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GABČÍKOVO-NAGYMAROS PROJECT

(HUNGARY/SLOVAKIA)

REPLY

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INTRODUCTION

This Volume contains 14 monitoring reports and studies carried out by 45 of the most well-reputed Slovak scientists and experts in the fields under consideration. A list of these authors is given below. These reports and studies respond to the "Scientific Evaluation" that forms Volume 2 of Hungary's Counter-Memorial and to Hungary's technical annexes in Volume 3 thereof and, more generally, to Hungary's whole "scientific" case.

Each Chapter dealing with environmental issues is based on the up-to-date and abundant data gathered under what is one of the most sophisticated monitoring systems existing for any barrage project today. Since the reports are based mainly on data from actual monitoring, the focus is necessarily on the Gabčíkovo section of the Project. This also reflects the focus of Hungary's "Scientific Evaluation", which is primarily an attempt to demonstrate that implementation of the Gabčíkovo section is damaging to water quality and to the ecosystems of Szigetköz.

By comparing the data before the Gabčíkovo section of the G/N Project went into operation with the data from the two and one half years since implementation, a reliable and accurate picture is given of the Project's actual impacts since the Gabčíkovo section was put into operation. For by far the larger part, these impacts are shown to be either insignificant, or beneficial.

List of Authors

ÁČ Peter, RNDr. CSc.
Faculty of Philosophy, Comenius University, Bratislava
(Filozofická fakulta Univerzity Komenského, Bratislava)

BANSKÝ Lubomír, Mgr.
Ground Water Consulting Ltd., Bratislava
(Podzemné vody, s r.o., Bratislava)

BOHUŠ Mirko, RNDr.
The Dept. of ecosozology and fysiotactics. Faculty of Natural Sciences, Comenius University, Bratislava
(Katedra ekosozológie a fyziotaktiky, Prírodovedecká fakulta Univerzity Komenského, Bratislava)

CSÖLLE Karol,Ing.
K.C.FOREST Ltd., Bratislava
(K.C.FOREST s r.o., Bratislava)

ČÍŽIK František,Ing.
Slovak Energetic Enterprises, Hydropower plants, Trenčín
(SEP Vodné elektrárne Trenčín)

DEGMA Peter, RNDr.,CSc.
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

FULAJTÁR Emil, Ing., CSc.
Research Institute of Soil fertility, Bratislava
(Výskumný ústav pôdnej úrodnosti, Bratislava)

GEDEON Matej
Ground Water Consulting Ltd., Bratislava
(Podzemná voda, s.r.o., Bratislava)

HLAVATÝ Zoltán, RNDr.
Ground Water Consulting Ltd., Bratislava
(Podzemná voda, s.r.o., Bratislava)

HÓK Jozef, RNDr.
Dionýz Štúr Institute of Geology, Bratislava
(Geologický inštitút Dionýza štúra, Bratislava)

HOLOBRADÁ Mária, RNDr.
Water Research Institute, Bratislava
(Výskumný ústav vodného hospodárstva, Bratislava)

HOLUBOVÁ Katarína, Ing., CSc.
Water Research Institute, Bratislava

(Výskumný ústav vodného hospodárstva, Bratislava)

HUCKO Pavel, Ing., CSc.
Water Research Institute, Bratislava
(Výskumný ústav vodného hospodárstva, Bratislava)

JANOTKA Viktor, Doc. RNDr., CSc.
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

KIRKA Anton, Ing., CSc.
Water investment organization, state enterprise, Bratislava
(Vodohospodárska výstavba, š.p., Bratislava)

KRNO Ilja, RNDr., CSc.
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

KOŠEL Vladimír, RNDr., CSc.
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

KOVÁČ Michal,RNDr., CSc.
Faculty of Natural Sciences, Comenius University, Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

KOVÁČ Peter, RNDr.
Dionýz Štúr Institute of Geology, Bratislava
(Geologický intitút Dionýza Štúra, Bratislava)

KOVAČOVSKÝ Pavel, RNDr. CSc.
Dept. of psychology, Faculty of Philosophy, Comenius University, Bratislava
(Katedra psychológie, Filozofická fakulta Univerzity Komenského, Bratislava)

KUBÍČEK Ferdinand, Ing.
Institute of Landscape Ecology, Slovak Academy of Sciences, Bratislava
(Ústav krajinnej ekológie Slovenskej akadémie vied, Bratislava)

MAKOVINSKÁ Jarmila, RNDr.
Water Research Institute, Bratislava
(Výskumný ústav vodného hospodárstva, Bratislava)

MATIS Dušan,Doc. RNDr., CSc.
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

MAŽÁRIOVÁ Katarína,Mgr.
Ground Water Consulting Ltd., Bratislava
(Podzemná voda, s r.o., Bratislava)

MÉSZÁROŠ Ivan, Ing.
Institute of Hydrology, Slovak Academy of Sciences, Bratislava
(Ústav hydrológie Slovenskej akadémie vied, Bratislava)

MOLNÁR Ludovít, Ing., CSc.
Institute of Hydrology, Slovak Academy of Sciences, Bratislava
(Ústav hydrológie Slovenskej akadémie vied, Bratislava)

MÓRIOVÁ Lubica
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

MUCHA Igor, Prof. RNDr., DrSc.
Ground Water Consulting Ltd., Bratislava
(Podzemná voda, s r.o., Bratislava)

NAGY Alexander, RNDr.
Dionýz Štúr Institute of Geology, Bratislava
(Geologický inštitút Dionýza Štúra, Bratislava)

PERESZLÉNYI Miroslav, RNDr. CSc.
Oil gaz research and prospecting, state enterprise, Bratislava
(Výskum a vyhladávanie nafty a plynu, š.p. Bratislava)

PETROVIČ Pavel, RNDr., CSc.
Water Research Institute, Bratislava
(Výskumný ústav vodného hospodárstva, Bratislava)

POLKO Ivan, Ing.
Hydroconsult, state enterprise, Bratislava
(Hydroconsult, š.p., Bratislava)

ORSZÁGH Ivan, Doc. RNDr., CSc.
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

OSZLÁNYI Július, Ing., CSc.
Institute of Landscape ecology, Slovak Academy of Sciences, Bratislava
(Ústav krajinnej ekológie Slovenskej akadémie vied, Bratislava)

RODÁK Dalibor, RNDr.
Ground Water Consulting Ltd., Bratislava
(Podzemná voda, s r.o., Bratislava)

RYCHLÍK Ivo, RNDr.
Dept. of psychology, Faculty of Philosophy, Comenius University, Bratislava
(Katedra psychológie, Filozofická fakulta Univerzity Komenského, Bratislava)

STANČÍKOVÁ Alžbeta, Ing., CSc.
Water Research Institute, Bratislava

(Výskumný ústav vodného hospodárstva, Bratislava)

ŠEFARA Ján, Doc. RNDr., DrSc.
Faculty of Natural Sciences, Comenius University, Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

ŠESTÁK Pavel, Ing.
Slovak Danube navigation, state enterprise, Bratislava
(Slovenská plavba dunajská, state enterprise, Bratislava)

ŠOMŠÁK Ladislav, Prof. RNDr., DrSc.
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

ŠÚTOR Július, RNDr., DrSc.
Institute of Hydrology, Slovak Academy of Sciences, Bratislava
(Ústav hydrológie Slovenskej akadémie vied, Bratislava)

TIRJAKOVÁ Eva, RNDr., CSc.
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

VARGA Ladislav, RNDr.
Hydroconsult, state enterprise, Bratislava
(Hydroconsult, state enterprise, Bratislava)

VASS Dionýz, RNDr., DrSc.
Dionýz Štúr Institute of Geology, Bratislava
(Geologický inštitút Dionýza Štúra, Bratislava)

VISKUP Jozef, RNDr., CSc.
Faculty of Natural Sciences, Comenius University,Bratislava
(Prírodovedecká fakulta Univerzity Komenského, Bratislava)

CHAPTER 1. CHARACTERISTICS OF SURFACE AND GROUND WATER REGIME IN THE IMPACT AREA OF THE GABČÍKOVO SECTION OF THE G/N PROJECT (MONITORING REPORT)

I. Mucha,
L. Banský
D. Rodák
Z. Hlavatý
M. Gedeon
K. Mažáriová

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1. Introduction

This report provides comprehensive information on surface and ground water level changes based on monitoring data. The collected data are expressed in figures, their interpretation is presented on maps and the basic principles of relationships between surface and ground water are demonstrated in some examples. All figures, maps and explanations contained in this report are based on data measured and collected in the framework of monitoring which started many years ago. They illustrate both the long-term pre-dam conditions as well as conditions existing during two years of operation of the Gabčíkovo hydropower Project. The data were provided by the Slovak Hydro-Meteorological Institute (SHMÚ) which is carrying out extensive monitoring work largely exceeding, through its long-term, comprehensive and systematic nature, the usual standard of surface and ground water monitoring undertaken for the purposes of other similar projects.

This report is the first comprehensive review of data concerning the surface and ground water levels collected after putting the Gabčíkovo section of the G/N Project into operation. It should help to evaluate the impact of the Project on the environment and interpret the monitored ecological changes.

The impact of the Gabčíkovo hydropower scheme on the environment occurs mainly through the intermediary of changes in surface and ground water regime. Hence, the impact of the hydropower scheme on natural conditions is propagated directly only in the places where changes in surface and ground water regime occur. In order to assist in an understanding of the meaning of these changes, the previous long-term pre-dam development is briefly summarised below.

A complex and systematic investigation of the geological conditions of the Danube lowland, where one of the broadest aquifers in Europe lies, has been performed by various organisations before and during the engineering, geological and hydrogeological survey undertaken in relation to the Gabčikovo/Nagymaros Project - mainly by the Geological Survey Enterprise, the Engineering Geological and Hydrological Survey Enterprise, the Geological Institute of Dionýz Štúr and others in Bratislava and, finally, the basin has been investigated from the geological point of view again quite recently in the framework of the international program DANREG (geological survey of the Danubian Lowland with the participation of Austria, Hungary and Slovakia).

The uppermost elements in this basin creating the aquifer are river deposited sediments consisting of gravel and sand of Quaternary and Rumanian age. Thin, non-continuous layers of clay, silt, lenses of moor sediments and also the in-fill of dead river arms are present in some places. The thickness of gravel and sandy sediments ranges from a few metres at Bratislava up to 462 m near Gabčíkovo and goes back to a few metres downstream of Sáp in the direction towards Komárno. Beneath this complex, systems of substantially less permeable aquifers and aquitards exist, which may be considered to form a relatively impermeable bedrock for the high permeable aquifer consisting of gravel and sandy river Danube sediments.

