lateral agreements indicate, this need has long ago been recognized and now we, the human and non-human inhabitants of the basin, are looking forward to political and financial steps to be taken by the governments of the Danube Basin, with the much needed support of international organisations and financing agencies. A conference or seminar to be convened, focusing on the sustainable development and integrated water management of the Danube basin, might give an impetus to such action.

# EINE SYSTEMTHEORETISCHE ANNÄHERUNG AN DIE BEWIRTSCHAFTUNG DER AQUATISCHEN UMWELT IM LICHTE DER ZUM THEMENBEREICH 5 DER KONFERENZ ENBEREICHTEN BEITRÄGE

(Einfürungsvortrag)


**Kurzfassung**

Im vorliegenden Einführungsvortrag werden verschiedene Tätigkeiten der Bewirtschaftung der aquatischen Umwelt, als Komponenten einer systemtheoretischen Annährung behandelt, von der Festlegung der Ziele, durch Monitoring, Datenevaluierung und Modellierung bis zur Auswahl und Anwendung der Strategien. Die zum Themenbereich 5 der Konferenz eingerichten Beiträge wurden den aufgezählten Systemelementen entsprechend gruppiert. Die eingereichten und gesichteten Beiträge konnten natürlich kein vollständiges und komplexes Bild über die im Donauraum durchgeführten sämtlichen einschlägigen Tätigkeiten vermitteln. Sie zeigen jedoch die Vielfalt der Probleme auf, denen die aquatische Umwelt des Gewässersystems der Donau gegenübersteht. Anscheinend gibt es besonderes schwerwiegende Probleme in einigen Teilen der früheren sozialistischen Länder, wo die präventiven oder korrigierenden Maßnahmen für Umweltschutz und Wassergütesteuerung entweder überhaupt nicht, oder nur mit geringer Wirksamkeit bzw. nur bei einem geringen Anteil der Verschmutzungsquellen getroffen worden sind. Mehrere Beiträge sind auf Modellierung ausgerichtet, obwohl die Maßstäbe der behandelten Einzugsgebiete (und Probleme) eine Erstellung von Modellkonzepten im integrierten Maßstab des Donaueinzugsgebietes (noch?) nicht zu ermöglichen scheinen. Es gibt jedoch auch Berichte über eine Koordinierung der Forschungen und Ansätze zu Alarmsystemen im ganzen Donauraum. Dem Gutachter scheint die Zeit reif geworden zo sein, daß sich auf das ganze Donaubecken erstreckende integrierte Wasser- und Umweltbewirtschaftungsprojekte lanciert werden. Verschiedene Ansätze zur internationalen Zusammenarbeit sowie zahlreiche bi- und multilaterale Abkommen weisen darauf hin, daß diese Notwendikeit bereits vor langem erkannt worden ist, so daß wir, die menschlichen und nicht-menschlichen Bewohner der Donaubeckens zur Zeit nur die Hoffnung hegen können, daß die Regierungen der Donauländer, mit der zweifellos sehr benönigten Unterstützung internationaler Organisationen und Finanzinstitutionen, die nun schon durchaus fälligen politischen und finanziellen Schritte unternehmen werden. Eine solche Aktion könnte durch eine Konferenz oder ein Seminar über die erhaltbare Entwicklung und die integrierte Wasserwirtschaft des Donaueinzugsgebietes eine wesentliche Anregung erfahren.


## 1. INTRODUCTION

In trying to find a concise framework for the integrated discussion and evaluation of the papers presented to theme 5 " Basic aspects of water quality and the state of water bodies: aspects of environmental protection and utilization of the biotopes of the Danube" of the Conference I selected the "umbrella" of the systems approach. This concept expresses the logical and necessary interlinkage of all activities related to the protection of the aquatic environment on one hand (**Figure 1**), and considers, on the other hand, the entire drainage basin a system which responds to natural and anthropogenic inputs with the quantitative and qualitative changes of its state. Thus, the tasks of the protection, control and management of the aquatic environment include;

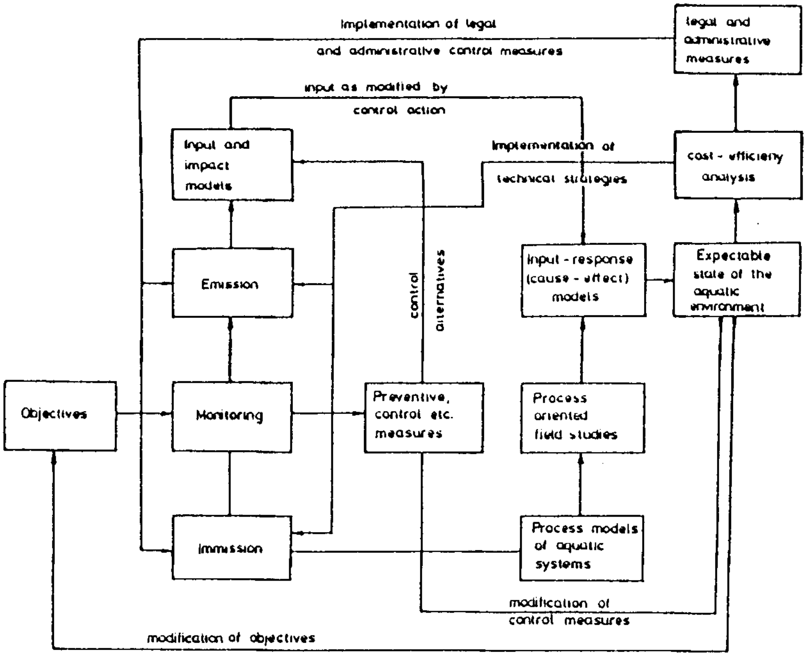



**Figure 1. Systems approach to managing the aquatic environment**
(Jolánkai, 1992)

- activities related to the survey, observation and assessment of the state of the environment and to the changes of this state (the response of the system). These activities can be termed the *immission monitoring* and assessment of the state of the state of the environment.

- activities aimed at the identification and quantification of the likely causes of the observed changes of the environment can be termed the ***emission monitoring*** and assessment of the causes of the observed changes.

- activities that relate to the quantification of the response of the system to the natural and anthropogenic inputs and their changes. These can be grouped into the overall term ***modelling*** which covers all efforts spent on the numerical description of the relationship between the inputs to and the responses of the system, including the prediction of the expectable effects of contemplated preventive, control and remedial measures.

- activities related to the identification and selection of potential *strategies of*

***controlling the state of the environment***. These activities cover very broad ranges from the controlling of anthropogenic impacts (such as the reduction of pollutant loads) to actions aimed at the modification of the properties of the system, (such as runoff control over the drainage basin and within the water bodies)

Having the most promising strategies selected on the basis of the assessment of their expectable effects (with or without simulation modelling) one should deal with all types of constrains on the actual implementation of these strategies. Simply saying one should select the ***technically feasible, economically possible (and optimum) and legally-administratively allowable*** strategies for implementation. To do so several problems have to be solved, among which the determination ***of cost-efficiency and cost-benefit relationships*** are the most important ones.

Eventually, the time when all activities of environmental management over the entire Danube catchment area will follow the above described logical chain in an organized and regulated manner, is probably very far. This is only partly due to the existence of political boundaries and administrative, legal, etc differences of the riparian countries. The rules of the systems approach are usually not being followed in smaller drainage basins lying entirely within a single country, either. There are many easy and complicated explanations for the lack of following a logical management schemes. The possible most simple one is that human nature, and thus the structure of human societies, -for some reason or other- does not like to follow strictly defined rules, not even logical ones.

However, instead of entering a very unstable philosophical terrain, my honourable task here is to review the papers presented for which I will use the above described systems approach as a kind of framework or guideline.

## 1. Review of papers grouped according to various element of a systems approach to environmental management

### 1.1 Objectives

All activities of the protection of the aquatic environment should (as well as should all human activities) start with the definition of objectives. From the point of view of a water engineer, a hydrologist, this objective means that "water should be made available in sufficient quantity and suitable quality for all desired water uses. Among these water uses the qualitative and quantitative need of the aquatic (and terrestrial) ecosystem for water should be defined as objectives of "environmental protection".

The quantitative need for water means the definition of quantity (volume and/or flow) of water needed for the existence and well being of various communities of the water bodies, of the transient zones, the "ecotones" and of the terrain, the drainage area. The definition of these quantities should be associated with that of the desirable time-point, frequency and duration of the occurrence (availability) of water for these communities.

In this context the convenor is inclined to state that the quantitative needs and requirements of various ecosystems have not yet been properly defined either for the Danube Basin, or for most of other drainage basins of the world, at least no in proper hydrological terms, that is in terms of the frequency and duration of flow, velocity and water stage needed for the survival and well being of various aquatic communities. Great impetus to interdisciplinary research into this field is still being needed.

The qualitative objective (need for water) means the specification of the "desirable" and "tolerable or allowable" concentrations of various substances in a unit volume of water from the points of view of various water uses, among them those of the aquatic (and other) ecosystem. In this context a general statement may be the following: While the quality criteria for anthropogenic water uses were defined in relatively good details, those of the aquatic ecosystem are probably less well specified. Another general statement might be that sets of criteria, the limit values of water quality standards, vary from country to country, although there have been many efforts made on the acceptance of basin-wide standards, such as those of the EC.

Recognizing that the evaluation of the state of water (the aquatic environment) is rather cumbersome on the basis of dozens of water quality parameters and factors, there were many attempts for using combined indexes. **Alexeenko** et al. have elaborated a formula for such a general index, called the General Pollution Class index GPS, and in their paper highlighted the advantages of its use on the basis of the data of an expedition and survey of the river Danube between river kilometres 18 and 1934, carried out in 1990. Data of 72 water samples of 27 sampling sites were utilized for the elaboration of 250 indices of various aspects of the state of water quality (such as hydrochemical, hydrobiological, radio-ecological, geoenvironmental, etc indices) and were used for an integrated assessment and classification.

## Monitoring and assessment of the state of water quality

Under this general title one usually means two types of observation and surveillance activities:

- routine measurements at selected sampling points with regular frequency and for a preselected set of parameters, and

- expedition like, usually more intensive, measurements aimed at the in-depth exploration of the state of water quality and the processes involved;

On the basis of papers submitted to and presented at the conference one can not get a clear picture of the monitoring systems of all riparian countries of the Danube Basin, and the convenor must admit that he did not have the time to make an ind-depth literature review for getting acquainted with the existing and contemplated monitoring systems.

In their paper **Chovanec and Grath** present a relatively detailed picture of the monitoring systems of Austria. The monitoring network comprises at present 1400 and

250 sampling sites for ground- and surface running waters, respectively. A gradual extension of the network system is contemplated. The final network will, by 1996, comprise 2000 ground water sampling sites, while the final expansion of surface water network has already been achieved in 1993. It is interesting to note, that the sampling frequency of streams is relatively low; six times a year, and 50 quality constituents are investigated. The frequency of ground water quality sampling is not given. It was also rather surprising to learn that no " obligatory surface water quality standards" exist in Austria.

With respect to the sampling frequency of routine monitoring networks one may state, that it will not, in general, allow for the determination of the dynamic changes of water quality. The latter depend on the hydraulic regime of streams (runoff or washout loads originating from the drainage basins), on the diurnal, weekly and seasonal variations of point source discharges, and finally on pollution incidents. Eventually, no country, can afford the running of a monitoring network with daily sampling frequency. Lack of knowledge, stemming from inadequate frequency, can be alleviated by running a certain number of automatic monitoring stations associated with periodical intensive field surveys. These latter could, in addition to temporary increased frequencies and spatially denser sampling points, involve significantly larger number of quality constituents.

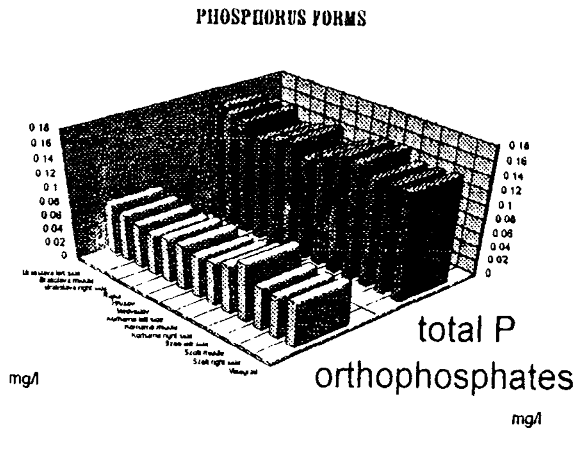



Figure 2.
(Makovinska and Ardó, 1994 -this conference-)

Such detailed surveys have been jointly carried out by Hungary and Slovakia along their common Danube reach, revealing very interesting features of the state of water quality of the Danube.

The paper by **Makovinska and Ardo** also report on such intensive surveys which involved 16 sampling sites along the common Hungarian Slovak Danube reach and the tributaries on the Slovak side, with analyses carried out for 70 quality parameters, among which phosphorus forms (**Figure 2**) indicate the danger of eutrophication. They also identified certain signs of quality improvement over the period of 2 years of the investigations. Although the authors did not mention, it is most likely due to the economic recession experienced in the former socialist countries, which is associated with the substantial reduction of industrial production and thus with the reduction of industrial pollution loads.

In the sequence of three papers by **Németh, Gulyás and Csányi** the results of hydrobiological research of the Upper Hungarian Danube (upstream of Budapest) are presented. In respect to phytoplankton it was found that the entire Danube reach is subject to "increased eutrophication", indicated by the presence of blue-greens and high chlorophyll-a concentrations. On the basis of zooplankton research the level of pollution of various side arms and tributary water courses could be well assessed. Similarly to the phytoplankton, the relative abundance and biomass of Crustacea and Rotatoria zooplankton increase from Rajka to Budapest. Multivariate methods were used in order to recognize the different sections of the river on the basis of spatial structure of the phytoplankton and the macrozoobenthon (**Figure 3.**). Characteristic sections of the river reach in concern were identified.

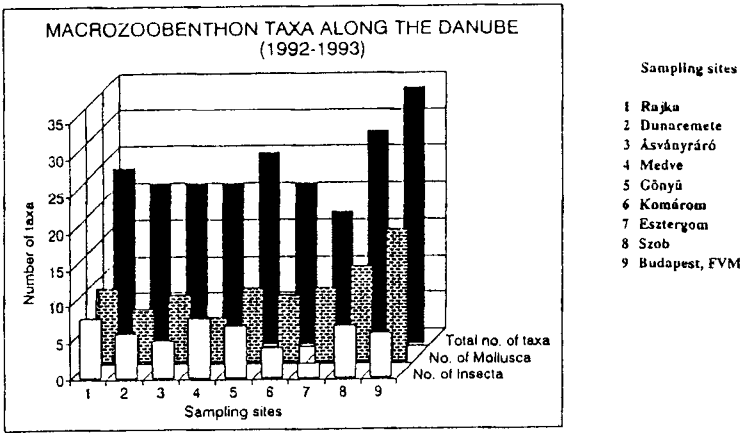


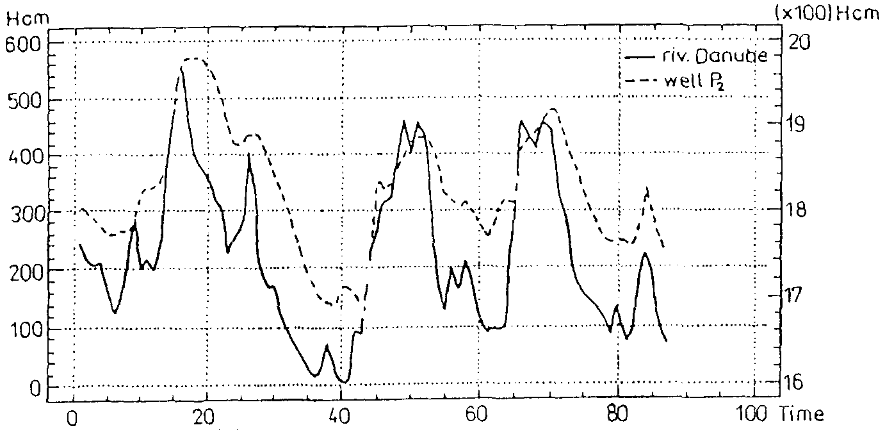

**Figure 3.**
(Csányi, 1994, -this conference-)

In his paper **Kovalchuk** presented a detailed review of the primary production and organic matter decomposition conditions of the Tisza/Tisa river and its tributaries on the basis of a comprehensive survey. It was found that organic pollution exceeds, in all investigated cases, the self purification capacity of the river system. The situation was especially bad in the fall. Ukraine being the upstream-most country in the Tisza river basin this pollution would create fairly hazardous conditions if the river had no substantial "dilution water" inputs by larger downstream tributaries.

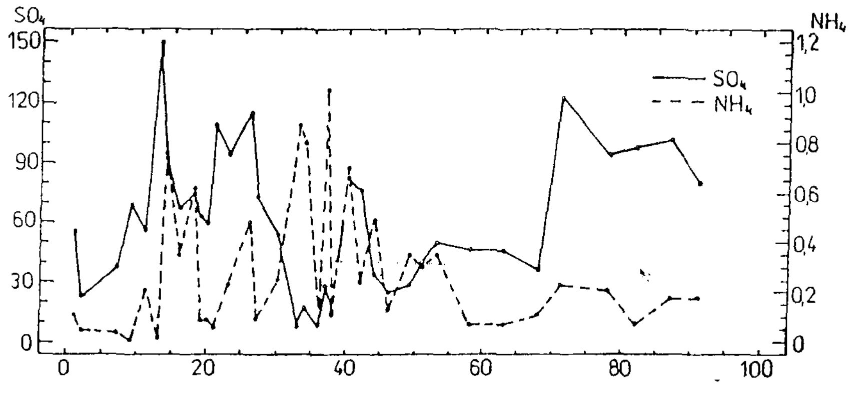
Dramatic accumulation of heavy metals in the bottom sediment of the Djerdap reservoir is reported. Moreover, in their paper **Perisic et al.** claim that pollutants accumulated in the sediments of reservoir Djerdap "contribute to a multiple degradation of ground water resources in the riparian zone".

Methods of monitoring and data evaluation aimed at the determination of groundwater vulnerability to agricultural pollution in large river plains are described in the paper by **Sarin and Brkic.**

Stochastic methods and time series analysis were used by **Matchkova et al.** for evaluating and predicting the ground water level and quality changes in function of the respective changes of the River Danube. One might ask the question whether the length of records (2 years) utilized for the purpose was'nt too short (**Figure 4.**)




Hydrographs of river stages and groundwater tables at the Belene profile.

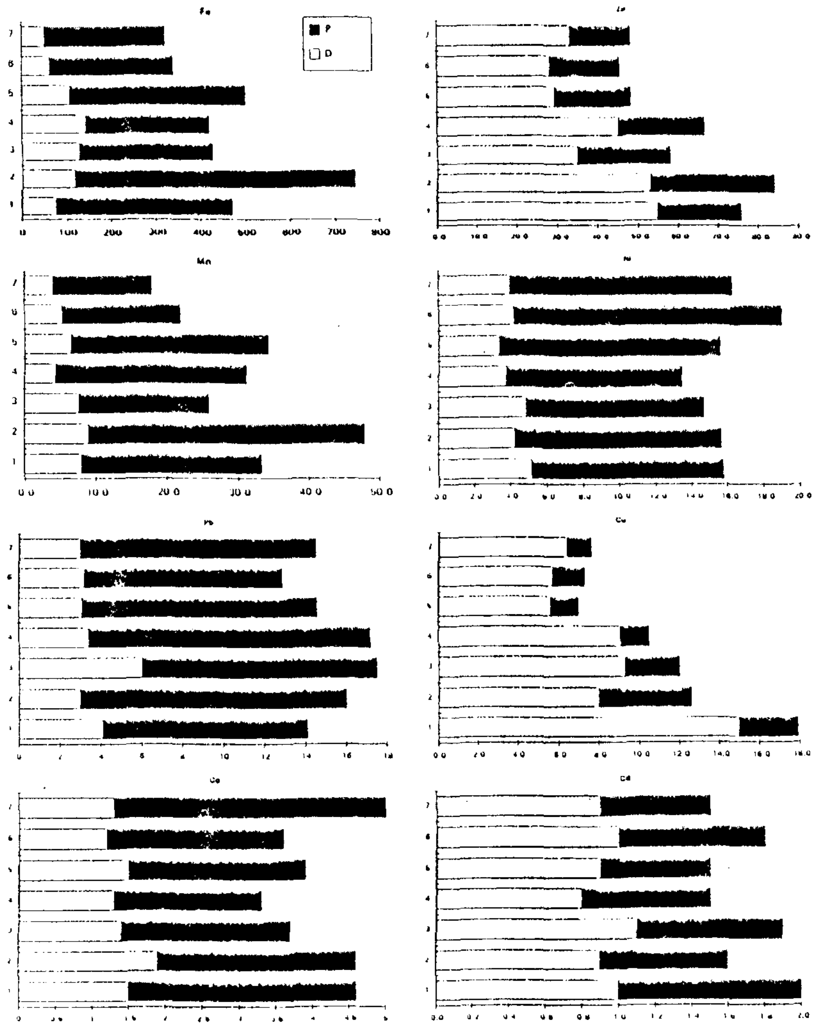



Concentrations of $NH_4$ and $SO_4$ in groundwaters of well 1 at Belene

**Figure 4.**
(Matchkova et al., 1994, -this conference-)

A comprehensive picture of metal pollution of the Middle and Lower Danube reach is given in the paper by **Osadchyi et al.** on the basis of the data of the "international expedition Blue Danube 90". Variation of the concentrations of eight metals in the water, in the particulate matter and in the bottom sediment is shown in clear graphs **(Figure 5.)** for seven stations.

**Figure 5.** (Osadichyi et al., 1994, -this conference-)




*Content of dissolved and particulate forms of trace metals (mcg/l) in the water of Danube. 1-Ukraine, 2-Roumania, 3-Bulgaria, 4-Yugoslavia, 5-Hungary, 6-Czechia & Slovakia, 7-Austria; P- particulate, D- dissolved.*

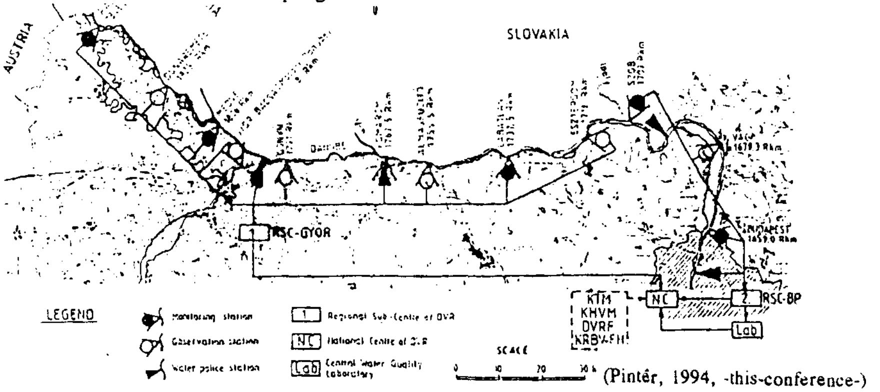
Concentrations of nitrogen and phosphorus forms, some chloroorganic pesticides and mercury are reviewed briefly along the same section of the river (between Vienna and the river mouth) in the paper by **Savitsky et al.** on the basis of the data of 26 sampling points. These experiments were also carried out in 1990, in the low flow period, likely during the same "Blue danube 90" expedition. It is a pity that the authors did not present the data in tabulated or graphical form. The authors claim that the Danube is prone to "evident pollution by pesticides", especially along its lower Yugoslavian and Ukrainian reaches. Phosphorus compounds are also enriched towards downstream.

Data of the same expedition, "Blue Danube 90" were utilized by **Snishko** in his paper for the development of a classification method relying on multivariate statistical means. It is a pity that no numerical results (tables or graphs) support the usefulness of the idea, which was presented in the form of flow charts and text only.

Results of long term (1977-1987) monitoring and experimental investigations on the determination of land use impacts on sheet erosion (an important process in the transport of non-point source pollutants) were reported for river basins in Western Ukraine by **Kovaltschuk**

Although geographically irrelevant to the Danube basin, the paper submitted by **Biondic and Ivicic** deals with generally important means of hydrogeological and hydrochemical monitoring, data processing and mapping. The methods outlined for the determination of the hydrogeological protection zones and the control means associated with restriction on infrastructural development are of general concern for the protection of important subsurface drinking water resources.

In respect to automatic monitoring stations the only information we got from the conference papers (**Pintér**) is that Hungary plans the re-establishment of two former automatic monitoring stations (at Rajka and Szob), which will also serve as components of an early warning water quality monitoring system of the Upper Hungarian Danube, aimed at the detection of accidental pollution events, emergency situations. This emergency warning system (**Figure 6.**) will be a component of a contemplated complex system of the environmental programme of the Danube basin.




(Pintér, 1994, -this-conference-)

**Figure 6.** DVR Danube early warning water quality monitoring system

## Modelling; data processing and evaluation, prediction and forecast

In the systems approach to managing the aquatic environment modelling, the use of models, play (should play) a central role (see Figure 1), since models provide the tool which can be used for the quantitative assessment of the likely outcome of contemplated strategies.

The basic principle of models used for environmental management is that the fate of water and its constituents should be followed (described, simulated) from the very source (from a given point of the hydrological cycle) until the place of their final destination (until another point along the hydrological cycle), describing the variations in time as well. From the water management point of view the"best" starting point is when and where precipitation water arrives onto the land surface and the final point of destination is a lake or the ocean, which is the ultimate sink of most of the (contaminating) constituents, which were carried away (transported) by water while it moved from a land unit upstream in the drainage basin along the surface and subsurface flow pathways until the final recipient (**Figure 7**).

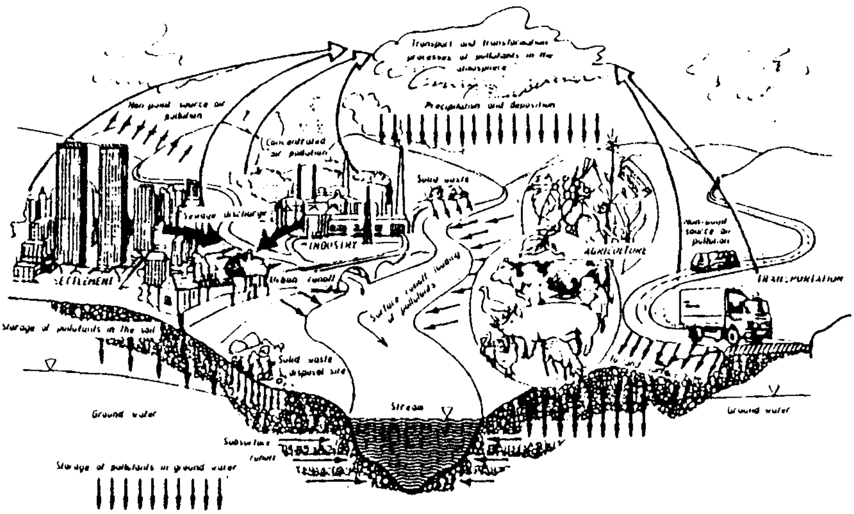



**Figure 7. Sources and pathways of pollution**
(Jolánkai, 1992)

Unfortunately the numerous modelling oriented papers of the Conference, focused solely on the description of in-stream processes, while no paper dealt with drainage basin modelling. Some way or other this seems to indicate for the Convenor the usual lack of understanding the fact, that most if not all the means of controlling the aquatic environment are to be found in the drainage basin and their land use structure.

Model equations of environmental management rely on the principle of the conservation of mass and momentum and of continuity. Thus the three-dimensional Saint-Venant equation and jointly with it the three-dimensional dispersion-convection equation (completed with terms accounting for internal reaction processes;- sources and sinks of mass) form the basis of all kinds of modelling. The structure of the models are then simplified, tailored, to the task, ending up with one-, two and relatively rarely three dimensional models.

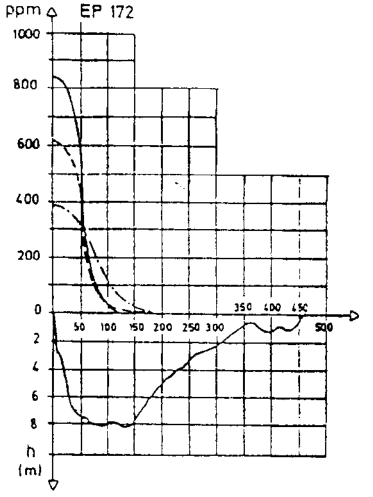



Figure 8
(Babic-Mladenovic and Varga, 1994, -this conference-)

A classical stream-modelling approach is presented by **Babic-Mladenovic and Varga** in their papers, dealing with two-dimensional parabolic model for flow and pollutant transport. While the comparison of calculated and measured flow fields seems to justify the approach, the simulated cross-sectional concentration profiles are not compared to measurement data but served for the analysis of sensitivity of the model to the values of the dispersion coefficient (**Figure 8**). In this context the Convenor would like to suggest, that it is relatively easy to obtain concentration measurement data downstream of effluent outfalls, thus providing a sound basis for the calibration of two-dimensional dispersion models.

Also verification of a likely similar model (model equations were not given) is provided in the paper by **Djuric et al.** for the Tisza and Sava rivers, with respect to flow velocity field, concentration and temperature distribution. In the respective figures concentration distributions are expressed in percentages of the maximum concentration of the dye used for an experiment (**Figure 9**). Semi-empirical formulae for the turbulence parameters are presented.

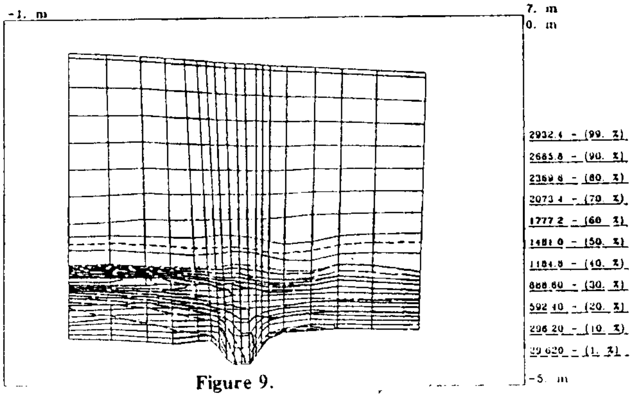



Figure 9.
(Djuric et al., 1994, -this conference-)

The particle tracking method is utilized by **Petreski et al.** for modelling the transport of pollutants. Measurement results of a laboratory channel are compared with the simulated ones. An interesting feature of the quasi 2D model is based on the "stream tube" concept, neglecting transversal flow component, and combining all transversal pollutant spreading effects in the dispersion coefficient $D_y$. It is somewhat surprising that the authors use an experimental function of the shear velocity for the determination of the value of the transversal dispersion coefficient, while the Convenors experience (Jolánkai, 1974) in this field indicates that the stream tube approach works out properly only when the dispersion coefficient is determined by fitting the model to field measurement data.

An analytical solution of the 2D dispersion-convection model is utilized in the paper by **Marinoschi and Simota** in conjunction with that of the 1D model, which latter should be utilized downstream of the point of full cross-sectional mixing. In this context the convenor wonders, why this model -and most of the other models presented to the seminar- deals solely with non-conservative substances. With the introduction of even a single first order decay (decomposition) term to account for internal processes, these models can be much better tailored to practical problems. Namely, in the reality there are almost no quality constituents which can be handled as conservative ones (they are subject to chemical reactions, biological uptake, microbial decomposition, settling, etc). The introduction of additional terms present no problems when numerical solutions are utilized, and analytical solutions are also available for a number of assumptions.

**Ignjatovic and Fehér** present water quality simulation results achieved by the European version of the traditional QUAL2 model, which is a dynamic one-dimensional transport and transformation model. The model was applied for the Ibar river system. Validation , verification, attempts were also made. The authors claim that discrepancies between measured and simulated data, in one occasion, was due to the effects of non-point sources, which are not considered in the QUAL2 model. In this context the Convenor wishes to stress again the importance of drainage basin processes. Substantial loads are carried by the runoff events into recipient water bodies, which in the mathematical models of the recipients can be handled by considering diffuse source terms. Another associated problem is the assessment (modelling) of the magnitude of these non-point source loads.

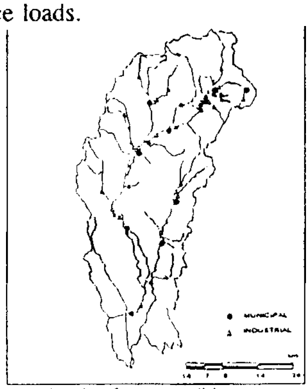

Location of waste water dicharges

**Figure 10.**

(Petrovic and Lapsansky, 1994, -this conference-)

Thus, the logical approach is to model drainage basin processes together with in-stream processes as it is provided, for example, by the SENSMOD model system ( Jolánkai, 1986; Jolánkai et al, 1993). Such models are the most effective when they are based on a Geographical Information System (GIS) of the drainage basin concerned, like in the paper by **Petrovic and Lapsansky.(Figure 10.)** This is the only way to provide a reliable inventory (data base) of all non-point sources of a drainage basin. Some results of the application of a GIS to the

This is the only way to provide a reliable inventory (data base) of all non-point sources of a drainage basin. Some results of the application of a GIS to the identification of "Chemical time bombs, hot spots" of the Slovak part of the Danube catchment are presented in their paper.

Effects of a potential waste dumping site of a thermoelectric power plant, near to the River Danube, have been investigated by **Milivojcevic et al.** by means of a non-steady 2D mathematical groundwater flow and transport model, calibrated against monitoring and field measurement data. Results have been used for actually designing protection measures.

## Control strategies

The likely reason why only very few papers of this conference are dealing with the strategies of environmental management in general or of water pollution control in particular is that the International Association on Water Quality IAWQ had its seventeenth biennial conference just now (July 24-29) and also in Budapest, where a substantial number of papers were dealing with this subject.

Although it would have been highly desirable to learn the concept of water pollution control and of the protection of the aquatic environment of the various riparian countries (with special respect to the former socialist countries, where to the Convenor's knowledge, the level sewerage, sewage treatment and industrial waste water treatment is still relatively low) there is a single paper only by **Babich** which presents briefly a nation wide scheme. Statements by this author confirm the Convenor's above described notion, namely that in Ukraine, and especially in the rural settlements, the level of waste water collection and treatment systems is very low and the purification efficiency of existing plants is poor. Among the most urgent tasks the author mentions first of all the need for "the prevention of surface and subsurface water contamination" and reports that in the Danube Basin (the Danube, the Tisza and the Prut rivers) serious water quality problems exist, with special regard to oil derivatives, phenols and nitrate. Nevertheless, the elaboration of complex long term plans for water quality management, with the final aim of eliminating non-purified waste water discharges, is also mentioned in the paper. The need for ecological rehabilitation of floodplain wetlands and oxbow lakes is also discussed. In this context a bilateral agreement between Ukraine and Moldova on the remedial supply of water to the Lake Yalpug from the Danube, is reported. Investigations aimed at the rehabilitation of the ecological conditions of the Lake Srebrena (**Figure 11.**), a biosphere reserve in Bulgaria (**Tsankov et al., Gerasimov et al.**), also with the means of supplying

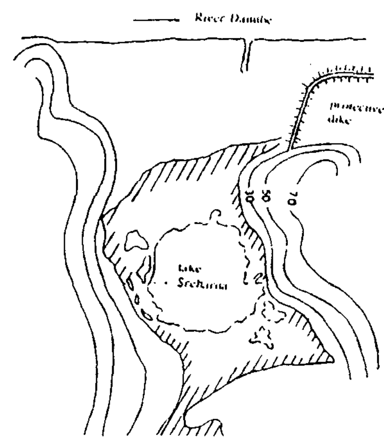


**Figure 11.** (Gerasimov et al, 1994, -this conference-)

water from the River Danube, are reported. The selection of the likely most efficient "inundation" strategy of the same nature preserve is the subject of another paper by **Gerassimov et al.** The theoretical frequency distribution of the annual extreme water levels were determined and a multikriteria analysis were utilized for finding the the optimum solution.

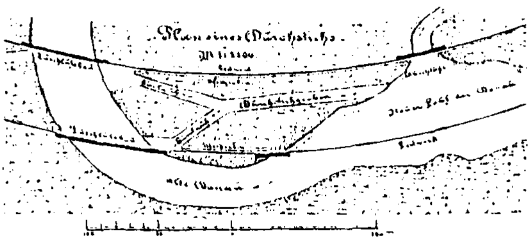


Figure 12. (Rietz, 1994, -this conference-)

Ecologically concerned riverine landscape reconstruction plans and actions of the Integrated River Danube Programme, IDP of the Baden-Würtenberg province on the upper-most Danube reach between the Black Forest and the City of Ulm are reported in the paper by **Rietz**. Ancient maps of the river regulation (**Figure 12**) were utilized for this work.

In the paper by **Göb and Wirth** a major sewer construction project of the city of Munich is described, aimed at the improvement of the water quality conditions of the River Isar and the middle Isar Canal. An improvement of the water quality of the River Isar, between 1989 and 1992, from quality Class II-III to Class II is reported, as the result of an investment of 650 million DM into the construction of the second Munich waste water treatment plant. A cascade storage system, providing dilution water, contributed also to this improvement.

**Muskatirovic and Batinic** present a complex analysis of the combination of strategies aimed at the protection of populated riparian areas from the harmful effects of the Iron Gate I. system. Series of deep wells have been established for ground water level lowering purposes. Reconstruction of existing stormwater drainage and sewer systems was proposed as means of counteracting adverse effects other than those associated with the higher water levels of the reservoir.

The idea of emergency waste water storage systems controlled in an on-line manner on the basis of automatic effluent and stream monitoring systems, briefly outlined in the paper by **Virág**, falls probably into the category of control actions of the long term future;- at least in the scale of the Danube basin, although such systems might prove to be very efficient in smaller industrial catchments.

## Summary

Eventually much more national and international activities concerning the protection of the aquatic environment are being performed in the Danube basin than what was reported by the papers submitted to the Conference. Some of these have been well summarized in the paper by **Tittizer**, which reports on the research activities coordinated by the International Working Group on Danube Research (IAD). From this paper one learns that virtually all interdisciplinary fields of research into the river basins aquatic ecosystem are covered, spanning from hydrology and hydrochemics, through micro- and macro biology to radiology. The main subject areas of the recent decade of the programme include: limnology of canalized and non-canalized river reaches, the effect of power stations on the ecosystem of the Danube, mixing of tributary waters with the main stream, interaction between surface and subsurface waters, and the performance of bi- and multilateral research projects.

Since the audience will not have a complete, clear picture of the ecological, environmental and water quality problems and problem solving efforts of the Danube basin, the convenor wishes to suggest -although it is far from his field of competence- that an international conference or seminar of the riparian countries be convened in the not very far future, with the major subject of the water quality and ecological problems of the aquatic environment in the Danube Basin. The strategies of sustainable social and economic development can be elaborated only after having obtained a very precise and clear view of all environmental problems of this vast river.

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(the papers of subject 5. of the Conference)

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XVII. KONFERENZ DER DONAULÄNDER
über hydrologische Vorhersagen und
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# METHODOLOGICAL ASPECTS OF COMPREHENSIVE ASSESSMENT AND CLASSIFICATION OF CONTINENTAL SURFACE WATERS

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## ABSTRACT

Methodological aspects of investigations are considered, and new approaches are proposed to comprehensive assessment and classification of continental surface waters. Results of evaluation of the proposed methodology are reported, illustrated by the example of processing the data of comprehensive examination of the Danube River performed by the 2nd International Environmental Expedition which was organized and carried out during the fall low-water period of 1990 by Perun Ukrainian Scientific and Technological Ecological Center [1].

## KURZFASSUNG

Im Vertrag sind die methodologischen Aspekte der Forschungen betrachtet und die neuen Betrachtungsweisen zur Bestimmung der Komplexbewertung und der Klassifizierung von Qualität der Oberflächenwässer des Festlandes angeboten sowie die Ergebnisse der Approbation von der angebotenen Methodologie der Arbeit nach dem Beispiel der Angabenbearbeitung von den Komplexforschungen der Donau dargelegt, die in Rahmen der Arbeit der II Internationalen ökologischen Expedition erfüllt wurden, die im Herbst 1990 bei Wassermittelstand durch das Ukrainische wissenschaftlich-technische ökologische Zentrum "PERUN" organisiert und durchgefürt wurde.

## 1. INTRODUCTION

The established procedure of management of continental surface waters (CSWs), as well as the existing systems of their quality monitoring, are oriented mainly to the needs of various water users, and, in most countries, fail to meet the present-day environmental requirements. This is demonstrated by ever-accelerating degradation of surface water systems. Relatively high technological achievements of a number of economically advanced countries cannot improve this situation, as technogenic impact of some environmentally troublesome countries on water resources has long extended beyond their own borders and become a global factor. Now, one comes to realize that, in order to keep CSWs suitable for human life, problems of their protection and recovery should be tackled in practical terms. In this respect, it is crucially important to improve the techniques of assessment and classification of CSWs, providing the procedural justification of hydroenvironmental monitoring. Only data obtained on this basis can allow developing an acceptable strategy of water management and specific directions of water conservation activities.

At the same time, technological expansion has drastically increased over the past few years in many countries, resulting in pollution of water resources with $10^7$ alien agents, some of which affect living organisms significantly at concentrations as low as $10^{-17}$ g/l. Under such conditions, amount, technical complexity, and high cost of work to be done to provide a correct assessment of CSW quality using conventional approaches are beyond any reasonable limits. Now, this problem is addressed "in terms of feasibility": most pollutants are ignored, whereas monitored is only a small part of those which, on the one hand, have unambiguously exposed their negative impact onto various water users, and, on the other hand, are economically and technically feasible for the entity carrying out the monitoring.

Ever deteriorating state of surface water systems and quality of deficient freshwater resources demonstrate that this situation cannot be considered satisfactory any longer.

## 2. BRIEF ANALYSIS OF SHORTCOMINGS OF EXISTING TECHNIQUES

In our opinion, the main shortcomings of currently used techniques of assessment and classification of CSWs are as follows:

1. Limited number and invariable list of CSW parameters used to assess the state of a great diversity of water bodies are inadequate to the actual complexity of the problem.
2. Performing investigations locally and independently at limited stretches of a water system by different (and often incompletely consistent with one another) techniques decreases significantly representativity and practical value of the results.
3. Assessment of CSW quality is based on standard indices specified in artificial conditions of laboratory for each pollutant separately, whereas actually a great diversity of such pollutants are affecting water systems simultaneously, and their joint effect is different from their simple sum: they can enhance or inhibit one another's actions and interact with each other, producing neutral or more toxic substances.
4. It is inefficient to assess CSWs using separate quality indices, when particular values of parameters measured with the best available accuracy are described by one of the six quality classes allowing very broad ranges of these parameters.

These drawbacks are aggravated by narrow and diverse orientations of various services performing CSW quality control (health service, water management, hydrometeorology, etc.). This situation is associated with specific requirements imposed on water resources by various users and with extreme complexity and tediousness of more detailed examination. However, now that environmental problems are acquiring primary importance, simplified approaches to hydromonitoring can be justified neither economically nor scientifically.

## 3. DIRECTIONS OF IMPROVING METHODOLOGY OF COMPREHENSIVE ASSESSMENT AND CLASSIFICATION OF CSWs

Directions of improving the techniques of comprehensive quality assessment and classification of CSWs, which form the methodological basis of hydroecological monitoring, are dictated by most pressing need to tackle ever aggravating environmental problems of continental surface water bodies. In our opinion, the most important directions are as follows:

1. Performing investigations of water objects as integral ecological systems over the entire stretch of the water body and area of the basin using unified or mutually consistent techniques.

2. Making the approach much more comprehensive, expanding significantly the range of analyzed pollutants, and mandatorily testing the adequacy of the performed analysis and the representativity of the obtained assessments by biological techniques of toxic pollution evaluation.

3. Improving techniques of processing and interpretation of hydroecological monitoring data for increasing representativity and versatility of the assessments.

However, for a large number of countries programs of comprehensive assessment and classification of CSWs developed on this base may be unfeasible to implement by the existing hydromonitoring entities in view of the inevitably increasing amount, technical complexity, and cost of investigation works. Therefore, introduction of such programs into the routine of hydroecological monitoring would also require new forms of interaction between separate monitoring branches, making possible implementation of the programs without any restructuring or significant increase of the workload of the relevant entities.

In our opinion, these forms may involve creation of large research associations (if necessary, international) open for participation of interested first-class experts from leading research centers on a part-time basis. These associations would be able to implement large-scale research programs. Examination of a particular water system by such an association would result in the integrated assessment and classification of water quality, and also in working out a set of preferential water quality indices to be regularly controlled by hydroecological monitoring entities available in any country.

An example of such an association is the 2nd Danube environmental expedition of 1990 whose research team, organized by Perun Ukrainian Scientific and Technical Ecological Center, has gathered experts from 24 leading research institutions of Ukraine, Russia, Moldova, Hungary, Yugoslavia, Romania, and some other countries of the Danube Region. Several years of fruitful joint work of highly skilled researchers on integrated investigations of the Danube prove that such teams can implement research projects of unmatched complexity with quite reasonable expenses.

## 4. METHODOLOGICAL FEATURES OF COMPREHENSIVE INVESTIGATIONS OF THE DANUBE

As already reported, the 2nd integrated environmental expedition was carried out on the Danube reach between the river sections 18 km (Vilkovo, Ukraine) and 1934 km (Vienna, Austria) during the fall low-water period of 1990 on board the motor vessel "Amur" of the Ukrainian Danube Steamship Line equipped with scientific instruments. At 27 sampling sites, selected and validated on the principle of impact and backround monitoring, 72 samples were taken of water, bed-loads, bank soils, microorganisms, algae, invertebrates, and fish. More than 250 indices characterizing various aspects of the Danube water quality were studied using hydrochemical, hydrobiological, microbiological, virusological, sanitary-toxicological, radio-ecological, zoological, geoenvironmental, and hydrometeorological tests. On the basis of these data, a relevant procedure was worked out, and integrated assessment and classificaton of the Danube water quality were made for the first time in the practice of Danube studies.

The performed work can be outlined as follows:

1st stage. Examination of the available data on the qualitative state of water resources and technological features of economic objects in the basin, and working out on this basis the research program and the list of water quality parameters to be studied.

2nd stage. Integrated experimental investigation of the water system according to the devised research program, and test measurements of the toxic pollution level of the system by biological methods.

3rd stage. Analysis of the obtained results and, on this base, integrated assessment and classification of the system's water resources, as well as determination of a set of preferential quality indices characterizing this particular system that should be regularly monitored.

Findings of the expedition are reported in more detail in a thematic issue of "Vodnye Resursy" (Water Resources) journal published by the Russian Academy of Sciences [1]. Here, we will focus only on some methodological aspects of the performed investigations.

1. Carrying out research works on such a large scale has allowed determination and scientific validation of a very small group of indices characterizing this particular water body. With these indices regularly measured, one can monitor the water quality of the studied system with a good reliability. Naturally, some water users may require measuring additionally certain parameters of particular importance for them. They can even add these parameters to the monitored set of preferential indices and obtain their own (specialized for their agency) assessment of the CSW quality. However, with the basic assessment available, complexity and cost of this work would be low.

2. On the other hand, development of techniques for integrated assessment and classification of CSWs on the base of the measured data is very important. Otherwise, it is impossible to handle correctly the problem (most pressing for many countries) of employing economic levers of water management. Shortcomings of the conventional (we call them "expert") techniques of water assessment and classification were discussed above. In this paper, we propose a much more advanced method of solving this problem: water quality is assessed by the "general pollution class" (GPC) calculated as follows:

$$K_l = \sum_{i=1}^{n} F_i(N_{i,l}) \div n_l$$

where

$K_l$ – is a general water pollution class at the l-th point of the water system;

$F_i(N_{i,l})$ – class of pollution at the l-th point corresponding to the i-th preferential index;

$N_{i,l}$ – value of the i-th preferential index at the l-th point of the water system;

$n_l$ – the total number of preferential indices at the l-th point of the water system.

Pollution class at the l-th point corresponding to the i-th preferential index $F_i$ is a continuous function depending on the absolute values of this index $N_{i,l}$ calculated by piecewise-linear interpolation of the absolute values of quality standards of surface flowing waters for the i-th preferential index [3].

General pollution classes calculated by the described technique for various river sections of the Danube (Fig. 1) have a very important merit: their values inherently reflect levels of all pollutants measured at this point, without any loss of measurement accuracy. This feature of the GPCs allows significantly rising the differentiation level of assessment of the actual state of water resources and can be widely employed in practice (for example, serving as a base for developing rates of payments for water use).

It is also significant that GPCs are calculated by formalized data processing using universal mathematical operations. Formalized algorythm of assessment of extremely involved systems like CSWs is essential both for scientists and for practical workers, because the assessment becomes unbiased and may serve as a standard. Without such a standard it is quite difficult for water management experts and hydroecologists from different countries to understand and interrelate one another's data. On the other hand, it is equally important that formalization of the CSW assessment opens the way to automatization of the processing and interpretation the measured water quality parameters. Undoubtedly, this will make the entire system of hydroecological monitoring working faster, more efficiently, and (most important!) producing unambiguous results.

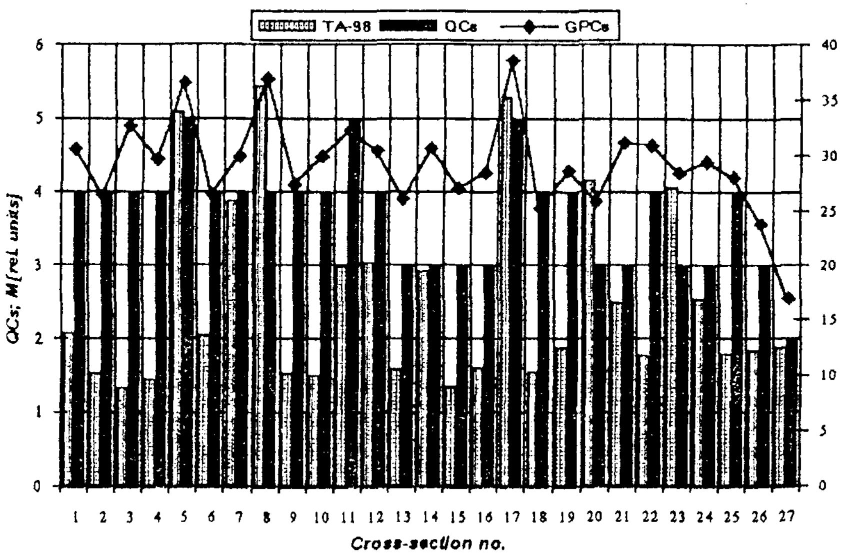


**Fig. 1.** Histograms of already published values of water quality classes (QCs) obtained by the conventional method using 15 preferential indices, and of mutagenic activity determined from the salmonellic test TA-98 at the 27 river sections of the Danube from Vilkovo to Vienna (experimental data of the 1990 Danube expedition [1]). For comparison, the values of general pollution classes (GPCs) calculated by the new method (using formula (1)) are also plotted. As distinct from the conventional QC estimates, GPC values are much more differentiated and correlate with the mutagenic activity much better.

## 5. CONCLUSIONS.

Methods of integrated assessment and classification of continental surface waters constitute the methodological base of the hydroenvironmental monitoring. Ways of improving these methods, proposed and demonstrated on the example of integrated investigations and assessment of the Danube water quality, allow performing an integrated CSW assessment which has the following advantages:

1. A significantly improved representativity, achieved by the highest currently

feasible number of factors taken into account, and also by testing the adequacy of the performed analysis using biological techniques of toxicity measurements.

2. A formalized algorythm of CSW assessment, allowing automatization of processing and interpretation of the measured water parameters. This will improve the quality and (most important) unambiguity of the results and their usability (for example, it is quite easy to work out on this base a technique of calculating rates for water use with a very high and unambiguous differentiation of payments depending on the water quality).

3. Versatility and practical orientation resulting from the very idea of the procedure, aimed at satisfying needs both of various water users and of hydroecologists.

4. Economic efficiency and feasibility for employment by entities of the existing hydroecological monitoring systems of most European countries.

Feasible and practically tested organizational forms of implementing this technique are demonstrated.

In conclusion, it should be noted that practical implementation of the above proposals will need certain financial resources and serious organizational and coordinating efforts of the participating entities. However, realization of these proposals will permit improving essentially the work of state agencies controlling quality and use of continental surface waters which are now a most critical natural resource. And it will be an important step on the road to the creation of economic levers controlling the use of natural resources and the state of environment.

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# WATER QUALITY MONITORING IN AUSTRIA: RESULTS OF THE FIRST INVESTIGATION PERIOD

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## Abstract

The new countrywide monitoring system in Austria provides data on both ground water and running water quality; it has been installed by the Federal Ministry for Agriculture and Forestry in close co-operation with the Federal Environmental Agency and the provincial authorities. The first period of data evaluation and interpretation lasted from December 1991 to September 1992 for groundwater and from December 1991 to December 1992 for running water, respectively. Then the monitoring network comprised about 1000 sampling sites for ground water and 150 sampling sites for running waters. At each sampling site about 60 physico-chemical parameters were analysed, ground water samples were taken four times a year and running water samples six times a year. Groundwater results for nitrate, pesticides and chlorinated hydrocarbons as well as running water results for BOD, ammonium, AOX, and atrazine are presented and discussed.

## Zusammenfassung

Im Rahmen der neuen flächendeckenden Wassergüte-Erhebung in Österreich werden die Qualität von Grundwasser und die Wassergüte von Fließgewässern durch das Bundesministerium für Land- und Forstwirtschaft in enger Zusammenarbeit mit dem Umweltbundesamt Wien und den Landesdienststellen erhoben. Der erste Auswertungszeitraum für den Bereich Grundwasser erstreckte sich von Dezember 1991 bis September 1992, jener für den Bereich Fließgewässer von Dezember 1991 bis Dezember 1992. Innerhalb dieses Zeitraumes wurden etwa 1000 Grundwasser- und 150 Fließgewässermeßstellen beprobt. Etwa 60 physikalisch/chemische Parameter werden an den Grundwassermeßstellen viermal, an den Fließgewässermeßstellen sechsmal jährlich erhoben. Für den Bereich Grundwasser werden Ergebnisse für Nitrat, Pestizide und chlorierte Kohlenwasserstoffe, für den Bereich Fließgewässer für die Parameter $BSB_5$, Ammonium, AOX und Atrazin dargestellt und diskutiert.

## 1. Introduction

The amendment of the Federal Act on Water Law in 1990 provides for a fundamental reformation and reorganisation of water quality control in Austria. Now one of the key elements of water management is the establishment of a country-wide water quality monitoring scheme for groundwater and running waters on the basis of the Federal Act on Hydrography, which has been amended too in 1990, and an ordinance on water quality monitoring ("Wassergüte - Erhebungsverordnung", "WGEV", BGBl. 338/91), which was issued on the basis of the latter act in 1991. A pilot study on ground water quality was carried out by Grath et al. (1992).

The main features are: the monitoring system provides up-to-date and detailed information on river and ground water quality to decision makers and the general public; changes in water quality are indicated very quickly; the main areas of water pollution can be detected and remediation measures carried out effectively; the progress of remediation measures can be supervised by monitoring.

The paper at hand shortly presents the first results obtained from the first period of data evaluation and interpretation lasting from December 1991 to September 1992 for ground water and from December 1991 to December 1992 for running waters.

## 2. Methods

A detailed description of the legal framework, administration, and data management (data collection, data transfer) within the monitoring system is given in Schwaiger et al. (1993a).The methods of the analytical procedures are laid down in the ordinance on water quality monitoring ("WGEV", BGBl. 338/91).

## 3. Sampling sites and investigation programmes

### Ground water:

As early as autumn 1991 the necessary field work for the monitoring network of the first phase comprising about 800 sampling sites was concluded in all provinces. The final acceptance of this network was reached in jointly-held discussions with the respective provincial authorities and the Federal Water Management Register. The gradual extension of the network to include about 2000 sampling sites in the year 1996 has already begun. The network currently comprises about 1400 sampling sites.

For the beginning of the investigation the monitoring network was laid out so as to concentrate on the large valley and basin topographies which include important ground water resources and are already subject to intensive and varied forms of economic exploitation. To be precise, the sites are: Seewinkel, Parndorfer Platte, Wulkatal, Southern Vienna Basin, Tullner Feld, Traisental, Machland, Eferdinger Becken, Linzer Becken, Welser Heide, Untere Salzach, Unteres Inntal, Walgau, Rheintal, the valley landscapes of the rivers Mur and

Mürz, Klagenfurter Becken, Glantal, Krappfeld, Jaunfeld, Zollfeld and other smaller valley landscapes as well as isolated karst springs.

The preliminary evaluations presented here are based exclusively on values obtained from sampling ground water in porous media; the first results from karst and crevice ground water bodies are to be published in the 1993 annual report on water quality in Austria (Wasserwirtschaftskataster / Umweltbundesamt, 1993).

In 1991/1992 investigations at all sampling sites in Austria were carried out on the parameters of group 1 (geogenic parameters plus nitrate, nitrite and ammonium) and 2 (metals, chlorinated hydrocarbons etc; for details see "WGEV" as well as on the pesticides of the triazin- and phenoxyalkanecarbonic acid groups and, finally, alachlorine and metolachlorine. These pesticides were selected both in view of the distribution of their usage and in view of the probability of the occurrence of these agents; the quality of the analyses of these parameters was assured by means of laboratory comparison tests.

### Running Water:

The results presented in the present paper comprise the samplings at 150 sampling sites. The main catchment areas as laid down in the Federal Law on Hydrography are indicated by numbers.

1: Rhine (12 sampling sites); 2: Danube upstream the Inn (1); 3: from Inn to Salzach (14); 4: Salzach (14); 5: Inn downstream the Salzach (3); 6: Danube from Inn to Traun (2); 7: Traun (17); 8: Enns (11); 9: Danube from Traun to Kamp (excluding Enns; 6); 10: Danube from Kamp to Leitha (excluding March), Moldau (4); 11: March (5); 12: Leitha (6); 13: Rabnitz and Raab (8); 14: Mur (13); 15: Drau (34).

The final extension of the monitoring network to 250 sampling sites was carried out in the autumn of 1993.

The investigation programme of the monitoring system comprises analyses of water, sediments, and biota. Water samples are collected six times a year (every two months), sediment samples as well as biological material are collected once a year. At some sampling sites water samples are taken twelve times a year because of special bilateral agreements on transboundary water management issues. At each sampling site about 50 variables are measured: they comprise basic variables like pH, conductivity, BOD, TOC, DOC, nutrients etc. as well as variables which - up to now - at best were subject of specific surveys such as AOX, pesticides, and PAH.

At present, Austria's water management lacks obligatory surface water quality standards; there is only a draft ordinance on running water pollution which sets different standards for rivers of mountainous and lowland regions.

## 4. Results and discussion

### Ground water:

Detailed results are presented in: Schwaiger et al. (1993b), Grath & Herlicska (1993) and Grath et al. (1993).

Nitrate:

The comprehensive, nationwide presentation of the results evaluated as part of this programme shows clearly that more than half of the sampling sites from which samples have already been taken show nitrate concentrations of less than 25 mg $NO_3$/l. There are, however, large regional differences. The investigated ground water areas in the west of Austria (Vorarlberg, Tyrol, Salzburg, parts of Carinthia) have lower nitrate concentrations which can be due to either local conditions (higher rates of precipitation, therefore faster ground water recharge) or the type of soil exploitation (a comparatively higher proportion of grassland cultivation).

As expected, higher nitrate concentrations are recorded in ground water areas where the soil is subject to an especially intensive agricultural exploitation as well as intensive livestock breeding. At the same time, these areas are regarded as disadvantaged on account of the comparatively low and temporally unfavourable distribution of rainfall.

Through existing pilot projects, the Federal Ministry for Agriculture and Forestry is concerned to find viable ways for a sustained reduction of nitrate pollution in ground water so as to assure an unrestricted use of ground water as a source of drinking water and therewith to create the basis for a remediation of ground water sources.

Pesticides:

The investigation programme included 17 pesticides (see 3.). The substance most often detected in concentrations above the Austrian threshold value (0.1 µg/l) is desethylatrazine which is a metabolite from atrazine, second is atrazine and third is desisopropylatrazine. Most sampling sites at which concentrations above 0.1 µg/l for the three mentioned pesticides were observed are in the ground water regions of Lower Austria, Upper Austria and Styria.

In the future the current pollution of ground water by atrazine and its metabolites will probably sink below the precautionary value of 0.1 µg/l thanks to the total ban on the use of atrazine as of 1st January 1994 as laid down in an ordinance on the ban of certain hazardous substances in plant pesticides (BGBl. 97/92).

