WORKING PAPER

A LARGE INTERNATIONAL RIVER: THE DANUBE SUMMARY OF HYDROLOGICAL CONDITIONS AND WATER MANAGEMENT PROBLEMS IN THE DANUBE BASIN

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International Institute
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PREFACE

The demand of policy makers and managers to find environmentally sound and sustainable economic development is obvious. At the same time, various branches of sciences dealing with environmental issues have become more and more specialized. The solution to problems – often of a global character – requires the interdisciplinary analysis of versatile systems consisting of natural, economic and social elements of the environment.

Within the long series of water related topics of IIASA's Environment Programme, a new project *Decision Support Systems for Managing Large International Rivers (LIR)* was recently launched. The formulation of environmentally sound management policy for land-use and water resources development requires the reliable prediction of the impacts of different human interventions in order to eliminate conflicts between different interest groups, and to preserve the quality of life in both the biosphere and society. Several models for the assessment of various environmental impacts already exist, but the large scale of river basins and the amount of data – the availability of which is even limited in some cases – require the development of aggregated systems of models that can provide decision makers with easily understandable information at various hierarchical levels. Considering this requirement, the objective of the project is to construct a computer-based interactive data and information system to facilitate the effective participation of policy making authorities in determining current conditions and expected changes in hydrological systems.

The outline of LIR emphasizes the importance of the preparation of case studies. Their role is not only to check the applicability on the system for solving actually occurring problems, but the analysis of the basins as cases will assist in selecting the crucial questions that should be answered by the Decision Support System. The Danube basin was chosen as the first case study to be investigated in the framework of LIR. The reason for this choice is partly that IIASA is located in the basin, and, thus all information easily accessible. The international character of the river (there are 8 riparian countries and 3 others sharing a small part of the catchment), the rapidly developing problems of the utilization of water (canalization, increasing transboundary pollution, seasonal water shortage), and the efforts of the riparian countries to improve the conditions of water resources development within the basin (which is clearly indicated by the fact that a joint declaration was signed) are also reasons supporting the selection of the Danube as the first case study.

Naturally, the hydrological conditions of the river system and the water management problems occurring within the catchment are well known for the experts in water sciences working in the riparian countries. For experts participating in the project and coming from other countries, or, representing other scientific disciplines, it is necessary, however, to summarize the most important information describing the water regime of the river system and the obstacles hindering the development of water resources in the basin. This working paper and the detailed list of references provide more information on water management in the Danube basin.

R.E. Munn
Environment Programme

A LARGE INTERNATIONAL RIVER: THE DANUBE SUMMARY OF HYDROLOGICAL CONDITIONS AND WATER MANAGEMENT PROBLEMS IN THE DANUBE BASIN

B. Hock* and G. Kovács

INTRODUCTION

The Danube basin was selected as the first case study to be analysed within the framework of the IIASA project aiming at the development of a decision support system (hereafter DSS) for managing large international rivers (hereafter LIR). It was felt necessary to prepare a paper which would provide the experts – working in the project but not being familiar with the water regime of the Danube – with the basic information on the hydrological condition of the river system as well as on the historical development and the present problems of water management within the basin.

The compilation of the paper was assisted by the excellent literature dealing with the versatile problems of water resources development in the basin. The list of references in this paper provides guidance for readers who are interested in obtaining more detailed information on some

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One publication that deserves particular mention is the Danube Monography (RZdD, 1986), the result of a joint project of the eight riparian countries where experts collected lengthy data series characterizing the quantitative regime of the Danube and its main tributaries. The data were harmonized by the Federal Hydrometeorological Institute in Belgrade and the Research Institute for Water Management in Bratislava, who accepted responsibility for coordination of national reports.

Finally, the entire material, which contains not only the hydrological data, but also the historical summary of water management activity in each country, was edited and published by the Bayerische Landesamt für Wasserwirtschaft in München. Detailed information on quantitative conditions and water resources development are available in this publication.

Unfortunately, this project was limited to traditional hydrology and the water quality problems were not dealt with in this framework. Therefore, it was necessary to give more detailed information on the conditions of water quality in this working paper, because in this field no such comprehensive publication can be offered, where the qualitative data are summarized in a similar way.

Analyzing the problems hindering the utilization of water resources in the basin, it was found that the major obstacle at present and in the near future is water pollution due to the release of waste waters not sufficiently treated from community systems and industries as well as the non-point source pollution originating from intensified agriculture and urban areas. Some qualitative parameters indicate that even the quality of bank filtered water – providing the largest amount of water for community water supply – is endangered by the increasing deterioration of river waters. This was also a motivation requiring more detailed information on quality conditions.

Also there was a third aspect giving reasons for studying the water quality problems of the Danube. The implementation of a regional UNDP/WHO project will commence in 1987 aiming at the determination and improvement of water quality conditions in the Danube basin within the framework of which the riparian countries will make joint efforts to solve this serious problem of water management. There are several common elements in the two projects (i.e. UNDP/WHO project on the Danube water quality and the IIASA LIR Danube case study). Therefore, it was decided that their implementation should be closely coordinated. Hence, while preparing this paper it was considered that this should also serve as a background document for the UNDP/WHO project.

There are two annexes to this report. The first is the Declaration by the riparian countries signed in December 1985; and the second is a summary evaluation of the environmental impact assessment of the Gabcikovo–Nagymaros barrage system.

In the Declaration, representatives of the eight riparian countries expressed their willingness to solve the problems of water management in a coordinated manner, as it was recognized that the obstacles hindering the reasonable utilization of water resources can be removed only by joint efforts in an international river basin. Decision was also reached concerning the institutional framework required to implement the programmes defined in the Declaration in the fields of water quality control, flood protection and general water management. The DSS of LIR and the results of the Danube case study are offered to the relevant authorities of the eight countries as usable tools to achieve the objectives put forward in the Declaration.

The modification of environmental conditions in the river and in the surrounding region due to the construction of barrages was raised in some riparian countries as a serious environmental concern. The same happened in Hungary in connection with the Gabcikovo–Nagymaros barrage system now under construction. A detailed environmental impact assessment was, therefore, prepared to survey the side-effects of the system, to determine the measures needed for the prevention of undesirable impacts and for the utilization of positive changes. A brief evaluation of this study is given in Annex II.

1. INTERNATIONAL IMPORTANCE OF THE DANUBE BASIN

The Danube is a characteristically international river, passing through eight countries (FRG, Austria, Czechoslovakia, Hungary, Yugoslavia, Romania, Bulgaria and the USSR), and draining very small areas of a further four non-riparian countries: Italy, Switzerland, Poland, Albania. Due to the relatively low contribution to the total area of the basin, the economic conditions of the latter countries and the impacts of their economy on the water regime will not be discussed in this paper. In addition, the Danube connects also the two different socio–economic groups of West and East European countries.

The size of the catchment belonging to the territory of various countries and the number of population living there (Figure 1, Table 1) demonstrate the importance of the river in the economic life of these countries. The ratio of catchment area to the total country area and catchment population to total country population are fairly significant (see Table 1) with the exception of the Soviet Union (WHO, 1976). The multi-purpose utilization of the Danube River is of vital importance for approximately 71 million inhabitants living in the basin (Lászlóffy, 1967).

With eight riparian countries sharing the waters of the Danube, the environmentally sound utilization of water resources and the development of suitable land use policy within the catchment are strongly required to maintain the proper quantity and quality along the whole river. The achievements of these goals pose many interesting international considerations and unique opportunities for cooperation.

Having recognized this necessity, in 1985 the eight Danube riparian countries issued in Bucharest a common declaration about the cooperation to be realized on the field of water resources management. In this declaration, the Governments expressed their readiness to cooperate in order to conserve and rationally utilize the water resources of the Danube River. The cooperation to be carried out in the framework of three working groups, will include all the eight Danube countries. The protocol entitled "Joint measures to be taken in the course of cooperation of the Danube countries aiming at the solution of the water management problems of the Danube River with special regard to its protection from pollutions", drawn

Figure 1. The Danube Basin (Kovács et al., 1983)

Table 1

Characteristic data of the Danube Basin*
(WHO, 1976; RZdD, 1986)

1	2	3	4	5	6	7	8
Country	Country's territory thousand km^2	Area of country in Danube catchment		Country's population million people	People of country in Danube catchment		% of Danube bank length in country
		thousand	% of country in Danube catchment		mill. people	% of country population	
FRG	248.7	59.6	24.0	58	10	17	23
Austria	83.9	80.7	96.3	7	7	100	12
Czechoslovakia	127.9	73.0	57.1	14	7	50	3
Hungary	93.0	93.0	100.0	10	10	100	12
Yugoslavia	255.8	183.2	71.6	19	13	68	17
Rumania	237.5	232.2	97.8	19	19	100	24
Bulgaria	110.9	48.2	43.4	8	4	50	7
USSR	22402.2	44.3	0.2	226	1	0.4	2
Other countries (I,CH,PL,AL)		3.0					

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*The data are estimated, since national statistics do not contain such breakdown at the time the Declaration was signed, already contained a concrete plan of actions for achieving the above-mentioned goals.

Paragraph 7 of the Declaration states that ". . . in order to successfully carry out the foreseen measures, the governments of the Danube countries will take advantage of the possible cooperation with the United Nations Organisation, with its specialized agencies as well as with other interested international organisations" (see Annex I).

In this connection, the Project Proposal of the UNDP/WHO European Regional Bureau prepared in 1986 deserves special attention, identifying the following goals for water quality protection of the Danube River:

- to safeguard human health by protecting drinking and irrigation water sources against pollution;
- to develop a common regional strategy towards the effective control of pollution of a large international river intersecting regions belonging to different socio–economic systems;
- to strengthen existing national water quality management practices;
- to promote the transfer and exchange of technology in water quality control activities.

So far, 5 Danube countries have announced their readiness to participate in the program (WHO, 1986).

Similar close cooperation can be established between IIASA and the Danubian countries in the implementation of the project LIR and, especially of the case study dealing with the Danube basin. Most of the countries have already expressed their interest and also their willingness to participate in the development of the decision support system. Further steps are needed to create formal connection between the LIR project and the panel representing the signatory countries of the Declaration.

Finally, considering the close interrelationship between and the supplementary character of the two projects (i.e. IIASA/LIR and UNDP/WHO), it is advisable to join the efforts of the two organisations in the implementation.

2. WATER RESOURCES OF THE DANUBE BASIN

2.1 Geographical Conditions

The river Danube is the 21st longest river in the world and the second longest in Europe, being almost 3000 km long from its source at a height of 1078 m in the Black Forests (FRG) to its delta on the Black Sea (USSR). Its basin of 817 000 km^2 represents 8% of the area of Europe. The creeks Breg and Brigach, with their springs in the Black Forest, get a new name (Danube), downstream of their confluence at Donaueschingen. Between this point and the delta the elevation difference is 678 m and the length of the river is 2857 km (Benedek–László, 1980). The bottom slope conditions of the river Danube are shown in Figure 2 (Lászlóffy, 1967).

In the stream system of a huge river like the Danube, there are also numerous important tributaries. About 120 rivers flow into the Danube itself, from which the greatest ones also have important tributaries (of 2nd order). A survey of the most important tributaries of 1st order is given in Table 2.

According to its geological structure and geographic layout the Danube basin can be divided into three regions, namely the upper, middle, and lower Danube basin.

a) The *upper Danube basin* covers the territory from the source streams in the Black Forest Mountain down to the Devin Gate eastward from Vienna. It includes in the north the territories of the Swabian and Falconian mountains, parts of the Bavarian Forest and Bohemian Forest down to the Austrian Mühl- and Waldviertel, and the Bohemian–Moravian Uplands.

Southward from the Danube extends the Swabian–Bavarian–Austrian foothill belt, comprising major parts of the Alps up to the watershed divide in the crystalline Central Alps.

b) The *middle Danube basin* creates a magnificent and unique geographic unit. It spreads from the Devin Gate, dividing the last promontories of the Alps (Leitha Mountains) from the Little Carpathians downstream of the confluence of the March/Morava and Danube, to the mighty fault section between the Southern Carpathians and the Balkan Mountains near the Iron Gate Gorge. The middle Danube section is the largest one. It is confined by

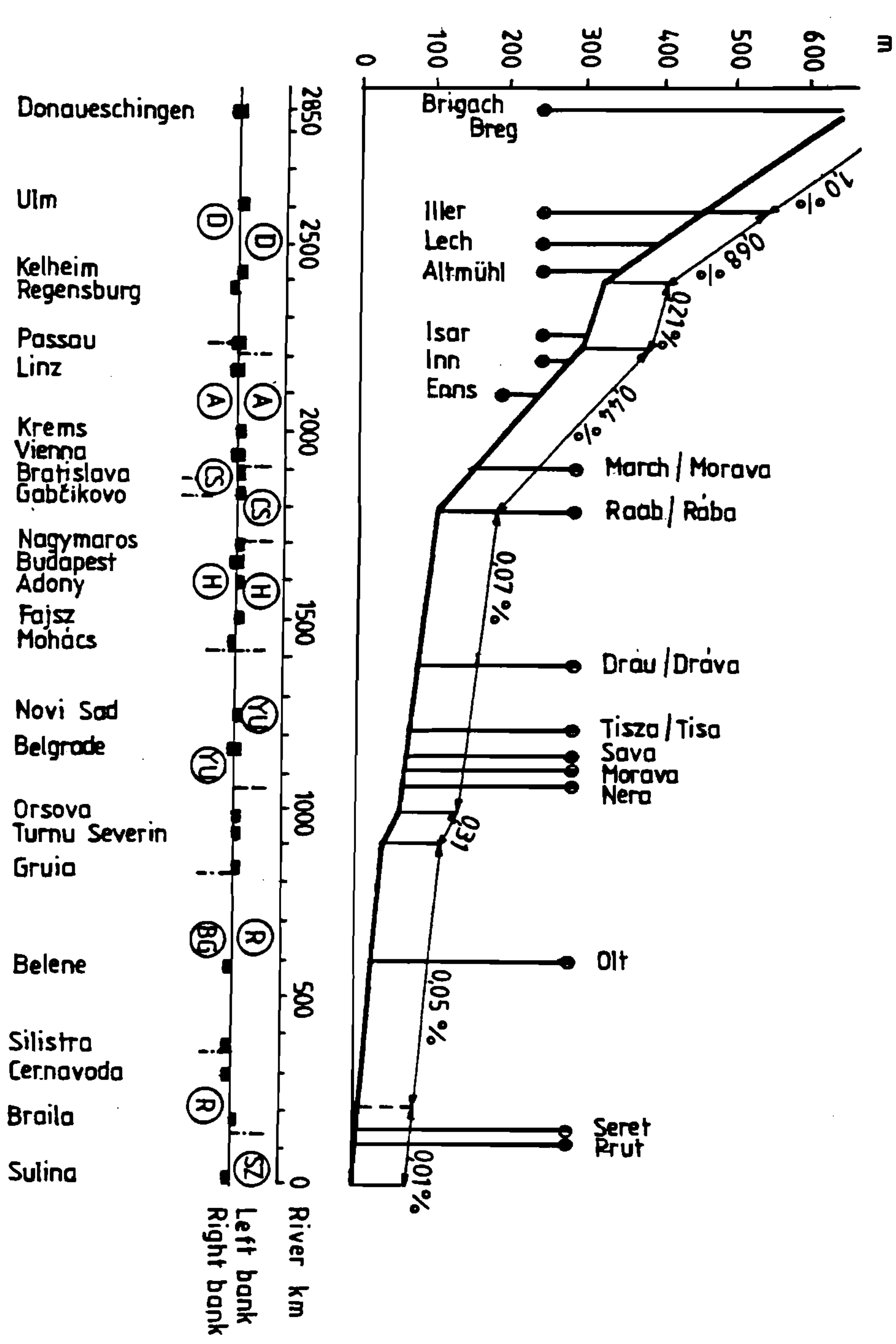

Figure 2. Bottom slope conditions of the Danube (Liepolt, 1967)

Table 2

The major tributaries of the Danube (RZdD, 1986)

	Mouth at Danube km	Side	Length km	Catchment area A, km^2
Iller	2 588	right	172	2 152
Lech	2 497	right	254	4 125
Altmühl	2 411	left	224	3 256
Naab	2 385	left	191	5 508
Regen	2 379	left	191	2 874
Isar	2 282	right	283	8 964
Inn	2 225	right	515	26 130
Traun	2 125	right	146	4 277
Enns	2 112	right	349	6 080
Ybbs	2 057	right	131	1 293
Kamp	1 981	left	147	2 134
March/Morava	1 880	left	329	26 658
Mosonyi Duna (Lajta,Rába,etc.)	1 794	right		18 061
Váh	1 766	left	378	10 641
Hron	1 716	left	284	5 465
Ipel'	1 708	left	233	5 151
Sió	1 497	right	190	14 728
Drau/Dráva	1 384	right	707	40 150
Tisza/Tisa	1 215	left	966	157 220
Sava	1 171	right	940	95 719
Temes	1 154	left	371	16 224
Velika Morava	1 103	right	245	37 444
Timok	846	right	184	4 630
Jiu	692	left	331	10 070
Iskar	637	right	368	8 646
Olt	604	left	670	24 010
Jantra	537	right	286	7 862
Vedea	526	left	215	5 450
Arges	432	left	327	12 590
Ialomita	244	left	400	10 430
Siret	155	left	726	47 610
Prut	134	left	967	27 540

the Carpathians in the north, by the Karnische Alps and Karawanken, Julische Alps in the east and southeast, and by the Dinaric Mountains in the west and south. This closed circle of mountains embraces the South Slovakian and East Slovakian Lowland, the Hungarian Lowland and the Transylvanian Uplands.

c) The *lower Danube* basin is composed of the Romanian–Bulgarian Lowland, the Siret and Prut river basins, and the surrounding upland plateaus and mountains. It is confined by the Carpathians in the west and the north, by the Bessarabian upland plateau in the east, and by the Dobrogea and the Balkan Mountains in the south. At the Prut mouth the Dobrogea promontories project into the Bessarabian upland plateau.

The Danube accepts waters from high mountains and their foothills, from highlands, plains, lowlands, and depressions. Therefore, its character varies from a high-mountainous stream to a lowland river.

The distribution of the Danube among its riparian countries is as follows:

In the *Federal Republic of Germany*, from the confluence of the source streams Brigach and Breg down to the Austrian border, the Danube flows a distance of 580 km. A reach about 180 km long is constrained by narrow valleys in which the Danube cuts its way through mountain ridges. On a stretch about 400 km long, the Danube passes through wide valleys.

The *Austrian* Danube is about 350 km long, including 21 km as frontier reach with the FRG and about 8 km with Czechoslovakia. About 150 km in total consists of sections passing through narrow valleys in which the Danube cuts its way through mountain ranges. Over about 200 km the Danube flows through the flatlands and four great basins. The descent of the Danube in Austria is about 150 m.

The *Czechoslovak* portion of the Danube on the left (northern) river bank reaches from the mouth of the Mach/Morava River about 172 km downstream to the mouth of the Ipel'/Ipoly. The section on the right (southern) river bank is only 22.5 km long, the remainder being an 8 km frontier with Austria, and a 142 km border with Hungary.

The *Hungarian* Danube reach is 417 km long, within an 142 km the border with Czechoslovakia. It starts on the mighty alluvial fan of the stream at the upper margin of the Pannonian Basin reaching as far as the centre of that Basin.

The *Yugoslavian* reach of the Danube, which is about 587 km long lies mainly (358 km) in the Pannonian Basin. Along this first reach, the slope of the river is only 0.05–0.04 per mill. Upstream from the fault gorge section at the Iron Gate, close to the mouth of the Nera River, it creates a common border with Romania and remains a frontier river down to the Timok mouth, about a 229 km long stretch.

In the downstream direction, the Danube is a frontier river between Romania and Bulgaria on a 472 km long reach.

The Danube flows through a 1075 km long reach of *Romanian* territory, starting in the area of the middle Danube above the mountainous reach of the Iron Gate down to the estuary, so that Romania has the largest portion of the Danube course. From this total length 229 km is the border with Yugoslavia between the Nera and Timok rivers. A further 472 km long section is the border with Bulgaria. Downstream from the Prut mouth the river follows the border with the Soviet Union on about 80 km down to the bend of the Kilia branch and further to the Black Sea estuary (RZdD, 1986).

The Danube Delta, covering an area of 5640 km^2, is the second largest one in Europe. Eighty per cent of it belongs to the *Soviet Union* and 20% to Romania (Liepolt, 1973).

2.2 Climate

Due to the elongated shape of the Danube Basin in a west-east direction and diverse relief features, the climatic conditions are also rather variable. In the western regions of the upper Danube, there is an Atlantic influence, while eastern territories are more continental in climate. In the upper and middle Danube basin, especially in the Drau/Dráva and Sava basins the climate is also influenced by the Mediterranean Sea.

The basic character of climate, determined by the spacious layout of the Danube, is differentiated and modified by the mighty mountainous systems into natural regions.

The dependence of climatic elements on altitude is a further contribution to the diversified climate, since the basin reaches from high mountain ranges covered with glaciers, over harsh mid-mountains and upland platforms, to hot (in summer) lowlands.

The climatic elements most important for water resources management are precipitation and snow cover. In the following, a detailed description of these two elements will be given. Note that the basic literature (RZdD, 1986) contains more detailed information about the other climatic elements (radiation, air temperature, evaporation, wind).

2.2.1 Precipitation

The amount of average annual precipitation fluctuates within the range from 3000 mm in high mountains to 400 mm in the delta region.

Already the *upper Danube basin* shows an astonishingly variable character. In the high alpine regions the values of 2000 mm are sometimes surpassed, the mountain marginal belts being extraordinarily rich in precipitation. The increment of mean annual precipitation values amounts to about 50 mm per 100 m rise in height in the northern alpine promontories and in the Alps. A further influence of mountains, occurs on the windward slopes where precipitation increases due to orographic lifting. Thus the isohytes almost parallel the height contours of the mountains. In the northern alpine foothills the amount of precipitation decreases in this way from about 1500 mm per year on the periphery of the mountains to 700 mm per year in the Danube valley. About 1500 mm per year of precipitation fall also in the Danube source area, in the Black Forest and in the higher regions of the Bavarian and Bohemian Forests.

Other territories show average precipitation values between 600 and 1000 mm, the valleys and basins (for instance the Naab valley, the Vienna Basin) being relatively dry with about 700 mm of precipitation. Relatively dry also are the intermontane valleys. The upper Inn river valley, extending in the west-east direction (Lower Engadin) is considered as a characteristic interalpine dry valley with only 600–700 mm of precipitation. Generally, the mean annual precipitation (annual series 1931–1960) in the German part of the Danube catchment area amounts to 950 mm per year.

In the *middle Danube basin* the highest values of mean annual precipitation occur on the outskirts of mountains surrounding the lowlands. The highest precipitation values 2000 mm to 3000 mm show the effect of the southward oriented mountain chains of the Julische Alps and the Dinaric system, which are exposed to the humid-warm air masses coming from the Mediterranean Sea. In the Carpathians the mean precipitation values are between 1000 and 2000 mm. In the rain-shadow of the mountains of the east Bohemian–Moravian Uplands, as well as in the Carpathian Foothills, the average precipitation amounts to 600–1000 mm. In the southern part of the central Danube Lowland the annual precipitation drops to 600–800 mm, in the Hungarian Lowland to 560 mm, and in the region of the middle Tisza/Tisa River to 500 mm. The dryness of the climate increases in the middle Danube Lowland in the northern and eastern directions.