The important factors in the creation of the aquifer were the existence of the granite threshold connecting the Alps and the Carpathians in the area of today's Bratislava (the upstream geological boundary of the aquifer) and the predominantly andesit hard rocks downstream, extending from Komárno to Nagymaros (the downstream geological boundary). These two hard rock boundaries and tectonic activities (uplift of these hard rocks) determined the sedimentation/erosion conditions, surface slope gradients and Danube water flow velocities and subsequently the development of the so-called Danube inland delta (alluvial fan below the granite threshold at Bratislava with its typical original morphology, i.e., changing river meanders, coarse sediment accumulations etc.). This alluvial fan represents a highly permeable and extensive aquifer capable of carrying high volumes of ground water. Water from the Danube infiltrates into the fan and flows downwards through the Danubian lowland nearly in parallel with the Danube river. In the lower part, where the river has a small gradient, because of the andesit hard rock threshold, river deposits are more fine grained and generally less permeable. Here the ground water flows back into the Danube river via its own river arms and the Danube tributaries.

2. The Review of Long-term Man-made Impact on Hydrological Development

Long-term hydrological development of the region was, in addition to geological conditions, influenced by a number of man's activities, in particular by:

- river regulations and anti-flood measures, straightening of the river bed, closing or raising artificially the entrance thresholds of previous meanders and river branches,
- narrowing the floodplain area and confining it between flood protection levees (dykes),
- construction of additional anti-flood measures, such as impermeable subsurface walls and sealing affecting the flow of ground water,
- fortification of river banks, excavation of fords and construction of spurdykes (groynes) to preserve navigation conditions during low-flow discharge, industrial dredging of sand and gravel,
- construction of river dams on the upper Danube which altered the bed-load balance,
- cultivation of farmland, introduction of commercial forestry, etc.

Such activities resulted in:

- concentration of the main Danube flow into one river channel,
- higher depth of water in the narrower riverbed and mainly in the fixed navigation channel (thalweg),
- higher flow velocities in the Danube, mainly in the navigation channel,
- changes in the bed-load transport, decrease of river sedimentation and increase of riverbed erosion,
- disconnection of river branches and meanders and their drying out,
- changes in the use and cultivation of the land.

The observations indicated the substantial deepening of the riverbed and the trend to further erosion of the river bottom. This caused a long-term lowering of water level in the Danube and river branches and the reduction of the surface water area. The changes in the river morphology and surface water regime were followed by changes in ground water regime that led to changes in soil moisture regime and changes of natural (water related) conditions. This trend accelerated, in particular, in the two recent decades.

The monitoring during two years of operation of the Gabčíkovo section of the G/N Project shows that on the greater part of this region affected by the recharge measures taken, the restoration of hydrological conditions known in the region two to three decades ago has occurred.

3. The Discharge Regime and Water Levels in the Danube and Malý Danube

The discharge regime and water levels in the Danube and Malý Danube have been measured on a number of gauging stations. The location of SHMÚ gauging stations is shown on Fig. 1. Numbering of stations used in this report corresponds to the database of Ground Water Consulting, Ltd. (GWC).

Fluctuation is one of the main elements of the Danube's discharge regime. The fluctuation during the period 1953-1994 as observed at gauging stations in Bratislava and Komárno is shown on Fig. 2. Simple linear regression lines demonstrate that the long term changes in the discharge are, at least in Bratislava, negligible. Annual average discharge in Bratislava is 2025 m^3/s, minimal measured discharge is 570 m^3/s, highest measured discharge is 10400 m^3/s. Forecasted 100, 1000 and 10000 year floods are 10600, 13000, 15000 m^3/s, respectively.

The same data on the Danube discharge at Nagymaros are 2421, 590, 8180 for measured discharge and 8700, 10000, 11100 for forecasted floods. It should be nevertheless noted that the data concerning the measured discharge in Nagymaros are influenced by the occurrence of two disastrous floods in 1954 (Hungarian territory) and 1965 (Slovak territory) during which large areas of the territory were flooded and the part of the discharge was thus dispersed in the region.

An important role for the retention of flood discharges is played by the floodplain. The retention function of the floodplain area between Bratislava and Komárno is clearly expressed in the lowering of the peak discharges at Nagymaros gauging station. For example, the highest measured discharge at Bratislava, 10400 m^3/s, was reduced to only 8180 m^3/s at Nagymaros.

The water level in the Danube is a result of the discharge, depth and shape of the riverbed, including the floodplain area, which, since the last century, is restricted to the area between flood protection dykes. The Danube water levels measured in Bratislava, Rusovce, Gabčíkovo and Komárno are presented on Fig. 3. At first sight it is evident that the discharge fluctuation did not change, but the water level was continuously decreasing. To show better the long-term development of water levels, a linear regression line is plotted through the data. Computed changes of discharge and water levels at gauging stations for the last 30 years before putting the Gabčíkovo Project into operation are given in Table 1.

Table 1. Decrease of discharge and water levels in the Danube estimated at gauging stations

Locality	River km	discharge m^3/s	water level m
Bratislava	1868.7	12.84	1.32
Rusovce	1855.9		1.10
Gabčíkovo	1819.6		0.20
Medvedov	1805.4		1.05
Klížská Nemá	1792.4		1.14
Zlatná na Ostrove	1779.2		0.98
Komárno	1767.1	74.63	0.63

The discharge into the Malý Danube (one of two main branches of the Danube) is measured at a gauging station at Malé Pálenisko. The long-term development of the discharge in the Malý Danube and the changes in the discharge downstream can be seen at gauging stations at Nová Dedinka and Trstice (see Fig. 4). The locations of these stations are shown on Fig. 1.

The long-term decrease of the water level in the Danube was one of the factors leading to the decrease of ground water levels and to changes in the ground water flow directions and velocities. This resulted, among other things, in changes in ground water flow quantities and in a general decrease of the utilisable ground water resources for example at locality Pečniansky les and Rusovce-Ostrovné Lúčky. In the upper part of Žitný Ostrov there have also been some other factors influencing the ground water regime, for example, the realisation of the hydraulic blanket around the "Slovnaft" refinery, the development of Petržalka on the right side of the Danube and the construction of water works supplying the capital and surrounding villages with drinking water, municipal sewage etc.

4. The Ground Water Level Regime

There is a basic network of more than 600 observation wells in the area where the ground water levels are measured - mainly by the Slovak Hydrometeorological Institute (SHMÚ). Measurements are carried out manually, on a weekly basis, or continuously, with the use of limnigraphs or other automatic recorders. The map with locations of SHMÚ observation wells is shown on Fig. 5 (numbering corresponds to GWC database system). Several methods are used to present ground water level data. The most common is the well hygrograph which visualises the ground water level fluctuation in time, which is the first step to characterise the ground water level development.

The ground water level fluctuation is basically conditioned by the mutual relationship and hydraulic interconnection between the Danube river water and ground water and the relationship between the ground water and difference between precipitation and evapotranspiration. This ground water level fluctuation is further influenced by various other factors such as, for example, drainage or irrigation of agricultural soils, etc. The typical example of the ground water level fluctuation is presented in profiles on Fig. 6a at Kalinkovo and on the right side of the Danube, close to the Slovak-Hungarian boundary in Fig. 6b. It can be seen that in the region close to the Danube (wells GWC No. 2046 and 2228) the shape of ground water level fluctuation corresponds closely to the water level fluctuation in the Danube. At a larger distance (wells GWC No. 2162 and 2003), the fluctuation is dependent upon the season and the relationship between precipitation, snow melting and evapotranspiration.

The irrigation canal network, drainage facilities and meliorations have a stabilising effect on ground water levels. The linear regression line is drawn in the figures to show the drop of average ground water levels in a long-term period. The long-term decrease on both sides of the Danube is evident on the large part of the territory. Such a development is most visible at wells chosen in the middle part of Žitný Ostrov in the profile at Dunajská Streda (Fig. 6c).

The average ground water level represented by the linear regression line for a precise date is called a reference ground water level. The reference ground water levels for the years 1962 and 1992 were used for drawing up the ground water level contour maps (ground water level equipotential lines) (Fig. 7). Ground water level change between 1962 and 1992 as the difference between these two contour sets is shown in Fig. 8. From these figures a considerable decrease of ground water level, which occurred in the last 30 years (before putting the Gabčíkovo part of the G/N Project into operation), is evident in the upper part of the Danubian lowland close to Bratislava.

The changes in ground water levels occurred at various places and were of various origins. While some were caused by the riverbed sinking, others resulted from pumping of water related to the hydraulic blanket at Slovnaft refinery, development of the new borough Petržalka, works at Gabčíkovo, works in connection with construction of protection measures related to the Nagymaros part of the G/N Project, agricultural ameliorations, changes in irrigation and drainage canal systems and irrigation patterns, exploitation of ground water for municipal water supply, etc. The decrease of ground water level in the major part of the area was irreversible and had, for a long time, already negatively influenced the natural conditions, mainly agriculture, forestry and ground water resources.

5. The Development of Ground Water Level Regime After the Damming of the Danube

The impact of the damming of the Danube (putting of the Gabčíkovo part of the Project into operation by means of the temporary solution known as Variant "C") can be evaluated on the background of the long term development shown on Fig. 6 and in detail on Fig. 9. On the wells situated close to the reservoir, e.g., GWC well No. 1998, an increase of ground water level was observed, while on wells situated near the bypass canal, wells No. 1983 and 1977, a temporary decrease of ground water level was registered. This situation lasted until May 1993 when the recharge system of water supply for the left side river branches was put into operation.

The immediate impact of the water supply into the river arms on the floodplain area can be seen on the well GWC No. 1977 Fig. 9, which is situated between the Danube and the headwater canal. A similar situation can be seen on the well GWC No. 1983 situated on the left side of the bypass canal.

To show the general situation in ground water levels, a map of average ground water levels for the period between July 1993 and July 1994 with reference water level contours characterising pre-dam conditions has been plotted (Fig. 10). The difference between these ground water levels (shown on Fig. 11) represents the impact of the putting of the Gabčíkovo part of the Project into operation.

The major impact is the general increase of ground water levels in the upper part of the Žitný Ostrov area as well as on the right side of the Danube on the Slovak territory. Another impact is the decrease of ground water levels close to the tailrace canal downstream of the Gabčíkovo site. The decrease of ground water level remains in the strip of the territory closely adjacent to the Danube old riverbed downstream of the Čunovo weir. This is a result of the drainage effect of the old riverbed. No significant changes were observed in the lower part of Žitný Ostrov, downstream of Sáp, except some areas near the Danube, where some changes in ground water level, not resulting from the operation of the Gabčíkovo Project, have occurred.

A certain decrease in the ground water level, which can be seen on the map in the northern part of the monitored area, is due solely to the dry years 1993 and 1994 and has no relationship with the operation of the Gabčíkovo project.

The changes in the ground water levels observed in the floodplain area and generally in the whole region confirm the positive impact of the Project, in particular on the upper part of Žitný Ostrov, and the important positive role of the water supply system for the left side floodplain area. The observations support the expectation that, after completion of the water supply facilities for the remaining part of the floodplain area in the vicinity of the tailrace canal (downstream of the Gabčíkovo site) and for the narrow area between Dobrohošť, the headwater canal and the old riverbed (the so-called dry triangle), a positive impact on ground water will occur here too.