Volatile Halogenated Hydrocarbons:

The investigation programme on ground water quality in Austria also included seven volatile halogenated hydrocarbons (tetrachloroethene, trichloroethene, 1,1,1-trichloroethane, trichloromethane, tetrachloromethane, 1,1-dichloroethene, 1,2-dichloroethane). These substances were selected from the large group of halogenated hydrocarbons, first, in view of the probability of their occurrence, and second, in relation to those substances for which individual limit values for drinking water were set in Austria.

The results show that the Austrian threshold levels and the Austrian drinking water standards are exceeded only by a few values, but the maximum concentrations detected in those few values are high. The reason for this fact lies in the physico-chemical properties of the halogenated hydrocarbons.

Chlorinated hydrocarbons are distributed in the aquifer as contamination plumes with high concentrations. These contamination plumes, however, can be detected only in some cases by the Austrian monitoring network described above. Therefore, areas in which the concentrations of chlorinated hydrocarbons are between the detection limit and the threshold level must also be subjected to further investigations to locate the sources of contamination.

**Running water:**

Detailed results of the data collected at 150 sampling sites within the first investigation period (Dec. 1991 - Dec. 1992) are presented in Chovanec & Winkler (1993a,b), Chovanec et al. (1993) and Chovanec (1994).

An evaluation of the BOD (5 days), $NH_4$-N, and atrazine data indicate severe pollution situations in the rivers in the north and east of the country (BOD: values of up to 12 mg/l in the rivers March and Thaya; ammonium: values of up to 3.1 mg/l in the river March and 2.1 mg/l in the river Strem; atrazine: values of up to 3.1 µg/l in the river Strem and 1.7 µg/l in the river Thaya). Limit values of the draft ordinance: BOD: lowland rivers (l.r.) 6.0/mountainous rivers (m.r.) 3.5 mg/l; $NH_4$-N: l.r. 0.5/m.r. 0.3 mg/l; atrazine: l.r., m.r. 0.1 µg/l. Both, waste water effluents as well as diffuse sources seem to cause this situation.

An extraordinary situation exists in the Vienna 'Donaukanal', the receiving water body of the effluents of the Vienna waste water treatment plant. Maximum concentrations found were: 68 mg/l BOD; 21.7 mg/l $NH_4$-N; 2.9 µg/l atrazine.

The analysis of AOX is a suitable means for evaluating waste water effluents of pulp and paper industries which are a major source of water pollution in Austria. Particularly in the catchment area of the river Mur the AOX concentrations are noteworthy. This region is strongly influenced by the effluents of pulp and paper plants. Nearly 50 per cent of the values measured in this region were above 50 µg/l, the limit value of the draft ordinance for both river types. Peak concentrations were found in the small river Pöls resulting from a pulp mill using chlorine or chlorine derivates for bleaching (maximum value 2,300 µg/l). The river Pöls, which is also characterized by high BOD concentrations (up to 15 mg/l), even affects the river Mur (maximum value 550 µg/l).

The impact of other pulp and paper mills in Austria on aquatic ecosystems could be reduced in the last years: some plants apply effective waste water treatment processes, other sites were closed. Low AOX concentrations found throughout the country (74% of all values between 0 and 10 µg/l) are probably due to the use of household chemicals.

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# WATER QUALITY OF THE DANUBE SECTION BRATISLAVA-VISEGRÁD

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Over two years [1991-1992] the water quality monitoring of the Danube section Bratislava-Visegrad on seven main river profiles and three tributary profiles have been done. The chemical, physical, biological, microbiological and radioactivity analysis in frequency of two times a month have been measured. Total number of parameters was 70 and profiles 16.
Relatively good oxygen conditions of whole Danube section have been found what was indicated by oxygen content and saturation.
Considering trofical characteristics the important compounds of phosphorus and nitrogen were widely represented. The values of parameters of industrial organic pollution are acceptable from the ecological point of view.
The content of heavy metals was relatively low. According to biological parameters the investigated Danube section was classified as betamesosaprobic. The microbiological condition of the Danube were unfavourable. The values of radioactivity and organic pollution were acceptable.

Wahrend zwei Jahren (1991-1992) wurde der Wassergütemonitoring am Donau durchgeführt. Von ingesamt 10 Beobachtungsstellen zwischen Bratislava und Visegrad liegen 7 Messtellen direkt am Donau und 3 Messtellen an drei Zuflüsse. Im laufenden Unterzuchungsjahren wurden die Wasserproben an allen Messtellen (ingesamt 16 Probeentnahmungsstellen) auf einheitliche Art und Weise zweimal pro Monat entnommen und die chemische, physische, biologische und mikrobiologische parametern (ingesamt 70 parametern) wurde gemessen.
Die relativ gute Sauerstoffbedingungen wurden in ganzen Dounauteil festgestellt, die durch den Sauerstoffinhalt und die Sättigung indiziert wurden. Die Werte von der organischen Mikroverunreinigung und Schwermetallen waren niedrig aus Sicht der ökologischen Bedeutung , die einige Analyten wurden gelegentlich in höheren Konzentrationen gefunden. Die mikrobiologischen Bedingungen von der Donau wurden als ungunstig klassifiziert.

**Introduction**

The Danube enters Slovak territory at the km 1880.2. The Slovak part of the Danube with its length of 172 km has four major tributaries: Morava, Vah, Hron and Ipel. This part of the Danube has mountain-like character with typical run-off. Summer flow maxima are 31.7% of the annual run-off, the winter maxima are 18.2% of the annual run-off. Water bearing is relatively constant within the annual cycle as well as in the long-term average.

The Danube is the dominant source of groundwaters in the surrounding area, therefore, river water quality has an essential impact on the quality of groundwaters influenced by the Gabcikovo water dam. This is the reason why monitoring of the Danube river water quality is performed as a special project. Monitored area is not strictly limited to the Gabcikovo dam surrounding area but includes a long part of the Danube and its tributaries.

In the monitoring project there are seven sampling sites on the Danube and one sampling site on each estuary of the major Danube tributary. Sampling frequency in 1991 was 12 samples per year. In the year 1992 the sampling frequency was increased to 24 per year due to requirements of the statistical evaluation. Evaluation of the water quality was based on the national standard CSN 75 7221 "Classification of the surface water quality" and included 57 parameters. Results obtained in the project were regularly compared and unified with results of the Hungarian monitoring team.

PARAMETERS OF OXYGEN REGIME

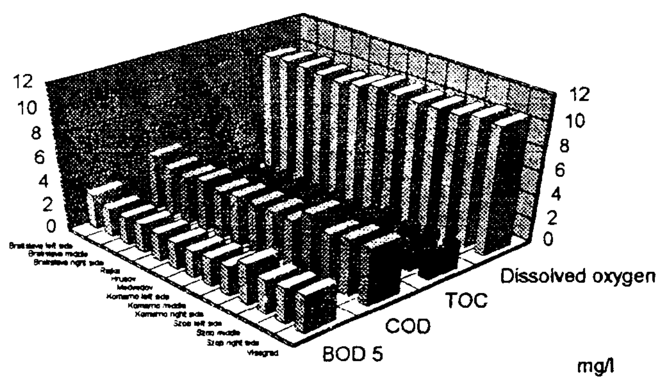


FIGURE 1

## Results

From the parameters of the oxygen regime (Fig.1) sufficient oxygen content in the whole monitored part of the Danube is apparent. None of the minimal concentration values did not fall below 7 $mg.l^{-1}$ what is limiting value for the first class of the surface water quality. Lower oxygen minimum in the Rajka sampling profile is the result of the organic pollution from the Petrzalka municipality. The influence of organic pollution from Slovak tributaries is visible in the sampling profile Szob-left side which had also lower dissolved oxygen concentration average. Relatively high dissolved oxygen concentration average in the Medvedovo down-stream can be explained by self-purification processes and by an intensive production of biogenic oxygen which is formed by phytoplankton. Oxygen formation is stimulated by low flow rate of the Danube in this part.

Biologically degradable organic pollution is characterized by means of $BOD_5$ value. In the monitored part of the Danube the $BOD_5$ values obtained during two-year period were in the interval 2.3 - 5.1 $mg.l^{-1}$. The influence of the point sources of the pollution was apparent in particular sampling profiles. Wastewater discharge from the municipality of Karlova Ves - Dubravka together with pollution load of the Morava river affect the $BOD_5$ value at Bratislava left-side sampling profile. The same influence has the wastewater discharge from Petrzalka to Rajka sampling profile and industrial and municipal wastewaters from Sturovo area together with pollution load of upstream Slovak tributaries to Szob left-side sampling profile. The maximal value of $BOD_5$ at Komarno right-side sampling profile indicates the influence of the Mosony Danube.

Wastewater discharges influence also the COD (Mn) value of the Danube river water, however, the differences measured were less significant. The characteristic interval of COD (Mn) values was 3.9 - 6.7 $mg.l^{-1}$

Similarly, only slight variations were found between Bratislava and Visegrad also for TOC having values in the interval of 2.03 -4.2 $mg.l^{-1}$ which represents the first class of surface water quality.

**Basic physico-chemical parameters.**

pH values had seasonal dynamics in all profiles due to phytoplankton activity, being increased in the vegetation period. Average pH values raised continuously from Bratislava to Visegrad. Similar increase was observed for average water temperature values being 1°C between Bratislava and Visegrad.

The mineralization of the Danube river water can be estimated from the values of dissolved substances varying between 24.9 - 51.6 $mg.l^{-1}$ and from values of conductivity which oscillated around 37 $mS.m^{-1}$.

The amount of non-dissolved matter depends primarily on the run-offs. Maximum values were detected during the flood in November 1992. Average values oscillated around 30 $mg.l^{-1}$. The influence of the tributaries was apparent mainly for Morava and Ipel.

Closely related to content of non-dissolved matter were the concentrations of total iron and manganese. The average values of total iron did not exhibit a trend behavior, however, for

NITROGEN FORMS

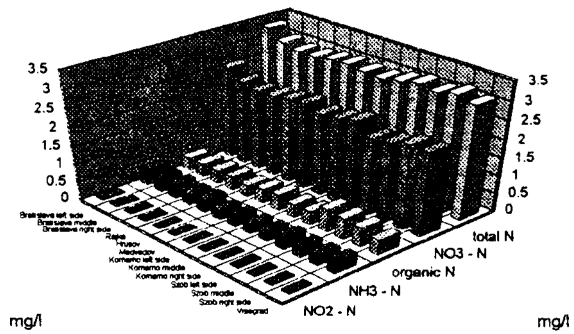


FIGURE 2

average concentrations of total manganese their increase downstream to Komarno was observed.

Nitrogen and phosphorus containing compounds play a key role in the growth of phytoplankton biomass (Fig.2). The $NH_3$-N values found in the Danube were very diverse, while $NO_2^-$-N values were relatively constant. The amount of $NO_3^-$-N represented approximately 60% of the total nitrogen and its values exhibited low dispersion in the longitudinal profile. Average concentrations of organic nitrogen had similar tendency with an increase in the Szob sampling profile probably due to the influence of tributaries.

PHOSPHORUS FORMS

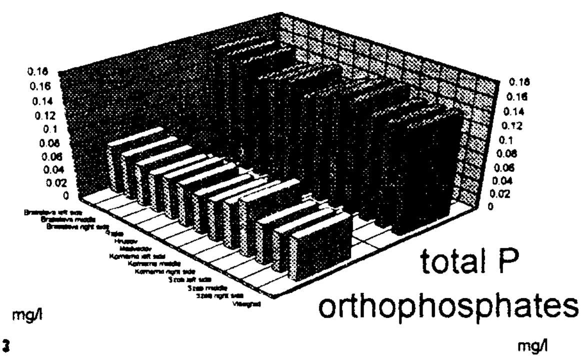


FIGURE 3

Average concentrations of orthophosphates were much less stable when compared to total phosphorus concentrations. They represented less than 50% of the total P load (Fig.3)

Approximate average concentrations of chlorides, sulphates, calcium and magnesium were 20 $mg.l^{-1}$, 35 $mg.l^{-1}$, 55 $mg.l^{-1}$ and 13 $mg.l^{-1}$, respectively. Slight rise of these ions in longitudinal profile in 1991 was more significant than in 1992. The values of total hardness corresponded with the calcium and magnesium content. The average values of hardness were constant in the longitudinal profile (2,5 - 4,8 $mmol.l^{-1}$). From determined concentrations of hydrogencarbonates it is apparent that Danube river water can be classified as hydrogencarbonate type.

The concentrations of phenols had the same value (0,003 $mg.l^{-1}$) in 9 sampling profiles, higher concentrations (0, 004-0,005 $mg.l^{-1}$) were found in profiles Rajka, Hrusov and Szob as a consequence of the upstream pollution. The levels of anionactive surfactants were relatively constant and low.

An important parameter for the Danube is oil pollution which is in national standards referred to as nonpolar extractables. The results of oil pollution measured by UV spectroscopy had low dispersion. The highest concentrations (0,033 - 0,038 $mg.l^{-1}$) were found in sampling profiles Rajka, Komarno middle, Szob left side and Visegrad. In other profiles concentrations of nonpolar extractables did not exceed 0,022 - 0,030 $mg.l^{-1}$.

**Heavy metals.**

Pollution of the Danube river caused by heavy metals is a serious environmental problem, therefore, eight parameters (Hg, Cd, Pb, As, Cu, total Cr, Ni and Zn) were monitored in all sampling profiles. Concentration ranges of cadmium (0,08 - 0,25 $g.l^{-1}$), lead (0,1 - 7 $g.l^{-1}$), arsenic, total chromium and nickel were relatively low. The most relevant heavy metal concentrations from the ecotoxicological standpoint, found in the monitored part of the Danube were those of mercury. The maximum concentration of mercury (0,6 $g.l^{-1}$) was found in the Hrusov sampling profile. This indicates the significant influence of the Bratislava agglomeration to heavy metal pollution.

**Biological parameters**

The biological classification of the Danube was based on the saprobity index evaluation. The average values of saprobity indexes during the monitoring period were in the range of 2.18 - 2.28 indicating the biological water quality of a betamezosaprobity type. Quality and quantity of bioseston varied during the sampling period. The characteristic phenomena were spring development of diatoms, an intensive growth of green algae in summer time and qualitative and quantitative reduction of phytoplankton in autumn and winter. The number of algae in the monitored part of the Danube between Bratislava and Visegrad was almost duplicated downstream. The diversity of algae corresponds satisfactorily with obtained values of chlorophyll-a.

**Microbiological parameters.**

The qualitative situation of microbiological pollution of the investigated part of the

Danube is unsatisfactory. Values of parameters measured (psychrophyllic, coliform and faecal bacteria, enterococci and Clostridium perfrigens) exceeded the critical levels. The major reason was the municipal pollution from Bratislava and Komarno areas.

**Radionuclides.**

Gross beta activity was monitored regularly in all sampling profiles in the whole duration of the project. Other parameters (tritium, cesium and strontium) were measured in selected profiles only, with lower frequency. Average values of gross beta activity in particular profiles were relatively undeviating in the range of 120 - 150 $mBq.l^{-1}$. Tritium concentrations varied between 3 - 14 $mBq.l^{-1}$, strontium concentrations varied between 4 - 8 $mBq.l^{-1}$ and cesium concentrations were more dispersed (6 - 56 $mBq.l^{-1}$). Generally, the radioactivity of the Danube can be classified as low.

**Specific organic micropollutants**

13 parameters from diverse groups of organic pollutants (chlorinated pesticides, triazines, volatile chlorinated hydrocarbons, polycyclic aromatic hydrocarbons and polychlorinated biphenyls) were monitored in selected sampling points.

Chlorinated pesticides (lindane, heptachlor, hexachlorobenzene, DDT and methoxychlor) were not found in concentrations higher than current detection limits of participating laboratories, i.e., 5-10 $ng.l^{-1}$.

Average concentrations of atrazine were lower than 100 $ng.l^{-1}$ what was a slight decrease when compared to previous year.

The average concentration of chloroform was 2 $g.l^{-1}$. Concentration increase of chloroform was apparent from Bratislava to Szob where the maximum value of 6 $g.l^{-1}$ was measured. The levels of carbon tetrachloride, trichloroethylene and tetrachloroethylene were lower than 0.45 $g.l^{-1}$.

The maximum values of polycyclic aromatic hydrocarbons (benzo(a)pyrene and fluoranthene) were on the 10 - 30 $ng.l^{-1}$ level and those of polychlorinated biphenyls (determined as Delor 103) were at 10 - 20 $ng.l^{-1}$ level.

*Generally, it can be summarized that concentrations of organic pollutants in* 1992 were substantially lower than in 1991 and concentration maxima in 1992 did not exceed the national standard limits for drinking water quality.

**Conclusion**

Comparing water quality data obtained over the period of two years the improvement of the water quality in many parameters ($BOD_5$, COD (Mn), nondissolved substances, total iron, total nitrogen, ammonia, orthophosphates, most of heavy metals and organic micropollutants) can be distinguished in 1992.

The exact information on contribution of various factors ( as e.g., hydrological regime, flood wave or sampling frequency) to this improvement will be possible to obtain after long-term observations.

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# HYDROBIOLOGICAL RESEARCH OF THE DANUBE BETWEEN RAJKA AND BUDAPEST. I. MACROZOOBENTHON

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## Abstract

The ecological state of the Danube river in the impact area of the Slovakian Hydroelectric Barrage System was studied between 1987 and 1993. As part of the hydrobiological survey of the water bodies, the macrozoobenthon community was investigated focusing mainly to the faunal description of the upper Hungarian Danube in order to collect basic ecological data. One identical stretch of the upper Hungarian Danube is formed by four sampling sites situated along the Szigetköz area. Gradual increase of taxon number is characteristic downstream until Budapest where the richest community was detected.

## Kurzfassung

Es wurde der ökologische Zustand der Donau innerhalb des Wirkungsfeldes des Slovakischen Hydroelektrischen Staustufensystems von 1987 bis 1993 untersucht. Im Rahmen der hydrobiologischen Untersuchung der Wasserkörper wurde die makrozoobenthische Gesellschaft, mit besonderer Rücksicht auf die Fauna-Beschreibung der Oberen Ungarischen Donau untersucht, um grundlegende ökologische Daten zu sammeln. Vier Probenahmestellen entlang der Kleinen Schüttinsel (Szigetköz) bilden einen homogenen abschnitt der Oberen Donau. Flußabwärts kann eine allmähliche Zunahme der Taxonzahl verzeichnet werden bis zu Budapest, wo die reichlichste Tiergesellschaft gefunden wurde.

Keywords: macrozoobenthon fauna, community structure, multivariate analysis.

## 1. Introduction

The investigated upper stretch of the Hungarian Danube impacted by the Slovakian water barrage system has two different major sections. The **Szigetköz flood plain** just after the Hungarian border contains numerous different types of water bodies including the main Danube (50 km) itself. The first 50 km section of the main river arm is characterized by strong current and high water velocities due to larger bed slope values (20-50 cm/km). An extended side arm system developed by river regulating activity follows the main Danube forming the active flood plain. The side arms receive direct surface inflow from the Danube only above 2300 $m^3$/sec due to the upstream inlets having stabilized level by rock fill dams.

The hydrogeological history of the area and the development of dead arms, old meanders, marshlands, more or less stagnant water bodies due to river engineering is discussed by GÖCSEI in details (1979).

The following **Danube River** (140 km) has rather uniform large river channel along its whole lenght with a faster section passing the Visegrád Mountains (Danube Bend) at 60 km upstream of Budapest. The sharp decrease of the slope after Gönyü results in slower current velocities. In a natural river bed where dredging and bank protection works take place nowadays, regulation and stabilization of the original channel was carried out during the last century.

Series of hydrobiological studies have been started at the Water Resources Research Centre (VITUKI) in 1981 concerning phytoplankton, zooplankton and macrozoobenthon communities, together with a limited extent of fish faunal survey. The basic purpose of the research was to predict the ecological impact of the barrage system. Therefore, knowledge of the original hydrobiological state of the Danubian water bodies using floral and faunal data before the operation of the barrage system was essentially important.

The taxon list of potamal molluscs living in the Hungarian Danube contains several aquatic snail and mussel species from the upper stretch having special zoogeographical importance (BOTHÁR 1966, RICHNOVSZKY 1970, 1979). However, data on the faunal distribution of molluscs were very seldom. Survey of the Szigetköz region describing the community structure of phytoplankton, zooplankton and macrozoobenthon by multivariate methods resulted in a typification of different water bodies (CSÁNYI 1989, NÉMETH 1989, GULYÁS et al. 1991). The estimated decrease of the fish stock and the average fish chatch in the Szigetköz and the River Danube as an essential impact of the barrage system are presented by JANCSÓ and TÓTH (1987). The leech fauna of the Danube and the adjacent region is discussed by PUKY (1989). Special notes concerning distribution of benthic taxa along the Danubian river system and differences between neighbouring water sheds due to hydrogeological history are analyzed (NESEMANN 1992, NESEMANN and CSÁNYI 1993). Predicted ecological effects of the Nagymaros-Bős water barrage system on the ichtyofauna and the benthic community caused by peak power generation technology are summarized (HOLČIK et al. 1981).

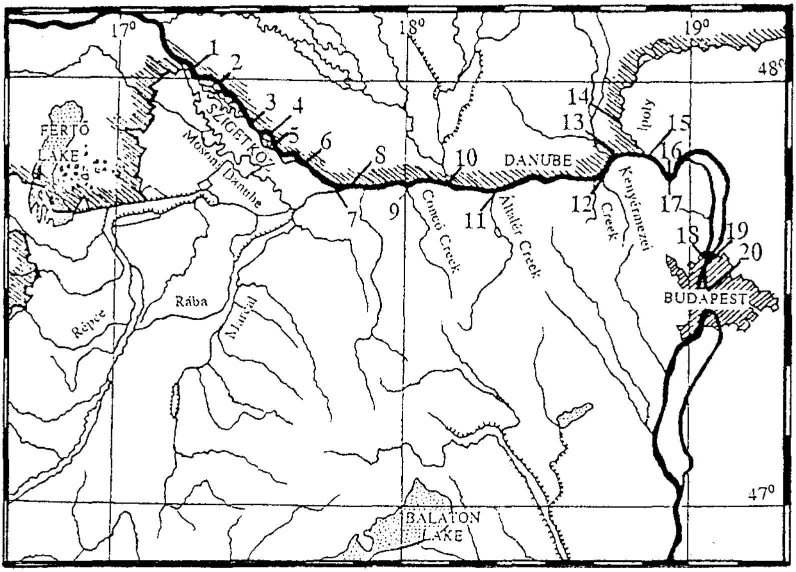
Due to spatial limitations, this paper deals only with the main Danube stretch. Detailed faunal results of the macroscopic invertebrate community (macrozoobenthon) are given as an attempt for the longitudinal typification of the river.

## 2. Material and methods

Sampling sites between Rajka and Budapest (1850 and 1659 river km) are listed in Figure 1. Capitals $\mathbf{M_K}$ and $\mathbf{M_D}$ at a given location are referring to the macroscopic invertebrate (macrozoobenthon) littoral **kick samples** and profundal **dredge samples**, respectively. Longitudinal sampling program started in 1987 and completed during the last five years at low water flow periods in order to reveal the invertebrate community of the Danube. Kick samples from the shore line were collected at 9 sites using the standard British FBA pond net with a mesh size of 950 $\mu$m (FURSE et al. 1984). An approximatelly 20 kg dredge sampler was applied successfully for sampling the middle deep parts of the Danube bed with motorboat. Cummulated results of data collected by kicking between 1987 and 1993 and by dredging in 1991 are presented in order to illustrate the species distribution along the Danube. The most important faunal results are discussed in detailes.

## 3. Results

The total number of benthic taxa in the **kick samples** was relatively high everywhere (Figure 2), but it increased to its maximum in the section just upstream of Budapest (36 taxa just at the Surface Drinking Water Works).




**1. Rajka (Z,$M_K$,$M_D$); 2. Cikolai side arm (Z); 3. Dunaremete ($M_K$,$M_D$); 4. Ásványráró (Z,$M_K$); 5. Ásványráró, port (Z); 6. Medve (P,Z,$M_K$,$M_D$); 7. Mosoni Danube, Vének (Z); 8. Gönyü (P,$M_K$,$M_D$); 9. Concó Creek (Z); 10. Komárom (P,Z,$M_K$,$M_D$); 11. Általér Creek (Z); 12. Kenyérmezei Creek (Z); 13. Esztergom (P,$M_K$,$M_D$); 14. Ipoly (Z); 15. Szob (Z,$M_K$); 16. Nagymaros (P,Z); 17. Visegrád ($M_D$); 18. Budapest, north, right bank (P); 19. Budapest, Surface Drinking Water Works (P,Z,$M_K$,$M_D$); 20. Budapest, Batthyányi Square ($M_D$).**

**P: phytoplankton; Z: zooplankton; $M_K$: kicked benthon; $M_D$: dredged benthon**

Figure 1. Map of the sampling sites on the Danube between Rajka and Budapest

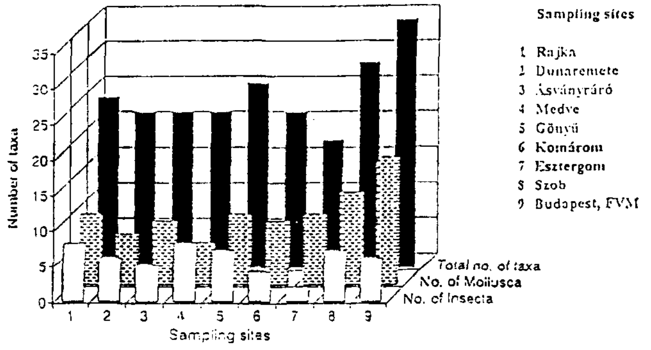



Figure 2. Macrozoobenthon taxa along the Danube River (cummulated results of kick samples collected in 1987-1993)

The cummulated taxon list contains 48 benthic taxa collected by kick sampling from the littoral zone of the Danube (Table 1). Alltogether 2 flatworm, 21 mollusc, 7 annelid, 5 crustacean and 14 insect taxa were found in the shallow, permanently enundated region of the river. Almost half of the taxa (22) were found at 5 or more sampling sites during the research period, indicating the relatively high number of common taxa.

Numerous new faunal data were gained during the last few years, some species were never detected in this river section. The aquatic neritid snail *Theodoxus fluviatilis* was known only in few locations of the Tisza river sofar. A considerable population was discovered in 1987 living just above Budapest. The species is distributed along the whole Budapest strech of the river according to the detailed survey carried out in 1990. New localities were revealed in the next years in Gönyü (1991), in Rajka (1992), dredging in the middle river bed).

All of these data suggest that considerable isolation exists between the populations within one river system. Similar results concerning other species of the same genus (*Th. transversalis* in the Tisza river system) were gained during the last few years but the reason of the disjunct occurences are unknown untill now. The characteristic Danubian snail, *Theodoxus danubialis* is found only in the lower half of the sampled river section, although this species is present at many sites in the Mosoni Danube, situated in the Szigetköz flood plain (NESEMANN 1992).

The data on the occurence of the *Potamopyrgus antipodarum* in the Danube are also new. Two thiarid species, *Esperiana esperi* and *Microcolpia acicularis* are found only in the lower range of the investigated area. These taxa live in the Mosoni Danube too, but are absent from the upper main Danube arm. *Hypania invalida*, the only pontocaspic polychaet worm of Hungary, is relatively common between Rajka and Budapest. New records of the aquatic bug, *Aphelocheirus aestivalis* are given in this report from the upper sterch (Ásványráró and Gönyü) having characteristic rapid currents.

Although the number of benthic taxa living in the profundal region of the Danube is much lower than in the littoral zone, the richness of the community has considerably increased downstream (Table 2). 14 taxa were found in the lowest cross section at Budapest, many of

Table 1. Macrozoobenthon taxa found in kick samples of the littoral (1987-1993)

| No. | TAXA | SAMPLING | | | | | | | SITES | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | TRICLADIDAE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Total |
| 1 | Dendrocoelum lacteum O.F.M. | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 4 |
| 2 | Dugesia sp. | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 3 |
| | MOLLUSCA | | | | | | | | | | |
| 3 | Ancylus fluviatilis O.F.M. | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 7 |
| 4 | Anodonta anatina L. | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 4 |
| 5 | Bithynia tentaculata L. | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 7 |
| 6 | Dreissena polymorpha Pallas | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| 7 | Esperiana esperi Férussac | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 3 |
| 8 | Lithoglyphus naticoides C.Pfeff. | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 8 |
| 9 | Microcolpia acicularis A.Férussac | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| 10 | Pisidium amnicum O.F.M. | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 |
| 11 | Pisidium sp. | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 7 |
| 12 | Potamopyrgus antipodarum Gray | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| 13 | Pseudanodonta complanata Rossm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 14 | Radix auricularia L. | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 5 |
| 15 | Radix ovata Draparnaud | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 8 |
| 16 | Radix peregra O.F.M. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 17 | Sphaerium corneum L. | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 8 |
| 18 | Theodoxus danubialis C.Pfeiff. | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 5 |
| 19 | Theodoxus fluviatilis L. | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 3 |
| 20 | Unio crassus Philippson | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 |
| 21 | Unio pictorum L. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| 22 | Valvata piscinalis O.F.M. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| 23 | Viviparus acerosus Bourguignat | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 4 |
| | ANNELIDA | | | | | | | | | | |
| 24 | Dina sp. | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 8 |
| 25 | Erpobdella octoculata L. | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| 26 | Glossiphonia complanata L. | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 4 |
| 27 | Glossiphonia paludosa Carena | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 28 | Hypania invalida Grb. | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 6 |
| 29 | Oligochaeta sp. | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| 30 | Piscicola geometra L. | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 4 |
| | CRUSTACEA (MALACOSTRACA) | | | | | | | | | | |
| 31 | Corophium curvispinum Sars | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| 32 | Dikerogammarus villosus Sovinski | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| 33 | Jaera istri Vieulle | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 8 |
| 34 | Limnomysis benedeni Czerniavsky | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 2 |
| 35 | Obesogammarus obesus Sars | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 3 |
| | INSECTA | | | | | | | | | | |
| 36 | Ablabesmyia sp. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 37 | Aphelocheirus aestivalis Fabr. | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 2 |
| 38 | Baetida sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 39 | Brachycentrus sp. | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 5 |
| 40 | Chironomida sp. | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| 41 | Clinotanypus sp. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 42 | Cricotopus sp. | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 8 |
| 43 | Heptagenia sp. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 44 | Heptagenia sulphurea Müller | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 8 |
| 45 | Hydropsyche contubernalis McL. | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 9 |
| 46 | Hydropsyche pellucidula Curtis | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 6 |
| 47 | Limoniida sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 48 | Polypedilum sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| TOTAL NUMBER OF TAXA | | 24 | 22 | 22 | 22 | 26 | 22 | 18 | 29 | 36 | 221 |

them are absent from the upstream stretch. The most common taxa are the *Dikerogammarus villosus* amphipod, the chironomid *Cricotopus sp.*, the *Hydropsyche contubernalis* and the *Oligochaeta sp.* Only two common mollusc taxa (*Pisidium sp.*, *Sphaerium corneum*) were present in the dredge samples above Budapest but 6 were detected in the last two sampling sites of the city. The three snail species (*Esperiana esperi, Potamopyrgus antipodarum, Theodoxus fluviatilis*) living in the main current were not described from the profundal region earlier. These faunal data supplement the monography of the Danubian Molluscs summarized by FRANK et al. (1990).

## 4. Conclusions

The macroscopic invertebrate community of the upper Hungarian Danube was investigated during the last 6 years in order to reveal the faunal distribution of taxa along the river. Two different sampling methods (kicking and dredging) resulted in similar conclusion. The number of taxa is gradually increasing downstream to Budapest. One identical section of the river containing four sampling sites has very similar macrozoobenthon community situated along the Szigetköz section, most probably due to similar, fast flowing conditions. Several da ta referring to the Danubian macrozoobenthon fauna are new, especially the results of the profundal region of the river.

Table 2. Macrozoobenthon taxa found in dredge samples of the profundal (1987-1993)

| No. | TAXA | SAMPLING | | | | | | | SITES | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | CNIDARIA | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Total |
| 1 | Hydra sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | MOLLUSCA | | | | | | | | | | |
| 2 | Dreissena polymorpha Pallas | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 3 | Esperiana esperi Férussac | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 4 | Pisidium sp. | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 2 |
| 5 | Potamopyrgus antipodarum Gray | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 6 | Sphaerium corneum L. | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| 7 | Theodoxus fluviatilis L. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| 8 | Viviparus acerosus Bourguignat | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | ANNELIDA | | | | | | | | | | |
| 9 | Aelosoma sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 10 | Criodrilus lacuum Hoffmeister | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 11 | Oligochaeta sp. | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 5 |
| | CRUSTACEA (MALACOSTRACA) | | | | | | | | | | |
| 11 | Corophium curvispinum Sars | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 12 | Dikerogammarus villosus Sovinski | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 8 |
| 13 | Limnomysis benedeni Czerniavsky | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 14 | Obesogammarus obesus Sars | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| | INSECTA | | | | | | | | | | |
| 15 | Cricotopus sp. | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 8 |
| 16 | Heptagenia sulphurea Müller | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 17 | Hydropsyche angustipennis Curtis | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| 18 | Hydropsyche contubernalis McL. | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 6 |
| 19 | Hydropsyche p. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | TOTAL NUMBER OF TAXA | 4 | 5 | 2 | 4 | 4 | 2 | 6 | 7 | 14 | 48 |

**Sampling sites:** 1. Rajka; 2. Dunaremete; 3. Medve; 4. Gönyü; 5. Komárom; 6. Esztergom; 7. Visegrád; 8. Budapest, north; 9. Budapest, Batthyányi square.

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# HYDROBIOLOGICAL RESEARCH OF THE DANUBE BETWEEN RAJKA AND BUDAPEST. II. ROTATORIAN AND CRUSTACEAN PLANKTON

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Abstract

The report covers results of the Rotatoria and Crustacea plankton investigations on the Danube in the period of 1987-1993. Faunal data collection was conducted to evaluate the ecological effects of the Slovakian barrage system on the river. Relationship between the hydrological regime and planktonic communities was investigated. Due to the considerably lowered flow velocities on the river section influenced by the barrage system, zooplankton communities occured in larger populations with the dominance of lenitic taxa. This indicates the growing eutrophycation tendency on the river section.

Kurzfassung

Der Beitrag beschreibt die Ergebnisse der von 1987 bis 1993 durch geführten Rotatoria- und Crustacea-Untersuchungen. Die faunistische Datenergebung erfolgte zweks Beschreibung der durch die slowakische Staustufe verursachten ökologischen Zustandänderungen. Es wurden die Beziehungen zwischen dem hydrologischen Zustand und den Planktongesellschaften untersucht. Im durch die Umleitung betroffenen Donaubett hat die Fließgeschwindigkeit drastisch abgenommen, infolge dessen großen Zooplankton-Populationen (mit lenitischer Taxon-Dominanz) entstanden. Dies weist auf eine zunehmende Eutrophisierung der untersuchten Donaustrecke hin.

## 1. Introduction

Detailed investigation of the Hungarian Danube section from mesofaunistical point of view has started in 1958. Early authors (Kertész 1963, 1967) listed in the river plankton the occurrence of 127 Rotatorian species belonging to 27 genera. In the following ten years no research was conducted on Rotatorian species on the Hungarian section of the Danube River, e.g., no scientific paper was published on the subject. Investigation of the Crustacean plankton was more detailed, the first reports were published before the beginning of the century, and after that (Daday 1885, Örley 1886, Kottász 1913, Jungmayer 1914, Dudich 1927, Éber 1955).

Longitudinal investigation of the main arm of the Danube was only conducted in 1962 (Ponyi 1962) that was followed by a comprehensive report edited by Liepolt under the title of "Limnologie der Donau". This report contained all the results of the research of the countries on the Danube.

A new chapter was opened when Bothár has iniciated her research concerning the Crustacean fauna both in the main and the side arm system as well. Her first publication appeared in 1968 that was followed by many others. Her main focuss was placed on the Danube section between Nagymaros-Göd-Budapest. To this date she identified 70 Cladoceran and moire than 40 Copepoda species from the Hungarian section of the Danube.

Zooplankton research on the upper Danube section has started in VITUKI in 1981. Later we have conducted investigations that were mainly focussed on the planktonic communities, hydrological regimes and their relationship to the hydrobiological state (VITUKI 1985, 1987, 1988, 1989, 1991).

In the frame of the Hungarian-Slovakian joint investigations water quality was monitored under the financement of the Ministry of Environment and Regional Policy in 1992. My task was to investigate the species composition of the planktonic Rotatiorian and Crustacea communities and abundance.

Investigation of species composition and species abundance of the Danube zooplankton was conducted between Bratislava and Budapest at seven sampling points, at two sampling sites on the Cikolai and Ásványi side arms, the Mosonyi Danube at Vének, the Conco Creek at Ács, the Áltelér Creek at Almásneszmély, the Kenyérmezei Creek at its confluence to the Danube, the Ipoly River at Letkés was sampled at bi-weekly freqency. Sampling points in tabulated form are listed in Csányi's report.

## 2. Material and method

Samples were taken at particular point as grab samples from the surface. 50-50 liters of water were filtered through 70 micrometer mesh size plankton net and filtrate was fixed on site by formaldehide (up to the final concentration of 4%). Determination of species was done bz a Leitz microscope. Determmination of species abundance was performed bz an Uthermöhl-type microscope using 5 ml volume counting chambers.

## 3. Evaluation of results

Analysis of the zooplankton samples revealed the occurrence of 161 zooplankton taxa. Highest species and individual number was observed in almost all the cases for the Rotatoria taxa (108 species), while the Copepoda (17 species) and Cladoceran (36 species) group was represented in lower number of species. Average abundance and the list of sampling sites are shown on Table 1.

We have recorded the occurrence of several rare species among which there were many species interesting from faunistical point of view as these were not described previously in the investigated streams. These were the *Eurytemora velox Lilljeborg*, Calanoida and the *Brachionus diversicornis f. homoceros* Wierzejski, Rotatoria species. The majority of the dominant species can be found almost always in the slow flowing streams and eutrophicated stagnant waters.

Zooplankton community of the Danube was dominated by the Rotatorian species, among which the *Brachionus angularis*, the *Keratella cochlearis*, the *Keratella cochlearis tecta* and the *Polyarthra vulgaris* species were occurring in almost any samples.

Amongst the Crustacean community elements only the nauplids and copepodit larvae of the Copepoda species can be found in similar abundance. At smaller relative frequency, but from many sampling points the following species were identified: Asplanchna priodonta, Brachionus quadridentatus, Brachionus leydigi tridentatus, Euchlanis dilatata, Filinia longiseta, Keratella quadrata, Synchaeta pectinalis, Bosmina longirostris, Chydorus sphaericus, Acanthocyclops robustus f. limnetica, Mesocyclops leuckarti. These are characteristic to the plankton communities of stagnant or slow flowing eutrophicated waters, sometimes in high abundance.

The Rotatoria and Crustacea communities of this section of the Danube can be described and characterized by the *Brachionus calyciflorus-Keratella cochlearis*, the *Keratella cochlearis tecta-Bosmina longirostris-Acanthocyclops robustus f. limnetica* species.

Amongst the so-called adjacent species, that are represented in low numbers there are planktonic ones: (*Brachionus diversicornis, Brachionus falcatus, Filinia terminalis, Kellikottia longispina, Keratella tropica, Testudinella clypeata, Bosmina coregoni, Leptodora kindtii*), those are that living in the vegetated littoral zone: (*Cephalodella catellina, Cephalodella gibba, Dipleuchlanis propatula, Trichocerca elongata, Ceriodaphnia laticaudata, Macrothryx hirsuticornis, Simocephalus vetulus, Sida crystallina*), while other are typically occurring in the muddy upper sediment layer: (*Brachionus leydigi, Trichotria tetractis, Alona affinis, Leydigia leydigi, Ilyocriptus agilis, Ilyocriptus sordidus*).

Individual abundance constantly increased from Bratislava to Budapest, while the rare and dominant species have remained the same almost every sampling location with on exceptional deviances. Maximum numbers of abundance were observed in the beginning of the summer period (May, June) and in fall (August, September). In September, in the prevailing small water level period in the area of Rajka and Medve some planktonic Crustacea species increased greatly (e.g., *Bosmina longirostris, Daphnia cucullata, Diaphanosoma bracyurum and Thermocyclops oithonoides*) apart from the usually occurring Rotatoria species.

Hydrological conditions have a strong influence on the species composition and abundance that is most expressed during floods, when both species and individual numbers showed a sharp decrease.

In many cases it was easy to see the effects of the polluted side-arms to the main arm. Downstream of the confluence point of the side-arm many cases species were found in the water body of the main arm that were drifted to there from the side-arms (e.g., members of the *Asplanchna, Brachionus, Euchlanis, Polyarthra, Synchaeta, Bosmina* genuses). This effect was most expressed at low water periods.

Number of species in the side-arms are characteristically lower but a few species form large populations. Populations of high individual abundances can be found on the flood area side-arm of the Szigetköz especially in June-September. Many so-called tichoplanktonic elements and rare species were found in the littoral zone, amongst the vegetation and on the bottom sediment. Therefore zooplankton composition of the side-arms differs considerably from the composition found in the Danube.

Species that are tolerant to organic pollution, and frequently occurring in eutrophicated waters were found as dominant in the Mosoni Danube, in the Conco and Általér Creeks. Species composition of these reflects fairly polluted water. Species composition in the Általér Creek largely effected by the water management (drainage) of the Tatai Öreg Lake. This lake is located 15 km upstream of our sampling site.

The lack of Rotatoria and planktonic Crustacea in the Kenyérmezei Creek can be explained by the heavy pollution of this stream. Zooplankton composition the Ipoly River is largely governed by the water regime of the Danube. Very rich zooplankton communities with rare species are occurring during the low water periods of summer and early fall.

Table 1. AVERAGE ABUNDANCE OF THE ZOOPLANKTON IN THE DANUBE AND IN ITS SIDE-ARMS IN 1992 (ind./100 liters)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rotatoria | 126 | 92 | 134 | 180 | 186 | 454 | 436 | 1328 | 560 | 994 | 1524 | 1390 | 54 | 1 3 4 |
| Copepoda | 34 | 30 | 234 | 52 | 44 | 70 | 60 | 52 | 620 | 572 | 370 | 132 | 40 | 3 4 |
| Cladocera | 6 | 6 | 46 | 24 | 6 | 8 | 6 | 14 | 332 | 46 | 40 | 10 | 2 | 4 6 |
| Total: | 166 | 128 | 412 | 256 | 236 | 532 | 502 | 1394 | 1512 | 1612 | 1934 | 1532 | 96 | 214 |

Sampling points: 1-Danube Pozsony middle of stream, 2-Danube Rajka right-hand side, 3-Danube Medve middle of stream, 4-Danube Komárom middle of stream, 5-Danube Szob middle of stream, 6-Danube Nagymaros middle of stream, 7-Danube Budapest Surface Water Works, 8-Cikolai branch Dunakiliti, 9-Ásványi side arm ship yard, 10- Mosoni Danube Vének, 11-Concó Creek Ács, 12- Általér Creek, Almásneszmély, 13-Kenyérmezei Creek confluence, 14-Ipoly River Letkés

## 4. Summary

Species composition of the planktonic Rotatoria and Crustacea elements in the Danube is characterized by the dominance of species indicating eutrophic stagnant and slow flowing waters in 1992. Amongst the Crustaceans only the Copepoda nauplid and copepodit larvae occurred in similar frequency.

Communities are characterized by the Brachionus calyciflorus-Keratella cochlearis tecta-Bosmina longirostris-Acanthocyclops robustus f. limnetica species.

Individual number (abundance) was shown a gradual increase between Bratislava and Budapest, but both the dominant and rare species were remained the same with but a few exceptions. Species composition of the communities and abundance were strongly influenced by the hydrological regime, that was best expressed in the sharp decrease in abundance and species numbers in high flow conditions. Effects of the polluted side arms was evident in many cases.

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# HYDROBIOLOGICAL RESEARCH OF THE RIVER DANUBE BETWEEN RAJKA AND BUDAPEST. III. PHYTOPLANKTON.

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## Abstract

The paper deals with the results of the phytoplankton studies carried out before the Slovakian Water Barrage System with the diversion of the Danube has been completed. Multivariate analysis of quantitative algological data indicated structural changes along the river stretch in connetion with hydrological conditions. Characteristic increase in phytoplankton biomass was detected between Rajka and Budapest.

## Kurzfassung

Der Beitrag befaßt sich mit den Phytoplankton Untersuchungen, welche noch vor der Inbetriebnahme des Slowakischen Staustufensystems und der Umleitung der Donau durchgeführt worden sind. Eine Multivariate-Analyse der quantitativen algologischen Dazten hat, im Zusammenhang mit den hydrologischen Bedingungen, auf strukturelle Veränderungen entlang der untersuchten Donaustrecke hingewiesen. Zwischen Rajka und Budapest wurde eine signifikante Zunahme der Phytoplankton-Biomasse nachgewiesen.

Keywords: phytoplankton, biomass, community structure.

## 1. Introduction

Several phytoplankton studies carried out on the upper stretch of the Hungarian Danube including the water bodies of the Szigetköz floodplain were dealing with algal floristics (KISS 1987, T. BARTALIS 1987, 1991) and community structure (NÉMETH 1989). The spatial heterogeneity of the chlorophyll-a content proportional to the phytoplankton biomass was studied in the Ásványi side arm (NÉMETH and SKOBRÁK 1985) together with the photosynthetic oxygen production (CSÁNYI, NÉMETH and GULYÁS 1985).

The goal of earlier phytoplankton research on the upper stretch of the Hungarian Danube including the Szigetköz floodplain was to detect characteristic algal communities of different water bodies in the area. Some rules established about the changes in the hydrobiological status in relation to hydrological conditions are based on the observations of spatial (1), and temporal (2) processes as well as the results of the enclosure experiments (3).

(1) spatial processes: hydrobiological investigations of the upper stretch of the Hungarian Danube (VITUKI 1987a, 1989, 1991).
(2) temporal variations: daily investigations of the structural changes of the phyto- and zooplankton in Ásványi Danube, in 1985 ( NÉMETH 1987, GULYÁS 1987, VITUKI 1987)
(3) Enclosure experiments for the reveal of the eutrophication processes of the Danube (VITUKI 1988, 1989, 1991, NÉMETH and GULYÁS 1990).

The longitudinal alterations in the structure and biomass of the phytoplankton of the upper section of the Hungarian Danube are the objectives of the present study.

## 2. Study area

The quantitative phytoplankton investigations along the longitudinal axis of the Hungarian Danube was carried out at 9 sampling points as follows:

1. Rajka (1848.4 river km)
2. Dunaremete (1825.5 river km)
3. Medve, bridge (1805.5 river km)
4. below the confluence of Mosoni-Danube (1802.4 river km)
5. Gönyü, port (1791.3 river km)
6. Komárom, port (1768.3 river km)
7. Esztergom, ferry (1718.5 river km)
8. Nagymaros, port (1694.6 river km)
9. Budapest (1659.0 river km)

The map of the sampling network is presented in the first part of this study.

## 3. Material and methods

Phytoplankton samples were fixed and preserved by Lugol's iodine and formaldehyde respectively. Population density of taxa was determined by counting with an Opton-type Utermöhl invertoscope using sedimentation chambers 2cm$^3$ in volume. For the biomass-estimation specific volume of all taxa were determined by measuring their linear dimensions and by approximation with simple geometric forms. For graphical representation of the phytoplankton biomass data was divided to five fractions (f1, f2,...f5) according to an arbitrarily chosen logarithmic interval scale. The boundaries of the individual categories of specific volumes of algal taxa ($\mu m^3$/individuum) were established as the volumes of spheres of 1-2; 2.1-4;...32.1-64 $\mu$m in diameter (Table 1).

Quantitative data were analyzed by multivariate classification methods using the SYN-TAX III. program package (PODANI 1988). Numerical classification based on the biomass data of the taxa was performed by hierarchical agglomerative clustering. Euclidean (E) and chord distance (C) as well as Ruzicka (R) and Gower (G) similarity coefficients (in distance form D=1-S) were used for the pairwise comparison of the samples.

Table 1.

| | $d_{sphere}$ ($\mu$m) | | | specific volume ($um^3$) |
|---|---|---|---|---|
| f1. | [1-2](1.41) | - | [2.1-4](2.83) | 1.5-12 |
| f2. | [2.1-4](2.83) | - | [4.1-8](5.66) | 13-95 |
| f3. | [4.1-8](5.66) | - | [8.1-16](11.31) | 96-758 |
| f4. | [8.1-16](11.31) | - | [16.1-32](22.63) | 759-6070 |
| f5. | [16.1-32](22.63) | - | [32.1-64](45.25) | 6071-48500 |

## 4. Results and discussion

The population density and the taxonomic composition of the phytoplankton in the upper reaches of the Hungarian Danube were investigated in 1987, 1989, and 1991, in order to recognize the different sections of the river on the basis of spatial structure of phytoplankton, and, to reveal dependence of spatial structural alterations upon the hydrological conditions.

Regarding to the considerable ecological impact of the Slovakian Danube diversion, the detailed analysis and revision of the earlier algological results are undoubtedly important. On the basis of qualitative and quantitative investigations, it was found that:

- centric diatoms (Cyclotella, Stephanodiscus, Thalassiosira spp.) and the chlorococcal green algae were dominant in phytoplankton of the Hungarian Danube at all times investigated;
- the main structural characteristics of the phytoplankton did not change within the time interval of investigations (1987-1991);
- filamentous, heterocystous blue-greens were occurred in some cases, indicating the slight increase of eutrophication of the river;
- two reaches of the Danube were distinguishable between Rajka and Budapest (1850 and 1640 river kms, respectively) on the basis of the longitudinal changes in abundance and composition of phytoplankton. The boundary of the two reaches changes in time, but it is located between Komárom and Nagymaros;
- relatively high concentration of chlorophyll-a was measured in autumn of 1991 at Ásványráró river section (48.7 mg * $m^{-3}$, 56.5 mg * $m^{-3}$ and 62.9 mg * $m^{-3}$ at 05, 12 and 17 September,

respectively) corresponding to the 5. "Meso-eutrophic" and 6. "eutrophic" degree according to the trophic scale of FELFÖLDY (1987).

The results of the phytoplankton investigations along the Danube in 13 July 1989 illustrate the statements concerning these structural changes.

The longitudinal variation in the concentration of suspended solids ($mg/dm^3$) and chlorophyll-a ($mg/m^3$) as well as phytoplankton biomass ($mg/dm^3$) are shown in Figure 1.

According to the observations, the following qualitative statements are taken:

- the concentration of suspended solids decreased, while the chlorophyll-a concentration and the algal biomass increased downstream;
- characteristic peak of chlorophyll-a and phytoplankton biomass occured under the confluence of the Mosoni Danube;
- maximum values of the chlorophyll-a concentrations and the biomass were measured at Nagymaros (sampling point 8);
- The ratio of the different fractions of phytoplankton is fairly constant along the river, but the elements of the largest specific volume occured below the confluence of the Mosoni Danube. Their increasing rate was detectable along the river together with the similar increase of the trophic degree.

The graphical representation i.e. dendrograms of the results of cluster analysis are shown in Figure 2. The groupings of sampling sites, according to the individual distance (similarity) coefficients are given by the following bracketed representations:

E: ((((((2,3)1)7)5)6)(8,9))4)
C: ((((((2,8)9)6)(3,7))1)5)4)
R: ((((2,7)(3,5))((8,9)6))4)1)
G: (((((((1.2)3)5)6)7)9)8)4)

On the basis of the structure of phytoplankton, 4 sections were distinguishable on the upper stretch of the Hungarian Danube in July 1989, considering the spatial changes of biomass, as follows:
(1,2,3): Rajka-Medve; (4): short river-section below the confluence of the Mosoni-Danube (5,6,7): Gönyü-Esztergom; (8,9): Nagymaros-Budapest.

In this non-nutrient limited water body, the phytoplankton biomass increeased downstream, parallel with the decreasing flow velocity. Considerable structural changes take place within the river section from Rajka to Budapest.

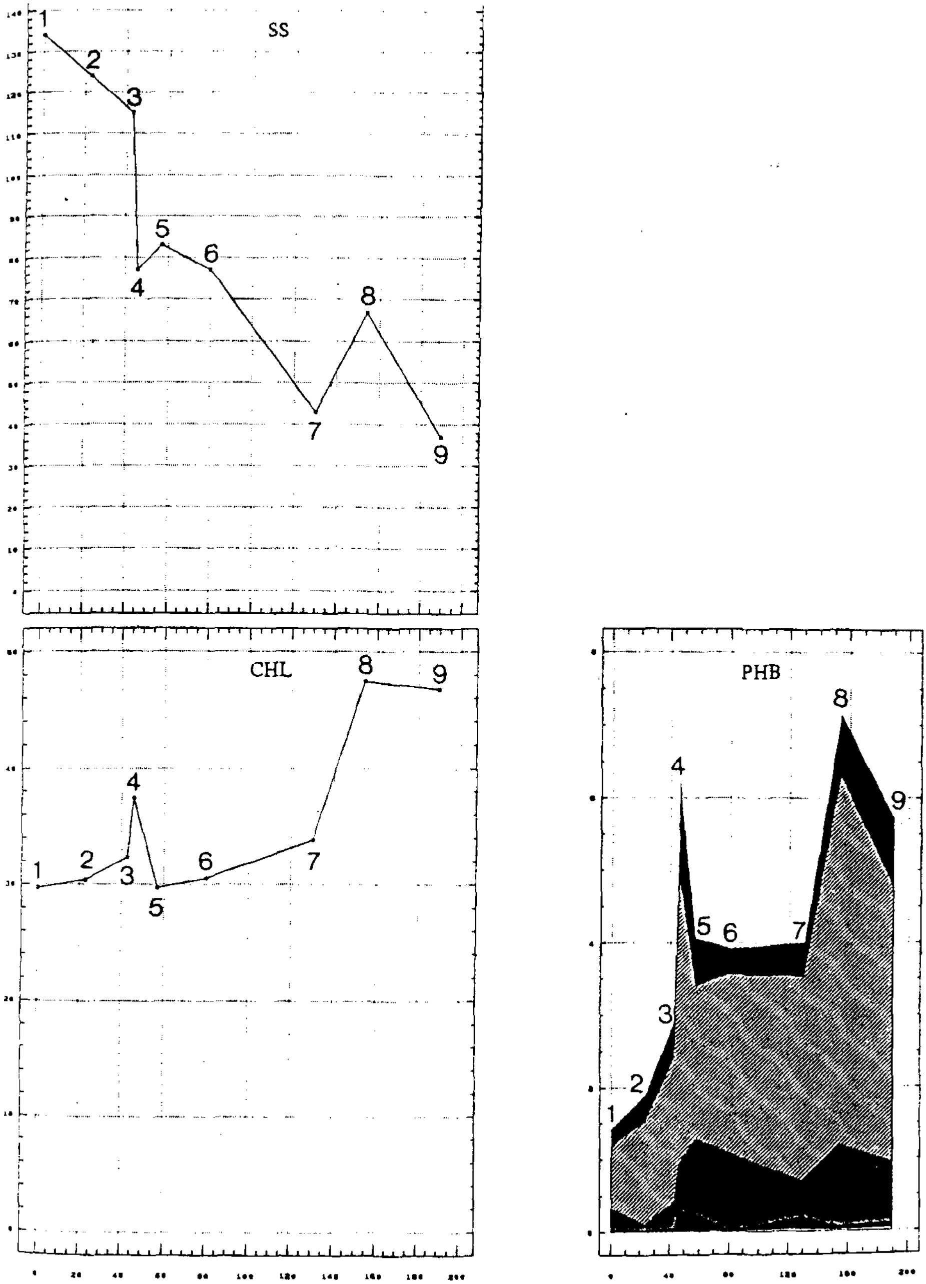


Figure 1. Changes of suspended solids (SS: mg/dm$^3$), chlorophyll-a (CHL: mg/m$^3$) phytoplankton biomass (PHB: mg/dm$^3$) versus distance (km) from Rajka.

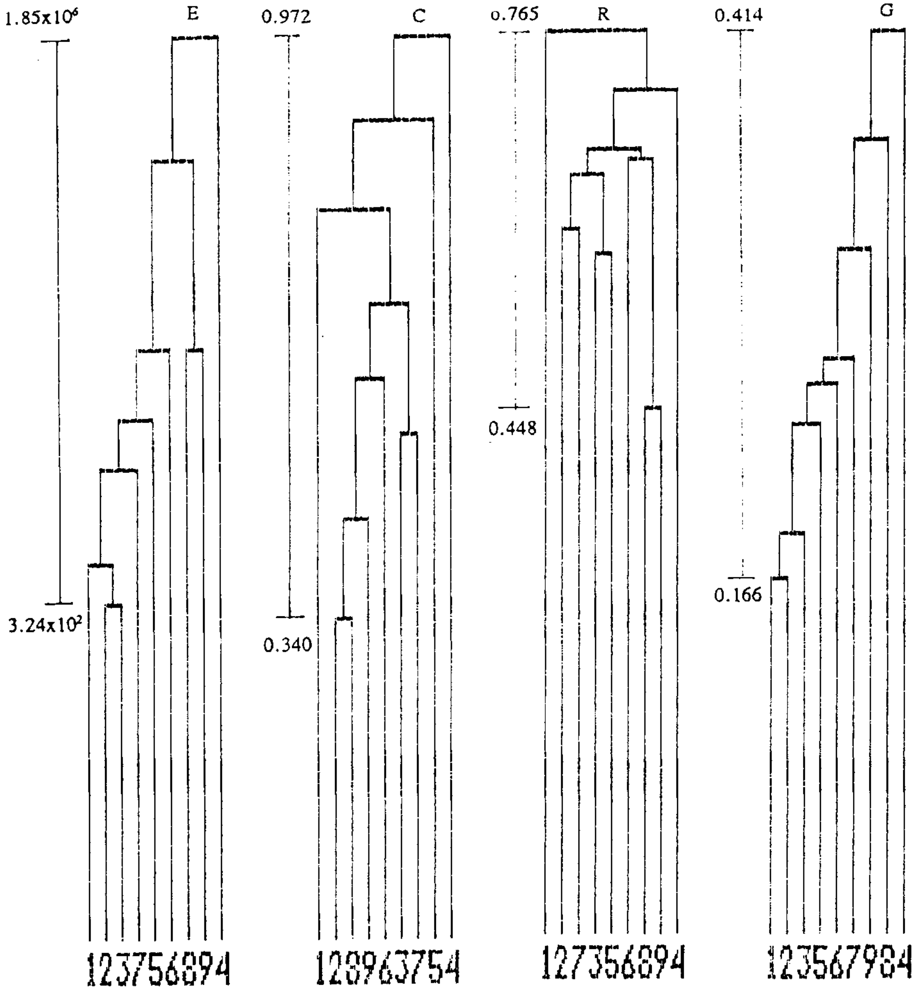


Figure 2. Dendrograms of sampling sites

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# PRIMARY PRODUCTION AND DESTRUCTION OF ORGANIC SUBSTANCES (OS) IN THE WATERS OF TISA BASIN IN UKRAINE

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Abstract

The complete data on the primary productivity and destructional processes by the benthic, planktonic and periphytic communities of hydrobionts in the Tisa basin were obtained for the first time in Ukrainian territory. It was shown that in all cases the exeeding of organic pollution over the natural self-purification in the river Tisa and it's tributaries took place. This exeeding was especially high in autumn.

DIE PRIMARPRODUKTION UND DESTRUKTION DER ORGANISCHER STOFFE IN DEM UKRAINISCHEN ABSCHNITT DER TISSA UND DES ZUFLUSSENS

Kurzfassung

Zum erstenmal , die Intensitat wurde fur Tissa mit Nebenflussen in Grenze Ukraine eine produktions-destruktiven Prozessen in Gruppen des Planktons, des Bentos und des Perifitons aufgestallt. Der Verfassen zeigt, das war die selbstwasserreinigung ein Tissa und des Tissaflusswasers im alles Falle ubergesteigern. Diese Erscheinung besonders bemerkbar im Herbst machen zich.

## 1. Introduction

Data on primary productivity and destruction of OS by the water communities allowed to evaluate the peculiarities of functioning of water ecosystems as a whole. The importance of the investigations in the river Tisa basin is doubtless for the complete lack of information. Only a separate data were obtained by Kovalchuk(1993) on the river Prut, Tisa, Latoritsa and Uz before present investigation.

2. Materials and Methods

Experiments on the total primary production and destruction of OS by the different ecological groups of hydrobionts were done by the bottles method in oxygen modification (Winberg, 1960). Benthic samples were exposed *in standart bottles* ($S=10cm^2$), *planktonic and periphytic* (mainly stones) in 0.5 - 1.0 litre bottles. Duration of the experiments on destruction (8 - 36 hours) and production (12 - 24 hours) was highly dependent on the season.

Sometimes samples were not exposed in the place of *sampling. This led to the using of temperature coefficients* proposed by Winberg (1983) to compensate changes in metabolism intensity.