In the plains of the *Lower Danube* the amount of precipitation reaches also only 500–600 mm, while the lowest precipitation values are recorded at the Danube estuary with less than 400 mm. In some years there is no precipitation at all over the entire summer period. Due to low precipitation and high summer temperatures, the region of the Danube estuary may be considered as a territory with steppe climate (RZdD, 1986).

2.2.2 Snow cover

The number of days with snow cover as well as the duration and thickness of the snow cover increase with the altitude. In alpine valleys only 58 days per year are characterized with precipitation falling in the form of snow (average over the period 1931–1970), while on the Zugspitze (3000 m) 191 days were recorded.

The shortest duration of snow cover (9–12 days) is at the Black Sea coast. The snow cover lasts for only 20–30 days in the plains of the middle Danube basin, 40–60 days in the upper Danube basin, the mean proportion of snow in the total annual precipitation being 10–15 per cent. In the alpine foothills and in high regions of mid-mountains the snow cover lasts more than 100 days. In those regions about 20–30 per cent of the annual precipitation fall in the form of snow. At an the altitude of 1500 m the snow cover stays from four months (Central Alps) to 6 months (peripheral mountains). At an altitude of 2000 m more than 6–8 months; and at 2500 m more than 8–10 months. The snow line is at an altitude of 2900 m on humid windward sides, and 3200 m in the Central Alps.

The snow cover stays for a longer period in the Carpathians than in the Alps. At altitudes above 2000 m the snow cover lasts 300 days in the Tatras, Bucegi, Fagaras and Retezat Mountains, and on the peak Lomnický Stit even 324 days.

In the highest mountain regions about 80–90% of the annual precipitation fall in the form of snow.

The snow cover thickness is generally slight in plains and lowlands. Snow, falling frequently already in October, lasts usually only 1–3 days. Continuous snow cover is usually formed in December and January, reaching the maximum of 15–20 cm in February, and melting away in March. In extraordinary cold winters, rich in snow, as for instance the period 1941–1942 in the upper Danube basin, or 1953–1954 in the lower Danube basin, 40–60 cm snow thickness were recorded in the lowlands. Such snow conditions are exceptions and are frequently followed by rapid warming, causing partial or complete snow melting.

In the medium altitudes of 1500–2000 m a snow cover starts to develop already in October–November. In February the average snow cover thickness may reach 150–250 cm. The snow melt period lasts from March to May.

At altitudes above 2000 m the snow cover maximum is attained in February, the snow cover thickness reaching in some places 500 cm or more.

The reliability and accuracy of data on snow cover thickness decrease with increasing altitude above sea level. Snow cover thickness varies locally due to snow-drifts. At high altitudes of the Carpathians and Alps 50–70 days with snow storms are recorded, while in the plains only 1–3 days with snow storms occur (RZdD, 1986).

2.3 Hydrological Regime of the Danube Basin

In the Danube Basin, systematic hydrological observations in the riparian countries are available for between 100 and 150 years.

At about the end of the last century the network for water level observations developed rapidly in the Danube Basin. By the beginning of our century, already several hundreds of gauging stations had been installed mostly on the main rivers. The development of regular observation of the smaller – third rank – tributaries has taken place, however, only after Second World War. In 1950 there were more than 1000 and today there are considerably more than 2000 gauging stations in the Danube Basin (RZdD, 1986).

2.3.1 Mean discharge conditions

The average runoff conditions of the Danube Basin are characterized on the basis of data series of 48 gauging stations, from which 24 are on the Danube itself and 24 on its most important tributaries. Of course, when selecting these gauging stations, neither all requirements regarding representativity and data quality nor length of record, i.e., the full observation period 1931/70, could be met.

Table 3 is a survey of the gauging stations selected and Figure 3 is a layout showing the sites of the gauges.

The values *MQ*, *MHQ* and *MLQ** computed from the data series of these 48 gauging stations, the ratio of the latter two values to *MQ* as well as the corresponding specific runoff values *Mq*, *MLq* are listed in Table 4.

Figure 4 is the hydrological longitudinal profile of the Danube River.

The Upper Danube is definitively characterized by the high runoff supplies from the Alps. Already the tributaries Iller, Lech and Isar bring considerable inflows but the greatest and definitive change is due to the Inn River. Although the catchment area of the Inn, 26,130 km^2, is only 52% of that of the Danube till the mouth of the Inn, the mean annual discharge of the Inn, 743 m^3/s, surpasses by 8% that of the Danube itself. In the domain of the mean flood discharges *MHQ*, this difference is even higher (60%) and only in the domain of mean low discharges *MLQ* is the value of the Danube

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*For explanation of the symbols *MQ*, *MHQ*, *MLQ*, *Mq*, *MHq*, *MLq* see footnote to Table 4.

Table 3

List of selected gauges in the Danube Basin (RZdD, 1986)

Nr.	Gauge	River	km	Catchment area A, km^2	Observed discharge data from the period
1	2	3	4	5	6
1	Ingolstadt	Danube	2 458.3	20 001	1931-1970
2	Regensburg	Danube	2 376.1	35 399	1931-1970
3	Hofkirchen	Danube	2 256.9	47 496	1931-1970
4	Passau-Ilzstadt	Danube	2 225.3	76 597	1931-1970
5	Linz	Danube	2 135.2	79 490	1931-1970
6	Stein-Krems	Danube	2 002.7	96 045	1931-1970
7	Wien-Nussdorf	Danube	1 934.1	101 700	1931-1970
8	Bratislava	Danube	1 868.8	131 338	1931-1970
10	Dunaalmás	Danube	1 751.8	171 720	1948-1970
11	Nagymaros	Danube	1 694.6	183 534	1931-1970
12	Mohács	Danube	1 446.8	209 064	1931-1970
13	Bezdan	Danube	1 425.5	210 250	1931-1970
14	Bogojevo	Danube	1 367.4	251 593	1931-1970
15	Pančevo	Danube	1 153.3	525 009	1931-1970
16	V. Gradište	Danube	1 059.8	570 375	1931-1970
17	Oršova	Danube	955.0	576 232	1931-1970
18	Novo Selo	Danube	833.6	584 900	1937-1970
19	Lom	Danube	743.3	588 860	1941-1970
20	Svistov	Danube	554.3	650 340	1931-1970
21	Zimnicea	Danube	554.0	658 400	1931-1970
22	Ruse	Danube	495.6	669 900	1931-1970
23	Silistra	Danube	375.5	689 700	1941-1970
24	Vadu Oii-Hirsova	Danube	252.3	709 100	1931-1970
25	Ceatal Izmail	Danube	72.0	807 000	1931-1970

Table 3
(Cont.)

1	2	3	4	5	6
26	Passau-Ingling	Inn	3.1	26 084	1931-1970
27	Salzburg	Salzach	64.4	4 427	1951-1970
28	Steyr	Enns	30.88	5 915	1951-1970
29	Moravsky Jan	March/Morava	67.6	24 129	1931-1970
30	Sala	Vah	33.9	10 620	1931-1970
31	Brehy	Hron	102.5	3 821	1931-1970
32	Ipelsky Sokolec	Ipel'/Ipoly	42.9	4 838	1931-1970
33	Neubrücke	Drau/Dráva	481.2	10 415	1951-1970
34	Landscha	Mur/Mura	114.4	8 340	1951-1970
36	Donji Miholjac	Drau/Dráva	74.6	37 142	1931-1970
37	Vilok	Tisza/Tisa	808.0	9 140	1954-1970
38	Tiszabecs	Tisza/Tisa	757.3	9 707	1938-1958
39	Szeged	Tisza/Tisa	172.7	138 408	1931-1970
40	Senta	Tisza/Tisa	122.0	141 715	1931-1970
41	Csenger	Somes/Szamos	46.6	15 283	1931-1970
42	Felsőzsolca	Slaná/Sajó	50.1	6 440	1931-1970
43	Mako	Mures/Maros	23.7	30 149	1931-1970
44	Sr.Mitrovica	Sava	136.0	87 996	1931-1970
45	Lj.Most	V. Morava	39.9	37 320	1931-1970
46	Orahovica	Iskar	27.5	8 370	1936-1970
47	Stoenesti	Olt	71.2	22 683	1950-1970
48	Storozinec	Siret	448.0	672	1953-1970
49	Lungoci	Siret	74.0	36 036	1950-1970
50	Cernovci	Prut	772.0	6 890	1931-1970

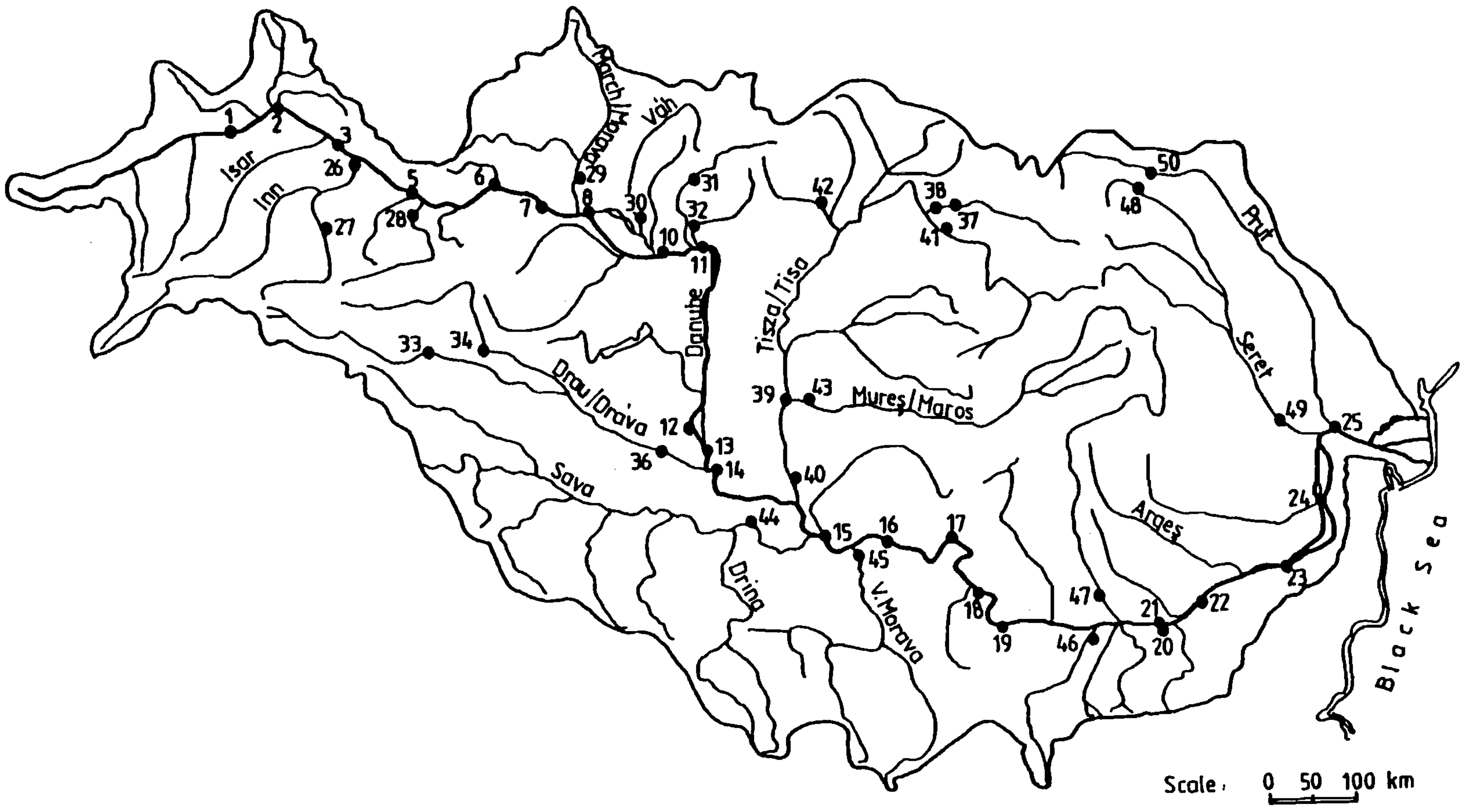

Figure 3. Hydrographic network of the Danube Basin with gauging stations, cfr. Table 3 (RZdD, 1986)

Table 4

Characteristic discharge values for the observation period[x] (RZdD, 1986)

Nr.	Gauge/River	MQ	MHQ	MLQ	$\frac{MHQ}{MQ}$	$\frac{MLQ}{MQ}$	Mq	MHq	MLq
			m^3/s					$l/s.km^2$	
1	2	3	4	5	6	7	8	9	10
1.	Ingolstadt/Danube	308	1084	123	3.52	0.40	15.4	54.2	6.16
2.	Regensburg/Danube	435	1468	193	3.37	0.44	12.3	41.5	5.45
3.	Hofkirchen/Danube	645	1864	307	2.89	0.48	13.6	39.2	6.46
4.	Passau-Ilzstadt/Danube	1430	4163	583	2.91	0.41	18.7	54.3	7.60
5.	Linz/Danube	1509	4279	593	2.84	0.39	19.0	53.8	7.46
6.	Stein-Krems/Danube	1864	5425	773	2.91	0.41	19.4	56.5	8.05
7.	Wien-Nussdorf/Danube	1943	5500	804	2.83	0.41	19.1	54.1	7.90
8.	Bratislava/Danube	2020	5750	844	2.85	0.42	15.4	43.8	6.43
10.	Dunaalmás/Danube	2314	5703	924	2.46	0.40	13.5	33.2	5.38

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[x] The symbols adopted are the following:
A - catchment area
MQ - multiannual mean discharge
Mq = MQ/A -multiannual specific mean discharge
MHQ - mean of annual peak discharges
MHq = MHQ/A - multiannual specific flood discharge
MLQ - mean of annual lowest discharges
MLq = MLQ/A multiannual specific low discharge

Table 4.
(cont./2)

1	2	3	4	5	6	7	8	9	10
11.	Nagymaros/Danube	2379	5556	956	2.34	0.40	13.0	30.3	5.21
12.	Mohács/Danube	2389	5095	1068	2.13	0.45	11.4	24.4	5.11
13.	Bezdan/Danube	2479	4924	976	1.99	0.39	11.8	23.4	4.64
14.	Bogojevo/Danube	3060	5795	1231	1.89	0.40	12.2	23.0	4.89
15.	Pancevo/Danube	5490	10072	2242	1.83	0.41	10.4	19.2	4.27
16.	V.Gradiste/Danube	5745	10636	2383	1.85	0.41	10.1	18.5	4.17
17.	Orsova/Danube	5699	10631	2334	1.87	0.41	9.9	18.4	4.05
18.	NovoSelo/Danube	5842	10677	2334	1.83	0.40	10.0	18.3	3.99
19.	Lom/Danube	5766	10534	2417	1.83	0.42	9.8	17.9	4.10
20.	Svistov/Danube	6175	11019	2602	1.78	0.42	9.5	16.9	4.00
21.	Zimnicea/Danube	6152	11090	2489	1.80	0.40	9.3	16.8	3.77
22.	Ruse/Danube	6264	11037	2646	1.76	0.42	9.3	16.5	3.94
23.	Silistra/Danube	6300	10952	2632	1.74	0.42	9.1	15.9	3.81
24.	Vadu Oii-Hirsova/ Danube	6216	10812	2621	1.74	0.42	8.7	15.2	3.70
25.	Ceatal Izmail/Danube	6550	10621	2934	1.62	0.45	8.1	13.2	3.63
26.	Passau-Ingling/Inn	743	2983	257	4.01	0.34	28.6	114	9.85
27.	Salzburg/Zalzach	181	1003	54.1	5.54	0.30	40.9	227	12.22
28.	Steyr/Enns	200	1297	46.8	6.49	0.23	33.8	219	7.91
29.	Moravsky Jan/March-Morava	110	629	29	5.72	0.27	4.6	25.1	1.21
30.	Sala/Váh	152	1048	38	6.89	0.25	14.3	98.7	3.58

Table 4.
(cont./3)

1	2	3	4	5	6	7	8	9	10
31.	Brehy/Hron	50	381	13	7.62	0.25	13.1	99.7	3.40
32.	Ipelsky Sokolec/Ipel /Ipoly	21	208	1.9	9.90	0.09	4.34	43.0	0.38
33.	Neubrücke/Drau/Dráva	266	910	98.3	3.42	0.37	25.5	87.4	9.44
34.	Landscha/Mur/Mura	143	610	46.3	4.27	0.32	17.1	73.1	5.55
36.	Donji Miholjac/ Drau/Dráva	554	1341	235	2.42	0.42	14.9	36.1	6.32
37.	Vilok/Tisza/Tisa	216	2163	49	10.0	0.23	23.6	237	5.35
38.	Tiszabecs/Tisza/Tisa	189	1815	39.6	9.60	0.21	19.5	187	4.08
39.	Szeged/Tisza/Tisa	813	2298	192	2.83	0.24	5.88	16.6	1.38
40.	Senta/Tisza/Tisa	766	2119	174	2.76	0.23	5.40	15.0	1.22
41.	Csenger/Szamos/Somes	127	879	22.8	6.92	0.18	8.31	57.5	1.49
42.	Felsőzsolca/Sajó/ Slaná	31.2	229	6.2	7.34	0.20	4.84	35.6	0.95
43.	Makó/Maros/Mures	175	710	46	4.06	0.26	5.80	23.5	1.53
44.	Sr.Mitrovica/Save	1613	4272	390	2.65	0.24	18.33	48.5	4.43
45.	Lj.Most/V.Morava	238	1302	52	5.47	0.22	6.38	34.9	1.38
46.	Orahovica/Iskar	59.5	423	10.7	7.11	0.18	7.11	50.5	1.28
47.	Stoenesti/Olt	162	988	41.7	6.09	0.26	7.14	43.5	1.83
48.	Storozinec/Siret	5.5	186	0.66	33.8	0.12	8.18	27.7	0.98
49.	Lungoci/Siret	172	1091	43.4	6.34	0.25	4.77	30.3	1.20
50.	Cernovci/Prut	61	1213	7.0	19.9	0.11	8.85	176	1.02

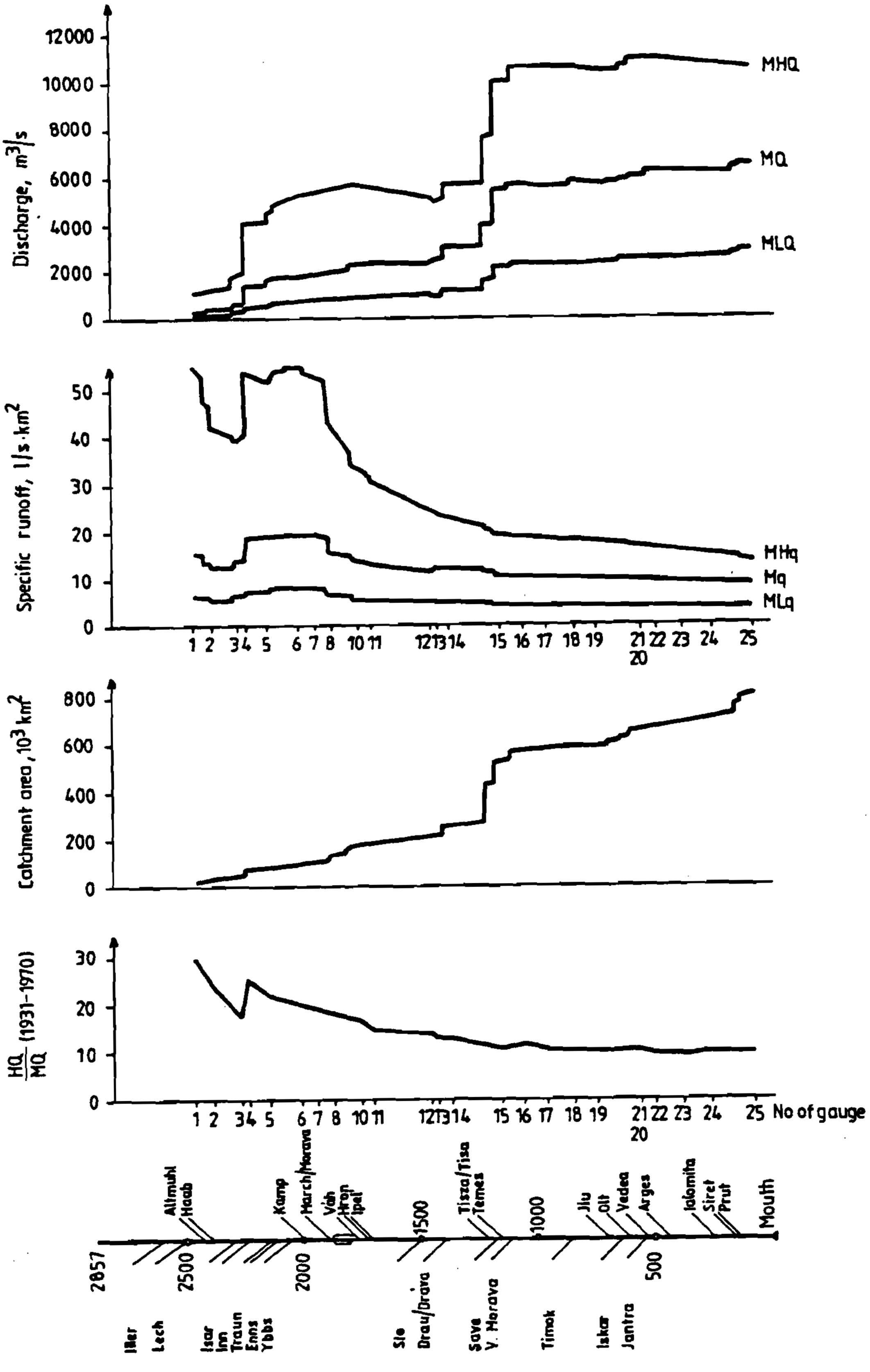

Figure 4. Hydrological longitudinal profile of the Danube (RZdD, 1986)

16% higher than that of the Inn. Considering the different specific runoff values, those of the Inn Basin are significantly higher in all three domains.

		MLq	*Mq*
		(l/s.km^2)	
Danube before Inn	6.46	13.6	39.2
Inn	9.85	28.5	114
Danube after Inn	7.46	19.0	53.8

The high specific runoff values of the Danube after the mouth of the River Inn are somewhat further increased by the Austrian alpine tributaries Traun, Enns and Ybbs (*Mq* and *MLq*), or, at least kept constant till the mouth of the March/Morava River (*MHq*). The mean annual discharge increases from 1430 m^3/s at the mouth of the Inn to about 1950 m^3/s at the gauging station of Wien-Nussdorf with a catchment area of 102,000 km^2.

Until the mouth of the Drau/Dráva River, the catchment area redoubles to about 210 000 km^2 while the mean discharge increases only by 530 m^3/s reaching the value of 2,480 m^3/s above the mouth of the Drau/Dráva River. Except the West Carpathians (Váh 14.3 l/s.km^2 and Hron 13.1 l/s.km^2), this great intermediate catchment area is very low in precipitation and runoff (March/Morava 4.5 l/s.km^2, Ipel'/Ipoly 4.3 l/s.km^2). In the Hungarian Lowland the specific runoff values fall even below 3 l/s.km^2. Correspondingly, the specific runoff values computed for the whole (accumulated) catchment also decrease (*MLq* from 7.9 to 4.6 l/s.km^2, *Mq* from 19.1 to 11.8 l/s.km^2). The largest decrease is that of the mean specific flood runoff *MHq* (from 53 to 23.4 l/s.km^2) due to the lowering of the peak discharges along this long river reach by the large retention capacity of the considerable areas inundated on the flood plain.