The measurements of the ground water levels confirm that there is a general trend towards the re-establishment of the situation known 20-30 years ago on the greater part of the territory.

6. The Ground Water Level Fluctuation Regime

The water level fluctuation in the Danube causes ground water level fluctuation in the river side zone. The width of the zone and magnitude of ground water level fluctuation in the river side zone are important for determination of the area directly influenced by the Danube as well as for evaluation of soil aeration, possibilities of vertical oxygen transport and transport of other chemicals in the zone of aeration (between the surface and the ground water) of this area.

The water level fluctuation is interpreted as an annual cumulative fluctuation (the sum of absolute values of fluctuation per year), based on weekly measurements. Fig. 12 shows the water level fluctuation in the Danube at chosen places. Figs. 13a, b, c show the ground water level fluctuation in profiles on the left and right sides of the Danube. The figures show the long term development of the water level fluctuation in the Danube and the long term trends of the ground water level fluctuation.

The trend towards the increase of the water level fluctuation, registered in previous decades, was related to the closing of the river branches, river regulations and antiflood measures, fortification of river banks and the construction of spurdykes (groynes) to assure navigation depth during lowflow discharge. The fluctuation of the Danube water level and the ground water level fluctuation were much smaller in the time when the Danube merely meandered across the floodplain with its many river branches. In addition, the confining of the Danube to a single channel in the upper reaches (Austria and Germany) resulted in an increase of the flood peak discharge.

Based on the data mentioned above, the zone of direct influence of the Danube can be determined (Fig. 14). This zone is 4 to 8 km wide. Behind this zone a seasonal ground water level fluctuation prevails. It is caused by seasonal changes in rain infiltration, snow melting and evapotranspiration and is influenced by irrigation and drainage canals and the discharge in the Malý Danube and, in the eastern part, also by the river Váh.

The area between Čičov and Komárno is not at all influenced by the Danube water level fluctuation, because of the change in the geological composition of the aquifer from fluvial to lacustrine sediments. The permeability of the lacustrine sediments is much smaller and the thickness of the Danube gravel sediment is too low. A similar situation exists on the right side of the upper reach of the Danube at the border between Austria and Slovakia, where the thickness of the Danube gravel sediments decreases rapidly.

7. The Interaction between Ground Water and Soil

It is evident that as far as the impact of the Project on soils, agriculture, forestry and environment in general is concerned, the central role belongs to the change in ground water levels and ground water level fluctuation regime and to the changes in the ground water interaction with the soil. This impact is realised via the aeration zone through capillary transport up to the soil. The soil moisture is strongly conditioned by the availability of precipitation water (including rain, snow melting in spring and irrigation water) and water transported from the ground water via capillary rise. This influences the plant transpiration, the soil aeration and temperatures, the vertical transport of nutrients and pesticides and the pollution of the ground water resulting therefrom and, also, in the long-term the development of soils and soil structures.

The capillary rise is determined mainly by the character of sediments or the type of soil, their thickness, the ground water level (depth) and its fluctuation. The capillary transport in gravel deposits is nearly equal to zero. The maximum capillary transport exists in loess (eolian sediments). Good capillary transport exists in finer sediments such as fine sand, silt, loam and agricultural soils.

For agricultural production it is important in which sediment and soil horizon the ground water level fluctuates and what is the depth and course of the ground water level fluctuation (mainly whether the ground water level in course of its fluctuation touches sediments with good capillary transport ability or not).

In the area of Szigetkoz and Žitný Ostrov the most important feature of the interaction of the ground water with the soil is the depth of the boundary between the gravel strata and overlying finer sediments or soils. If the ground water level during the vegetation period is permanently in the finer sediments overlying the gravel, such depth is optimal from the agricultural production point of view. This optimal depth of ground water level fluctuation generally ranges from 0.6 m to 2.5 m (for maize slightly more and for barley slightly less). Water logging of soils take place only if the ground water level is too shallow, mostly in the depth close to the surface as is usual in some zones in the floodplain area. Usually it occurs if the ground water level is in the depth from 0 to 0.5 m. In agricultural areas with shallow ground water level the optimal depth of ground water level is ensured by drainage systems. This is the case for example in the eastern (lower) part of Žitný Ostrov.

To show the seasonal ground water level fluctuation around the average and the time of its occurrence, two profiles have been chosen; the first one in the upper part of Žitný Ostrov (Fig. 15a), the second one in the lower part of Žitný Ostrov (Fig. 15b). The first diagram is typical for areas influenced directly by the Danube, the second one for areas not influenced by the Danube. To compare these two diagrams with the Danube the long-term seasonal water level fluctuation in the Danube is presented on Fig. 16. The figure shows the average daily discharges in the Danube, the minimal and maximal measured discharges and the standard deviation characterising the distribution of discharges around the average.

It can be seen that discharges in the Danube are highest in May, June and July, and lowest in the period from October to January. In the upper part of Žitný Ostrov (Fig. 15a), there is a seasonal impact of the Danube on the ground water levels with its minimum in the winter and spring period, ending in May. The fluctuation of ground water level is up to 1 m near the Danube. On the contrary, in the lower part of the area the ground water level maximal values are in spring, which shows the large impact of melting of snow and distribution of evaporation throughout the year, factors independent of the Danube. The ground water level fluctuation is smaller in comparison with the upper part of the area, by up to approximately 0.6 m.

Important information is gained from the comparison of the position of the ground water levels in relation to the gravel and finer-structured sediments and soils overlying the gravel as they existed in 1962, 1992 and after the putting of the Gabčíkovo Project into operation in 1992. For this comparison, a map of thickness of finer sediments with good capillary transport ability, based on VÚZH data, was prepared (Fig. 17). Shallow soils are prevailing in the upper part of the area while for the lower part of the area deep soil horizons are typical.

On the basis of the surface topographical map and ground water level maps for 1962, 1992, 1993/94 (Figs. 7 and 10), the maps revealing the depth of ground water levels under the terrain were produced (Figs. 18, 19, 20). The areas with the depth of ground water levels less than 0.5 m are the areas with water logging conditions. Another extreme is the depth of ground water table more than 8 m under the terrain. As can be seen on the map (Figs. 18, 19, 20), the depth of ground water is only exceptionally less than 0.5 m and this occurs only in the floodplain area and in the lower part of Žitný Ostrov, not directly influenced by the Gabčíkovo hydropower Project.

From the comparison of the three maps it is obvious that the ground water levels have in general increased after the damming of the Danube to nearly the level which existed in the 1960s. The situation has particularly improved, in comparison with the pre-dam situation, mainly in the area close to the reservoir, downstream of Bratislava and its right bank borough Petržalka.

To present the general situation as far as the relationship between the ground water levels and the possibilities of capillary transport is concerned, three maps reflecting the situation as it existed in 1962, 1992 and 1993/1994 with the following properties have been produced (Figs. 21, 22, 23): the orange colour indicates areas where the ground water level is permanently in the gravel strata and where no possibility for capillary transport from the ground water into the soil exists. The yellow colour marks areas where the ground water level during fluctuation touches overlying finer sediments and where thus for at least some period (usually in spring - summer) the water supply of the soil via capillary rise exists. The light green colour depicts areas where the ground water level is mostly in finer overlying sediments, except for some periods during the seasonal ground water level fluctuation. Thus the soils are for most of the time supplied with moisture from the ground water, except during the winter season. Finally, the dark green colour indicates areas where ground water is constantly in the overlying finer sediments and ground water can always supply the soil with moisture.

A comparison of the three maps reveals the long term development of the ground water levels and the possibilities of the water supply of soils via capillary rise. After the putting of the Gabčíkovo Project in operation, there is an improvement of the water supply to soils via capillary transport in the upper part of the area in comparison with the pre-dam conditions. The improvement for deep rooting plants and trees has occurred also at the places where the rising ground water level has not reached the overlying finer sediments, as it is just downstream of Bratislava. Figs. 17 to 23, showing the thickness of soils overlying the gravel and depth of ground water level below surface, also show that except in the inundation area there is no water logging, which means improvement in the inundation area in comparison with pre-dam conditions. There is also no additional water logging of agricultural soils resulting from the putting of the system into operation, contrary to the situation which existed in certain areas in the 1960s.

8. Ground Water Quality

The ground water quality is characterised by the chemical composition of the ground water. Apart from natural processes (being the basic factors determining the ground water quality), the ground water quality is influenced also by the pollution by nitrates from fertilisers or sulphates from chemical industry. The classical way to get information concerning the ground water quality is in situ measurement, sampling and water analyses.

Ground water samples are taken regularly from two types of objects: from observation wells and from municipal water supply wells. There are more than 900 wells installed in the area with more than 1500 screened parts of bore-holes. Observation wells sampled during 1994 number more than 100 objects (approximately 200 depth intervals called screens). In general, the continuously exploited, protected and carefully sampled municipal water supply wells are considered as the sources of the most reliable information about ground water quality. Approximately 110 of these wells are located at different distances from the reservoir and provide a source of reliable data.

The ground water quality is usually expressed in diagrams and maps. To evaluate changes in ground water quality resulting from human activities the most viable way is to plot long-term series of measured data. From a huge number of parameters regularly measured for this purpose, only a few - the most important - have been chosen to demonstrate the general ground water quality of the region and its changes, if any, after two years of operation of the Gabčíkovo Project.

Because of the specific situation consisting in the infiltration of the Danube water into the aquifer, which exists along the whole area of the Gabčíkovo section of the G/N

Project, the time series of the Danube water and ground water quality are also presented. The ground water chemistry time series have been chosen to show the areas with typical conditions of ground water quality. The observation points of the time series are located on the left Danube side at Rusovce, the right Danube side close to the reservoir at Kalinkovo, at Šamorín and near Gabčíkovo. The location of all water supply wells in operation in 1994 and four typical water supply wells used for this presentation are shown on Fig. 24. Selected time series of parameters from the Danube and from these typical water supply wells are shown (for the purpose of comparison together) on Figs. 25-29.

To demonstrate the ground water quality the following parameters have been chosen from among 333 measured parameters (for complete list of parameters see Tab. 2):

- Chloride - originates from natural sources, sewage, industrial effluent, and mainly urban run-off containing de-icing salt. Sources can be also geologically based saline intrusions combined with high evapotranspiration. Limit in SN 75 7111 standard norm for drinking water is 100 $mg.l^{-1}$.

- Sulphates - occur naturally in numerous minerals and are used principally in chemical industry. They are discharged into water in industrial wastes and mainly through atmospheric deposition. Limit in SN standard is 250 $mg.l^{-1}$.

- Oxygen - the presence of oxygen indicates good water quality.

- COD(Mn) - Chemical Oxygen Demand represents the contents of organic carbon and other oxidable species in water. Limit in SN standard is 3 $mg.l^{-1}$.

- Iron - one of the most abundant metals in the earth's crust. It is found in surface waters at levels up to 50 $mg.l^{-1}$. SN standard for drinking water is 0.3 $mg.l^{-1}$ .Higher content is a sign of reduction conditions in the ground water. Water containing higher amount of iron should be treated, e.g., by aeration, which is the typical method for removing iron from water.