Taken into consideration the complicated calculations the computer program "PRODUCT" on Turbo Basic had been developed by the author.

High intermixing of water in the Tisa waterflows reduced to a minimum the anaerobic component of destruction which is very important in reservoirs (Kovalchuk et al., 1991).

3. Results and discussion

The most complete data on the total primary production and destruction of OS were obtained in summer. *In seasonal* aspect the high intensity of investigated processes was observed in spring (Table 1). Especially high levels of the processes had been established to the Lower reaches of Tisa (in Ukrainian territory) during the high-flood water period. In this period the daily destruction exceeded 20 $kkal/m^2*d$ that corresponded with mineralization of 20 g of "wet" OS per day. In interhigh-flood period the levels of destruction of OS in the Lower reaches of Tisa were obviously lower and don't exceeded 4 $kkal/m^2*d$. The Middle reaches of Tisa had been characterised by the same levels of the process.

Evidently lower temperature (+3-5°C) and not high concentration of OS (<7 mg by the bichromic oxydation , that corresponded with 20 g of OS in $m^3$ of water) had meant slow preceeding of production-destructional processes in Stogovets (the Upper reaches of Tisa).

Situation had changed in summer and summer-autumn period (Table 2). The role of periphytic and planktonic communities was related in a whole . Daily destruction of OS by plankton in clear mountain rivers (Stogovets, Bila Tisa before the village Lugi, Teresva), don't exeeded 0,3-0,7 $kkal/m^3*d$ with total production 1,3-1,6 $kkal/m^3*d$. In the other sites of Tisa the level of the process discussed was higher, exceeding in peculiar cases 10 $kkal/m^3*d$ (Tisa near the village Veljatin and the lake Sinevir). Significantly in invastigated waters of the Tisa's basin - the Tereble - Rikske Reservoir and the Sinevir lake there was a considerable predominance of the destruction over the

Table 1. Daily destruction and the total primary production of OS by the benthic communities of Tisa and it's tributaries in April 1991 (kal/m²*d)

| Waterflows | Date | Control of oxygen concentration | t° | Wea. | Bentos | |
|---|---|---|---|---|---|---|
| | | | | | D | A |
| 1.Stogovets | 26.04 | n. 10.000 | 4.0 | cl. | 900 | 860 |
| 2.Tisa b.Velijatin | 25.04 | n. 9.000 | 9.3 | ser. | 7250 | 7060 |
| 3.The same place | 29.04 | n. 9.000 | 9.0 | ser. | 3100 | 5990 |
| 4.Tisa n. Vilok | 19.04 | n. 9.000 | 8.1 | cl. | 20550 | 2890 |
| 5.The same place | 25.04 | n. 9.000 | 9.1 | ser. | 2950 | 7870 |
| 6.The same place | 29.04 | n. 9.000 | 12.8 | ser. | 3450 | - |

t°- temperature, D - destruction of OS, A - total primary production, Wea.-weather, ser.- serene, cl.- claudy, var. cl.- variable claudy, b.-before, n.-near, a.-after.

primary production (Table 2).

Values of the total primary production that had been established in ivestigated region were considerably lower as in the Lower reaches of the Danube (Shcherbak et al., 1987). Daily primary production in the photic layer of the river Danube was 7-10 kkal/m³*d (recounted by myself) without any essential fluctuations during the year. It was find (Tsishkarishvili, 1987) that in the Ritza lake (Caucasus) the mean value of the total primary production was 0,3 kkal/m³ *d and the mean destruction in plankton 0,5 kkal/m³ *d. Taking into consideration that my experiments were done in the littoral part of the Sinevir lake it was significantly the obvious exceeding of the destruction over production in both lakes.

The destruction of OS by the periphytic communities usually exeeded 2 kkal/m²*d but sometimes achieved to 10 kkal/m²*d. Only the Upper reaches of the Bila Tisa and it's tributary the river Stogovets were characterised by a very low level of the periphytic OS destruction. Undoubtedly it was coused by the temperature (Table 2). Usually the primary production of OS by the periphytic communities exeeded 1,5-2,5 times over destruction (presence of net production). As regards the Lower reaches of Tisa (in Ukrainian territory) and the area near the Veljatin village had shown the opposite situation in connection with an intensification of self-purification prosesses.

Data on the production-destructional processes in the benthic communities had confirmed as a whole the absolute indexes obtained to periphyton. However the exeeding of the primary production over destruction was never observed.

The late autumn (November) was characterised by the

Table 2. Daily destruction and the primary production of OS by the benthic, periphytic and planktonic communities of the river Tisa and it's tributaries in summer and summer-autumn period 1991 (kal/m³*d or kal/m²*d accordingly)

| N | Station | Date | t° | Wea. | Plankton D | Plankton A | Periphyton D | Periphyton A | Benthos D | Benthos A |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Chorna Tisa | 15.08 | 11 | ser. | 3700 | 0 | - | - | 1022 | 1573 |
| 2. | Bila Tisa | 16.08 | 12 | ser. | 700 | 1300 | 400 | 1153 | 252 | 294 |
| 3. | Tisa a. Rahov | 16.08 | 18 | var. cl. | 2800 | 200 | 2667 | 1769 | 1316 | - |
| 4. | The same place | 19.08 | 18 | ser. | - | - | - | - | 10660 | - |
| 5. | Tisa b. Velijatin | 20.08 | 20 | ser. | 2700 | 1700 | 4876 | 6999 | 12705 | 5566 |
| 6. | The same place | 21.08 | 20 | ser. | - | - | 4876 | 7237 | - | - |
| 7. | Tisa b. Velijatin | 26.08 | 18 | ser. | 17400 | - | 10977 | 6616 | - | - |
| 8. | The same place | 27.08 | | ser. | - | - | 10978 | 4252 | - | - |
| 9. | Tisa n. Vilok | 22.08 | 21 | ser. | 7800 | 800 | 4061 | 4386 | 7456 | 3134 |
| 10. | Shopurka b.V.Bichkov | 27.08 | 15 | cl. | 9900 | - | 4081 | - | - | - |
| 11. | Tisa a. Solotvino | 28.08 | 14 | cl. | 2300 | 4000 | 1660 | 4652 | 2195 | 1959 |
| 12. | Stogovets | 31.08 | 8 | cl. | 300 | 1300 | 700 | 1121 | - | - |
| 13. | Bordjava n. Dovge | 8.09 | 15 | ser. | 3400 | 2600 | 2356 | 5093 | - | - |
| 14. | Rika n. Lipcha | 8.09 | 16 | ser. | 1100 | 1000 | 2892 | 4278 | - | - |
| 15. | Rika b. Midzgir'ja | 9.09 | 13 | ser. | 3400 | - | 1258 | 3742 | - | - |
| 16. | Ter.-Rik-ske Res. | 10.09 | 12 | ser. | 1600 | 0 | - | - | - | - |
| 17. | Sinevir lake | 11.09 | 13 | ser. | 10700 | 1000 | 2401 | 3127 | - | - |
| 18. | Teresva n. Tirnovo | 11.09 | 14 | cl. | 500 | 1600 | 2952 | 2796 | - | - |
| 19. | Teresulka | 12.09 | 13 | ser. | 1400 | 1200 | 1458 | 2507 | - | - |

extremely decreasing of the production-destructional activity of all ecological groups (Table 3). The usual OS destruction in plankton was less than 2 kkal/m³ *d and in some areas (Stogovets, Rika near the village Lipcha, Tisa after Tiachev) it was less than 1 kkal/m³* d. Under unstable hydrological regime in autumn, short period of sunshine and

Table 3. Daily destruction and the total primary production of OS by the benthic, periphytic and planktonic communities of the river Tisa and it's tributaries in autumn 1991(kal/m³ *d or kal/m²*d accordingly)

| N | Station | Date | t° | Wea. | Plankton | | Periphyton | | Benthos | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | D | A | D | A | D | A |
| 1. | Tisa a. Rahova | 13.11 | 3 | cl. | 903 | 0 | 245 | 0 | - | - |
| 2. | Tisa b. Velijatin | 2.11 | 5 | ser. | 1536 | 1600 | 79 | - | 42 | 220 |
| 3. | Tisa n. Vilok | 9.11 | 6 | var. cl. | 2133 | - | 100 | 107 | - | - |
| 4. | Stogovets | 13.11 | 3 | var. cl. | 500 | - | 238 | 45 | - | - |
| 5. | Bordjava n. Dovge | 2.11 | 3 | ser. | 855 | - | 285 | - | - | - |
| 6. | Rica n. Lipcha | 2.11 | 3 | ser. | 296 | - | 32 | - | - | - |
| 7. | Rika b. Midzgir'ja | 7.11 | 4 | cl. | 2100 | 2363 | 1599 | 323 | - | - |
| 8. | Ter.-Rikske Res. | 7.11 | 5 | cl. | 1829 | 2058 | - | - | - | - |
| 9. | Tisa a. Tijachevo | 9.11 | 5 | var. cl. | 484 | 0 | 223 | 688 | - | - |

abrupt changes of weather the total primary production of OS had not been established in some cases. When presented the total primary production of phytoplankton was as high as destruction.

Abrupt "cleaning" and "mobilyty" of stones in the water flows provide evidens to decreasing the production-destructional activity of periphyton. The phytoperiphyton could'nt restored the velocity of vegetation in circumstances of a low water transparention and fall of a solar radiation. This had coused missing of a previous thickness of the peryphitic community. In benthos the productionally active leyer was washed away producing the abrupt decreasing in intensity of the process of the primary productivity.

It was higly interesting to made calculation of a self-purification in Tisa during the year. Based on the data of correlation between the primary production, destruction of OS and results of permangan and bichromic oxydation one could calculate an approximate balance and the admissible level of OS content that would be self-purificated. E.g. in summer the site Tisa after Solotvino was characterised by the level of OS 15g O/m³, or (adequate) 50g OS in 1m³ of water. Exceeding of the total production over destruction in planktonic community is 1,7 kkal/m$^3$ *d, which corresponded with 1,7 g OS/m$^3$*d. Taking into consideration the middle depth in the sampling area (1,5m) only 7-8 % of the total OS (5,5 from 75 g) was of the autochtonic origin. Consequently the self-purification ability of the river had been exeeded more than 10 times (75:5.1). The redundant of biogenous elements had created good conditions for the auto-eutrophication.

Case described above was a result of the most unfavourable situation. Ordinarly the exeeding wasn't so high , e.g. simulteneous calculation to Bordjava give the following ballance: the middle depth of the river is 0,5 m; 1m included 5g OS exeeding of destruction over total production in plankton - 0,6 g/m$^3$*d; exeeding of the total production over destruction in periphyton is 2,8 g/m$^3$ *d. So, 2,2 g or 40% of the whole OS was of an autochtonic nature. Therefore the exeeding over the self- purification is only 1,2 -1,3 times (0,9g OS under 1m$^2$ and 5:4,1).

In autumn the situation became worse. Under the level of OS concentration closely related with the case previously discussed (Bordjava, summer) in connection with the extremely reduced ability of a self-purification the excess was more high. Calculation to the site Tisa after Tiachev gave exeeding over the self-purification 10-12 times, to the site Tisa after Rahov - 12-14 times.

Thus the data for the first time obtained to conditions of the mountain rivers of the Transcarpathian region are allowed to establish the high role of autochtonic OS in water pollution. The part of autochtonic OS fluctuated dependently on the site and season between 5 and 60%. It was higher in summer and lower in autumn. Exeeding over the self-purification in tributaries of the basin and Tisa itself was observed in all cases, especially in autumn it was usually more than 10 times.

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# PECULIARITIES OF TRACE METAL DISTRIBUTION IN THE ABIOTIC ENVIRONMENTS OF DANUBE'S WATER ECOSYSTEM

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Results of the study of content, spatial distribution and transformation of such metals as Fe, Mn, Zn, Cu, Pb, Ni, Co, Cd in the system "water-particulate matter-bottom sediments" of the river Danube are presented. Quantitative data have been obtained and comparative analysis of the contamination levels of the different environ0

ments of Danube's ecosystem has been carried out on the 1900 km piece of the river. Peculiarities of trace metal distribution in the different types of bottom sediments have been studied.

BESONDERHEITEN DER VERTEILUNG DER SCHWERMETALLEN IN DEN ABIOTISCHEN MILIENS DER DONAUWASSERÖKSYSTEM

Die Forschungsugebnisse des Behaltes, der räumlichen Verteilung und der Transformation von Fe, Mn, Zn, Cu, Pb, Ni, Co, Cd wurden im Donausystem "Wasser-Schwebstoffe-Geschiebeablagerungen" vorgelegen. Die quantitative Daten wurden ergeben und die vergleichende Analyse der Verunreinigungsstuffe der verschiedenen abiotischen Miliens des Donauökosystems wurden im Donauabschnitt mit den Länge mehr als 1900 km vergewirklicht. Die Besonderheiten der Verteilung der Schwermetallen wurden in den verschiedenen Zusammensetzungen der Geschiebeablagerungen untergesucht.

The main objectives of these studies are to obtain quantitative data for comparative characterization and estimation of the trace metal pollution's level of different components of Danube's ecosystem in the limits of some Danube's states, to investigate peculiarities of trace metal distribution in the different type of bottom sediments.

Primary data were obtained during the international expedition "Blue Danube 90" in 1990.

The obtained results characterize the period of low water levels of Danube. The long rainless period on the considerable part of the catchment in 1990 resulted in absence of surface runoff and in consequence the minimum amount of particulate matters in the water (5.0-4.5 mg/l). The velocity of water flow for this period on the non-regulated pieces varied in the range of 0.28-2.24 m/c.

Figure 1 shows the investigation's results of content of trace metals' dissolved and particulate forms.

**Figure 1.** *Content of dissolved and particulate forms of trace metals (mcg/l) in the water of Danube. 1-Ukraine, 2-Roumania, 3-Bulgaria, 4-Yugoslavia, 5-Hungary, 6-Czechia & Slovakia, 7-Austria; P- particulate, D- dissolved.*

It has been determined that trace metals according to their concentrations could be arranged in the following descending sequence Fe > Zn > Mn > Pb > Ni > Cu > Co > Cd. Such metals as Fe, Mn, Zn and Cu are very unequal distributed along the river. The concentrations of these metals trend to increase downstream with the maximum on the Roumanian and Ukrainian pieces of the river (Fig. 1). The total content of Fe increases from 322.0 to 745.0 mcg/l; Mn - from 18.0 to 48.9 mcg/l. The particulate forms dominate for both of these metals (80%). The dominated forms of Cu and Zn for this period are dissolved forms (65 and 85% of total content accordingly). The total concentration of Zn increases from 48.0 mcg/l on the Austrian piece of Danube to 84.0 mcg/l on the Roumanian piece; Cu - from 7.6 mcg/l in the upper range to 17.9 mcg/l on the Ukrainian piece. The contents of Pb, Ni, Co and Cd in the water vary insignificantly along the river. Average concentrations of these elements account to 14.0, 17.0, 4.0 and 1.7 mcg/l accordingly. Co, Pb and Ni migrate predominantly in the particulate forms (64-72.5%); Cd - in the dissolved form (56%).

According to specific content of trace metals' particulate forms (percentage of total concentration) the mentioned above metals form following sequence: Fe > Mn > Pb > Ni > Co > Cu > Zn > Cd. This sequence is accounted for high affinity of Fe, Mn, Pb and Ni ions to clay minerals. Sorption of ions on the surface of particulate matters occurs as a result of physical adsorption, ion exchange and also chemical sorption with formation of chemical associates of ions with particles' surface.

The results of roentgenostructural analysis showed that particulate matters of Danube water are represented by quartz, feldspars, calcite, hydromicas, montmorillonite (in order of content decrease). Clay minerals (calcite, hydromicas, montmorillonite) play decisive role in trace metal sorption and transforming dissolved trace metals into particulate form.

The trend of trace metal interphase distribution in the system "water-particulate matter" is determined by individual chemical properties of each metal, amount of particulate matter in the river stream, its granulometric and mineral composition and also by physicochemical conditions of water environment. The particulate matters with the size of 0.05 mm and less have the largest sorption capacity. They stay in the river stream long time in conditions of high velocity and play determinative role in interphase distribution of trace metals in the system "water-particulate matter".

The decrease of stream velocity, that is observed in Danube reservoirs and at the mouth of the river, causes considerable decrease of particulate matter amount and also amount of trace metals included in their composition in the river stream as a result of sedimentation. Figure 2 shows data of trace metal content in bottom sediments of different Danube's pieces. The maximum values are observed in the silt deposits with high content of organic substances. Considerable part of upper and middle Danube has not conditions for active silt accumulation in consequence of high stream velocity (0.34-2.15 m/c). Bottom sediments on these pieces of the river (excepting local littoral zones) are represented mainly (95%) by sandy fractions.

Granulometric analysis of bottom sediments of the reservoir Dzherdap-1 showed that specific content of fractions with the particles' size ≤ 0.05 mm accounts to 94.4%. In the lower part of Danube (Ukrainian piece) in dependence of depth (7.0 - 14.5 m) and stream velocity (0.28 - 0.43 m/c) the content of mentioned fractions ranges from 35.1 to 85.4%.

Practically for all extent of the upper and middle Danube, excepting local littoral zones and pieces of tributary confluences (Tisa, Sava), bottom sediments

are represented by sandy deposits with negligible concentrations of trace metals (near to background). The maximum content of trace metals is characteristic for silt

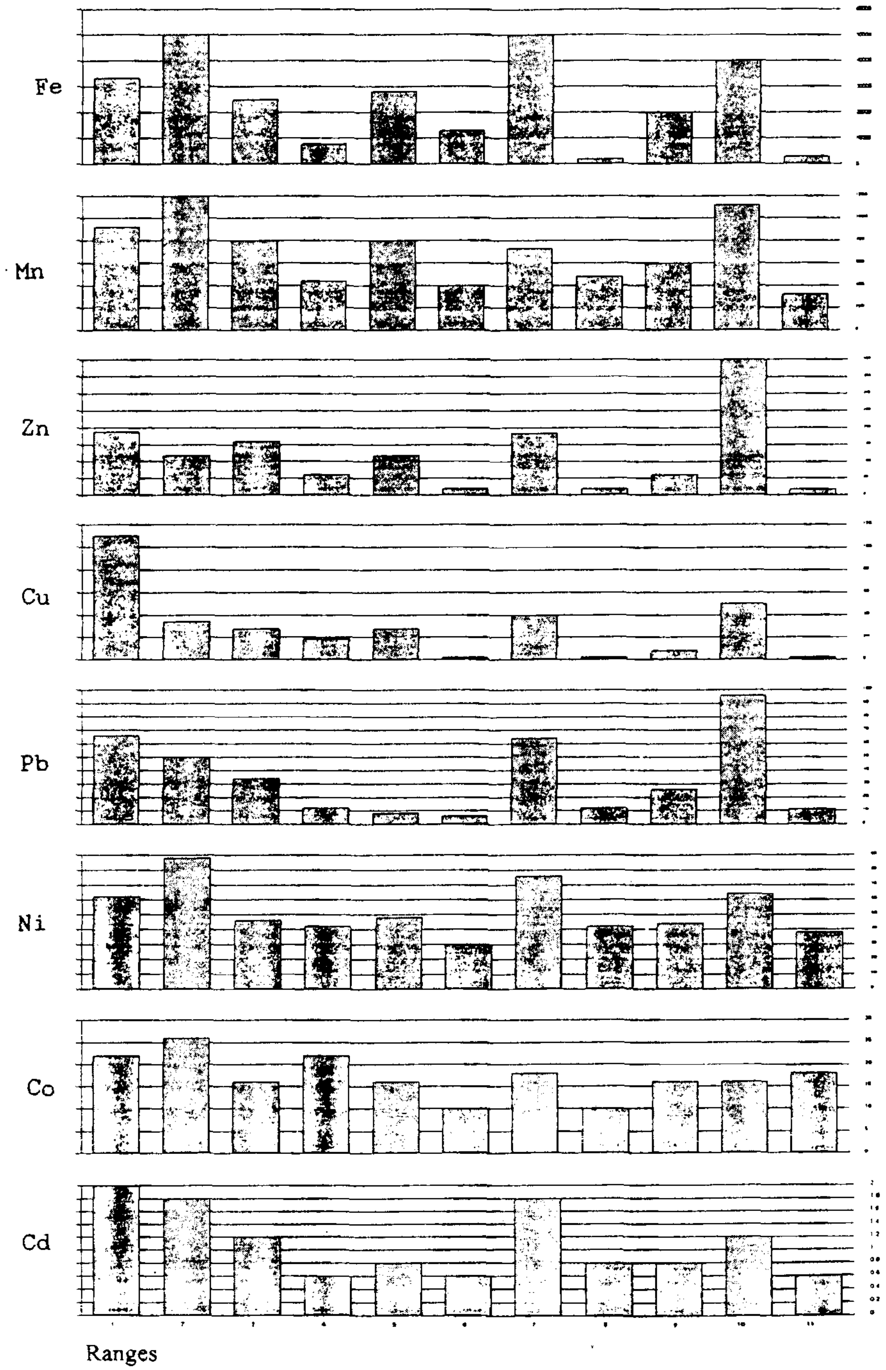


**Figure 2.** *Content of trace metals (mg/kg of dry mass) in the bottom sediments (0-3 cm) of Danube. The locations of ranges see in Table 1.*

sediments, which occur in the deep water zones (reservoirs and mouths).

**Table 1.** Locations of the ranges of bottom sediments' sampling on the river Danube.

| Range [1] | Location of range |
|---|---|
| 1 | Downstream of Kiliya, Ukraine |
| 2 | Downstream of Ismail, Ukraine |
| 3 | Up-stream of Ismail, Ukraine |
| 4 | Downstream of Reni, Ukraine |
| 5 | Borch's arm, Roumania |
| 6 | Silistra-Kelerashi, Roumania |
| 7 | Nikopol-Turnu-Menurele, Bulgaria-Roumania |
| 8 | Oryakhovo-Beket, Bulgaria-Roumania |
| 9 | Vidin-Klafat, Bulgaria-Roumania |
| 10 | Downstream of Tisa's mouth, Yugoslavia |
| 11 | Gabchikovo, Czech & Slovakia |

Investigations of bottom sediments of Dzherdap-1 reservoir (Table 2) showed that the upper layer (0-2 cm) and deeper layer (22-25 cm) are the most enriched as compared with the other samples from different pieces of the river. The reservoir Dzherdap-1 is the powerful barrier. Its bottom sediments at the expense of active processes of sedimentation accumulate considerable amount of trace metals, which are in the composition of particulate matters. According to calculations 1 square kilometer of bottom sediments in the reservoir Dzherdap-1 contains in the upper 25 cm layer 4961 t of Fe, 148 t of Mn, 84 t of Zn, 19 t of Cu, 11 t of Ni, 3 t of Co, 0.6 t of Cd.

**Table 2.** Content of trace metals (mg/kg of dry mass) in the core of bottom sediments (0-25 cm) of the reservoir Dzherdap-1

| Layer, cm | Fe | Mn | Zn | Cu | Pb | Ni | Co | Cd |
|---|---|---|---|---|---|---|---|---|
| 0-2 | 48400.0 | 1440.0 | 820.0 | 186.0 | 166.0 | 102.0 | 26.0 | 4.8 |
| 2-7 | 55600.0 | 1800.0 | 960.0 | 208.0 | 196.0 | 114.0 | 28.0 | 6.8 |
| 7-17 | 46000.0 | 1280.0 | 780.0 | 202.0 | 158.0 | 96.0 | 26.0 | 6.4 |
| 17-22 | 48400.0 | 1360.0 | 680.0 | 160.0 | 144.0 | 102.0 | 24.0 | 6.4 |
| 22-25 | 50000.0 | 1520.0 | 740.0 | 178.0 | 146.0 | 110.0 | 28.8 | 5.2 |

The main factor, which determines trace metal distribution in bottom sediments, is dispersion degree of particles. The study of trace metal content in different granulometric fractions showed, that decrease of their size is accompanied with increase of concentrations of practically all metals. The fractions with the size of 0.1-1.0 mm are represented by sandy materials and practically don't take part in the process of water environment's self-purification. Bottom sediments with fractions' size ≤ 0.05 mm are the most dangerous. If hydrodynamic condition changed they could be involved in the river stream and transported for long distances.

In the reservoir of Dzherdap-1 more than 96% of Fe, Zn, Pb, 95% of Cu, Ni, Cd, 92% of Co are contained in the fractions < 0.05 mm. In the river's mouth these values are: Fe 62-89%, Mn 60-69%, Zn 73-78%, Cu 83-91%, Ni 64-88%, Co and Cd 77-84%.

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# SOME CHANGES IN THE WATER QUALITY AND WATER USE, DUE TO BACKWATER REGIME IN THE DJERDAP I RESERVOIR

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ABSTRACT

Effects of the changes in the water quality to different users in the run-of-the-river reservoir of the Danube Hydro Power Plant Djerdap I were analyzed trought the following considerations:
-the determination of specific changes in the water quality in this reservoir compared to a classic lake sistem,
- the study of the sediment and its impact on the surface and the graundwaters,
- the defining the level of the water treatment needed for the water supply.
Conditions of the run-of-the-river reservoir flow resulted in the sedimentation of the plankton material, thus causing numerous changes in the system. High levels of suspended matter, BOD load, heavy metals and other matter's removal from the water result in the transient Red-ox potential stage in the sediment.
Fine sedimented fractions of inorganic mass and detritus at the decomposition stage contribute to a multiple degradation of ground water resources in the riparian zone.

## GEWASSERNUTZUNG UND QUALITATSANDERUNGEN IM STAUSEE DES WASSERKRAFTWERKS DJERDAP I

Die Analyse umfasst den Einfluss der Gewasserqualitatsanderungen im Stausee des Wasserkraftwerks Djerdap I auf Gewassernutzniesser. Folgendes wurde analysiert:
- Gewasserqualitatsanderungen im Stausee verglichen mit diejeningen im naturlichen Seesystem,
- Der Sediment und sein Einfluss auf Oberflachen - und Grundwasser,
- Der Einfluss auf die Grundwasseraufbereitung zur Wasserversorgung.
Der eingestaute Abfluss im Stausee verursacht die Sedimentation von Plankton und dadurch mehrere Systemveranderungen. Hoher Abscheidungsgrad von Suspensionen, BSB, Schwermetallen und anderen Stoffen aus dem Wasser resultiert mit Ubergangswerten von Red-ox Potential im Sediment. Der feine anorganische Sediment und Detritus aus der Abbaustufe verursachen eine mehrfache Degradation des Ufergrundwassers.

## 1. INTRODUCTION

The maintenance of water quality standards in downstream sections of rivers, particularly long ones, is a growing problem in the efforts to meet the demands of many various users in the basin. A universal problem in this domain is eutrophication of reservoirs and rivers which is extremely difficult to control. The reason is the complexity of nutrient removal processes from the pollution point sources, and the extremely difficult control of these substances from diffuse pollution sources. That is why the phenomenon of water quality degradation is likely to prevail in th future. Eutrophication of water systems is manifested in an increased organics (plankton an other organisms) production resulting in a numerosity of adverse effects on water quality. The eutrophication effects on numerous water users are expressed in th need of a higher processing level. Hence, the maintenance of the water quality standards for natural resources is becoming an increasingly limiting factor of development, because it greatly burdens the economy of production by demands for investment in treatment technology of water for direct use and for protection of receiving water bodies from further pollution. Water quality degradation due to eutrophication has both short and long-term effects which are very often beyond the field of consideration.
An example of complex effects in this process on water users is th Danube section run-of-te-river reservoir Djerdap I. It drains an area of over 800000 square kilometres, and provides a high level o primary production in its section upstream of Belgrade. That is the reason of inefficiency of the steps taken and the river's always high background of organic load.
Specific hydrodynamic characteristics of the river give different contour conditions for physico-chemical and biochemical processes in the river sections of natural flow-upstream section, and under dam backwater conditions-Djerdap I run-of-the-river reservoir. Of some interest is the comparison between the effects of eutrophication in the Sava Lake, which is a typical example of a high organic production system and the effects of the run-of-the-river reservoir Djerdap I on water users.

## 2. SPECIFIC CHANGES IN THE RUN-OF-THE-RIVER RESERVOIR

The effects of run-of-the-river reservoir on the water quality in the system significantly differ from those in a standard lake systems. The considered Danube section is a part of the Djerdap Da I backwater. Changes in the composition of water mass, in this section, are considered in earlier contributions. The geometry of the basin and discharges have an appreciable influence on the changes. Plankton biomass reduction from upstream section has a high-level effect on the quality of percolating water, besides the changes in the storage system. The Sava Lake, which is a typical example of the eutrophic system including production and related processes in the system itself, has similar effects on the processes controlling the composition of infiltrating water.

## 2.1. Production of organic matter and related phenomena

The process of water accumulation, impoundment and storage, enhances eutrophication which begins with a higher primary production. The considered Danube section has a different behaviour. Many studies report (Perišić et al.1990,1991) the absence of eutrophication in the backwater at a high nutrient load. Results of these studies are consistent with the model of a great length of the Danube (Muller, 1991). The available data give conventional eutrophication parameters for the two systems as summarized in Tab.1.

Tab.1. Eutrophication evaluation for Djerdap I storage(*) and the Sava Lake (**)

| | |
|---|---|
| Transparency (*I, **D) | Phytoplankton biomass (*D,**I) |
| Suspended solids (*D, **I) | Zooplankton (*D, **I) |
| Chlorophyll a (*D, **I) | Primary production (*D, **I) |
| Epilimnetic oxygen supersaturation (*D, **I) | |

(I- increasing in the system; D- decreasing in the system)

The plankton biomass reduction in the Danube backwater is resulting in a high-load deposit from organic matter production. Transportation proceses relevant to : sedimentation, reaeration, intensity of exchange on the contact layer water/ sluge changed considerably, depending on the discharge. Some basic data related to the transport processes in the storage are shown in Tab.2. The data presented in Tab.2. and criteria for the evaluation of the stratification based on the value of Froude's number (Water Resources Enginers,1969)

$$F_d = 10^{-5} \frac{L}{z\ t}$$

where: L-storage length (m),z-mean depth (m),t-retention time(yrs), enable us to evaluate the potentials of this process. In keeping with this principle, for the values od $F_d >> 0.32$,the reservoir is thermally homogeneous which is the case with the analyzed section of the river Danube.

## 2.2. Organic decomposition and oxygen demand in the reservoir

The removal of oxidable organics has evidently high effects in the backwater section (Tab.1). The efects of BOD removal are extremely high, particularly under the minimum flow conditions. A significant drop in organic load was noted with the increasing discharge in the downstream end, BOD5 was higher. Consequently, the effects of a reduction BOD5 content in the studied section ranged from 25 to over 75 percent, which gave a high constant value of composite BOD reduction (Kr) for single subsections.

Oxygen deficit due to the reduced reaeration effects (K2) in the backwater section is a highly limiting factor of the Danube water quality at this section.

## 2.3. Sadimentation processes and their effects

Reduction of suspended matter and codeposition of detritus is typical of a slow flowing body, which was noted, together with a high plankton biomass reduction, in the Danube backwater section. Analogous processes evolve in the storage system of a shallow-lake type, the Sava Lake at Belgrade, one function of which is the infiltration basin. The Sava Lake, by the Vollenweider (1982) method, has the trophy rate between trophic and hypereutrophic states (Perišić et al. 1987). There are two storage systems : one the Sava Lake, being controlled by classic limnologic laws, and th other, Djerdap I reservoir where eutrophication is much reduced i spite of high nutrient content. Either system, however, is characterized by sediment with a high detrit rate, which is the dominant suspension phase in the Sava Lake.

Tab. 2. Biochemical degradation and reaeration in the studied section (characteristic discharges, water temperature about 15°C)

| Section | Discharge $m^3/sec$ | $BOD_5$ mg/l in/out | Dissolved $O_2$, mg/l in/out | Mean velocity m/sec | Retent. time days | $K_r$ 1/day | $K_2$ 1/day |
|---|---|---|---|---|---|---|---|
| | 1850 | 8.17/5.18 | 7.74/6.56 | 0.21 | 3.14 | 0.145 | 0.202 |
| Smederevo | 3300 | 5.59/3.44 | 9.21/8.65 | 0.47 | 1.57 | 0.309 | 0.358 |
| to | 9500 | 3.39/1.71 | 7.02/6.90 | 1.30 | 0.57 | 1.23 | 0.731 |
| V. Gradište | 11900 | 5.24/3.35 | 9.77/10.2 | 1.65 | 0.44 | 1.02 | 0.865 |
| | 1850 | 5.18/3.15 | 6.56/5.11 | 0.18 | 4.44 | 0.112 | 0.111 |
| V.Gradište | 3300 | 3.44/1.87 | 8.65/6.72 | 0.22 | 3.99 | 0.162 | 0.128 |
| to | 9500 | 1.71/1.52 | 6.90/6.86 | 0.65 | 1.32 | 0.189 | 0.274 |
| D.Milanovac | 11900 | 3.35/2.62 | 10.2/10.4 | 0.80 | 1.10 | 0.224 | 0.317 |
| | 1850 | 3.15/2.26 | 5.10/4.51 | 0.10 | 4.03 | 0.082 | 0.043 |
| D.Milanovac | 3300 | 1.87/1.28 | 6.72/6.68 | 0.16 | 2.79 | 0.136 | 0.060 |
| to | 9500 | 1.52/1.44 | 6.86/6.80 | 0.49 | 0.91 | 0.060 | 0.131 |
| Tekija | 11900 | 2.62/2.33 | 10.4/10.0 | 0.60 | 0.74 | 0.158 | 0.151 |

Sediment compositions (Tab.3) of these two storage systems give a picture of the similarities in the deposition processes.

Tab. 3. Some parameters of typical sediment compositions

| Composition parameter ppm. | Cultivated land | Sluge from wastewater p. (Čikago) | Sava Lake depósit | Djerdap I storage deposit |
|---|---|---|---|---|
| N (tot.) | 2250 | 39900 | 1250 | 1040 |
| P (tot.) | 840 | 16000 | 3480 | 2800 |
| Fe | 20000 | 8800 | 18000 | 14000 |
| Mn | 370 | 95 | 1050 | 980 |
| Cu | 20.0 | 57.8 | 38.0 | 118 |
| Cr | 20.0 | 207 | 56.0 | 87.0 |
| Cd | 1.0 | 14.8 | 2.9 | 2.6 |
| As | 4.4 | 29.0 | 46.0 | 34.0 |
| Hg | 0.22 | 6.1 | 0.48 | 1.15 |

Decomposition of organic matter in the sediment evolves during the deposition and in the subsequent solid phase, as has been stated i

earlier work (Perišić et al. 1991) on many measurements of degradation and secondary effects (changed red-ox potential, metal elution, etc.). Mineralization produces a very fine-textured sediment.
Percolation and recharge of the alluvial aquifer, particularly the source of Belgrade water supply, are significatly limited where this type of deposit is being formed. The degradation of alluvial ground water sources from the river and its sediments evolves through many processes which increasingly require an advanced water treatment technology for supply from these sources.

## 2.4. Some influences on the ground water treatment level

Ground water from the Sava and the Danube riparian zones through the city area has long been used for the municipal water supply. Water treatment includes aeration for separation of $H_2S$, oxidation and separation Fe and Mn, ammonia oxidation and subsequent disinfection with chlorine. The need for chlorination of water from these resources has grown in the last several years.
Since chlorine consumption in water depends on the amount and kind of the material reacting with chlorine, the raw water processing level directly defines the balance and kinetics of chlorine consumption. The removal of suspended and dissolved mater in treatment plants includes more or less successful elimination of certain contents. Chlorine consumption in water treatment, its kinetics and amounts, is not any more given much consideration, because it has been abandoned as a disinfectant to avoid formation of the purgable organics halogen. Data from Choisy-le-Roi water supply (Bablon, 1987) give decisive elements for evaluation of the effects of individual water treatment stages on the chlorine consumption balance and kinetics.
Chlorine consumption for water of varied treatment levels at this plant have been compared, for example, with those for water treatment plant at Banovo Brdo. This gave a picture of the general quality of drinking water from the riparian alluvion of the backwater river section.
The available treatment solutions do not satisfy the current standards, as shown by statistics (Tab. 4), because the excesses over the standards are much beyond the permissible level.

Tab. 4. Chlorine content in the Belgrade water supply network (statistical data, many years averages )

| | | | |
|---|---|---|---|
| Chlorine content (mg/l) | > 0.5 | 0.2 - 0.5 | 0.0 |
| Sampling rate ( % ) | 14.5 | 81 | 4.5 |

## 3. CONCLUSIONS

Production of organic matter in the reservoir system (Sava Lake) or its formation in the upstream river section generates similar effects on the sediment composition and leads to degradation of water quality with short and long-term consequences. Specific effects of a reduced primary production from the settled out planktonic material, in Djerdap I backwater of the Danube, similarly to integral processes in the Sava Lake, lead to the formation of an organic-rich sediment. Sediment compositions of the two analysed systems indicate effects of heavy metal concentration

in planctonic material and their short and long-term effects on water quality in the lake system and in percolated water.
Fine sedimented fractions of inorganic mass and detritus at the decomposition stage contribute to a multiple degradation of ground water resources in the riparian zone. The degradation affects organic materials, red-ox process and related ionic species. Stabl degradation effects of ground water demand higher chlorination; this calls for a more advanced treatment technology for drinking water as the first in a sequence against eutrophication effects.

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# GROUNDWATER VULNERABILITY EVALUATION APPROACH IN NORTHERN CROATIAN PLAINS. CASE STUDY: RAVNIK-KUTINA AREA

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ABSTRACT

The paper deals with one of the pilot areas of a current applied hydrogeology research project based on the electro-hydraulic analogy. In large river plains filled with loose clastic sediments and saturated with groundwater of a commonly low salinity, the geohydraulic parameters controlling the vertical groundwater flow through covering aquitards are substituted with their approximate "counterparts": hydraulic conductivity index, $\kappa$, and leakage index, $\lambda$. These parameters are determined by means of the specific electrical resistivity of those sediments. The maps showing the distribution of $\lambda$-values may be used for a quick, low-cost evaluation of groundwater vulnerability to heavy agricultural pollution by fertilizers and pesticides.

## VERSUCH EINER BEWERTUNG DER GRUNDWASSERGEFÄHRDUNG IM FLACHLAND VON NORDKROATIEN. FALLSTUDIE: GEBIET VON RAVNIK-KUTINA

KURZFASSUNG

Es wird über ein noch laufendes Forschungsvorhaben der angewandten Hydrogeologie berichtet. Die in einem Versuchsgebiet begonnene Bewertung beruht auf dem Zusammenhang zwischen den elektrischen und den hydraulischen Eigeschaften der Gesteine. Das Gebiet besteht aus großen Flußenbenen, die mit unverfestigten klastischen Sedimenten erfullt sind. Die Salinität des Grundwassers ist generell gering. Die hydraulischen Parameter, welche die vertikale Bewegung des Wassers durch wenig durchlässige Deckschichten bestimmen, werden aus den spezifischen elektrischen Widerständen der Sedimente abgeleitet. Die diesen Parametern angenähert entsprachenden Grössen "Index der hydraulischen Leitfähigkeit", $\kappa$, und "Leakage-Index", $\lambda$, werden auf Karten dargestellt, aus denen die Grundwassergefährdung durch Dungemittel und Pestizide ohne großen Aufwand ermittelt werden kann.

## INTRODUCTION

The demand for potable water has been ever more oriented towards the extraction of groundwater. This process is particularly obvious in the European lowland plains composed of large, thick river and lake sediments where the water demand is always very high. The protection of groundwater quality in those areas, naturally, becomes an ever more pressing concern.

The paper is part of a research project in which the geoelectro-hydraulic analogy is used to help in the solving of several important horizontal and vertical groundwater flow problems. The Ravnik-Kutina case study area, situated in the river Sava plain some 100 km downstream of Zagreb, is one of ten project pilot areas. For this area, only the groundwater vulnerability to pollution from the land surface is considered within this paper.

Numerous small villages string out along the mountain piedmont and its ridges, at the Sava river bank and on the loess terrace. Petroleum industry plants and their large waste disposal storage are situated at or close to the town of Kutina, at the eastern border of the study area. An international highway and a trunk railway pass along the piedmont. The mountain slopes, terrace and river valleys are agriculturally cultivated, but not yet intensively. The Lonjsko Polje, as a National Park with invaluable river and marsh flora and fauna, will remain uncultivated.

## COMPUTATION OF THE LEAKAGE INDEX

The principal task in the research pilot areas, to determine a reliable $\kappa/\rho$ curve, was achieved using the data on hydraulic conductivity, K, identified by the calibration of the Ravnik pumping site model (Urumović et al. 1993) and the values of specific electrical resistivity, $\rho$, obtained from two phases of resistivity sounding. A substantial basis was provided by an earlier such curve defined within a complex hydrogeological exploration carried out in the Hutovo Blato area, in Herzegovina (Šarin 1965). The $\kappa$-$\rho$ curve of Hutovo Blato was made on the basis of a precisely interpreted shallow resistivity sounding and a great number of grain size analyses from the core of several shallow exploratory boreholes while a surprisingly accurate and useful relationship between laboratory measurements of permeability and pertaining grain size analyses of loose clastic sediments was found in an old handbook (Justin et al. 1944).

The $\kappa$-$\rho$ curve, that was finally accepted for the Ravnik-Kutina area, was used to determine $\kappa$-values from $\rho$-values for each resistivity sounding station performed in that area. From the obtained $\kappa$-values, the values of leakage index, $\lambda$, were computed for each resistivity sounding station. For that, the equation to compute the leakage coefficient, L (Hantush 1964) is used, but, instead of the vertical hydraulic conductivity, our discussed approximate parameter, the hydraulic conductivity index, is used. Thus,the modified equations are:

$$\lambda = \kappa/m' \qquad\qquad \lambda = 1/\sum_{i=1}^{n}(m_i'/\kappa_i)$$

where $\lambda$ is leakage index in LI units; $\kappa$ and $\kappa_1$, $\kappa_2$, ..., $\kappa_n$ are hydraulic conductivity indices of only one or of the first, second, ..., n-th layer in HCI units; m' and $m_1'$, $m_2'$,..., $m_n'$ are pertaining thicknesses of only one covering layer or of the first, second ..., n-th covering layer, in metres.

The electrical resistivity data of resistivity sounding stations occurring on the loess terrace could not be used for the determination of their $\kappa$-values. The unsaturated zone is too thick there, occasionally more than 40 m. Let us remind that the discussed $\kappa/\rho$ relationship is valid only if loose sediments are saturated with water and the $\kappa$-$\rho$ curves are not valid for the unsaturated zones. A thorough hydrogeological reinterpretation of geoelectric data may help in eliminating the effect of that zone if its thickness does not exceed several metres.

## GROUNDWATER VULNERABILITY

A map showing the distribution of all $\lambda$-values in the Ravnik-Kutina area was prepared (Fig. 1). The $\lambda$-values were not determined for the loess terrace and this is

## THE RELATED APPLIED HYDROGEOLOGY RESEARCH PROJECT

The Institute of Geology of Zagreb, financially supported by the Ministry of Science and Technology of the Republic of Croatia, has launched a research project based on the geoelectro-hydraulic analogy. The field geoelectric measurements, i.e. the measured specific electrical resistivity, ρ, of loose sediments saturated with fresh groundwater, are used to determine the approximate values of the geohydraulic parameters controlling groundwater flow. There is number of several papers dealing with similar subjects and some of them may be selected (Van Dam & Muelenkamp 1967, Pfannkuch 1969, Duprat et al. 1970, Zohdy et al. 1974, Kelly 1977, Mazac & Landa 1979, Kosinski & Kelly 1981, Allessandrello & Lemoine 1983, Kelly & Frohlich 1985, Huntley 1986, Ahmed et al.1988). The main project researcher has been sporadically interested in various applications of the geoelectro-hydraulic analogy for hydrogeological purposes since 1965 (Šarin 1965, 1990; Šarin et al. 1978, Šarin & Brkić 1993).

In order to indicate the approximate nature of the values obtained that way, instead of "true" geohydraulic parameters: hydraulic conductivity, K, transmissivity, T, and leakage coefficient, L - we refer to the hydraulic conductivity index, κ; transmissivity index, τ; and leakage index, λ. For the same reason, their units are named HCI, TI and LI but they are approximately equal to m/day, $m^2$/day and $day^{-1}$, respectively.

The project is aimed at finding a reliable relationship between the hydraulic conductivity index, κ, and electrical resisitivity, ρ, for the northern Croatian lowland. To that end, ten areas were selected from that region as research pilot areas. Once a reliable κ-ρ curve or curves are defined, on the basis of κ-values, the corresponding τ and λ-values can be computed for each resistivity sounding station. The maps showing the distribution of τ and λ-values may considerably contribute to the solution of several important horizontal and vertical groundwater flow problems of large river plains.

## FEATURES OF THE STUDY AREA

The case study area is a lowland of nearly 200 $km^2$. It belongs to the valleys of the river Sava and its left tributary, the Lonja. The slopes of a small mountain, the Moslavačka Gora, border the area to the northeast. To the west, there is a low eolian terrace. The southwestern part of the study area, belongs to a long alluvial depression, the Lonjsko Polje, large parts of which are seasonally inundated.

Neogene clastics form the mountain slopes. The terrace is composed of Pleistocene loess, while the valleys and Lonjsko Polje were filled with Quaternary alluvial, lacustrine and marsh deposits. The Quaternary deposits contain a large aquifer, 30 to 150 m thick and reaching occasionally to a depth of about 250 m. It is composed of sand, rare gravel and silty or clayey strata. The covering aquitard, ranging in thickness between 0 and 120 m, consists of silty and clayey strata with sand lenses. The precipitation (about 900 mm a year) infiltrates through the aquitard and recharges the aquifer. The 11 drilled wells at the Ravnik pumping site, range in safe yield between 2 and 13 l/s, in specific capacity between 1.5 and 5.2 l/s/m and in transmissivity between 250 and 600 $m^2$/day (Urumović et al. 1986, 1993).

shown by special symbols on the map. The sites, where no aquifer was detected within about 250 m of the land surface, also have special symbols on the map.

All the remaining geoelectric points are indicated with their leakage index values in the map. These $\lambda$-values are divided into four classes: greater than $10^{-2}$ LI, $3x10^{-4}$ to $10^{-2}$ LI, $10^{-5}$ to $3x10^{-4}$ LI and lower than $10^{-5}$ LI. It may be repeated that the unit 1 LI is approximately equal to 1 $day^{-1}$. The numerical boundaries $10^{-2}$ LI and $10^{-5}$ LI have been defined on an empirical, hydrogeologically founded basis.

On the map, several areas with different degrees of vulnerability risk are shown. (1) Between the rivers Sava and Lonja, there is no covering aquitard, thus, this area is very vulnerable - class A. (2) Around the village of Kostrinja, the aquitard is 5 to 20 m thick and the area is evaluated as medium risk - class B. (3) Southwest of the village of Osekovo, there is an area where the aquitard is 10 to 30 m thick and it is considered medium risk - class C. (4) East of the Osekovo-Kostrinja line, the aquitard is extremely thick, over 90 m in places. It is considered not vulnerable - class D. (5) At the Ravnik pumping site area, the aquitard is 30 to 50 m thick, but several sites have very high $\lambda$-values. This area should be regarded as vulnerable but it consists of several classes - B, C and even a small area of A. (6) To the north and northeast of the village of Potok, the aquitard does not exist, hence, this area is very vulnerable - class A. (7) The area to the west of the pumping site of Ravnik may be considered vulnerable mainly because of its position close to the Ravnik pumping site - class B.

The degree of vulnerability of the loess terrace has not been evaluated for the above mentioned reasons, but, taking in consideration the usually high vertical permeability of loess deposits, the terrace may be considered to have at least the medium degree of vulnerability. There is a belt occurring at the slopes of the Moslavačka Gora and at the entire eastern margin of the study area where no aquifer was detected down to a depth of about 250 m. Therefore, this belt could be treated as not vulnerable. This is important information since, east of that belt, close to the village of Repušnica, there is a large petroleum waste water disposal storage.

## CONCLUSION

The reason for presenting this paper is the authors' wish to demonstrate a simple, quick and low-cost applied hydrogeology research method. The best feature of this method is, probably, its ability to provide a good basis for the evaluation of groundwater vulnerability to agricultural pollution in large river plains. In order to demonstrate this, the groundwater vulnerability map of the Ravnik-Kutina area, one of ten research pilot areas, was prepared (Fig. 1).

It is necessary to emphasize that the presented map was made using only existing exploratory data. It may be also added that, if the researchers engaged in the research project had designed the network of resisitivity sounding stations for this map, they would have used a considerably smaller number of sounding stations. Similar results would have been achieved with density of only one station per 6 $km^2$. Such a density is four times lower than that of the resistivity sounding stations in the geoelectric profiles marked with letters A to J occurring in the southern half of the map. Even these profiles were designed and supervised by the authors of this paper within a special hydrogeological exploration project in 1992 and the discussed $\kappa/\rho$ correlation was born in mind. The remaining profiles (marked in the map by the

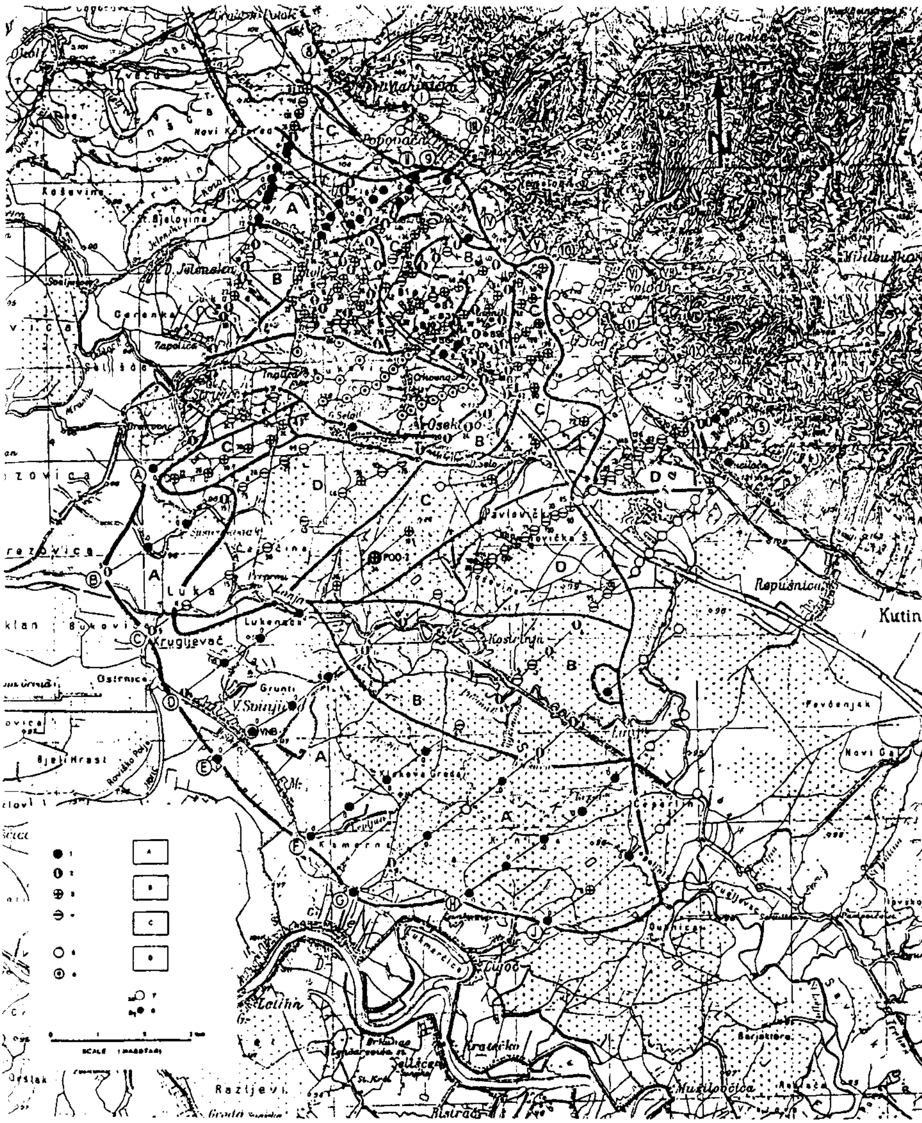

Fig.1 Groundwater vulnerability map of the Ravnik-Kutina area
Abb.1 Die Karte der Grundwassergefardung des Gebiet Ravnik-Kutina

Legend /Legende: 1 - $\lambda > 10^{-2}$ LI, 2 - $\lambda = 3\times10^{-4}$ to $10^{-2}$ LI, 3 - $\lambda = 10^{-5}$ to $3\times10^{-4}$ LI, 4 - $\lambda < 10^{-5}$ LI, 5 - Without aquifer /Ohne Grundwasserleiter, 6 - Loess terrace /Lössterrasse, 7 -Resistivity sounding station and covering aquitard thickness /Meßpunkt der Wiederstandssondierung und Mächtigkeit der wenig durchlässigen Grundwasserdeckschichten, 8 - Drilled well /Geborter Brunnen, A - Area of high vulnerability /Gebiet großer Gefährdung, B and C - Area of medium vulnerability /Gebiet mittlerer Gefährdung, D - Area of low vulnerability /Gebiet geringer Gefährdung figures I to IX and 5 to 12) were designed earlier and only by geophysicists.

At the end, the authors wish to add that the researchers participating in the project had to solve a series of not always simple problems in applying the discussed "κ/ρ analogy". However, a team of experienced hydrogeologists did it and can achieve it elsewhere.

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# THE VARIABILITY OF SOME HYDROGEOCHEMICAL PARAMETERS AND GROUNDWATER LEVELS AT THE BULGARIAN PART OF THE DANUBE RIVER AND ITS TERRACES

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ABSTRACT: Two experimental profiles at the "Kozloduy" and "Belene" lowlands, where a nuclear power station is in operation and another one is in construction, were established. Each consists of one observation point for surface waters, three points for ground waters and one for a drinking water supply station. The water samples were taken in the period 1992-93 while the sampling frequency depended on the seasonal and hydrometeorological conditions. The macro components, integral parameters and some biogenic elements in different migration forms as well as 12 most important heavy metals were determined.
For better understanding the behavior of the ingredients analyzed, stochastic methods for time series analysis were used. Relations between the statistical estimates at different points of the two experimental profiles were found. Corresponding time lags for the water levels and the hydrochemical parameters were evaluated.

# ÜBER DIE VARIABILITÄT VON EINIGEN HYDROGEOCHEMISCHEN PARAMETERN UND GRUNDWASSERSTÄNDEN IM BULGARISCHEN FLUSSABSCHNITT DER DONAU UND IN IHREN TERRASSEN

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KURZFASSUNG: Es wurden zwei experimentelle Profile in der Kozloduj und Belene Tiefebenen eingerichtet, wo ein Kernkraftwerk ("Kozloduj") in Betrieb ist und ein weiteres ("Belene") - im Bau. Jedes Profil besteht aus einem Beobachtungspunkt fur Oberflächen-(Donau-)wasser, drei Punkten (Bohrungen) fur Grundwasser und einem Punkt fur Trinkwasserversorgungsanlage. Die Wasserproben wurden in 1992-1993 entnommen und die Probenahmefrequenz war von den Jahreszeit- und hydrometeorologischen Bedingungen abhängig. Die summarischen Parameter, die Hauptbestandteile und einige biogene Elemente in verschiedenen Migrationsformen, so wie 12 wichtigeren Schwermetalle wurden bestimmt.
Zum besseren Verstehen des Verhaltens von den analysierten Parametern wurde die stochastische Zeitreihenanalysenmethode angewendet. Die Beziehungen zwischen statistischen Bewertungen in verschiedenen Punkten der zwei experimentellen Profile wurden gefunden. Die entsprechenden Zeitverschiebungen fur die Wasserstände und die hydrochemischen Parameter wurden beurteilt.

## 1. INTRODUCTION

The main goal of this work was to study the interrelations: Danube river water - groundwaters in its terraces at the Bulgarian part of the river basin and especially the influence of the river quantity and quality on the groundwater characteristics. For this purpose two monitoring profiles at the Kozloduy and Belene lowlands, where one nuclear power station (Kozloduy) is in operation and another (Belene) is under construction, were established (Fig. 1). Each profile consists of one observation point for the Danube river water, three points (shallow wells, situated at different distances from the river) for groundwaters equiped with level gauges and one point near the profile being a drinking water supply station. Naturally, the precipitations were also taken into account.

The water samples (all together 446, 26 of which are from precipitated waters, 82 from the river channel and 338 from the wells and pumping stations) were taken with frequency depending on the seasonal and hydrometeorological circumstances during the period 1992-1993. Samples were analysed in the town of Pleven (Laboratory of the National Institute of Meteorology and Hydrology) and in Sofia (University of Mining and Geology).

## 2. GROUNDWATER LEVELS VARIABILITY.

Naturally the groundwater levels are influenced by the river ones (Fig. 2 and 3) resulting in significant correlation coefficients between 0,43 and 0,82. The groundwater level response delay depends on the nature and the space homogeneity of the water bearing aluvial materials as well as on the distance of the corresponding monitoring points from the river channel. So the response is faster for the groundwater levels in the Belene lowland which acquifer is more homogenous and with better transmissivity - 500-4700 $m^2/d$ as compared with the Kozloduy lowland - 150-2200 $m^2/d$ (Antonov, Danchev, 1980).

The crosscorrelations show the almost equal way of reacting for wells 1 and 3 (No 1 for the nearest well to the river) - see for instance Fig. 4 (Belene lowland). This observation is also valid for the Kozloduy lowland.

The large minus area of lag values in Fig. 4 gives an evidence for an important phenomenon from hydrochemical point of view - the migration of water and of dissolved substances is taking place almost 9 - 10 months in the direction from the terrace groundwater to the river (with exception for the pumping station areas).

## 3. GROUNDWATER QUALITY

The polluted Danube river waters and/or precipitated ones can contribute to the groundwater quality deterioration. So in January 1992 in the Danube channel we found 0.38 mg/l Pb, 28.62 mg/l Fe, 0.46 mg/l Cu, 15.8 mg/l Al, 2.52 mg/l Mn and in the precipitated waters in the region - up to 3.2 mg/l Zn, 1.75 mg/l Fe, 1.10 mg/l Al, 0.25 mg/l Mn and 0.24 mg/l Pb. The clay sandy terrace sediments coverring the aluvial acquifers can accumulate the sporadicly comming pollutants as Pb, Fe, Mn, Zn, Cu, Ni, Cd, Al etc. and leach them when groundwater levels fluctuate. The dissolved organic substances are relatively abundant (the permanganate oxidizability medians vary between 1.48 and 3.03 mg/l), so the complex forming reactions are also "helping" the above mentioned process.

Some representative chemical line charts are given in Fig. 5, 6 and 7 to show the differences between the migration of $SO_4^{2-}$ and $NH_4^+$ in the river and ground waters. The redox processes are more important in the Danube river for the reverse dependence observed whereas the leaching of ingredients form the solid phase is from time to time more significant in the groundwaters.

The crosscorrelation functions of some selected pairs of hydrochemical parameters were calculated and a summary of the significant correlation coefficients (for

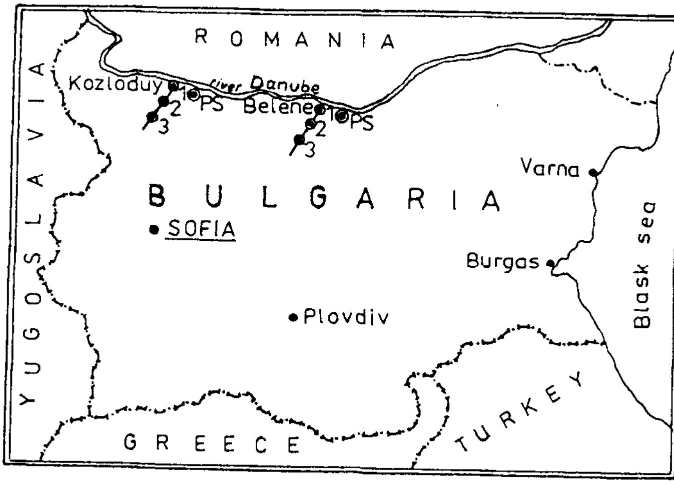


Fig. 1. Scheme of the sampling profile.