Within the following 270 km long Danube reach in Yugoslavia, the three greatest tributaries join the Danube. They increase the accumulated catchment area of the Danube by 150% (from 210,000 km^2 at Bezdan to 525,000 km^2 at Pancevo) and the mean discharge by 120% from 2480 m^3/s to 5490 m^3/s. These tributaries are: the Drau (Drava) river (A = 40,000 km^2, MQ = 554 m^3/s), the Tisza (Tisa) river (A = 157, 000 km^2, MQ = 766 m^3/s), and the Sava river (A =95, 700 km^2, MQ = 1610 m^3/s). The increase rates of the mean low discharge (from 976 to 2,240 m^3/s) and of the mean flood discharge (from 4,290 m^3/s to 10,070 m^3/s) are more or less the same. The relatively high runoff rates of the Drau/Drava (Mq =15 l/s.km^2) and the Sava River (Mq = 18 l/s.km^2) originate from the rainy catchments of the Southern Alps and the Dinaric Mountains. On the other hand, the Tisza/Tisa river, collecting the major part of the waters of the Hungarian Lowland, achieves at its mouth only a mean specific discharge of 5.4 l/s.km^2 in spite of its many tributaries from the Carpathians.

Contrary to the absolute values mentioned, the changes of specific runoff rates related to the accumulated catchment area of the Danube are not significant along this 270 m long reach:

MLq	from	4.6	to	4.3	l/s.km^2
Mq	from	11.8	to	10.4	l/s.km^2 and
MHq	from	23.4	to	19.2	l/s.km^2

Along the about 1,000 km long reach between the Iron Gate and the mouth of the Danube in the Black Sea, the catchment area increases by almost 300,000 km^2 up to 817,000 km^2 while the increase of the mean annual discharge is only about 1000 m^3/s (from 5,490 to 6,550 m^3/s). The mean specific runoff from this area is, in spite of inflows from the Carpathians (Olt 7.1 l/s.km^2) and the Balkan Mountains (Iskar 7.1 l/s.km^2), rather low: 3.7 l/s.km^2, i.e. even lower than the specific runoff from the relatively poorly contributing area between the mouths of the March (Morava) and the Sava rivers with its 4.9 l/s.km^2.

Although the decrease of the mean specific runoffs related to the whole (accumulated) Danube Basin seems to be insignificant (*Mq* from 10.4 to 8.1 l/s.km^2, *MLq* from 4.3 to 3.6 l/s.km^2 and *MHq* from 19.2 to 13.2 l/s.km^2), the real extent of the changes will be clear when considering the relative indices of decrease, which are: for *Mq* 22%, for *MLq* 15% and for *MHq* 31%. The disproportionately strong decrease of the mean specific flood runoff also shows the impact of the long river bed reaches and the relatively large inundation areas.

The increase of the discharge along a river can also be visualized by duration curves. They are shown, for selected gauging stations of the Danube, in Figure 5.

The seasonal changes of the multiannual means of the monthly discharges can be applied, in connection with the climatic factors of the runoff event, for the description and characterization of the hydrological regime. The variation of the monthly mean discharges along the Danube are shown in Figure 6.

The monthly discharges of various probabilities are shown for one selected station in Figure 7 (Ujvári, 1967; RZdD, 1986).

2.3.2 Flood conditions

Flood events can occur in the whole Danube Basin both due to storms or to snowmelt and rain. In the second case, the runoff is increased also when the soil is frozen or water-saturated. The floods caused only by snowmelt are hardly dangerous in the Upper Danube Basin. However, the importance of floods is quite high for the flat catchments along the Middle and Lower Danube.

In the alpine region, summer cold air intrusions are of particular importance since they trigger low-pressure activities in the Mediterranean region. In the warm sector of low-pressure areas moving from the Gulf of Genoa in northern or north-eastern directions over the Alps, the very hot and vapor-saturated air of the Mediterranean region is carried in the northern direction. When the migration velocities are slow, the precipitations can last several days and cause considerable floods, beginning in the southern alpine region (catchments of the Drau (Dráva) and of the Upper

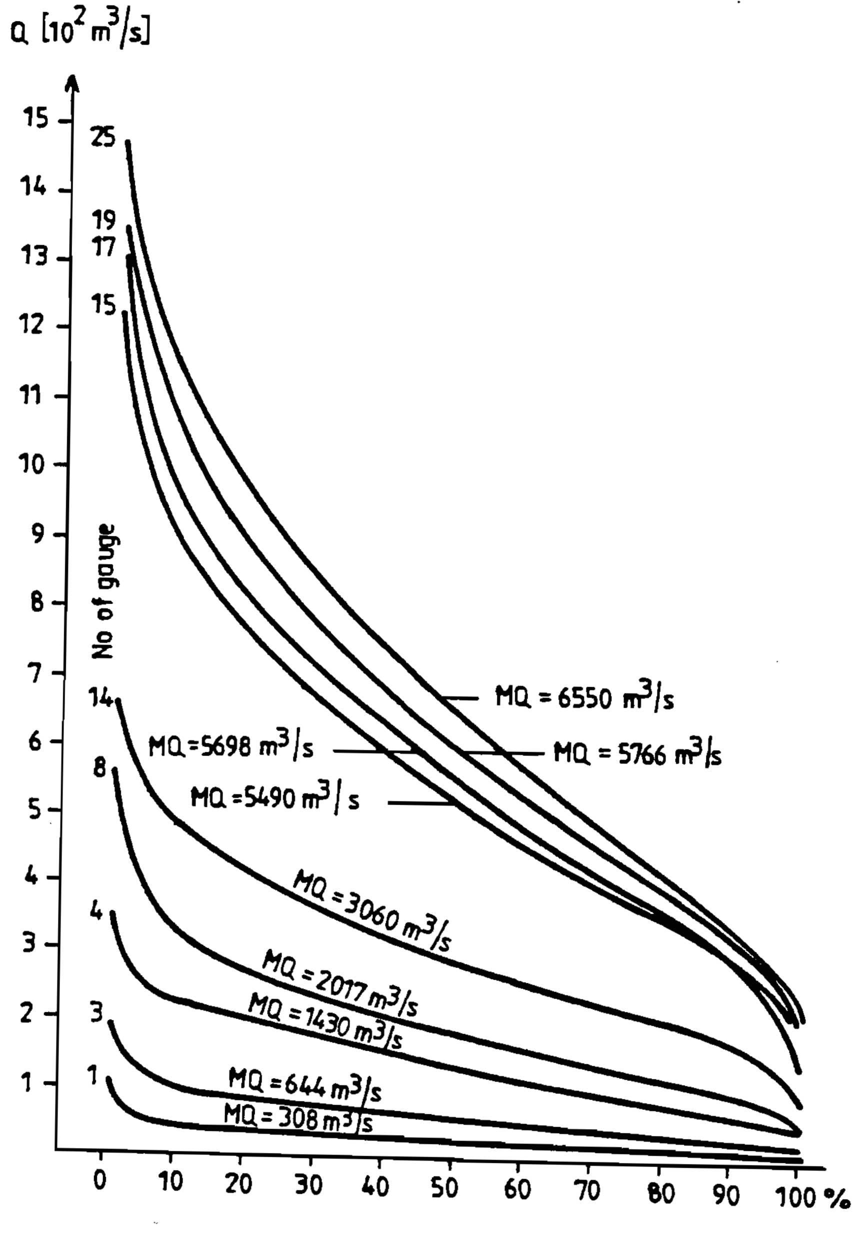

Figure 5. Discharge duration curves of selected gauges on the Danube (RZdD, 1986)

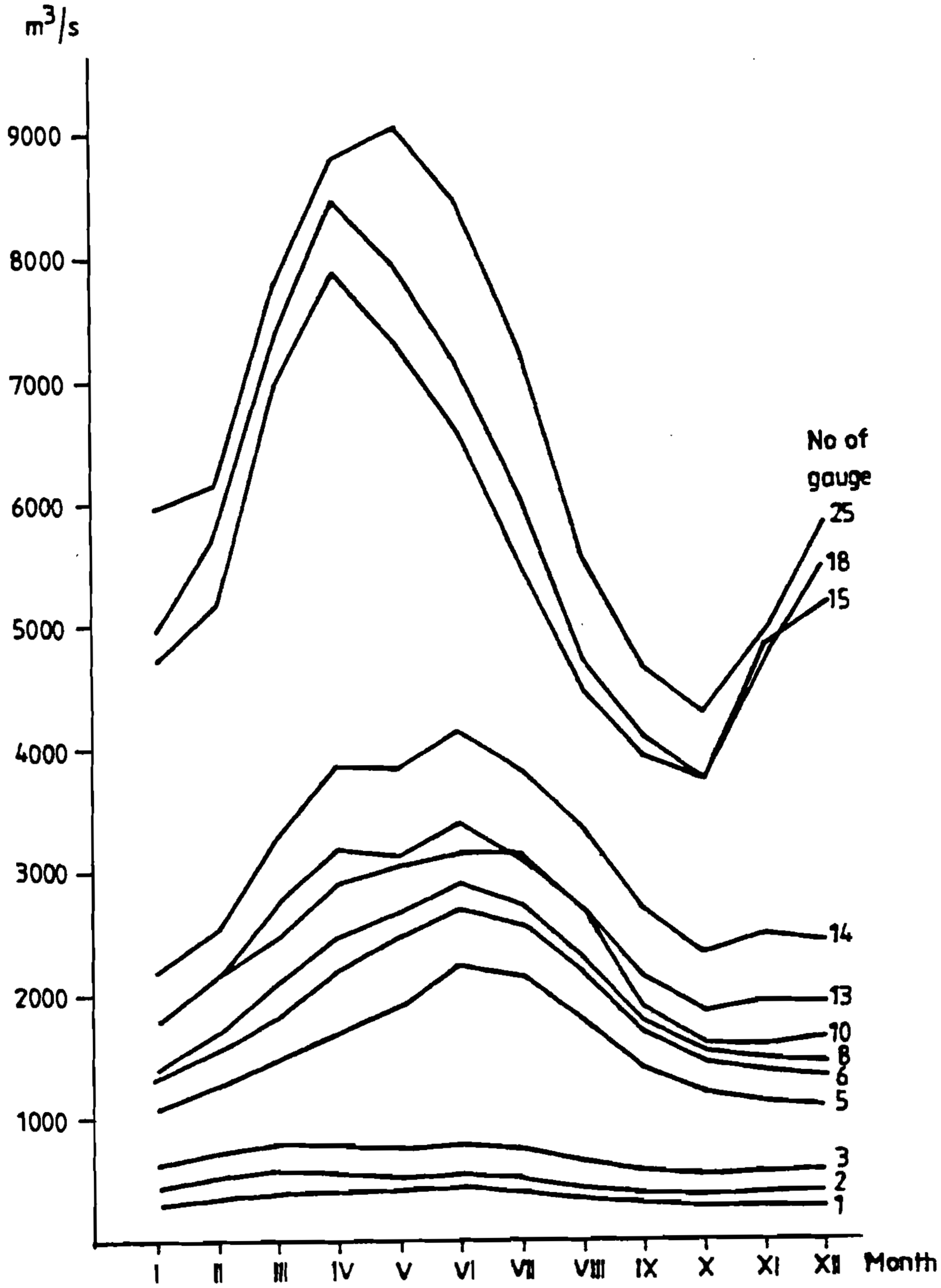

Figure 6. Inter-annual distribution of monthly mean discharges along the Danube (RZdD, 1986)

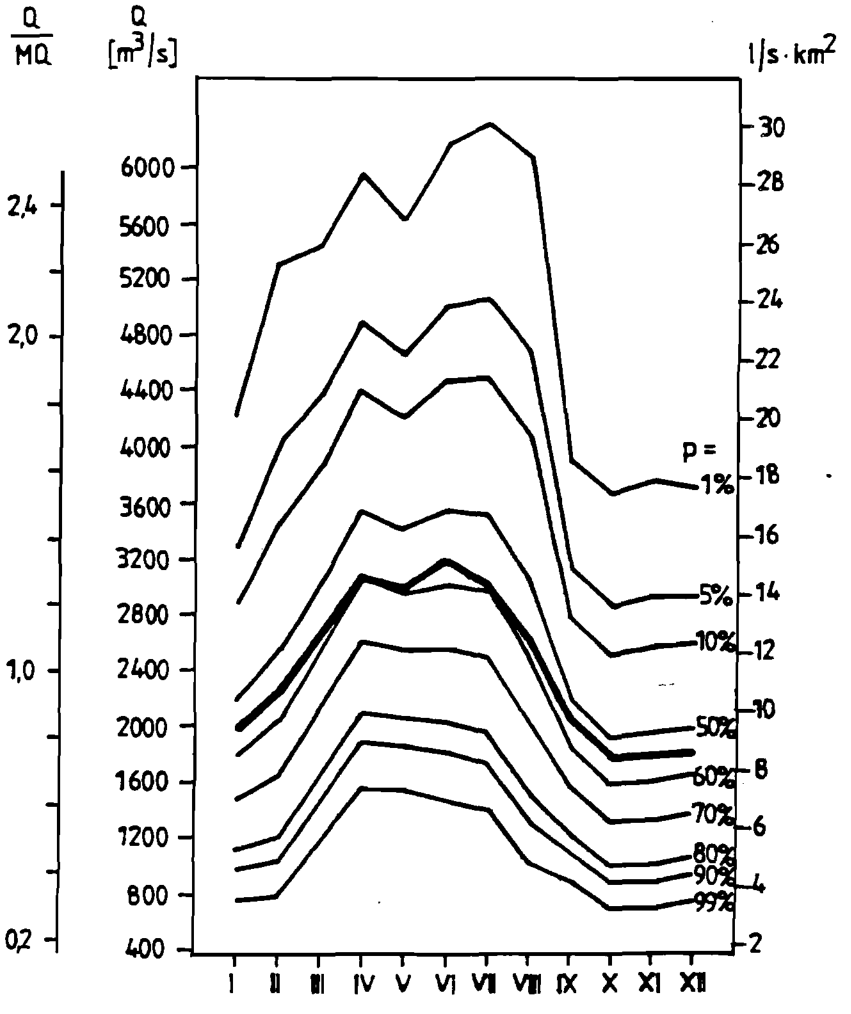

Figure 7. Inter-annual distribution of monthly mean discharges of various probabilities at the gauge Danube/Mohács, 1930/70 (RZdD, 1986)

Sava rivers), through the Bohemian Forest and the north-eastern domains of the Carpathians, up to the basin of the Oder (Odra) river. On the northern edge of the Alps, this weather situation is often connected with enhanced precipitation coming from West or Northwest. Above them, a humid, warm air from the South streams causing additional abundant orographic precipitation. The great floods of 1940, 1954, 1965 and 1966 were caused by this type of weather situations. Additionally, a snowmelt in the mountains may be superimposed covering great height differences from the very low up to the very high regions. This happened during the floods of 1940 and 1965.

Summer storms can lead to great or even very great floods almost in the whole Danube Basin. In the southern regions under Mediterranean influence there is a further storm period in late autumn (mostly November) which also can cause great floods (Drau/Dráva, Sava and the tributaries from the Balkan Mountains).

The greatest floods known on the Danube upstream from the mouth of the Inn were due to snowmelt with rain onto a more or less frozen soil surface (March 1945, February 1862, December/January 1881/1882). During the common observation period 1931/70, floods of March 1947 and March 1956 along the upper Danube reach gave only a slight idea of what nature could do in that area. Along the course of the Danube, both floods mentioned reached really considerable dimensions. This type of flood – snow melt combined with spring precipitation – occurs on the middle and lower Danube, particularly downstream from the Tisza (Tisa) mouth, relatively often with great discharges.

The seasons or months, respectively, in which the probability for flood events is the highest, can be read from the curve of 1% surpassing (e.g. see Figure 7). This does not exclude, of course, the possibility of great floods can occur during other periods as well. As examples of this situation, the floods on the river Inn of February 1862 (4,500 m^3/s), September 1899 (6,600 m^3/s) and September 1920 (5,310 m^3/s) can be mentioned.

In earlier times, along several Danube reaches there were also floods due to ice jams. They caused great damages and were therefore very much feared. The danger of such floods decreased considerably due to river training. The floods are practically eliminated along the Upper Danube, due to the closed barrage chain from Ulm to Vienna. As a result of the operation of the barrages, no ice drift takes place any more along this stretch. Rare cases can be mentioned as exceptions when a very sharp cold wave occurs during a flood.

The propagation of floods along the Danube may follow very different forms. For example, a mighty flood on the Upper Danube, such as that of 1954, can flatten out as it moves toward the Lower Danube in such a way that it will be absorbed there by the recession hydrograph of a small, belated spring flood (Figure 8). On the other hand, it might also happen that small incipient flood waves on the upper reach develop to great floods on the Middle and Lower Danube. It also can clearly be recognized that the wave peaks can considerably flatten along the long transport reaches and the relatively great flood plains of the Middle and Lower Danube whenever the intermediate areas do not contribute to a further sharpening of the flood event (RZdD, 1986).

2.3.3 Low-water conditions

The seasons or months, respectively, in which low discharges (streamflow droughts) often occur, are very well recognizable from the form of the 99% exceedance curve (e.g. Figure 7). Since the duration of low discharges generally is longer, their impact on the mean discharge of the corresponding month is also stronger than that of a steep flood wave with a small water volume. Thus, the graphical representations are more reliable as far as the occurrence of streamflow droughts is concerned than in respect to the occurrence of floods. Low discharges can very often be observed along the whole Danube in autumn and winter. Due to the variability of the features of the various catchments, the minimum values occur in one place mostly in autumn, and in winter in other catchments.

The absolute minimum values almost coincide in time from the source to the mouth of the Danube, since the events resulting in low discharges depend on a synoptic weather situation of long duration.

Such a case happened in the autumn of 1947 when extremely low discharges were observed along the entire Danube. During the period from 30 August to 2 November there was almost no precipitation (its value being in the surroundings of Vienna only 13% of the multiannual average value of that period), leading to an extreme drought and very low discharges in all streams of the Danube Basin.

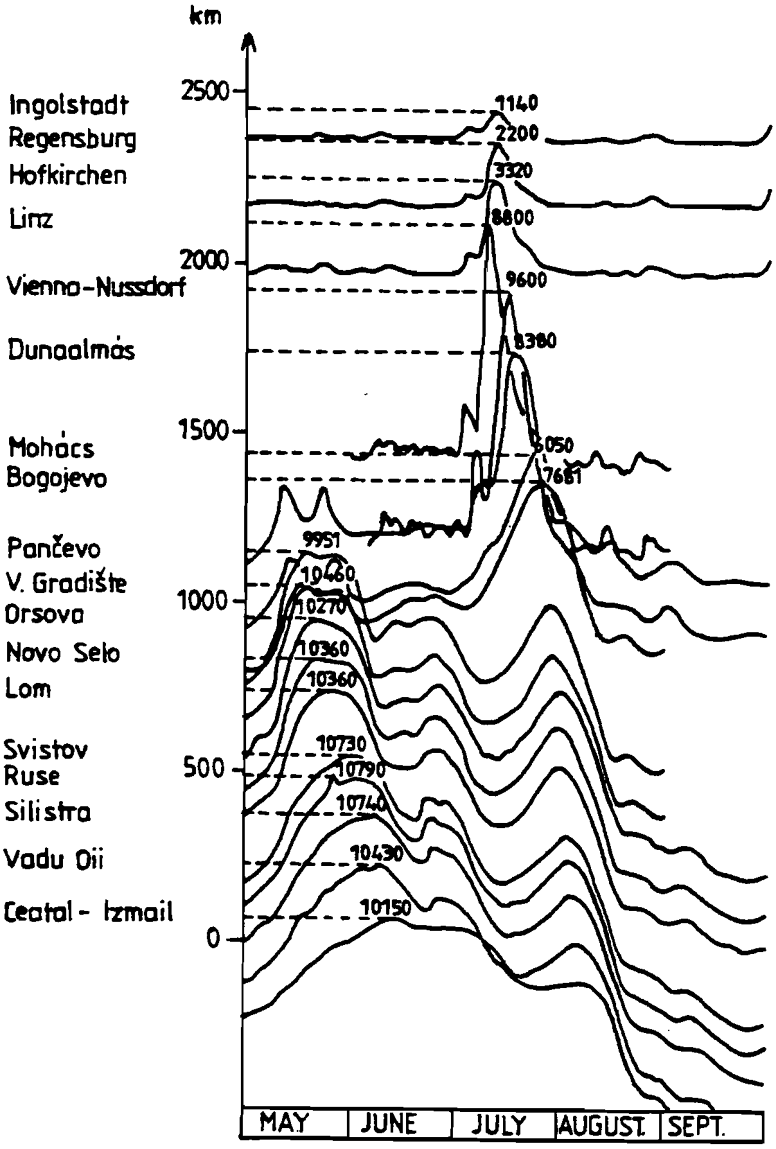

Figure 8. Flood hydrographs at different gauging stations on the Danube in 1954 (RZdD, 1986)

In January 1954, a more extreme low discharge occurred along the whole Danube, even lower than in 1947. A longer dry period in thé autumn of 1953 had been followed by a cold winter so that the whole precipitation was accumulated in the snow cover. In such a way the year 1954 brought for a long reach of the Upper Danube two very rare extremes: the low discharges in January and the mighty flood in July.

In the years 1933, 1934, 1948 and 1964 further very clear-cut streamflow drought periods were observed along the whole Danube. The low discharges along the Danube for all the periods mentioned are graphically represented in Figure 9. The inhomogeneities, recognizable in the figure might be due to the problems of discharge measurements, which can be considerable not only in the range of high discharges but in that of low ones as well.

The low discharges of an area (base flow) depend mostly on the amount of water stored either on the surface (in lakes) or in the aquifers. Along the Upper Danube, there are two contrasting extremes: the foothill belt of the Alps, rich in lakes and extended gravel fields on the southern side, while in the north, the Bavarian and Bohemian Forests are made of basement rocks, which have poor storage capacity.

For general characterization of the low discharge conditions of a river or a catchment area, one could use, besides the average low discharge period, also the ratio *MLQ*:*MQ* (see Table 4, RZdD, 1986).