- Ammonia ions - originate from metabolic, agricultural and industrial processes. Ammonia in water is an indicator of possible bacterial, sewage, and animal waste pollution and anaerobic conditions of ground water. Limit in SN standard is 0.5 $mg.l^{-1}$.

- pH according to SN standard should be from 6 to 8.

- Nitrates - are naturally occurring ions that are part of the nitrogen cycle. Naturally occurring nitrate levels in surface and ground water are generally a few milligrams per litre. In general, the increase of nitrate levels, whenever observed, is due to the intensification of farming practices. SN standard recommends less than 15 $mg.l^{-1}$ of nitrates and the limiting value is 50 $mg.l^{-1}$.

- Cadmium - a typical component of heavy metal pollution. It is used in the steel industry and in plastics. Cadmium is released to the environment in wastewater and regionally from fertilisers and local air pollution. Limit in SN standard is 0.005 $mg.l^{-1}$.

- Lead - is used principally in the production of lead batteries, solder in food processing, alloys and as lead containing additives in petrol, therefore typical pollution occurs near the roads. Limit in SN standards for drinking water is 0.05 $mg.l^{-1}$.

The Danube water quality is well suited for ground water recharge. Dissolved oxygen is slightly increasing and COD decreasing, which means an improving tendency of Danube water quality. There are no significant concentrations of pollutants which could propagate into ground water by ground water recharge from the Danube.

The Rusovce village water supply, located in the area close to the Hungarian boundary, is typical for ground water quality on the right side of the Danube. This ground water flows towards the Hungarian territory. Before the damming of the Danube the ground water quality was characterised by high contents of sulphate, chloride and nitrates. After the damming there is continuous decrease of these three components, which indicates the more intensive infiltration of the Danube water into the aquifer. This signifies a general improvement of ground water quality. The changes in the heavy metals concentrations are not significant.

The Kalinkovo waterworks is the system of water supply wells closest to the reservoir. After a comparison of the ground water quality in the periods before and after damming of the Danube, we can state that there are only very small changes. There is a slight decrease in nitrate concentration to the value 7 $mg.l^{-1}$.

The Šamorín water supply well field is in the impact area of the lower part of the reservoir. The measurements show that the changes in the ground water chemistry are not significant.

The Gabčíkovo water supply system of wells represents the locality in the middle part of the territory influenced by the Gabčíkovo part of the Project. The measurements indicate that the groundwater quality was not changed after the damming of the Danube.

9. Concluding Remarks

From the methodological point of view, the proper quantification of changes in such a complex field of extensive data and processes as a ground water regime and quality can be evaluated only by means of interpretation of monitored data. This report describes the reality of surface - ground water relations, as it exists two years after the putting of the Gabčíkovo hydropower Project into operation. It is based exclusively on monitored data, many of them being collected during a period of more than 30 years, and it uses the simplest means for their presentation.

The monitoring, study and interpretation of ground water regime processes in the Danubian area have a well established background. Basic methods of studying and interpreting the processes in the ground water processes in the area of Danubian lowland were described already by Professor Dušan Duba in the book "Hydrology of Ground Water", published in 1968. This book provides evidence of the range of the principal observation network of ground water in Slovakia as it existed (already) in 1965.

Simulation and the use of numerical models are part of the survey of quantitative and qualitative changes in ground water regime. They help to reveal and understand such changes. The models must nevertheless be built on real data and a real understanding of the deterministic processes in ground water. Ground water flow, boundary conditions and hydrogeological conditions must be known to the researcher. The neglect of these basic requirements may lead to speculative conclusions based only on assumptions. Key findings are as follows:

Based on ground water level fluctuation data, the zone of direct influence of the Danube has been determined - <u>see</u>, Fig. 14. This zone is 4 to 8 km wide. Beyond this zone, seasonal ground water level fluctuation prevails. By comparing the maps showing the possibilities of capillary transport between ground water and soils (Figs. 21, 22 and 23), the improvement in comparison to pre-dam conditions is visible. There is improvement of water supply to soils via capillary transport in the whole upper part of the area. Improvement for deep rooting plants and trees is noted also at the places where the ground water level has not reached the overlying finer sediments, as is the case just downstream of Bratislava. Changes of ground water level in the lower part of the territory are not significant and on the whole territory there is no additional water logging of agricultural soils.

The improvement of ground water quality and recovery (increase) of ground water levels were measured on the right side of Danube, close to the Hungarian boundary. On the left side area, Žitný Ostrov, there are no significant ground water quality changes and no indication of heavy metal or other types of pollution in ground water.

Fig. 11 represents the impact of putting the Gabčíkovo section of the Project into operation. The major impact is the general increase of ground water levels in the upper part of Žitný Ostrov as well as on the right side of the Danube on Slovak territory. Another limited impact is the decrease of ground water levels close to the Gabčíkovo tailrace canal. A decrease of ground water levels also occurs in the area close to the Danube, downstream of the Čunovo weir. This is a result of the drainage effect of the old riverbed. Decrease in the northern part of area is due to the dry years 1993 and 1994.

The Gabčíkovo hydropower structures, after two years of operation, have led on the prevailing part of the territory to the recovery of water-related conditions to those known in the region a few decades ago. The measured changes in ground water levels in the floodplain area and in the whole region confirm the positive impact on the upper part of the area and the important positive role of water supply for the Danube left side floodplain. It is also confirmed that after completion of the water supply of the floodplain area close to the Gabčíkovo tailrace canal and the small area at Dobrohošt between the bypass canal and Danube (the so-called dry triangle), there will be a positive change to the previous situation. Downstream of Sáp no significant changes were measured except in some areas near the Danube, where there are some changes in ground water level but not resulting from the Gabčíkovo system.

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Tab. 2: List of Water Quality parameters

*AOX	Atrazine	DDD
*DDE+Dialdrin	Barium	DDD-orto-para
*Delor 103	Benzene	DDD-para-para
*Delor 106	Benzo(a)anthracene	DDE-p,p
*TDE	Benzo(a)pyrene	DDT
*Terbutiaz	Benzo(b)fluoranthen	Dead organisms
*Terbutrin	Benzo(k)fluoranthene	Denitrification bacteria
*Tripton	Beryllium	Dibenz(a,h)anthracene
1,1,1-trichloroethane	Bioch. Oxygen Demand [5] after filt.	Dibromochloromethane
1,1,2,2-tetrachloroethylene	Bioch. Oxygen Demand after	Dibromomethane
1,1,2-trichloroethane	Biochemical Oxygen Demand [1]	Dichlorobenzene
1,1,2-trichloroethylene	Biochemical Oxygen Demand [10]	Dichloromethane
1,1-dichloroethylene	Biochemical Oxygen Demand [28]	Dichlorophenol
1,2-dichloroethylene	Biochemical Oxygen Demand [5]	Dieldrin
1,2-dichloroethylene (cis)	Bioseston saprobility index	Diphenyl
1,2-dichloroethylene (trans)	Boron	Discharge immediate
1,2-dichloropropane	Bromochlormethane	Discharge-average, daily
1-methylnaphthalene	Bromodichlormethane	Dissolved organic species
137 Cs isotope activity	Bromoform	Dissolved species
2,2',4,4'-tetrachlorobiphenyl	Ca corrosive CO2	Dissolved species - loss by ignition
2,2,3,3,4,5,6,6-oktachlorobiphenyl	Cadmium	Dissolved species dried
2,2,3,3,4,6,6-heptachlorobiphenyl	Calcium	Dissolved species ignited
2,2,3,4,6- pentachlorobiphenyl	Caprolactam	Electrical Conductivity at 25°C
2,2,4,4,5,6-hexachlorobiphenyl	Carbon tetrachloride	Electrical Conductivity at
2,3-dichlorobiphenyl	Carbon total	Endosulfane
2,3-dichlorophenol	Carbonate	Endrin
2,4,5-trichlorobiphenyl	Carbonate hardness	Enterococcus
2,4,5-trichloropfenol	Carbontetrachloride	Equilibrium CO2
2,4,6-trichlorophenol	Carboxyl acides	Ethylbenzene
2,4-D acid	Cerium	Ethylenedichloride
2,4-dichlorophenol	Chemical Oxygen Demand - Cr	Evaporation residue - dried
2,5-dichlorophenol	Chemical Oxygen Demand - Mn	Evaporation residue - loss by
2,6-dichlorophenol	Chemical Oxygen Demand after	Extractable organic - bound Cl
2-chlorobiphenyl	Chemical Oxygen Demand after	Extractable species
3,4-dichlorophenol	Chemical Oxygen Demand after	Faecal coliform bacteria
4-nitrophenol	Chemical Oxygen Demand after	Faecal streptococci
Abioseston	Chloride	Fats
Abioseston - tripton	Chlorobenzene	Fatty acides
Absorbance	Chloroform	Fe - flakes
Acenaphthene	Chlorophenol	Fe and Mn- bacteria
Acenaphthylene	Chlorophyll	Fe corrosive CO2
Acetaldehyde	Chromium	Fe- bacteria
Acidity pH=4.5	Chromium [VI+]	Fermentation test
Acidity pH=8.3	Chromium total	Flagelata
Activ chlorine	Chromium trivalent	Fluoranthene
Acute toxicity	Chrysene	Fluorene
Air temperature	Ciliata	Fluoride
Aldrin	CO2 fixed	Formaldehyde - fixed
Alkalinity pH=4.5	Cobalt	Formaldehyde - free
Alkalinity pH=8.3	Coliform bacteria	Formaldehyde - total
Aluminium	Coliform bacteria - para coli	Free ammonia
Ametryn	Color	Free CO2
Ammonia ions	Color visually	Free sulfane
Ammonia-toxic	Colorless flagellum	Gallionela
Amorphous matter	Copper	Hardness
Amount of organisms - consumers	Corrosive CO2	Hardness Ca
Amount of organisms - producers	Costridium	Hardness Mg
Anorganic carbon	Cyanide	Heptachlor
Anthracene	Cyclohexane	Heptachlor epoxide
Arsenic	Cyclohexanol	Hexachlorhexane-mixture
Asbestos	Cyclohexanone	Hexachlorobenzene