Table 1. Maximal values of the time lags for the significant cross-correlation coefficients of the parameters with higher variance - Belene profile.

| | Surface water parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ground water parameters | $SO_4$ 1 2 3 P | $NO_3$ 1 2 3 P | $NH_4$ 1 2 3 P | Ok 1 2 3 P | Fe 1 2 3 P | Mn 1 2 3 P | Al 1 2 3 P | Zn 1 2 3 P |
| $SO_4$ | - 0 - 0 | - | - | - | - | - | - | - |
| $NO_3$ | - | 0 0 0 0 | - - 0 - | - - 0 - | 0 - - 8 | 0 - - 8 | 0 - - 8 | 0 - - 8 |
| $NH_4$ | - | - | 0 7 0 0 | 7 0 0 - | - | - | - | - |
| Ok | - | - | - | - 0 0 5 | - | - | - | - |
| Fe | 0 0 - - | - - - 7 | - - - 7 | 6 - - 7 | 0 0 0 - | 0 0 0 - | 0 0 0 - | 0 0 0 - |
| Mn | - 6 - - | - - - 0 | 3 - 4 - | 0 - - - | - | - | - | - |
| Al | 0 0 - - | - | - | - | 0 0 0 2 | 0 0 0 2 | 0 0 0 2 | 0 0 0 2 |
| Zn | - - 8 2 | 4 7 - - | 4 - - - | 7 - - - | - - 8 2 | - - 8 2 | - - 8 2 | - - 8 2 |

Table 2. Maximal values of the time lags for the significant cross-correlation coefficients of the parameters with higher variance - Kozloduy profile.

| | Surface water parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Ground water parameters | $SO_4$ 1 2 3 P | $NO_3$ 1 2 3 P | $NH_4$ 1 2 3 P | Ok 1 2 3 P | Fe 1 2 3 P | Mn 1 2 3 P | Al 1 2 3 P | Zn 1 2 3 P |
| $SO_4$ | - | - - 0 4 | 0 0 - - | - | - | - | - | - |
| $NO_3$ | - | - - 0 0 | - - - 4 | - | - | - | 0 - - - | 4 - - - |
| $NH_4$ | - | - | - - - 4 | - | - | - | - 0 - - | - 0 - - |
| Ok | - | - | - | 0 - 0 - | - | - | - | - |
| Fe | - | - | - | 0 0 0 - | 0 0 0 - | - | 4 4 0 - | 4 4 4 - |
| Mn | - | - | - | - | - - 0 - | - - 0 - | - 0 7 - | - - - 0 |
| Al | - | - 8 - - | - | - | 0 0 0 - | - | 0 0 0 - | 0 - 0 - |
| Zn | - | - 8 - - | - | - | - - 0 - | - | - - 0 - | - - 0 0 |

Note: - The columns 1,2 and 3 correspond to the order of the wells in the profile while the well 1 is nearer to the river bank; P means the pumping station column.
- The values of the lags means time in weeks. The special case "0" means lag between zero and 7 days.

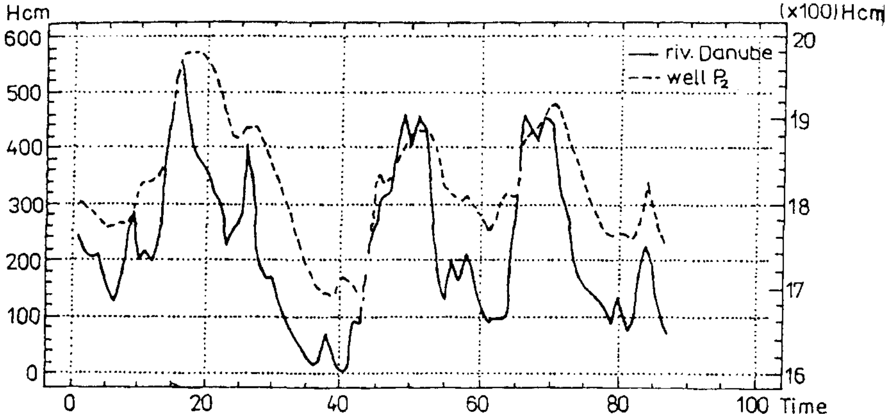


Fig. 2. Hydrographs of river stages and groundwater tables at the Belene profile.

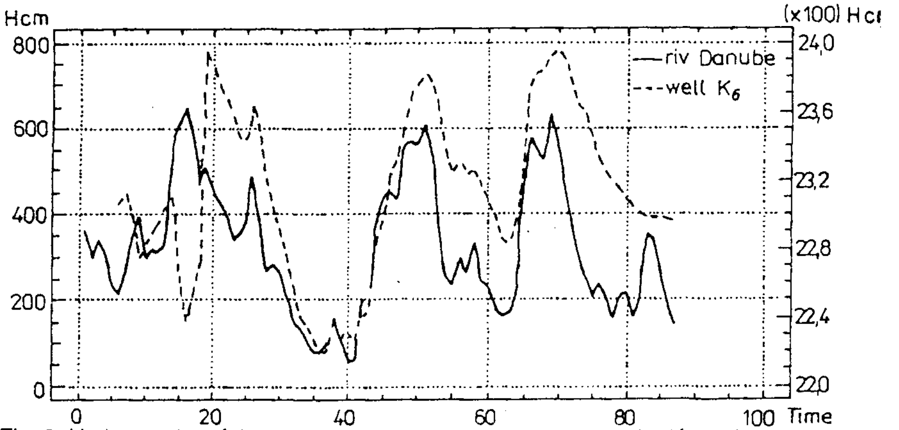


Fig. 3. Hydrographs of river stages and groundwater tables at the Kozloduy profile.

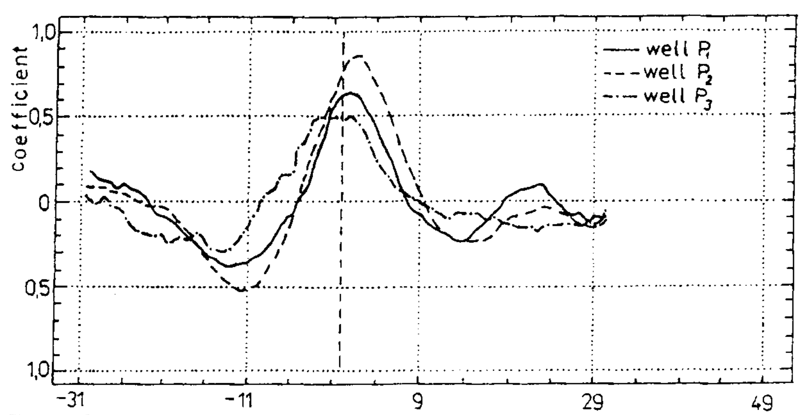


Fig. 4. Cross-correlation functions for the Belene profile of the river stages and the groundwater tables for the three wells under consideration.

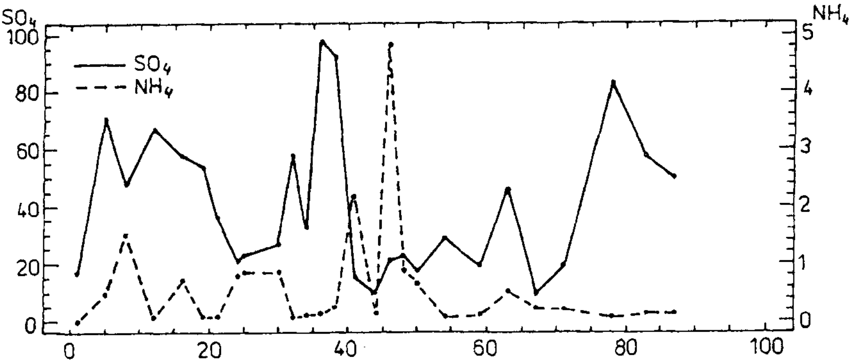


Fig. 5. Concentrations of $NH_4$ and $SO_4$ in river waters at Kozloduy

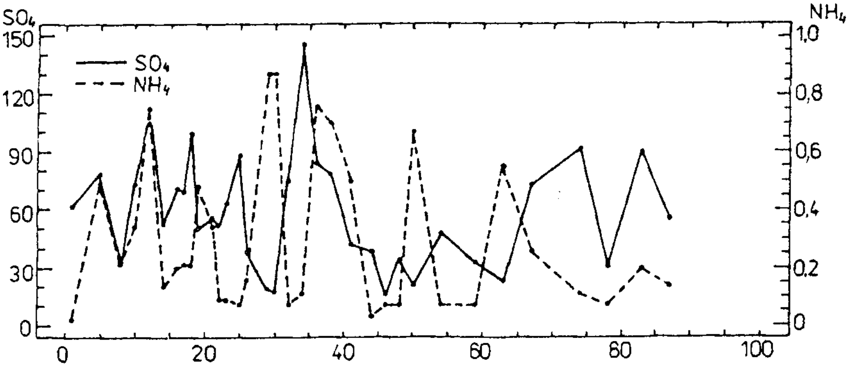


Fig. 6. Concentrations of $NH_4$ and $SO_4$ in groundwaters of well 3 at Kozloduy

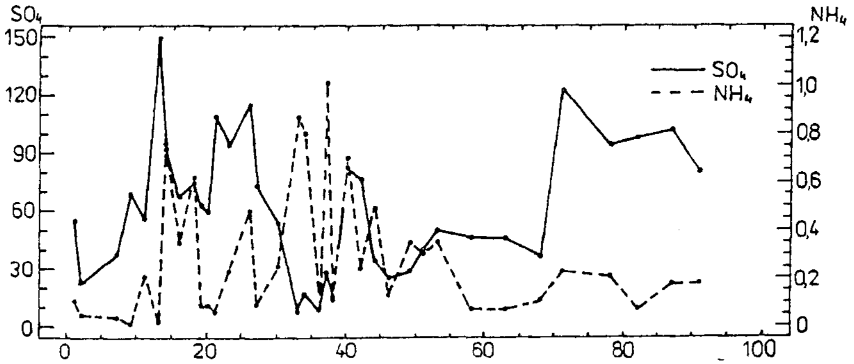


Fig. 7. Concentrations of $NH_4$ and $SO_4$ in groundwaters of well 1 at Belene

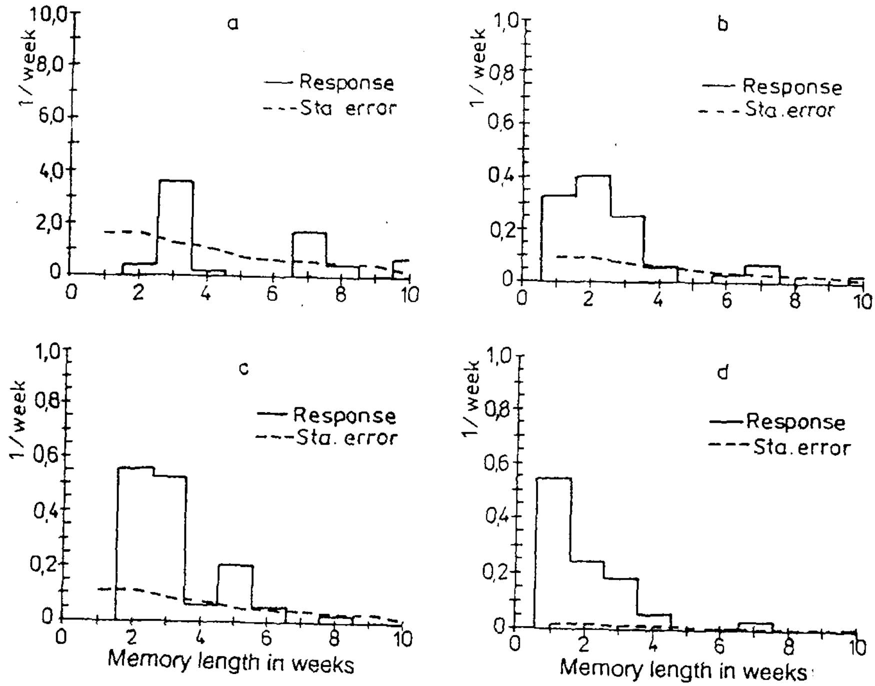


Fig. 8. Responce funtion of the Zn concentration transformation in the river waters to the groundwaters at Belene profile:
a - well 1; b - well 2; c - well 3; d - pumping station

tolerance probability 0.95) and corresponding time lags are given in Table 1 and 2. One could see that significant relationships exist between different ingredients in the river and groundwaters for various time steps - lags. The analysis shows that predictive links river - groundwater are possible. Having in mind the above mentioned results, the single input single output model for nonparametric response function estimation was also applied (Kachroo and Liang, 1992). The assumed memory length was 10 weeks for all calculations. The pulse response functions for the transformation of the Zn concentrations are given on figure 8 as an example. Certain delay is observed especially for the wells of the profile. The time lag for the pumping station is less than one week as far as the water exchange rate is higher.

## 4. CONCLUSIONS

One of the goals of data processing and analysis is the estimation of ways to predict the distribution and variability of the chemical ingredients (for instance heavy metals) in ground waters as a function of the changes in the river waters. The present paper demonstrates some relevant possibilities.

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# THE PROTECTION OF GROUND WATER IN THE KUPA RIVER SOURCE REGION

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*SUMMARY*

*The Kupa River, a tributary of the Sava, rises in the karstic Gorski Kotar region, which is located between the Sava valley and the Adriatic sea. The source region of the Kupa river contains significant reserves of ground water which are still of high quality, at the levels of the standards for drinking water of that part of Croatia. In dry periods during summer, water flows out from the region at a rate of about 9 $m^3$/s, and in wet periods up to several hundred $m^3$/s, which also represents a significant potential source of energy. The problem is one of preserving the natural environment while making optimal use of this water potential for several different purposes. Currently 150 l/s of water from the region is supplied to the local population, but considering the uncertain future of water supplies to Zagreb from the Sava alluvium and the Adriatic tourism zone (Rijeka, Istria), Gorski Kotar ground water reserves have gained strategic importance to the water supply of the Western part of Croatia.*

*The Gorski Kotar region is mainly made up of karstified carbonate rocks, which are the main water-bearing rocks of the region. The presence of impermeable clastic rocks directs flows of ground water towards the largest springs. However, their mainly allochthonous structural position in relation to the porous carbonate rocks makes the hydrogeologic picture of this region very complex.*

*In these natural conditions, and in a region of intense urban and transport development, preventative protection of the water resources is an exceptionally important and complex task. In relation to this, the proclaimed policy of sustainable development must be taken into account. An assessment of the present situation of this water bearing region and forecasts of future events can only be achieved by a good knowledge of the geological and structural relations, the tracking of a large number of underground streams and constant monitoring of water quality at the sources.*

*ZUSAMMENFASSUNG*

DER GRUNDWASSERSCHUTZ IM QUELLGEBIET DES FLUSSES KUPA

*Der Fluß Kupa, der linke Nebenfluß der Sawe, entspringt im Karstgebiet von Gorski Kotar, das sich im Raum zwischen dem Sawetal und der Adria befindet. Das Quellgebiet der Kupa enthält bedeutende Grundwasserreserven, die heute noch von hoher Güte und auf dem gleichen Niveau mit dem Trinkwasserstandard in diesem Gebiet Kroatiens sind. Im Sommer, in der Dürrperiode, fließen aus diesem Bereich ein paar hundert m3/s Wasser aus, was ein beträchtliches Energienpotential darstellt. Das Problem ist, wie man bei der Erhaltung der Umwelt dieses Wasserpotential optimaler und für mehrere Zwecke ausnutzen kann. Heute wird nur 150 l/s Wasser aus diesem Gebiet zur Wasserversorgung der lokalen Einwohner verwendet, aber angesichts der ungewissen Zukunft in der Wasserversorgung der Stadt Zagreb aus dem Sawe-Alluvium und des adriatischen Touristengebietes (Rijeka, Istrien) sind die Grundwasserreserven in Gorski Kotar zur Wasserversorgung im Westen der Republik Kroatien entscheidend geworden.*

*Das Gebiet von Gorski Kotar besteht aus überwiegend karstigen Karbonatfelsen, und das sind die wichtigsten Wasservorkommen in diesem Gebiet. Die wasserundurchlässigen klastischen Felsen richten die Grundwasserläufe zu den größten Quellen, aber ihre vorwiegend allochthone strukturelle Lage im Verhältnis zu wasser-undurchlässigen Karbonatfelsen macht das hydrogeologische Bild dieses Gebietes sehr komplex.*

*Unter solchen natürlichen Bedingungen und im Gebiet einer intensiven und verkehrsreichen Entwicklung ist der vorbeugende Schutz des Wasserbestandes ein außergewöhnlich wichtiges und komplexes Unternehmen. Dabei muß die proklamierte Politik der zu erhaltenden Entwicklung berücksichtigt werden. Nur durch gute Kenntnisse von geologisch-strukturellen Verhältnissen, die große Anzahl von Grundwasserterrassen und die ständige Kontrolle der Wassergüte aus den Quellen ermöglicht es, den heutigen Zustand dieses wasserreichen Gebietes zu bewerten und zukünftige Vorgänge vorherzusagen.*

## INTRODUCTION

Gorski Kotar is the name of the mountainous region between the Karlovac depression and the Adriatic sea (see fig. 1). It is now the only region connecting Pannonian Northern Croatia with Adriatic Southern Croatia.

In this situation, the accelerated construction of infrastructure links in Croatia involves exactly that region. In addition to the existing transport links and oil pipeline, a new highway is under construction and a high speed railway line is in the planning stages. Settlements which have so far had only peripheral importance (e.g. Delnice, Skrad, Lokve and Mrkopalj) find themselves at the center of activity but almost completely unequipped with infrastructure. All this imposes a heavy burden on the karstic strata of the region, which is one of the moist promising water channels in Croatia. More than a thousand square kilometers of land drain into the deeply cut valley of the Kupa river, where large quantities of good quality water flow from a dozen karstic springs. Measurement of total quantities at the profile, on the edge of the zone where the Kupa rises, shows that it is a matter 9 $m^3/s$ in the driest summer periods, which is also the quantity required by the major urban areas of Western Croatia. Clearly, this quantity can be significantly increased by technical intervention of various kinds, for example accumulation during peak flows, direct collection from individual springs.

Research in the Gorski Kotar region began as early as the second half of the 19th century, but that included only minor geological observations, mainly in areas made up of strata from the Paleozoic period. The first geological maps of the region were produced in the first half of the 20th century. A complex geological and hydrogeologic investigation of the Kupa source region with an assessment of the possibilities of water accumulation in the river valley was carried out in 1957 by Herak. In 1962 the same author set up the basic evidence for the allochthonous structure of parts of the Paleozoic and Triassic strata. In his later works (in 1980, 1986 and 1990) he used examples for Gorski Kotar to assess the structural relation of parts of the Dinaric mountains. The most thorough description of the region was made during the preparation of the Delnice sheet of the Basic Geological Map of Croatia (Savić, 1985). Still, the author joined the then numerous advocates of autochtonic structures in Dinaric mountains. He did not handle the water problem as a possible key element in his karstic structural ratio estimate. When a hydrogeological study of Kupa river basin was made in 1972. (Bojanić, Ivčić), all of the waterways connected to the basin were photographed and a preliminary water balance was also made. In last ten years many hydrogeologic studies have been undertaken, mainly to preserve protected areas for the increasing sources (Vučković, Smić, 1984, Golac, 1985), but these were not sufficient for complete water carrier protection. Data collected in these projects served as a basis for determining the drainage conduit of the new highway. The latest study in this series was "Protection of water resources of the river Kupa basin with special look at potable water sources in the Delnice region" (Biondić, 1993). The hydrogeologic interpretation of the whole region in this work is based on known data and also determines protected areas of local water sources.

## HYDROGEOLOGIC DESCRIPTION

The river basin of the upper course of the Kupa contains the high mountain zone of Gorski Kotar, from village Prezid to village Mrkopalj in the south part of the basin. The highest mountain peak is Risnjak (1528 m), other mountain peaks also have altitudes more than 1000 m above sea-level. In these parts there are also numerous small karstic fields and it should be mentioned that all of them are formed at almost the same altitude (between 600 and 700 m). This shows the geomorphologic and hydrogeologic evolutionary phase of this typical karstic region. The most important karstic fields are near Prezid, Gerovo, Mrzle Vodice, Lokve, Delnice, Ravna Gora and Mrkopalj. The Kupa River canyon cuts deep into the surrounding terrain in comparison to fields of about 300 m above the sea-level. Because of this, the Kupa has the hydrogeologic function of a drainpipe for the surrounding karstic mountain area. Most of the water in the Kupa basin flows into the Sava River, only a small part of surface and underground water from the high karstic fields from the bordering area accumulate and flow into the Adriatic basin as potential hydroenergy. The Kupa River and its left tributary Čabranka also serve as the border between Croatia and Slovenia, so Croatia only has rights to the basin on the right sides of the rivers. This area contains the larger part of the Kupa basin's water potential.

The geological construction of Gorski Kotar is very complex. The oldest are clastic rocks in the area of Mrzle Vodice (carbon). The area contains many rocks of clastic complex from the Permian age, near Gerovo, Mrzle Vodice and Fužine in the upper part and between Kupjak and Brod na Kupi in the middle part of the basin. The rock complex from Mesozoic times is mostly dolomite, which is of the upper Triassic age and limestone, which is of the Jurassic age. Limestone of the Cretaceous age is rare though can be found near Brod na Kupi. Theories about the allochthonous construction of the Dinaric mountains were proved by tracing the underground water of Kupa basin. The narrow basin area of the Kupa River belongs structurally to carbon platform of Dinaric mountains (Herak, 1986). The primary platform has been camouflaged by a process of subduction, neotectonic forms and very active erosion. Up-side-down folds are the basic structural feature of these parts. In many places, the allochthonous placing of water-proof clastic rocks is from Paleozoic times, which is very important for the hydrogeologic interpretation of this region.

The Kupa and Čabranka River basins are situated in the border region between the Danube and Adriatic basins. It is a small part of that regional border but the hydrogeologic description of Gorski Kotar and our approach to water resource protection can be used as a model for the analysis and protection of the border regions of macro-basins, for example the Danube basin, because these are the only border regions that still contain reserves of truly high quality potable water.

The Kupa River is water rich in all seasons even though the summer season brings a decrease in quantity. The largest source within the basin ends near Brod na Kupi where an average 28 $m^3$/s flows through. The Kupa River provides 15.5 $m^3$/s; The Čabranka provides 3.15 $m^3$/s, and all of the other sources together provide another 9 $m^3$/s, mostly sources on the right side of the river. This large water potential is practically unused because only 150 l/s is used to provide local towns and villages with water. The quality of the water is generally considered high even though there are certain differences because of the different loads in the basins. Existing data shows that the major source - the Kupa is in the best shape because a part of its water comes down from the mountainous area (Risnjak National Park). The Velika and Mala Belica and the Čabranka are of somewhat lower quality with bacterial pollution from time to time. The sources most at risk are the Kupica and the Zeleni Vir near Brod na Kupi where the water is not only polluted with bacteria but with other dangerous contaminants.

What happens in the basin and what are the hydrogeologic conditions in that area which provide such a water quantity? Tracing underground currents has proved that the waters that flow into the Kupa canyon flow under water-proof clastic rocks and that these rocks do not influence the flow. The only part where the rocks influence the flow is in places where they have been lowered to great depths by neotectonic movements. There they influence the flow of water from the deep karstic underground (Fig. 1). The speed of underground flow is from 0.5 to 3.0 cm/s, which is normal in the Dinaric karstic region. No data exists on how long the water remains in the karstic underground, but experience from the neighboring Kvarner Gulf tells us that the period is under 5 years during the most severe drought periods. Still this dynamic has a positive quality influence on the water in that basin. The biggest problems are high water surges that increase the source supply more than 10 times.

How to protect this very sensitive karstic region without stopping the normal life currents? In first place there are restrictive measures that are being used for all karstic regions in Croatia. The chart below shows the basic hydrogeologic elements needed to form a sanitary and technical protection zone.

CHARACTERISTIC DATA

| Sanitary Protection Zones | Time needed for the water to flow to the facility | Necessary Underground Water Speed in cm/s | HG Basis |
|---|---|---|---|
| IA | | Enclosure of manipulative space around the source | 1:1000 |
| IB | | Possible surface flow to the source | 1:1000 |
| II | 24 hours | Zone of flow > 3 cm/s | 1:5000 |
| III | 1-10 days | 1 - 3 cm/s | 1:25000 |
| IV | 10-50 days | < 1 cm/s | 1:50000 |

Area zoning according to hydrogeologic elements is strictly defined for every mentioned protection zone. It is obvious that all this is not enough to completely protect such a valuable water resource because it is an area with developed infrastructure (highways, railroad, oil pipeline) and urban centers. It has been necessary to strictly regulate the existing and the construction of new infrastructure in the most sensitive areas for underground water - the karstic fields. Today the waste water of these towns goes through chasm zones directly underground without any purification. Because of this, the underground water are in danger from pollution. It is necessary to activate complete research and overhaul projects of the water basin as it represents a part of Croatia's strategic water reserves. It is also important for further urban and tourism development in both Adriatic and continental Croatia.

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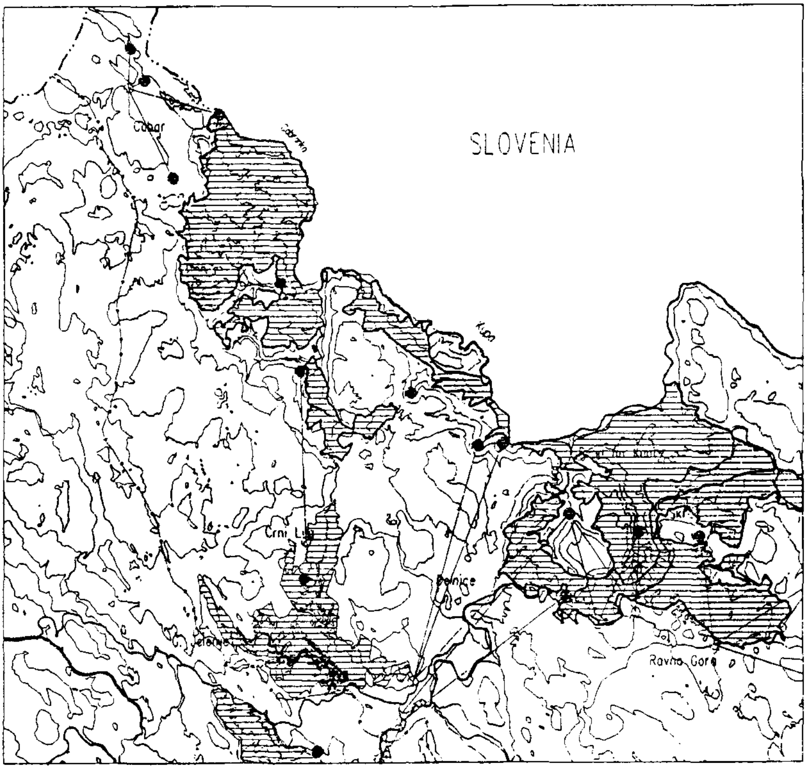
# HYDROGEOLOGICAL MAP

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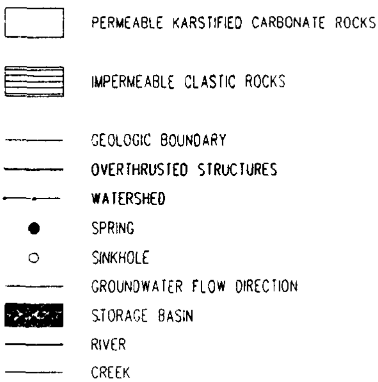

XVII. KONFERENZ DER DONAULÄNDER
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# THE CONTENT AND DYNAMICS OF NITROGEN-BEARING AND SOME OTHER BIOLOGICALLY ACTIVE SUBSTANCES IN THE DANUBE

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This paper contains the results of the study of the content, distribution and space dynamics of various dissolved compounds of nitrogen, the total of dissolved phosphorus, some chlororganic pesticides (ChOP) and the soluble forms of mercury in the Danube's water. It also includes the water quality estimation, the comparative characteristic of the level of concentration of the mentioned substances both for the examined part of the Danube as a whole and within the limits of the separate countries located along the Danube.

## BESTAND UND DINAMIK DER STICKSTOFF BEHALTENDEN UND EINIGEN ANDEREN BIOAKTIVEN STOFFE IM DONAUWASSER

Hier sind die Forschungsergebnisse der Behaltes, Verhältnisses und der räumlichen Dinamik der verschiedenen wassergelösten Stickstoffsverbindungen, des gesamten wassergelösten Phosphores, einigen Chlororganischen Pestiziden und gelösten Quecksilber Formen im Donauwasser. Die Wassergüte wurde beschätzen. Die vergleichende Charakteristik der Konzentrationen diesen chemischen Substanzen wurde auf dem Donauforschungstraum ungesamt und auch in der Grenzen der einzelnen Donauländer gezeigt.

At present the total content of nitrogen and phosphorus in the river's water as well as concentrations, correlation and dynamics of various soluble compounds of these elements influence evidently on the river's water quality, the present and potential possibility of the eutrophication of ponds and channels as well as their sanitary conditions. The development and the vital activity of hydrobios are under the large threat of biologically active pollutants of anthropogenic origin such as pesticides and especially toxic heavy metals, of which mercury is the most typical one. The pollution of the river's water by the mentioned substances is evidently observed in basins of the large river systems covering the regions with developed industry and intensive land use.

This paper deals with the results of studying the content and space distribution of ammonium, nitrate, nitric, organic and the total of the dissolved nitrogen ( $N_\Sigma$ ), the total of the dissolved phosphorus ( $P_\Sigma$ ), hexachlorocyclohexane (HChCH), 4,4'-dichlorodisphenyltrichloromethylmethane (DDT), their isomers and metabolites as well as the total of the dissolved mercury for the section of the Danube from Vienna (Austria) to the river's mouth. The study was carried out during the low water period (September-October, I990) when the water level was the lowest that was ever observed for this river.

Listed substances were studied from 26 sampling stations which were evenly arranged along the studied section of the Danube. Water samples were taken from the research ship. They were preliminary processed immediately after sampling. Desired components were finally identified in the stationary chemical laboratory.

The content of $N_\Sigma$ and $P_\Sigma$ was determined by photometric measurement method after the decomposition of the dissolved organic substances according to Kjeldahl ( $N_\Sigma$ ) or after the processing of samples by potassium or ammonium peroxysulphate in acid medium ( $P_\Sigma$ ). Such ingredients as $NO_3^-$, $NO_2^-$, $NH_4^+$ and $PO_4^{3-}$ were tested by spectrophotometric measurement methods according to the conventional hydrochemical procedures [I]. Prior to be tested, the samples were passed through the membrane filter 0,45 $\mu$m.

The residual of HChCH, DDT and their isomers or metabolites was determined in nonfiltered samples after the extraction of the above substances with benzene or chloroform. During the final stage of testing one used the method of gas-liquid chromatography.

The total of the dissolved mercury was determined in water which was passed through the membrane filter 0,45 $\mu$m, by the high-sensitive (0,003 $\mu$gHg/l) flame-free atom-absorbtion method.

As is proven by the study, the $N_\Sigma$ content in the Danube's water ranged from 0,54 to I,78 mg/l when its concentration average in the studied section of the Danube constituted I,I8 mg/l. In most cases (some 60 percent) the content of $N_\Sigma$

in surface layers of the river is somewhat higher than that in thebottom ones.

The highest single and average $N_\Sigma$ concentrations were observed for the Hungarian, then Jugoslavian and Ukrainian sections of the Danube. In this case the definite variations in the $N_\Sigma$ dynamics for the studied section of the river were not revealed. At the same time the determined values of $N_\Sigma$ for the Ukrainian section in particular were almost twice as much as the averageof the mentioned indice (0,6I mg/L) which were measured in the Danube's water in I982-I984 [2]. This testifies that the contamination of the Danube by the dissolved nitrogen-bearing substances has decreased. During the period of studies the $N_\Sigma$ concentrations were changed within the limits that are typical for the mesotrophic ponds (0,7-I,3 mg/L).

Nitrogen of the dissolved organic compounds considerable contributes (6I,6-79,0 percent) to the $N_\Sigma$ value (near Vienna it reaches 93 percent). The content of organic nitrogen ( $N_{org}$ ) in the studied water has changed from 0,2I to I,53 mg/L. The Austrian and Slovakian sections of the Danube are noted for the lowest absolute concentrations of $N_{org}$ (at an average of 0,6-0,7 mg/L), The average content of $N_{org}$ increases to 0,82-I,04 mg/L downstream. At the same time the distribution of the single $N_{org}$ concentrations for these sections were distinguished by a considerable degree of the heterogeneity (from 0,5 to I,53 mg/L). As for $N_\Sigma$ , the maximum $N_{org}$ content was found within the Jugoslavian, Hungarian and Ukrainian sections of the river.

Nitric nitrogen ( $N_{NO_3^-}$ ) prevails amongst the mineral forms of the element in question. Its share in the mineral compounds total constitutes 60,0-93,2 percent. The value of $N_{NO_3^-}$ was changed from 0,2 to 0,4 mg/L for the various sections of the Danube, that is typical for the mesotrophic ponds. The average share of $N_{NO_3^-}$ in the total of the fixed nitrogen constituted I7,2-34,5 percent. The maximum contribution of nitric nitrogen to $N_\Sigma$ (22,9-56,5 percent) is observed for the Slovakian section of the Danube. The said contribution did not exceed 20-30 percent for the other sections.

The average ammonium nitrogen content ( $N_{NH_4^+}$ ) in the Danube's water constituted 0,03-0,08 mg/L. The highest single concentrations of the mentioned ingredient (up to 0,3 mg/L) were found in the Danube's water within the borders of Jugoslavia and Ukraine. The overall contribution of $N_{NH_4^+}$ to the contamination of the Danube by the nitrogenous compounds is small.

Nitrites ( $N_{NO_2^-}$ ) were found as "traces", i.e. their quantities did not exceed the thousandth and hundredth fractions of miligram per litre of water. Because of their low concentrations, no regularities in the $N_{NO_2^-}$ distribution in the Danube's water were observed.

The correlations being found among the studied forms of nitrogen are most likely to testify, that under conditions of a limited surface runoff, the level of concentrations of the dissolved nitrogen-bearing compounds is under the definite effect of the domestic sewage discharged into the Danube, which contain a considerable quantity of biogenic organic nitrogen. The Jugoslavian section is noted for the relatively "fresh" pollution of the Danube's water which is marked by th decrease in the content of nitric nitrogen in $N_{\Sigma}$ and by the relative increase in the ammonium nitrogen content. On the contrary, within the borders of Slovakia a relative $N_{NO_3^-}$ content in the fixed nitrogen total substantially increases that is the evidence of the water pollution which took place earlier (upstream).

The total of the dissolved phosphorus for the studied section of the Danube amounted to 0,I-0,45 mgP/L. The evident differences in the distribution throughout the vertical profile of the river were not observed. At the same time there is a clearly defined tendency for the regular incresa of $P_{\Sigma}$ content downstream. The lowest $P_{\Sigma}$ concentrations (0,I-0,I6 mg/L) are characteristic for the Austrian, Slovakian and Hungarian sections of the Danube. Downstream the mouth of the Sava river the $P_{\Sigma}$ content evidently increases and comes to 0,38-0,42 mg/L. Then in the sampling station Djerdap-I it decreases again (up to 0,24-0,28 mg/L). Downstream $P_{\Sigma}$ concentrations increase in a gradual manner reaching 0,39-0,45 mg/l for this section. The founded levels of concentrations of the mentioned ingredient evedently exceed the value of the similar index (about 0,I mg/L) which was common to the Danube's water for the procedeng years [2] and pointed to the fact tha the anthropogenic loading for this water has increased.

The pesticides to be studied were found in all water samples. DDT and its metabolites are the main water pollutant Their content reached 8I,4-97,2 percent of the organochlorine pesticides total (OChP) that were found in the Danube's water

The total concentration of all HChCh isomers was changin from 0,002 to 0,675 $\mu$g/L. However, in most cases their maximum total did not exceed 0,034 $\mu$g/L that corresponds to the levels of the overall pollution of the river's water by the listed pesticides [3]. The highest $\Sigma$HChCH concentrations were found upstream of Reny (0,32), in the upper water Djerdap-I (0,I0I) and near Novy-Sad (0,675 $\mu$g/L). Increasing of $\Sigma$HChCH is initiated mainly by its $\beta$-isomer which, as a r le, is not abundant in nature. It is likely that in these cases there is the local water pollution by $\beta$-HChCH or by the other substance such as heptachlorine that possesses the similar chemical properties. The average of $\Sigma$HChCH in the Dan be's water constitutes 0,0I5 $\mu$g/L (with regard to the extr mely high values - 0,065 $\mu$g/L), i.e. it is not too far reaq ved from the analogous average of long-term pollution of ot her rivers (0,023-0,045 $\mu$g/L) [3]. As a whole, the Jugoslavi and Ukrainian sections of the Danube are the most polluted ones by HChCH.

The content of DDT and its metabolites was varying from 0,0I4 to 3,8I μg/L. Σ DDT concentrations of 0,0I4-0,I3 μg/L account for 80 percent of all cases. Higher levels were found downstream of the Kiliya irrigation system (up to 0,39 μg/L) and downstream from Bratislava (I,89 μg/L). The extremely high concentration of Σ HChCH was found near Novy-Sad. Thus, the substantial water pollution by ChOP takes place because of the exposure to the localized source of contamination.

The rather high concentrations of DDT and its metabolites were found in the water of the Slovakian section of the Danube. Here the Σ DDT average came close to 0,225 μg/L, i.e. it almost reached the highest concentrations occured in the surface water.

As for the Bulgarian, Romanian and Hungarian sections, both the single and total average concentrations of DDT (0,0I4-0,I2 and 0,022-0,067 μg/L respectively) practically did not exceed the average of the long-term concentrations of the mentioned pesticide (0,033-0,065 μg/L), that was conditioned by the overall DDT dissipation /3/. The Jugoslavian and Ukrainian water sections were characterized by the highest concentration average of DDT, amounted to 0,995 and 0,505 μg/L respectively.

When estimating the quality of water it should be noted that now the Danube's water is exposed to the evident pollution by pesticides.

The dissolved forms of mercury were found in one third of the examined water samples. The highest concentrations of this element (0,005-0,02I μg/L) were present in water of the Bulgarian section of the Danube (it constitutes 85 percent of all samples). Traces of mercury (0,003-0,006 μg/L) were seen in 40-50 percent of samples taken in the Hungarian and Jugoslavian sections. The Ukrainian, Romanian, Slovakian and Austrian sections of the river did not show the dissolved forms of mercury. There is no tendency to their accumulation in water.

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# FORSCHUNGSMETHODIK DER FORMIERUNGSPROZESSE DER QUALITÄT DER NATÜRLICHEN GEWÄSSER UND IHRE KLASSIFIZIERUNG NACH GENETISCHEN MERKMALEN

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Kurzfassung:Die angebotene Methodik,die in der Schewtschenko-Universität Kiew ausgearbeitet wurde,kann für die Forschungen der Formierungsprozesse der Wassergüte und für die Klassifizierung der natürlichen Gewässer nach genetischen Merkmalen angewandt werden. Sie basiert auf der Nutzung von multivariablen statistischen Methoden der Datenanalyse. Die dargestellte Methodik wurde bei Auswertung der Forschungsergebnisse der internationalen ökologischen Expedition "Die blaue Donau - 90" angewandt.

# METHODS OF INVESTIGATION OF NATURAL WATERS QUALITY FORMATION PROCESSES AND THEIR CLASSIFICATION ACCORDING TO GENETIC CRITERIA

Summary:Proposed methods,which have been developed in Kiev Shevchenko University,can be used for investigation of water quality formation processes and classification of natural waters according to genetic criteria. It is based on the use of multivariate statistical methods of data analysis.Presented methods have been applied to process the results of investigations of international environmental expedition "Blue Danube-90".

Die Formierung der Wassergüte stellt eine Gesamtheit der Tauschprozesse von chemischen Substanzen natürlicher Gewässer mit anderen natürlichen Medien(Luftatmosphäre, Gesteine,Freiland,Pflanzen- und Tierwelt) und anthropogenen Quellen dar.Bedingt lassen sich fünf Faktorengruppen ausgliedern,die die Wassergüte regulieren und zwar der hydrometeorologische,hydrochemische,hydrobiologische,physikalisch-geographische und der anthropogene Faktor(Abb.1). Abb.1 zeigt die genetische Struktur der Beziehungen zwischen der Ursache und der Folge im Formierungsprozeß der Wassergüte.Diese fünf aufeinanderbezogene Faktorengruppen können als Blöcke der Wassergüteregulierug bezeichnet werden.Sie zeichnen sich durch eine ganze Reihe von Kennwer-

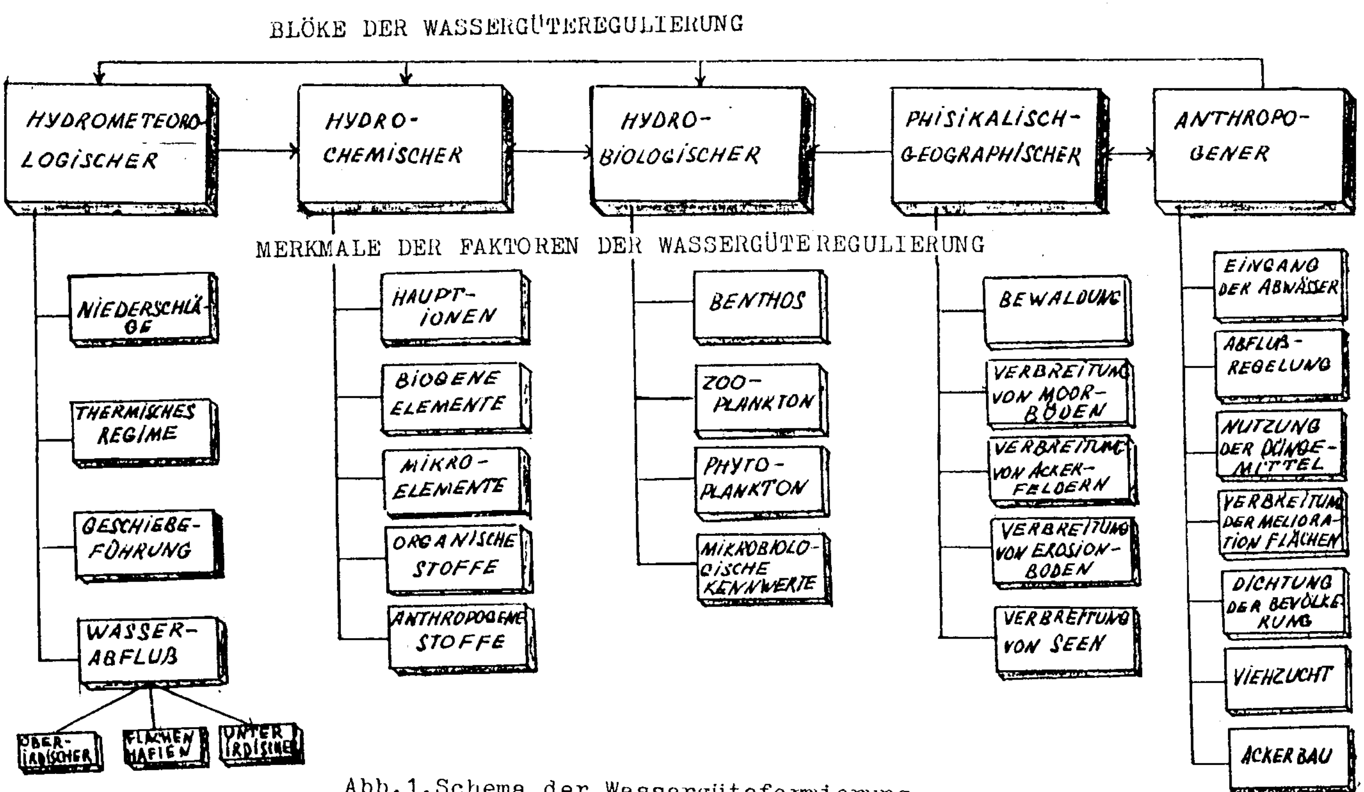


Abb.1.Schema der Wassergüteformierung
Scheme of water quality formation

ten aus, die die interne Struktur und die Besonderheiten dieser Faktoren darstellen. Der hydrometeorologische Faktor umfaßt solche Charakteristiken des Wasserabflusses wie oberirdischer Abfluß, flächenhafter Abfluß, unterirdischer Abfluß, die Geschiebeführung sowie die meteorologischen Kennwerte (Menge der Niederschläge, Thermisches Regime usw.). Hydrochemischer Block bedeutet die Gesamtheit der physikalisch-chemischen Prozesse, die sich zwischen den Hauptgruppen der wassergelösten chemischen Substanzen (Hauptionen, biogene und organische Stoffe, Mikroelemente, anthropogene Verunreinigungstoffe) ablaufen. Diese Charakteristiken hängen aufs engste mit den Charakteristiken anderer Faktoren (Blöken) zusammen. Hydrobiologischer Block zeigt den Vorlauf der biologischen Prozesse im Wasser. Er umfaßt solche Kennwerte wie Benthos, Zooplankton, Phytoplankton, mikrobiologische Kennwerte. Nötigenfalls kann man diesen Block durch die anderen Charakteristiken ergänzen oder transformieren.

Der physikalisch-geographischer Block spiegelt die Besonderheiten des von der Landschaft formierenden Wasserabflusses wider. Er kann folgende Charakteristiken umfassen: Bewaldung, Verbreitung von Moorböden, Ackerfeldern, Erosionsböden und Seen.

Der anthropogene Block ist ein sehr wichtiger Bestandteil der Wassergüteregulierung. Seine Rolle im Formierungsprozeß der Qualität der natürlichen Gewässer formiert sich durch folgende Merkmale: Eingang der Abwässer, Abflußregelung, Nutzung der Düngemittel, Verbreitung der Meliorationsflächen, Dichtung der Bevölkerung, Entwicklung der Viehzucht sowie des Ackerbau.

Die Zahl der Merkmale in diesen Bestandblöcken ist von verschiedenen Ursachen (Möglichkeit der Instrumentenmessung der Charakteristiken der Formierungsfaktoren, Besonderheiten des Einflusses der natürlichen und anthropogenen Faktoren usw.) abhängig.

Die Mannigfaltigkeit der Faktoren, die den Formierungsprozeß der Wassergüte bewirken, bedingt die Kompliziertheit ihrer Untersuchung und das Fehlen sicherer Theoretischen und methodischen Erarbeitungen erschwert die Ermittlung des Formierungsmechanismus der Wassergüte, verzögert die Erarbeitung von wissenschaftlich fundierten Steuerungsverfahren sowie von Grundlagen zur rationellen Nutzung und Regelung der Wasserqualität.

Eines der möglichen Vorgehen bei der Untersuchung der Besonderheiten der Formierung der Wassergüte ist die angebotene Methodik. Sie basiert auf der Ausnutzung von multivariablen statistischen Methoden der Datenanalyse. Diese Methodik wurde im Laboratorium für Hydroökologie und Hydrochemie der Schewtschenko-Universität Kiew ausgearbeitet. Die ergebnisse ihrer Anwendung sind in den unten angeführten Arbeiten/1-5/ veröffentlicht worden.

Die Ausnutzung der Methodik wird in mehrere Stufen unterteilt (Abb.2). Zuerst geht die Erfassung und die Vorbereitung von Ausgangsdaten aus den Beobachtungen sämtlicher möglicher Faktoren hervor, die an der Formierung der Wassergüte in einem konkreten Wasserobjekt beteiligt sind.

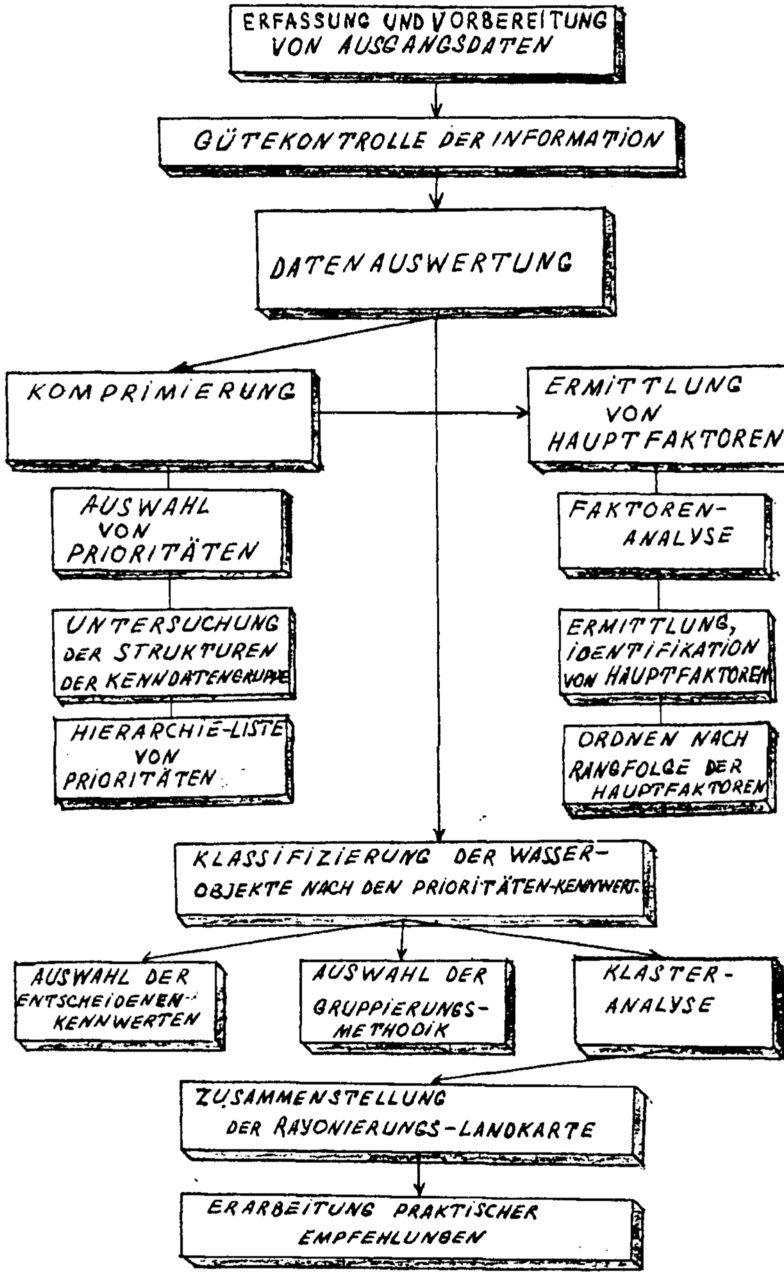


Abb.2.Schema der Auswertung der Forschungsergebnisse
Scheme of the researches results processing

Die Datenfassung wird durch komplexe Expeditionsforschungen im Wasserobjekt verwirklicht.Sie läst sich durch verschiedene andere Monitoringsdaten ergänzen.Der Forscher soll nach der Erfassung einer optimalen Anzahl der Charakteristiken der Forschungsprozesse bestrebt sein.Eine zu geringere Anzahl wird nicht imstande sein die Besonderheiten der Formierungsprozesse aufzudecken. Eine viel zu größere Anzahl führt anderseits zu einem wesentlichen Arbeits- und Zeitaufwand und zu einem viel zu hochen Kostenaufwand bei den Untersuchungen.In diesem Arbeitsstadium spielt die praktische Erfahrung des Fprschers und die Genauigkeit seiner theoretischen Vorstellungen über der Formierungsprozesse der Wasserqualität eine große Rolle.Für diese Arbeit wäre es notwendig,Spezialisten und Experten heranzuziehen. Solche Erfahrung haben wir bei der Verarbeitung der Materialen der Expedition "Blaue Donau-90"angesammelt.

Nach der Erfassung der Information soll ihre Repräsentativität kontrolliert werden.

In der nächsten Etappe machen wir die Datenauswertung mit Hilfe einer EDV-Anlage. Zuerst wird die Komprimierung der Information in jeder Kenndatengruppe verwirklicht.Für diese Prozedur wird der mathematische Apparat der Faktoren analyse genutzt.Sie umfast der Auswahl von Prioritäten-Kennwerten in jeder Kenndatengruppe,die Untersuchung der internen korrelationsregressiven Strukturen der Kenndatengruppen sowie der Auswahl von Analogie-Kennwerten. Die Prioritäten-Kennwerte werden aus der Größe der Faktorenbelastung ermittelt.Im weiteren wird die Hierarchie-Liste von Prioritäten-Kennwerten aufgestellt.Die letzeren Kennwerte werden aus der Datenbank ausgeschlossen. Bei der Auswertung der Ergebnisse der Expedition "Die blaue Donau-90" hatte die Komprimierungsprozedur die Zahl der Kennwerte von 252 bis auf 28 Indexe verringert.

Im weiterem wird die Ermittlung von Hauptfaktoren der Wassergüteformierung realisiert.Zuerst kommt es zu der Faktorenanalyse des Prioritäten-Kennwert-Komplexes(28 Indexe am Beispiel der Auswertung der Donauforschungsergebnisse), der den Formierungsmechanismus der Wassergüte kennzeichnet. Dann wird die Ermittlung,die Identifikation und das Ordnen nach Rangfolge der Formierungsfaktoren der Wassergüte durchgeführt.Sie stellt eine wichtige Etappe der Auswertung der Forschungsdaten.Danach wird die korrelationsregressive Analyse der internen Struktur der Faktoren und Aufstellung aufgrund der analytischen Ergebnisse eines Blockdigramms für die Formierung der Wassergüte durchgeführt.Das ermöglichte die zu ermittelnden Faktoren richtig zu identifizieren.Wir haben 8 Hauptfaktoren bei der Auswertung der Donauforschungsergebnisse durch die Erfüllung dieser Etappe der angebotenen Methodik festgestellt. Ihrer Gesamtbeitrag zu den Formierungsprozessen der Wassergüte beträgt 77,9%.Das ist die Summe der Beiträge der einzelnen Faktoren zu der gesamten Dispersion aller Charakteristiken der Formierungsprozesse.Im allgemeinen hat uns die Anwendung der zweistufigen Komprimierung der Datenbank die Möglichkeit das große Datenmassiv bis auf 8 Hauptfaktören zu reduzieren,die die Grundinformation über die Formierungsprozesse der Wassergüte beinhalten.

Die Ergebnisse der vorhergehenden Etappen wird von uns für die Klassifizierung von Oberflächengewässern aufgrund der Formierungsbedingungen ihrer Qualität ausgenutzt. Zuerst wird die Auswahl von entscheidenen Kennwerten und Gruppierungsmethodik vorgenommen. Die Prioritäten-Kennwerte werden für jeden Hauptfaktor ausgewält.

Für die Klassifikation wird die Klaster-Analyse angewandt. Mit Hilfe der Klaster-Analyse läst sich die Klassifizierung der Wasserobjekte nach einem Komplex von Prioritäten-Kennwerten der Wasserqualität realisieren. Als Kriterium für die Ähnlichkeit haben wir hier den Euklidesabstand angewandt. Die Anwendung der Klaster-Analyse ermittelte für die Donau 16 Gebiete, die in 7 ungleichartige Gruppen (Klaster) zusammengefast werden können.

Die Ergebnisse der Verarbeitung der Forschungsdaten werden in weiteren für die Zusammenstellung der Rayonierungs-Landkarte aufgrund der Formierungsbedingungen der Wassergüte und für die Erarbeitung praktischer Empfehlungen ausgenutzt.

Die angebotene Methodik kann bei komplexen ökologischen Forschungen verschiedener Wasserobjekte erfolgreich angewandt werden.

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# THE TENDENCIES OF THE FLUVIAL SYSTEMS STATE CHANGE IN THE WESTERN UKRAINE IN THE XXth CENTURY

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The comparative morphometric analysis of the different time (1855-1980) topographic maps, as well as the field investigations allowed to estimate the affect of the linear and sheet erosion upon the basins of the different rank river systems in the Western Ukraine. The dynamic indices of these phenomena are determined. The many year (1977-1987) stationary and experimental study of the erosion-accumulation processes in the different basin systems units, and the information about the human impact upon the natural environment made possible to evaluate the scale of the degradation processes, and to elucidate the change tendencies in the water, the drift, and the dissolved matter run-off.

Auf Grund der morphometrischen Vergleichsanalyse der zu verschiedenen Zeiten (1855-1980) herausgegebenen topographischen Karten, sowie auch der Felduntersuchung von verschiedenen Flußsystemen der Westukraine ist die Stufe der Oberflächenbeschadigung ihrer Becken durch Linear- und Flächenerosion festgestellt worden. Dabei sind die Kennziffern der Dynamik dieser Erscheinungen (1925-1980) ermittelt. Die in Laufe von 1977 bis 1987 durchgeführen stationären und experimentellen Untersuchungen von erosions-akkumulativen Prozessen in verschiedenen Gliedern der Beckensysteme und die Information über den Charakter der wirtschaftlichen Beeinflussung des Umwelt ermöglichen es, die Maßstäbe der Degradierungsprozesse einzuschätzen, die Trends der Veränderung des Wasserabflusses, der Aufschüttungen und der gelösten Stoffe in den Becken der Kleinflüsse festzulegen.

The relief forms of the fluvial genesis are the most typical morphological feature of the humid morphoclimatic belt. Their specific and age spectrum, modern and retrospective state, tendencies of development are determined by the genesis and the history of the relief development, by the geomorphological structure of the region, by the influence of the zonal and the azonal factors. The main river systems of the region are: the Western Bug, the Dnister, the Prut, and the Tysa. The basin of the each river integrates the lower rank basin systems which are characterized by the great heterogeneity of geologic-geomorphic structure, the diversity of landscapes, the significant differences in the economic development and the anthropogenic transformation of the natural environment components. The indices of the water, drift, and dissolved matter run-off from the every basin system integrally reflect its ecologic-geographical state, distribution and development of modern relief shaping processes, intensity of the economic impact (Kovaltchuk, 1993). The monitoring investigations of these river systems parameters gives an opportunity to define the tendencies and the scale of the environmental situation change, the reasons and the factors which cause disadvantageous phenomena, evaluate the relief-shaping effect of the exogenous processes, carry out the prognosis of behavior of the whole systems and their elements, stipulate and realize the complex nature protecting measures which are aimed on the regulation of intensity of the erosion-accumulation, slide, mud flow, and other processes; protection of soils, surface and underground waters from pollution, prevailing of the small river channels mudding, projecting and creation of the stable, high-productive basin natural-economic systems of different use.

Such kind of investigations are conducted for long time in the Dnister, the Tysa, the Western Bug, and the Prut basins (Kovaltchuk, 1990; Kovaltchuk, Shtoiko, 1989, 1992; Kovaltchuk, Volos, Holodko, 1992).

The starting point of the study is a selection of the rank classification scheme of the river system tributaries. For the hydroindicative analysis the Scheidegger scheme which is supplemented by the Harzman methodical developments, can be regarded as optimal. The Strahler - Filosofov scheme is more suitable for the evaluation of the structure changes scales, especially in the upper units of fluvial systems. The proposed methodology includes three stages of study. On the first stage the next is done: 1) selection of the different- time one-scale topographic maps and evaluation of their accuracy; 2) numeration of water flows and definition of the river systems rank; 3) calculation of the different rank river number in the river systems; 4) definition of the different rank rivers length on the different time maps; 5) construction of the different-time graph-schemes of the river systems structure; 6) analysis of the water flow convergation angles and the channel slope ratios; 7) drawing of the isoline different-time maps of the rivers density; 8) drawing of the maps of river density changes total and mean annual indices; 9) compilation in the same manner of the cartoscheme series of state and many year dynamics of: forested areas; cultivated areas; settlement and transport areas; eroded areas and areas under gullies; 10) analysis of the many year information on the water, drift and dissolwed matter run-off, air temperature and precipitation dynamics in the different rank basins; 11) estimation and evaluation by correlational and factoral analysis of the reasons that cause the rivers system transformation, the water and the drift matter run-off, and the small rivers ecological state changes.

On the second stage the field investigations are conducted and the next tasks are fulfilled: 1) the investigation of the small river sources in order to fix their location and tendencies of change; 2) inventory of the springs, river sources, high moors, lakes, ponds and reservoirs with the description of their ecological state; 3) registration on the maps and special questionnaires of the distribution, and impact upon the water flows of the anthropogenic processes and economy objects; 4) stationary study of the erosion-accumulation processes in the typical phases of the hydrologic regime; 5) experimental study of the different factors influence upon the intensity of erosion processes; 6) investigations on the dynamic of the ground and underground water levels; 7) evaluation of the run-off control rate of the small rivers, and of its impact upon the ecological state of rivers and channel processes; 8) survey of the fluvial systems ecological state.

On the third stage the attention is concentrated on: 1) the systematization and interpretation of data; 2) the collection and analysis of the historical-geographic information on the dynamics of fluvial systems and processes; 3) the evaluation of the anthropogenic component of the run-off; 4) the evaluation of the connection between the river systems structure parameters with the water and drift run-off indices; 5) the prognosis of the channel and basin processes development; 6) the changes basin systems ecological state; 7) the working-out the recommendations on the erosion-accumulation processes regulation within the catchments and in the channels; 8) the stipulation of the rational nature utilization schemes and the monitoring of the ecologic-geographic situation.

The erosion-accumulation processes are the greatest danger that can disbalance the different rank fluvial systems of the region. Their main inices are: the stage of *the soil cover erosion, the density of the area dissection* by gullies, the intensity of the processes development on slopes.