2.3.4 Water balance of the Danube basin

The water balances to be compiled for the whole Danube basin as well as for its balance areas (subcatchments and national areas) is confined to the most simple variant of the water balance: only the long-term mean values of the three basic balance elements:

- precipitation (P)
- evaporation (E)
- runoff (R)

will be investigated. In this case, it is not necessary to separate the components of precipitation (rain and snow), aerial evaporation (soil evaporation, free water surface evaporation and transpiration of plants), and runoff (surface runoff, intermediate flow, groundwater runoff). Since the water consumption of water users is considerable only in the case of irrigation and the area of irrigated fields is relatively low in the basin, the

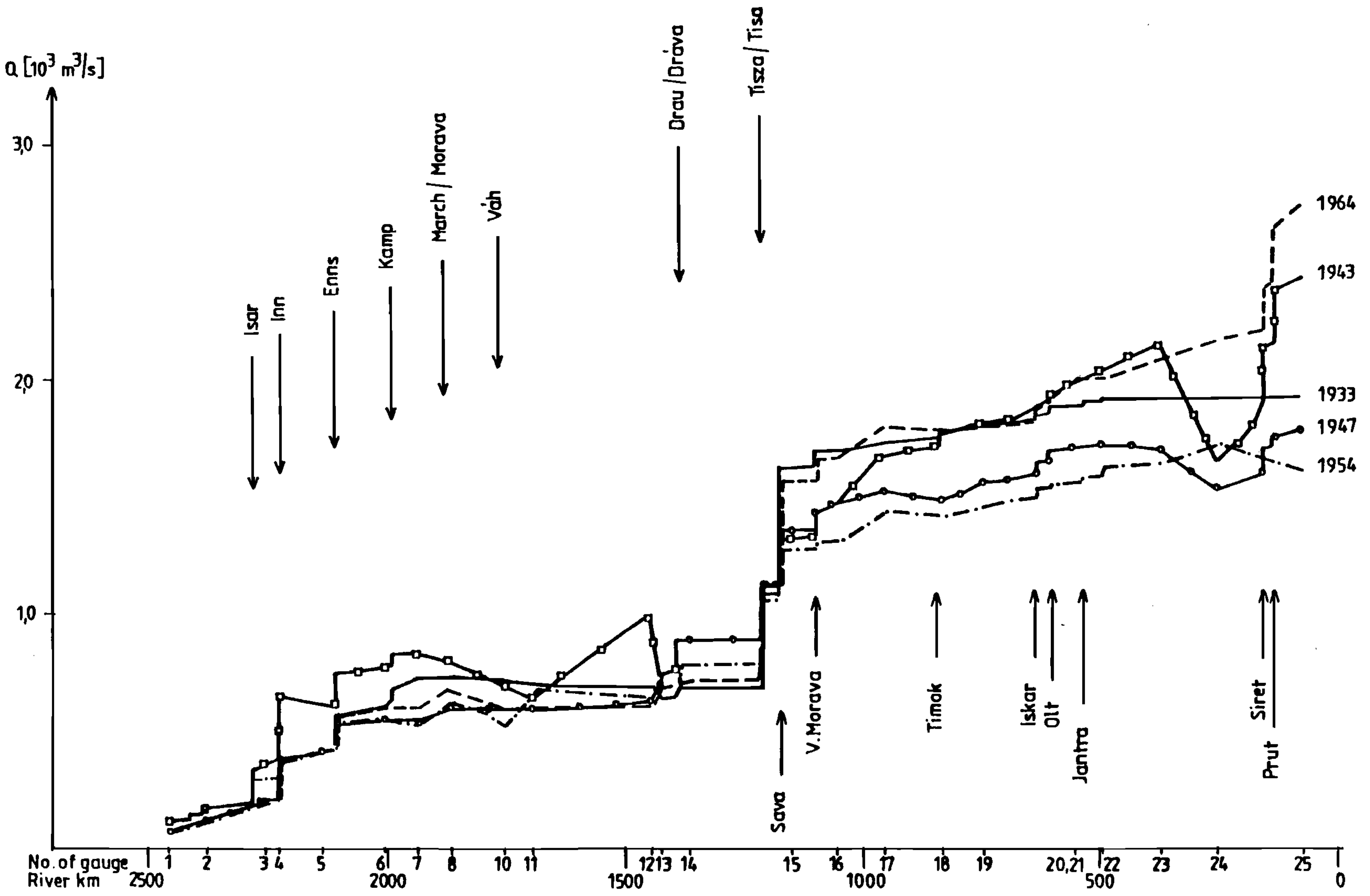

Figure 9. Discharges along the Danube during extreme low-water periods (RZdD, 1986)

difference between water intake and return flow is also negligible in the long term and large scale water balance. There is a further simplification acceptable when long-term mean values are considered in the balance equation: the changes of the water volume stored in the soil and on the terrain can also be neglected (Domokos-Sass, 1986).

The balance elements mentioned above have been investigated for the 47 sub-catchments of the Danube basin.

The water balance elements of the most important sub-catchments of the Danube basin are listed in Table 5, grouped according to the physico-geographical character of the sub-catchments: high mountains, mid-mountains and hilly regions.

The sub-catchments of the high mountainous region, all of them in the Alps (with the exception of the Váh catchment) provide average territorial precipitation values between 900 and 1500 mm. The runoff coefficient is between 0.44 and 0.68.

While Table 5 yields information about the water balance and runoff coefficient conditions of the tributaries, Table 6 contains statistics on water balance elements and runoff coefficients for the accumulated catchments of 5 different Danube sections.

The contribution of each Danube country to the total discharge leaving the country's downstream border can be calculated from the data of the water balance:

1.	Federal Republic of Germany	90.5%
2.	Austria	62.2%
3.	Yugoslavia	34.8%
4.	Czechoslovakia	32.5%
5.	Romania	17.4%
6.	Soviet Union	9.5%
7.	Bulgaria	7.4%
8.	Hungary	5.0%

Table 5

Water balances for selected regions of the Danube Basin
(RZdD, 1986)

Subcatchment			Areal mean value of			Runoff coefficient
Nr.	River	Catchment area km^2	Precipitation P mm/a	Evaporation E mm/a	Runoff R mm/a	$\alpha = \frac{R}{P}$
			High mountains			
2	Lech	4 398	1 349	536	769	0.57
6	Isar	8 369	1 174	536	614	0.52
8	Inn	26 976	1 315	436	868	0.66
10	Enns	5 940	1 483	483	1 016	0.68
14	Váh	9 714	906	534	415	0.46
24	Drau/Dráva	41 810	998	575	435	0.44
28	Sava	94 778	1 091	634	514	0.47
			Mid-mountains and hilly land			
4	Naab	5 645	767	490	288	0.37
12	March	27 633	640	483	141	0.22
13	Raab/Rába	14 702	738	592	130	0.18
16	Nitra	5 415	694	549	157	0.23
18	Hron	5 251	809	514	290	0.36
20	Ipel'/Ipoly	4 594	661	531	139	0.21
22	Sió	15 129	663	572	81	0.12
26	Tisza/Tisa	158 182	744	560	177	0.24
30	V. Morava	38 233	746	540	216	0.29
32	Jiu	10 731	831	576	278	0.33
34	Iskar	7 811	725	455	230	0.32
36	Olt	24 810	873	592	234	0.27
38	Lom	3 380	599	512	66	0.11
40	Arges	11 814	800	577	190	0.24
42	Ialomita	10 305	738	556	146	0.20
44	Siret	45 420	757	550	157	0.21
46	Prut	28 945	606	470	96	0.16

Table 6

Runoff balances of selected Danube sections (RZdD, 1986)

Name of boundary section	Catchment area km^2	Areal mean value of precipitation P mm/a	Areal mean value of runoff R mm/a	Runoff coefficient $\alpha = \frac{R}{P}$
Danube to Lech	15 654	914	370	0.40
Danube upstream of Enns	92 154	1097	600	0.55
Danube upstream of Tisza/Tisa	423 182	834	301	0.36
Danube upstream of Sava	529 156	878	337	0.38
Danube mouth	817 000	816	264	0.32

The difference between 100% and the above percentage values is part of the transit water volume which generally increases from the source down to the mouth of a river.

2.3.5 Water temperature and ice conditions

The annual average water temperature of Danube varies between 9 and 12°C. The minimum temperature is 0°C along the whole river, whereas the maximum is 21°–28°C. Midsummer ranges of the three reaches are 16–17°C, 18–22°C and 22–23.5°C, respectively (WHO, 1982).

Standing ice cover occurs usually in January. The period of permanent ice cover is 5–8 days in the upper Danube, 22–23 days downstream of the confluence with the Drau/Dráva river and 28–30 days in the delta region (Liepolt, 1973).

It should be noted that earlier ice statistics may be misleading, due to warm water discharged into the river (sewage and industrial waste water, cooling water of power plants), the effect of river barrages and the activity of ice-breaker vessels (cfr. Para 2.3.2).

3. ECONOMIC CONDITIONS OF THE DANUBE BASIN

A short review is given here for each Danubian country, summarizing the most important economic activities and land use forms within the catchment.

Federal Republic of Germany. In the southern part of Bavaria there are natural gas, oil and brown coal resources. In the vicinity of the Czechoslovakian border pirite, lead, zinc, tin and brown coal resources can be found. The agriculture is characterized by ploughland cultures and livestock breeding. In addition, meadow and grassland culture are also well developed. In the southern part there are large forests.

Austria. Here brown and black coal, various metals, natural oil and gas resources are available. Crop lands are mostly confined to the basin of Vienna and to the southeast zone of the country, near the Hungarian border. More than half of the country's area is covered by forests, while non-fertile areas extend in the highest regions of the Alps with permanent snow and ice cover.

Czechoslovakia. In this part of the Danube basin, along the lower reach of the March/Morava river, there are natural oil and gas resources, while in the basins of the Hron and Váh rivers various metal ores, smaller natural gas and brown coal resources are found. Ploughland cultures characterize the valley of Morava river and the southern part of Slovakia. The middle and upper parts of Slovakia are mostly covered by forests with pastures and meadow cultures in the valleys.

Hungary is characteristically agricultural country with a fairly well developed industry. The main agricultural products are: wheat, maize, sugar beet, potato, grapes for wine, fruits, fodder, vegetables. Livestock breeding is also developed. Mining and mineral resources involve: bauxite, brown coal, natural gas and oil, lignite, uranium, bentonite, gravel, pirite.

Yugoslavia is rich in mineral resources. Coal and ore resources are abundant (copper and bauxite being the most important), while oil and gas resources are scattered. Cropland culture dominates in the north, and grassland and pasture in the south. Forests cover the land at higher elevations.

Romania is also rich in mineral resources. Here rich natural gas and oil resources are well known. There are considerable black coal resources too. Non-ferrous metals can be found at several locations. The majority of the country's territory is cropland. The mountainous regions of the Carpathians and the Transylvanian Middle Ranges are covered with forests and extensive pastures.

Bulgaria. This part of the Danube basin consists of mainly agricultural land. In the vicinity of Sofia brown coal, and along the north-west border black coal resources can be found. Forests cover the ridges of the Balkan Mountains along the basin.

USSR. Most of this part of the Danube basin belongs to the catchment of the Prut river, and is mainly agricultural land. There is no significant mineral resource (Rado, 1985).

Along the banks of the Danube, there are 10 major cities with a population exceeding 100,000: Regensburg (125,000), Linz (260,000), Vienna (1,650,000), Bratislava (250,000), Budapest (2,000,000), Novisad (170,000), Beograd (1,100,000), Braila (120,000), Galati (150,000), Ruse (176,000). Other major cities (over 100,000 inhabitants) in the Danube basin are Munich, Augsburg, Innsbruck, Salzburg, Graz, Miskolc, Debrecen, Szeged, Pécs, Györ, Nyiregyháza, Székesfehérvár, Kecskemét, Zagreb, Osijek, Subotica, Bucaresti, Brasov, Cluj-Napoca, Timisuara, Jasi, Craiova, Oradea, Arad, Sibiu, Bacau, Pitesti, Tirgu-Mures, Baie Mare, Satu Mare, Sofija, Pleven (Radó, 1985).

The waterway provided by the Danube enhances the development of industries: the gradual improvement of this waterway allows the transportation of more and more cargo.

In the Danube basin tourism represents also a significant economic factor.

Among the water uses fishery plays an important role with a total catch of 4,400 tons/year (Table 8). A further 45,000 ton/year are taken from ponds in the floodplains and the delta (Liepolt, 1973).

The GNPs per capita in the countries of the Danube basin are summarized in Table 7 (Radó, 1985).

4. UTILIZATION OF WATER RESOURCES IN THE DANUBE BASIN

The development of water management in the countries of the Danube basin depends on their geographical location and on the degree of economic development. In the upper part of the basin the morphological and climatic conditions limit the development of irrigation. In this region the basic forms of water uses are the industrial and drinking water supply, and hydroelectricity generation. The other important type of hydraulic structures is the canalization of the river by constructing barrages. These structures facilitate the utilization of the continuously renewing energy content of the river, improve navigation and reduce the risk of floods. The canalization was also extended to the upper reaches of the tributaries.

Along the middle and lower reaches of the Danube, flood protection, river regulation, agricultural, industrial and communal water supply are the dominating water uses. Along the lower Danube an increase in the demand for supplementary irrigation is expected (WHO, 1982).

The water demand data within the basin estimated for the year 1980 and predicted for 2000 are summarized in Table 9 (OMFB, 1975; Kovács et al. 1983). It is interesting to note that the prediction assumed an annual increase of 4–6% in water demand. Considering the world-wide economic recession which strongly affected this region, the estimated increase might be exaggerated. By evaluating the present conditions it can be supposed

Table 7

GNP per capita in the countries of the Danube Basin

(Radó, 1985)

Country	GNP (US $)
FRG	13 450
Austria	10 210
Czechoslovakia	5 820
Hungary	4 180
Yugoslavia	2 790
Rumania	2 540
Bulgaria	4 150
USSR	4 550

that the demand predicted for 2000 will be achieved only during the first quarter of the next century. The slowing down of the increase in demand especially characterizes the development of irrigation.

The largest amount of water abstracted from the Danube and its tributaries is used for cooling purposes in industry, and in thermal and nuclear power plants. It was earlier estimated that up to 20 nuclear reactors are likely to be constructed within the basin (IAEA, 1975). However, only 7 are now operating.

Table 8

Annual average fish catch in the Danube River

(Liepolt, 1973)

Country	t/year
FRG	100
Austria	200
Czechoslovakia	345
Hungary	450
Yugoslavia	700
Rumania	600
Bulgaria	1100
USSR	900
Total	4400

5. HYDROTECHNICS

5.1 Preliminary Remarks

The development of hydraulic structures and water resources management along the Danube and in its basin is closely interrelated with the development of population, economy, culture and technology in this region. Constructions have always served the fulfillment of actual requirements and have utilized the available technical and economic tools.

The first hydraulic structures in the basin originate from the time of the Roman Empire. The middle ages was a period of stagnation, in accordance with the low demands. The basis of the present water management was laid down in the second half of the 18th century, when the increase in both

Table 9

Water consumption of the countries in the Danube Basin
(OMFB, 1975; Kovács et al. 1983)

Country	1980 (10^6 m^3/year)				2000 (10^6 m^3/year)			
	Communal and Industrial	Irrigation	Fisheries	Total	Communal and Industrial	Irrigation	Fisheries	Total
FRG	170	-	-	170	303	-	-	303
Austria	120	237	-	357	207	682	-	889
Czechoslovakia	220	1970	12	2202	591	3740	12	4343
Hungary	411	4710	265	5386	729	9297	282	10308
Yugoslavia	224	1220	95	1539	381	4056	95	4532
Rumania	595	12760	623	13978	984	26934	698	28616
Bulgaria	148	5680	-	5828	201	8608	-	8809
USSR	82	1029	18	1129	85	1738	20	1843
Total	1970	27606	1013	30589	3481	55055	1107	59643

population and economy considerably accelerated in the basin. Since then, the requirements for the rivers and water resources rapidly increased. The most important demands were: rivers should be navigable by larger ships independently from the discharge conditions; in the frequently inundated river valleys the developing settlements and agriculture should be better protected; continuous and safe supply of water of suitable quality is required for communities, industry and irrigation; the energy content of rivers should be utilized for the economy and since rivers are recipients of wastes produced in the hydrological cycle in the society, their self-purification capacity should be maintained. In order to achieve the goals outlined, large number of hydrotechnical constructions and water resources systems have already been realized. Consequently, river beds, suspended sediment and bedload transport, the water quality and even the flow discharges have been considerably changed along several stretches. The large hydraulic structures and systems – those already realized and recently planned – have large radii of influence and, therefore, they are not independent of each other, but their impacts are interwoven. When greater projects are planned and realized, it is necessary that the neighbouring countries inform each other, take into account mutual interests, harmonize their measures and even realize some projects jointly.

A common task is to utilize the available water resources of the Danube and the basin area in a possibly optimal way and to protect the environment as well as to fight jointly against the dangers of floods and droughts. This task itself has already contributed considerably to create a new consciousness of interdependence and cooperation of the Danube countries and to develop it further in the future (RZdD, 1986).

5.2 River Training

At first we review the most important river training activities realized on the Danube by the riparian countries.

Federal Republic of Germany

The approximately 85 km long Danube reach from Sigmaringen to the mouth of the Iller at Ulm, was first regulated in the years 1850–89. Downstream from Ulm till the gorge at Weltenburg the entire stretch was regulated starting from the year 1806 and implemented mainly in the period 1829–85. The meandering course was shortened by 21% constructing several cut-offs and a stabilized river bed was provided for the average flow in this way. On another German section of the Danube, the river training was confined to the cut-offs, of three large river loops between Regensburg and Vilshofen.

Between 1931 and 1970, the regulation of the low-water bed was performed from 2.376 km (Regensburg) to 2,250 km (Vilshofen) in order to improve navigation conditions. However, it turned out that it was not feasible to maintain the depth required for navigation permanently due to progressive deepening of the bed and canalization of the stretch became necessary.

Austria

In 1773, Empress Maria Theresia founded the first national authority for planning and implementing river training. The "Imperial Directory for Navigation" existed till 1885. This authority, like other subsequent organisations, focused its activity on the improvement of navigation conditions on dangerous rocky sections of the stream, and on the construction of hauling tracks. In 1778–91 the most dangerous stream section, the "Greiner Strudel" was trained by rock blasting and construction of river banks. In 1829 works on the "Aschacher Kachlet" had been performed and from 1850 to 1866 the navigation conditions in "Brandstatter Kachlet" were improved by rock blasting of the "Hausstein–Felsen" near Grein. The completion of training works of the substantial part of the Strudengau continued till 1905.

In 1850 the first large regulation works were started in the area where the original bed was divided into several branches by deposited sediments. Sharp bends were removed by means of guide structures and cut-offs. Adjacent tributaries were closed and a channel width for mean water of 320–410 m was gradually provided with uniform bank fortification. As early as 1920 the majority of regulation works for mean and low water stages (aiming at navigation improvement) were completed in the respective sections.

Czechoslovakia

The reach between the March (Morava) mouth and Gönyü (i.e. about half of the whole reach) lies on a gigantic alluvial fan. Due to continuous sedimentation it is extraordinarily difficult to perform and maintain successful regulation here. By means of a mean-water regulation, carried out from 1886 to 1896, a stable main channel was provided among numerous river branches. At the same time curvatures were smoothed, cut-offs constructed, and side branches closed below the level of mean water. The stabilization of the waterway for navigation by means of this regulation was less successful on this crucial Danube reach than elsewhere. The low-water regulation necessary for this purpose was, therefore, continued since 1900 by means of groynes. However, it is still difficult to maintain even by permanent dredging a 2 m deep and 80 and 120 m wide waterway at low water stages.

Hungary

River training started in 1870, after a detailed geodetic survey of the entire Danube reach, which created a reliable data base for this activity. Substantial support for this activity was given by numerous ice floods, since the river channel originally divided into several branches creating narrow meanders, which were not able to transport ice masses coming from upstream sections of the Danube. Ice clogging caused an increase in water level upstream, ice jams inundating large areas on the plain, and after suddenly breaking through the ice jams, heavy floods occurred along the lower stretches causing serious damages. Therefore, the first task was the construction of a uniform main river channel with continuous track between Devin and Vének (1880–1791 km). The engineering works included: cut-off of branches, straightening of bends, cutting across loops and revetment of banks.

After the catastrophic flood of 1838, when 15% of the houses of Buda and 50% of Pest were destroyed, the regulation of this stretch was also implemented. The Soroksár side branch was cut off, the main Budafok branch dredged, protecting walls and bank revetments built.

By the beginning of World War I the major part of mean-water regulation works had been finished over the entire Hungarian Danube. Thus, a substantial improvement of the convergence of flood discharge and ice had been attained. The original length of the Danube was shortened by constructing 30 cut-offs from472 to 417 km.

The significance of rapidly developing water transport considerably increased the importance of river training. Engineering works were already started in the 19th century to remove shoals and to construct groynes and guidance embankments for low-water regulation, thus creating a waterway with sufficient capacity having the depth of 2.5 m and minimum width of 150 m.

Yugoslavia

Riverbed training in the Pannonian Lowland started in 1895 downstream from Paks in Hungary, and were identical to those described above concerning the Hungarian Danube section, namely, closing of side branches, straightening of meanders, cut-offs, river bank revetment regulation for low water by means of groynes and guidance embankments. Three large cut-offs upstream of the Drau (Dráva) inflow should also be mentioned. By the beginning of World War I the section down to the mouth of the Tisza (Tisa) was completed. A waterway having a depth of 1.8 m and a width of 100 m was thus provided. In the period between the two world wars, training works continued to be carried out downstream from the mouth of the Tisza (Tisa).

From the time of the construction of Traian's road by the Romans on the right river bank until the beginning of the 19th century, no attempts were made to improve the extraordinary difficult navigation conditions along the cataract section of the Iron Gate (Djerdap/Portile de Fier). From 1834 to 1837 the well-known Széchényi road had been carved in the rocks on the left river bank to provide help for navigation at low water stages. Already in those days several cliffs and rocks were removed by blasting. Thus, a small waterway within the cataracts Kozla-Dojke was created. After various projects had been prepared and international agreement attained, extensive training works were implemented between 1890 and 1898 to improve navigation through cataracts. They included construction of five canals 60 m wide each, with minimum depth of 2 m, their total length being 13 km, leading through the cataracts.

To carry out the improvement of this waterway the removal of 650,000 m^3 of rocks was required, which would be a difficult task even with modern technology. Due to strong streamflow, reaching 5 m/sec in the 73 m wide and 3 m deep canal within the Iron Gate during high water, only limited navigation was possible with special barges. A haulage road was, therefore, constructed during World War I, and locomotives took over the haulage. In spite of all efforts, navigation through the whole cataract section remained rather burdensome, requiring the help of pilots and sometimes being completely unfeasible. The final solution of all navigation problems was achieved by the construction of the barrage Djerdap (Portile de Fier I), impounding the whole cataract section.

Romania

The regulation of the Iron Gates cataract section, where the Danube borders Yugoslavia, has already been described above. To enable large maritime ships to reach Danubian ports, the Sulina branch in the Danube delta was straightened by 10 cut-offs reducing the length from 85 km to ca. 62 km in the period between 1857 and 1902. Thus, a waterway having a depth of 7.3 m and a width of 80 m was provided un to the port Tulcea. This waterway was extended to Braila, about 170 km upstream of the estuary. The maintenance of navigation on this waterway requires continuous dredging of sediment.

5.3 Navigation

One of the goals of river training described so far has always been the safeguarding of navigation.

The Danube, especially its middle and lower reach, had become of foremost importance since the earliest times as a natural waterway. Since ancient times transport of heavy cargoes was substantially easier by water than overland, only the dimensions of vessels has changed (Kresser, 1984).

International cooperation of Danube countries concerning navigation is based on several agreements concluded since 1856. During the Danube Conference held in 1948 in Beograd, the "Danube Commission" was founded with headquarters in Budapest. Within the scope of activity of this commission all common problems concerning navigation, and hydraulic structures serving navigation have been dealt with. Thus recommendations concerning the dimensions to be guaranteed on the waterway (navigable depth, width, curvature, slope, size of lock gates, discharge capacity, etc.) for the whole navigation route from Regensburg to the Black Sea have been worked out. The considerable increase of water transport on the Danube since the foundation of the Danube Commission testifies the successful cooperation among Danubian countries within this organisation.