Tab. 2: List of Water Quality parameters

Hexachlorocyclohexane	Nonpolar extractable species IR	Total amount of algaes
Hexachlorohexane alfa	Nonpolar extractable species U1	Total CO2
Hexachlorohexane beta	Nonpolar extractable species U2	Total Organic Carbon
Hexachlorohexane delta	Nonpolar extractable species UV	Total volume alfa activity
Heyer test	o-dichlorobenzene	Total volume beta activity
Humic species	Odor	Total volume beta activity after
Hydrocarbone bacteria	Organic nitrogen	Transparency
Hydroxide	Other Cl- hydrocarbons	Triazin
Ice phenomenon	Oxygen	Tritium
Ignition residue	Oxygen difference	Uranium
Insoluble species - dried	Oxygen saturation	Urea derivatives
Insoluble species - ignited	p,p-DDE	Urotropine
Insoluble species - loss by ignation	p-dichlorobenzene	Vanadium
Iodine 131	Pentachlorophenol	Vinylchloride
Iodine number	Perylene	Volume activity of radon 222
Iron	pH	Water level
Iron divalent	Phenanthrene	Water level below the terrain
Iron total after filtration	Phenol	Water temperature
Iron total after sedimentation	Phenol volatiling with a steam	Weather
Iron trivalent	Phenolnaphtalene	Zinc
Langelier index	Phosphate	Zooplancton saprobility index
Lead	Phosphorus total	
Lead 210	Phthalate	
Lead 214	PO4-phosphorus	
Lindane	Polyaromatic hydrocarbons	
Lisnosulfone acid	Polychlorobiphenyls	
Lithium	Potassium	
Living organisms	Prometrin	
Look after 24 hours	Propazine	
Look after sampling	Psychrophilic bacteria	
m-dichlorobenzene	Pyrene	
Macroflauna saprobility index	Radium 226	
Magnesium	Redox potential - measured	
Manganese	Redox potential - recalculated to	
Manganese organic	Reducing species	
MCPA	RG-tritium	
Mercury	Root	
Mesophilic bacteria	Root system growth ratio	
Methanol	Saprobility index	
Methoxychlor	Schyzomycetes	
Metribuzin	Sediment	
Microflora saprobility index	Sedimentable species	
Mineral oil	Selenium	
Mineral oil visually	Silica	
Mineralization	Silver	
Mist	Simatrine	
Mn- bacteria	Simazine	
Molybdenium	Sodium	
Myxobacteria	Spore-forming aerobic organisms	
Myzeta	Spore-forming anaerobic	
Naphthalene	Sr 90 isotope activity	
Nickel	Stabil O18 oxygen isotopes	
Nitrate	Strontium	
Nitrification bacteria	Strontium and yttrium	
Nitrite	Sulfate	
Nitrogen -NO2	Taste	
Nitrogen -NH4	Temperature test	
Nitrogen -NO3	Tensides	
Nitrogen total	Tetrachloroethane	
Non-carbonate hardness	Thorium 232	
Nonpolar extractable species	Toluene	

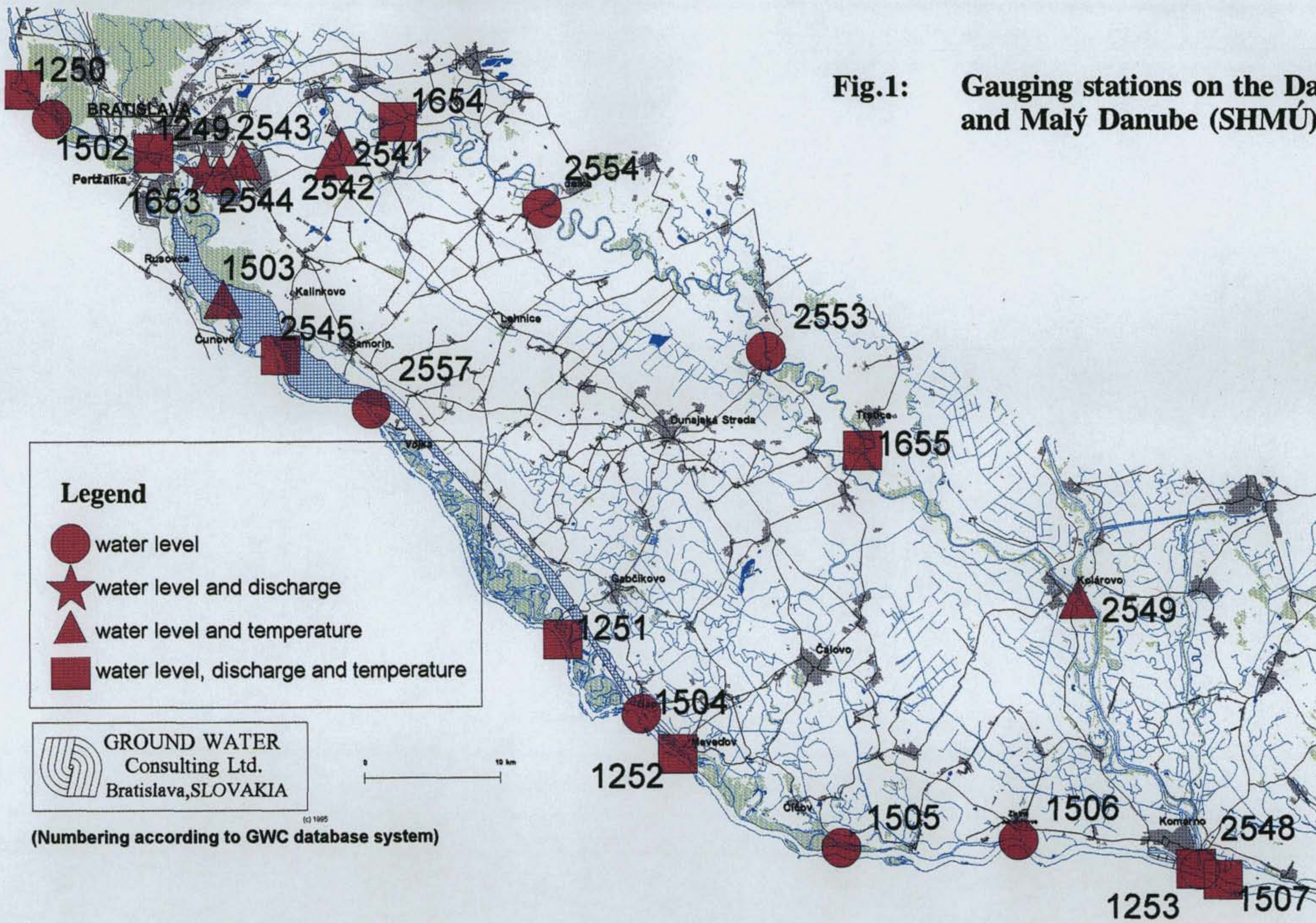
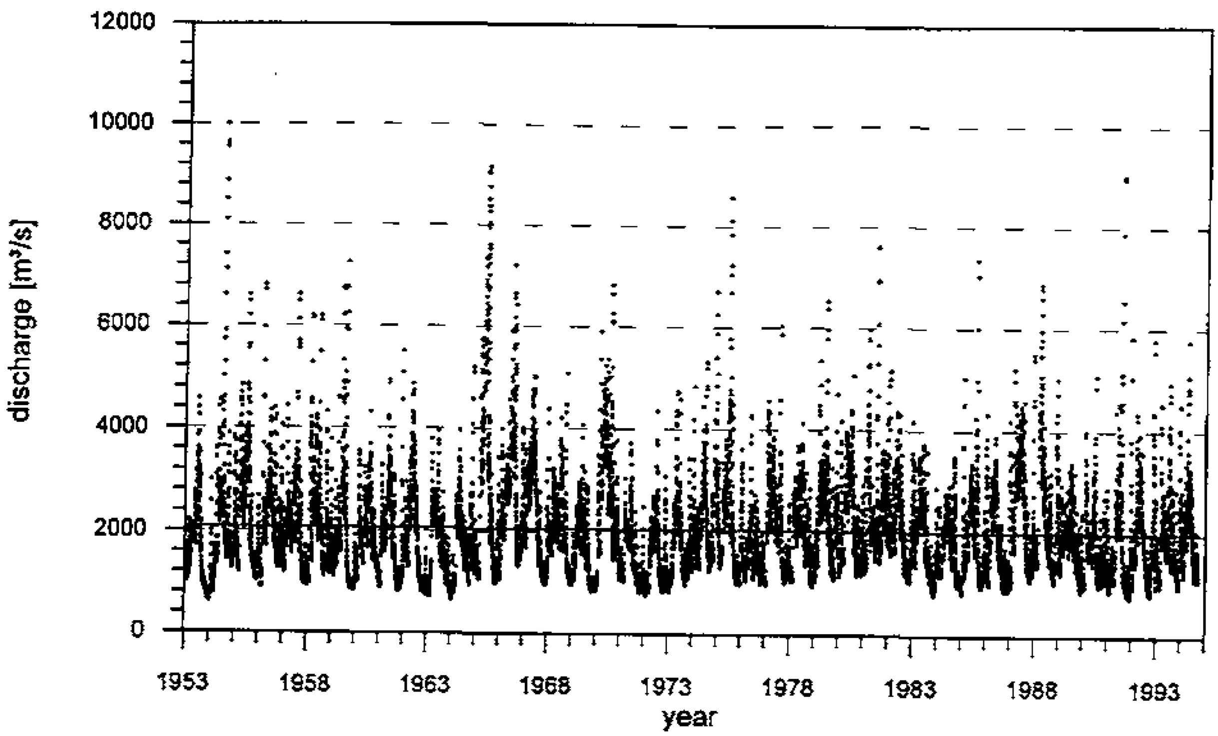


Fig.1: Gauging stations on the Danube and Malý Danube (SHMÚ)