It is estimated that the agricultural lands erosion rate in the basin systems is 20-88%. The highest indices are in the basin systems of the Podolian and the Volynian Uplands, the Precarpathia, the low-mountain and the Waterdivide-Verchovynian zones of the Ukrainian Carpathians. During the last 30-35 years under the anthropogenically activated erosion processes the erosion rate have increased on 10-28%, and in the most developed basins - up to 35-40%. The significant expanding of the eroded lands caused the soil fertility declination, the accumulation increase in the flood plains and channels of the small rivers, the pollution of the surface waters, and the worsening of the environmental situation.

The soil wash-out intensity from the different relief elements and different rank basin systems significantly exceeds marginal values. Depending on the slope angle and land-use the wash-out speed changed from 0.001-3.5 up to 16.4 mm/year. The soil wash-out by the rain water estimates 60-70% of the total wash-out, and during the winters without, or with small, snow cover - up to 100%. The mean denudation tempo of the small gully basins which are occupied by the agricultural vegetation varied from 0.06-0.8 mm/season to 0.1-1.3 mm/year. Intensity of the erosion change in the I-II rank river basins reaches 0.05-0.23 mm/season and 0.08- 0.36 mm/year. In the catchments of the higher ranks the medium tempo of denudation, which is calculated by the drift run-off volume, is 0.01-0.08 mm/year. Only in the extreme cases it reaches 0.3 mm/ year.

The comparison of the indices which were obtained through the stationary investigations witness that with the increase of the basin area the mean tempo of the erosion processes declines. Investigation of the slopes, ravine bottoms, small river flood-plains after the snow melt and stormy rains has shown that a significant part of the erosion products does not reach the permanent water flow channels, but accumulates on the way of its movement - from the water divide to the river channel. Special study (Kovaltchuk, 1993) shows that the re-accumulation on the concave slope elements is about 16-66%. In the extreme cases the 80% of the drift run-off can be re-accumulated. Beyond the boundaries of the cultivated gully basin 18-71% of the erosion volume products are brought out. Relatively large part of the drift (58-79%) accumulates in the flood-plain of the I-II rank rivers, which contact with the gully basins. 18-43% of the drift which is brought out from the slopes and the gully catchments accumulates in the river channels (Fig.1).

In the water and drift run-off many year regime of the III-IV rank rivers the cyclic oscillations are discovered, as well as the anthropogenically determined tendency of the water and drift run-off increase from 50's to 70-80's. If the period from the beginning of observations up to 1960-1962 is assumed as the model one, than in 1963-1970 the drift run-off increased in 1.2-1.5 times in the Western Bug basin. In the Dnister tributaries basins the index of the drift run-off increased in 1.5-4.1 times, in the Prut tributaries basins - in 1.4-2.6 times, in the Tysa and Uz basins - in 1.6-3.1 times, and in the Latorycja basin - more then in 3 times (Table 1). Tendency of the drift ran-off modulus increase was observed also during the next periods - up to 1981-1985. In 1981-1985 and 1985-1990 in some basins the drift run-off modulus was stabilized or declined, and in the other remained to increase. The factors that determined the drift run-off modulus change tendency were felling of woods (Carpathians and Podillya), cultivation on steep slopes, increase of the erosion processes intensity in the watersheds.

A significant role in the provision of drift into the channels and flood-plains of different rank rivers is played by the linear erosion. The density of gullies in basins was evaluated through the analysis of the large-scale topographic maps for the years 1925, 1955, 1980. The gully density changes in the limits of 0-2.5 (locally to 6.9) km/sq.km, the summit density - 0-22 (locally 27-50) units/sq.km. Gully area is 0.1-5.1% of the land use area for some farms. During the last 30 years it increased in some basins in 2.5 times. The mean tempo of the linear growth does not exceeds 0.1-2.6 m/year on 1 summit. Almost 32% of gullies have exhausted their erosion potential and are now in the stage of ravine.

The intensive drift accumulation in the low rank river channels, worsening of the soil cover filtration properties in the basin systems, declination of the underground water role in the feeding of permanent water flows caused a complex of degradation processes in the river systems. The latter are: shallow of the small rivers, their mudding and drying, occupation by hygrophile vegetation, worsening of the water resources quality, lowering the underground water levels, etc. For the evaluation of the degradation phenomena scales the river systems structure state was analyzed for the periods of 1855, 1925, 1955, and 1980 (Kovaltchuk, Shtoiko, 1992; Kovaltchuk, Volos, Holodko, 1992; Kovaltchuk, 1990, 1993). The advanced saturation of the river system structure by the I-II rank water flows is indicated. It estimates 75-94% of the all water flows number, and 59-75%

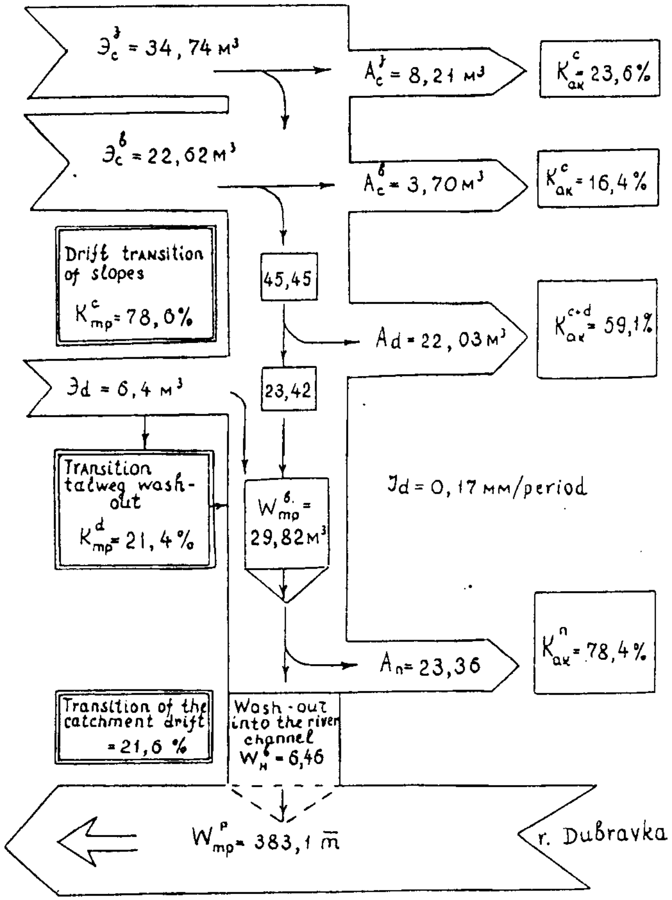


Fig.1. Correlation between the volumes of the soil erosion, the drift transit, and the re-accumulation in the different rank fluvial systems in the sow melt period 5-16.03.1979.

$Э_c^з$, $Э_c^в$ - erosion on the slopes of the western and eastern aspects; $A_c$, $A_d$, $A_n$ - drift accumulation on slopes, in the bottom of the catchment, and in the flood-plain ($m^3$); $K_{ак}^c$, $K_{ак}^d$, $K_{ак}^n$ - the coefficients of the drift re-accumulation on the slopes, in the bottom of the catchment, and in the flood-plain (%); $W_{тр}^{б,р}$ - the volumes of the transit drift of the catchment, the river basin ($m^3$): $K_{тр}^c$, $K_{тр}^d$, $K_{тр}^б$ - the coefficients of the drift transition on the slopes, in the bottom of the catchment, and in the flood-plain (%).



Table 1

## Tendencies in the Drift and Water Run-Off Changes for Some Rivers of the Western Ukraine

| | Period | Duration, years / T / | Medum modulus of the drift run-off m/sq*km year (Mn) | Coefficient of the drift run-off change / $K_{rp} = \frac{M_n}{M_1}$ / | Medium water run-off leyer in the watershed, mm ( H ) | Coefficient of the water run-off change / $K_{rp} = \frac{H_n}{H_1}$ / | Medium water run-off medium drift run-off ratio / $\frac{H_n}{M_n}$ / |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| | **Tysa River - Rachiv** | | | | | | |
| | 1947-1962 | 16 | 58,0 | 1,00 | 702,0 | 1,00 | 12,10 |
| | 1963-1970 | 8 | 180,9 | 3,12 | 778,9 | 1,11 | 4,31 |
| | 1971-1975 | 5 | 117,0 | 2,02 | 659,8 | 0,94 | 5,64 |
| | 1976-1980 | 5 | 146,0 | 2,52 | 803,4 | 1,14 | 5,50 |
| | 1981-1985 | 5 | 58,8 | 1,01 | 754,0 | 1,07 | 12,82 |
| | 1986-1988 | 3 | 64,7 | 1,12 | 690,3 | 0,98 | 10,67 |
| | Uz River - Uzgorod | | | | | | |
| | 1947-1962 | 16 | 108,4 | 1,00 | 454,3 | 1,00 | 4,19 |
| | 1963-1970 | 8 | 206,3 | 1,90 | 525,6 | 1,16 | 2,55 |
| | 1971-1975 | 5 | 154,4 | 1,42 | 444,0 | 0,98 | 2,88 |
| | 1976-1980 | 5 | 177,2 | 1,63 | 540,4 | 1,19 | 3,05 |
| | 1981-1985 | 5 | 138,2 | 1,27 | 494,0 | 1,09 | 3,57 |
| | 1986-1988 | 3 | 105,7 | 0,98 | 422,7 | 0,93 | 4,00 |
| | Dnister River - Sambir | | | | | | |
| | 1946-1962 | 17 | 62,3 | 1,00 | 249,6 | 1,00 | 4,01 |
| | 1963-1970 | 8 | 255,8 | 4,11 | 452,6 | 1,81 | 1,77 |
| | 1971-1975 | 5 | 236,8 | 3,80 | 458,6 | 1,84 | 1,94 |
| | 1976-1980 | 5 | 206,0 | 3,31 | 593,2 | 2,38 | 2,88 |
| | 1981-1985 | 5 | 268,0 | 4,30 | 420,2 | 1,68 | 1,57 |
| | 1986-1988 | 3 | 92,3 | 1,48 | 360,0 | 1,44 | 3,90 |
| | Striy River - Upper Synovydne | | | | | | |
| | 1951-1962 | 12 | 73,3 | 1,00 | 520,3 | 1,00 | 7,10 |
| | 1963-1970 | 8 | 134,6 | 1,84 | 591,0 | 1,14 | 4,39 |
| | 1971-1975 | 5 | 352,0 | 4,80 | 530,2 | 1,02 | 1,51 |
| | 1976-1980 | 5 | 320,0 | 4,37 | 655,2 | 1,26 | 2,05 |
| | 1981-1985 | 5 | 228,0 | 3,11 | 608,6 | 1,17 | 2,67 |
| | 1986-1989 | 3 | 116,0 | 1,58 | 487,7 | 0,94 | 4,20 |
| | Prut River - Chernivci | | | | | | |
| | 1947-1962 | 16 | 111,5 | 1,00 | 283,5 | 1,00 | 2,54 |
| | 1963-1970 | 8 | 292,1 | 2,62 | 325,8 | 1,15 | 1,12 |
| | 1971-1975 | 5 | 388,0 | 3,48 | 351,0 | 1,24 | 0,90 |
| | 1976-1980 | 5 | 290,0 | 2,60 | 427,6 | 1,51 | 1,47 |
| | 1981-1985 | 5 | 256,0 | 2,12 | 349,8 | 1,23 | 1,48 |
| | 1981-1988 | 3 | 121,7 | 1,09 | 250,3 | 0,88 | 2,06 |

of the total river length. Prevailing of the very short (less than 1 km) low discharge water flows among the I-II rank rivers is one of the main preconditions of the high sensibility of the river systems to the anthropogenic impact. Such indices reflect the scales of the degradation phenomena in the Dnister basin. During the last 200 years 29.5% of the total rivers number of the different ranks are transformed. In some basins the increase of the rivers number (up to 30% counting the melioration channels), as well as decline (up to 89%) is observed. Among the transformed water flows mainly are the rivers of the I rank (71%). The total length of the river net on the Dnister left bank diminished on 1071 km or 15.4% (Kovaltchuk, Shtoiko, 1992). In some basins the river length diminished on 64%. The river length transformation coefficient on the I stage (1772-1855) did not exceed 1.8%, on the II - (1855-1925) - 5.5-15%, on the III (1925-1955) - 7-22%, and on the IV (1955-1980) -10-31%. The respected data on the river number are 2.0-3.7%, 14/23%, 23-56%, 28-61%.

The obtained data are regarded as the information and the scientific basis for the production and realization of the complex schemes for the optimization of nature utilization, the improvement of the environmental situation, the regulation of the slope and the channel erosion-accumulation processes.


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# EARLY WARNING WATER QUALITY MONITORING SYSTEM TO PROTECT MAIN DRINKING WATER USES ALONG THE RIVER DANUBE IN HUNGARY

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Abstract

Changes of water quality of the River Danube observed in Hungary and the results of the evaluation of the accidental pollution events of the past decade indicate, that the safety of operation of water uses which are sensitive to abrupt water quality deterioration (and especially of the potable water supplies based on surface water intake facilities) is endangered by the frequently occurring water pollution incidents. The method resulted in the UNDP/WHO-KHVM Project on the "Protection of Bank-filtered Drinking Water Resources" was the basis of the further developments concerning the Danube early warning water quality monitoring system. The technical-economic characteristics of the system have been elaborated in four alternative versions, as follows: (1) a system that protects the surface water intake work of Budapest; (2) a system which monitors transboundary pollution incidents; (3) the early warning system DVR of the Upper Hungarian Danube; and (4) a full or complete emergency warning system of the Upper Hungarian Danube. The protection of the water users has been evaluated and the water users to be warned/notified were listed. Proposals for follow-up activities, including the relevant administrative and organizational tasks are also included.

**Ein auf Wassergüte-Monitoring basierendes rechtzeitiges Warnungs-system für den Schutz der Trinkwassernutzungen entlang der ungarischen Donaustrecke**

Kurzfassung

Die in Ungarn beobachteten Veränderungen der Wassergüte sowie die Ergebnisse der Auswertung der unfallartigen Wasserverschmutzungen im letzten Jahrzehnt weisen darauf hin, daß die Sicherheit des Betriebes von Wassernutzungen, welche gegenüber den plötzlichen Verschlechterungen der Wassergüte empfindlich sind (und insbesondere der auf Oberflächenwasserentnahmen basierenden Trinkwasserversorgungen) durch die häufig vorkommenden Wasserverschmutzungs-Unfälle ernsthaft gefährdet ist. Die Basis für die Weiterentwicklung eines auf Wassergüte-Monitoring basierenden rechtzeitigen Warnungssystems bildete die aus dem UNDP/WHO-KHVM-Projekt "Schutz der uferfiltrierten Wasservorräte" resultierende Methode. Die technisch-ökonomische Charakteristika des auf systems wurden in vier alternativen Versionen erarbeitet, undzwar: (1) ein System, welches das Oberflächenentnahmewerk von Budapest schützt: (2) ein System, welches die im Ausland stattfindenden Wasserverschmutzung-Unfälle wahrnimmt: (3) das rechtzeitige Warnungssystem DVR an der Oberen Donau; und (4) ein vollständiges oder komplettes Notfall-Warnungssystem für die Ungarische Obere Donau. Die zu warnenden Wassernutzungen wurden ausgewertet und aufgelistet. Die präliminäre Studie beinhaltet außerdem auch Vorschläge für die nachfolgenden Aufgaben, u.a. für diejenigen administrativen und organisatorischen Charakters, mit deren Hilfe der institutionelle Hintergrund gesichert werden kann.

## 1. Background

Water quality deterioration caused by accidental pollution events put at risk, and even temporarily stopped, the use of surface water in several cases, even in rivers as large as the Danube. The safety of potable water supplies derived from surface waters was especially endangered by these water pollution incidents, the majority of which were caused by contamination with mineral oil and oil derivatives. The observation of randomly occurring water pollution incidents and the prediction of their effects is a highly complex task which cannot be solved on the basis of data derived from the national routine water quality monitoring network.

Early warning water quality monitoring system are needed to safeguard the operation of waterworks whose some supply is surface water. A properly designed system is able to forecast certain parameters of the slug (body) of pollution moving downstream, thereby providing information for the timely introduction of preventative or control measures. Regional early warning system which cover a considerable stream length (such as that on the River Rhine) are not available at present either in Hungary or in any of the neighbouring countries.

Preparatory activities were carried out for the establishment of early warning water quality monitoring systems in Hungary in the framework of the HUN/86/007 project on the "**Protection of Bank-filtered Drinking Water Resources**". The 5-year project was carried out with the support of the United Nations Development Programme (UNDP), the World Health Organization (WHO) and with the assistance of the Ministry for Transport, Communication and Water Management (KHVM) of Hungary. It had the objective of increasing the safety of drinking water supply from bank-filtered water resources and of developing practical methods for the protection of these water resources [1]. The principles of establishing an "**Early warning water quality monitoring system for the River Danube**" were elaborated in the framework of this project for the Danube section between Budapest, (river kilometre 1659), and Rajka, (rkm 1848).

The project activity was extended in 1993 to prepare the pre-investment study of the Danube early warning water quality monitoring system to accelerate the possible implementation, providing thus assistance for the public works having surface water intake to increase their operational safety [2].

## 2. Water quality conditions of the River Danube

The bulk of the country's surface water resources arrives from abroad and thus the water quality conditions vary as a result of the activities of the water management and environmental protection activities of the upstream countries. These surface waters are also prone to frequent accidental pollution events. Water quality deterioration caused by Hungarian or foreign polluters endangers the safety of the operation of water users, especially potable water supplies which are based on surface water intake facilities. Abrupt water quality deterioration caused by accidental pollution events have endangered and even caused a shut-down of surface water intake works in several cases, even in rivers of the magnitude of Danube.

The evaluation of the water quality conditions in the River Danube, having due regard to the interests of water users, was carried out considering two aspects. First, the general state of water quality and its variation was evaluated on the basis of the data derived from the regular water quality monitoring network. Second, the data-base of accidental pollution events was analyzed in order to study the behaviour of abrupt water quality changes, since some of the water users (particularly the water companies) are very sensitive to such sudden changes and their operations are mostly affected by such pollution incidents.

In 1991 the River Danube entered the country at Station Rajka with Class I. water quality, as defined in the currently valid Hungarian classification system [3]. This water quality is characterized by low concentrations of organic matter, phenols and dissolved solids, while nitrite- and phosphate ions, as well as mineral oil derivatives indicated the presence of upstream sources of pollution. It is to be noted that the orthophosphate ion and the mineral oil index (UV) exceeded, in certain cases, the limit values of quality in Class I. Along the river reach which forms the country border, increasing concentrations of quality parameters were observed, due to pollution loads caused by point sources and tributaries on both sides of the river. Downstream of Esztergom water quality falls into Class II. [4].

Regular microbiological analyses of the quality of surface waters are being carried out by the National Public Health Institute (OKI) for three microbiological indices (Coliform, Faecal-coliform and Enterococcus bacteria). On the basis of the 1991 data, the Danube section between Rajka and Budapest belonged to Class III. (of a four-class qualification system). The may be of interest to note that mostly untreated discharges of sewage from Budapest (downstream of the section under consideration) cause the quality to deteriorate further the index is depressed to Class IV [5].

There are many fewer measurement data available for inorganic micropollutants (metals). Nevertheless it can be unambiguously stated that even the measured maximum concentrations of cadmium, nickel, total chromium and copper fall into Class I., while those of zinc and lead correspond to quality Class II. Similarly there are relatively few data available for organic micropollutants and the measured concentrations of the selected representative components (chlorinated hydrocarbons, Triazine type pesticides, volatile chlorinated hydrocarbon solvents, polycyclic aromatic hydrocarbons and polychlorinated biphenyls) were below the limit value set for drinking water. Among other pollutants (phenols, detergents, oil) oil almost always falls into Classes II and III., and this is the component which also exhibits a substantial long term deterioration tendency. There were no appreciable changes in the quality of Danube in 1992 and 1993.

In the period of 1982-1991, 768 accidental water pollution events were observed in the area of the three Danubian Water Authorities and Environmental Inspectorates (the North-Transdanubian, the Middle- and Lower Danube Valley areas). Recent changes of the pattern of the number of accidental water pollution events are illustrated by the Figure 1. Those of foreign origin produced incidents occurred eventually on the Danube reach between Rajka and Szob. Most of the incidents were associated with mineral oil and oil products (43%).

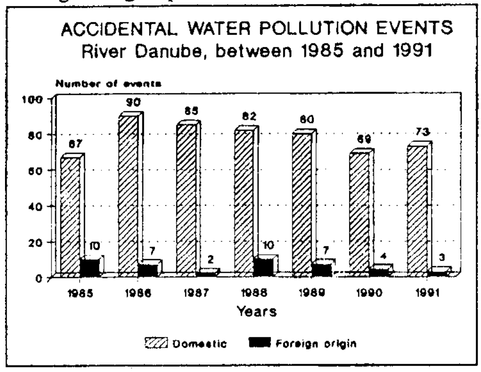


Figure 1.

### 3. Endangered water uses

The most important water users, which are at the same time the most sensitive ones to the unfavourable changes of water quality, are shown in Figure 2. illustrating also the potential sources of pollution of the area.

There are two Waterworks endangered by river quality deterioration along the Danube stretch studied, the Surface Waterworks of Lábatlan (rkm 1737,5) and the Waterworks of Budapest (rkm 1659). The Waterworks of Lábatlan (average production: 3000 m$^3$/d at present) belongs to the category of extremely vulnerable water users, since it has no sufficient clean-water storage capacity. Thus, a lasting water pollution incident on the River Danube would cause serious problems for the drinking water supply of the population served by the waterworks. The most important drinking water user of the entire Danube

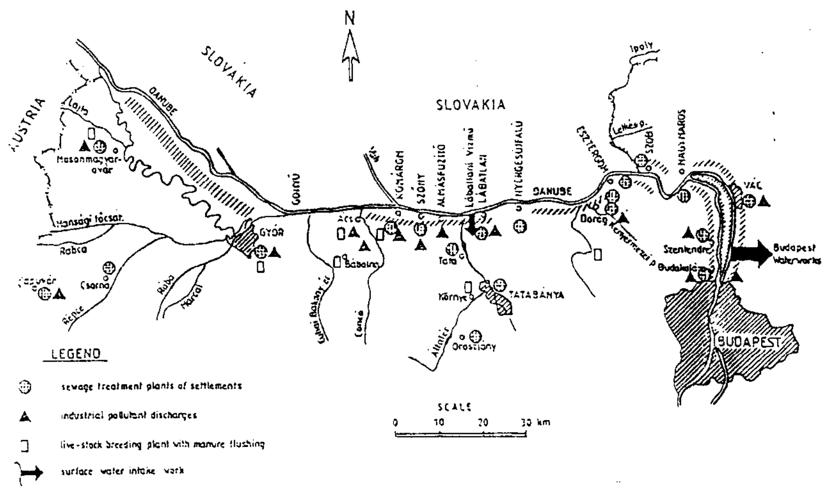


Figure 2. Location of important water resources and polluting sources.

reach under consideration is the Waterworks of Budapest, which produced 341,6 million m$^3$ drinking water in 1992 [6]. Nevertheless of the total production, 25,5 million m³ was produced by the water treatment plant having surface water abstraction, which is of course very sensitive to the quality changes of the river. The surface water intake, which is only intermittently operated in peak consumption periods had eight shut-downs during the past decade because of pollution incidents during the operational periods.

## 4. The proposed "DVR Danube early warning water quality monitoring system"

The objectives of the system to be established are:

to observe abrupt water quality changes caused by accidental or other pollution events in the Danube reach of concern, to forecast the passage of contaminants and to inform the concerned water users which are sensitive to water quality deterioration in due time, releasing warning or alarm signals as required, thus providing the possibility for the selection and implementation of appropriate prevention or control strategies.

The warning system DVR may be considered to be the first stage of a complete Hungarian Danube emergency warning system, which may be a major component of the overall national emergency (catastrophe) warning and alarm system.

The proposed early warning system DVR will include three major components:

* the water quality monitoring system;
* the model system DUNAWARN for the simulation of the effects of pollution incidents and for the forecasting of expectable water quality changes;
* information subsystem for the transmission of monitoring data and alarm signals.

The **monitoring system** includes 13 potential sites along the river stretch for observation stations and automatic water quality monitoring stations (AWQMS) respectively. Figure 3. shows the layout of the full establishment of the system.

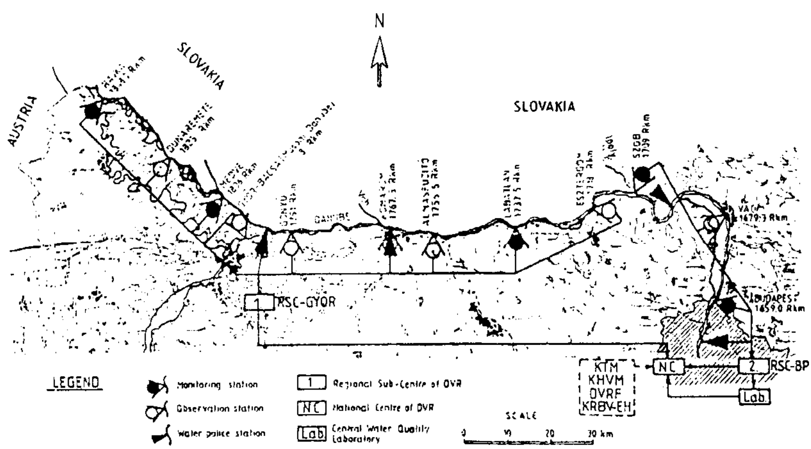


Figure 3. DVR Danube early warning water quality monitoring system (Alternative 4.: full establishment)

The field observation network is also planned to be developed, as well as the involvement of the Water Police Stations and other organizations are also advised.

The ***model system* DUNAWARN** is a *tool for predicting and forecasting* the propagation of the effects of accidental pollution events of the Danube Reach under consideration. It consists of two sub-models: a hydrodynamic model and a mixing model. The hydrodynamic model is one-dimensional and enables the calculation of the time of travel of water and pollutants as well as the other hydraulic parameters needed for the mixing submodel for the Danube reach between Rajka and Dunaujváros. In order to be able to handle large numbers of data the model was calibrated for five flow stages between the extremes of 900 $m^3/s$ and 10,000 $m^3/s$. The mixing model is a depth-integrated two dimensional model based on the analytical solution of the dispersion-convection equation. The coefficients of longitudinal and transverse dispersion are considered constants for a given river reach, but their value may vary from river-reach to river-reach. It is assumed that the pollutants are conservative ones, knowing that all pollutants are subject to decomposition, settling, decay etc. The neglect of these processes, however, serves the interest of safety.

The **information subsystem** will provide connection between the observation points and the regional sub-centres, the Budapest National Centre, and also with important water users. Locally installed VHF wireless equipment, digital mobile radio-telephone and perhaps the satellite connection via INMARSAT-M might be considered as the means of connection between automatic water quality monitoring stations and the regional sub-centres of the system.

The pre-investment study of the DVR early warning water quality monitoring system developed four alternatives for decision making purposes considering the river stretch between Rajka and Budapest as follows:

(1): warning system to protect the surface water intake of the Budapest Waterworks (one AWQMS at Szodliget with on-line connection with the Waterworks, appr. 25 km upstream from intake) around **73 million HUF**

(2): warning system to protect the country border (two AWQMS at Rajka and Szob connected to the Budapest National Centre) around **76 million HUF**

(3): warning system DVR, as proposed by the WHO Project (four AWQMS and seven observation station, two regional sub-centres and the National Centre)around **172 million HUF**

(4): full design of DVR (five AWQMS, five observation stations, three Water Police Stations and extended field observation network, two regional sub-centres and the National Centre) around **241 million HUF**

The North-Transdanubian Water Authority and the North Transdanubian Environmental Inspectorate submitted a joint proposal for the organization of the Győr Regional Sub-Centre of the early warning system, in order to eliminate operational problems during alert periods [7].

Activities of the "Environmental Programme for the Danube River Basin" have been launched by the European Community. In the framework of this programme, an international working group is dealing with the elaboration of the principles of a regional emergency warning system of the Danube basin [8]. The VITUKI as institution to serve as the Hungarian National Centre (as Principal International Alert Centre = PIAC) of the "Danube Accident Emergency Warning System" was recently assigned. should be selected, as it was requested by Brussels Program Coordination Unit of the Danube Environmental Programme. This National Centre should maintain appropriate communications with the similar centres of the upstream and downstream countries as a 24 h service. Thus it should be able to receive, at any time, information on transboundary water pollution incidents from the Austrian (Centre in Vienna) and the Slovak (Centre:Pozsony/Bratislava) centres and should forward similar information and data to the downstream countries (Rumania, Bucharest; Slovenia, Ljubjana; Croatia, Zagreb)[7]. The communication unit of the Hungarian PIAC will be the National Hydrological Forecasting Centre, while the expert unit will be the Institute for Water Pollution Control, both in VITUKI Plc. The institutional framework icluding the decision making unit responsible for decisions to make warnings based on the information from expert unit is under discussion at present.

Authors of the study believe that in the short term the realistically achievable development alternative is Alternative 2., the water quality warning system of the country border. The more so, since this design closely fits to the "Danube Accident Emergency Warning System" the activities of which have already been launched by the "Environmental Programme for the Danube River Basin" of the EC countries. The practical implementation of this system will be possibly made with the support by EC given to the respective riparian countries of the Danube Basin.

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# TWO-DIMENSIONAL PARABOLIC MODEL FOR FLOW AND POLLUTANT SPREADING SIMULATION IN MEANDERING RIVERS

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**SUMMARY:** The paper presents development and application of the mathematical model for simulation of flow and pollutant spreading in meandering rivers. This model is an extended version of two-dimensional depth-averaged parabolic mathematical model using curvilinear co-ordinates, developed earlier by the autors. The model was applied for calculating the flow characteristics and pollutant spreading along a strong curve of the Danube River in Yugoslavia.

# 2D PARABOLISCHE MODELL. ZUR BERECHNUNG DER STRÖMUNG UND STOFFAUSBREITUNG IN NATÜRLICHEN FLÜSSEN

**ZUSAMMENFASSUNG:** Dieses Blatt präsentiert die Entwicklung und die Anwendung von mathematische Modell zur Berechnung der Strömung und Stoffausbreitung in natürlichen Flüssen. Dieses Modell ist durch Verbreitung von früheren 2D parabolische Modellen in Kurvenlinien Koordinaten gemacht. Diese Modell ist verwendent in Projekt von Wasser Versorgung der Stadt Novi Sad in Yugoslavien.

## 1. INTRODUCTION

Mathematical description of flow, pollutant and sediment transport is one of the most difficult tasks of river hydraulics. It requires basically the application of the general Reynolds 3D-equations, for accounting the most of phenomena prevailing in a river meander. The development of these models for practical application is still in its initial stage. In many practical situations, however, the 3D effects, even those caused by secondary motions across a river curve, are eroded by the river turbulence and the approach of depth-averaging could be applied. If this assumption is fulfilled, the 3D equations could be integrated over the river depth and the depth-averaged equations obtained. In this paper a extended version of depth-averaged parabolic models developed by Pavlovic (1981), Rodi et al (1981) and Pavlovic and Rodi (1985) is presented. This model was modified for application to natural meandering rivers. The test case was a strong curve of the River Danube in Yugoslavia. The results of computations are compared with the field measurements (velocity and concentration profiles, streamlines pattern).

## 2. MATHEMATICAL MODEL

### 2.1 Mean Flow Equations

The standard depth-averaged parabolic model consists, when the orthogonal Cartesian co-ordinate system (x-y, Fig. 1) is used, of a continuity equation, x-momentum equation and of the temperature/concentration equation. This set of equations describes horizontal distributions of the longitudinal velocity component $\bar{U}$, lateral component $\bar{V}$ and temperature $\bar{T}$ or concentration $\bar{C}$. If the curvilinear system "s-n" is introduced, where s follows one of the curved river banks, and n is normal to it, an additional equation is obtained; this is the simplified y-momentum equation, expressing the variation of the longitudinal pressure gradient across the river, and thus accounting for the effects of the curvature. The resulting system reads then as follows:

$$\frac{\partial h\bar{U}}{\partial s} + \frac{\partial h\bar{V}}{\partial n} = 0 \qquad (1)$$

$$\bar{U}\frac{\partial \bar{U}}{\partial s} + \bar{V}\frac{\partial \bar{U}}{\partial n} = \frac{1}{\rho}\frac{\partial \bar{P}}{\partial s} + \frac{1}{\rho h}\frac{\partial}{\partial n}(h\bar{\tau}_{ns}) - \tau_{bs}\frac{1}{\rho h} \qquad (2)$$

$$\frac{1}{\rho}\frac{\partial P}{\partial n} = \frac{\bar{U}^2}{R} \qquad (3)$$

$$\bar{U}\frac{\partial \bar{C}}{\partial s} + \bar{V}\frac{\partial \bar{C}}{\partial n} = \frac{1}{\rho h}\frac{\partial}{\partial n}(h\bar{J}_n) + S_c + LD \qquad (4)$$

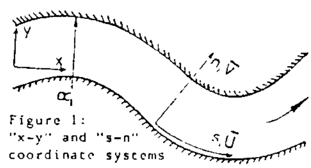

Figure 1: "x-y" and "s-n" coordinate systems

In this system, Eq. 1 is the continuity equation, Eq. 2 the streamwise (s)-momentum equation, end Eq. 3 the simplified lateral (n)-momentum equation. Finally, Eq. 4 describes transport of the scalar quantity $\bar{C}$ (or $\bar{T}$). R is the local radius of curvature of the reference line (bank), while $\bar{\tau}_{ns}$ is the turbulent stress and $\bar{J}_n$ the turbulent pollutant mass flux. The later terms are calculated via a suitable turbulence model (see next paragraph). The bottom shear stress $\tau_{bs}$ is calculated by using the usual quadratic law. $S_c$ is the source (or sink) term, and LD is the lateral dispersion term due to curvature (for details see Pavlovic and Rodi. 1985).

### 2.2 Turbulence Model

The "k-ε" two-equations model is used here to calculate the horizontal distributions of the depth-averaged turbulent stress $\bar{\tau}_{ns}$ and the lateral turbulent flux $\bar{J}_n$. It employs the concept of eddy viscosity/diffusivity, which reads as follows:

$$\frac{\bar{\tau}_{ns}}{\rho} = \bar{\nu}_t\left(\frac{\partial \bar{U}}{\partial n} - \frac{\bar{U}}{R}\right) \qquad \frac{\bar{J}_n}{\rho} = \bar{\Gamma}_c\frac{\partial \bar{C}}{\partial n} \qquad (5)$$

The eddy viscosity $\bar{\nu}_t$ and the eddy diffusivity $\bar{\Gamma}_c$ are related to the kinetic energy $\bar{k}$ and its dissipation rate $\bar{\varepsilon}$, by dimensional analysis:

$$\bar{\nu}_t = C_\mu\frac{\bar{k}^2}{\bar{\varepsilon}} \qquad \bar{\Gamma}_c = \frac{\bar{\nu}_t}{\sigma_c} \qquad (6)$$

The horizontal distributions of $\bar{k}$ and $\bar{\varepsilon}$ are obtained from the solution of the following semi-empirical transport equations:

$$\bar{U}\frac{\partial \bar{k}}{\partial s} + \bar{V}\frac{\partial \bar{k}}{\partial n} = \frac{\partial}{\partial n}\left(\frac{\bar{\nu}_t}{\sigma_k}\frac{\partial \bar{k}}{\partial n}\right) + \nu_t\left(\frac{\partial \bar{U}}{\partial n} - \frac{\bar{U}}{R}\right)^2 + P_{kv} - \bar{\varepsilon} \qquad (7)$$

$$\bar{U}\frac{\partial\bar{\varepsilon}}{\partial s} + \bar{V}\frac{\partial\bar{\varepsilon}}{\partial n} = \frac{\partial}{\partial n}\left(\frac{\bar{\nu}_t}{\sigma_\varepsilon}\frac{\partial\bar{\varepsilon}}{\partial n}\right) + C_1\frac{\bar{\varepsilon}}{\bar{k}}\bar{\nu}_t\left(\frac{\partial\bar{U}}{\partial n} - \frac{\bar{U}}{R}\right)^2 + P_{\varepsilon v} - C_2\frac{\bar{\varepsilon}^2}{\bar{k}^2} \tag{8}$$

$P_{kv}$ and $P_{\varepsilon v}$ are terms expressing the bottom produced turbulence. The model uses as an empirical input the dimensionless eddy diffusivity $e^* = \bar{\Gamma}_c/(\rho U_* h)$. An analysis of field measurements (Fischer et al., 1979) and of the test computations (Pavlovic, 1981) has shown that this coefficient has in rivers a typical value of $e^* = 0.6$. However, in meandering rivers it is increased due to lateral dispersion (term LD in Eq. (4) ), and has values even several times higher than 0.6. Its determination, therefore, requires in most cases field experiments. The empirical constants appearing in expressions (6) to (8) have the following standard values (Rodi, 1980): $C_\mu = 0.09$, $C_1 = 1.44$, $C_2 = 1.92$ , $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.3$, $\sigma_c = 0.5$.

### 2.3 Solution Procedure

The solution of the mean flow equations (1) to (4), completed with the turbulence model equations (5) to (8), requires boundary conditions at the inlet section and along the river banks. These are usually: measured or estimated U-velocity distribution, estimated $\bar{k}$- and $\bar{\varepsilon}$-distributions, and measured starting concentration profile or given pollutant flux at the discharging channel outlet. The equations are solved by using the marching-downstream procedure, which is based on the procedure of Patankar and Spalding (1970); this procedure was here extensively modified to account the open channel flow features and curvature effects, as well as for simulating pollutant discharges (for details see Pavlovic (1981), Rodi et al., (1981) and Pavlovic and Rodi, 1985).

Practical application of the presented mathematical model includes several steps to be performed: 1D-backwater calculation, which provides the following inputs into the 2D model: cross-sectional mean velocity, bottom shear force, channel geometry characteristics corresponding to the actual river discharge, etc; (b) definition of the forward step as a function of river curvature; (c) definition of river bank radii as a function of s; (d) solution of model equations set; graphical presentation of velocity and concentration profiles, etc.

## 3. MODEL APPLICATION AND CONCLUSIONS

The mathematical model was applied within the Study of Water Supply of Novi Sad City. The problem of non-sufficient capacity of the present sources for water supply of this town should be solved by using the new ground water sources on the area along the left bank of the Danube River (Fig. 2). The area is located immediately downstream from two waste water outlets, endangering the river and ground water quality. One of the many tasks of this study was to investigate effects of dislocating openings of the discharging pipes across the river. The study was based on field measurements, which included: surveying of the river bathymetry, velocity measurements, surveying of streamlines, suspended and bed load sampling, as well as taking water samples for determination of its quality parameters. The measurements were performed during two campaigns: first in May, at the Danube discharge of 4000 $m^3/s$, and the second in August, at the discharge of 2000 $m^3/s$ (mean annual discharge is 2970 $m^3/s$). Some of the results are presented in Fig. 2 (streamlines, i.e. trajectories of surface and submerged floats) and Fig. 3 (velocity profiles).

The calculations were started from the river km 1256 and covered a 5 km long reach downstream. The numerical grid had 25 points in the lateral direction. Because of its "self-adjusting" feature, it was capable of fitting the irregular river alignment. Fig. 2

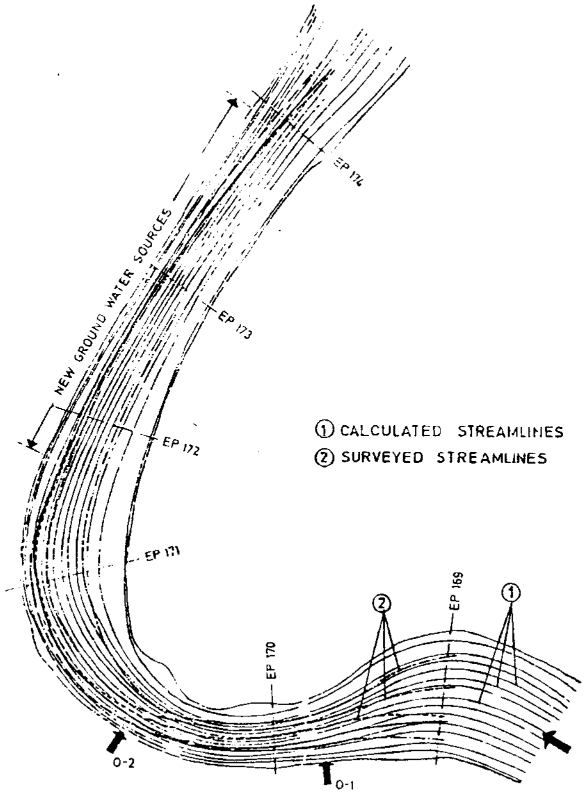


FIG 2 - COMPARISON OF CALCULATED AND SURVEYED STREAMLINES

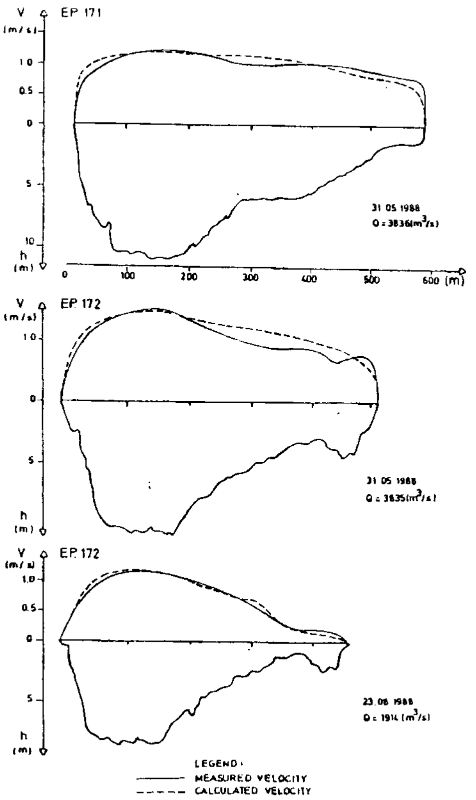


FIG. 3 - CALCULATED AND MEASURED VELOCITY DISTRIBUTIONS

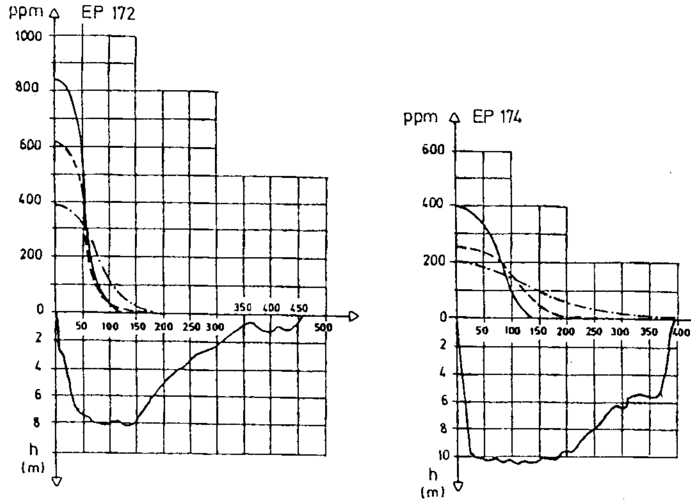


FIG.4 - CONCENTRATION PROFILES FOR DIFFERENT VALUES OF $E^*$
(SENSITIVITY ANALYSES)

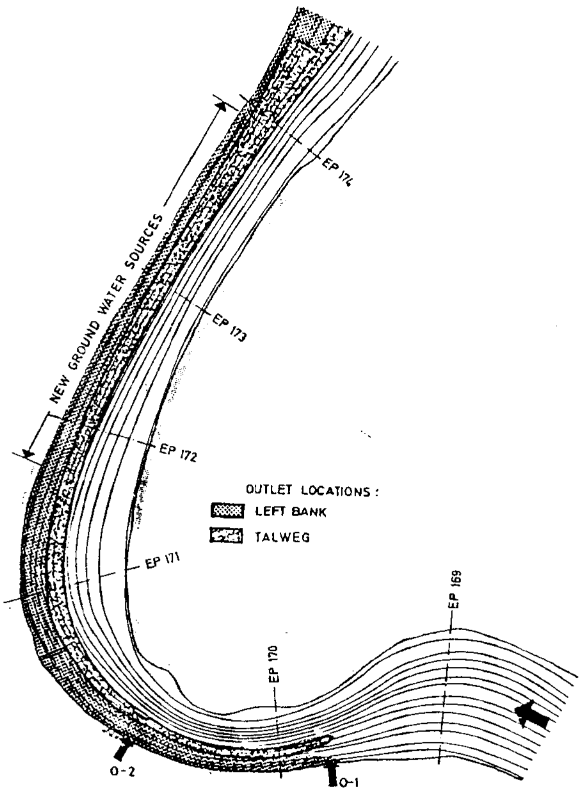


FIG.5 - WASTE WATER SPREADING FOR DIFFERENT LOCATIONS
OF DISCHARGE OUTLET

shows this grid (representing in the same time the calculated steamlines), together with the measured streamlines. Calculated velocity distributions are given in Fig. 3 and compared with the measured ones, showing a satisfactory agreement. The calculations of waste water spreading were performed using several values of the diffusivity coefficient e*. Results of this sensitivity analysis are given in Fig. 4. Due to non-satisfied conservation in measurements, measured profiles of water quality parameters could not be used to "calibrate" the value of e*, and the estimated values were used. The effects of dislocating the waste water outlets across the river are shown in Fig. 5. They are rather weak; the waste water zone, namely, is in all cases pushed towards the left bank. This is mainly due to the curvature effects.

The computations have been carried out on the VAX 11/780 computer of the Jaroslav Cerni Institute in Belgrade. One run took typically about 3 minutes of CPU time.

The presented comparisons of the calculated and measured flow field characteristics are quite satisfactory. The main problem is, however, related with the estimation of the diffusivity coefficient. In the present study the knowledge of this parameter was not so important. In many cases, however, it must be obtained from the appropriate tracer experiments in the field.

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# PREDICTION ON VELOCITY, CONCENTRATION AND TEMPERATURE FIELDS ON THREE CASES OF DANUBE RIVER BASIN

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## Abstract

In our previous investigatons, we used two-dimensional, depth-averaged elliptic mathematical model with body-fitted coordinates and "k-ε" turbulence model, for prediction of velocity, concentration and temperature fields in open channel flow.

This paper presents the similar mathematical model with the simpler model of turbulence. The turbulence viscosity was calculated on the empirical basis and adiopted as the unique one for the whole field of calculation. The mentioned model was verified on three cases in Danube river basin in Yugoslavia: calculation of velocity field on the Tisza river; calculaton of velocity and concentration fields on Sava river at intake structure and calculaton of velocity and themperature fields on Sava river in the zone of intake and outlet structure.

# BERECHUNG DER GESCHWINDIGKEIT, KONZERTRATION UND DER TEMPERATUR IN DREI BEISPIELEN DES WASSERSTROMS IN DEN FLÜSSEN DES DONAU-FLÜSSGEBIETES

## Das Resumee

In den vorrangehenden Forschungen für die Errechnung der Geschwindigkeiten, Konzentrationen und Temperaturen, benutzten wir ein zweidimensionales eliptisch-matematisches krummliniges Koordinaten System als Modell für mitlere Tiefen und dabei gebrauchten wir das "k-ε" Modell der Turbulenzen.

Mit der hier prasentierten Arbeit, zeigen wir ein ahnliches matematisches Modell, mit einer einer einfacheren Turbulenz. In diesem Modell errechnet sich die turbulente Viskosität mit Hilfe von durchschnitlichen Wasserlaufkarakteristiken und empirischen Angaben, und sie ist massgebend fur das ganze Wasserstromgebiet, als eine konstante Einheit. Dieses Modell wurde verifiziert durch drei praktische Beispiele des Wasserstroms in den Flüssen des Donau-Flussgebietes sind: die Berechnung des Wasserlaufes in Flusse Tisa, die Berechnung der Gesch windigkeit und Konzetration im Gebiete der Wassererffasunf der Sava, und die Berechnung der Geschwindigkeiten und Temperaturen in der Zone der Wassererffassunf und des Wasserablaufes der Sava.

## 1. INTRODUCTION

In our previous investigatons presented in papers [1],[2] and [3], we used two-dimensional, depth-averaged elliptic mathematical model with body-fitted coordinates and "k-ε" turbulence model for prediction of velocity, concentration and temperature fields in open channel flow.

This paper presents the similar mathematical model with the simpler model of turbulence. The mentioned model was verified on three cases in Danube river basin in Yugoslavia: calculation of velocity field on the Tisza river; calculaton of velocity and concentration fields on Sava river and calculaton of velocity and temperature fields on Sava river.

## 2. MATHEMATICAL MODEL

Previously used depth-averaged elliptical mathematical model with body-fitted coordinates consists of the mean-flow equations and is completed with two semiempirical transport equations, for k and ε, with "k-ε" turbulence model. Simplification of the turbulence model was done in the following way:

$$k = \left(T \cdot C_0^{1,5}/C_\mu\right)^{0,5} \cdot U_0^2\,; \quad \varepsilon = C_0 U_0^3/h_0\,; \quad C_0 = n^2 g/h_0^{0,333}\,; \; \nu_t = k^2 C_\mu/\varepsilon$$

Notations in equations are as usual. The turbulence viscosity $\nu_t$ was calculated on the empirical basis and adopted as the unique one for the whole field of calculation, according to [4]. In this way, the complexity of the mathematical model and the time of calculation were both reduced.

## 3. EXPERIMENTAL VERIFICATION

The scale model measurements were used for the first verification of the simplified mathematical model. This was an extremely curved reach of the Tisza river near the Adorjan village in Yugoslavia. In order to avoid the problems arising from the similarity considerations, the scale model (1:50/150) was used as a prototype for the mathematical model. The velocity distributions were measured in 40 cross-sections. The measured velocity vectors are shown in figure1.

The scale model measurements were also used for the second verification of the mathematical model. This was a reach of the Sava river, were the intake structure of the Belgrade Water Supply System was constructed. The velocity distributions were measured in the 19 cross-sections. Besides the velocity measurements, dye spreding experiments were also conducted. The measured iso-concentration lines (relative concentration, i.e. C/Cmax) are shown in figure 3.

For the third verificaton of the mathematical model, the field measurements on the Sava river were used. The flow pattern and temperature field in the zone of intake and outlet structures of the Thermal Power Plant "Nikola Tesla"-A were measured. The measured iso-temperature lines are shown in figure 5.

## 4. RESULTS OF CALCULATIONS

For easier comparisons, the results of calculations are presented together with the results of measurements. In all three examples, velocity fields were done first, and then the second and the third examples of concentrations and temperatures.

The figure 2 shows the calculated distribution of velocities in a strong curve of the river Tisza. Comparing it to the figure 1, it could be stated that the measured and the calculated distribution of the velocities are very similar. In a river curve, two recirculaton zones were formed. The position and the lenght of the measured recirculaton zone are the same as the calculated ones. The widths of calculated zones are smaller than the measured ones.

In the second example - figure 4, the calculated distribution of iso-concentration lines is presented. The comparison with measured lines presented in figure 3, shows very good concordance. The quantity of pollution in intake structure is almost the same.

In the third example - figure 6, the calculated distribution of themperature is presented. Better concordance is achieved in zone of intake and and outlet structure than in a far field.

## 5. CONCLUSIONS

Results of calculations obtained with proposed simplified mathematical model and both scale model and field measurements, were in very good concordance.

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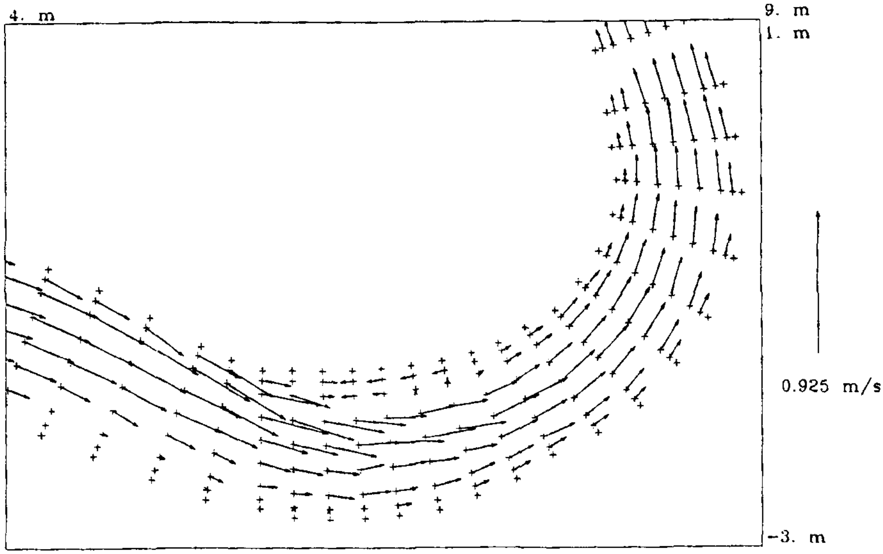


Figure 1: Measured velocity vectors in Tisza river

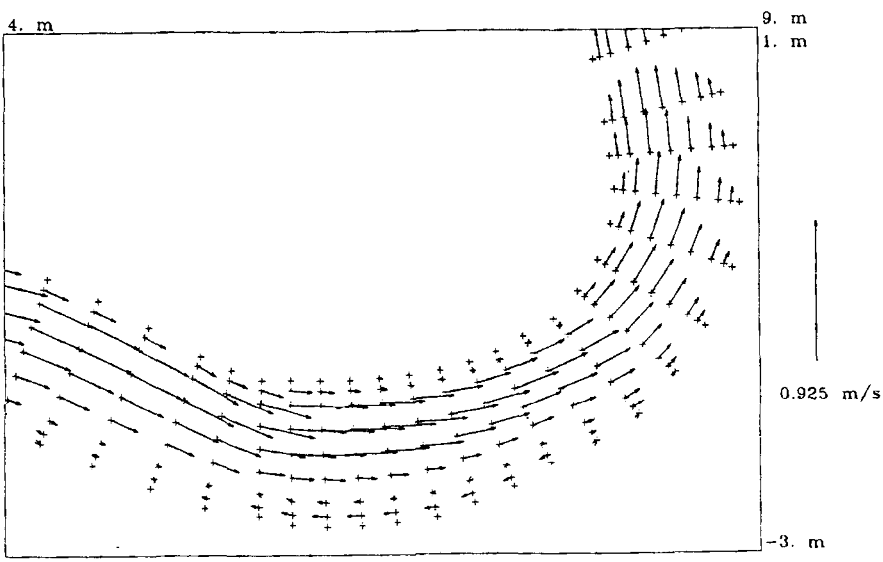


Figure 2: Calculated velocity vectors in Tisza river

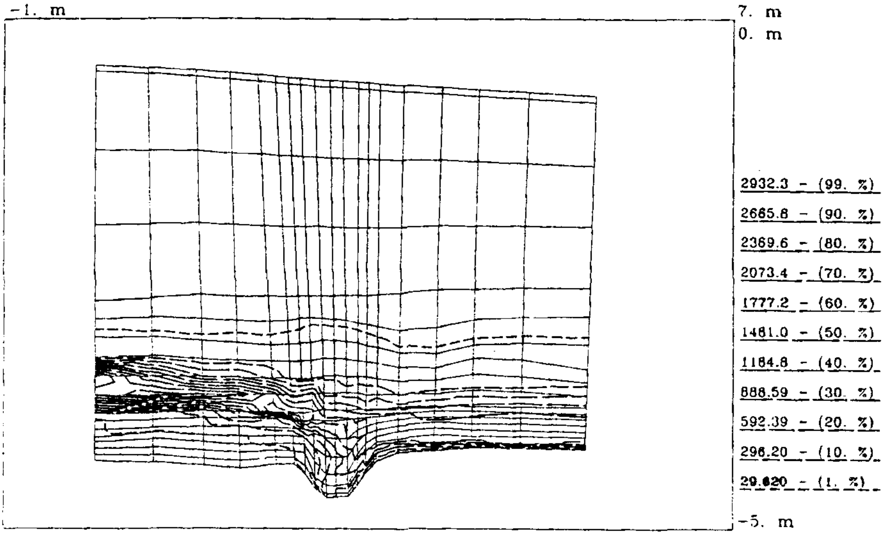


Figure 3: Measured concentraton distribution on Sava river intake structure zone

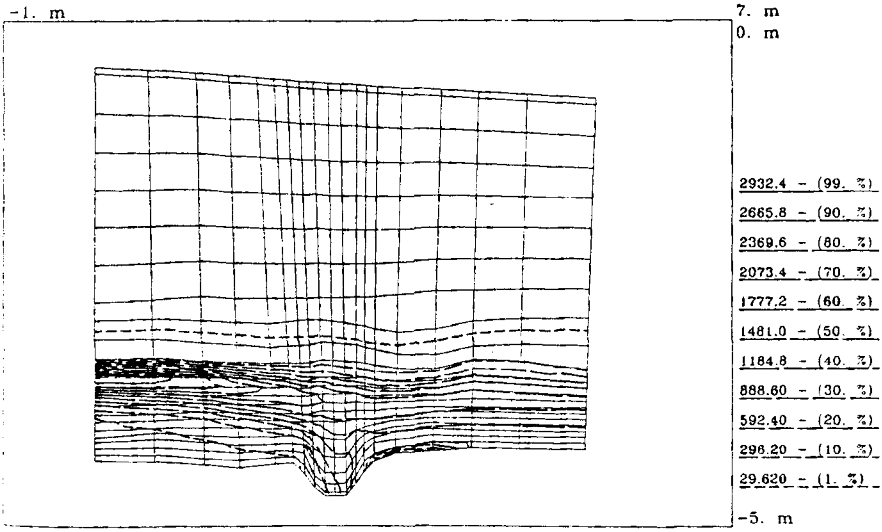


Figure 4: Calculated concentraton distribution on Sava river intake structure zone

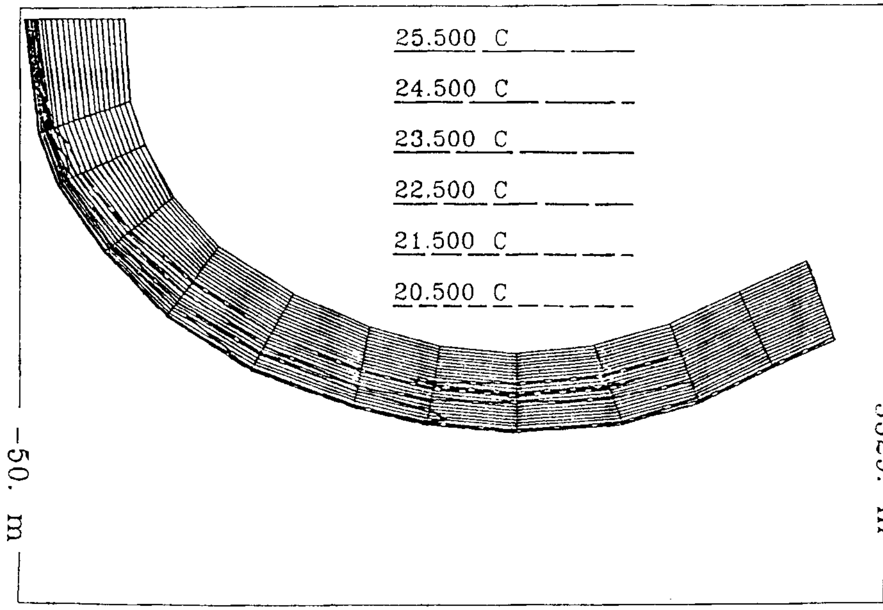


Figure 5: Measured temperature field on Sava river at intake and outlet structure

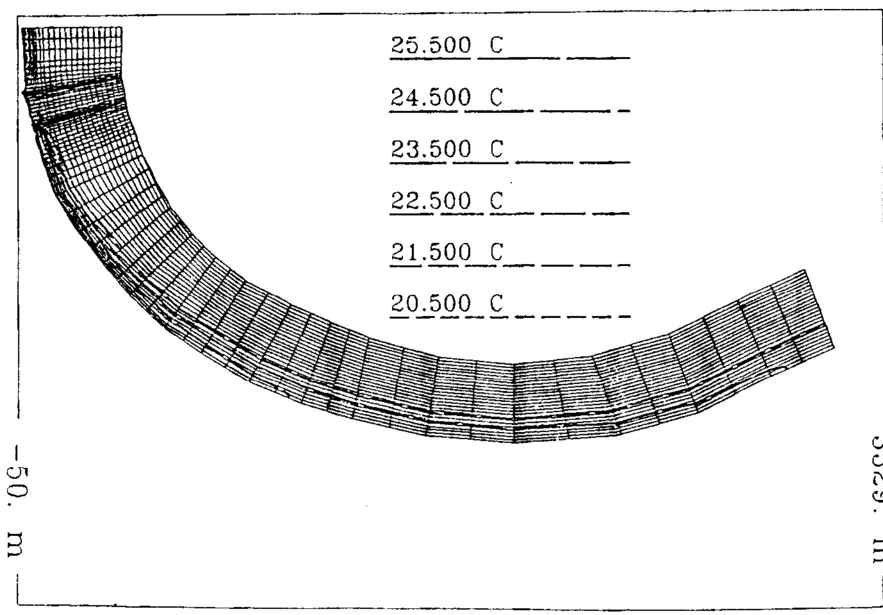


Figure 6: Calculated temperature field on Sava river at intake and outlet structure

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# Particle Tracking Model of Pollution Transport in Compound Open Channel Flow

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## Abstract

The paper deals with the mathematical simulation of transport in open channels by means of models based on particle tracking method. Fluid domain is a two-dimensional strip in horizontal plane obtained by integration of all the values over the depth. Results of simulation have been checked against experimental data and compared with the results of simulation obtained by the continuous model. An attempt has been made to compare the discontinuous model parameters (i.e. the parameters which define the distribution of random numbers by which the flow field is generated) with the standard parameters of the continuous model (i.e. the dispersion coefficients). The possibilities of application of particular models in simple (rectangular) and complex cross-sections have been considered.