In addition to the Danube, some tributaries are also naturally navigable, or were adapted by the respective countries for navigation:

- the Drau/Dráva up to Cadarice (105 km),
- the Tisza/Tisa up to Dombrád (about 600 km) as well as its tributary Bodrog up to the Hungarian–Czechoslovak border,
- the Sava up to Sisak (583 km) for smaller ships,
- the Prut on a short section of its lower course.

The Backa Canal (Yugoslavia), connecting the Danube with the Tisza/Tisa is also navigable (RZdD, 1986).

The basic data of goods transported on European waterways are summarized in Table 10. It is seen from the table that the contribution of the Danube water system to this navigation is fairly modest (4–5%). This proportion will, however, be rapidly changed when the Danube–Main–Rhine Canal (see Section 5.4) interconnecting the two systems is finalized (Kovács et al., 1983).

The huge amount of goods to be transported economically requires a naval fleet of increased tonnage capacity; an increased depth is therefore needed for navigation. Here it must be mentioned that the Hungarian Danube reach, especially the common Czechoslovak–Hungarian stretch, does not meet the recommended dimensions of the Danube Commission and the required depth cannot be achieved by applying the traditional river

Table 10

Goods transported on important European waterways, as of 1970 (OMFB, 1973)

Region	Country	Transported goods 10^6 t/year	
West European waterways network	Belgium	91.6	714.4
	Czechoslovakia	1.7	
	France	110.4	
	The Netherlands	241.4	
	Poland	8.8	
	GDR	13.7	
	FRG	237.5	
	Schwitzerland	9.3	
Danube and its tributaries	FRG	2.5	61.2
	Austria	7.6	
	Czechoslovakia	2.6	
	Hungary	2.8	
	Yugoslavia	22.1	
	Rumania	3.4	
	Bulgaria	5.4	
	USSR	14.8	
European part of USSR without Danube			343.0

training (Benedek et al., 1980). This is clearly indicated by Figure 10, which represents the ratio of the costs spent for the maintenance of the waterway along the various stretches taking the average cost as 100%. Even with such efforts only 2.0–2.2 m navigation depth can be ensured along the critical reach, contrary to the minimum depths of 2.5 m and 3.5 m prescribed by the Danube Commission before and after the opening up of the Danube–Main–Rhine Canal system, respectively. In the vicinity of the fords temporary navigation restrictions have to be ordered from time to time (OMFB, 1973).

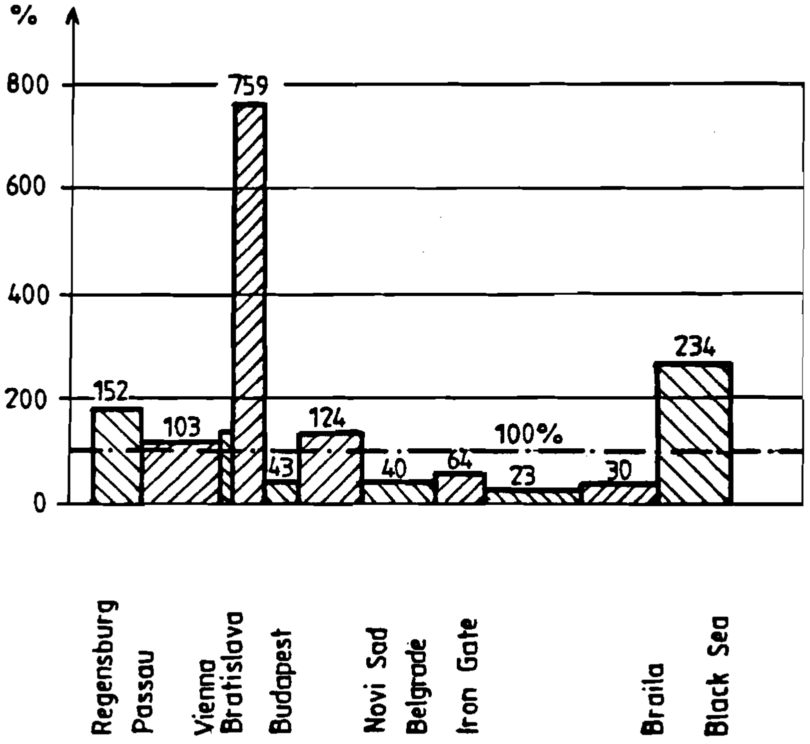

Figure 10. Costs of river training works assuring navigtion along the Danube (OMFB, 1973)

It should also be noted that among the most significant developments which could affect the regime of the river there are the proposals to improve navigation by constructing inter-river canals to connect different international river systems with each other, or with the sea, namely:

- Rhine–Main–Danube canal, providing a continuous waterway from the North Sea to the Black Sea,
- Danube–Odera–Elbe canal, providing links between the Baltic and the Black Seas,
- Danube–Morava–Vardar–Axios canal, providing a link with the Aegean Sea (WHO, 1983).

5.4 Flood Control

In the following, a short review will be given, for each Danube country, about the flood control situation along the Danube.

Federal Republic of Germany

Flood protecting levees built in 1849–1897 from 2,540 km (Dillingen) to 2,510 km (Donauwörth) hindering henceforth the floods to overflow the banks and inundate the territory covering the area of about 115 km^2. Flood protecting levees from 2,460 km (Ingolstadt) to 2,427 km (Eining) were built in 1913–24 and fortified in 1965–75. They protect an area of 80 km^2. Flood protection levees from 2,376 km (Regensburg) to 2,256 km (Hofkirchen) were constructed in 1930–56, protecting an area of about 120 km^2, but giving only partial protection for the territory between Regensburg and Straubingen. On the basis of experiences gained during the floods in 1954 and 1965 these levees and the inland drainage have to be improved.

Numerous completed dams and impounding reservoirs took over a part of the flood protection by lowering flood peaks.

Improved flood protections of Kehlheim and Regensburg are planned for the future. The protection measures envisaged for Passau should proceed also in the future through rebuilding of old houses and changing the utilization of their ground-floor.

Austria

Subsequent to flood disasters in 1830 and 1864 the first more extensive measures were performed in 1869–1875 for the protection of Vienna against floods. The core of engineering works was a 26 km long river training work for which two large cut-offs had been established. For the first time in Central Europe they were implemented over the whole length and dredging the complete width, while in the past it was usual to rely on the river itself to perform this work over a long period. The amount of earth moved in this operation was, therefore, as high as 16.5 mil.m^3.

Other measures were also included, such as closing structures for the Danube Canal, various flood control embankments and levees. Since 1898–99 a 180 m wide waterway in the regulated section was provided by means of groynes, securing navigation at low water stages.

From 1882 to 1920 about 200 km of flood control levees were constructed from Vienna down to the March (Morava) river, in the Tullnerfeld and in Linz area.

Following the severe floods in 1954 flood protection in the town of Linz was increased considering the flood with 500-year return period as design value. The system was further improved parallel to the construction of the barrage at Abwinden–Asten.

The present flood control system in the Vienna area is being improved to handle a discharge of 14,000 $m^3.s^1$, which corresponds to the peak discharge of an extraordinary high flood. For this purpose a release canal will be constructed, separated from the Danube canal by a 17 km long and 200 m wide island. In the downstream direction the levee system is dimensioned for a discharge of about 13,200 $m^3.s^1$, since in the case of more serious floods it is necessary to take also into consideration, with respect to the lower lying downstream countries, the retention of the March (Moravian) Field.

Czechoslovakia

Flood control embankments had been built already in the second half of the 19th century. Except for two short stretches where the banks are relatively higher a complete system of levees was built for the entire northern Danube bank and southern Little Danube bank. Disastrous floods, most recently in 1965, stimulated here, as well as on the opposite bank, fortification and raising of levees and improvement of drainage within the protected area.

Hungary

A quarter of the Hungarian territory, about 23,000 km^2, is a potential inundation area from which 23% lies directly in the Danube valley. Therefore, flood mitigation and protection is of major importance in this country. As early as in the 16th century protection levees were constructed there. A systematic construction of flood protection dykes started in the first half of the 19th century. Since 1840 there has been legislation to regulate the implementation of hydraulic structures, river training, construction and maintenance of flood control structures, and the necessary drainage of excess water. According to this regulation Water Associations were established unifying all interested persons and organisations in a given region and a part of the investments was covered by the members. A decisive motive to complete the levee system was the occurrence of severe floods in 1881 and 1888. By the end of the 19th century the protection system was practically completed.

The straightening of the Danube between dykes caused a further increase of flood stages, so that many previous levees were too low after the completion of the whole system. In the first half of the 20th century the levees were raised and fortified, so that a safe protection against floods of 60–year return period was provided.

At the beginning of the present stage of flood control development the legal basis has been modified. Proceeding from the circumstance that the safety of the main protection line has not only local, but also national significance, the state took over the responsibility from the associations for important flood-control dykes. From the total main flood control line in Hungary, having a length of 4,183 km, 1,350 km lies along the Danube. It is supplemented by the secondary lines of 260 km length and by the special protection of Budapest, the length of which is 18 km.

The significance of flood control in Hungary is evident from the following data: Within the potential inundation area live a quarter of the total population; about 30% of the railway network, and 20% of highways lie there.

Yugoslavia

Large inundation areas requiring flood protection spread only along the middle Danube reach in the Pannonian Basin. Systematic construction of flood control levees also started in the 19th century. By World War I a continuous protection system had been constructed linked to the Hungarian levees, reaching on the left bank down to the mouth of the Tisza (Tisa), and on the right bank to the mouth of the Drau (Dravá). Further downstream, the levee system on the left river bank was still deficient at that time, while on the right bank flood control dykes were constructed only at Petrovaradin and Zemun.

In the period between the two world wars the system of levees was expanded (for instance, at Pancevo on the left bank and at Smederovo and Godominsko Polje on the right bank).

After World War II some new sections were built to complete the flood protection. A part of old dykes was raised, fortified, and restored according to experiences gained during the catastrophic flood in 1965 and based on advanced soil mechanics.

At present there is a continuous system of dykes on the left bank from the Hungarian border down to the mountainous reach of the Iron Gate. Due to local conditions on the right river bank, it was sufficient to construct levees at only a few sections: from the Hungarian border down to the mouth of the Drau (Drava), at Petrovaradin and Zemun, as well as at Smederevo. The latter was also required because of the construction of the Djerdap I (Portile de Fier) barrage.

The crest of flood control dams is usually 1.5–1.7 m above the water stage of a food of 100-year return period.

Bulgaria

Over the years from 1930 to 1950, about 300 km of flood control dams were constructed to protect an area of about 72,600 ha. The height of the levees was dimensioned according to the extreme flood in 1897.

Romania

The construction of flood control levees for protection of agricultural land was initiated in the 19th century. The protected area was increased from ca. 50,000 ha in 1940 to ca. 100,000 ha in 1960 and has been further increased up to the present to ca. 400,000 ha. The total length of flood control levees is 1,000 km (RZdD, 1986).

5.5 Barrages

The idea to construct a navigable waterway connecting the Main and the Danube and thus the North Sea with the Black Sea, dated back to ancient times. As early as 793, Charlemagne tried to create a connection between the two river systems, close to the town Treuchtlingen (FRG), where the distance between two tributaries of the two systems is only 2 km and the difference in altitude is only about 10 m.

From 1836 to 1845 the "Ludwig-Donau-Main Kanal" of 177 km long was built from Kehlheim to Bamberg with 100 navigation locks. Unfortunately, this canal soon lost its significance since the 120-ton vessels hauled by horses could not stand the competition from the railway, which in those days was installed. In 1945, this canal was still in operation and only in 1949 was it finally abandoned.

Since 1959 the new Main-Donau-Kanal has been under construction, its dimensions being: 55 m water level width, 31 m bottom width, 4.0–4.25 m water depth, 12 m wide and 190 m long navigation locks adequate for a pair of 1,500 ton and 90 m long Type Europe II barges. The 204 km long canal between Regensburg and Bamberg is divided into 18 sectors from which 103 km with 10 sectors is canal with standing water, and 101 km is impounded stretch of rivers.

In connection with the new Main-Danube waterway, the completion of which is envisaged for the first half of the decade 1990–2000, 15.0 $m^3.s^{-1}$ of water should be conveyed from the Danube to the Main river basin. However, water withdrawal should take place only when the Danube discharge is above the average low discharge MLQ.

In 1984 a 64 km long Danube–Black Sea canal between Cernavoda and Constanta (Romania) was completed, at first only for internal operation. The mean width is 90 m, depth 7.5 m, both ends are provided with 310 m long and 25 m wide twin navigation locks. The navigation route was shortened by 370 km. This canal, the construction of which required the removal of 300 million m^3 of earth (more than in the case of the Suez Canal: 275 million m^3) also provides water for irrigation of 700,000 ha of arable land in Dobrogea.

In the following, a short review about barrages on the Danube is given for each Danube country.

Federal Republic of Germany

The Kachlet barrage (2,230 km) at Vilshofen, built in 1924–27 was the first member of the canalization system of the Danube. It improved navigation in the rocky stretch of the "Hilgardsberger Kachlet". It was followed by the barrage at Jochenstein, constructed in cooperation with the Federal Republic of Germany and Austria on the common border in 1952–55. During the period 1952–84 a continuous chain of 15 barrages was built from Ulm to Ingolstadt. In the majority of these schemes a part of the former inundation area is overflowed during flood events, to prevent the unfavourable increase of flood discharges in the downstream section. The releases take place, in a regulated way through spillways and movable weirs. The alluvial forests are often inundated, though the agricultural land is submerged only during disastrous floods.

Three barrages, Regensburg (2,381 km), Bad Abbach (2,401 km) and Geisling (2,354 km) were built with the purpose of extending the waterway on the Danube up to Kelheim and to interconnect it with the Main-Danube canal.

At present one barrage is under construction at Straubing (2,324 km), whose purpose is to improve navigation conditions. Some others are also planned (one to extend the waterway until the Kachlet barrage and two more downstream from Ingolstadt to prevent the rapid scouring and deepening in this reach.

Austria

The systematic development of the Danube cascades began with the construction of the barrage at Jochenstein, on the German–Austrian border, completed in 1954. Up to the present about 250 km of the 350 km long Austrian Danube section is canalized and there are plans to further develop this cascade system.

Barrages in flatlands of the Danube basin are supplemented by dyke systems to provide protection for the densely populated inundation area against floods. However, larger retention areas remain preserved, similarly as in the German Danube section, also after the construction of barrages. In all five, completed water schemes situated in the plain high-water overflows were built into the parallel lateral levees, thus making possible the overflow of water above a certain flood-discharge onto the former inundation plain. In this way at higher floods a significant portion of the flood retention is maintained. In addition, the former inundation conditions in the alluvial plains and forests are preserved.

Czechoslovakia

Since 1978 the hydropower plant Gabcikovo has been construction jointly with Hungary. With its large derivation canal it differs from all other completed and planned water schemes on the Danube. The combined navigation and hydropower canal should divert a discharge of 5,200 $m^3.s^{-1}$ from the Danube at Dunakiliti, which returns to the main river bed only after a length of about 30 km. It is planned to construct in cooperation with Hungary downstream from Gabcikovo another water scheme at Nagymaros. Only after completion of this barrage will it be possible to create a complex water utilization scheme for peak hydropower production. The two barrages will also provide a final solution of flood control on the Danube reach concerned.

Hungary

The canalization project at Gabcikovo–Nagymaros, to be constructed jointly with Czechoslovakia, has already been described above. More details can be found in Annex II.

Yugoslavia

For solving the serious problems concerning navigation on the Danube and for utilizing of the hydraulic power potential, Yugoslavia and Romania constructed jointly in the period 1964–72 at 942.94 km a dam of 32 m height, the "Hydroenergy and Navigation System Djerdap (Portile de Fier I)". The backwater extends at low water stage as far as 270 km to the mouth of the Tisza (Tisa). In case of flood, the head is reduced to 6.5 m, so that at high floods the backwater ends a distance of about 120 km at Veliko Gradiste.

In 1984 the barrage Gruia (Portile de Fier II) at 863 km was put in operation. Its backwater zone is linked with the scheme Djerdap (Portile de Fier I), thus serving as compensation reservoir during the peak operation of the hydropower plant. This project was implemented also as a common Yugoslav–Romanian scheme.

Romania

Both river power projects at the Iron Gate I and II have already been dealt with in connection with the development in Yugoslavia (RZdD, 1986).

5.6 Hydropower

In order to characterize the problems of barrages from the viewpoint of energetics, in Figure 11, the longitudinal section of energy-potential (discharge multiplied with slope) of the Danube is shown. The diagram clearly indicates that the highest specific power resources are concentrated in two reaches: between Passau and Gönyü, and downstream from Belgrade, in the Iron Gate region.

The first reach (between Passau and Gönyü) is especially significant due to its high slope of 150 m along about 435 km length of the river. At the second reach (downstream of Belgrade) the high energy potential is due to the great discharges of the river.

A sudden break in the slope of the river bed at Gönyü can be seen in Figure 11. This results in problems of sediment accumulation at the breakpoint. Accordingly, the annual bed load transport at Bratislava is about 650,000 m^3 while it is only 13,000 m^3 above Budapest. This is the reason for the well-known "bottle neck" in the navigation along the critical Czechoslovakian–Hungarian reach (Benedek, 1986).

The plans for the complex utilization of the Danube's water resources involve 49 river barrages of which so far 31 have been constructed. The sections and capacities of these hydropower plants are listed in Table 11. The locations of these hydropower stations according to countries is shown in Table 12. The tables show that the present utilization of the total capacity (61%) will be gradually increased to more than 90% by the turn of the century (DoKW, 1985; OVH, 1985). Figure 12 gives some information on the extensive hydropower utilization of the Austrian Danube section (DoKW, 1985).

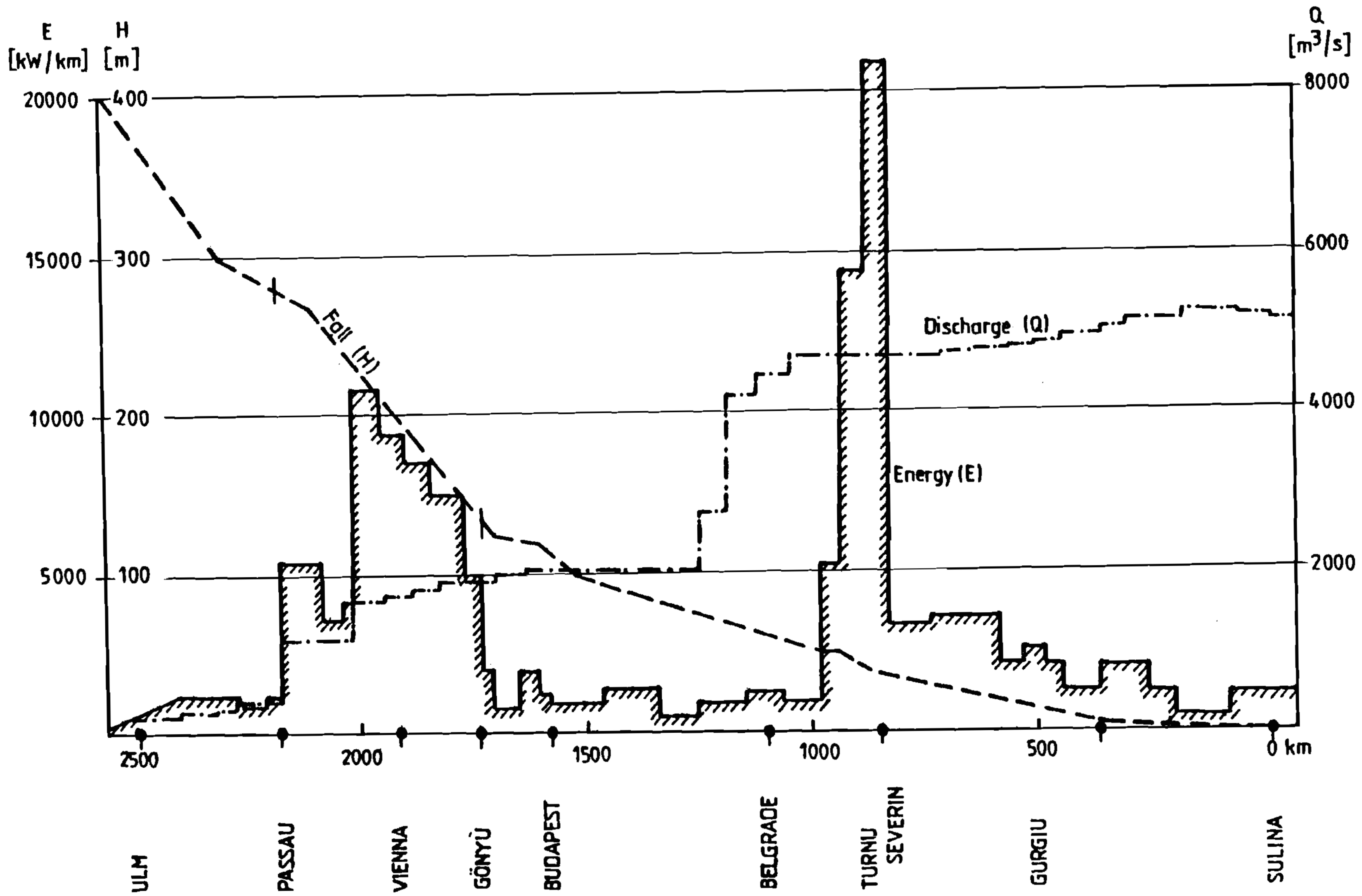

Figure 11. Energy profile of the Danube (Benedek–Lászlo, 1980)

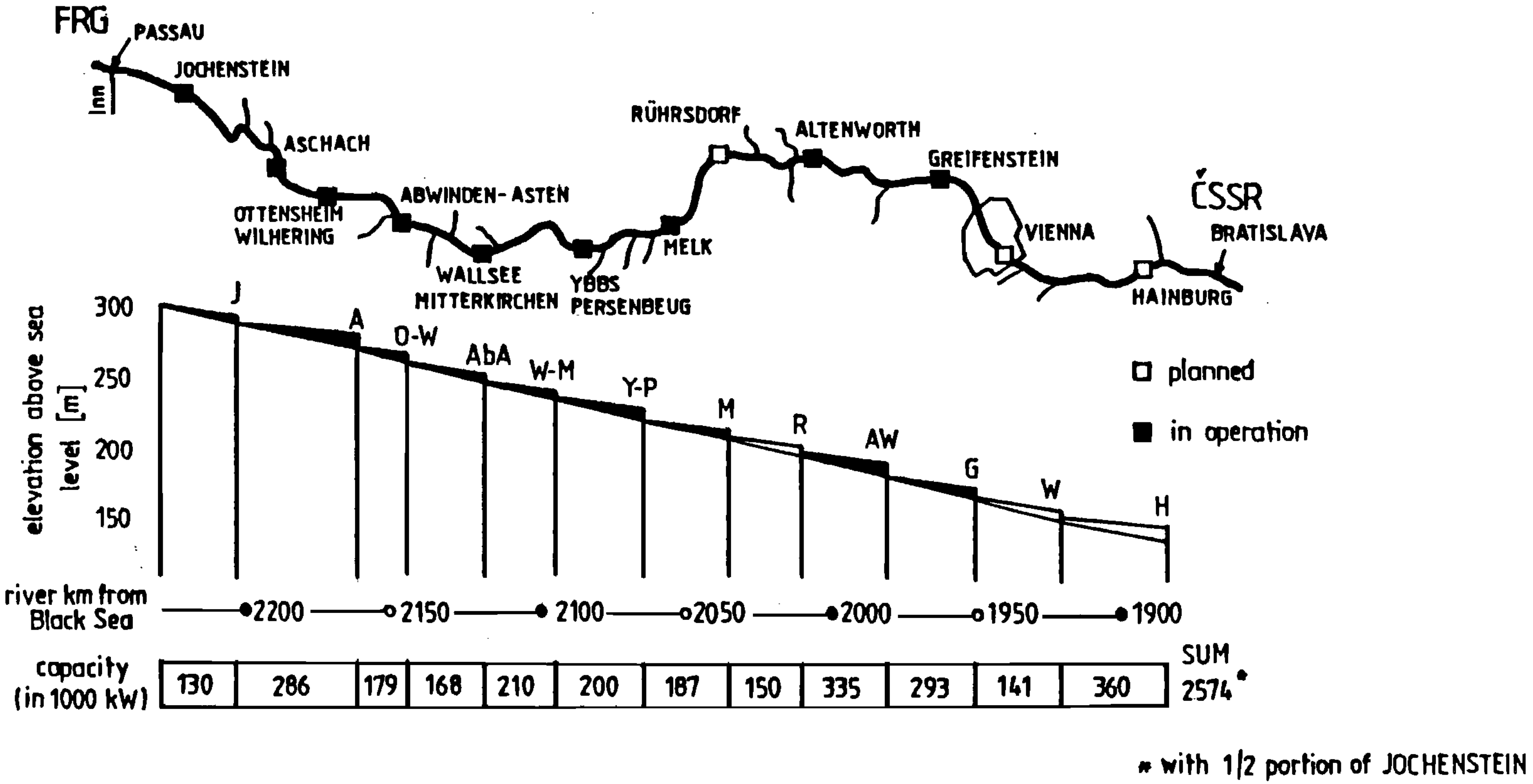

Figure 12. Austrian hydropower stations (DoKW, 1985)

Table 11

Existing and planned hydropower stations in the Danube Basin (OVH, 1985; DoKW, 1985)

Serial No.	River barrage or hydro-power stations	Capacity MW	Power output Gwh
1.-20.	20 hydro-power stations between Ulm and Kelheim	230	1367
21.	Bad-Abbach	-	-
22.	Regensburg	20	130
23.	Geisling	-	-
24.	Straubing	40	270
25.	Deggendorf	20	130
26.	Aicha	-	-
27.	Vilshofen	-	-
28.	Kachlet	54	319
29.	Jochenstein	130	850
30.	Aschach	286	1648
31.	Ottensheim-Wilhering	179	1143
32.	Abwinden-Asten	168	1028
33.	Wallsee-Mitterkirchen	210	1320
34.	Ybbs-Persenbeug	200	1282
35.	Melk	187	1180

Table 11
(cont.)