THE DANUBE DISCHARGE AT BRATISLAVA



THE DANUBE DISCHARGE AT KOMÁRNO

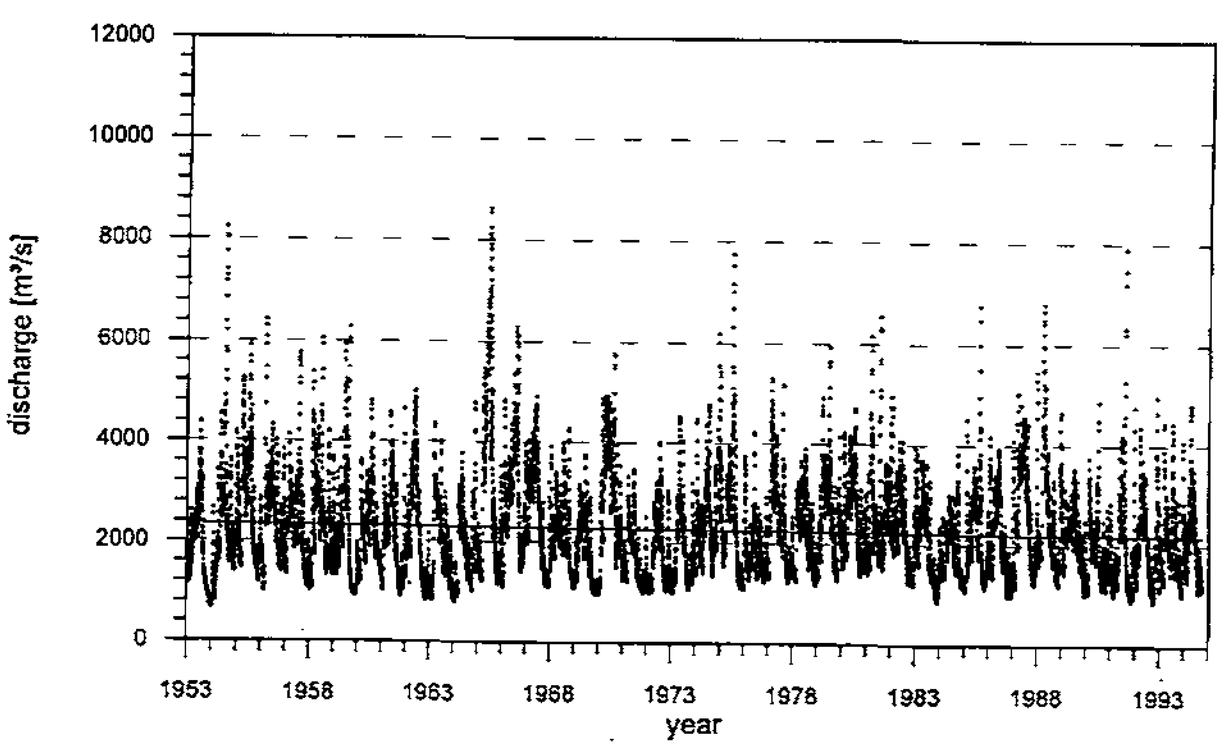


Fig. 2: The Danube discharge at Bratislava and Komárno

Based on SHMÚ data

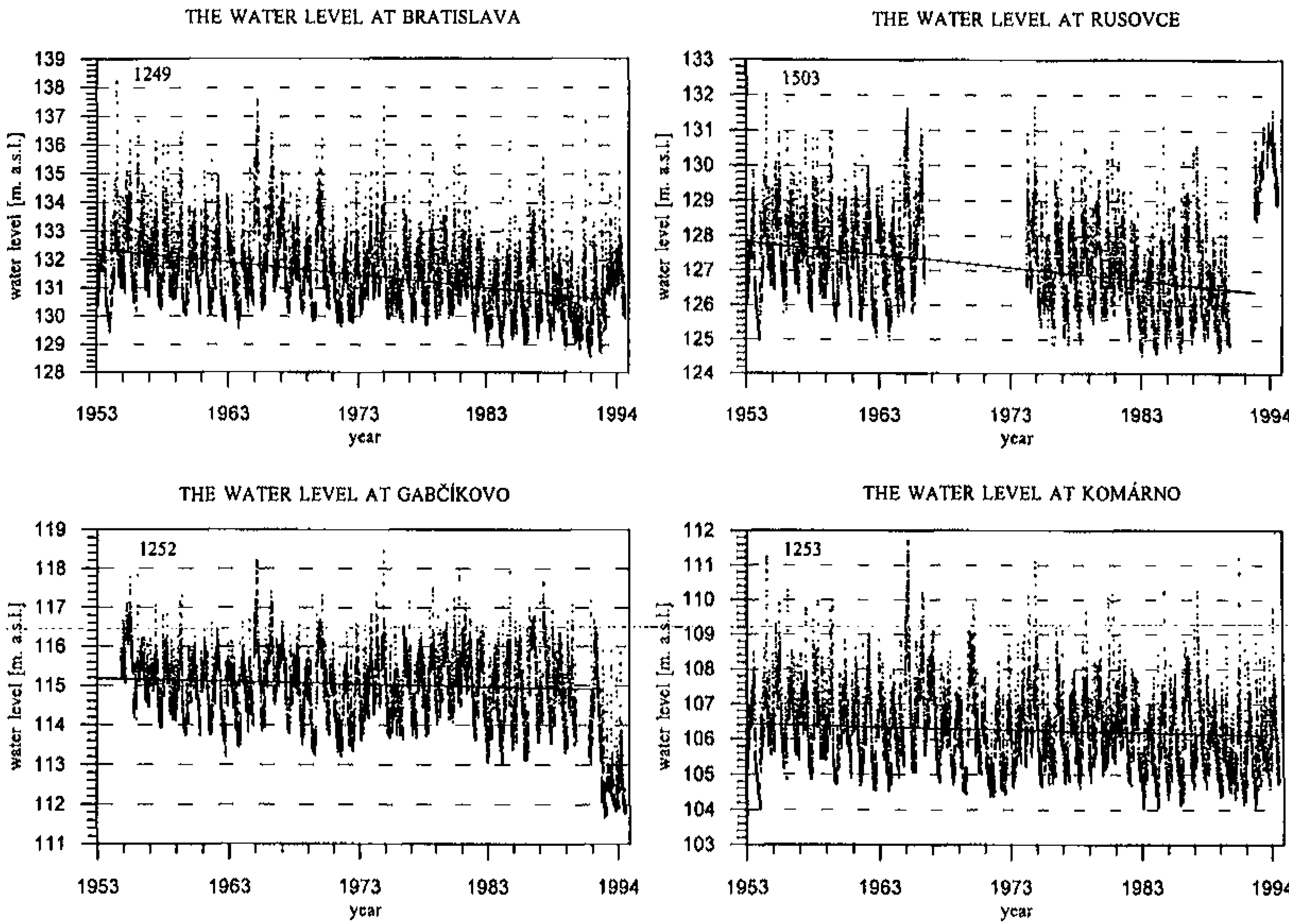


Fig. 3: The Danube water levels at Bratislava, Rusovce, Gabčíkovo and Komárno

Based on SHMÚ data

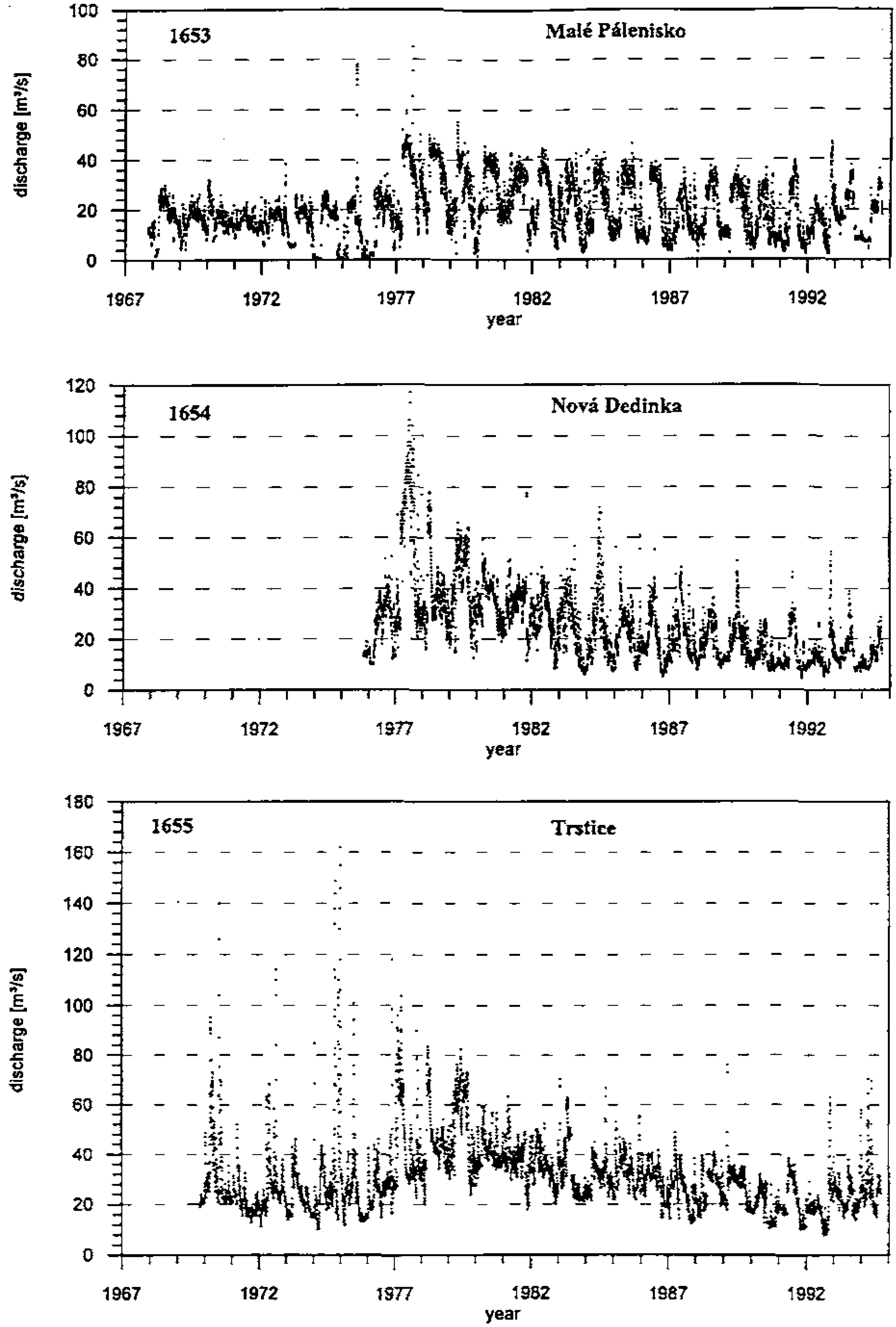


Fig. 4: The Little Danube discharge at Malé Pálenisko, Nová Dedinka and Trstice

Based on SHMÚ data