# "Particle Tracking" Transportmodel von Verschmutzung im Kanal mit dem Zusammengesetzten Querschnitt

Dieser Text betätigt sich mit der mathematische Simulation von Transport in die offene Kanäle mit Anwendung von dem Modell daßauf der Methode von Teilchenfolgen gegründet ist. Das Flußgebiet ist ein zweidiemnsionales Band in waagerechte Ebene, daßdurch die Integration aller Tiefparametern erhalten ist. Die Simulationergebnisse waren mit den Experimentalangaben verglichen. Man hat es versucht die Parameter von diskontinuirten Modell (z.B. Parameter die Verteilung von zufällige Nummer bestimmen) mit Standardparameter von kontinuirten Modell (z.B. Dispersionkoefficient) zu vergleichen. Die Möglichkeit für die Anwendung von der bestimmten Modellen in der Kanälen mit einfacher (rechteckinger) und zusammengesetzten Querschnitt ist betrachtet.

# 1 Introduction

Problem of water pollution becomes very significant nowadays. Prediction of pollution transport is very important, because the high concentration of some materials thrown into the recipient can cause killing life in it. Proper release may be possible if the transport process is known in advance.

There is a lot of numerical models based on Eulerian approach to contaminant transport in rivers with mean concentration as a representative quantity of contaminant presence in water. Concentration is a continuous variable in the flow domain, thus related models are *continuous models of transport.*

On the other hand *particle tracking models* are based on Lagrangian approach. The contaminant is represented by a finite number of particles released at a point which is a source of contaminant and tracked in their way downstream.

Particle tracking model offers some advantages over standard continuous models and it is expected to be used more frequently in the future [Heslop and Allen, 1993, Aya, 1991]

The particle tracking model has been used for the simulation of the passive tracer transport in a compound open channel flow [Petreski, Djordjević and Ivetić, 1993]. Compound open channel flow is interesting because of the complexity of the flow structure. An important aspect of this flow situation is the transverse transfer of momentum between the fast moving parts of the stream in main channel and adjacent slower moving parts.

For contaminant transport in compound open channel flow, the experimental results and the results from the continuous model have already been available [Djordjević, 1993]. Upstream boundary condition was taken in the far flow field, where vertical mixing was completed, so the problem was considered as two-dimensional in horizontal plane.

# 2 Particle tracking model

This model is based on the idea that the contaminated matter in the water can be represented by a big number of particles which can be released at any point of the flow domain. The movement of every particle is caused by an instantaneous velocity $(U, V)$ (at the current position), which consists of deterministic part $(\overline{U}, \overline{V})$ and stochastic part $(u, v)$. Particle trajectory is obtained by the integration of instantaneous particle velocities over finite time steps.

In this paper mean velocity field was determined on the basis of previous investigations [Djordjević, 1993]. Generator of the random number with the Gaussian distribution $(N(0, \sigma))$ was used to represent the randomness of the velocity fluctuations. Standard deviation was chosen according to experimental results [Imamoto and Ishigaki, 1989]. The results of the measurement of the turbulence intensity are shown in Fig. 1. It can be noted that peaks of intensity appear in the interaction region. Adopted standard deviations ($\sigma_u$ and $\sigma_v$) are presented in the same figure.

Velocity fluctuations in turbulent flow are not mutually independent. Some correlation between them exist, and in this model it is introduced in the next form:

$$u_n^i = u_{n-1}^i \sin\Phi + \bar{u}_n \cos\Phi \tag{1}$$

where $u_n^i$ is the velocity fluctuation in direction $i$, at the moment $n$, $\bar{u}_n$ is an uncorrelated velocity fluctuation generated at the moment $n$, and $\Phi$ is some sort of correlation parameter defined as follows [Ivetić, 1989]:

$$\Phi = arctan\left[2\sqrt{(\Delta t/T)/(1-\Delta t/T)}\right] \tag{2}$$

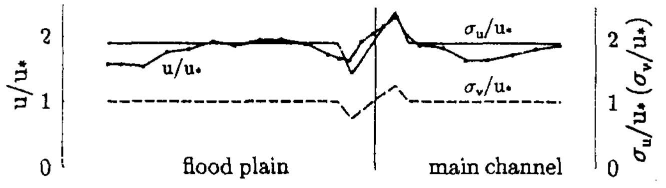


Figure 1: Experimental data of lateral distribution of the turbulence intensity [Imamoto and Ishigaki, 1989] and of adopted standard deviation

Time interval $T$ is the integral time scale and defines time in which auto-correlation exists. For open channel flows with depth $h$ integral time scale can be estimated from $T = 0.72h/u_*$ [Aya, 1991], where $u_*$ is friction velocity. Time step of integration $\Delta t$ has been determined in order to satisfy the assumption of local equilibrium between the production and the dissipation of turbulent energy.

# 3 Continuous model

Transport of chemically stable and neutrally buoyant substance (passive tracer) in steady open channel flow is described by the mass conservation equation

$$\frac{\partial C}{\partial t} + \overline{U}\frac{\partial C}{\partial x} = \frac{1}{h}\frac{\partial}{\partial x}\left(hD_x\frac{\partial C}{\partial x}\right) + \overline{U}\frac{\partial}{\partial q}\left(h^2\overline{U}D_y\frac{\partial C}{\partial q}\right) \tag{3}$$

where $C$ is depth averaged concentration of substance, $t$ time, $x$ longitudinal (downstream) coordinate, $\overline{U}$ depth averaged velocity in $x$-direction, $h$ water depth, $D_x, D_y$ longitudinal and transverse dispersion coefficients respectively, $q$ cumulative discharge through a single stream tube.

Equation (4) can be derived from its basic form by replacing the transverse coordinate by the cumulative discharge. This transformation enables flow to be divided into a set of stream tubes. In this approach the transverse velocity is eliminated and the simulation of 2D dispersion is significantly simplified without losing any correctness.

In continuous model turbulent diffusion is performed by dispersion coefficients in next form: $D_x = 6hu_*$ and $D_y = 0.2hu_*$ (by taking local $u_*$ values which are related with local velocities).

# 4 Description of the problem

Measurements were carried out in a straight, concrete laboratory channel, about 24 meters long and 68 centimeters wide, with an average bed slope of about 0.15%. Its typical cross section, shown in Fig. 1a, consists of the main channel (MC) and a flood plain (FP).

Length of the channel was divided into 17 sections (1.5m apart). Horizontal projection of the channel is shown in Fig. 1b.

The tracer was injected instantaneously in the first section at $x = 0.0$. Three cases were examined. In the first case water flowed only through the deeper part of the channel (rectangular cross section). The injection was undertaken at the centre of the MC. Concentration was measured at the 7.5m, 15m and 22.5m far from the point of injection.

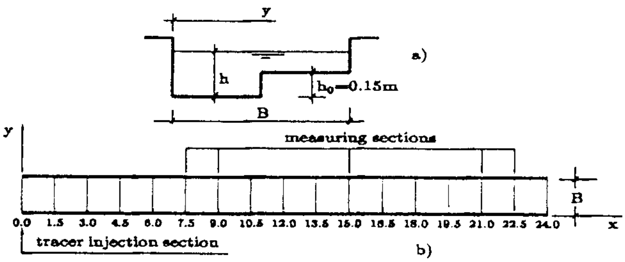


Figure 2: a) Cross section of the experimental channel, b) Horizontal projection of the channel

In the other two cases water flowed over the entire channel width. The injection was performed at the centre of the MC and near MC/FP interface respectively. Concentration was measured at the 9m, 15m and 21m far from the point of injection.

Some characteristic quantities for considered cases are given in the next table: The

| No | $B(m)$ channel width | $h(m)$ depth in MC | $Q(m^3/s)$ discharge | $M(mg)$ tracer mass | $y(m)$ point of injection |
|---|---|---|---|---|---|
| 1 | 0.35 | 0.101 | 0.011 | 40 | 0.171 |
| 2 | 0.68 | 0.246 | 0.0225 | 20 | 0.170 |
| 3 | 0.68 | 0.2505 | 0.023 | 20 | 0.340 |

concentration distributions measured at 7.5m and 9m, for rectangular and compound open channel flow respectively, were taken as the upstream boundary condition for both models, assuming that vertical mixing of tracer was completely realized.

# 5 Results of simulation

**Rectangular open channel flow** Results of simulation of contaminant transport in rectangular channel are shown in Figure 3. Measured concentrations are indicated by dashed lines and the calculated values by solid lines.

Number of particles, which represent the passive tracer, was 10,000 in all cases, though mass of concentration was different.

An excellent agreement is obtained between experiments and calculations with particle tracking model as well as with continuous model. Excellent agreement is in peaks of concentration and in spatial and temporal distributions.

**Compound open channel flow** Two different cases were examined: a) the tracer was injected at the centre of the MC ($y = 0.25B$), and b) the injection was near MC-FP interface ($y = 0.5B$) ($y$ is the distance from the outer MC bank).

Results obtained by particle tracking and continuous model are presented in Figures 4 and 5. There is a firm agreement between measured and calculated values, although it is not as good as in the first case (rectangular channel). This result could have been expected because of the 3D nature of flow, thus the compound open channel flow is more

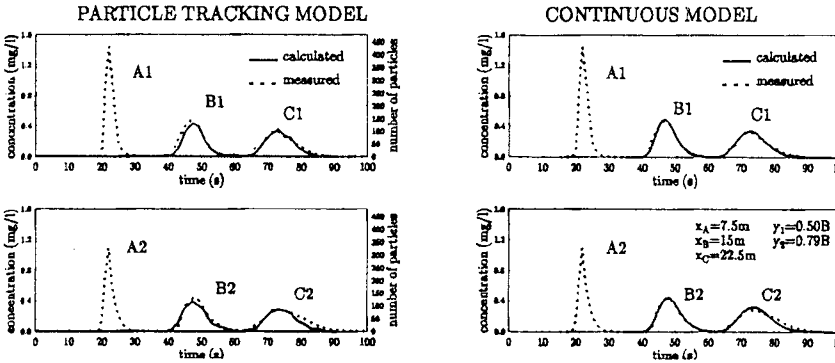


Figure 3: Concentration distributions in rectangular channel after instantaneous injection in $y = 0.5B_{MC}$

difficult to simulate using a 2D model. Regardless of that, spatial and temporal agreement is present in these cases as well.

The third case (Fig. 5) is characteristic because the tracer is injected just in the region of interaction of MC and FP. Results obtained by calculation show the biggest discrepancy from measured values, because of the intensive secondary circulation in this part of the channel which can not be easy performed in 2D model.

## 6 Conclusions

Particle tracking model was explained and applied for simulation of passive tracer transport in rectangular and compound open channel flows. Results obtained for three different cases were compared with experimental data and the results obtained by continuous model.

Transport in rectangular channel, simulated by both models, was in exellent agreement with experimental data. Results of the transport simulation in compound channel show some discrepancy from measured data, but spatial and temporal agreement is good.

Continuous model is much more complicated, but it does not give much better results then particle tracking model. So, particle tracking model can be used for transport simulation, as well as the first one. Results depend on representation of the flow field (mean velocities and velocity fluctuations) and the number of particles.

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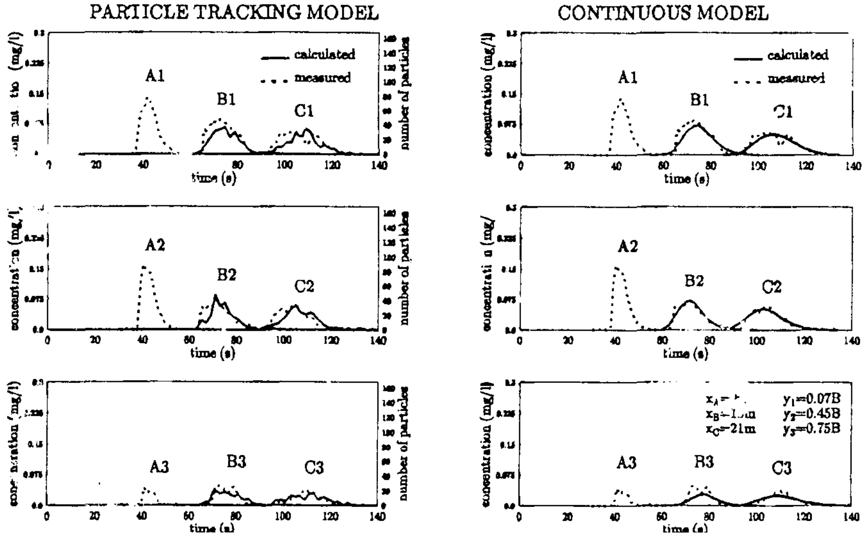


Figure 4: Concentration distributions in compound channel after instantaneous injection in $y = 0.25B$

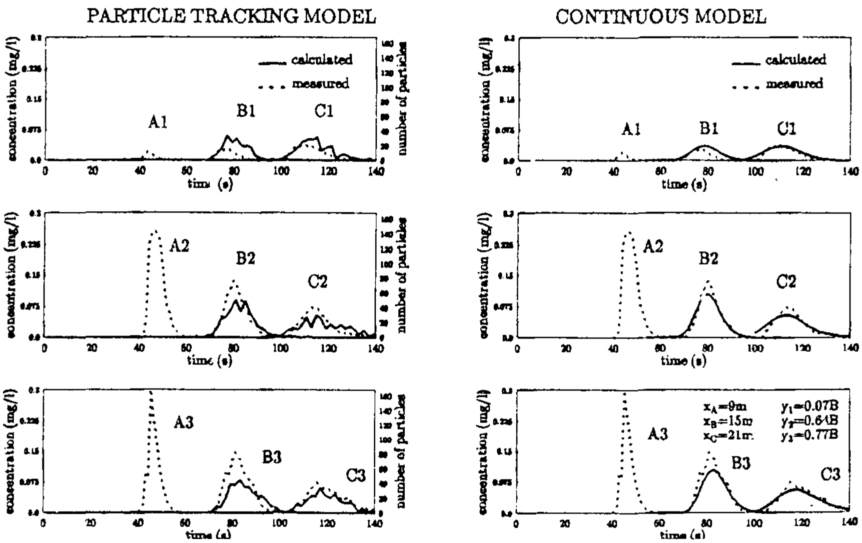


Figure 5: Concentration distributions in compound channel after instantaneous injection in $y = 0.5B$

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# POLLUTION SIMULATION FOR DANUBE, ACCORDING TO MATHEMATICAL MODELS OF DISPERSION IN VARIOUS HYPOTHESES

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**Abstract:** The purpose of the paper is to establish some mathematical models for the description of the pollutant propagation in rivers and to deduce analytical solutions which will be used to select the most appropriate model for a certain situation, for the Danube river. The models have been stated by taking into account some physical and hydrological hypotheses able to preserve the generality and reliability of the model for Danube river and to permit the obtaining of analytical solutions. These last eliminate the errors due to the applicaton of numerical methods.

# SIMULATIONSVERSUCHE FUR DIE DONAUVERUNREINIGUNG, AUFGRUND MATHEMATISCHES MODELLIERENS DES DISPERSONSPROZESSES, UNTER VERSCHIEDENEN HIPOTHESEN

**Kurzfassung:** Das Ziel dieses Beitrags ist es, verschiedene mathematische Modellierungsweisen für die Beschreibung des Transportprozesses der verunreinigenden Stoffen in Flüssen festzustellen und analytische Lösungen abzuleiten, die dann benützt werden, um das unter bestimmten gegebenen Bedingungen (im Falle der Donau) am besten angemessene Modell auszuwählen. Die verschiedenen Modelle wurden durch die Betrachtung mancher physischer und hydrolgischer Hypothesen aufgestellt, deren Fähigkeit, die Allgemeingültigkeit und Zuverlässigekeit des Modells im Falle der Donau zu bewahren, geprüft wurde, und die es erlauben, analytische Lösungen zu erhalten. Mit Hilfe der letzteren können die durch die Verwendung numerischer Methoden bedingten Fehlergebnisse beseitigt werden.

## 1. INTRODUCTION

The study of the pollutant propagation in rivers, downstream the pollution source, depending on their flow regime, requires the necessity of a more available mathematical modelling.

For the pollutant transport simulation in the Danube river, a mathematical model is proposed. According to certain hydrological and physical hypotheses available for the Danube river, the model enables the determination of the solutions using an analytical method. These solutions allow the elimination of the errors due to the application of the numerical methods.

Bath the two-dimensional case and the one-dimensional one are treated.

## 2. THE TWO-DIMENSIONAL PROBLEM

The first part of the paper refers to the solution (concentration - $C(t,x,y)$) for a two-dimensional dispersion problem, in a medium whose velocity is considered unidirectional along the Ox axis and represented by the constant value $V$. The dispersion coefficients denoted by $K_x$ and $K_y$ are assumed to be constant. A first order reaction is taken into account and it is characterised by the constant and positive coefficient $r$. This allows the consideration not only of a chemical pollutant but also of a radioactive one. A pollution source $F(t,x,y)$ accidentally occurred completes the description of the problem, imposing the model (1) in the domain represented by an infinitely long channel parallel to the Ox direction, with a rectangular section, $D = R*[0,B]$, $B$ being the width of the river. The processes is studied for $t>0$:

$$\begin{aligned}
&\frac{\partial C}{\partial t}+V\frac{\partial C}{\partial x}=K_x\frac{\partial^2 C}{\partial x^2}+K_y\frac{\partial^2 C}{\partial y^2}-rC+F,\ t>0,\ (x,y)\in D\\
&\lim_{t\to\infty} C(t,x,y)=0\\
&C(0,x,y)=0\\
&\left.\frac{\partial C}{\partial y}\right|_{y=0}=\left.\frac{\partial C}{\partial y}\right|_{y=B}=0
\end{aligned}\qquad (1)$$

The last boundary condition is deduced by the fact that the lateral walls are insulators. The source function $F(t,x,y)$ acting at the initial moment $t_0=0$ in the point $(x_0, y_0)$ has the form:

$$F(t,x,y) = \frac{m}{H}\delta(t)\delta(x-x_0)\delta(y-y_0) \tag{2}$$

where $m$ represents the total quantity of pollutant injected, $H$ the depth of the river and $\delta$ the Dirac function.

Using the method of Green function the solution for the boundary value problem (1) was determinated in (Marinoschi, 1993a) as:

$$C(t,x,y) = \frac{m}{BH}\frac{1}{2\sqrt{K_x \pi t}}\exp\left[-\frac{(x-x_0-Vt)^2}{4K_x t}\right]\times$$
$$\times\left[1+2\sum_{n=1}^{\infty}\exp(A_n^2 t)\cos\frac{n\pi y_0}{B}\cos\frac{n\pi y}{B}\right] \tag{3}$$

with: $A_n = K_y n^2 \pi^2 / B^2 + r$.

This formula was used to obtain the numerical results further discussed.

For the illustration of this case the following input data were used:

- a chemical passive pollutant ($r$ = 0);
- the source located at km 432 (the confluence with the Argesh river) characterised by a discharge $Q_s = 55\ \text{m}^3/\text{s}$ and a concentration $C_s = 10$ g/l;
- the Danube discharge downstream the source considered in two cases: $Q_1 = 4000\ \text{m}^3/\text{s}$ and $Q_2 = 6000\ \text{m}^3/\text{s}$ and the corresponding velocities $V_1 = 0.8\ \text{m/s}$ and $V_2 = 1.0\ \text{m/s}$;
- the width of the river corresponding to this reach and to the above discharges; $B_1 = 540$ m and $B_2 = 700$ m;
- the dispersion coefficients $K_x = 100\ \text{m}^2/\text{s}$ and $K_y = 10\ \text{m}^2/\text{s}$.

For the dispersion coefficient $K_x$, the following formula was used (Fisher, 1968):

$$K_x = 74.8R\left(\frac{Q}{A}\right)^{0.238}\frac{1}{H^{0.762}} \tag{4}$$

where $R$ - hydraulic radius; $H$ - average depth and $K_y = K_x/10$ (Bansal & Asce, 1971).

From the numerical results, it can be concluded that:

- in a cross section near the point of injection the concentration is maximum on the bank where source is located (left bank) and decreases to zero to the right bank;

- consequently to the increasing of the distance from the source, the pollutant wave extends to the right bank, such that at a certain distance the concentration becomes to be uniform in the cross section.

It results for the above example, that for $Q_1 = 4000\,\mathrm{m}^3/\mathrm{s}$, the distance at which the concentration is made uniform is of about 20 km downstream the source and for $Q_2 = 6000\,\mathrm{m}^3/\mathrm{s}$ the distance is about 35 km.

In the intermediate sections the concentration variation was studied for 4 points: left bank, $1/3B$, $2/3B$ and right bank.

Figure 1 shows the time dependence of the pollutant concentration in two cross sections (the cross section where the concentration has been homogenised and the cross section upstream) and for two flow regimes.

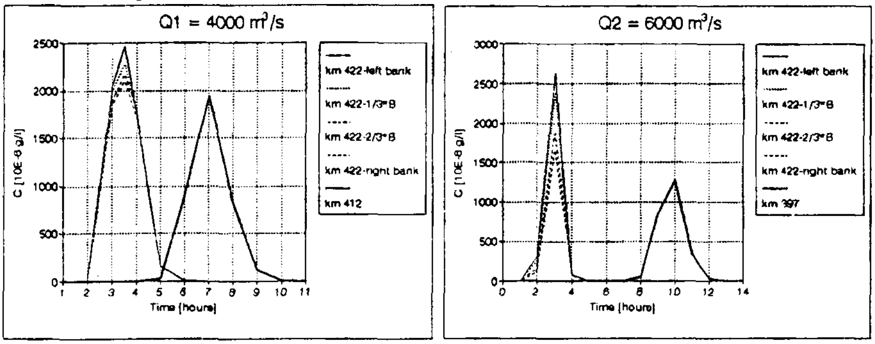


*Fig. 1 The variation of the pollutant concentration Two-dimensional model*

According to all these it can be concluded that as the homogeneous mixture is reached, the one-dimensional case can be applied.

## 3. THE ONE-DIMENSIONAL PROBLEM

For the one-dimensional case a solution of convection-diffusion equations with different velocities corresponding to different reaches was developed in (Marinoschi, 1993b). The motion considered unidirectional along the Ox axis is represented for each established reach (indicated by the subscript "$i$") by its associated velocity $V_i$ and by the value $K_i$. Taking into account a pollution source variable in time and situated in a point $x_0$, the convection-diffusion equation modelling the phenomenon written for each reach is for $t>0$:

$$\frac{\partial C}{\partial t}+V\frac{\partial C}{\partial x}=K\frac{\partial^2 C}{\partial x^2}+F(t,x),\ t>0,\ x\in R$$

$$\lim_{t\to\infty} C(t,x)=\lim_{x\to\pm\infty} C(t,x)=0 \qquad (5)$$

$$F(t,x)=\delta(x-x_0)\varphi(t)$$

The solution of (5) expressing the concentration $C(t,x)$ is:

$$C(t,x)=\int_0^{t^+}\mathrm{d}\tau\int_R\frac{1}{\sqrt{4K\pi}}\frac{1}{\sqrt{(t-\tau)}}\exp\left[-\frac{(x-x_0-Vt+V\tau)^2}{4K(t-\tau)}\right]\varphi(\tau)\mathrm{d}\tau \qquad (6)$$

which can be used preserving a mathematical cautiousness imposed by the singular integral computation.

The modification of the river velocity within a downstream reach implies the changing of the computation of the propagated values in the following way. Suppose that the velocity changes in the point $x=x_i$, becoming $V_i$. The pollution wave formed upstream the point $x_i$ will reach the point $x_i$ and will be taken into account since the moment of time $t_i$ beginning with the concentration $C_{i-1}(t,x_i)$ becomes greater than a specific previously defined value. Hence it can be considered as a pollutant delivered by a time variable source $C_{i-1}(t,x_i)$ which will propagate downstream $x_i$, for $t>t_i$ and where $C_{i-1}$ is the computational result obtained for the reach "$i$-1". The solution will be:

$$C_i(t,x)=\frac{1}{\sqrt{4K_i\pi}}\int_{t_i}^{t^+}\frac{1}{\sqrt{t-\tau}}\exp\left[-\frac{(\mathrm{x}-\mathrm{x_i}-V_it+V_i\tau)^2}{4K_i(t-\tau)}\right]C_{i-1}(\tau,x_i)\mathrm{d}\tau \qquad (7)$$

Numerical investigations based on this relation are further presented.

For the pollutant source it was adopted the same variant as in the two-dimensional case.

For the characterisation of the flow regime for two consecutive reaches downstream the source there were considered 2 variants for discharges and velocities:

a) - $Q_1=4000\ \mathrm{m^3/s}$, $V_1=0.7\ \mathrm{m/s}$, $V_2=0.7\ \mathrm{m/s}$;

b) - $Q_2=6000\ \mathrm{m^3/s}$, $V_1=1.0\ \mathrm{m/s}$, $V_2=0.9\ \mathrm{m/s}$.

For the both cases it was adopted $K_x=100\ \mathrm{m^2/s}$.

The figure 2 comparatively present the pollutant wave at the bottom of the second reach, obtained through the computational application of one-dimensional model both in the case of variable velocity and in the case of constant velocity.

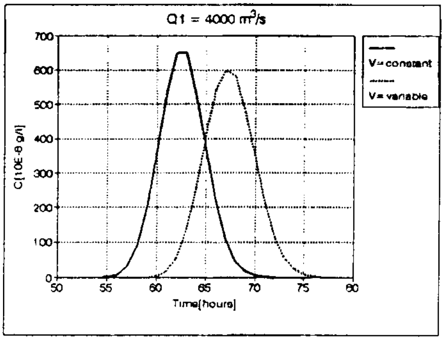


*Fig. 2 The variation of the pollutant concentration One-dimensional model*

The figure 2 comparatively present the pollutant wave at the bottom of the second reach, obtained through the computational application of one-dimensional model both in the case of variable velocity and in the case of constant velocity.

For the one-dimensional case, a perturbation technique for the solution of convection-diffusion equations with variable velocity was developed in (Marinoschi, 1994). There the velocity of the river is regarded as a continuos function $V(x)$ for $x \in R$ and only as been composed by consecutive velocities $V_i$ for each. For this model numerical results are not here discussed.

## 4. CONCLUSIONS

For the simulation of a passive pollutant transport for the Danube river a two-dimensional model must be first used up to the distance for which the homogenate is reached. Downstream this point the one-dimensional model with variable velocity is available.

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# SIMULATION AND WATER QUALITY MANAGEMENT STUDY OF THE IBAR WATERSHED

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## ABSTRACT

The main objective of this paper is to present the results of a water quality simulation study for River Ibar. The QUAL2EU model was applied for the dry season of 1989 and 1990 for the river section from the Leposavić gauge to the mouth of the river. The daily water quantity data collected during a two-year period (1989 and 1990), and weekly and monthly quality data collected during a four-year period (1987-1990) was analyzed statistically to determine the corresponding initial and boundary conditions. Hydrological and hydraulic parameters were determined for the model from systematic observations of the existing basic hydrological network. Dissolved oxygen (DO) and biological oxygen demand (BOD ) were simulated. The model calibration was carried out and the most important model parameters were estimated from the data of the dry season of 1990. Model was verified for the same season of 1989.

## ZUSAMMENFASSUNG

Das Hauptobjekt dieses Beitrags ist die Präsentierung der Resultaten einer Simulationsstudie für Wassergüte des Flußes Ibar. Das Modell QUAL2E wurde für die Strecke des Flußes zwischen dem Meßort Leposavić und der Mündung während der trockenen Jahreszeiten von 1989 und 1990 angewendet. Sowolt die Tageswerte der zwiejährigen Periode (1989 und 1990) als die wöchentliche und monatliche Daten einer vierjähringen Period (1987-90) der Waßergüte wurden gesammelt. Diese Daten wurden statistisch analysiert um die entsprechenden Anfangs- und Grenzbedingungen zu bestimmen. Hydrologische und hydraulische Parameter wurden aufgrunde der systematischen Beobachtungen des vorhandenen hydrologischen Grundbeobachtungsnetzes determiniert.

Der gelöste Sauerstoff (GB) und der biologische Sauerstoffbedarf (BSB) waren simuliert. Die Kalibration des Modells wurde durchgeführt und die wichtigsten Modellparameter wurden aufgrunde der Daten der trockenen Jahreszeit von 1990 geschätzt. Das Modell wurde für die selbe Jahreszeit von 1989 bestätigt.

## 1. INTRODUCTION

The Ibar river is one of the most heavily polluted rivers in the Republic of Serbia. At the same time, its water is extensively used for drinking, as well as for other purposes such as food industry and recreation. The area is also an important touristic region. In view of this situation, the need for an accurate river water quality model is obvious to promote the elaboration of a reliable water quality management strategy for the basin. The QUAL2UE model was chosen for this purpose (Brown and Barnwell, 1987). The simulation was done for two water quality parameters (dissolved oxygen and biological oxygen demand for the dry season of 1989 and 1990. The model was also used to study the impact of alternative waste loads (magnitude, quality and location) on ambient water quality.

## 2. DESCRIPTION OF THE IBAR WATERSHED AREA

The total length of the Ibar is 280 km. The highest elevation is 2400 m, and its lowest elevation is 212 m above mean sea level at the mouth of the river. The catchment area is geologically and geomorphologically inhomogeneous. Upstream, the river has the characteristics of a mountain stream. In the vicinity of the health resort town of Mataruška Banja, the Ibar becomes an alluvial river.

The Ibar catchment has an area of 8059 $km^2$. The most significant tributaries are the Sitnica, Raska and Studenica. The climate in the Ibar catchment area is continental with four different seasons. The rainy and dry periods can generally be clearly separated. The multi-annual precipitation is approximately 770 mm. Approximately 30% of the Ibar catchment is covered by forest, 30% is under the grassland, while the rest is occupied by plough-lands and urban areas. The multi-annual average of the river Ibar flow, at the upstream gauge (Ribarić) is 11.4 $m^3/s$; at the most downstream gauge (Kraljevo) is 63.2 $m^3/s$.

The Ibar catchment is a well-established industrial zone. Heavy industry, mining and thermal power plants are located in the vicinity of the Sitnica river. The main pollution sources are the settlements of Novi Pazar, Baljevac and Kraljevo. In addition, depositions from the atmosphere on agricultural and urban areas directly pollute surface and subsurface waters by surface land runoff, base flow, and subsurface runoff in the form of non-point sources of contamination.

A statistical analysis of water quality parameters was carried out to estimate the past and present state of the water quality for the investigated section of Ibar river. The ranges of measured values of 1987, 1988, 1989 and 1990 at all selected gauges and all analyzed water quality parameters (DO, $BOD_5$, $NH_4^+$ and $NO_3^-$) are presented in Table 1.

Table 1. Water quality parameters

| River | Gauge | DO | $BOD_5$ | $NH_4^+$ | $NO_3^-$ |
|---|---|---|---|---|---|
| Ibar | Kraljevo | 7.9-17.5 | 0.3-7.7 | 0.0-3.3 | 0.0-3.8 |
| Ibar | Ušće | 7.1-14.0 | 1.9-6.6 | 0.0-4.7 | 0.2-3.9 |
| Ibar | Raška | 3.1-15.7 | 0.2-9.9 | 0.0-3.0 | 0.0-7.9 |
| Ibar | Leposavi | 7.5-12.7 | 2.4-5.0 | 0.0-3.4 | 0.0-5.4 |
| Studen. | Ušće | 8.3-14.9 | 1.2-2.5 | 0.0-3.0 | 0.0-1.4 |
| Raska | Raška | 7.8-14.9 | 1.0-4.3 | 0.0-3.9 | 0.0-5.9 |

Remark: All units are in mg/l.

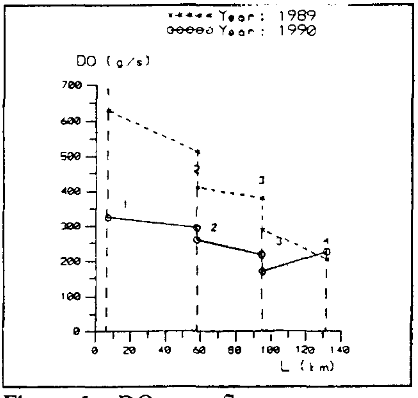

Figure 1. DO mass flow.

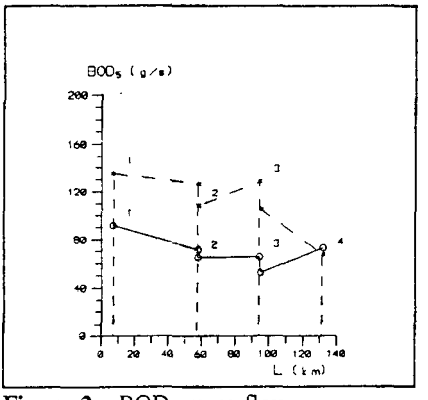

Figure 2. $BOD_5$ mass flow.

Constituent mass transport rates (g/s) are shown in Figures 1 through 4, which show the dependency of water quality on external loads within this aquatic system, as well as those stemming from tributaries.

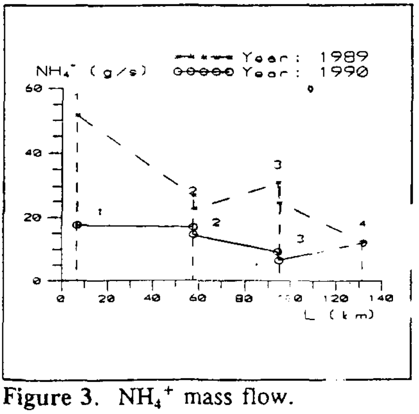

Figure 3. $NH_4^+$ mass flow.

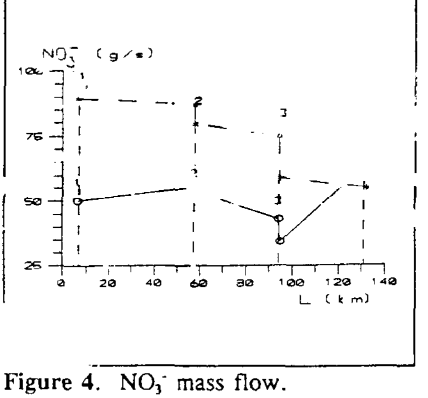

Figure 4. $NO_3^-$ mass flow.

## 3. THE QUAL2EU COMPUTER MODEL

The QUAL2EU, linear computer model (Brown and Barnwell, 1987) was chosen to simulate the water quality profile of Ibar river. It can simulate up to 15 water quality constituents, in any combination desired by the user. The model can also simulate multiple waste discharges, withdrawals, tributary flows, and incremental inflow/outflow. Hence, the program has a capability to account for additional flows into or out of the system which are not represented by point source inflows/outflows or headwaters. Another characteristic of the model is its ability to compute dilution flows required to meet any pre-specified dissolved oxygen level.

Hydraulically, the QUAL2EU model is limited to the simulation of periods during which both the stream flow in the river basin and the output waste loads are essentially constant. Initial conditions for temperature must always be specified, whether or not temperature is simulated.

## 4. APPLICATION OF THE MODEL TO THE IBAR RIVER SYSTEM

The Ibar river section from the most upstream Leposavić gauge to the Kraljevo gauge (the downstream boundary condition in our case study) is divided into six reaches with uniform characteristics. Dissolved oxygen (DO) and biological oxygen demand ($BOD_5$) constituents were simulated. Three streams were included into the simulation as point sources. Industrial and sewage loads originating from the settlements of Novi Pazar, Baljevac and Kraljevo were also included in the simulation as point sources. Model calibration was done for the dry season 1990.

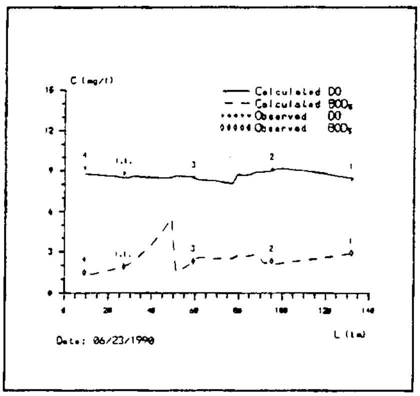


Figure 5. Calibration for Jun 23, 1990.

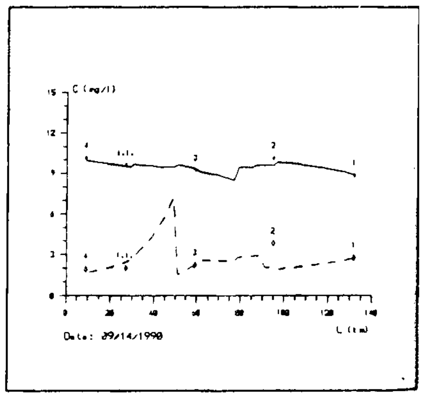


Figure 6. Calibration for Sept. 14, 1990.

Computational results are depicted in Figures 5 through 8. The best simulation results were obtained when the parameter values listed in Table 2. were used.

The validation step was based on observed data for the year 1989 (Figures 9 through 10). The results obtained with the adopted model and the selected variables proved to be satisfactory. Errors between calculated and observed data occurred owing to the presence of several non-point sources which were not considered in the simulation process.

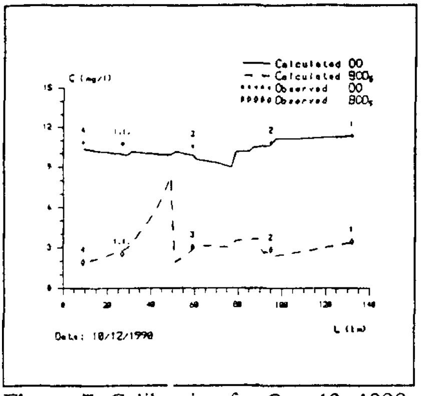


Figure 7. Calibration for Oct. 12, 1990.

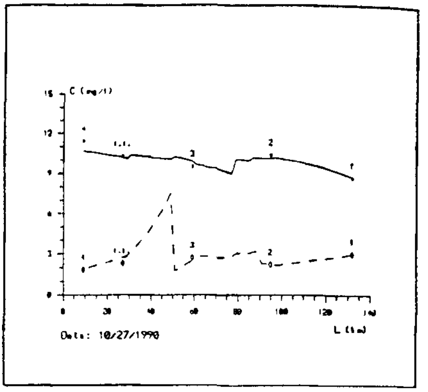


Figure 8. Calibration for Oct. 27, 1990.

Table 2. Estimated parameters

KBOD $= 0.30$ day$^{-1}$
$K_2$ = option 5 day$^{-1}$

| Reach N$^0$ | $K_1$ | $K_3$ | $K_4$ |
|---|---|---|---|
| 1 | 0.00 | 0.50 | 0.00 |
| 2 | 0.60 | 0.40 | 2.50 |
| 3 | 0.01 | 0.00 | 2.00 |
| 4 | 0.80 | 0.50 | 2.50 |
| 5 | 0.30 | 2.30 | 0.00 |
| 6 | 0.05 | 1.50 | 0.00 |

where:

KBOD - is BOD conversion rate coefficient, day$^{-1}$
$K_1$ - is deoxygenation rate coefficient, day$^{-1}$
$K_2$ - is reaeration rate coefficient, day$^{-1}$
$K_3$ - is the rate of loss of carbonaceous BOD due to settlings, day$^{-1}$
$K_4$ - is sediment oxygen demand rate coefficient, day$^{-1}$

## 5. RESULTS AND CONCLUSIONS

The investigated area is a known industrial district where water quality is a major concern. The available hydrological and water quality observations enabled a detailed description and analysis of water quality in the Ibar catchment. Data for 1987, 1988, 1989 and 1990 were used in the analysis. Results obtained with the QUAL2UE computer model reflect the complexities of the processes involved in the model.

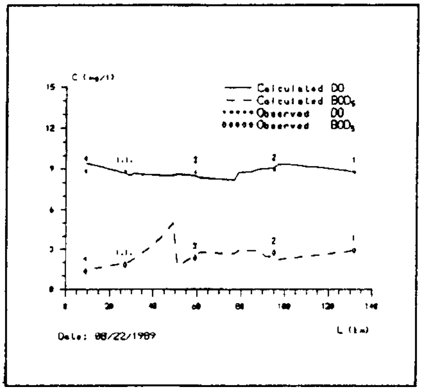


Figure 9. Validation for Aug. 22, 1989.

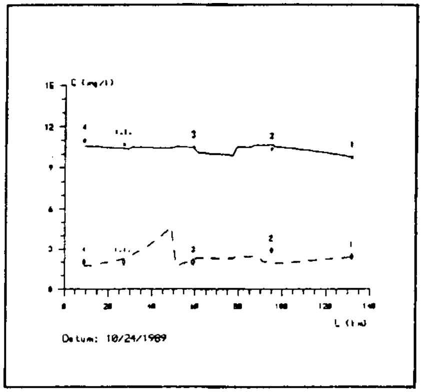


Figure 10. Validation for Oct. 24, 1989.

The attempt in this study to calibrate and use the model shows that a relatively good correspondence can be reached between the observed and simulated values. The generally positive experience of using the model was distorted by only one negative facts. First, most of the observations were simulated relatively well, except for the biochemical oxygen demand at the end of long dry periods with low flow. These periods were affected by pollution from non-point sources which were not included in the model. Substantial differences were discovered between the simulation results and observed values at cross-sections downstream of the mouth of the Raska river at the end of September and early October. Second, similar discrepancies occurred in the Ibar river between the towns of Ušće and Kraljevo where uncontrolled industrial effluent made it impossible to properly calibrate the model. Despite of the limited extent of this study, the QUAL2UE model proved to be an extremely useful tool for planning and managing water quality control in the Ibar catchment, and likely for other watershed, as well.

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# CHEMICAL TIME BOMBS - HOT SPOTS - STUDY IN THE SLOVAK PART OF THE DANUBE CATCHMENT AREA

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Summary: Specific oriented inventory of hot spots based on the CTB concept has been studied in Slovakia since 1991. A brief description of the research project structure, developed data banks and supplementary sampling in the Nitra river subcatchment is given. Some results are discussed and 4 layers of inventory are presented in the graphical form using PC ARC/INFO technology.

# CHEMISCHE ZEITBOMBEN ("CTB") - HEIẞE FLECKEN - FORSCHUNG IM SLOWAKISCHEN TEIL DES DONAUEINZUGSGEBIETES

Kurzfassung: Seit 1991 läuft in der Slowakei eine spezifisch orientierte Zusamenstellung von heißen Flecken durch, die am CTB - Konzept gegründet ist. Kurze Beschreibung der Forschungsprojektstruktur, zusammengestellten Databanken und Nachtragsprobenentnahmen im Eizugsgebiet von Fluß Nitra ist angeführt. Einige Resultate werden diskutiert und 4 Schichten in der graphischen Form in PC ARC-INFO Format presentieren die Hauptquellen von "hot-spot"-Verziechniß.

## 1. INTRODUCTION

Based on the international activities concerning the environmental studies in the CEE countries the "Chemical Time Bombs (CTB)" concept in the hot spots inventory was introduced in Slovakia.

The first initiative arised in the cooperation of IIASA, the Dutch foundation 'MONDIAL ALTERNATIEF' and the Ministry of Housing, Physical Planning and Environment (VROM) in The Netherlands within their all-European study of growing environmental problems.

As the focal point for the whole Danube catchment area was chosen at the first meeting of the steering committee the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences and the director of the Institute, Prof. Dr. G. Várallyay was appointed the chairman of this committee. The Project and budget proposals have been sent to EC and we have been waiting, sorry to say, waiting for the promised support till today.

In former Czechoslovakia the Federal Commission for Environment supported project proposals in full extent and over the years 1991 and 1992 an equivalent of app. 220 000 ECU for our study (1/3 of it on the nowadays territory of Czech Republic - the Morava river basin) was used. After splitting Czechoslovakia into two parts, the project, sponsored by the Slovak Ministry of Environment has been further developed in 1993 inly in the Slovak Republic. Results obtained within first two - tree years of this complex study were successfully applied in the international Environmental Programme for the Danube River Basin.

## 2. METHODOLOGY, CONCEPT, STRUCTURE AND SOME RESULTS

The methodology of the whole CTB project was drawn up in a very simple way in the Proceedings of an European workshop on CTB, held in De Bilt, Utrecht on June 21 - 23, 1990 [1], further that the literature on the Rhine river basin environmental measures has to be studied and that the full terminology is in an IIASA Executive Report No.16 [2] by W. M. Stigliani. In mentioned material the definition of CTB was formulated as follows:

A Chemical Time Bomb concept is a concept that refers to a chain of events resulting in the delayed and sudden occurence of harmful effects due to the mobilization of chemicals stored in soils and sediments in response to slow alterations of the environment.

The programme for the Danube Catchment area was discussed in Budapest and the conclusions and proposals were summarized by Csikós [3].

The general concept and further definitions were given by Stigliani [2]:

**Chemical Time Bombs refer to manifest environmental changes, occuring over a relatively fast time scale (years to decades) caused by slow alterations (decades to a century) in some key variables that serve to buffer the system against adverse effects of compounds.**

The detailed description of the project for the Danube Catchment area was presented by Varallyay (1992) at the SETAC - Potsdam workshop [4].

The structure of the project in Slovakia was based on the scheme given by the proposed programme for the whole river basin and is grouped into 3 main topics - A - screening maps, B - methodological tasks and C - case studies.

Part "A" - mapping of hot spots had been processed by the Dionýz Štúr Geological Institute (GÚDŠ) in cooperation with the Water Research Institute (VÚVH), the Research Institute for Soil Fertility (VÚPÚ), and a private consulting firm (HYDEKO). Within 3 years of hard work a database of point pollution sources of rivers and specific categories of scattered pollution has been created.

This part has a separate final (sub)report for each Danubian subbasin with

- a brief characterization of the particular (sub)basin
- categorization of surface water quality
- tables with the water quality data for the period of 1989-90 according to the ČSN 75 7221
- a list and brief description of major pollution sources
- the full list of registered pollution sources in 1990 (according to the criteria of the State watermanagement balance system)

Some maps

- 1:200 000 Point sources of surface water pollution
- 1:1 000 000 Water quality in Slovak rivers (1989 - 1990)
- 1:500 000 CTB' hot spots and their possible impact on surface water

are included in those reports.

List of landfills was also worked out by the VÚVH, the VÚPÚ contributed by the analysis of soil vulnerability with respect to buffering, hydrogeological conditions and subsoil analysis, and, finally, mapping was performed by the GÚDŠ and HYDEKO. The last firm was investigating on the localities with former mining activities and waste rock dumps as to estimate their risks, focused on complex evaluation of hot spots and setting up the related data bank using dBase structure. A specific trend analysis was computed for the time series of groundwater quality in the Little Danube Island region.

New methodology of soil vulnerability categorization and mapping based on the evaluation of the humus content, pH and soil particle size have shown 6 classes and 13 subclasses. From the point of view of soil contamination 10 following localities were specified as hot spots:

1. Bratislava, 2. Sereď - Šal'a, 3. The Upper Nitra (region Prievidza - Nováky), 4. Žiar n/Hronom, 5. Dolná Orava (Istebné - Široká), 6. Ružomberok, 7. Košice, 8. Strážske - Vranov - Humenné, 9. Middle Spiš (Rudňany - Krompachy), 10. Jelšava - Lubeník.

Within first two years of common work with colleagues from the Morava river basin analyses of PCB and other organic pollutants were performed at the Masaryk University of Brno. The Geographical Institute of (former) Czechoslovak Academy of Sciences proposed a methodology of ecological mapping for the Morava subcatchment. Landfills analyses was done by the AQUATIS Brno. Some soil studies and a hydrogeological support was provided by the Geological Survey and Research Institute for soil reclamation and protection in Brno. Summarization for the Morava river was in hands of the branch office of TGM' Water Research Institute in Brno.

Part B was oriented on methodological issues problems and was done mostly at the VÚVH. A detailed comparison of analytical methods and standards used in former COMECON countries and EC countries was performed. Some new effective methods for specialized research, as for instance bio - monitoring were analyzed. Mathematical modelling of processes of pollution propagation into the saturated zone of the aquifer played also a certain role in the study. Both authors of this paper focused special attention on the GIS technology of results storing, analysing and presentation. Outside the VÚVH soil characteristics and soil acidification risks were considered and mathematical modelling of some processes in open river channels was performed at the Masaryk University of Brno.

Part C - case studies - is dealing with the Nitra river basin. In this watershed, two series of samplings were performed in 1991 and 1992 and one only in 1993. Work done was oriented toward the study of interactions between surface water, groundwater and sediments. It was stated, that the stage of surface river waters and upper layers of groundwater have a very poor quality. All analytical results have to be mutually related as to support the decision system for evaluation of revitalization actions.

The full list of tasks, authors and organizations cooperating in the project can be obtained on request in the VÚVH.

## 3. GIS TECHNOLOGY AND SOME RESULTS

Application of Geographical Information Systems (GIS) technology started at the VÚVH within the scope of this environmentally oriented project. As far as chosen technology is concerned it was important to take into consideration, that state authority and environmental offices are equipped with the PC version of ARC/INFO and this software was granted by the Slovak Ministry of Environment for use within this project evaluation.

Further for the raster data the ILWIS (Integrated Land and Water Information System) was obtained so that there is a relatively good starting position for specific GIS data processing and presentation.

Within the study

- use of the DEM (digital elevation model) with the grid 100 by 100 m was introduced, the basic hydrologic - ecological parameters (elevations, slope, orientation, precipitation) were processed,

- hot spots for the Nitra river basin were digitized and are presented in Figures No. 1 to 4 and

- the most important data were transformed into more simple ones and friendly user software like ArcView and MapViewer was applied .

As a supporting database the dBase IV has been used and linkage of tables and maps is at present on the programme of the work.

## 4. CCNCLUSIONS

Chemical Time Bombs Project oriented on the improvement of environmental conditions in the Danube Catchment area has been started in the former ČSFR and has been continuing only in the Slovak Republic. Further development and orientation of related research is depending deeply on the expected and more close international cooperation and on the financial support for CEE countries (as promised earlier). Anyway obtained results were used in Slovakia in the inception reports for Slovak subbasins, processed by different companies based on the EC support.

Let's hope, that the initial initiative of the foundation 'Mondial Alternatief' and the Netherlands Ministry of Housing, Physical Planning and Environment (VROM) will be successfully finalized in the Danube river basin in the same manner as it seems to be done within the programme "Salmon 2000" in the Rhine river basin. Cooperation in this field is rather urgent and should contribute to the quick improvement in environmentally sound water management within the basin.

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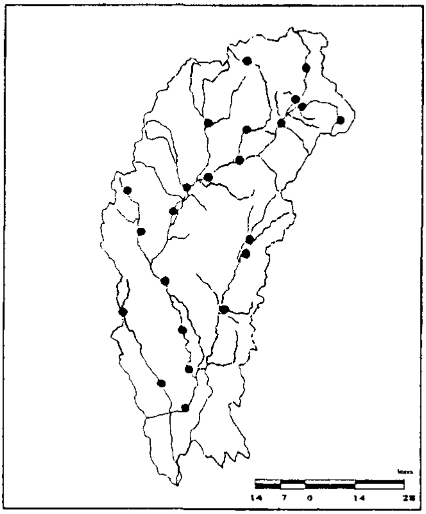


*Fig.1* Spatial distribution of settlements with more than 2000 citizens

*Abb.1* Raumliche Verteilung von Siedlungen mit mehr als 2000 Einwohner

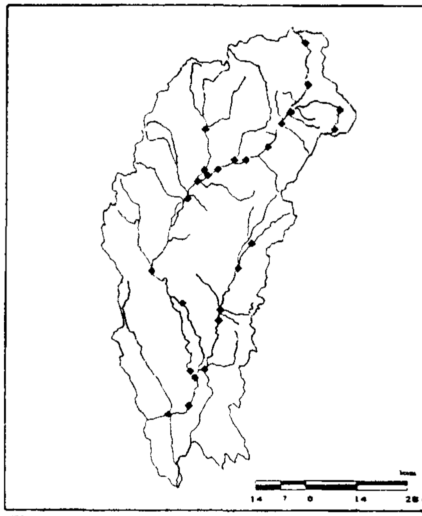


*Fig.2* Scheme of the monitoring network

*Abb.2* Schema des Monitoringnetzes

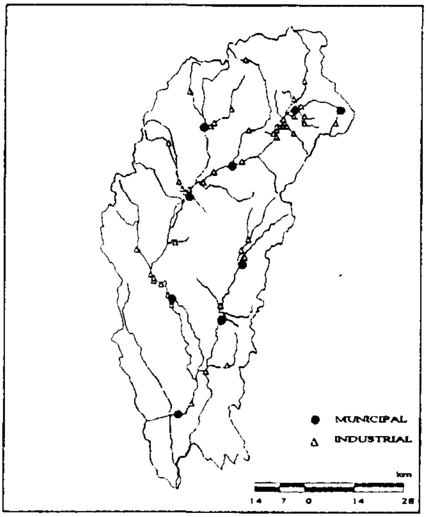


*Fig.3* Location of waste water dicharges

*Abb.3* Lokalisierung von Abwasserabflüße

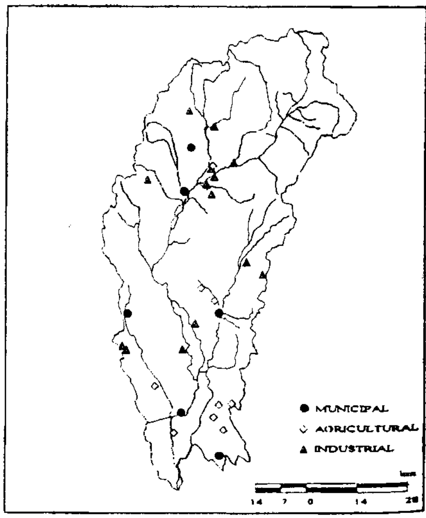


*Fig.4* Location of landfills

*Abb.4* Müllablageplatzierung

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# PREDICTION OF THE GROUNDWATER CONTAMINATION FROM A POTENTIAL THERMOELECTRIC POWER PLANT DUMP SITE

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## ABSTRACT

The paper presents an overall methodology and some important specific results of a two-year study conducted for the Electric-power Industry of the Republic of Serbia, for the purpose of determining the possible environmental impact of proposed manner of depositing the ash and slag tailings of a thermoelectric power plant near the Danube river. Investigations were done for the location of a dump site in the interior of an open-pit lignite mine bordering the Danube. The emphasis was put on prediction of the influence of such waste dump on groundwaters of surrounding aquifer. For that purpose, specially planned laboratory-, field- and study-works were carried out. Mathematical modelling was successfully applied for prognostic computations of groundwater pollution transport. A data base was implemented for the management of various data related to this environmental problem.

# DIE PROGNOSE DER GRUNDWASSERVERUNREINIGUNG INFOLGE EINER POTENTIALEN KOHLENKRAFTWERKABFALLDEPONIE

## ABSTRAKT

Im Artikel sind die Methoden und einige konkrete Resultate der zweijährigen Studie für die serbische Elektrowirtschaft präsentiert, zwecks Abschätrung des möglichen ökologischen Einflusses der vorgeschlagenen Lösung für die Ablagerung der Schlacke und Asche des Kohlenkraftwerks in der Nähe von Donau. Es wurde die Deponie im Raum der Lignitgrube neben der Donau untersucht. Amwichtigsten war die Prognose des Einflusses dieser Deponie auf das umliegende Grundwasser. Deshalb wurden Labor- und Terrain- untersuchungen durchgefuhrt, sowie die entsprechenden Studien bearbeitet.

## 1. INTRODUCTORY REMARKS

Lignite is the dominant fuel in thermoelectric power plants in the Republic of Serbia. The combustion of lignite leads to significant amounts of ash and slag. The deposition of this waste becomes significant ecological issue. Namely, such large dumps are sources of various more or less harmful chemical compounds that may contaminate both groundwaters and surface waters in their closer and further vicinity. Therefore, these waste dumps may cause serious damages to inhabitants of surrounding settlements and both to the agriculture and the industry as well.

The paper presents an approach to foreseen a possible impact of a **potential** thermoelectric power plant waste dump. Due to space limitation we present only some of results obtained within a two-year study.

## 2. PROBLEM STATEMENT

The Electric-power Industry of the Republic of Serbia was interested to determine the possible environmental impact of proposed manner of depositing the ash and slag tailings of a thermopower plant near the Danube river. The location of the possible ash and slag dump should be **in the interior of an open-pit lignite mine** bordering the Danube river. Since the groundwater of the surrounding aquifer is going to be the most vulnerable to the contamination from this type of the ash and slag depositing, the groundwater contamination had to be in the focus. The task was to determine major contaminants from this particular ash and slag waste as well as the transport of these contaminants in the groundwater. Directions of the contaminant propagation and the dynamics of the transport of contaminants should be forecasted.

This phase of the investigation should be limited to the prediction of the groundwater contamination from ash and slag dump in the case that it wouldn't be undertaken any specially designed groundwater protection measures.

## 4. PROBLEM SOLVING

Since the specified problem from the field of contaminant hydrology is rather complex a multidisciplinary approach to problem-solving was adopted. The analysis and the solution of the problem were done by a team of specialists from different disciplines: geology, hydrogeology, hydrochemistry, mining, mathematics and computer science.

The problem-solving methodology included several types of specially designed investigations: 1. laboratory investiga-tions, 2. field-works, 3. study-works.

One of the first steps was to determine chemical components which would most significantly be diluted in water, thus contaminating groundwater of the surrounding aquifer.

ralogical analysis of the samples of ash and slag from thermoelectric power plant and hydrochemical analysis of the groundwater bellow and around an existing ash and slag (surface) dump shows that two of the most significant contaminants are : sulphate ($SO_4^{2-}$) and magnesium ($Mg^{2+}$).

Laboratory investigations included specially designed laboratory tests of the transport of selected major contaminants through the samples of the porous material of the aquifer downstream of the potential dump site. These lab-tests make possible to determine some important parameters relevant to the transport of these contaminants in groundwater.

Since the researched area was geologically well investigated before (for mining reasons) only some limited additional drilling had to be done. Systematic observation of hydrodynamic and hydrochemical regime of groundwater and surface waters were conducted on the established observation network, in a period of 15 months. Mineralogical analysis of the field samples of ash and slag as well as of aquifer material were performed.

A synthesis of available geological and hydrogeological data pertinent to the considered environmental problem was made. Fig.1 shows both the hydrogeological map and a typical hydrogeological cross-section of researched area.

In order to determine the migration of major contaminants in the groundwater the approach based on the quantitative analysis was adopted. The mathematical modelling methodology was employed as a tool to perform this analysis. For this reason, the following non-steady two-dimensional mathematical models of groundwater contaminant transport were developed and applied: convection-dispersion model and convection-dispersion-sorption model of the transport.

For the purpose of illustrating the application of the mentioned mathematical models we here present one numerical prediction of the transport of the sulphate contaminant in the groundwater of the aquifer surrounding the potential ash and slag dump site. Fig.2 gives the solution of the convection-dispersion model of the sulphate contaminant transport for the time $\tau$ = 100 years after completion of waste dump formation. Since the hydraulic characteristics of the newly formed media in the open-pit space - after the exploitation is over - is unknown now, a sensitivity analysis had to be done. The solution shown in this Figure was obtained for the so-called variant 2 of the hydraulic characteristics of the mentioned porous media. The numerical predictions were made using the random-walk method of solving the transport equation.