Serial No.	River barrage or hydro-power stations	Capacity MW	Power output Gwh
36.	Rührsdorf	150	800
37.	Altenwörth	335	1950
38.	Greifenstein	293	1720
39.	Wien	141	620
40.	Hainburg	360	2075
41.	Gabcikovo	700	2630
42.	Nagymaros	146	978
43.	Adony	150	775
44.	Fajsz	100	650
45.	Novi Sad	250	1500
46.	Iron Gate 1	2050	10000
47.	Iron Gate 2	400	2400
48.	Turnu Marmureie	760	3800
49.	Cernavoda	400	3000
	Total	7959	43565

Table 12

Capacity and power-output of the hydropower stations on the Danube, grouped according to countries

(DoKW, 1985)

Serial No.	Country	MW (1985)	MW (2000)	GWh (1985)	GWh (2000)
1.-28.	FRG	283	364	1735	2216
29.	FRG-Austria	130	130	850	850
30-40.	Austria	2008	2509	12071	14766
41-42.	Czechoslovakia-Hungary	-	846	-	3608
43-44.	Hungary	-	-	-	-
45.	Yugoslavia	-	-	-	-
46-47.	Yugoslavia-Rumania	2450	2450	12400	12400
48.	Bulgaria-Rumania	-	760	-	3800
49.	Rumania	-	400	-	3000
	Total	4871	7459	27056	40640
	Total (%)	61.2	93.7	62.1	93.3

WATER QUALITY

6.1 Preliminary Remarks

Abstracted water becomes polluted during use: this is an inevitable processs. Historically society has relied on dilution and natural purification taking place when the waste water is returned to the Danube. However, with increased abstraction, there is a corresponding diminution in the volumes of clean water remaining to dilute and promote the self-purification of the returned waste water. The situation is worsened when the waste water is contaminated with many materials resistant to natural degradation, which persist and are accumulated in the channel. Unfortunately, such potentially harmful materials are becoming more common constituents of waste waters from many domestic, industrial and agricultural sources.

The problem becomes more complicated considering that with today's complex range of chemicals and many by-products produced in their manufacturing and use, routine analytical measure may be of limited value unless the analyst is provided with some guidance on what to seek.

To solve the problem, riparian countries have entered into bilateral and multilateral arrangements, some of them long standing, on shared water resources, but such agreements tend to be limited both in number and scope, usually concentrating on navigation, energy production, flood control or sharing water quantity, rather than directed to controlling water quality. Some multilateral and bilateral agreements having impact on the Danube are shown in Table 13 (WHO, 1982).

6.2 Water Quality Sampling Network and Data Evaluation

Unfortunately, one cannot speak of a harmonized water quality sampling network along the Danube. For example, the frequency of sampling in the FRG, in Austria and in Hungary are quite different. The sampling network related to the Hungarian stretch of the Danube is shown in Table 14 (OVH, 1984). In the FRG, samples are taken from the Danube every second week, while in Austria monthly (Danecker et al. 1981).

Table 13

Some multilateral and bilateral agreements having impact on the Danube (WHO, 1982)

Year	Countries	Topic of agreement
1948 (1960-Austria)	(Austria), Bulgaria, Czechoslovakia, Hungary, Rumania, Ukraine, USSR, Yugoslavia	Danube Convention on navigation of R. Danube
1950	Hungary, USSR	Convention to prevent floods and regulate R. Tisza
1952	Rumania, USSR	Convention to prevent floods and regulate R. Prut
1954	Austria, Yugoslavia	Convention concerning water management questions relating to R. Drava
1954	Austria, Yugoslavia	Convention concerning water management questions relating R. Mura
1955	Rumania, Yugoslavia	Agreement concerning control of frontier waters
1955	Hungary, Yugoslavia	Agreement concerning water management
1956	Austria, Hungary	Treaty concerning water management in frontier region
1956	Albania, Yugoslavia	Agreement concerning water management in frontier region
1957	Hungary, Yugoslavia	Agreement concerning fishing in frontier waters
1957	Rumania, USSR	Agreement extending R.Prut convention (1952) to Tisza, Suceava and Siret, and other frontier waters
1958	Czechoslovakia, Poland	Agreement concerning use of frontier water resources

Table 13
(cont.)

Year	Countries	Topic of agreement
1958	Bulgaria, Yugoslavia	Agreement concerning water management
1959	Rumania, USSR	Agreement extending R.Prut convention (1952) to Danube
1963	Rumania,Yugoslavia	Agreement relating to navigation and power generation Iron Gates
1967	Austria, Czechoslovakia	Treaty relating to management of frontier waters
1969	Hungary, Rumania	Convention relating to control of frontier waters
1971	F.R. Germany, Czechoslovakia	Local (non-government) commission dealing with pollution and management of frontier waters

Regular collection of water quality data on the Hungarian reach of the Danube has been going on for about 20 years. From 1968, monthly, fortnightly, or weekly samples have been taken from regular points (VITUKI, 1978). Samples in general are taken from the main current, but owing to the anomalies which had already arisen in the sixties, in some points the measurements are carried out at different points on a cross-section. (For example, left bank, main current, right bank). At the regular sampling points, the measurement of the general physical, inorganic and organic chemical parameters is predominant (Benedek et al., 1978.)

From the other Danube countries we have no information about their sampling systems.

The evaluation of water quality data is carried out using different methods in the riparian countries. In the FRG and in Austria the biological aspects of water quality are emphasized, while in the CMEA countries the chemical ones. Not only the evaluation but also the classification systems

Table 14

Water quality sampling network on the Hungarian Danube reach (OVH, 1984a)

Place of sampling	Section, Rkm	Frequency of sampling yearly
Rajka	1848,4	52
Komárom, upstream from River Váh	1766.8	26x3
Almásneszmély, downstream from River Váh	1751.8	26x3
Szob, downstream from River Ipoly/Ipel'	1708.0	26x3
Surface water intake of Budapest	1659.0	52
North of Budapest	1654.5	52x3
South of Budapest	1629.0	52x3
Dunaföldvár	1560.6	26x3
Fajsz	1507.8	26
Baja	1479.7	52
Mohács	1451.7	26
Hercegszántó	1433.0	26

are different in the riparian countries. As a consequence, comparison of the individual national river sections is almost impossible (WHO, 1982).

So it is not worthwhile displaying and comparing water quality maps produced by different riparian countries (Danecker et al., 1981, OVH, 1984b, Massing, 1980).

6.3 Chemical Evaluation of Water Quality

As a result of the high levels of oxygen concentration occurring along the river, coupled with the generally high dilution available to effluents discharged into it, the Danube exhibits an excellent self-purification capacity and much evidence is available to demonstrate its power of recovery downstream of polluting discharges, at least in respect of degradable materials. However, even with such pollutants, problems can occur in winter, when ice cover and low temperatures reduce the rates of oxidation and different kind of organic and inorganic materials may subsequently affect the taste and odour of potable water supplies derived from the river (Liepolt, 1979).

The presence of high concentrations of ammonia has also been identified as a possible factor endangering the use of some reaches of the Danube as sources of potable water supply (Benedek et al., 1980, VITUKI, 1985). The maximum ammonium-ion concentrations occur in winter when the water temperature is low and the nitrification processses are suppressed, while striking nitrate concentrations are typical in early spring owing to the high surface runoff from cultivated areas (see Figure 13) (Laszlo-Homonnay, 1985).

Extreme values of some classical chemical components of the Danube are summarized in Table 15, based on samplings and analyses carried out between 1956 and 1964 in the 8 riparian countries (Liepolt, 1967).

Regarding such a conventional parameter as BOD_5, the water quality of the Danube is fairly good (see Table 16) (Benedek-Laszlo, 1980). Here it must be mentioned that the water quality of the Danube is presently much better than the water quality of the Rhine (KfW, 1977), but downstream of larger waste water discharges locally both the micropollutants and the decomposable organic content greatly increase in the sediment (WHO, 1982).

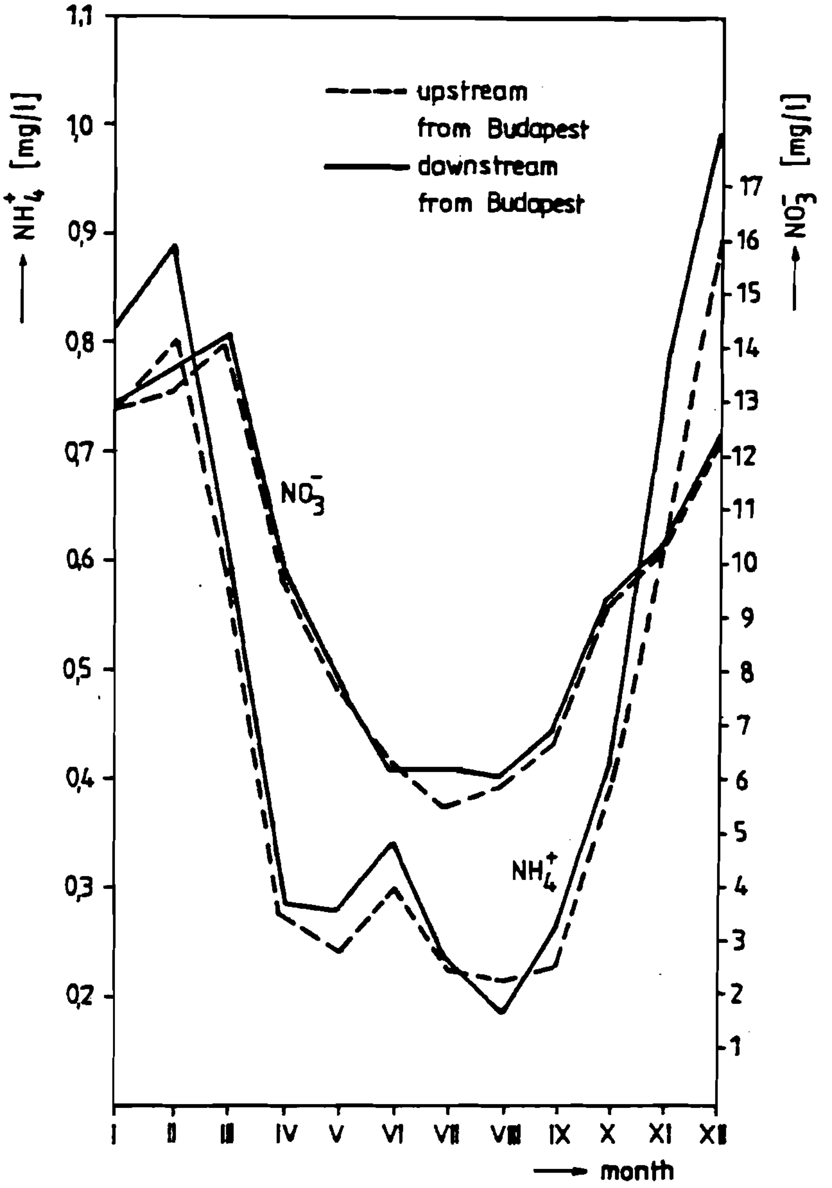

Figure 13. Monthly average values of NH_4^+ and NO_3^- upstream and downstream from Budapest based on sampling between 1979–84 (VITUKI, 1985)

Table 15

Extreme values of some conventional chemical components on the Danube River, 1956-1964 (Liepolt, 1967)

Component	Dimension	Minimum value	Maximum value
pH	-	6.5	8.7
Conductivity	µS	228	448
Total hardness	Gd°	6.1	24.0
Carbonat hardness	Gd°	4.2	22.0
Calcium, Ca^{2+}	mg/l	22	69
Magnesium, Mg^{2+}	mg/l	1.9	20
Iron, Fe^{3+}	mg/l	0.0	1.5
Sulphate, SO_4^{2-}	mg/l	4	45
Chlorid, Cl^-	mg/l	2	40
Ammonium, NH_4^+	mg/l	0.0	11.5*
Nitrit, NO_2^-	mg/l	0.0	2.1
Nitrát, NO_3^-	mg/l	0	21
Ortophosphat, PO_4^{3-}	mg/l	0	1.68
COD ($KMnO_4$)	mg/l	2.5	22.3
Dissolved oxygen	mg/l	4.2	15.8
Oxygen-saturation	%	30	165

* This value is not realistic. It may have been measured close to a sewage outlet

Table 16

BOD_5 profile of the Danube upstream of the Iron Gate in the early seventies (Benedek-László, 1980)

River km	BOD_5 (mg/l)	References
2581	2.5	Bayerisches Landesamt, 1972
2458	3.9	" "
2361	6.0	" "
2297	7.3	" "
2203	5.0	" "
2040	8.0	Von der Emde, Fleckseder, 1977
1870	9.5	" "
1848	4.0	VITUKI, 1975
1694	4.2	"
1580	5.9	"
1452	4.6	"
1185	3.4	Miloradov, 1977
1110	3.7	"
860	4.9	"

As can be concluded from the regular monitoring and survey of the Hungarian Danube section, water quality is mainly determined by the pollution caused by the upstream countries. Regarding the conventional parameters, water quality of the Hungarian stretch is fairly good (the entire reach is in the second class (OVH, 1984a)), but some troubles are caused by certain pollutants of industrial origin, such as heavy metals and oil derivatives (Benedek-Laszlo, 1980).

One of the biggest pollution sources of the Danube is Budapest with two million inhabitants, with a rather developed industry and with very modest sewage and waste water treatment. In spite of this, due to the high dilution (60–100 times dilution at low flow) and to the excellent self-purification capacity of the river, there is no enormous difference in the water quality of the Danube upstream and downstream of Budapest (Table 17) (VITUKI, 1985).

The ratio of accumulated heavy metals in the bottom deposit in the Hungarian Danube and its tributaries is as high as 2 to 20 times the background values (see Table 18) (Literathy-Laszlo, 1980, Somlyody-Hock, 1985).

Some tributaries of the Danube system can present problems, particularly when they contain effluent residual derived from neighbouring countries over which the water user has no control. One such river is a secondary tributary of the Danube, the Slana (Sajo), where a high degree of reuse by successive water users takes place. Its quality is far from satisfactory as a result of lignine sulphonic acid in the river water entering Hungary, in addition to containing high concentrations of heavy metals (WHO, 1977a).

As has been mentioned in connection with the navigation problems (Chapter 5.2), the Danube Commission is confined to hydrological surveys and waterway regulation. The only water quality task is the supervision and prevention of water pollution caused by navigational vessels (Benedek-Laszlo, 1980).

Table 17

Characteristic water quality data of the Danube upstream and downstream from Budapest, 1980-1984 (VITUKI, 1985)

Component	Dimension	$\bar{C}^{+}$		$C_{95\%}^{++}$	
		upstream from Budapest	downstream from Budapest	upstream from Budapest	downstream from Budapest
Temperature	°C	10.7	10.8	19.9	20.3
Total dissolved solids	mg/l	283	284	353	358
pH	-	7.9	7.9	8.5	8.5
Dissolved oxygen	mg/l	10.6	10.5	8.1	7.7
COD_d	mg/l	20.8	22.9	28.6	31.9
COD_p	mg/l	7.0	7.4	9.5	9.9
BOD_5	mg/l	5.3	6.3	7.9	9.5
Total hardness	mg/l	107	108	132	134
NH_4^+	mg/l	0.46	0.51	1.07	1.22
NO_2^-	mg/l	0.10	0.11	0.18	0.19
NO_3^-	mg/l	9.7	9.8	15.4	15.6
PO_4^{3-}	mg/l	0.40	0.41	0.76	0.84
Oil	mg/l	0.22	0.22	0.50	0.54
Phenols	mg/l	0.003	0.004	0.011	0.013
Detergents (anionactive)	mg/l	0.13	0.13	0.30	0.33
Na %	%	11.0	11.4	16.4	19.1
Pantle-Buck index	-	2.6	2.7	2.8	2.9

— II. Class

═ III. Class

$^{+}$ average values

$^{++}$ values of 95 % duration

Table 18

Bottom deposit pollution along the Hungarian Danube reach

(Literáthy-László 1986; Somlyódy-Hock, 1985)

Heavy metal compnnent	Background values, mg/kg (Taylor,1976)	Measured sediment mg/kg	
		minimum	maximum
Zinc	43 - 98	16	4 200
Chromium	3.9 - 8.4	3	186
Copper	9.2 - 16.8	1	74
Lead	12.9 - 32.9	4	140
Mercury	0.02 - 0.12	0.03	2.0
Cadmium	0.7 - 1.2	1.0	6.0
Manganese	3.8 - 1156	20	1 200

6.4 Biological and Bacteriological Evaluation of Water Quality

With respect to hydrobiology it can be said that the only informal international activity for the Danube is being conducted by the SIL–IAD (International Society for Limnology, International Working Community of the Danube Countries) International Research Committee. Its primary task is to coordinate the hydrobiological research activities on the Danube accomplished in the riparian countries. However, investigations carried out by the Committee itself. The Committee issued a monograph on the

Danube crossing eight countries, an accomplishment of which was supported by the experts of every riparian country (Liepolt, 1967). Unfortunately, since the publication of this excellent work a lot of changes of water quality have taken place on the Danube catchment.

In the framework of the research activities of SIL–IAD, in Austria the socio-ecological effects of the impoundments are being studied (Oeko., 1984), which extends beyond the routine activity of SIL–IAD. In Czechoslovakia bacteriological and zooplankton research is emphasized (Rotschein, 1976, 1981; Daubner, 1972). In Hungary the fish fauna, the primary production and oxygen balance aspects have mainly been studied (Bartalis, 1984; Berczik, 1976; Bothár, 1973; Dvihally 1971; Nemeth, 1971, Toth, 1982). In Yugoslavia saprobiological and fish-faunistical investigations, while in Bulgaria zooplankton and zoobenthos studies are carried out. Soviet and Romanian experts are involved in research of the phyto- and zooplankton and reeds of the Danube delta and fish-faunistical investigations (Curcin, 1985; Levina–Sergejev, 1985, Zankov et al., 1984).

The activity of SIL–IAD covers the following 3 fields:

- description of the main characteristics of the river,
- continuous survey of the changes in these characteristics,
- investigation on the impacts of human activities (Liepolt, 1979).

Along most reaches of the Danube the water quality of biological grade II (β-meso-saprobic) can be measured, but downstream of major polluting discharges, quality drops to grade III (α-meso-saprobic). This indicates that current pollution control measures are inadequate, which could lead to future restrictions on water uses and to higher treatment costs (WHO, 1976).

The suspended solids content fluctuates in the range of 30–100 mg/l on the average, but in the cases of extreme floods, 1500 mg/l, which is the highest value to have occurred. Suspended plankton consists mainly of diatoms, and the brown assimilative pigments thereof give the brown and by no means "blue" colour of the Danube water. The bottom sediment includes gravel, gravelly sand and sandy loam; the biomass of the bottom fauna is only 5–6 kg/m^2 (Benedek et al., 1978).

From the bacteriological point of view it has been found that bacteriophages and enteroviruses show high survival rates in the Danube and may even resist the water treatment processses currently given to some potable supplies (WHO, 1977a). Bacterial counts in the river can exceed the recommended limits for irrigation or aquatic recreation (Benedek et al. 1980).

As is well known, downstream of major waste water discharge points (Bratislava, Budapest) the hygienic situation is rather severe. Table 19 shows a typical bacteriological picture of the Danube, at the water intake of Mohács and, in the water distribution system of Pécs for which the water is provided by this intake (Geldreich, 1984). The virological investigations by public health organisation need further development.

6.5 Sewage and Waste Water Disposal

6.5.1 Present situation

The list of the major towns situated along the banks of the Danube or located in the catchment is included in Section 3. The common characteristic of these cities is that they – with a few exceptions – do not have sewage and waste water treatment plants, or, if they do, the treatment efficiency is not adequate. Due to this fact, the Danube and its tributaries receive significant organic and inorganic loads.

In addition, the Danube receives non-treated or partially treated effluents from a wide range of industries including pulp and paper mills, iron and steel mills, petroleum refineries, chemical plants, cement works, coal and other mineral processsing, breweries, sugar refineries and canneries. The paper, petroleum, iron and steel industries have been identified as those most urgently in need of industrial pollution control measures (WHO, 1977b).

Industrial pollution of the Danube may be potentially more serious in the upper reach, as more industrial plants are sited there and lower volumes of flow are available for diluting the resulting effluents (Liepolt, 1979).