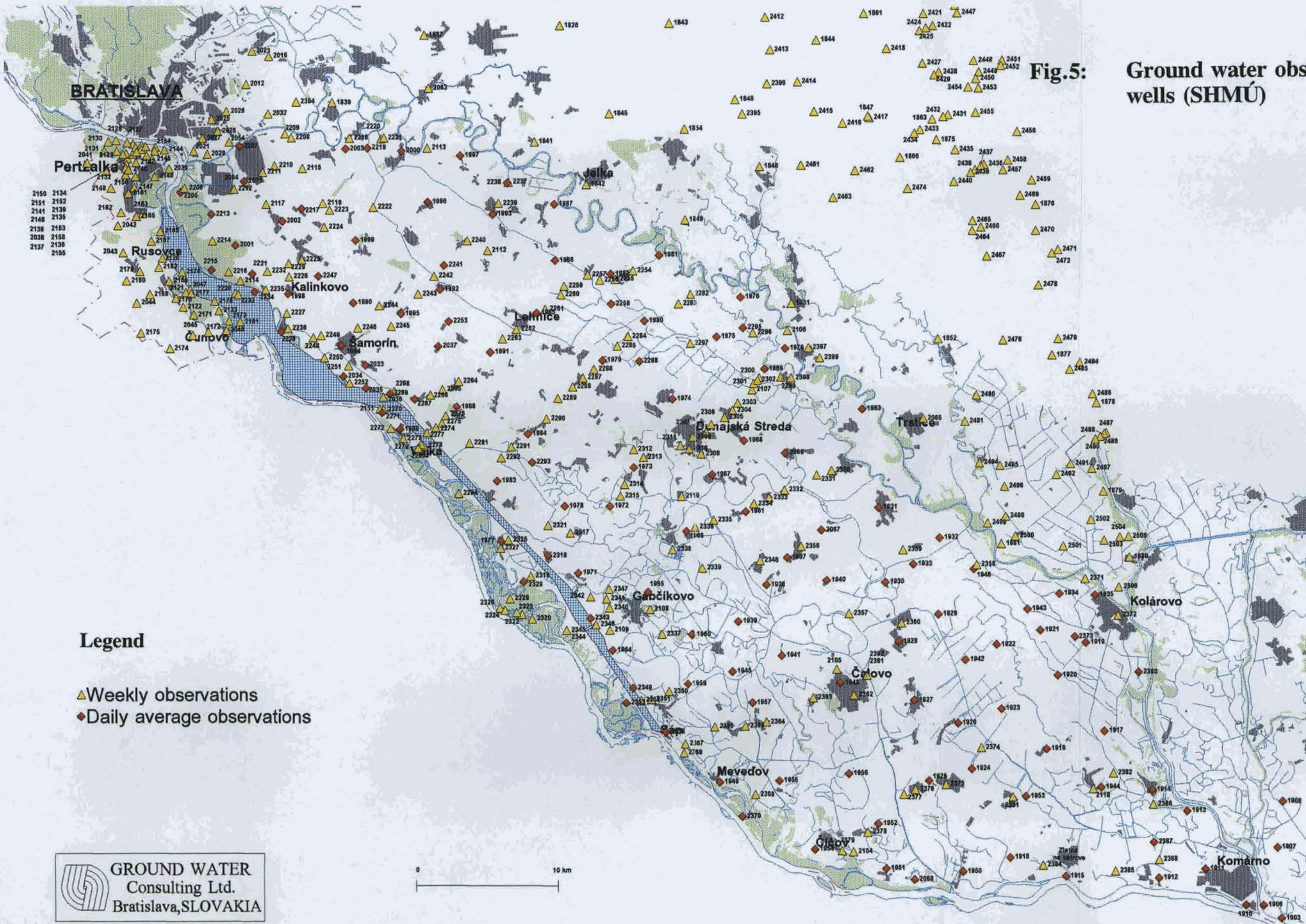


Fig.5: Ground water observation wells (SHMÚ)

(Numbering according to GWC database system)

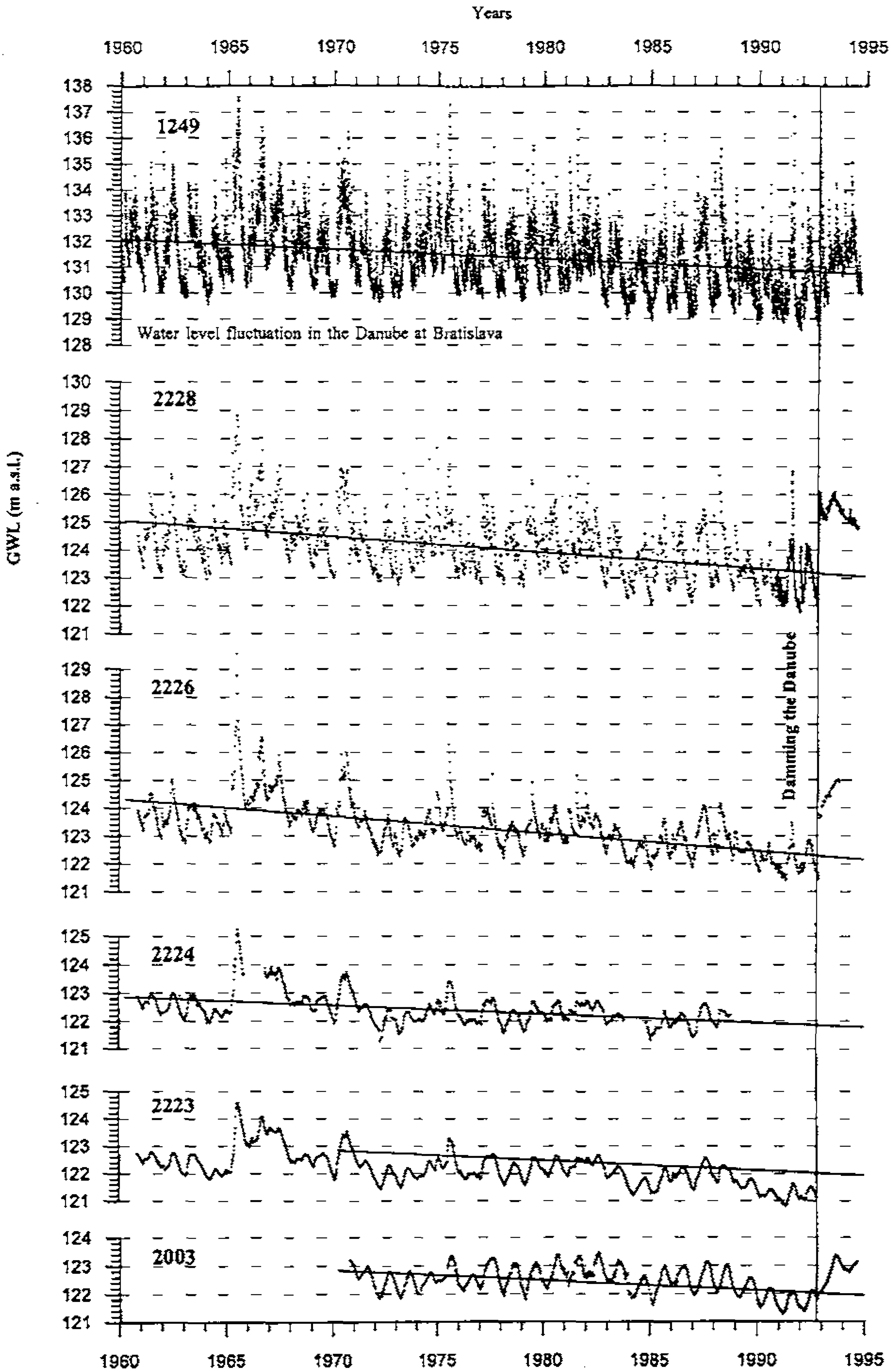


Fig. 6a: Water and ground water level fluctuation in the Danube and in the wells across the area (upper part of Žitný ostrov, left side of the Danube)

Based on SHMÚ data

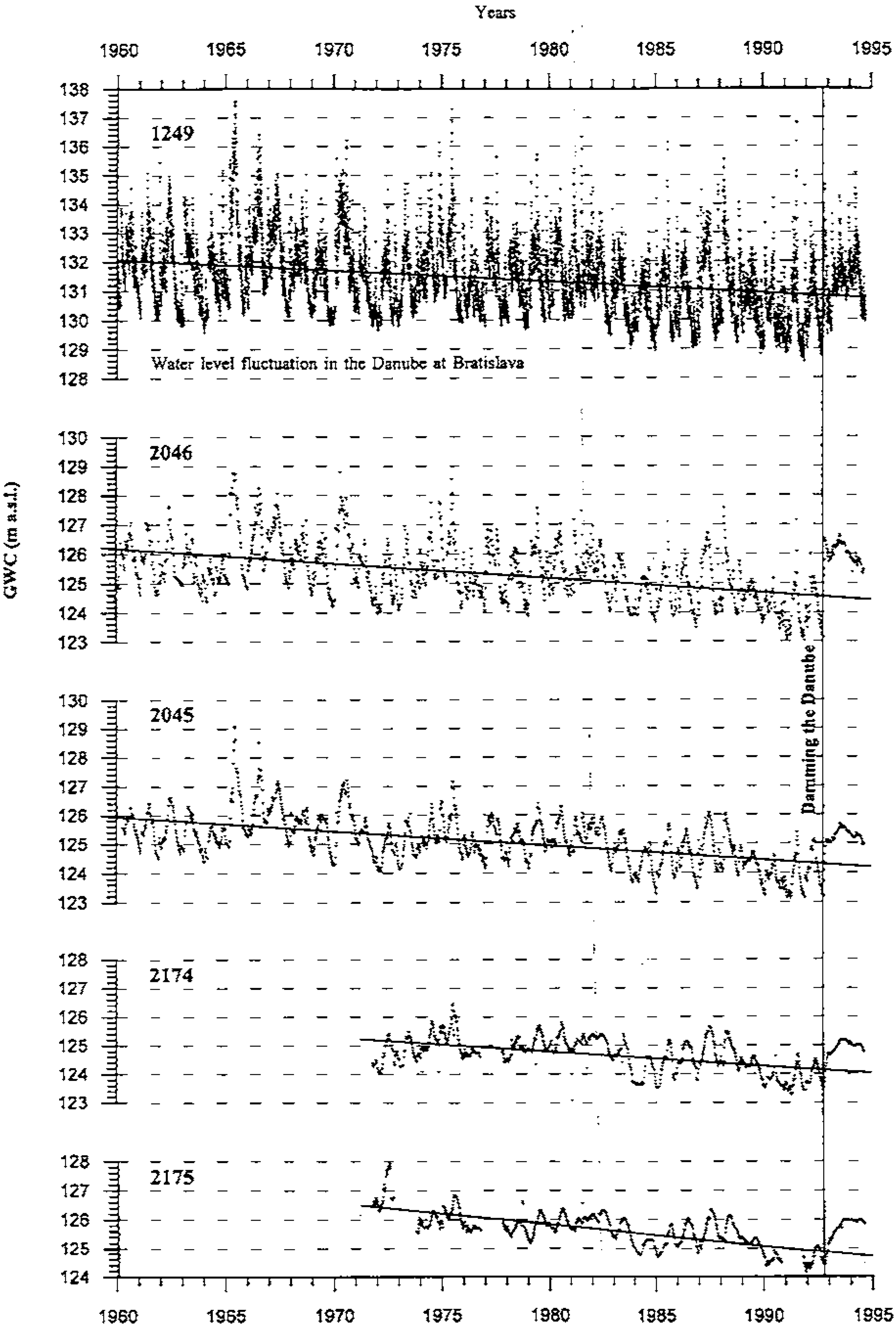


Fig. 6b: Water and ground water level fluctuation in the Danube and in the wells across the area (right side of the Danube)