As an integral part of study-works, a data base was designed and implemented for the entry, storing, retrieval

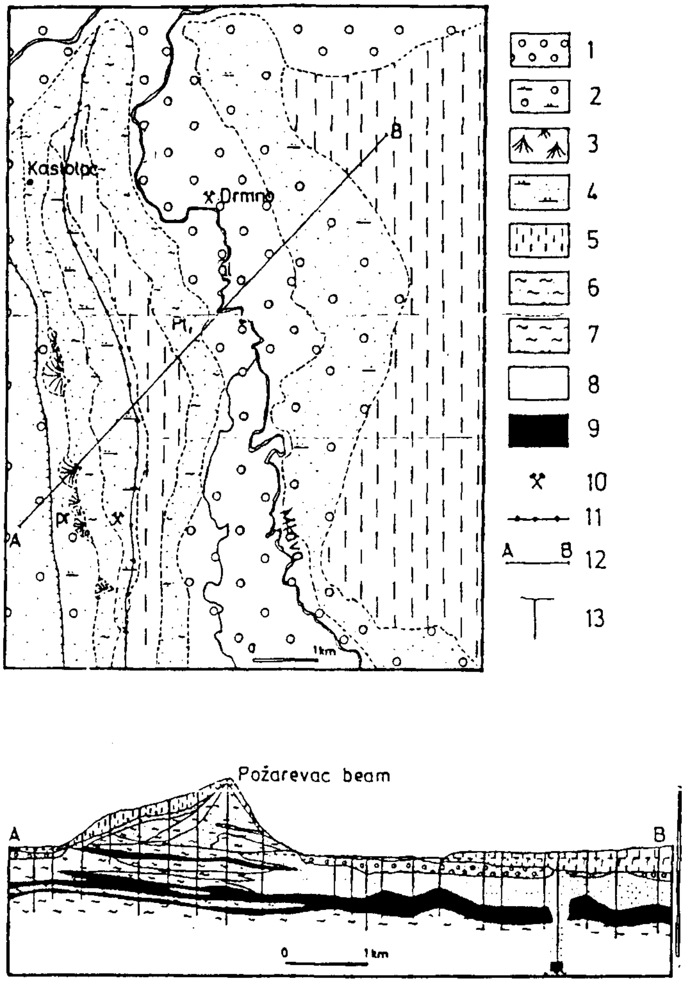
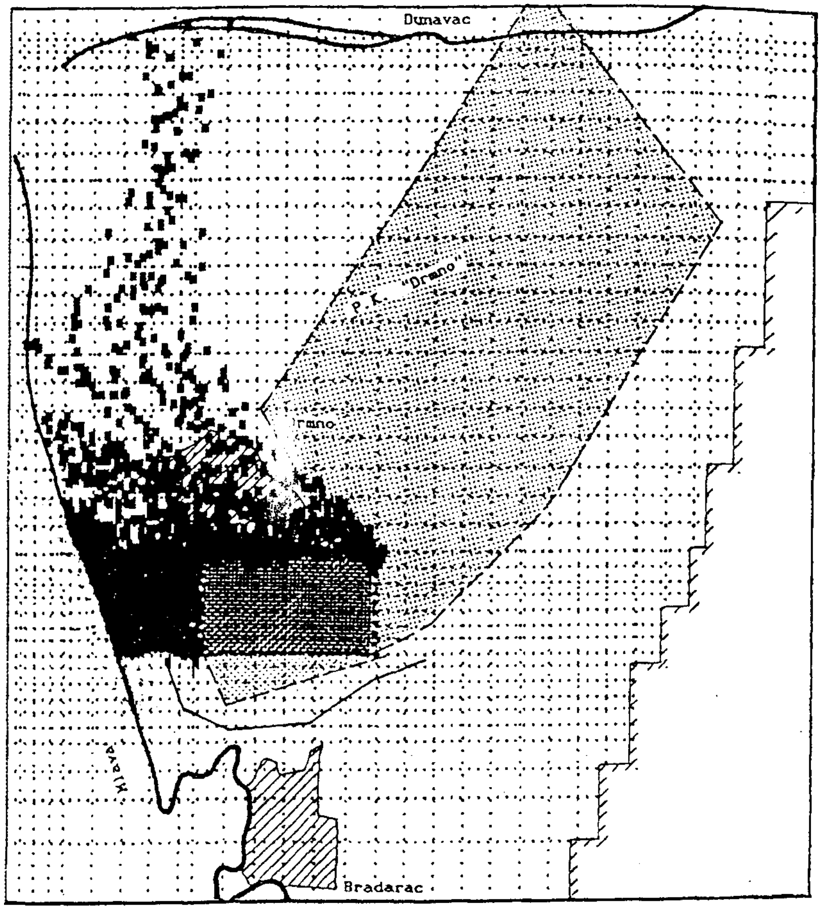



Fig. 1 Hydrogeological map and cross-section of the Drmno area
Explanation: 1. alluvial deposits with clay and siltstone; 2. alluvial terrace - gravel, sand, siltstone; 3. prolluvium -gravel, sand, siltstone; 4. delluvium - loessoidal siltstone and sand; 5. loessoidal sediments; 6. sand and clay; 7. clay; 8. sand; 9. coal; 10. open-pit; 11. surface and groundwater devide; 12. cross- section 13. research drill hole




L E G E N D

- ----- Open-pit boundary
- Newly-formed media
- Screen
- Waste dump
- -¦-¦- Discretization grid
- Particles of sulphate contaminant

Fig.2 Solution of convection-dispersion model of sulphate transport and presentation of various hydrological, hydrogeological and hydraulic data related to the contamination problem under consideration. It is structured as an relational data base, implemented on a PC-computer. Detailed description will be given in the forthcoming paper.

## 4. CONCLUSION

A two-year study on environmental impact of a potential thermoelectric power plant dump was successfully completed. Investigations were done for the location of the ash and slag dump in the interior of an open-pit lignite mine bordering the Danube river. The research methodology had a multidisciplinary approach. On other side, it encompasses specially planned laboratory investigations, field-works and study works.

Investigations prove that the major contaminants from the ash and slag dump are going to be : sulphate and magnesium.

Quantitative analysis was undertaken in order to forecast the migration of major contaminants from potential waste dump. Mathematical modelling proved to be a powerful tool to make numerical prognosis for the transport of contaminants in the groundwater. The results of these prognosis lead to the general conclusion that the considered potential waste dump in the interior of the open-pit mine will cause non-permissible, long-term contamination of the groundwater surrounding this dump.

Next, it is concluded that appropriate protection measures must be carefully designed and implemented before the waste dump is formed.

The data base developed to archive and retrieve various technical information, proved to be a very useful way of keeping and using numerous data related to the considered groundwater contamination problem.

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# COMPLEX USE AND PROTECTION OF WATER RESOURCES OF THE DANUBE ON THE TERRITORY OF UKRAINE

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Abstract: An estimate of the water supply and water contamination situation in the Danube basin area is given, data on the water security of the region's population is presented.

The present-day and forecast patterns of water consumption distribution among territories and branches of industry are reviewed. Proposals aimed at stabilizing and improving the water-related aspect of the ecological situation in the Danube basin are stated.

# KOMPLEXE AUSNUTZUNG UND BEWAHRUNG DER WASSERVORRÄTE DER DONAU IM GEBIET VON UKRAINE

Kurzfassung: Im Bericht werden wasserwirtschaftliche Zustandbewertungen im Donanbechen und Angaben über die Wasserversorgung der Bevölkerung in dieser Region dargestellt. Es sind jetziger Zustand und Perspektive der Land-und Branchenausnutzung des Gewässers betrachtet. Es wurden die Vorschläge für Stabilisierung und Verbesserung des wasserwirtschaflichen und ökologischen Zustandes im Donaubecken formuliert.

Ukraine is one of eight Danube basin countries, across which the Danube river flows: the Danube's run-off is formed on the territory of twelve states. 5.7% of the Danube's water catchment area lies within the borders of Ukraine, being responsible for 5.5 $km^3$ of the 202 $km^3$ of the Danube's average annual run-off in the river's mouth. Over a length of 170 km the Danube makes the border-line between Ukraine and Romania.

More than 60% of the run-off in the mouth of the Danube flows through the Kilia estuary.

Calculations have put Ukraine's annual demand for the Danube water at 26.9 $km^3$. That volume has been recommended as Ukraine's demand for the Danube water for the year of 2010 to be taken into account in water supply balances of the Danube river.

The whole territory of the Transcarpathian region, partly the territories of the Chernivtsi (75%), Ivano-Frankivsk (37%) and Odessa (35%) regions lie in the Ukrainian part of the Danube basin. At present, the total Danube basin water supply to the population and public economy branches amounts to 2.0 - 2.5 billion $m^3$ annually.

The current water supply to cities, towns and villages situated in the basin somewhat lags behind the population's demand and the rate of housing and municipal facilities construction. Only 43 out of 81 towns and townlike settlements have centralized water supply systems. The situation with waste water disposal systems in the local towns is even worse, with only 31 settlements having it. The daily municipal water consumption in this region of Ukraine is 235 l per capita.

The volume of water consumption by the municipal economy in the Danube basin is going to increase somewhat in view of the impending improvement of public services and amenities.

Industrial water supply is carried out through local systems using both surface and underground water. The volume of water in the circulating water supply makes up 60% of the total industrial water consumption.

At present, the primary industrial water consumers in the Danube basin are the food, forest and woodworking, engineering and metal-working, petrochemical industries, as well as some others. It is expected that some years later the engineering and metal-working industry will go to the top of the list of top industries in the area, followed by the food and then light industries. It is planned that industry will use circulating and repeated water supply systems as often as possible, which will make it possible to lower the growth rate of industrial consumption of fresh water from natural water sources and the dumping of waste water into them.

The main water consumers in the rural areas are village population, cattle farms and some other agricultural production facilities.

Centralized water supply covers just 20% of the basin's rural population. 80% of the population use water from local sources (both underground and surface ones). The daily rate of per capita water consumption for household requirements and drinking ranges from 31 l (the Chernivtsi region) to 59 l (the Odessa region), which is below the present-day requirements.

Nearly in all areas belonging to the Danube basin the rate of construction of waste-water disposal systems in the villages has been very low so far. There are no such systems in most of the rural area settlements; the existing ones involve mainly public and municipal service facilities, and the purification efficiency is low.

The main sources of agricultural water supply are underground waters.

It is planned that before the year 2010, centralized water supply systems will cover 50% of the rural population. The lowest percentage will be in the Transcarpathian, Ivano-Frankivsk and Chernivtsi regions. This results from the fact that a majority of the rural population in these regions dwell in small villages and use good quality water from underground sources through decentralized water supplies. In the Odessa region the rate of centralized water supply coverage by the year of 2010 is expected to reach 78%.

The Danube and Prut rivers are the sources for the irrigation systems situated mainly in the southern part of the area in question. Irrigation areas are to be increased due to the planned construction and expansion of large irrigation systems like the Danube-Dniester, Tarutynska, Starotroyanska, Bolgradska ones, as well as the irrigation facilities on the Repida island.

Most of the irrigation systems to be constructed will lie in the basins of rivers of the Black Sea littoral, where local water resources are very scarce. Therefore it is planned that these systems will use water from the Danube. As a rule, it is planned that water will make its way down from Danube water filled lakes into the irrigation systems during the periods of high water level. This type of water supply has been envisaged for the Chervonoyarska and Starotroyanska systems from Lake Kytai, the Danube-Dniester system from Lake Sasyk, the Tarutynska system from Lake Yalpug. During the periods of low water levels water will be supplied into the systems by pumping plants.

Among problems whose solution is most urgent for the area in question the following ones should be indicated:

- prevention of surface and underground water contamination;
- construction of flood prevention facilities;
- construction of a complex of installations to remove salt from Danube basin lakes and maintain satisfactory quality of water in them;
- completion of scientific investigations and implementation of a complex of technical measures aimed at providing the area with water of required quality.

In the Lower Danube, in the basins of the Tysa and Prut rivers, the main sources of contamination are sewage from municipal facilities of towns and villages, enterprises of the chemical, petrochemical, forest, woodworking, and food industries, as well as from agricultural facilities.

The following conclusions can be drawn from recent analyses of water quality:

- as for organic and biogenic substances, the quality of surface waters of the Danube basin, as a rule, is either within the admissible range or slightly above it;

- as for specific contamination (petroleum products, phenols etc), water quality does not meet the requirements;

- Danube water can be used for household needs and drinking after being purified at water-treatment plants;

- the development of the fish industry is hampered by the high level of nitrates, phenols, petroleum products and the like;

- the largest technogenic pressure is exerted on the river stretches within city or town limits (Yaremcha and Chernivtsi on the Prut, Chop on the Tysa, Uzhgorod on the river of the same name).

Implementing the provisions of the Declaration of Cooperation of the Danube Basin Countries, all enterprises and organizations situated in the Ukrainian part of the Danube basin have been working out a number of water quality preservation measures and making them a part of their economic and social development plans since 1988. These measures are aimed at gradual decrease and eventual stoppage of the dumping of non-purified sewage into the Danube.

A complex of measures has been outlined aimed at regulating the shipment of oil petroleum products, prevention of dumping bilgeway and ballast waters from the vessels, and restriction of the use of motor boats and small vessels in recreational areas.

In agriculture, this has been planned:

- to see that all dairy farms and complexes switch over to water-free removal of dung, to introduce water-protection belts along rivers and around bodies of water and strictly observe rules on economic activities applicable to such areas;

- to prohibit the storage of fertilizers on open-air sites;

- to plant forests on 1586 ha and make meadows on 167 ha.

Special attention ought to be payed to the ecological state of the Danube basin lakes.

The water-protection and water supply authorities consider the present-day ecological situation in the zone of the Danube lakes to be unsatisfactory. A most catastrophic situation has arisen in Lake Yalpug which is a source of drinking water supply for the town of Bolgrad and a number of other settlements. It results from the adverse effect on the natural conditions inside the lake caused by highly contaminated sewage from Moldova and from water-development works built by the fish industry in the area restricted by the lakes Yalpug, Kurulgui and the Danube, as well as by improper nature management within the lake's basin.

The ecological situation has also significantly worsened in the lakes Kahul, Katlabukh, Kytai, which are sources for land irrigation in the Odessa region and Moldova and are used for fishing and recreation. Their separation from the Danube disturbs the natural hydrological conditions, decreases the exchange of water two or three times, and that leads to a 2-4-fold increase in mineralization and the worsening of virtually all main hydrochemical characteristics. The water of the Danube lakes (except Lake Kahul) is conventionally suitable for drinking water supply, and can be used for irrigation, only when applied together with special chemical amelioration agents.

In order to improve the ecological and water supply situation, construction has been started of a complex of facilities to supply water from the Danube into Lake Yalpug. The construction is the result of an agreement between the presidents of Ukraine and Moldova.

Protection from floods which cause great damage to our country's economy has long been and still remains one of the most crucial water-related economical problems in the Ukrainian part of the Danube basin, both in the river's mouth and along its Carpathian tributaries (the Tysa, Prut, Syret and their tributaries).

Since the 1950s, construction of local flood-protection facilities has been going on in all parts of the area. Since the 1960s, special flood- and sill-protection measures have been taken as a part of complex and general development projects, consisting of a combination of hydraulic engineering, forest amelioration and other works.

Bilateral and multilateral conventions have been signed with neighbouring countries aimed at resolving water-related problems, including those arising from the need in flood-protection.

Flood-protection measures taken in recent years include river embankments near settlements, fields and meadows, double-sided diking of water-meadows, bank consolidation, and straightening of river beds.

Currently, flood-protection relies on the following:

- on the Danube - on dikes totalling over 300 km in length;
- on the Tysa and its tributaries within the Transcarpathian region - on dikes totalling over 340 km in length.

However, dikes along the Tysa and Danube have insufficient height and width in many places to guarantee that lands are protected from extreme floods.

The occurrence of high floods has been on the rise in recent years, which is the result of unpractical economic activities in the area. These are, first of all, large-scale felling of hydrologically active forests, as well as improper cultivation of land on the slopes, elimination of bushes on mountain meadows and pastures. Just in the last 30 years, 116 high floods have occurred on the Tysa and 32 - on the Prut, having assumed catastrophic proportions on rivers of their basins in 1952, 1955, 1964, 1969, 1970, 1974, 1980, 1981, 1989, 1991, 1992, 1993.

On a commission of the Cabinet of Ministers of Ukraine, the State Water Economy Committee has worked out the "Complex Long-term Program of Flood-protection Measures in Ukraine before the Year 2000".

The implementation of the whole bulk of flood-protection measures will lead to the decrease of flood-related damage by 60-70%. It should be noted that that target can be reached only when economical activities in the river basins (forest exploitation technology, mining of mineral resources, construction of pipelines, building of roads etc), especially up in the mountains, are carried out properly and do not violate the acting nature protection legislation.

The program also envisages:

- use of space- and land-based remote-control laser equipment for forecasting natural disasters;
- restoration of hydrological observation posts in mountain areas, which have been closed down in recent years;
- installation of telephone communication facilities at meteorological stations and hydrological posts and improvement of communication;
- re-equipment of hydrometeorological stations and posts with modern technical facilities;
- provision of network information processing centers with modern computers, radio stations, and switching devices;
- improvement of the existing software and forecasting techniques.

The implementation of these measures will increase the mountain area forecast reliability term up to 9 - 12 hours for small rivers and up to 18 - 36 hours or more for larger rivers.

On December 8, 1985 in Bucharest representatives of eight Danube basin countries have signed a declaration on cooperation in the handling of Danube water problems, having laid special emphasis on protecting the river's waters from contamination.

The cooperation was to proceed along two main lines:

- determination of water quality of the Danube river through organization of water quality monitoring;
- drawing up the water economy balance of the Danube.

The drawing-up of the water economy balance of the Danube will lead to the revelation of possible deficits and surpluses of water during certain time intervals or years. If deficits are uncovered, it is necessary to work out some technical measures aimed at covering them. Ukraine, which is situated in the river's mouth and whose demand for water is rather high, can cope with that task.

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# HYDROCHEMICAL INVESTIGATION GROUNDING THE NECESSITY OF CONNECTION BETWEEN THE LAKE SKREBARNA AND THE DANUBE

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In this article are presented the results on the water quality and bed materials in Srebarna lake and the Danube in region where the connection between waters of the lake and the river vill be realized. The data from the investigations carried out in 1960, 1985, 1993 are used. The water state is assesed in relation to the content of mineral and organic compounds, biogenic elements, index of oxygen regime and heavy metal content. Bed materials are considerated in relation to quantity of organic material and heavy metal content. The attempt is made to prognosticate the change of water quality and hydrodinamic processes after realizing of the connection with the Danube.

## HYDROCHEMISCHE UNTERSUCHUNGEN, DIE NOTVENDIGKEIT DER VERBINDUNG VON SREBARNA-SEE MIT DER DONAU BEGRÜNDEN

Es werden Daten über die Qualität des Wassers und der Ablagerungen von Srebarna-See und dem Ort an der Donau vorgelegt, wo die Verbindung von Fluß und See stattfinden wird. Die mit der Zeit entstehenden Veränderungen werden auf Grund von im 1960, 1985und 1993 durchgeführten Erforchungen festgestellt. Das Vorhandensein von Mineralien,organischen Substanzen, biogenen Elementen sowie der Sauerstoff-und Schwermetall-Gehalt werden eingeschätzt. Es wird versucht die Veränderung der Wasserqualität von Srebarna nach Verbindung mit der Donau vorzusagen.

## I. INTRODUCTION

The Biospheric preserve Srebarna Lake is a subject of present study. The Lake is situated next to the Danube river / 385.00 km/. Presently Srebarna Lake has a status of a protected area under the aegis of UNESCO and it is of particular interest as something ascertained by the nature as well as from the point of view of tourism.

During the last 45 years a number of drainage measures were put into practice within the region without any specific argumentation and all of them were aimed towards assimilation of given areas of swamps. Those measures led to severe deterioration of environment. Nowadays in 1993 the situation is nearly catastrophic. The World Bank invested some funds for development of a project for recovering the normal condition of Srebarna Lake step by step. A basic part of all the investigations previously conducted is the hydrochemical diagnosis of the Lake present state along with recommendations for measures required for preserving the Lake.

## II. GENERAL CHARACTERISTICS OF SREBARNA LAKE

Srebarna Lake is situated immediately / about 1.5 km / by the Danube river to the north-west from Silistra town. By the drainage of Aidemir lowland in 1949 Srebarna Lake area was of 5 square km. flooded area with maximum depth of 3.5m. Linking with the Danube river was through tributarying and water run-off canal during the summer high water. In summer the area of the Lake was reduced to 2 square km. and the debth was not more than 1 m. All the lakeside belt was overgrown with thick rush. The basin was on the line between a lake and a swamp tending to swamp nature.

After drainage measures carried out in the region of Aidemir lowland the link with the Danube river was cut off and the fluctuation of the Srebarna water level became insignificant. Nowadays the size of the Lake is as follows: length at average water level in the north - south direction - 1.5 km; maximum width - 1.3 km; free lake surface in summer - about 1.3 km; maximum debth - 2 m; water capacity - about 2.5 mill. cubic m. Srebarna Lake itself is not continious water area but a totality of linked in between basins / Fig.1 / Supply of the Lake is realized mainly by cavern spring water in its southern part and in spring - through two small rivers: Srebarna and Kalneja. During the summer evaporation is greater in comparison to the flow / the rivers are running dry / and the Lake water level is reduced significantly.

## III. HYDROCHEMICAL CHARACTERISTICS AND MAIN RESULTS

Main feature of nature phenomena of that type is the seasonal alteration of water chemical behaviour depending on predominant supply and the year cycle of syntesising and decomposition of the organic matter. E.g. for the lake that predominant supply between April-June was through the Danube river and through the surface water, for the next period July - March the supply is through the surface waters of the Lake and through the subsoil waters.During the summer months July - September the underwater supply is predominant.

In present study the results of investigations carried out in 1960, 1985 and 1993 are used according to the following types of factors of the hydrochemical regime: content of mineral substances / $\sum i$, HCO3, SO4, Cl, Ca, Na, K /, contents of organic matter / O2, permanganate oxidation - Ok, BOD5 /; contents of biogenic substances / NO3, NO2, NH4, PO4, Fe / and toxic elements / Ni, Cu, Cd, Pb, Mn, Al, Zn, Se, As, Mo / in the water and the sediments /deposits/.Those investigations included Srebarna Lake, the Danube river and the two small rivers, emptying into the Lake.

Presently / at munimum water capacity / the average mineral content in Srebarna Lake waters is rather high $\sum i$ = 1178.3 mg/l (Table 1). Maximum peak values go up to $\sum i$ = 1222.7 - 1258.0 mg/l (Table 1). Those are strongly mineralized waters with $\sum i$ over 973.0 mg/l. In the same time the general mineralization of the Danube is 3.5 times lower - $\sum i$ = 297.7 mg/l, and that of the supplying tributary Kalneja river - twice lower,i.e. $\sum i$ = 776.7 mg/l (Table 1). In comparison with previous investigations that data shows significant increase of the mineral content as follows: regarding 1985 - 137.4 % and regarding 1960 - 77.6 % . Taking into consideration the above cited when Lake waters are mixed with the Danube waters in correlation 1 : 1 / in spring / the mineral content of Srebarna Lake which could be expected is of the order of $\sum i$ = 350 - 400 mg/l and that is a normal condition for closed water reservoir.

Regarding the single ions of the mineral content,the waters of Srebarna Lake were with clear expressed hydrocarbonate nature. In 1960 the hydrocarbonate ions / HCO3 / prevailed over the others both in weight and equivalence. In fact they were 50 % of the overall ions content of ions / HCO3 average = 321.9 mg/l/ (Table 1). After that period their content gradually began reducing and in 1985 it is HCO3 at average = 178.3 mg/l ( Table 1). It is obvious that a process of change of the Srebarna Lake waters nature has started. In the same time the waters of the Danube are of hydrocarbonate nature / HCO3 at average = 211.8 mg/l - 1985 and at average HCO3 = 167.7 mg/l - 1963 /, and the tributary Kalneja river as well / HCO3 = 390.4 mg/l and HCO3 = 542.9 mg/l respectively /. On that basis a conclusion is made that the change of the waters nature is a result of processes occured inside the Lake.

The most significant changes are observed in the consentration of sulfate ions /SO4/. Their content is increased nearly ten times / at average SO4 = 487.3 mg/l / in comparison to that of 1960 and 12.7 times - in comparison to 1985 ( Table 1). Considerable quanitites of sulfates flow into Srebarna Lake in the process of dying off the microorganisms and oxidation of substances of vegetable and bestial origin. After living cells dying off, the hydrotrophic bacteria eliminate S in the form of H2S, which easily oxidates in sulfates at the presence of oxygen.

At the same time the sulfate ions quantity in the Danube waters on 27 August, 1993 at Q = 3800 m3/s is 33 mg/l and at Q = 7200 m3/s on 8 July, 1985 SO4 = 50.4 mg/l. (Table 1). For Kalneja river those results are as follows: on 27 August, 1993 - Q = 0.008 m3/s SO4 = 35.5 mg/l and on 8 July, 1985 - Q=0.064 m3/s, SO4 = 18.1 mg/l (Table 1). All those results corroborate the above cited ,i.e. the great quantity of sulfate ions is accumulated as a result of processes occured inside the Lake. The original sulfate content of Srebarna Lake waters could be reached through considerable reduction of anaerobic decomposition of the organic matter. That includes felling of rush every year or its firing in winter as well as water flooding from the Danube in 1:1 ratio. The results concerning the rest of the ions are given in Table 1.

Exclusively high content of S in the sediment probes is found out in all the regions of Srebarna Lake which have been tested. The concentration is in the range of 8400 to 23000 mg/l as those concentrations are many times over the natural background. The high content of S is related to the anaerobic processes of putrification of the organic matter which is a siginificant part of the sediments.

The quantity of organic matter expressed by the factor of permanganate oxidizability /Ok/ proved to be very high at average Ok = 106.6 mg/l. The maximum measured value in point N 2 - Ok max = 121.6 mg/l (Table 1). In order to be seen the role of photosynthesis we shall mention that under nearly the same oxygen content in Srebarna Lake and the Danube, the difference between the organic matter quantities is of an order / Ok for the Danube = 11.2 mg/l /. In the same time the pollution of organic matters brought by the Kalneja river is Ok = 16.0 mg/l ( Table 1). The following conclusion could be made for the oxygen regime: Potentialities for zero values of diffused oxygen factor are available at pollution of the Lake and in summer time at sunrise. The intensive processes of purification of the swamp verdure and beast remains determine the high percent of organic content in tested probes of bottom deposits. That factor is in the range between 40 to 46 percent.

The limits of change of biogenic elements content in the water of Srebarna lake are given in Table 1. It should be pointed out that the concentration of nitric and phosphatic ions in the Lake is several times higher than that of the Danube waters while there are opposite results for the ferrum. Thus in that case it could be counting upon the dilution by the Danube as well.

The waters of Srebarna Lake do not contain : Ni; Cu; Co; Pb, Zn; Se; As; Cd; Mo. From all those elements the Zn is the single element found in the waters of the Danube Zn = 0.01 mg/l and in the waters of Kalneja river Zn = 0.09 mg/l. But those concentrations could be disregarded as very small and because it is not possible for them to influence in any case. The waters of Srebarna Lake contain very small quantity of Alluminium Al which is alterated in the range of Al = 0.03 - 0.16mg/l. In the same time the waters of the Danube and Kalneja river are of higher concentrations - Al = 0.26 mg/l and Al = 5.81 mg/l accordingly.

The waters of the Danube river terraces in this region are characterized by the content of Manganese Mn. Concentration of Mn in the waters of Srebarna Lake is not very high and its alteration is in the range of Mn = 0.00 - 0.16 mg/l. The Danube waters and Kalneja river waters are of higher Mn content. Concentrations registered are: for the Danube - Mn = 0.11 mg/l and for Kalneja river Mn = 0.43 mg/l.

Content of analysed heavy metals in the sediments is in the range of the natural background. There are some places where increase content of Cd and Se is registered as the maxumum values are: 2.0 mg/l for Cd and 3.13 mg/l for Se. The content of heavy metals in the river sediments of the Danube immediately next to the inlet of the future canal "The Danube-Srebarna" have been analysed. The results show that the content of the most part of the heavy metals in the sediments of the Danube is higher than that in the sediments of the Lake. But significant pollution of the Lake shall not come after its water flooding.

Analyses which were carried out show that nowadays the state of Srebarna lake waters quality is not in accordance with the high requirements needed for biospheric preserve. Recovery of the qualitative content of the waters could be observed after the following complex of measures has been done:

1. Water flooding of Srebarna Lake through the water of the Danube in ratio not less than 1:1;
2. Restriction of organic matter / rush/ presence in the Lake. That could be done by usage of that matter for industrial needs or by firing when pollution of the Lake is obvious.
3. Restriction of weathering of slopes;
4. Establishing of reliable monitoring related to the measures for water supply of Srebarna Lake by the Danube waters.

TABLE 1

| index | st.1 | | st.2 | st.3 | | st.4 | st.5 | st.6 | | st.7 | | st.8 | | st.9 | | st.10 | st.11 | st.12 | | st.13 | st.14 | st.15 | | average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1985 | 1993 | 1993 | 1985 | 1993 | 1993 | 1993 | 1985 | 1993 | 1985 | 1993 | 1985 | 1993 | 1985 | 1993 | 1993 | 1993 | 1985 | 1993 | 1993 | 1993 | 1985 | 1993 | 1960 | 1985 | 1993 |
| Σi | 518.0 | 1180. | 1165. | 580.0 | 1172. | 1169. | 1135. | 520.0 | 1222. | 580.0 | 1138. | 508.0 | 1202. | 470.0 | 1152. | 1010. | 973.0 | 392.0 | 302.7 | 1258. | 1147. | 646.0 | 766.7 | 663.3 | 496.3 | 1178. |
| HCO3 | 298.9 | 174.9 | 176.9 | 344.2 | 173.8 | 179.9 | 170.8 | 246.3 | 179.9 | 285.5 | 176.9 | 286.7 | 176.9 | 286.7 | 195.2 | 393.4 | 332.4 | 211.8 | 167.7 | 237.9 | 240.9 | 390.4 | 542.9 | 321.9 | 293.6 | 178.3 |
| SO4 | 35.0 | 492.8 | 475.3 | 28.5 | 479.8 | 488.1 | 475.7 | 47.1 | 511.5 | 32.9 | 438.9 | 35.4 | 491.8 | 49.4 | 487.2 | 239.5 | 232.9 | 50.4 | 32.0 | 521.0 | 525.9 | 18.1 | 25.5 | 48.1 | 38.1 | 487.3 |
| Cl | 45.4 | 152.0 | 154.0 | 34.0 | 170.0 | 150.4 | 155.8 | 38.4 | 144.8 | 43.2 | 147.2 | 49.4 | 149.6 | 35.4 | 124.4 | 110.8 | 120.0 | 27.0 | 22.0 | 137.6 | 139.6 | 20.0 | 16.0 | 146.4 | 41.0 | 150.5 |
| Ca | 65.7 | 40.9 | 68.2 | 68.1 | 40.9 | 39.3 | 39.3 | 49.6 | 58.2 | 65.7 | 40.9 | 62.5 | 41.7 | 62.5 | 41.7 | 19.2 | 18.4 | 62.4 | 32.7 | 44.9 | 45.7 | 70.9 | 65.7 | 53.5 | 62.4 | 53.4 |
| Mg | 19.9 | 89.5 | 89.5 | 25.6 | 91.0 | 90.5 | 89.5 | 16.6 | 90.0 | 12.9 | 89.5 | 19.5 | 90.0 | 19.5 | 92.4 | 69.1 | 53.5 | 15.3 | 23.3 | 103.6 | 105.1 | 31.1 | 43.3 | 45.2 | 19.0 | 90.2 |
| Na+K | 50.5 | 210.5 | 197.0 | 49.4 | 207.0 | 205.0 | 197.2 | 38.4 | 222.8 | 47.5 | 195.0 | 53.5 | 238.8 | 53.5 | 200.8 | 198.2 | 209.5 | 28.6 | 17.2 | 201.2 | 78.2 | 46.6 | 68.5 | 113.5 | 48.8 | 208.2 |
| O2 | 8.37 | 7.34 | 7.34 | 7.65 | 8.19 | 6.82 | 6.82 | 8.00 | 9.42 | 8.01 | 7.92 | 7.29 | 9.28 | 7.65 | 7.64 | 8.19 | 8.05 | 8.20 | 9.56 | 8.74 | 9.28 | 5.16 | 4.09 | - | 7.82 | 7.86 |
| Ok | 43.4 | 103.3 | 121.6 | 43.7 | 111.2 | 119.2 | 96.0 | 42.4 | 93.6 | 42.2 | 93.8 | 42.9 | 107.2 | 43.0 | 113.6 | 58.4 | 68.0 | 9.0 | 11.2 | 192.0 | 90.4 | 15.1 | 16.0 | - | 42.9 | 106.6 |
| BOD5 | 26.2 | - | - | 29.8 | - | - | - | 26.9 | - | 26.2 | - | 25.5 | - | 25.5 | - | - | - | 8.8 | 9.4 | - | - | 13.8 | 14.6 | - | 26.7 | - |
| NO3 | 2.15 | 11.00 | 10.40 | 1.10 | 10.00 | 15.10 | 6.20 | 1.32 | 14.90 | 1.50 | 10.20 | 1.40 | 12.30 | 1.10 | 8.90 | 7.80 | 5.20 | 3.20 | 2.40 | 11.50 | 11.30 | 58.00 | 3.50 | - | 1.42 | 1.40 |
| NO2 | - | 0.00 | 0.00 | - | 0.00 | 0.00 | 0.00 | - | 0.00 | - | 0.00 | - | 0.00 | - | 0.00 | 0.00 | 0.00 | 0.20 | 0.27 | 0.00 | 0.00 | 8.11 | 1.14 | - | - | 0.00 |
| NH4 | 0.08 | 0.10 | 0.12 | 0.08 | 0.10 | 0.24 | 0.10 | 0.10 | 0.60 | 0.08 | 0.10 | 0.00 | 1.24 | 0.08 | 1.24 | 1.56 | 1.24 | 0.12 | 0.00 | 0.24 | 0.40 | 0.48 | 0.20 | 0.00 | 0.07 | 0.40 |
| PO4 | 0.20 | 1.31 | 0.92 | 0.15 | 0.78 | 0.94 | 0.87 | 0.20 | 1.28 | 0.21 | 0.82 | 0.29 | 1.20 | 0.15 | 2.12 | 1.26 | 1.36 | 0.32 | 0.75 | 1.27 | 1.25 | 1.89 | 0.99 | 0.02 | 0.20 | 1.14 |
| Fe | 0.19 | 0.03 | 0.06 | 0.82 | 0.06 | 0.03 | 0.06 | 0.84 | 0.07 | 0.19 | 0.03 | 0.43 | 0.03 | 0.06 | 0.23 | 0.08 | 0.12 | 1.06 | 0.48 | 0.08 | 0.10 | 1.91 | 7.41 | 0.30 | 0.43 | 0.06 |



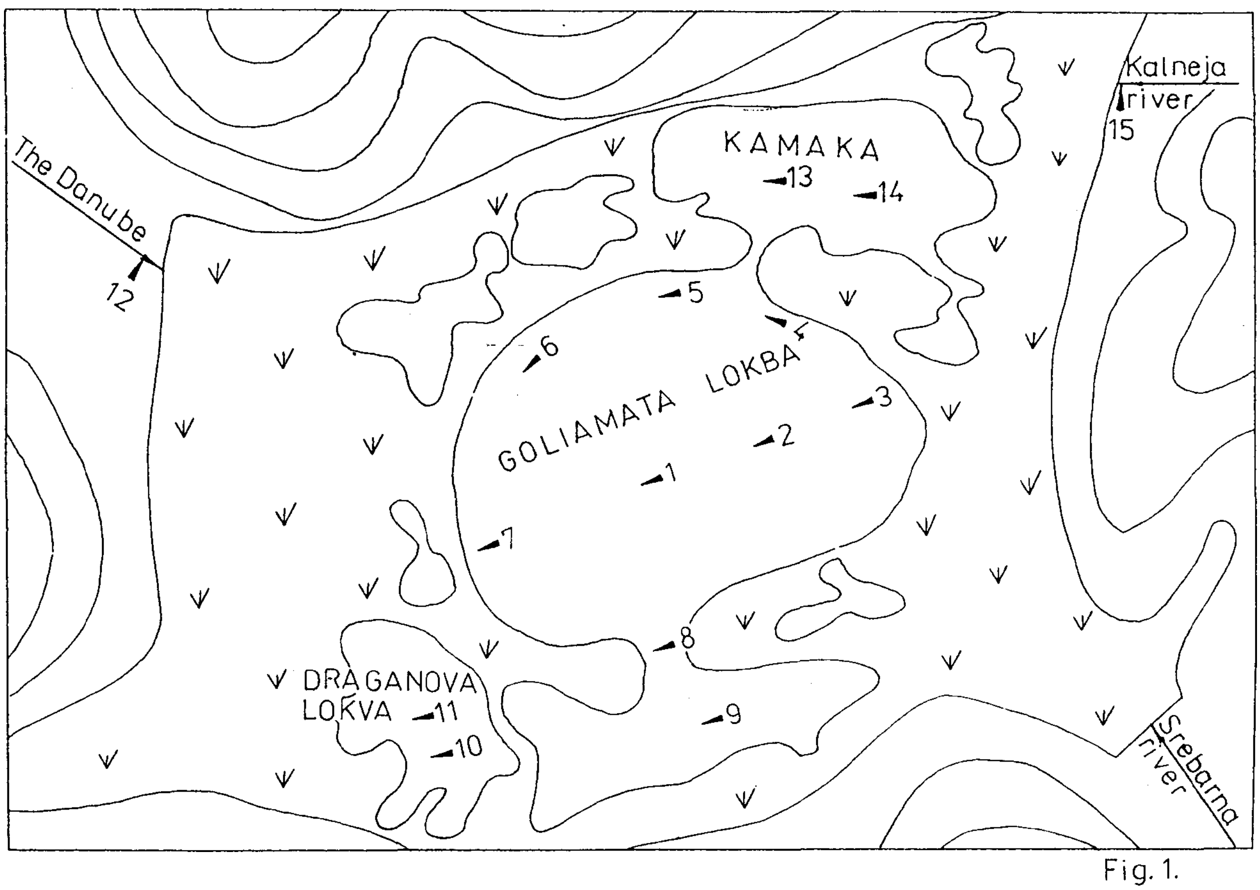


Fig. 1.

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# IMPROVEMENT OF THE CONDITION OF THE ECOSYSTEM OF THE LAKE SREBARNA BY INUNDATION WITH DANUBE WATERS

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The water balance of the Danube river-side lake-reserve Srebarna is destroyed by: the cyclical variations of the river Danube run-off in present phase of low water levels; the anthropogenic local impact over the inflow from the watershed of the lake and the constructed damps along the river. The possibilities are determined for improvement the ecological state of the reserve through inundation. The hydrological investigations find out that the maximum and minimum annual water levels at the Silistra gauge station are not affected by the local hydrotechnical constructions along the river. Theoretical frequency distribution curves of annual extremes are obtained through the multycriterion method of Gerassimov (1988) for approximation and multycomponent criterion optimization of the empirical distribution. Different decisions of inundation of the reserve are exposed with possible annual spillage of the high Danube waters over the natural riverside bank. The selection of the most effective decision is made on the basis of the results of multiplecriterion experts's evaluation.

## Verbesserung der Entwicklungsbedingungen des Seeekosystems "Srebarna" durch Verwaesserung mit Donauwasser

Der Wasserhaushalt des Donaukuestensees - Schutzgebietes "Srebarna" wurde durch: Zykloschwankungen des Donauabflusses in der gegenwaertigen Phase der Wasserarmut, oertliche antropologische Wirkung auf den Zufluss von dem Wassersammlungsgebiet des Sees und die gebauten Flussdaemme gestoert.Die Moeglichkeiten fuer die Verbesserung des Ekozustandes des Schutzgebietes wurden durch Verwaesserung bestimmt. Die Gewaesserkundeuntersuchungen sind auf die ungestoerte Gleichartigkeit der jaehrlichen Maximal, - und Minimalwasserstaende bei der hydrometrischen Station Silistra begruendet.Die theoretischen Verteilungkurven der jaehrlichen Extremumen wurden mittels der Gerassimovmethoden (1988) fuer Approximation und Mehrkriteriumoptimisation der empirischen Verteilungen ermittelt. Es sind unterschiedliche Loesungen fuer Verwaes-serung des Schutzgebietes vorgestellt auf Grund der Moeglichkeiten fuer den alljaehrlichen Ueberfall des Donauhochwassers ueber das Naturufer. Die

Wahl der wirksamsten Loesung ist auf Grund der Mehrkriteriumexpertauswertung gemacht worden.

## I. Introduction.

The problems of the Srebarna biosphere reserve and the possible approaches to preserve it have been subject of heated discussion over the past few years in the academic community in Bulgaria. The lake Srebarna which has the statute of a reserve is placed in the Western part of the riverside Ayedemir lowland. The inflow in the lake is from underground waters that dispose here, the surface inflow from lake's watershed and overflow over the Danube river bank during high waters. In 1948-1952 the Aedemir lowland has been drained and along the river bank embankments have been built. As a result the amplitude of the annual fluctuations of the lake water level has decreased and its mean water level has come close to the preceding mean summer water level. In the last years part of the riverside embankment in its Western part has been destroyed at about the 600th *m* facilating the overflow of high river waters. The impossibility for natural drainage and removing the alluviums has caused the intensification of the euthrofication processes as during the last 10-15 years not less than 200-$300*10^3$ $m^3$ deposits of organic origin have been accumulated. The authors examined the hydrological conditions and proposed alternative solutions for partial reconstruction of the hydraulic link between the lake and the Danube river.

## II. Primary data and statistical tests.

The Danube river is considered as a water resource of unfinal volume and the hydrological investigations are based on data for the water levels at the hydrometric station (HS)at Silistra. The corresponding river levels along the lake are obtained by the slope at different water levels. The homogeneity of data for maximum and minimum annual levels for the 1941-1992 period is verified according to the following criteria: the parametric of Student and Fisher and the nonparametric ones of Wilcoxon, and the signs. The samples for the minimum and the maximum water levels are divided into two periods: up to 1971 when the "Iron gate-I" dam was set in operation, and second from 1972 to 1992.

The use of the Stuart *t*-criterion for testing the homogeneity of the samples for the mean water levels is correct when they have normal distribution or close to it. The distribution of the maximums is closer to normal than that one of the minimums. At a level of confidence $\alpha$=5% and degrees of freedom $\kappa$=50, the results obtained confirm their homogeneity.

The non-parametric criterion of Wilcoxon has no limitations to the kind of empirical distribution and is quite precise to the mean values. The tests discover that at a confidence level $\alpha$=5% the maximum and the minimum values may be considered as homogeneous. The results obtained are verified also by the check-up sign criterion and they show that at level of confidence $\alpha$=5%, the "Iron Gate-I" dam caused no changes in the natural run-off process of the river Danube in the section nearest to the lake. This permits us to use the full volume of the data from 1941 to 1992. Tests for randomness are made according to the criteria for the local extremes (turning-point test) and the one for the median (median cross-point test). According to these criteria at a level of confidence $\alpha$=5% the randomly arrangement of the members of the rows of the maximum values and of the minimum ones is confirmed also. The results obtained give reason for further application of statistical methods. For investigating the periodicity the annual quantities at Russe for the 1930-1990 period are used. The cumulative curve of the differences $(Q_i\text{-}Q_{cp})$ is:

$\sum_{i=1}^{N}(k_i - 1) = f(i)$, where: $K_i = Q_i / Q_{cp}$; $Q_i$ - the water quantity for the year $i$; $N$=62 - number of the years, $Q_{cp} = \Sigma Q_i / N$.

As seen on Fig. 1 in the 1934-1954 period ($n$=31) a complete cycle with low and high water levels phases is observed. Between 1955 and 1964 another complete cycle is evolved. Since 1965 a phase of high water level begins which ends in 1982. During the last years, after 1982 a phase of low water level is observed which can explain the rare recurrence of Danube waters input to the lake.

## III. Theoretical distributions-methods and results.

The empirical probability of the annual maximum and minimum water levels arranged in a descending series are calculated using the formula:

$$p = \frac{m - 0.25}{n + 0.5} \qquad \text{(III.1)}$$

The theoretical curves of distribution of the annual extremes are obtained by the method of **Gerasimov S.** (1988), based on multy-criteria approximation. This method consists of the following steps.

III.1. Transformation of the secured values of unexcellence through the regressing subordination of the quantiles of the normal distribution.

III.2. Determination of the regression coefficients.

III.3. Logarithmic transformation of a random variable $Y$ with or without correction $ln(Y)$ or $ln\ (Y\text{-}a)$;

III.4. Application of the following reciprocally connected approximations.

III.4.1. Polynomial regression of the following kind:

$$\ln y = \sum a_i . x^i \qquad k = 1, \ldots, n \qquad \text{(III.2.)}$$

where: $a$ - regression coefficients, $k$ - degree of the polynom and for $k>2$ the polynoms are unmonotonous and unsuitable for extrapolations.

III.4.2. Log-normal approximation with correction $y_0$ to the quantile for

$$k>1, \qquad \ln(y - y_0) = a.x + b \qquad \text{(III.3.)}$$

where $y_0$ is determined on three ordinates of the polynom (III.2.):

$$y_0 = \frac{y_{0.05} \cdot y_{0.95} - y_{0.50}^2}{y_{0.05} + y_{0.95} - 2 \cdot y_{0.05}} \qquad \text{(III.4.)}$$

III.4.3. Power approximation of the following form:

$$\ln y = a_1 . x^{b_1} + c_1 \qquad \text{(III.5.)}$$

where the parameters $a_1$ and $b_1$ are determined by the regression:

$$\ln(\ln y - c_1) = \ln a_1 + b_1 . \ln x \qquad \text{(III.6.)}$$

If there are zero values the calculations are performed through the translation of the abscise: $y' = y + 1$ (III.7.)

III.5. The optimal approximations are chosen from great number through multicriterial optimization. This procedure is based on:

III.5.1. Minimum of the deviations. It is characterized by:

III.5.1.1. Mean square deviation: $\sigma_{\Delta y} = \sqrt{\frac{1}{n-1}\sum_{1}^{n}(y_i - \overset{*}{y})^2}$ (III.8.)

III.5.1.2. Mean absolute deviation: $\overline{\Delta y} = \frac{1}{n}\sum_{1}^{n}\left|y_i - \overset{*}{y}_i\right|$ (III.9.)

III.5.1.3. Median of the absolute deviations: $med\ \Delta y = \Delta y_{0.5} = \left|y_i - \overset{*}{y}_i\right|_{0.25}$ (III.10.)

III.5.1.4. Quantile extension: $S_{0.25} = \left|y_i - \overset{*}{y}_i\right|_{0.75} - \left|y_i - \overset{*}{y}_i\right|_{0.25}$ (III.11.)

III.5.2. Maximum resemblance between similar distributions.

III.5.3. Guarantee and insurance of the calculations (bigger maximums and less minimums).

III.5.4. Rejection of the data with great deviations (errors).

III.5.5. Smoothness of the approximation and possibility for extrapolation.

III.5.6. Physical possibility for appearance of the extremes.

The optimal approximations are calculated for the empirical probabilities of exceeding of the annual extreme levels. It has been determined that the quantile for $P(H>H_p)$=63,2% is 625 *sm*. This level exceeds with 14 *sm* the top of the river bank along the lake. Thus, with recurrence once every year, it is possible the overflow of Danube waters in the lake. As it is set forth below, different alternative solutions of the link between the lake and the Danube river are considered. For specifying the types of equipment, the distributions of the maximum water levels with duration 1, 3, 5 and 10 are examined. The results received for the conditional curves at different frequencies of recurrence are shown on Fig. 2

**IV. Alternative solutions for the inundation of the reserve Srebarna.**

Seven alternative solutions for the inundation of the reserve have been proposed. They are based on detail hydrological, hydraulic, hydrogeological and geological investigations. They are divided into three groups. The specified engineering equipment in the first group give the possibility for partial regulation of the in- and out-flow towards the river Danube. The solutions included in the second group ensure a free and not regulated water exchange between the lake and the river Danube. The third group generalizes decisions by which a total regulation of the access of the Danube waters towards the lake is achieved.

The method for multy-criteria expert assessment (**S. Gerasimov**, 1988) has been used for the objectification and optimisation the choice of the appropriate alternative solution. Its basic idea is the objectification of the general valuation by introducing of criteria valid for all the alternative solutions. The criteria are defined and classified into two groups, characterising their "advantages" and "disadvantages". The optimisation is made on the basis of their interrelation. The simplest way for formalization is the arrangement of the alternative solutions in a descending series at the scale of "advantage" and in ascending ones - according to their "disadvantage". The sum of the ranks of the all criteria for each of the alternative solutions gives the possibility for an arrangement on the scale of the optimum. Another way is the restriction of the assessment to a certain rating (value). If the maximum rating coincides with the number of the alternative solutions, it transforms into a rank rating. For assessment are used the proportions:

- for the "advantage" solution $$a = \frac{x_{max} - x_i}{x_{max} - x_{min}} \qquad \text{(IV.1.)}$$

- for the "disadvantage" solution $$a = \frac{x_i - x_{max}}{x_{max} - x_{min}} \qquad \text{(IV.2.)}$$

The definition of the criteria is important and requires initial condition. The authors have tried to determine the most important ones according to their experience and knowledge guided by the main purpose of the project. In the first group the criteria are included giving an account of the "naturalness" of the alternative solutions. The assessments are made according to the possibilities for restoring of the natural state of the reserve and hydraulic link with greatest frequency and duration, regulated and ensured against harmful anthropogenic influences. The "exploitation" criteria include: reliability of the system for exploitation and reliability for regulation. In the group of "economic" criteria are presented the investments, the amortisations and the exploitation expenses. The results are illustrated in table 1. According to the first group of criteria the highest valuation receives alternative solution VI followed by alternative solution V. Using the "exploitation" criteria the general assessment does not change. The "economic" criteria changes the arrangement, so the highest valuation receives the solution based on alternative solution V. The latter, presented on Fig. 3 is recommended as optimal.

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Gerasimov S. 1988. Approximation and multy-criteria optimisation of empirical distributions. Problems of meteorology and hydrology, volume 4, Sofia, pp. 31-44 (in Bulgarian).

| | alternative solution | | | | | | |
|---|---|---|---|---|---|---|---|
| critera | I. | II. | III. | IV. | V. | VI. | VII. |
| criteria for "naturalness" | 7 | 10 | 10 | 10 | 12 | 16 | 12 |
| "exploitation" criteria | 5 | 4 | 3 | 4 | 5 | 5 | 4 |
| "naturalness"+"exploitation" | 12 | 14 | 13 | 14 | 17 | 21 | 16 |
| "economic" criteria | 9. | 5.1 | 4.8 | 4.8 | 7.5 | 2.0 | 2.0 |
| **total** | **21.0** | **19.1** | **17.8** | **18.8** | **24.5** | **23.0** | **18.0** |

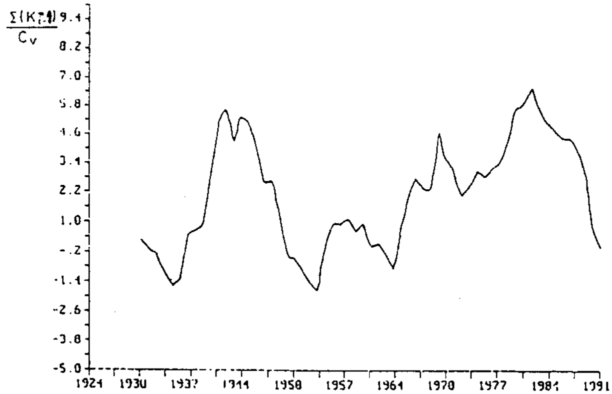


Fig. 1. Cumulative curve of differences for annual discharges at Russe.

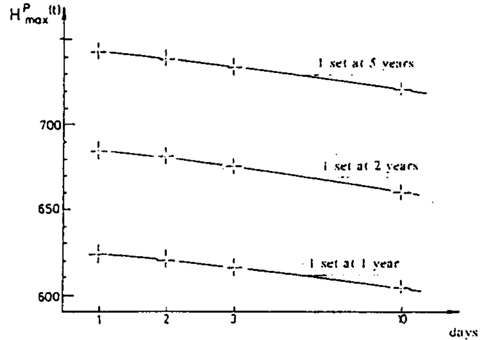


Fig. 2. Distribution of the maximum water levels with duration 1, 3, 5, 10 days.

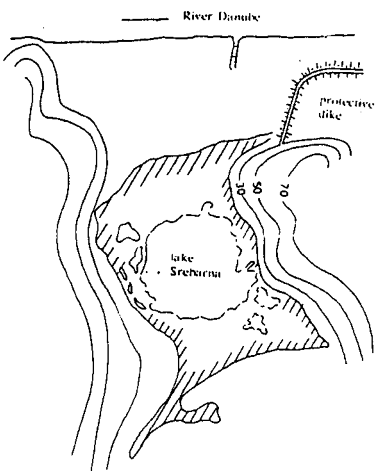


Fig. 3. Alternative solution # 5. Embankment along the lakely cushion zone in the reserve. Overflow along a wide border.

XVII. KONFERENZ DER DONAULÄNDER
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# Das Integrierte Donauprogramm des Landes Baden-Württemberg

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**Kurzfassung:**
Aus dem historischen Geschehen und aus den heutigen Bedürfnissen wurde ein Leitbild für die Donau vom Schwarzwald bis Ulm entwickelt. Vielfältige in das Gesamtkonzept eingepaßte Maßnahmen sollen die Donau und ihr Tal sukzessive dem Leitbild näherbringen.

# The Baden-Wuerttemberg Integrative River Danube Program

**Summary:**
The course of the historical development as well as the present demands led up to a basic conception for the Danube River from the Black Forest along to the City of Ulm. Manyfold activities, well adepted into the whole idea, shall move the Danube River and its valley step by step near about to the complete plan.

## 1. Die Oberste Donau

Als "Oberste Donau" soll hier der Donauabschnitt vom Schwarzwald bis nach Ulm - die baden-württembergische Donau - verstanden werden, weil der Name "Obere Donau" im internationalen Sprachgebrauch bereits für den oberen schiffbaren Teil von Ulm abwärts üblich ist.

**Vergleich / Comparison**
einschl. Breg, dem größeren der beiden Quellflüsse

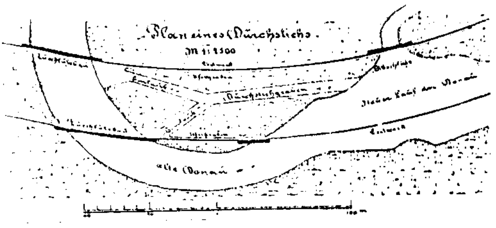
| | Länge[km] | Einzugsgebiet[km²] | Fallhöhe[m] |
|---|---|---|---|
| Oberste Donau | 247 | 5 460 | 540 |
| Gesamte Donau | 2 827 | 817 000 | 1 000 |
| Anteil Ob.Donau. | 8,7% | 0,67% | 54% |

Die Quellflüsse der Donau - Brigach und Breg - entspringen auf etwa 1 000 m über dem Meeresspiegel in den Hochlagen des Schwarzwalds im Gebiet der Uhrenstadt Furtwangen. Bei Donaueschingen vereinigen sie sich. Der Fluß trägt ab dort den Namen Donau.
Nun folgen 200 km Flußstrecke in sehr unterschiedlichen Landschaftstypen. Zuerst schwingt die Donau in weiten Mäandern durch die Baar, die eine Senke zwischen Schwarzwald und Schwäbischer Alb bildet. Bei Geisingen tritt sie in den weissen Jura der Schwäbischen Alb ein, in dessen Karst sie insbesondere bei Immendingen und bei Fridingen bedeutende Wasserverluste erleidet. Das Wasser kommt in ca 11 km Entfernung und 165 m tiefer wieder zum Vorschein und fließt dem Bodensee zu. Ab Mühlheim bahnt sich die Donau in der obersten Formation des Jura, den harten Schwamm-und Marmorkalken, in vielen Windungen, tief zwischen bizarren Felsen eingebettet, ihren Weg, um bei Scheer schließlich in die tertiären Bildungen der oberschwäbischen Molasseformation auszutreten. Auf dieser letzten Strecke verläuft sie zunächst in eiszeitlichen Moräneschottern, die die Molasse überlagern, hat diese aber stellenweise bereits bis auf die nackte Obere Süßwassermolasse (Flinz) abgetragen. Bei Munderkingen hat sie nochmal einen Vorsprung des Jura zu durchbrechen und verläuft dann bis Öpfingen in meist weichen, vielfach wechselnden sandigen Schichten der Molasse, um sich danach bis zum Verlassen des Landes bei Ulm in den hier die Molasse überlagernden eiszeitlichen Schmelzwasserablagerungen zu bewegen.
Ab Ulm prägen die Iller und die anderen Alpenzuflüsse der Donau ihren alpinen Charakter auf.

## 2.Der Donauausbau
### zwischen Scheer und Ulm im 19.Jahrhundert

Wachsende Bevölkerung und Mißernten führten um die Wende vom 18. zum 19.Jahrhundert zu großer Not. Innere Kolonisation sollte helfen."Dem Wasser Land abringen" war das Zauberwort, die höchste Bestimmung des Menschen, wie es der große deutsche Dichter Johann Wolfgang v. Goethe (1749-1832) in seinem Hauptwerk "Faust" als "der Weisheit letzter Schluß" erkennt. Wie die Lage an der Donau war, kann man dem Verwaltungsbericht [1] entnehmen. Durch die vielen Windungen, Uferabbrüche, Versandungen, Versumpfungen und die Überschwemmungen der Felder und Wiesen schon bei den meist zur Erntezeit eintretenden Sommerhochwässern "mochte die Bevölkerung bei der Bebauung der ausgedehnten Flächen die für eine vollkommene Ausnützung des Bodens nötige Sorgfalt nicht mehr verwenden."
Für eine durchgreifende Verbesserung war ein umfassender Ausbau erforderlich. Dem stand jedoch entgegen, daß die Donau zwischen Scheer und Ulm 20 mal territoriale Grenzen wechseln mußte. Dies änderte sich, als die Landkarte Südwestdeutschlands in der Folge der Koalitionskriege durch Säkularisation, Preßburger Frieden und Mediatisierung (1803 bis 1806) neu geschrieben wurde. Nun waren alle kirchlichen, vorderösterrei-

chischen, reichsstädtischen und die Territorien der kleinen Reichsstände in diesem Gebiet dem württembergischen Staate eingegliedert und der einheitliche Korrektionsplan konnte unter dem "rex agricolarum" König Wilhelm I von Württemberg (1816-1864) entworfen und, zur Hälfte von den Gemeinden und zur anderen Hälfte vom Staate finanziert, im wesentlichen bis zum Ende des 19.Jahrhunderts ausgeführt werden.
Durch Verkürzung mittels Durchstichen und Zuschlußbauten sowie die Anlage von Deichen erhielt die Donau einen stark verkürzten und befestigten Lauf.



Donauausbau bei Erbach, 1883/84

Plan aus [1]

Foto (aus Archiv Regierungspräsidium Tübingen)

Der Erfolg stellte sich zunächst ein, wie einer Beschreibung des Oberamtes Ehingen von 1893 [2] zu entnehmen ist:
"Die heutige Flußrinne ist, zwischen Munderkingen und Donaustetten zum großen Teil ein Werk der Menschenhand. Einst füllten endlos wechselnde Flußschlingen das Thal und wer die leichten Kurven des jetzigen Donaulaufs betrachtet, hat keine Ahnung von dem Zustand trostloser Versumpfung, welcher dereinst herrschte; der Kunst des Ingenieurs ist hier ein großes Werk gelungen".
Weitere Eingriffe ins Tal brachte der Eisenbahnbau und der Wasserkraftausbau sowie, insbesondere nach dem 2. Weltkrieg, eine verstärkte Besiedlung der Talbereiche, auch in Flächen, die bei extremen Hochwässern überschwemmt werden.

## 3. Das Integrierte Donauprogramm - IDP

Die einst so erfolgreichen Maßnahmen zeigten aber auch im Laufe der Zeit ihre negativen Auswirkungen wie ökologische Verarmung, Erosionen mit Uferzusammenbrüchen und sinkendem Grundwasserspiegel einerseits, Auflandungen mit Vernässungen an anderer Stelle und vor allem ein erhöhtes Schadenspotential in Überflutungsbereichen, das nach Abhilfe ruft.
Das Integrierte Donauprogramm des Landes Baden-Württemberg will die Donau und ihr Tal den heutigen Bedürfnissen entsprechend gestalten.

Es stützt sich auf ein wasserwirtschaftlich-ökologisches Konzept, das davon ausgeht, daß die Flußlandschaft der Donau folgenden **Ansprüchen** genügen soll:

- Lebens-, Wirtschafts- und Erholungsraum für die Menschen
- Trinkwasserspender von überörtlicher Bedeutung
- Rückhalte- und Ausgleichsraum für den Wasserabfluß
- Lebensraum für Lebensgemeinschaften der Fluß- und Talaue
- Großbiotop von internationaler Bedeutung für die Vogelwelt.