Table 19

Bacteriological water quality from the Danube-water intake at Mohács to the distribution network of Pécs (Geldreich, 1984)

Type of water	Coliform total (per 100 ml)	Fecal Coliform (per 100ml)	Fecal Strep. (per 100ml)	Clostridia (per 40 ml)	SPC(37°C) per ml	NH_4^+ mg/l
nube-water at Mohács	5 200-72 400	200-4.600	<100-500	64-240	3800-98,000	0.17-1.32
arified water of Mohács	160-1200	-	-	-	210-960	0.2 -0.96
ored mixed water at Pécs	40-2100	-	-	-	95-850	0.04-1.10
ter reaching the active carbon	1-200	-	-	-	37-110	0.06-0.60
rified drinking water	xx	-	xx	-	4-32	0.01-0.39
ored drinking water	xx	-	xx	-	3-43	<0.1 -0.42
ter in the network	xx	-	xx	-	4-9	<0.1

Data from the period October 1983 to March 1984

: Practically not demonstrable

Some information of the major pollution sources in the riparian countries determining the character and nature of the pollution load is given in Table 20 (Benedek, 1986).

There is no adequate warning and emergency system between the riparian countries; accidents which result in water pollution are of particular concern. In just one year there were almost 20 accidents in the Danube catchment resulting from oil pipeline failures alone (WHO, 1977a).

In the past, the most serious accidental spills occurred in Vienna, Bratislava and Vác (40 km north of Budapest) (WHO, 1982). In 1976, at the Nussdorf water works near Vienna alcylphenols in the water caused a longer quarantine of this plant (Frischherz–Bolzer, 1984) and in 1980 at Vác organic solvents resulted in the same situation. Significant hazard was caused to the Bratislava water works by the leakage of oil resources at a nearby oil refinery (WHO, 1982). In all these cases the rehabilitation of the contaminated wells either lasted for an extended period or the wells had to be abandoned.

The forecasting of such events and the organisation of their control is a very important task for all Danube countries (WHO, 1984; Benedek–Hammerton, 1985; Katona, 1984).

Thermal pollution so far has not caused any detectable damage, although the river is being used as a source of cooling water for industry and for power generation (Liepolt, 1979). Similarly, at the current level (see page 41) of development of nuclear power stations along the river, the safety precautions should provide adequate protection from radioactive discharges (IAEA, 1979).

6.5.2 Future developments

The amount of pollution derived from domestic sewage will increase as a result of the necessary improvements of water supply and sanitation. More connections to a piped water service and, particularly, more connection to sewer systems can intensify the load discharged to the water course, even if some treatment is given. This is particularly true in respect to nutrients, which intensify the growth of algae and fungi, affecting the oxygen balance of the Danube in this manner.

Table 20

Major pollution sources along the entire Danube

(Benedek, 1986)

River km	Cities[x]		Tributaries with major industrial pollution (pulp and paper, chemical, etc.)
	with waste treatment	without or with partial waste treatment	
2370	Regensburg FRG		
2220	Passau region FRG		
2130	Linz A		
2120			Enns A
1930	Wien/Vienna/A		
1880			March/Morava A/CS
1870		Bratislava Cz	
1800		Győr region H	
1760			Váh CS
1650		Budapest H	
1250		Novi Sad Yu	
1170			Sava YU
1170		Beograd (Belgrade) Yu	
1100			Morava YU
690			Jiu R
600			Olt R
530			Jantra BG
430			Arges RO

[x] with population equivalent of 500.000 or more

Increased water use will result, inevitably, in increased volumes of industrial effluents being discharged into the river system. With greater sophistication of industrial manufacture, it appears probable that the quantities of bio-resistant chemicals requiring disposal will also increase. This potential pollution will come not only from direct discharges of liquid effluents but also from the need to dispose of sludges and other solid wastes derived from industry and settlements (WHO, 1982).

Construction of sewage and industrial effluent treatment plants will not completely overcome the pollution problems, as it has been established that a considerable part of the pollution load originates from non-point sources, mainly from urban and agricultural runoff (Benedek et al., 1980), although additional hazards are presented by inadequate control over indirect pollution of groundwater (and subsequently of the Danube) from dumping of waste materials (Ainsworth, 1981).

The development of more nuclear power generating capacity within the Danube catchment will call for increased quantities of cooling water, increasing the risk of local thermal pollution (WHO, 1982).

6.6 Bank-Well Filtration for Water Supply

6.6.1 Basic problems of bank-well filtration

The most important utilization of the Danube water is the drinking water intake through bank-well filtration for potable and other supply purposes.

The water quality of the bank-filtered wells is endangered by three effects caused by the increase in pollution load of the Danube:

- simultaneously with the deterioration of "raw water" the purification capacity of the filter layer also decreases,
- another mechanism is accumulation of micropollutants in bottom sediment as precipitation,
- anaerobic conditions in the filtration layer (Benedek–Laszlo, 1980).

The nitrate content of the groundwater along the Danube is mostly due to the agriculture. In order to reduce it, there is a project underway in Hungary, supported by UNDP in cooperation with FAO (UNDP–FAO, 1982–86).

Use of water is often hampered by micropollutants mostly bound to the suspended sediment; silting causes the accumulation of pollutants in the bottom sediment. This phenomenon deserves more detailed attention from the point of view of water uses because when settled, it menaces bank-filtered water quality, while in suspended form it menaces direct drinking water- and irrigation water-intakes. To this group of micropollutants belong the different forms of heavy metals, e.g., mercury, cadmium and organic compounds of higher molecular weight and of less polar character, such as polyaromatic hydrocarbons, several mineral oil fractions and oil derivatives (Benedek–Laszlo, 1980).

If the oxygen content in the water is not sufficiently high or the bottom deposit is over-polluted with inorganic material, zero oxygen might occur in the benthos, or in the filtration layer (anaerobic conditions).

In water abstraction regions where anaerobic filtration processses dominate in the aquifer, the following characteristic water quality changes occur during bank-well filtration: The dissolved oxygen, redox potential and pH decrease, nitrate is reduced to nitrite and ammonia, iron and manganese are redissolved.

The pollutant removal efficiency of the bank-well filtration process is sufficient for the majority of components at the present pollution level of the Danube. Downstream of Budapest at a typical horizontal well, the removal efficiencies can be seen in Figure 14. Considerable redissolution of iron and manganese is typical in the anaerobic filtration layer. Flow from the background zone towards the wells is responsible for the high values of potassium, sulphate, chloride, calcium, hardness, conductivity, magnesium, sodium (Laszlo–Homonnay, 1985).

As a consequence of the three effects mentioned above, the conventional technology (disinfection via chlorination for health protection) is not satisfactory for potable water and the introduction of post-withdrawal treatment is necessary at some water works along the Danube (Benedek–Bulkai, 1981; WHO, 1984).

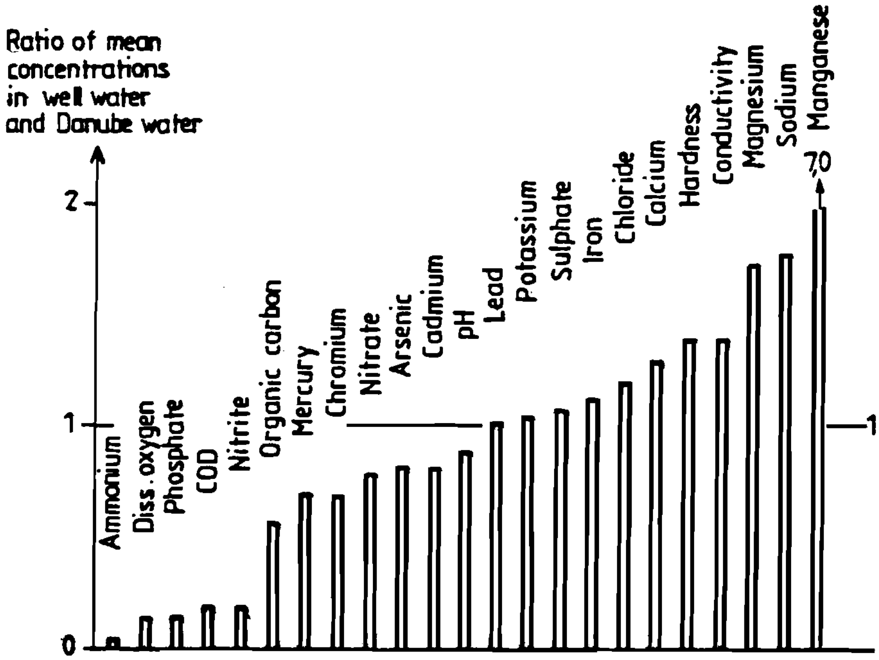

Figure 14. Water quality changes due to bankwell filtration (Laszlo–Homonnay, 1985)

6.6.2 Bank-well filtration at different Danube countries

Federal Republic of Germany

Along the Danube there is no bank-well filtration system in operation.

Austria

Bank-well filtration of river water has been practised for more than 40 years to supply Vienna. The water work at Nussdorf can meet about 15% of Vienna's water demand with a maximum output of 100,000 m^3/day. After chlorination it is pumped into reservoirs and to the supply system (Frischherz–Bolzer, 1984).

The city of Linz also obtains its drinking water from bank-well filtered Danube water. Austria obtains only 1% of its potable water supply from bank-well filtration (WHO, 1981).

The use of bank-well filtrated water in Austria poses the following problems:

- There are sometimes taste and odour problems originating from unknown waste water effluents upstream of Vienna.
- There is no effective alarm system for river water contamination (Frischherz–Bolzer, 1984).

Czechoslovakia

Bank filtered water constitutes an important proportion of drinking water supplies. The city of Bratislava is dependent on bank filtered water from the Danube with the capacity of 160,000 m^3/day. The water works of Bratislava have been damaged by petroleum derivatives coming from the "background" (Lehoczky, 1978). In addition to natural recharge by the Danube, the Zitny Ostrov aquifer is expected to provide the key future source of drinking water for Southern Slovakia (UNDP–WHO, 1977).

Hungary

There is a quite different situation in Hungary, where about 22% of the population relies directly on the Danube for its drinking water and about one-half of the industrial water is obtained from the river (Benedek, 1977).

Europe's largest bank-well abstraction scheme supplies drinking water to Budapest. The Municipal Water Works obtain approximately 310 million m^3/year drinking water from bank-wells located along the Danube upstream and downstream of Budapest in a length of 90 km. Bank-well filtration plus additional disinfection by chlorination has resulted in high-grade drinking water quality for decades (Laszlo–Homonnay, 1985).

Fortunately, the water gained from bank-filtered wells is of a fairly good quality because in the slightly polluted filter layers the aerobic conditions promote the physical, chemical and biochemical processses providing decomposition of oil, phenols and detergents, nitrification processses and adsorption of heavy metals (Benedek–Laszlo, 1980).

It may be mentioned here that the bank filtered water resources located along the Hungarian Danube stretch are over 5.5 million m^3/day, and about 2 million m^3/day are located along other tributaries (WHO, 1983).

Yugoslavia

Both Belgrade and Zagreb rely heavily on bank-well filtered water for potable supply, the former obtaining 95% of its total needs via this system. Zagreb obtains potable water of excellent quality from the relatively unpolluted waters of the Sava river. Novisad also obtains its water via an extensive radial bank-well filtration system operating along the banks of the Danube. In the province of Voivodina, where more than 10% of Yugoslavia's population live, 15% of all water requirements are satisfied by bank-well filtration supplies.

Romania

An increasing number of drinking water supplies depend on water obtained via bank-wells located along the banks of the Danube. Bank-well filtration is important in supplying both Craiova and Galati with drinking water. At another location on the banks of the Jiul river, a bank-well filtration capacity of 60,000 m^3/day is in operation.

Bulgaria

No information is available.

USSR

There is no bank-well filtration system in operation along the Danube (WHO, 1984).

It is to be noted that along the Danube the situation of bank-well filtration, for the time being, is much better than along the Rhine in the FRG, where the most common treatment applied is oxygenation and activated carbon filtration to remove organic micropollution (WHO, 1984).

In all probability a similar situation will develop along the Danube in the distant future. As a consequence, the investment and operating costs will be much higher than now.

6.6.3 Direct surface intake

The quality of the water is satisfactory almost over the entire length of the Danube and suitable even for drinking water supply by direct surface intake, after a simple treatment, filtration and chlorination as it is applied in Budapest (about 20% of the entire water demand is met directly from the river). As a consequence of the rapid industrialization of the riparian countries, however, the hazard of persistent micropollutants is growing and presumably the simple water treatment technology will not be satisfactory in the near future (Benedek–Laszlo, 1980).

6.7 Effects of River Training and Barrages

6.7.1 General remarks

The multipurpose utilization of the Danube water is of vital importance for the approximately 71 million inhabitants in the river basin. The economic development in the riparian countries, and the increase of navigation accelerated by the Rhine-Main-Danube canal interconnecting the two important transcontinental waterways ranging from the Atlantic Ocean to the Black Sea will likely cause water quality problems affecting considerably the riparian countries from the point of view of public health (Benedek–Laszlo, 1980).

It is worth mentioning that a large stream like the Danube may create a lot of water pollution control problems even without the barrages already in operation and under construction (Benedek et al., 1980).

Construction of river barrages and other regulatory structures (i.e. groins) after the installation of bank-wells may significantly alter the hydraulic conditions in a river and may have an effect upon the groundwater level, too. Reduced velocity in the river bed may lead to increased deposits of the smaller-grained, silt-like material, and may cause a reduction in dissolved oxygen content of the river water, leading to subsequent water quality changes, (solubility of iron and manganese, reduction of sulphates and nitrates, problems of taste and odour, etc., in the impounded water, WHO, 1984).

The high concentrations of nutrients discharged into the Danube as constituents of sewage and other effluents increase eutrophication, so that much of the brown colour of the river is associated with assimilated brown pigments from diatoms growing on those nutrients. The effects of biological growth and decay on the quality of impounded water can influence the use or the treatment requirements of the water (WHO, 1982).

Bio-resistant materials, persisting in the water, can be accumulated by aquatic organisms or absorbed on the suspended solids in the water course; they also can be deposited and accumulated in the sediments. Alterations in the flow regime of the river, by constructing river barrages or groins, may thus provide a long-term reservoir of pollutants, capable of subsequently being mobilized by bio-chemical or physical processses and so providing further hazards to water quality.

Deposition of sediments, possibly contaminated with toxic metals and organic chemicals, will be increased by reiterated improvements of river regulation systems intended to improve navigation and facilitate hydroelectric power generation (WHO, 1982).

An increase of navigation expected as a result of improved river regulations, can also lead to an increase in the likelihood of accidents resulting in increased pollution of the river water (WHO, 1984).

The inter-river canals particularly when considered in combination with the proposed impoundment reservoirs, have a potential to change the ecosystem of the Danube. It is probable that the improved communication and transport facilities provided by such links will encourage still more urban and industrial development in the river basin as wider markets for industrial and agricultural products become available. The risk of pollution of the Danube will increase with the transfer of water between the different river systems, while the extra traffic and development so generated will increase the risk of accidents (WHO, 1982).

6.7.2 Experiences by different Danube countries

Federal Republic of Germany

Reports on publications dealing with this topic are not available.

Austria

Whenever a new barrage has been built in the Austrian Danube section the water of the wells, along new impoundments has begun to deteriorate with increasing iron and manganese contents causing taste and odour problems due to dissolved oxygen depletion and anaerobic conditions (Frischherz–Bolzer, 1984).

An example of barrage construction in the Austrian stretch of the Danube serves to demonstrate some of the changes which can be expected and the problems that can result. At the water intake site of Godworth, sited upstream of the power station of Ottensheim–Wilheving, the water level in the Danube has subsequently been raised by an average of 9 m above the original level due to canalization. This has resulted in reduced flow velocities and an increase in deposit of organic matter in the river bed, causing blanketing and subsequent reduced capacity of the bank-well filtration plant.

At the water works of Ybbs and at the water supply facilities at Goldwarth supplying the town of Linz, the reduced oxygen levels in the river water, resulting from an increase in organic matter in the river sediments, have necessitated the introduction of post-extraction treatment to produce a drinking water of acceptable quality (WHO, 1984).

In Austria a complex investigation about the ecological, technical and sociological impacts of one of the barrages (Altenwörth, downstream of Krems) has been started (Oeko., 1984).

Czechoslovakia and *Hungary*

Gabcikovo–Nagymaros barrage system is being planned and constructed (see Annex II). According to a forecast, suspended solids content which decreases by 30% over a river stretch of about 70 km downstream of Bratislava at present, will decrease by 55% after the construction of the barrage (Benedek et al., 1978; Rotschein, 1976). The regular dredging of this sediment should be included as part of the normal maintenance service.

Additionally, the decomposing organic and pathogene microorganism content originating from untreated municipal wastes, will obviously result in anaerobic decomposition and consequently an oxygen loss in the bottom sediment, thereby creating better conditions for the growth of zoobenthos. The mass thereof will be even greater than 100 g/m^2 over the backwater reach of the barrages. No significant change can be expected, however, in floating zoo- and phytoplankton, and probably the diatoms will dominate in the future, too (Rotschein, 1976).

It is worthwhile to mention an investigation carried out by the Hungarian Research Centre for Water Resources Development (VITUKI). Its aim was to forecast the effect of the barrages to the trophic conditions, to the change in primary production and planktonic communities. The research has been carried out in existing river branches of low flow velocity and of increased transparency. While the main Danube is mesotrophic, some of the branches studied are in eutrophic condition. The number of algae and the biomass are several times higher in the low flow branches. As a consequence, the meso-trophic level of the Danube will be higher when impounded. This means that the extended nutrient input and all the waste water discharged should be controlled by an increased treatment program (VITUKI, 1985).

Yugoslavia and *Romania*

The Yugoslavian experiences related to the Iron Gate barrage (Djerdap) can be summarized as follows:

- Since the construction of the barrage the turbidity in the lacustrine part of the reservoir has decreased and there has been intensive sedimentation of suspended organic and inorganic particles;
- The temperature gradient down to 20 m (the maximum height of impounded head water is 33.5 m) was low in August ranging between 0.2°C and 0.5*degrees*C, so that stratification did not occur;
- The oxygen deficiency was higher in the lacustrine part than in the fluent one, less being absorbed from the atmosphere and more being required for the decomposition of organic matter;
- The $KMnO_4$ consumption showed a temporary increase in the lacustrine part suggesting that there was a temporary increase of the content of soluble organic matter;
- The phosphate and ammonia content as well as the concentration of total solubles were also higher, from time to time, in the lacustrine part of the reservoir than in the fluent part;

- There was a greater $KMnO_4$ demand and a higher concentration of phosphate and total dissolved salts at 20 m depth than in shallower water.
- The vertical distributions of the phosphates, ammonia, dry residuals, sulphates and the $KMnO_4$ demand showed that there was a temporary chemical stratification although it was not strongly marked.
- The concentrations of calcium, biocarbonate, carbonate hardness and alkalinity was not significantly different in the two parts of the reservoir (Jankó, 1978; Petrović, 1975; Petrović, 1978).

Reports dealing with the effects of impoundment on the operation of Water Works in Belgrade are not available.

Bulgaria and *USSR*

There is no hydropower system in operation.

Finally, two reaches of the Danube have to be mentioned where post-extraction treatment is necessary although they are not affected by any barrage:

- At the Lobau water treatment plant (near Vienna), the bank-well filtered water has to be treated for iron and manganese removal because of the low dissolved oxygen level in the filtration layer.
- Similar situation is present at a plant of the Budapest Municipal Water Works, located south of Budapest where ozone-oxidation is used for iron and manganese removal of bank-well filtered water (WHO, 1984).

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ANNEX I

(Draft translation from Hungarian)

DECLARATION ON THE COOPERATION OF THE DANUBE COUNTRIES ON WATER MANAGEMENT AND ESPECIALLY WATER POLLUTION CONTROL ISSUES OF THE RIVER DANUBE

Accepted in Bucharest
13 December, 1985

At the Bucharest Conference dealing with the issues of water management of the Danube, representatives of the governments of the Danube countries

- being aware of the high importance of the rational management and pollution control of the Danube water for the welfare and the health of the peoples of the Danube countries as well as for the economical and social development thereof,
- being convinced that besides the coordination of national efforts and necessary measures among the neighbouring Danube countries, the efficiency of actions against the pollution of the Danube water could essentially be increased by means of a multilateral cooperation of all Danube countries,
- taking into account the importance of the educational work to be performed in wide circles of the youth in the interest of protecting, preserving and especially improving the quality of the Danube water,
- guided by generally accepted principles and rules of international law, including the Constitution of United Nations, in accordance with the interests and the sovereignty of all Danube states,

- striving for the consideration of the content of the Closing Document of the Conference for European Security and Cooperation as well as of the theses of the Closing Document accepted on the Madrid meeting of the representatives of the European countries, in order to promote regional cooperations aiming at pollution control and utilization of water resources,

declare the following:

1. The preservation and rational utilization of water resources, the prevention, termination and control of their pollution constitute an organic part of the national water management and environment protection policies of the Governments of the Danube countries.

   Taking into consideration the fact that the water of the Danube is being utilized for various purposes, among others for water supply of the population, the Governments of the Danube countries – in the interest of the present and future generations as well – are ready to take measures, according to the prescriptions of the legal rules valid in the different countries and within the frame of the techno-economic possibilities, to safeguard the water of the Danube from pollution, with special regard to dangerous and radioactive substances and to a gradual decrease of the degree of pollution, taking into account also the ecological requirements connected with the water of the Danube. The Governments also effectuate on their respective territories a systematic monitoring of the waste waters released into the Danube and authorize the introduction of these waters only in accordance with the legal rules valid in the different countries; they also control the accomplishment of the conditions of introduction and at the same time observe the changes in water quality.

2. The complex measures, worked out for long ranges by the proper efforts of the Governments of the Danube countries, and especially the execution of these measures, can be completed and confirmed, in a way corresponding to the goals defined above, by means of bi- and multilateral international cooperation.

For this purpose, the Governments of the Danube countries strive for the following:

2.1 In the framework of their bi- and multilateral cooperations they carry out systematical observations on the water quality of the Danube, on the basis of programmes and methods enabling the collection of comparable data. To that end, they work out appropriate programmes and methods not later than within one or two years following the signing of this Declaration.

The water quality observations will be performed in the crosss-sections where the Danube steps from the national territory of one Danube country to that of another; when the Danube constitutes the state border, in the beginning and final crosss-section of the common frontier reach, or in other sections determined in the frame of bilateral relations. If it is necessary, the Danube countries interested can determine, in the frame of their bilateral relations, other crosss-sections as well, such as those up- and downstream of the major tributaries of the Danube, up and downstream of major towns and impounding reservoirs, and further in the main branches of the Danube delta at the Black Sea those representative crosss-sections, downstream of which no anthropogenic impact can modify the water quality any more.

In 6 months time, after having fixed the methodology, water quality observations and analyses will be started, according to that methodology. In two years after the start of the observations the water quality characteristics of the Danube, as observed during the given period, will be determined by data processing according to the methodology fixed.

2.2. The Governments inform each other about their organs competent for monitoring of the pollution of the water of the Danube and establish the methods and the programme of water quality observations; they also designate their organs to which the results and evaluations regarding the water quality of the Danube as well as all urgent informations connected with accidental pollutions and measures aiming at their removal, mutually have to be reported.

2.3 The Governments will study the possibility of automatization of the observation of the Danube's water quality and of the installation of automatized monitoring systems in the cross-sections mentioned above.

2.4 The Governments will inform each other, through their abovementioned competent organs, whenever necessary but at least every two years, about the results of analyses and evaluations performed in the observation crosss-sections. They inform each other on their measures aiming at the protection of the Danube water from pollution as well as about the agreements taking effect between Danube countries to this purpose, including the results achieved by means of their realization; they also inform each other about the technical solution of sewage treatment, about water analyses, investigations of water resources and the internal state norms for water quality protection.

2.5 The Governments promote, whenever necessary, but at least every two years, the organisation of the meeting of the representatives of the competent organs of the Danube countries aiming at comparing the results of the analysis and evaluation of the Danube's water quality as well as at the solution of other problems arising in the course of the cooperation to be realized on the basis of this Declaration.

2.6 The Governments inform each other about their competent organs working out the balances of water resources and needs, and about the results of these works whenever regarding a frontier reach of the Danube. Within a year, after signing this Declaration, a harmonized method for comparing the water balances of the Danube countries will be developed in order to obtain comparable results in the border sections. On this basis, they will strive for compiling the summarized water balance of the Danube.

3. In the interest of realizing the goals of this Declaration, the Governments of the Danube countries will gradually strive to arrange, by means of bi- and multilateral agreements, the concrete issues of the water quality control of the Danube which are of basic interest for the respective states.

4. In order to fight against floods on the Danube and against the dangerous ice phenomenon causing floods, the Governments of the Danube countries will inform each other, through their competent organs, about the development and passing of floods as well as about the ice phenomena forecast for the crosss-sections selected by agreements.
5. The Governments of the Danube countries continue – among others by means of creating legal rules – with striving for taking measures for protecting, preserving and improving the environment and for the enforcement of increased responsibility, particularly in the field of protecting waters from pollution.
6. In order to realize the measures foreseen by this Declaration, the competent organs of the Danube countries – to be appointed for taking these measures – will coordinate their measures in alternation with each other, beginning with the competent organ of the state taking the initiative and continuing according to the order of succession agreed upon at the first meeting.
7. In order to successfully carry out the measures laid down by this Declaration, the Governments of the Danube countries will take advantage of the possibilities of cooperation with the United Nations Organisation, with its specialized organs as well as with other international organisations interested.

The original copies of this Declaration will be guarded by the Government of Romanian Socialist Republic.

The Government of each Danube country will receive from the Government of Romanian Socialist Republic the attested duplicate of this Declaration.

Each Danube state will make public and spread the text of this Declaration and ensure its widespread knowledge.

The Government of the Romanian Socialist Republic is invited to hand over the text of this Declaration to the Secretary General of the United Nations Organization, in order to pass it, as an official working document of the United Nations Organisation, to all members of that Organisation, furthermore to hand it over to the Secretary General of the World Meteorological Organisation, to the Managing Director of the United Nations Educational, Scientific and Cultural Organisation, to the Director of the World Health Organisation, to the Managing Secretary of the United Nations Organisation's Economic Commission for Europe, to the Director General of the International Atomic Energy Agency, to the President of the Danube Commission and to the Director of the United Nations Organisation's Programme for Environmental Protection.

The representative of the Danube countries have signed the Declaration aware of the high importance of this document.

Accepted in Bucharest, on the 13th of December, 1985, in Bulgarian, Czech, Hungarian, German, Russian, Romanian and Serbo-Croatian languages.

ANNEX II

ENVIRONMENTAL IMPACT ASSESSMENT OF THE GABCIKOVO–NAGYMAROS BARRAGE SYSTEM

In September 1977, an agreement was signed between the Governments of Czechoslovakia and Hungary on the implementation of a joint project aiming at better utilization of the stretch of the Danube between Budapest and Bratislava, where the river is the common border between the two countries along a length of about 140 km. The project includes two subsystems.

- The upper one has a barrage at Dunakiliti closing the main arm of the Danube and diverting the discharge into a derivation canal having a length of 30 km. On the canal there is a hydropower plant and a navigtion lock at Gabcikovo. The tailwater canal returns to the main arm at Palkovicovo.
- The lower subsystem is a river barrage constructed in the bed at Nagymaros. it is composed of three main parts: the weirs closing the bed, the hydropower plant and the navigation lock.

The construction of the system started in 1978. Since then the derivation canal was almost completed. The construction of the structures at Gabcikovo is also in a well developed phase. At Dunakiliti the foundation of the barrage was finalized. According to the timetable in 1990 the power plant on the derivation canal will be in operation. At Nagymaros only preliminary work was done until now. It is planned to start the construction in 1987 and finish in the early 90s so that the whole system should be completed before 1994.

In the meantime some environmental concerns were raised in connection with the modification of the river regime. The Hungarian National Water Authority, which is responsible for planning and designing the system, have an environmental impact assessment prepared in cooperation with the National Environment Authority. For this study, the results of numerous earlier investigations were utilized together with the recommendations of several special committees set up by the Hungarian Academy of Sciences for the analysis of the environmental and agricultural impacts of the barrage system. The purpose of this paper is to give a short evaluation of this environmental impact assessment.

DEVELOPMENT OF WATER MANAGEMENT IN THE DANUBE VALLEY

Water management in large river valleys aims at the utilization of natural resources (water, energy, bed load) and other economic advantages (transport, recipient of wastes, recreation) offered by the river. Four main phases can be distinguished in its development:

- *flood-plain management*, when man adapts his activity to the natural conditions determined by the random character of the water regime and utilizes the advantages provided by the presence of water considering the limitations determined by these conditions;
- *primary control of water regime* (river training, flood control and water control over the catchment), when larger areas become arable, navigation is improved and settelements can move near the river establishing closer contact with water by decreasing the damages which might be caused by random hydrological events;
- *river canalization*, the main purpose of which is the stabilization of the water level, the decrease of its fluctuation and the utilization of the energy in the river by constructing barrages and maintaining stretches with low slope between them;
- *complete* (quantitative and qualitative) *control of runoff*, which can be achieved by regulating the discharge according to the demands using the retention capacity of large reservoirs and by efficacious treatment of wastes released into the river.

Naturally there are no sharp limits between these phases. They are overlapping each other and may be interwoven in space and time. The subsequent phases can be well recognized, however, as the main character of water resources development in any river valley.

In the Danube valley, the river was always a decisive factor influencing the socio-economic development of the riparian countries. Until the eighteenth century, this relationship was absolutely extensive, the societies tried to utilize the advantages provided by the river (navigation, fishery), but the development was limited by random events characerizing the water regime (particularly by severe floods). The transition to the second phase of water management (i.e. primary control by constructing flood protecting structures and river training) took place gradually depending on the level of economic development at various stretches of the Danube, and it was completed practically in the whole basin at the beginning of this century. The need for canalization also followed the economic development, and it became almost a general requirement for the fifties. Most of the barrages along the Upper Daube were completed between 1925 and 1985. In the basin of the Middle Danube the construction started in the forties, and the work is still going on. Along the Lower Danube the canalization reached only the planning phase until now.

THE PURPOSE OF GABCIKOVO–NAGYMAROS BARRAGE SYSTEM

The need for canalization along the stretch of the Danube upstream Budapest was raised at first by navigation. Member countries of the Danube Commission have assumed an obligation to ensure the undisturbed traffic of ships having submergence of 2.5m between their borders and accepted a recommendation to increase this depth to 3.5 m if possible. Between Bratislava and Györ this goal cannot be achieved by usually applied river training. The navigable depth is only about 2.0 m in the largest part of the year and even less in low-water periods, although considerable amount of money is spent for dredging and river training structures. The importance of this East–West European waterway will be even increased after completing the Rhine–Danube canal, a fact that urges the improvement of navigation conditions along this stretch.

It is obvious that the flood risk should be decreased as the value of the protected area increases. Not only the enormous damages caused in both Czechoslovakia and Hungary by the large floods in 1954 and 1965, but the high costs of flood protecting activity had needed in other years when the floods were not so extremely high but similarly dangerous indicates the need to improve the protecting systems. The multipurpose structures of canalization can also meet this requirement.

There are still areas where random hydrological events may cause considerable damages in agriculture. Such areas are the higher flood plains not yet endiked, and innundated by high floods, low lands without efficient control of surface runoff or where the groundwater level is influenced by the water level of the Danube which may create unfavourable conditions in extreme cases. The necessary water control can be solved in a more economical way in these cases when it is combined with the construction of structures serving the purpose of canalization.

Experts working in energy industry have different opinions of the reasonable rate of thermal, nuclear and hydro stations within the development of power production, the capacity of which should always cover the ever-increasing demand of society. The judgement of environmentalists on the impacts of such stations differs similarly. In spite of divergences in opinions it can be stated that one of the main goal of canalization is the utilization of Danube's energy. It is a waste to leave the discharge of Danube, which is continuously renewed energy resource not requiring the use of any raw material, to run down in its bed without doing the work what it can do for our society. The investments required to construct a hydro power station is higher than that needed in the case of a thermal or nuclear plant, but the difference is reimbursed in a few years by the almost negligible operation cost. The economic analysis has shown, for instance, that the cost of a thermal or nuclear power plant having the same capacity in energy production as the Gabcikovo–Nagymaros system can cover not only the price of the hydropower stations, but about 63% of the total investment of the whole canalization if the costs of investment, operation and maintenance is converted into capital for a period of twenty years. Since the lifespan of hydraulic structures is considerably longer than 20 years, the comparison is more favourable for hydropower generation. Although the living conditions of aquatic ecosystems are modified by the control of both water level and velocity, air pollution or radiation hazard from other power sources may cause much more serious damages in the environment. Another advantage of hydro power is its flexibility, namely, the production can be changed rapidly according to the increase or decrease of consumption. This is a very important aspect especially in energy systems with high portion of nuclear plants, the regulation of which is not desirable.

THE TASK OF PLANNING AND DESIGN

In Hungary an office having the same structure and responsibilities like a ministry (National Water Authority) coordinates all activities related to water resources development. Hence, the planning and design of the barrage system was also the responsibility of NWA. Details related to the activities of other economic branches were coordinated with the relevant ministries and authorities (e.g. the required capacity of the hydropower plants with the Ministry of Industry being responsible for energy industry, the navigation conditions with the Ministry of Transport and the evaluation of environmental impacts with the National Environment Authority). The Hungarian Academy of Sciences also gave assistance by providing the planners with scientific recommendations prepared by various commissions of the Academy. The research, design, and management of constructions were and are continuously implemented mostly by institutes belonging to NWA (Research Centre for Water Resources Development, Design Bureau for Hydraulic Structures, Investment Bureau for Water Management), but other institutes were also involved to solve special problems requiring interdisciplinary approaches.

Considering all the aspects listed and comparing the goals to the development conditions along the stretch of the Danube upstream Budapest it was obvious that the demands can be met economically only by constructing a multipurpose water resources system, i.e. by the canalization of the river. Apart from the interest of the main users (i.e. navigation, water management, power generation) some further aspects should have also been taken into account like the increasing demand for recreation, the utilization of the gravel dredged from the river bed for building industry (which already caused about 60–70 cm lowering of the water level in low flow periods at the most sensitive stretch) and last but not least the preservation of the quality of life and environment in the Danube valley. The task in the planning period was to compare a large number of possible variants and select the one which satisfy all these demands in the best combination ensuring at the same time reasonably positive cost-benefit balance.

It is obvious that there are unavoidable damages caused by constructing barrages which should be considered as an additional cost of the project (e.g. the value of the land occupied by the structures or innundated). Most of the harmful impacts foreseen can, however, be prevented by constructing and operating sufficient supplementary structures. Naturally all expenses should be allocated as an integer part of the total investment. An example of such preventive measures is the recharge of groundwater where the lowering of the water table is expected due to the change in the water regime of the river. There are also positive secondary effects the utilization of which should also be planned (e.g. the stabilized water level and the large water surface upstream the barrages provide an excellent opportunity for recreation and water sports). In general it can be stated that the new natural and social environment created by the construction of the barrage system is not worse than the earlier conditions, if sufficient measures are taken to prevent the harmful changes and to utilize the advantages offered by the new conditions. Apart from selecting the best variant of the system another important task was therefore to predict its secondary effects in the natural and social environment as well as to design structural and operational measures needed to prevent – or at least to minimize – the undesired impacts, and to make use of the positive ones.

The planning required a long series of international negotiations not only because the stretch of the Danube to be utilized is the common border between Czechoslovakia and Hungary, but also because the agreement of the member states of the Danube Commission is necessary according to the Belgrade Convention for every large scale modification of the navigation conditions along the Danube. Another important aspect of international harmonization was the determination of the sections of barrages. Some sections had to be regarded as fixed points (e.g. a barrage had to be constructed downstream the Iron Gate to improve the navigation conditions along the gorges located here). The large cities located at relatively low levels (Vienna, Bratislava, Budapest, Novi Sad, Belgrade) limited the rise of water levels along their banks. It was also necessary to ensure the continuous navigable water way and the possible highest utilization of energy by limited overlapping of backwater stretches.

HISTORY OF PREPARATORY PLANNING

The planning period of the Gabcikovo–Nagymaros barrage system started in 1951 and ended in 1977 when the intergovernmental agreement was signed by Czechoslovakia and Hungary for the multipurpose utilization of the common stretch of the Danube. Although the task of planning was very versatile as it was summarized above, there were quite other reasons requiring such long preparation.

At the beginning the cost-benefits ratio of the hydropower plants seemed to be favourable compared to coal thermo-plants, but in the fifties the oil took over gradually the place of coal and the hydroplants were not able either to compete with the oil price being very low in that time. Such economic aspects prolonged again and again the decisions concerning the construction of the barrages.

Delay was also caused by the fact that financially favourable conditions were needed simultaneously in both participating countries to accept the responsibility of investing large capital into a system which takes part only partially in direct production and serves partially the improvement of the infrastructure. Other aspects of internal policy (e.g. the proportional development of the various regions in the countries) might reduce in some time the willingness of the interested parties to start the construction of the large barrage system.

After the first oil crisis when the economic prosperity was still increasing, it was reasonable to decide the implementation of the canalization for the utilization of the continuously renewing energy of the Danube. The agreement was signed and the construction started immediately in 1978.

The long-lasting planning period caused by the fluctuating interest of the participating parties required quite considerable financial and mental efforts but it had also several advantageous consequences. In the plans reworked again and again the results of the rapid technical development was always considered raising gradually the efficiency in this way. The policy makers did not want to tell either definite yes or no, but their intention was only to delay the final decision. They asked, therefore, the investigation of new variants or the analysis of some expected impacts. Although these studies were not synthetized in an environmental impact assessment – this term was not yet used and even known in the fifties and sixties – they contained most of the important information needed for the evaluation of environmental changes.

The detailed survey of the natural and socio–economic conditions, the evaluation of several practicable options of the system and the studies analysing the most serious impacts made it possible to select the most realistic version of the hydraulic structures immediately after a green light was given for the construction. The same materials were used for the preparation of an environmental impact assessment when same environmental objections were raised against the project. The availability of a large number of feasibility studies facilitated the preparation of the assessment in a relatively short time.

ENVIRONMENTAL CONCERNS RELATED TO THE PROJECT

As the anxiety for the preservation of environmental values gradually increased all over the world, the preparation of detailed impact analyses became a general requirement in connection with all large structures. At the beginning of the eighties more and more environmental objections were also raised against the barrage system. It was therefore necessary to summarize the studies prepared earlier, to carry out supplementary research and to answer the questions in the form of a comprehensive assessment of the expected environmental changes. The objective of this assessment was not only to survey the impacts but also to propose measures needed for avoiding undesired processes and to determine the positive changes the utilization of which may increase the efficiency of the system. The detailed description of all debated problems is not possible in a short article, but some of the most important points and results are listed below.

Along the 30 km long derivation canal the water level will be lowered considerably in the river, which would also cause the depression of the groundwater table, if no protective measures were applied. Two options were investigated: (i) to supplement the water provided earlier by capillarity for the plants in the form of irrigation, or (ii) to construct a combined drainage and recharge system which can control the water table according to the requirement of agriculture. The second alternative was applied in the final design because it offers not only the prevention of damages but also the improvement of the agricultural conditions. Field and laboratory experiments, simulation models and several similar systems already in operation, e.g. along the canalized stretches of the Rhine and the Rhone, prove the relatively high reliability of the effectiveness of groundwater control.

Some discharge should be released through the natural river bed even in low water periods when almost the total amount of water is conveyed to the power station in the derivation canal. The opinions concerning the size of this discharge were, however, very different: the interest of power generation was to minimize the release, while the larger the discharge the smaller the change in the aquatic ecosystem. The requirements for the minimum allowable discharge varied from 50 to 500 m^3 s^{-1}, where the minimum natural discharge is about 700 $m^3 s^{-1}$ and the multiannual average value is 2,000–2,200 $m^3 s^{-1}$. Unfortunately, the science of hydrobiology is not developed enough to be able to quantify biological processes. It was not possible, therefore, to predict the quality of aquatic life depending on the size of the discharge released in the natural bed. It was decided that the final value should be determined on the basis of operational experiments between 50 and 200 m^3s^{-1}, but some river training should be implemented maintaining a unified bed even in the case of such small discharges.

The next problem was the maintenance of the self-purification capacity of the river. The velocity decreases considerably upstream the barrages, a fact that modifies both the oxygen balance and the structure of the aquatic ecosystem. The simulation of the chemical processes indicated that the expected lowering of oxygen content is negligible because the two opposite actions (the decrease of velocity and the increase of surface area) are almost compensating one another. The effect of aeration at the sections of barrages may even surpass the lowering of dissolved oxygen along the backwater stretches. The research aiming at the determination of the relationship between the biotop and the hydraulic character of rivers is only a presently developing topic in hydrobiology. Therefore, it was not possible to give quantified predictions concerning the expected biological impacts of canalization.

Considering the results of the chemical models and the experiences gained at already canalized river stretches (according to which the improvement of water quality is more probable than its deterioration) it was stated that harmful changes are not expected. The field experiences proving the validity of this sttement include the detailed evaluation of the long series of quality data collected along the canalized stretches of the river Tisza, and the information on the impacts of barrages being in operation since decades along the Upper Danube. The analysis emphasized the need of the more efficient treatment of sewages released from settelements and industrial plants into the backwater stretches. Since one of the most serious obstacles of the utilization of Danube's water resources is the rapidly growing pollution of the river, it is a positive feature of the barrage system, that its construction urges the improvement of sewage treatment in the basin.

The most important source of water supply in the region is the bank-filtered water. Wells tapping the alluvial gravel filling up the flood plain provide the water, which is directly recharged from the river. The gravel layers act as natural filters and, therefore, the water is suitable for direct consumption without any pretreatment. Canalization may endanger the quantity and quality of bank-filtered water along the backwater stretches by the deposition of fine silt over the gravel layer, which increases the resistance against the percolation and may create anaerob conditions in the groundwater resulting in the increase of iron and manganate content. Downstream the barrages the lowering of the water level may also decrease the yield of wells, if considerable dredging is implemented to increase the head utilized at the power station.

In the case of the Gabcikovo–Nagymaros system downstream dredging was planned below the section of Nagymaros. In the meantime, however, considerable amount of gravel was exploited here for building industry causing the sinking of low water levels with 50–70 cm, which is more than the value envisaged in the plan. The remaining task is only to improve the tracing of the bed which aspect was not considered during exploitation. This activity rather improves than deteriorates the conditions. Undesirable effects can be caused, however, if the bed is further deepened due to the drag force of water being poor in suspended sediment after crossing the barrage. The prediction of the modification of bed morphology would require better knowledge of bedload movement than the one existing at present especially under the very complicated conditions prevailing at the stretch in question (influence of stabilized banks, strong contractions, rocky thresholds, etc.). Further research is needed and the relatively slow development of processes allows the implementation of protective measures on the basis of the evaluation of changes monitored during the operational period.

Several examples indicate that the most reasonable way to protect the water supply plants exploiting bank-filtered water against the impacts of silting along backwater stretches is the regular dredging of the fine material from the surface of the gravel. The most detailed experiences concerning the impacts of impoundment on the operation of bank filtered water supply schemes were gained at the well field providing water for Linz. Although the water level was raised considerably in the river, the yield of wells decreased due to the deposit of a silt layer over the aquifer. The change in water quality indicated also the development of anacrobic conditions below this clogging layer. Several experiments were carried out to improve the production of wells but results were achieved only by dredging the clogged layer. A slight decrease of the yield from the wells at Belgrade was also observed due to the backwater effect of the barrage constructed at the Iron Gate. Although the detailed survey was not able to make clear distinction between the impact of the barrage and the normal ageing of wells, it was proposed as a conclusion of research that dredging should be carried out also here for the improvement of the well fields. Considering these experiences the regular dredging of the bed in front of the plants exploiting bank filtered water was included in the operational plan of the barrage system as a part of the normal maintenance service. The detailed design of this activity requires first of all the continuous monitoring of the changes in bed morphology. Further research of bed load and sediment movement in natural beds may also assist the managers with the determination of the efficient policy of protecting the quantity and quality of bank-filtered water resources.

SOME GENERAL CONCLUSIONS OF THE IMPACT ASSESSMENT

The most important conclusion of the environment impact assessment of the Gabcikovo–Nagymaros barrage system was the statement that there is no such serious harmful impact foreseen, which may give any grounds to modify basically the accepted plan or to stop the construction started already. In some cases the objections raised against the system provided good ideas to improve both the design and the plan of operation. The application of groundwater control, the development and maintenance of a unified small water bed where the derivation canal lowers the discharge of the river, or, the need of regular dredging as a part of the maintenance service can be mentioned as examples. In several other cases the anxiety was not justified.

It is obvious that the natural processes are influenced by numerous random events. Therefore, to reach a safety of 100% in any prediction would be an unrealistic target. It is necessary, however, to indicate the range of uncertainty and the task of design is to construct flexible systems, the operation of which can be adaptable to the actual conditions developing in the environment. To achieve this goal the continuous observation of environmental changes is needed. The monitoring system is, therefore, an indispensable part of any large hydraulic structure and water management system.

The uncertainty caused by the randomness of influencing factors is further increased by the limited knowledge of the development of natural processes. To increase the reliability of impact assessments the scientific research should be continued for the better understanding of the hydrological cycle and its interactions with the environment. According to the present case, the weakest eye within the chain of the various branches of sciences is hydrobiology. Here our knowledge is limited to the description of different aquatic ecosystems but not sufficient for the quantification of expected changes. Similarly, further research is needed in the field of river morphology and sediment transport.

It is also worthwhile to mention that the raising of environmental obstacles against the barrage system was intensified simultaneously with the worldwide economic depression in the early eighties. Most of the various interest groups in competition with the system to get a larger share from the very limited funds for investments hide their direct goals behind the shield of environment. The groups of the different lobbies (e.g. coal, oil, nuclear, hydropower within energy industries) were further enlarged by people having individual reasons to oppose the implementation of the barrages (e.g. whose property was expropriated). It was very difficult to make distinction between the real environmental concerns and the obstacles raised only to impede the implementation of the system. Although it was evident that this second group could not be convinced, their questions had to be equally answered even in cases when the objections had no physical, scientific background at all.

The final conclusion is that the preparation of a comprehensive environmental impact study is a very useful and indispensable part of the planning and design of large hydraulic structures. It assists the designer to think over the concept of the plan again and to improve gradually some elements of the system considering the far-reaching interactions. The policy makers being responsible to make decisions concerning the economic development of a country require also the evaluation of all primary and secondary effects because the better utilization of the advantages offered by the system and the minimization of undesirable impacts may improve the efficiency of the investment. The protection of environmental values in general and the sound utilization of water resources especially cannot be solved without the considerable participation of the general public. The impact assessment also serves their reliable information.