Die Basis für das IDP ist eine wasserwirtschaftlich-ökologische **Zustandserfassung.** Alle ihre Fachgutachten bestätigen, daß der Landschafts- und Naturhaushalt der Donau und ihres Talraumes bereits empfindlich gestört ist, durch:

- Weitgehende Kanalisierung der Donau und ihrer Zuflüsse
- Ausdehnung der Bebauung in die Überschwemmungsgebiete
- Landwirtschaftliche Nutzung bis an die Ufer
- Stauhaltungen und Ausleitungen zur Wasserkraftnutzung
- Ausufernde Freizeitaktivitäten.

Die wichtigsten nachteiligen **Folgen** sind:

- Hochwasserschäden steigenden Ausmaßes
- Gefährdung des Grundwassers
- Gestörter Geschiebehaushalt
- Austrocknen von Auelebensräumen
- Unterbrechung der Fließgewässer durch Einbauten und Staue
- Verarmte Flora und Fauna.

Deshalb soll sich die zukünftige wasserwirtschaftlich-ökologische Entwicklung der Donau und ihres Talraumes an folgendem **Leitbild** orientieren:

- Bewahren des Talraums als Lebens- Wirtschafts- und Erholungsraum für die Menschen
- Schaffen eines vielgestaltigen, veränderlichen und durchgängigen Flußlaufes mit ausgeglichenem Geschiebehaushalt
- Wiederherstellen und Bewahren einer wertvollen Kultur- und Naturlandschaft mit Elementen wie vor dem großen Ausbau.

Hierfür sind folgende **konkrete Ziele** zu verfolgen:

- Hochwasserschutz für die bebauten Ortslagen, u.a. durch Rückhalt größerer Wassermengen in der Aue
- Schutz des Grundwassers und Stützung seines Spiegels
- Naturnahe Umgestaltung naturferner Gewässerabschnitte
- Bereitstellung von Randbereichen für die Flußentwicklung
- Sicherung der Wasserkraftnutzung an bestehenden Wehranlagen
- Beseitigung von Hindernissen für die Wasserfaunenwanderung
- Entwicklung und Pflege besonders empfindlicher Biotope
- Entwicklung und Pflege von Still- und Fließgewässern im Biotopverbund
- Entwicklung und Pflege der Lebensräume für bedrohte Tiere und Pflanzen, hier besonders der Wiesen- und Auewaldarten
- Aufbau von Auewäldern als Weich- und Hartholzaue
- Förder- und Ausgleichsmaßnahmen für die Landwirtschaft
- Vorsorge für eine sanfte Erholung.

Die vielfältigen Abhängigkeiten erfordern, daß die überörtlichen Wirkungen ( Hydrologie, Morphologie, Fließgewässerökologie ) und die lokalen Interessen ( Siedlung und Gewerbe ein-schließlich Hochwasserschutz, Landwirtschaft, Verkehr, Natur- und Landschaftsschutz, Naherholung ) ständig miteinander verknüpft werden.

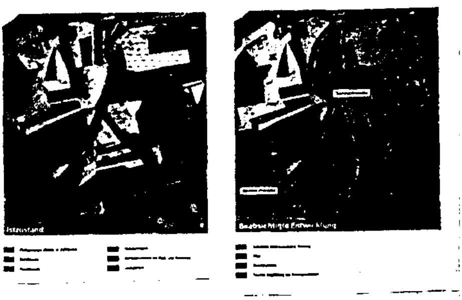
**Das Integrierte Donauprogramm stellt sich deshalb als ein Bündel verschiedenartiger Aktivitäten dar,** wie:

- Ausrichten des öffentlichen und Steuern des privaten Handelns auf die Ziele des Leitbildes hin.
- Strategische Steuerung bei Regional- und Bauleitplanung
- Wahrnehmen zufälliger Möglichkeiten wie Grunderwerb in Flurbereinigungen, Koordinierung mit Biotopvernetzung.
- Regelungen wie Ausweisung von Überschwemmungsgebieten
- Generelle Planung der Maßnahmen mit überörtlicher Wirkung
- Sukzessive Verwirklichung der Gestaltungsmaßnahmen in pragmatischer Anpassung an Planungskapazität, Verfahrensfortgang und verfügbare Finanzierungsmittel.

## 4. Erste IDP-Maßnahmen

**Renaturierung des Blochinger Sandwinkels**

1855/56 Verkürzung des Donaulaufs von 1 600 m auf 1 000 m. 1992/93 Renaturierung. Anlegung eines höhergelegenen S-förmigen unbefestigten Laufs von 1 4oo m Länge. Abstützung mittels rauher Rampen gegen den bisherigen Lauf, der zur Hochwasserabfuhr wegen der oberhalb liegenden Ortschaft, die sich dem letzten Entwicklungsstadium (Tiefenerosion) angepaßt hat, weiter herangezogen werden muß. Großzügiger Grunderwerb für die Bewegungsfreiheit des Flusses.



**Blochinger Sandwinkel**

Planung 1989, Reg. Präs. TÜ.
(die größere Schlinge liegt im Plan unten)

Foto Nov.1993, Reg. Präs. TÜ.
(die größere Schlinge liegt im Foto oben).

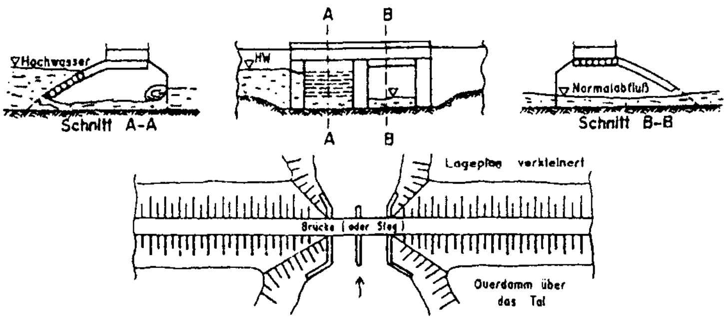
Flußlandschaft Donauwiesen

Zwischen Riedlingen und Zwiefaltendorf durchfließt die Donau ein feuchtes Wiesental mit Auflandungstendenz. Das Gebiet wurde 1991 unter Naturschutz gestellt. Durch Extensivierungen und flankierende wasserwirtschaftliche Maßnahmen ( Schaffung altarmähnlicher Gebilde soll hier u.a. ein idealer Nahrungsbiotop für den Weißstorch (Vogel des Jahres 1994) entstehen. Die wasserwirtschaftlichen Maßnahmen sind planfeststellungsreif geplant, das Wasserrechtsverfahren ist eingeleitet.

## Überörtlicher Hochwasserschutz

Die Donau verfügt in den breiten Talbereichen noch über ausgedehnte Überschwemmungsflächen, die bei extremen Hochwässern wirksam werden. Sie reichen jedoch nicht aus; zahlreiche Ortslagen leiden unter Hochwasser (Schäden 1980 allein ca 20 Mio DM). Örtliche Entlastungsmaßnahmen schaden den Unterliegern. Auch durch die vorgesehenen Renaturierungen wird der Abfluß in der Regel beschleunigt, weil durch den wieder nach oben geholten Grundwasserspiegel der entsprechende unterirdische Porenraum zur Dämpfung des Hochwassers nicht mehr verfügbar ist. Das Programm sieht deshalb vor, übergebietlichen Hochwasserschutz durch Retentionsmaßnahmen mit örtlichem Ausbau so zu kombinieren, daß für alle bestehenden Ortslagen etwa der gleiche Schutzgrad erreicht wird.

Die Abflußverzögerung soll schadbringende Hochwasserscheitel in mehreren gesteuerten Einrichtungen dämpfen. Das Durchflußverhalten ist dabei der Charakteristik natürlicher Überschwemmungsgebiete weitgehend angepaßt.




**Regulierbauwerk**
für gezielte zusätzliche Retention über natürlichen Überflutungsflächen (nur bei extremen Hochwässern)

Sie werden dort eingerichtet, wo die beanspruchten Flächen auch jetzt bereits Überflutungsgebiete sind. An geeigneten Stellen werden dafür Querwälle über das Tal gelegt und der Fluß wird unter einer Art Brücke hindurchgeführt. Unter der Brückenplatte sind Drosselorgane versteckt, die nur bei großen Hochwässern heruntergelassen werden, unter denen aber der hohe Basisabfluß stets hindurchfließt. Der Fluß wird so nicht mehr gestört als unter einer Brücke und bei extremen Hochwässern steht das Wasser etwas höher und etwas länger im Überschwemmungsgebiet. Die Flächen, innerhalb derer sich die gesteuerte Rückhaltung abspielt, sollen weitgehend erworben und zumindest teilweise als naturhafte Flußauen entwickelt werden. Eine erste solche Anlage oberhalb Riedlingens wird z.Zt. im Raumordnungsverfahren überprüft.

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# GEWÄSSERSCHUTZ DURCH STADTENTWÄSSERUNG AM BEISPIEL DES MÜNCHNER NORD-WEST-SAMMELKANALES UND DES DONAU-ZUBRINGERS ISAR

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Zum Schutz der Oberflächengewässer, des Grundwassers sowie vor Überschwemmungen von Kellern und Unterführungen muß auch in München die Stadtentwässerung laufend ausgebaut werden.
In enger Abstimmung u.a. mit

- der Obersten Wasserbehörde im Bayerischen Staatsministerium für Landesentwicklung und Umweltfragen,
- dem Bayerischen Landesamt für Wasserwirtschaft und
- dem Wasserwirtschaftsamt München

führt die Landeshauptstadt München deshalb zur Verbesserung der Gewässergüte von Isar und Mittlere Isarkanal (bei einem Gesamtkostenaufwand von ca. 370 Mio. DM) das Projekt des Nord-West-Sammelkanales voran.

# WATER-POLLUTION PREVENTION AND URBAN DRAINAGE, ILLUSTRATED BY THE EXAMPLES OF THE MUNICH NORTH-WEST COLLECTION SEWER AND OF THE RIVER ISAR, TRIBUTARY TO THE RIVER DANUBE.

In Munich, as in other towns and cities, the urban drainage system has to be constantly updated and improved in order to ensure the protection of the surface waters and the ground water, and to prevent the flooding of cellars and underpasses. The Bavarian State capital Munich, in close cooperation with (amongst others),

- the senior water authorities in the Bavarian State Ministry for Regional Development and Environment,
- the Bavarian State Office for Water Resources and
- the Office of Water Resources in Munich

is therefore going ahead with north-west collection sewer projekt (at a total cost of about DM 370m) to improve the water quality of the Isar and the Middle Isar Lateral Canal.

## 1. Einführung

Seit dem Mittelalter gehört die Aufrechterhaltung der Hygiene zu den wichtigsten Aufgaben der Münchner Stadtentwässerung. Dienten dazu früher Stadtbäche und Rinnsteine in den Straßen, so entstanden zu Beginn des 19. Jahrhunderts die ersten Abwasserkanäle im heutigen Sinne. Die Stadthygiene und die zunehmende Bodenversiegelung zwangen zum weiteren Ausbau der Kanalisation. Durch das Ableiten der Niederschläge in die Kanäle nahmen die Überschwemmungen von Kellern, Unterführungen und tiefliegenden Stadtteilen ab. Dies kam unter anderem dem Gewässerschutz zugute. Heute werden ca. 80 % der Einzugsfläche des Münchner Kanalnetzes im reinen Mischverfahren entwässert. Dabei werden Regen- und Schmutzwasser ("Mischwasser") zusammen in einem Kanal der Kläranlage zugeführt. In Außenbereichen kommt ein modifiziertes Mischverfahren zur Anwendung, bei dem neben dem Schmutzwasser nur das Niederschlagswasser der öffentlichen Straßen in den Kanal eingeleitet - und das Regenwasser der Dach- und Hofflächen örtlich versickert werden (vgl. [2]).

Insgesamt sind in München mehr als 2100 km Kanäle verlegt (Stand: 01.01.1993). Rund 1.29 Mio. der Einwohner Münchens (das entspricht 99 %) sind an das Kanalnetz angeschlossen. Im Münchner Norden und Nordwesten liegt der größte Teil der derzeit nicht kanalisierten Gebiete (Anschlußgrad hier: ca. 97 % der Bevölkerung). Zum Anschlußgrad an gemeindliche Abwasseranlagen in Bayern vgl. [3].

Neben Erweiterungen der Klärwerke und dem Bau von Regenrückhaltebecken sind weitere große Abwasserkanäle notwendig, um das Mischwasser bei starken Regenfällen kurzzeitig zu speichern und dosiert den Klärwerken zuzuleiten, um so hydraulische Überlastungen der Klärwerke zu vermeiden. Deshalb führt die Landeshauptstadt München das Projekt des Nord-West-Sammelkanales voran. Leider konnten die 1938 begonnenen Planungen, nach dem Aufbau der Zerstörungen des 2. Weltkriegs, erst im Jahre 1970 wieder aufgenommen werden.

An diesen Hauptsammelkanal werden im Endausbau rund 50 % des Stadtgebietes angeschlossen sein, die derzeit noch über die Innenstadt zu entwässern sind. Die Bauzeit für den rund 30 km langen Kanal wird insgesamt mehr als 17 Jahre (1982-1999) betragen. Derzeit ist rund die Hälfte des Nord-West-Sammelkanales fertiggestellt. Ziel ist es, auch bei Starkregen durch das Vermeiden von Mischwasserabgaben in die Isar und den Mittleren Isarkanal, die Gewässergüte unterhalb Münchens weiter zu verbessern (Abb. 1).

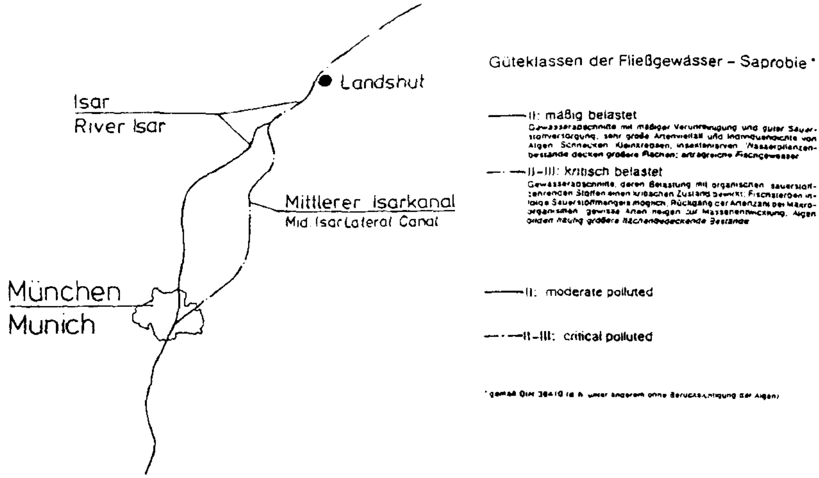


Abb. 1: Gewässergüte der Isar und des Mittleren Isarkanales unterhalb Münchens (Stand Dezember 1992). Leicht verändert aus: Wasserwirtschaft in Bayern, H. 26 (1993).

Fig. 1: Water quality in the river Isar and the Mid. Isar lateral Canal downstream from Munich (Dezember 1992). Taken, with slight alterations, from: Wasserwirtschaft in Bayern, Vol. 26 (1993).

## 2. Wasserwirtschaftliche Vorgaben

Die Münchner Schotterebene neigt sich von Süd nach Nord mit einem natürlichen Gefälle von 1:300. Das West-Ost-Gefälle beträgt 1:1000 bis 1:2000. Damit kann die Stadt größtenteils im Freispiegelgefälle entwässert werden. Die mittlere Niederschlagshöhe beträgt in München pro Jahr 950 mm, d.h. 950 $l/m^2$ (zum Vergleich: Hamburg 741 mm/a; Frankfurt 653 mm/a). München gilt darüber hinaus als eine der am stärksten versiegelten Großstädte Deutschlands.

Es ergibt sich ein Verhältnis von bebauter Fläche und Verkehrsfläche (17609 ha) zur Gesamtstadtfläche (31.045 ha) von rund 57 % (zum Vergleich: Hamburg 46 % ; Frankfurt a.M. 48 %). Obwohl das Münchner Stadtgebiet einen versickerungsfähigen Untergrund aufweist (Stichwort: Münchner Schotterebene), ist wegen der Flächenknappheit (Versiegelung), der heutigen hohen Verkehrsbelastung und der gewerblich-industriellen Nutzungen eine Versickerung der Niederschlagswässer häufig nicht möglich. In den nordwestlichen Stadtgebieten ist es außerdem aufgrund des hohen Grundwasserstandes schwierig, das Regenwasser schnell genug zu versickern. So müssen (bei zwar ausreichendem Gefälle) vergleichsweise große Niederschlagsmengen und daraus entstehende Ablaufmengen in kurzer Zeit im Kanalnetz abtransportiert werden.

## 3. Gewässerschutz

### 3.1 Gewässergüte der Isar und des Mittleren Isarkanales im Bereich München

Das Bayerische Landesentwicklungsprogramm fordert für die Isar und den Mittleren Isarkanal (MIK) die Gewässergüteklasse II (ein mäßig belastetes Fließgewässer mit guter Sauerstoffversorgung und großer Artenvielfalt an Fischen, Kleintieren, Insektenlarven und Wasserpflanzen). Der wasserwirtschaftliche Isar-Rahmenplan und der Münchner Gesamtentwässerungsplan übernehmen diese Zielsetzung.

Bereits zwischen 1989 und Dezember 1992 verbesserte sich die Gewässergüte der Isar von Güteklasse II-III (kritisch belastet) auf II (mäßig belastet). Hier macht sich das Auflassen mehrerer großer Mischwassereinleitungen sowie eine Steigerung der durchschnittlichen Wasserführung (durch die sog. Eisbachüberleitung) bemerkbar. Nach Investitionen von ca. 650 Mio. DM wurde 1989 das Klärwerk München II in Betrieb genommen. Wegen der nachfolgenden Entlastung des Klärwerks München I steigerte sich die Gewässergüte des MIK unterhalb Münchens von III (stark verschmutzt) auf II-III (kritisch belastet; [1]). Nur im Bereich der Speicherseen unmittelbar nach Einleitung der geklärten Wässer des Klärwerks München I hat die Wasserqualität noch Güteklasse III (stark verschmutzt).

### 3.2 Gewässerschutz durch Kaskadenspeichersystem

Nach Wiederaufnahme der Planungen im Jahre 1970 zeigten sich die Vorteile einer Ausbildung des Münchner Nord-West-Sammelkanales als Kaskadenspeichersystem. Das sind stufenförmig angeordnete Stauraumkanäle, die miteinander durch Überlauf- bzw. Einstaubauwerke verbunden sind. Diese Bauwerke haben die Funktion, das oberhalb gelegene Kanalstück durch eine hochgezogene Schwelle und einen schiebergedrosselten Ablauf zum Einstau zu bringen. Bei Speicherfüllung wird so eine Verringerung der Belastung in den unterhalb gelegenen Kanalabschnitten ermöglicht.

Für weite Strecken des Nord-West-Sammelkanales wurde (bei einem Kanalgefälle von 1:1750) als Kanalprofil die Form eines Rechteckquerschnittes von 5.65m Höhe x 3.80m Breite mit geringfügig ausgerundeter Sohle gewählt. Dies bedingt eine Speicherkapazität des Kanals in Höhe von rund 260.000 $m^3$.

So können zukünftig auch bei Starkregen große Mengen an Mischwasser zurückgehalten werden, was zu einer Entlastung des Münchner Kanalnetzes, der Isar und des MIK führen wird. (Bei einer Belastung des Systems mit einem einjährigen Bemessungsregen erfolgt noch keine Einleitung von ungereinigtem Mischwasser in die Isar). Die Mischwässer sollen nach der eventuell notwendigen Zwischenspeicherung zum Klärwerk München II geleitet werden (Abb. 2). Danach werden die gereinigten Wässer südwestlich des Münchner F.-J.-Strauß-Flughafens der Isar zugeführt.

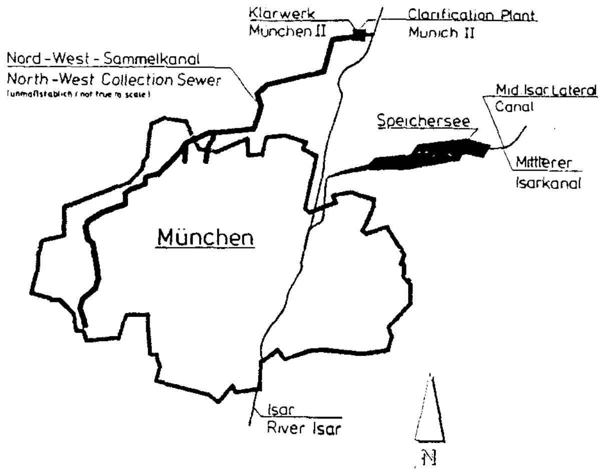


**Abb. 2:** Nord-West-Sammelkanal München

**Fig. 2:** North-West Collection Sewer Munich

## 4. Ausblick

Anfang der 1940er Jahre lautete für den Verbindungskanal zwischen den nordwestlichen Münchner Stadtteilen und der neu zu konzipierenden Kläranlage "München Nordost" (heute: München II) die Entwurfsbezeichnung noch "großer Querkanal". Später wurde als Arbeitsname "Nördlicher Hauptsammler" gewählt. Für die Raumordnungsverfahren während der 1970er und 1980er Jahre verwendete man schließlich den Namen "Nord-West-Sammelkanal".
Zu prüfen bliebe, ob nicht für diesen größten je in München gebauten Abwasserkanal nach seiner Fertigstellung auch ein anderer würdiger Name in Frage käme. Der Name des Münchner Ehrenbürgers und Präsidenten der Bayerischen Akademie der Wissenschaften MAX VON PETTENKOFER (1818-1901) steht über die Stadtgrenzen hinaus für Hygiene, Gesundheit und Gewässerschutz. Seine Anregungen waren für die Münchner Stadtentwässerung wegweisend [4].

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# PROBLEMS RELATED TO THE PROTECTION OF RIPARIAN POPULATED AREAS FROM THE EFFECTS OF THE IRON GATE I SYSTEM

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ABSTRACT

The paper discusses problems related to the protection, from surface and ground water, of the riparian zone along the right bank of the Danube in the vicinity of the reservoir of the hydroelectric power plant and navigable system Iron Gate I.

Hydraulic engineering facilities designed to alleviate the harmful consequences of both surface and ground water have been erected in several riparian zones of the Danube, particularly in certain urban areas. Notwithstanding these facilities, local occurrences of high groundwater levels pose a threat to residences and the industry. An attempt is made in this paper to explain the phenomenon and indicate feasible steps towards its elimination. Consideration is given to three specific localities: Kiseljevo, Kličevac and Veliko Gradište.

## *PROBLEME DES UFESIEDLUNGSSCHUTZES GEGEN EINFLUESSE DES WASSERKRAFTWERKSYSTEMS DJERDAP I*

*KURZFASSUNG*

*In dieser Arbeit werden Probleme des Ufersiedlungschutzes gegen Oberflaechen- und Grundwasser am linken Donauufer in den Akkumulationszone des Wasserkraftwerkes Djerdap I bearbeitet.*

*Hydraulische Objekte gegen schaedliche Oberflaechen- und Grundwasserauswirkungen sind an einigen Uferteilen der Donau aufgebaut, besonders in gewissen urbanisierten Gebieten, aber auch daneben bedrohen oertliche Erscheinungen des hohen Grundwasserstandes die Wohn-und Industrieobjekte. Diese Arbeit sollte das Phaenomen erlaeutern und auf moegliche Schritte zur Beseitigung des Gleichen hinweisen. Drei spezifische Lokalitaeten wurden in Betracht genommen: Kiseljevo, Kličevac und Veliko Gradište.*

## 1. INTRODUCTION

A long-term study of the problems related to the protection of the riparian zone of the Iron Gate I system from increased groundwater levels indicated that in certain cases the effects were contrary to those expected, even though wide ranging protection measures had been implemented.

This conclusion was surprising to the authors of the present paper, in view of the fact that the designed and implemented measures were in compliance with contemporary design and engineering methods applied in similar cases.

It is the wish of the authors to attempt to shed light upon and point out the possible causes of local occurrences of high groundwater levels in the areas in which, from the viewpoint of contemporary technology and hydraulic engineering, appropriate protection measures have been implemented.

## 2. HYDROGEOLOGIC AND HYDRAULIC CHARACTERISTICS OF THE CONSIDERED REGION

### 2.1 Introductory Remarks

Hydrogeologic characteristics of the protected area have a significant impact on the methods of protection from permanently increased groundwater levels, as well as the protection effects achieved thereby.

As a rule, the geologic profiles in the riparian zone of the Iron Gate I system on the left bank of the Danube are multilayered, with four basic and characteristic layers interspersed with interlayers which have a lesser, although not insignificant, effect on the groundwater regime. The basic characteristics of the four layers are:

1. Semipervious layer towards the surface comprising silty and clayey sands, whose average thickness is 2 to 4 m and the coefficient of permeability of the order of $10^{-7}$ (m/s);

2. Semipervious layer of clayey and sandy silt, whose thickness is approximately 1 to 2 meters and the coefficient of permeability $K = 10^{-8}$ (m/s);

3. A layer comprising gravel and gravelly sand; the thickness varies over a wide range, of the order of 12 to 5 m, and it is significantly more permeable with a coefficient of permeability of the order of $K = 10^{-3}$ to $10^{-4}$ (m/s).

4. Beneath these three layers there is impervious marly clay.

Unless appropriate protection measures are undertaken, permanently raised water levels of the Danube result in a permanent increase of groundwater levels.

The topography of the terrain has a significant effect on the groundwater regime and the vertical water balance characteristics whose variation depends on the degree of urbanization of the protected region.

In principle, in the riparian zone of Iron Gate I there are two basic hydrogeologic profiles of previously mentioned characteristics. The first is situated in the Danubian plain, while the second comprises parts of the plain and the intermediate zone between the plain and hilly regions.

It should be pointed out that this differentiation of two basic types represents an idealization of the field conditions, in order to emphasize the significance of the semipervious interlayers which, complying with the laws of sedimentation, lense out towards the slope and are often not registered with sufficient accuracy during exploratory drilling.

In both cases the groundwater regime will depend on the nature of the boundary conditions:
- the water level regime of the river;
- the regime of groundwater inflow from the hinterland; and
- the vertical water balance regime at the surface of the considered region.

The change of the groundwater regime caused by increased water levels of the Danube for the stated hydrogeologic profiles is essentially different.

In the first case the lower water-bearing layer is saturated by inflow from the river, but also by inflow from the hinterland. The superposition of these two influences results in overflow of groundwater to the upper water-bearing layer, through the lensed out semipervious layer.

The said overflow cannot occur in the second case since the semipervious layer does not lense out and, in addition, the elevation of the layers precludes such an occurrence. In this case the piezometric head of the water-bearing layer is increased and results in vertical infiltration through the semipervious layer. (This infiltration phenomenon exists in the first case as well, but it is less significant.)

The usual methods of protection of the Iron Gate riparian zone, depending on local conditions and engineering and economic analyses, generally include:

- a series of vertical wells;
- an open drainage channel in the surface layer; and
- a horizontal drain.

A deep drainage trench is the only means that will fully eliminate the effect of increased water levels of the river on the level regime in the hinterland. In view of the thickness of the layers, the implementation of such a protection measure would not be reasonable. Instead, a series of deep vertical wells is used which reach the bottom impervious layer.

As a rule, open drainage channels are created in the surface layer and cannot therefore control the groundwater regime in the lower water-bearing layer. Their primary function is that of a reclamation channel used to control surface and ground water regimes in the upper portion of the semipervious surface layer.

A horizontal drain is generally used for local groundwater regime control, and the domain of influence is a function of its depth.

## 2.2 Groundwater Regime Control by a System of Vertical Wells

Even when the interlayers are semipervious, a system of vertical wells can fully replace a drainage trench if the well screens include all the water-bearing layers, at least with regard to the drawdown at a certain distance from the row of wells (or as the mean piezometric level of the row of wells). The method of conformal mapping yields that the mean drawdown $\Delta H$, affected by the *series of wells, is the same as that in the case of a fully penetrating trench at distance (a) from the* river:

$$\Delta H = \frac{(Q-2b\cdot q)}{T\cdot b}\cdot a + \frac{q}{T}\cdot a,$$

where b is the half-distance between wells; q is the inflow from the hinterland; a is the distance of the row of wells from the river bank; and Q is the inflow to the well.

In other words, everything happens as if the inflow from the hinterland were at 2bq, and the discharge from the river at (Q - 2bq).

At the half-distance between wells the level increases by $\Delta S$, and at the row of wells by the seepage resistance approximately equal to

$$\Delta\Pi_B = \frac{Q}{2\pi\cdot T}\cdot \ln\left(\frac{b}{\pi\cdot r}\right)$$

where r is the well radius.

These losses are to be added to the seepage resistance due to local losses at the entrance to the well.

This proves that for the given assumptions a system of wells may be used to efficiently control the water level in the riparian zone as well as farther into the hinterland.

A deviation from the above scheme may occur for the following reasons:

- By-passing of the well series if it is not sufficiently long;
- Vertical components of the water balance which are often significantly altered due to urbanization;
- Inflow from the lower water-bearing layers, that is of no significance for the riparian zone of the Danube's right bank downstream of Belgrade;
- The fact that the river interface is never ideal and certain seepage losses occur due to clogging of the river bed. However, it is obvious that in terms of drainage problems this effect is positive in the considered case and cannot therefore be neglected.

## 2.3 Change of Groundwater Balance due to Urbanization

Several vertical components of the water balance affected by urbanization will be considered, whose changes may affect the groundwater level in the surface layer and result in groundwater pollution, wetting of buildings, etc. All of these factors will depend on:

- *Hydrogeologic conditions*, distribution of pervious and impervious layers, inflow from the hinterland, etc. and
- *Degree of urbanization.*

The latter effect will be reviewed in more detail, assuming that prior to the urbanization process the population used water from locally dug wells. In effect, under observation is the transition of a standard rural settlement in the riparian zone of the Danube into an urban environment.

The onset of urbanization always involves an increase of impervious surfaces due to erection of buildings and paving of roads. These surfaces, where in practical terms evapotranspiration used to be equal to infiltration (since the runoff coefficient in plains is very close to zero), now acquire runoff coefficients close to one and the increase of positive vertical components per unit surface area is equal to

$$P \cdot (\eta_2 - \eta_1)$$

where P is the precipitation over the considered period (l/s · ha); and $\eta_1$ and $\eta_2$ are respectively the previous and the altered extent of impervious surfaces resulting from construction.

Urbanization very often includes the construction of septic tanks and these are in most cases pervious. (This is against the law but, unfortunately, in practice most septic tanks are of this kind.) Groundwater is rapidly polluted, especially when shallow wells are dug and when semipervious layers exist.

One may say that pollution of surface groundwater is unavoidable in the initial stages of urbanization.

The pollution of groundwater in dug wells leads to the need for bringing water from elsewhere. The amount of water now increases commensurate with the consumption, according to the standard formula

$$\Delta q_v = n \cdot q_p$$

where n is the population per hectare and qp is the specific consumption per person (l/s · ha).

An additional source of groundwater are losses from the water supply network which may be as high as 50% of the total water consumption.

If irrigation is also performed by water from elsewhere, it is logical that it results in an increase of groundwater levels and this is already a well-known problem.

Further degrees of urbanization involve the construction of a water drainage infrastructure beginning with a sewage system. This stage also represents the beginning of correction of the groundwater regime affected by urbanization, although the problems are not so simple since water losses from the sewage system are seldom insignificant. A major role in the repair of the groundwater regime is played by a precipitation drainage system, provided that such a system does collect water from the majority of the impervious surfaces, as well as the entire populated area. In certain parts of such areas there is the need to provide additional (horizontal) drainage assuming, of course, that there exists the basic form of protection towards the river, in the case of a riparian zone.

With regard to the vertical components (as well as others), the final stage of urbanization represents a significant improvement over natural conditions.

## 3. PROTECTION PROBLEMS IN CERTAIN POPULATED AREAS IN THE RIPARIAN ZONE OF THE IRON GATE SYSTEM IN THE LIGHT OF THE PREVIOUS CONSIDERATIONS

When the groundwater regime in the protected riparian zone of the Iron Gate reservoir was evaluated, certain areas were observed in which the regime did not conform to the implemented protection measures.

Three characteristic localities are distinguished in the present paper: Kiseljevo, Kličevac and Veliko Gradište.

The common factors for all three localities are their inclusion in the implementation of protection measures and the fact that the accomplished effects are not fully satisfactory.

*Kiseljevo* is located in the immediate vicinity of the Silver Lake 1.50 km from a very hilly region from which it is separated by a system of amelioration channels.

The groundwater regime at Kiseljevo is controlled by an induced water level regime of the Silver Lake characterized by a significant decrease of the water level relative to the natural conditions. Notwithstanding, however, several buildings are endangered by high groundwater level. In addition, an increase of water level and pollution have been noted in the wells.

This case is a typical example of a deteriorated groundwater regime that is not caused by the change of the Danube's water level. The only remaining possible reason is the negative effect of urbanization as explained in the previous section of this paper.

The protection measures at Kiseljevo may be improved by efficient drainage of precipitation and waste water by means of a suitable sewage system.

*Kličevac* is located in the intermediate region between the Ram-Kličevac Marsh and the slopes of the Homolje Mountains.

Extensive reclamation works have been carried out in the Ram-Kličevac Marsh which provided protection from excessive groundwater. The region is drained by two systems:

- The basis of the first is the main recipient Dunavac (a branch of the Danube) towards which the system of channel gravitates.
- The second system comprises the Zavoj pumping station with a gravitational drainage network to the Dunavac.

The second system comprises the Zavoj pumping station with a gravitational drainage network to the Dunavac.

An evaluation of groundwater hydrographs for this region over the preceding period generally indicates a decrease, except in the region of Kličevac for which certain studies conclude that high groundwater levels are recorded near the high terrace at Kličevac, as well as partially in the village of Rečica, as a consequence of perched water from the hills.

This apparent contradiction (protected Marsh and high groundwater level) may be explained in two ways:

- Increase of groundwater level due to more intense urbanization, as there is no basis to assume that inflow from the hills has increased; and
- The overflow phenomenon, from the lower water-bearing layer, which is possible in view of the characteristics of the hydrogeologic profile.

In order to provide a valid answer to this question it would be necessary to:

- complete the hydrogeologic profile by additional drilling in the elevated terrain above the Village of Kličevac in order to accurately determine the zone of lensing out of the impervious layer;
- construct piezometers along the hydrogeologic profile in the zone of Kličevac, if feasible pairs of deep and shallow. (The screen should be designed after obtaining detailed information on the hydrogeologic composition prevailing in the region.)

If all of the said information leads to the conclusion that urbanization is the cause of increased groundwater levels, it would be necessary to construct an infrastructure for the removal of precipitation and waste water from the populated area.

However, if overflow is the cause of increased groundwater level, the problem would have to be solved by a system of deep wells and pumping from the lower water-bearing layer, in addition to the existing channel network in the Marsh.

*Veliko Gradište* is protected from increased groundwater levels by a system of deep wells (a total of 12 spaced 100-300 m apart). This protection measure yielded positive results, with minor deviations in certain parts of the town. Periodic changes of the operating regime resulted in increased groundwater levels, indicating the need for continuous operation in the prescribed regime.

As already stated above, certain parts of the town experience deteriorated groundwater regimes even though the implemented protection system, generally speaking, yielded positive results and satisfied all the prerequisites for successful operation.

Since the wells were dug deep, local groundwater level increase as a result of the overflow phenomenon is ruled out. However, as a semipervious interlayer exists, emptying of the upper layers into the lower layers is not naturally possible and the wells cannot therefore have an efficient role throughout the town.

In view of the above, it may be concluded that increased water levels of the Danube in the zone of the wells associated with Veliko Gradište are not the cause of increased groundwater levels of the upper layer in certain parts of the town. The problem, which exists, may be solved by removal of precipitation and waste water with expansion and reconstruction of the existing network, as well as by adding horizontal drains in selected parts of the town.

In the zone beyond well influence, or where the influence is insufficient, the series of wells should be extrapolated in order to prevent side inflow to the region protected from the face.

## CONCLUDING REMARKS

The aim of this paper was to indicate the complexity of groundwater regime evaluation and the design of optimal protection measures by means of specific examples of localities in the protected region of the riparian zone of the Iron Gate system.

Superficial observation may lead to the conclusion that any deterioration of the groundwater regime in the riparian zone is solely the consequence of the altered water level regime of the Danube.

However, if evaluation also includes vertical water-balance parameters, the effects of urbanization and the characteristics of the hydrogeologic profile, it may be shown, as the authors did in this paper, that the groundwater regime is not exclusively dependent on the permanent increase of the river's water level. This fact is significant for the selection of protection measures against increased groundwater levels.

If increased groundwater level is a consequence of increased water level of the river, the solution to the problem should be sought at the riverbank/hinterland interface, by applying such measures that will preclude the propagation of negative effects to the hinterland (i.e. a series of deep wells of sufficient density).

If urbanization has disturbed the vertical groundwater balance, the problem needs to be solved by means of a precipitation and waste-water removal system, assuming that there exists a basic system of protection from increased water levels of the river.

If increased groundwater levels are caused by overflow, the problem needs to be solved by an open channel network upstream of the protected zone.

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# STORAGE OF ACCIDENTAL WASTE WATER SPILLS AND ITS EFFECT ON REDUCING POLLUTION LOADS TO RECIPIENTS

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## ABSTRACT

Accidental waste water spills create hazards to the aquatic ecosystem of recipient water bodies, and represent risks to the economy as well as to human health.
The paper describes the concept of automatically monitoring treatment plant effluents and on-line controlling a system of gates which latter provide for the automatic storage of waste waters of worse than permissible quality.

Emergency storage of accidentally occurring spills is of great environmental significance, as it provides for the protection of the water quality of recipient water bodies, reducing pollution loads to tolerable levels.

## SPEICHERUNG HAVARIENARTIGER ABWASSERÜBERLÄUFE UND IHRE AUSWIRKUNG AUF DIE VERMINDERUNG DER SCHMUTZSTOFFBELASTUNG DER VORFLUTER

### ZUSAMMENFASSUNG

Die havarienartigen Abwasserüberläufe gefährden das aquatische Ökosystem der rezipierenden Wasserkörper und stellen ein Risiko sowohl für die Wirtschaft als auch für die menschliche Gesundheit dar. Die Studie erörtert das Konzept einer automatisierten Beobachtung der Effluenten aus Abwasserkläranlagen sowie eines online gesteuerten Schleusensystems für die automatische Speicherung von Abwässern unter einem bestimmten zulässigen Qualitätsniveau.
Der Notfall-Speicherung von havarienartig vorkommenden Abwasserüberläufen kommt aus der Sicht des Umweltschutzes eine hohe Bedeutung zu, gewährleistet sie ja den Schutz der Wasserqualität der rezipierenden Wasserkörper, indem sie die Schmutzstoffbelastung auf ein tolerierbares Niveau herabsetzt.

## INTRODUCTION

Waste waters of industrial plants and communal sewage waters are collected by sewers and conveyed to waste water treatment plants, wherefrom the treated effluents are discharged into recipient water bodies in a concentrated manner. In this study we are dealing with these concentrated sources of pollution and with techniques aimed at assuring-maintaining effluent loads which are tolerable from the view point of recipient water bodies.

Failures of industrial production technologies as well as those of the treatment processes of waste water treatment plants occur rather frequently, creating hazards to water quality and aquatic life and risks to the safe operation of downstream water users. Impairment of the safe operation of drinking water intake facilities is one of the most crucial problems created by such accidental spills.

Taking into account the damage done to water quality and aquatic life, as well as other risks, one can usually prove -also in economic terms-, that the construction and operation of emergency storage systems for industrial and communal waste water dischargers is a reasonable investment in many water management systems.

One of the most efficient means of controlling accidental pollution load is the provision of emergency storage right at the sources of such potential spill discharges. The most frequently used solutions include the provision of dilution water in one hand and the storage of contaminated waste water volumes on the other hand (4). In this latter case sufficient retention time is provided for the waste water to allow for the removal/decomposition of harmful contaminants by purification (settling,decay, degradation, etc) processes, that take place in these reservoirs. Nevertheless both remedial actions (dilution, decomposition) are frequently left to the recipient water body, without actually knowing whether they will have sufficient capacities for it or not.

## THE CONCEPT

A more sophisticated solution for emergency storage is when the stored waste water is recycled back to the treatment process until the quality of the final effluent reaches the tolerable level (allowable load into the recipient water body in concern).

In designing such storage systems first one should determine whether the construction of the system is economical or not. For this reason first the total cost (the damage) to be avoided (4) by the construction of the system should be assessed in monetary terms;

$$d=\sum_{i=1}^{n} d_i$$

where

$d_1$ - is the damage caused by the loss of production,

$d_2$ - is the damage done to the ecosystem and to the channel bed (upsilting etc),

$d_3$ - damage done to drinking water production, downstream of the spill

$d_4$ - damage done to industrial water users

$d_5$ - cost of solving the problem by the dilution method,

$d_6$ - cost of combatting water quality damage

It is to be noted that some of these damage components can be readily assessed, while other ones should be determined on the basis of careful field and model studies (3). To this latter category belong, for example, the damage caused to the aquatic ecosystem downstream of the spill, for which a water quality (ecosystem) model study should be carried out for all potential input loads caused by the spill. This is a question that would lead us far from our subject and we refer only to the relevant literature (3, 9. 10).

The situation becomes even more difficult when more than one potential sources of accidental spill have to be considered in a water system. In this case the construction of a water quality model of the stream network is unconditionally needed and the allowable (tolerable) pollution loads -as well as the damages associated with the violation of the standards- have to be assessed with the application of such models, as it was shown for the case of multiple sources in the modelling chapter of the Benedek-Litheraty (editors) book (3) and in the book by Jolánkai (10).

Having the sites of emergency storage selected on the basis of a comprehensive cost/damage-benefit analysis, as briefly indicated above, the system can be constructed. For this purpose I suggest the automatic system as shown in **Figure 1.**

In this figure the following notations are used:

| | | |
|---|---|---|
| I.P | - | industrial plant, |
| S.T.P | - | waste water treatment plant, |
| $E.ST_i$ - | | the i-th emergency storage unit, |
| P.S.D | - | point source discharge |
| H1 - H1- H2- H2 | - | hydraulic connection lines, |
| 1,2,...7, | - | numbering of control gates |
| A.W.S | - | automatic water sampler, |
| M.S. | - | monitoring station, |
| A.S.A | - | unit measuring the activity of the activated sludge, |
| P.L.C | - | Programmable logical control unit, |
| U.M.U | - | upstream monitoring unit, |
| D.M.U | - | downstream monitoring unit, |
| C.P.U | - | central computer unit |
| S.P.S | - | standby power supply, |
| P.H | - | pump house, |
| dotted line | - | water sample line to sensors, |
| double-dotted line | - | sample to temperature sensors |

line with dots in bracket- control command transmission line

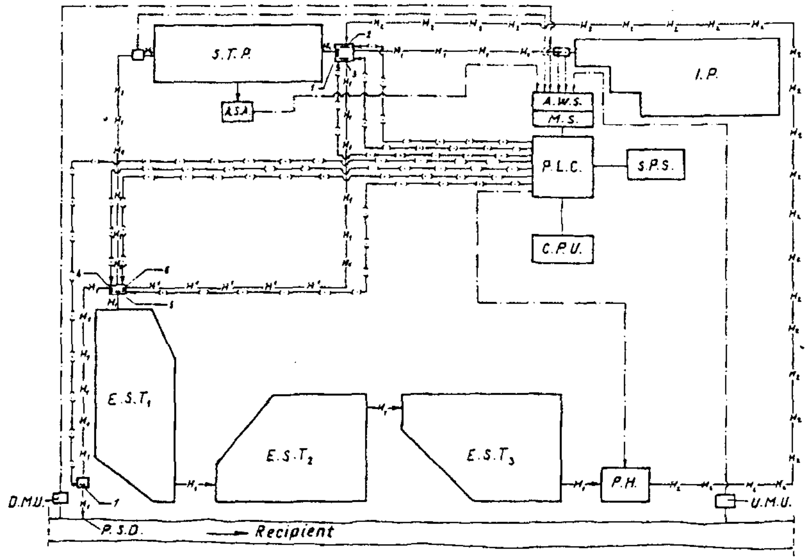


Figure 1. Schematic flow diagram of the emergency storage facility

The parameters to be monitored should be selected in function of the industrial production technology and in that of the communal sewage. Parameters that can be monitored automatically include (7): temperature, pH, dissolved oxygen, conductivity and turbidity. Other parameters of concern can be

- ammonium and nitrate ions,
- oil derivatives
- dissolved organic micropollutants, such as phenols, chlorinated hydrocarbons, organic solvents, etc (8)

Values of the parameters selected should be determined from the samples taken by the automatic sampler device (AWS) or provided by the automatic monitoring station (M.S). Concentration values are then converted to mass flux values and enter the programmable logical control unit (2). Data are stored in the central computer unit together with all other characteristic data of the system. Volumes of water to be stored should be calculated in function of the current data of the waste water and of the recipient stream in an on-line manner (which means that the mathematical model of the recipient shall be also handled by the central computer unit in the form of an appropriate algorithm), together with the rates of recycling.

In the case of an activated sludge system the decomposition activity of the system should be also continuously monitored (5), since industrial accidental spills of toxic substances might basically deteriorate the biological processes and thus the removal capacity of such systems.

An essential function of the system is the monitoring of the final effluent, before it is discharged into the recipient, so as to be able to determine the volume (rate) of the effluent which should be stored in the emergency storage spaces. Eventually both the discharge and the state of the water quality of the recipient stream should be monitored as well (1, 10) and this is performed by the upstream monitoring station (U.M.U). It should be emphasized again that the allowable/tolerable effluent discharges (mass fluxes) will be determined in function of the water quality criteria set for the recipient, using the water quality mathematical model of the stream, the algorithm of which latter is an inherent part of the operation control programme of the central computer unit.

For the storage system there are two basic solutions: either to construct emergency storage ponds, or -when local environmental and/or municipal development criteria require so- the construction of underground storage tanks. Eventually both type of structures should be constructed with appropriate sealing so as not to allow the leaching of the contaminants from the storage spaces.

In addition to quality requirements one should pay due attention to the temperature of the effluent so as to avoid thermal pollution. In this context open storage reservoirs would be more favourable, as they allow for rapid cooling of the waste waters. In the case of underground storage tanks the natural cooling process is rather slow, thus one might need to construct a separate cooling system for this purpose.

## CONCLUSIONS AND RECOMMENDATIONS

In trying to assess the necessity of the development of automatically controlled emergency storage systems, briefly and schematically outlined above, one may start with consideration on the number of accidental events of the past. In Hungary the number of accidental water pollution events had been steadily increasing in the past, with the peak number of incident of 231 in 1987. Since that time the number of incidents have been decreasing. In 1992 the number of events was 115, of which 5 were of foreign origin. This decreasing tendency is most likely due to the effects of economic recession.

Nevertheless, upon the expectable renewal of economic growth one may expect the increasing of the number of such events also in the, perhaps not so far, future. In order to protect the quality of waters and the aquatic environment it is highly advisable to make preparations for the prevention of accidental waste spills.
The most straightforward, and perhaps also the most economical, solution of such preventive counter measures is the provision for on-line automatic effluent control at all potential sources of accidental spill.

Although the time of introducing such automatic on-line control systems at each potential accidental polluters of the entire Danube basin is probably very far, it is certainly the time now to start the elaboration of such schemes at a smaller scale, at smaller sub-catchments of the countries of the Danube Basin.

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XVII. KONFERENZ DER DONAULÄNDER
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# ÜBERBLICK ÜBER DIE FORSCHUNGSTÄTIGKEIT IM RAHMEN DER INTERNATIONALEN ARBEITSGEMEINSCHAFT DONAUFORSCHUNG (IAD)

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Kurzfassung:

Aufgabe der Internationalen Arbeitsgemeinschaft Donauforschung (IAD) ist die Koordinierung und Förderung der Arbeiten auf dem Gebiet der Gewässerkunde, der Wasserwirtschaft und des Gewässerschutzes in den einzelnen Donauländern. Dies erfolgt durch 12 Fachgruppen der IAD. Die wichtigsten und aktuellsten Themen sind in den Dekadenprogrammen der IAD zusammengefaßt. Für die Dekade 1987-1996 sind über 70 Einzelthemen definiert. Anhand einiger ausgewählter Beispiele werden die bisher erzielten Ergebnisse vorgestellt.

# REVIEW OF RESEARCH ACTIVITIES WITHIN THE SCOPE OF THE INTERNATIONAL WORKING GROUP DANUBE RESEARCH (IAD)

Summary:

The task of the International *Working Group Danube Research* (IAD) is the coordination and support of work done in the area of hydrology, water management and protection of waters in each of the Danube countries. This is achieved by 12 working groups of the IAD. The most important themes are summarized in Decade Program of the IAD. For the decade 1987 - 1996 more than 70 single themes are defined. On the basis of some selected examples results achieved so far are presented.

Die Internationale Arbeitsgemeinschaft Donauforschung (IAD) wurde im Jahre 1956 gegründet, mit dem Ziel, die Arbeiten auf dem Gebiet der Gewässerkunde, der Wasserwirtschaft und des Gewässerschutzes in den einzelnen Donauländern (Anliegerstaaten) zu fördern und zu koordinieren. Sie ist in die Societas Internationalis Limnogiae (SIL) eingebunden und unterliegt gemäß Statut deren Satzung. Diese Einbindung gibt der IAD auch ihre rechtliche Grundlage.

Der IAD gehören z.Z. 11 Donauländer an: Deutschland, Österreich, Slowakei, Ungarn, Kroatien, Rest-Jugoslawien, Rumänien, Bulgarien, Moldavien und Ukraine.

Die Planung, Förderung und Koordinierung der wissenschaftlichen Arbeiten erfolgt durch 12 Fachgruppen der IAD, die teils nach wissenschaftlichen Disziplinen (Chemie/Physik, Radiologie, Toxikologie, Mikrobiologie/Hygiene, Phytoplankton/Phytobenthos, Makrophyten, Zooplankton, Zoobenthos, Fische/Fischerei), teils nach spezifischen Problemen (Stoffhaushalt, Saprobiologie, Delta/Vordelta) gebildet wurden.

Die wichtigsten und aktuellsten Themen in den einzelnen Fachbereichen sind in den Dekadenprogrammen der IAD zusammengefaßt. Diese Programme dienen als Leitlinie für die Forschungstätigkeit im Rahmen der IAD. Für die Dekade 1987 - 1996 wurden folgende allgemeine Themen definiert:

- Vergleichende limnologische Untersuchungen der gestauten und ungestauten Donaustrecken

- Einfluß der Kraftwerke und der Staustufen auf das Ökosystem Donau

- Wechselwirkungen zwischen Nebenflüssen und Hauptstrom

- Wechselbeziehungen zwischen Oberflächen- und Grundwasser

- Weiterentwicklung und Vereinheitlichung von Untersuchungsverfahren und Methoden

- Durchführung bilateraler und multilateraler Untersuchungen und Forschungsprojekte.

Über 70 weitere, den einzelnen Fachgruppen zugeordnete Spezialthemen, runden das Forschungsspektrum in der Dekade 1987 - 1996 ab.

Aus der Fülle der Themen werden in Folgenden exemplarisch für die einzelnen Fachdisziplinen einige Beispiele genannt (die vollständige Aufzählung der Themen erfolgt bei WEBER 1993):

- Chemie/Physik: Untersuchung potentiell toxischer Stoffe (Schwermetalle, Pestizide, Erdölprodukte) im Wasser und Sediment der Donau; Erfassung der Dynamik der Schwermetalle und ihrer Akkumulation in der Nahrungskette (Wasserorganismen), in den Schwebstoffen und Sedimenten.

- Radiologie: Beobachtung der Transmission der einzelnen Nuklide in den verschiedenen Medien; Ermittlung des Verhaltens von Radionukliden im Oberflächengewässern.

- Stoffhaushalt: Untersuchung der Auswirkung der Phosphatbelastung auf das Algenwachstum in den staugeregelten Abschnitten der Donau; Anwendung von Gütemodellrechnungen zur Auswertung stoffwechseldynamischer Befunde.

- Mikrobiologie/Hygiene: Bestimmung physiologischer Bakteriengruppen und deren Bedeutung im Stoffkreislauf; Erforschung der Physiologie und Ökologie pathogener und potentiell pathogener Keime.

- Phytoplankton/Phytobenthos: Ermittlung der Auswirkung anthropogener Einflüsse auf die qualitative und quantitative Zusammensetzung des Phytoplanktons und Phytobenthos; Vergleichende algologische Untersuchungen im Längsprofil der Donau.

- Makrophyten: Untersuchung des Beitrags der Makrophyten zur Ansiedlung von Wasserorganismen; Entwicklung von Methoden zur Bestimmung der Makrophytenbiomasse.

- Zooplankton: Untersuchung der zeitlichen und räumlichen Entwicklung des Zooplanktons in verschiedenen aquatischen Lebensräumen; Erforschung der Auswirkung von Ausbau und Aufstau der Donau auf das Zooplankton.

- Zoobenthos: Untersuchung der Auswirkung von Wasserbau und Schiffahrt auf das Makrozoobenthos; Ermittlung der in ihrem Bestand gefährdeten Makrozoen in der Donau (Erstellung einer "Roten Liste" für die Donau).

- Fische/Fischerei: Untersuchung anthropogener Einflüsse auf die Populationsdynamik und Artenzusammensetzung der Ichthyofauna; Erstellung eines Fischarten- und Fischwasserkatasters.

- Saprobiologie: Ermittlung der Throphie und Saprobie der einzelnen Donauabschnitte; Verbesserung der Methodik zur saprobiologischen Bewertung der Donau.

- Delta/Vordelta: Erforschung der Produktivität natürlicher Ökosysteme im Donaudelta; Ermittlung der zeitlichen Entwicklung der Gewässergüte der Deltaarme und der wichtigsten Deltaseen.

Stellvertretend für die Vielzahl der bisher in den einzelnen Donauländern durchgeführten Arbeiten sollen hier die Ergebnisse der Untersuchungen über die Auswirkungen des Aufstaus der Donau auf das Fließgewässerökosystem kurz beschrieben werden. Faßt man die Ergebnisse dieser Untersuchungen zusammen, so kommt man zu den folgenden Schlüssen:

1. Die durch die Herabsetzung der Fließgeschwindigkeit hervorgerufene intensive Sedimentation (Ablagerung feinkörnigen Sediments am Gewässergrund) und weitgehende Beruhigung der Gewässersohle (kein oder nur geringer Geschiebetrieb) führte zu einer Umstrukturierung der benthalen Fauna (Makrozoobenthos). Dabei wurden strömungsliebende (rheophile) Arten (typische Bewohner der Fließgewässer) durch Organismen des Stillwassers (limnophile Arten) verdrängt. In Bereichen mit erheblicher Sedimentation (Oberwasser der Staustufen) wurden die für das Fließgewässer charakteristische Hohlräume im Gewässerboden mit feinkörnigem Sediment zugesetzt. Die für die freifließende Donau typische lithoreophile Fauna verschwand somit und an ihre Stelle traten psammo- und pelophile Arten (sogenannte Schlammbewohner). Günstige Lebensbedingungen für die lithophile Arten bieten im Oberwasser der Staustufen lediglich die mit Bruchsteinen befestigten Ufer.

2. Durch die Verlängerung der Verweilzeit wurde die Entwicklung des Planktons begünstigt. Diese Entwicklung wurde durch das oft verbesserte Lichtklima infolge erhöhter Sedimentation unterstützt. Als Folge einer exsessiven Planktonentwicklung sind zu nennen: Erhöhung der Biomasseproduktion, Beeinträchtigung der Trinkwasserversorgung durch algenbürtige geruchs- und geschmacksintensive Stoffe, Sekundärverunreinigungen und Intensivierung der biogenen Sauerstoffversorgung.

3. Durch die Stauerrichtung wurde die Entwicklung der Makrophytenbestände gefördert. Als günstige Lebensräume für Makrophyten sind die Flachwasserzonen im Uferbereich der Stauhaltungen anzusehen, vorausgesetzt, daß diese Bereiche nur geringen Wasserstandsschwankungen ausgesetzt sind und durch Wellenschlag (Sog und Schwall) nicht allzu stark beeinträchtigt werden.

4. Die Ichthyofauna erfuhr infolge verminderter Fließgeschwindigkeit, veränderter Substratbeschaffenheit, anders strukturierter Nahrungsgrundlage, erhöhter Wassertemperatur und oft insgesamt schlechterer Sauerstoffversorgung einen beträchtlichen Strukturwandel. Kalte und sauerstoffreiche Bereiche der Donau bevorzugende Kieslaicher (z.B. Barben) wurden durch krautlaichende Fische (z.B. Karpfen, Rotauge, Rotfeder) verdrängt. Letztere bevorzugen stehende bis langsam fließende sommerwarme Gewässer mit gut entwickeltem Wasserpflanzenbestand.

5. Durch die Stauregelung der Donau wurden für die überwinternden Wasservögel günstige Lebensbedingungen geschaffen.

6. Die Stauregulierung der Donau bewirkte eine Verkürzung der Selbstreinigungsstrecke und damit eine Entlastung der stromabwärts gelegenen Abschnitte. Längere Verweilzeiten und die erhöhte Sedimentation sind Ursachen einer Verminderung der organischen Stofffrachten und Konzentrationen. Der Abbau organischer Stoffe wurde durch die erhöhte Wassertemperatur noch zusätzlich unterstützt. Durch Adsorption an das feinkörni-

ge Gewässersediment wurden dem Wasserkörper toxische Substanzen wie Pestizide, Ölprodukte und Schwermetalle entzogen. Dadurch wird die schädigende Wirkung dieser Substanzen im Wasserkörper zuerst unterbunden. Diese Substanzen stellen jedoch *weiterhin eine potentielle Gefahr* für die Donau dar, da sie jederzeit durch Remobilisierung freigesetzt werden können. In stärker belasteten Gewässerabschnitten wirkt sich die verminderte Sauerstoffversorgung der tieferen Wasserschichten und der Sedimente in einer Stauhaltung nachteilig auf die Gewässerbeschaffenheit aus. Eine zeitweise Rücklösung oder Remobilisierung organischer und anorganischer Substanzen aus dem Sediment kann zu einer starken Herabsetzung der Sauerstoffkonzentration im Wasser führen.

7. Bei der saprobiologischen Beurteilung der gestauen Donau ist äußerste Sorgfalt geboten, insbesondere dann, wenn ein Vergleich der Saprobitätsverhältnisse vor und nach dem Aufstau vorgenommen werden sollte. Das Verschwinden aus dem Besiedlungsbild rheophiler und oxybionter Arten (Indikatoren der oligo- und betamesoraproben Zone), infolge einer Stauerrichtung, kann eine Verschlechterung der Saprobitätsverhältnisse vortäuschen, ohne daß eine Zunahme der organischen Belastung stattgefunden hat. Dieser Zustand darf keinesfalls im Sinne einer abwasserbedingten Verschlechterung der Wasserqualität gedeutet werden, er ist lediglich der Veränderung im biologischen Status der Donau zuzuschreiben.

Zusammenfassend läßt sich festhalten, daß die mit der Stauregelung der Donau einhergehenden Veränderungen der hydrologischen und morphologischen Verhältnisse zwangsläufig zu Veränderungen des Fließgewässerökosystems führen. Da jedoch diese Veränderungen vielfältiger Natur sind, darf eine pauschale Bewertung aufstaubedingter Beeinträchtigungen nicht erfolgen. Vielmehr muß von Fall zu Fall eine Analyse der Veränderungen vorgenommen werden und daraus eine Bewertung der Beeinträchtigungen abgeleitet werden.

Aus der Reihe der vielfältigen Forschungstätigkeiten soll noch die im Jahre 1988 durchgeführte wissenschaftliche Expedition auf der Donau von Wien bis Vilkovo hervorgehoben werden. Über 100 Wissenschaftler aus den einzelnen Donauanliegerstaaten untersuchten die physikalischen, chemischen und radiologischen Eigenschaften des Wassers und der Sedimente sowie die im Wasser und am Gewässergrund lebende Tier- und Pflanzenwelt. Die Analyse der dabei erzielten Ergebnisse erlaubt eine Charakterisierung des biologisch-ökologischen Zustands der Donau und eine Bewertung der durch anthropogene Einflüsse verursachten Veränderungen des Ökosystems. Des weiteren konnten viele Daten und Informationen über hygienisch-bakteriologische Aspekte, über die Gewässergüte, aber auch über das Selbstreinigungsvermögen der Donau in den einzelnen Abschnitten gewonnen und ausgewertet werden.

Wegen der Bedeutung dieser Untersuchungen für künftige wasserwirtschaftliche Planungen aber auch im Hinblick auf Fragen zur Ökologie und Naturschutz an der Donau sollen diese Untersuchungen turnusmäßig wiederholt werden.

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