Based on SHMÚ data

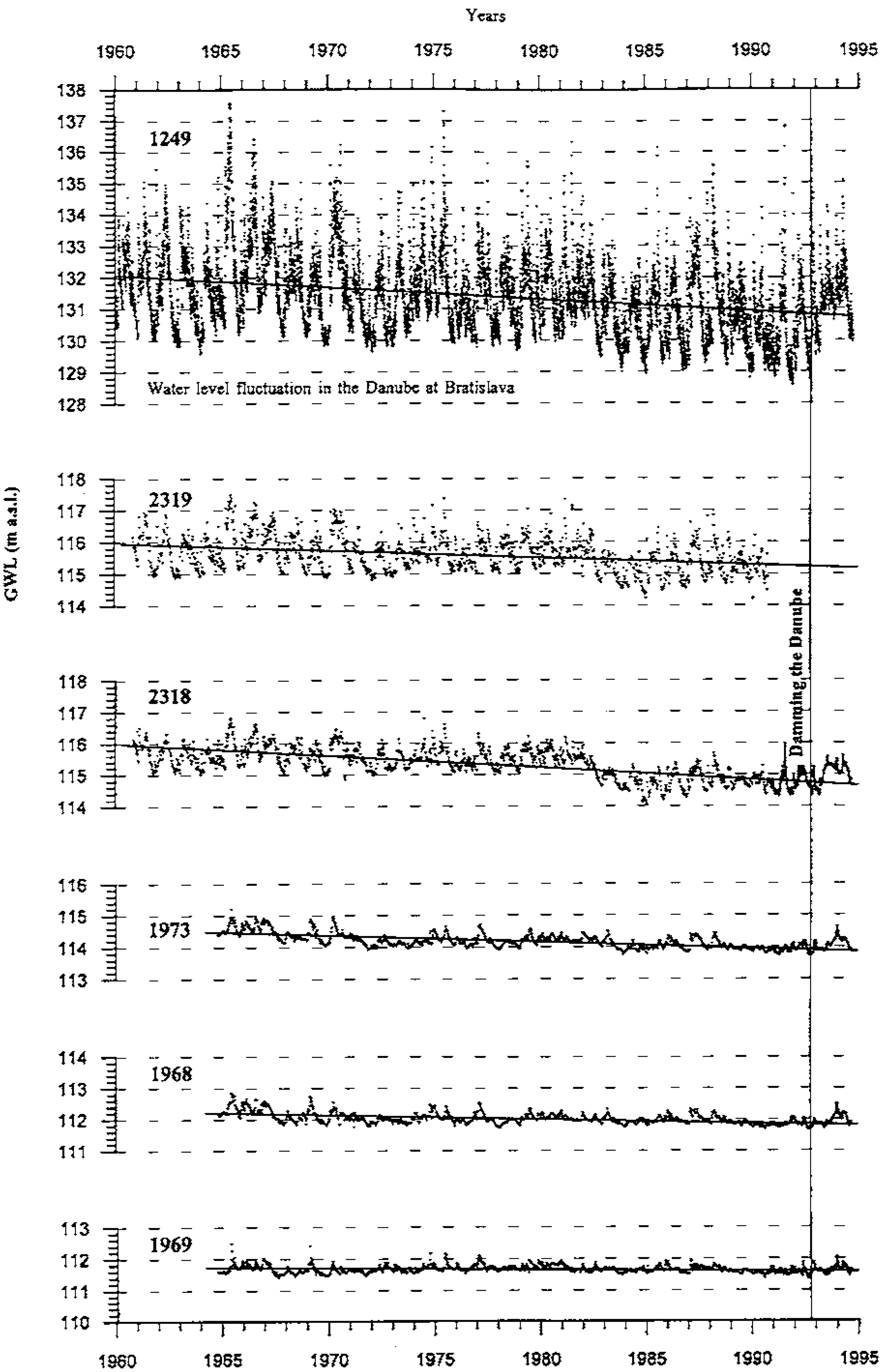


Fig. 6c: Water and ground water level fluctuation in the Danube and in the wells across the area (middle part of Žitný ostrov)

Based on SHMÚ data

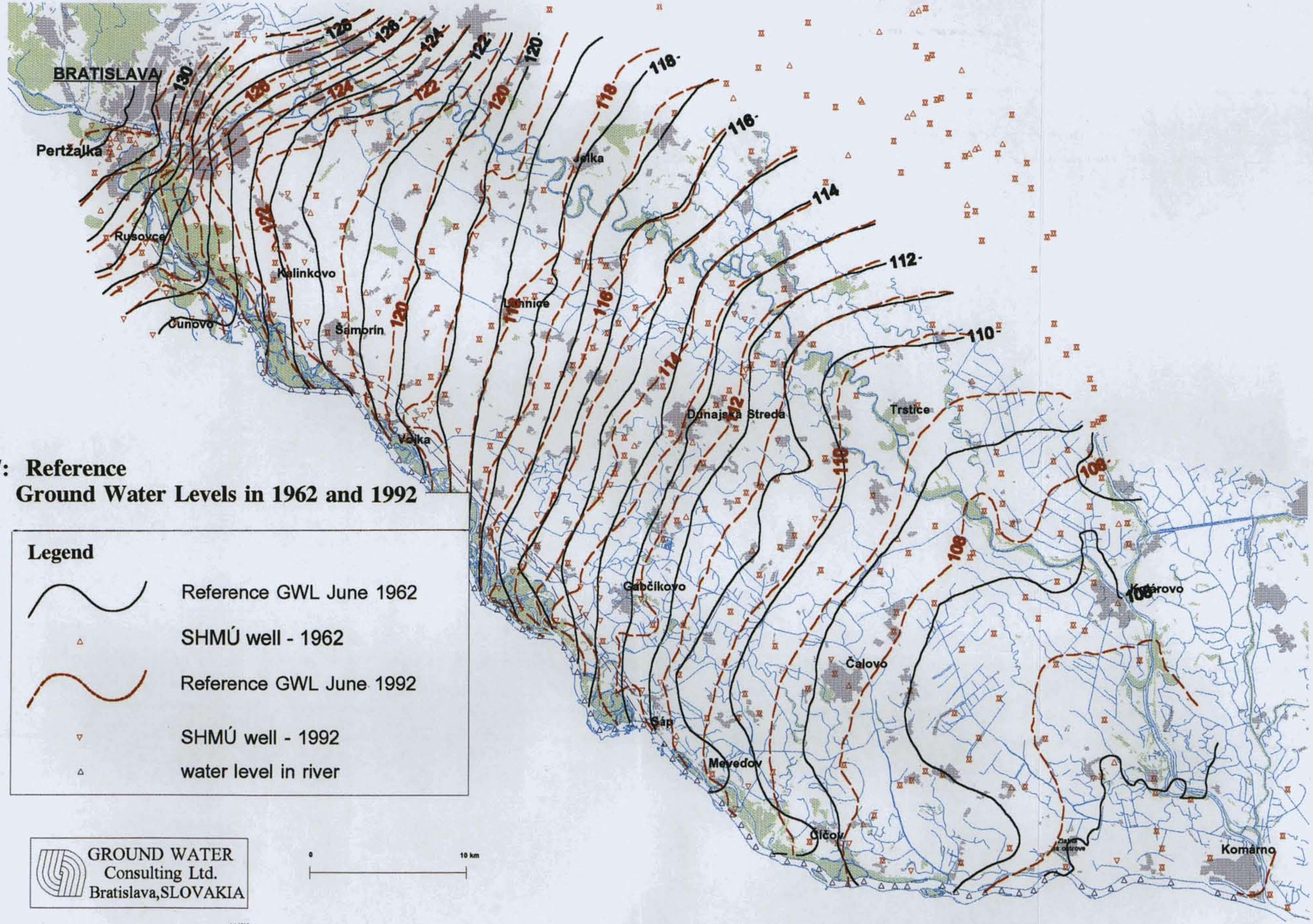


Fig.7: Reference Ground Water Levels in 1962 and 1992

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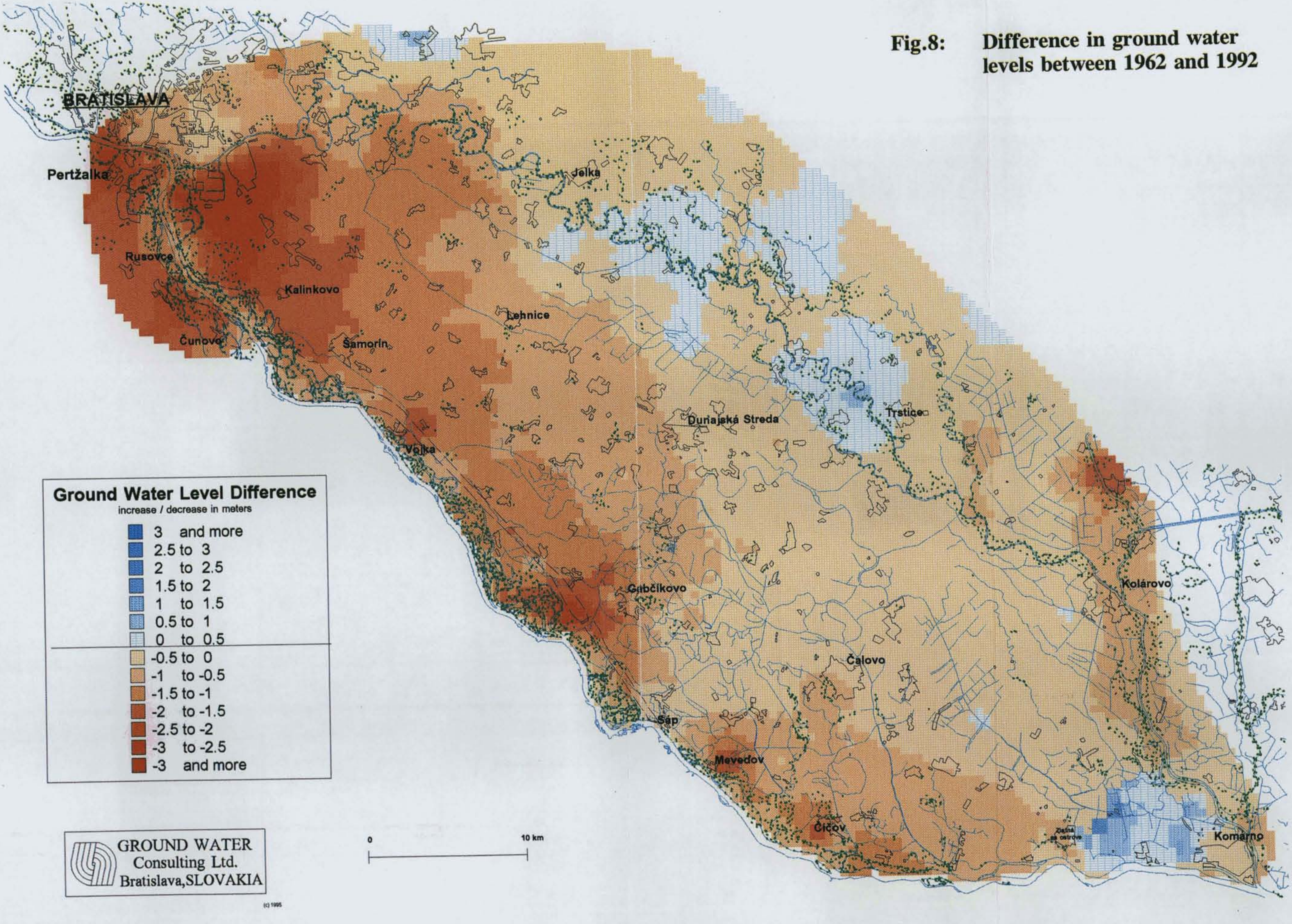
Fig.8: Difference in ground water levels between 1962 and 1992



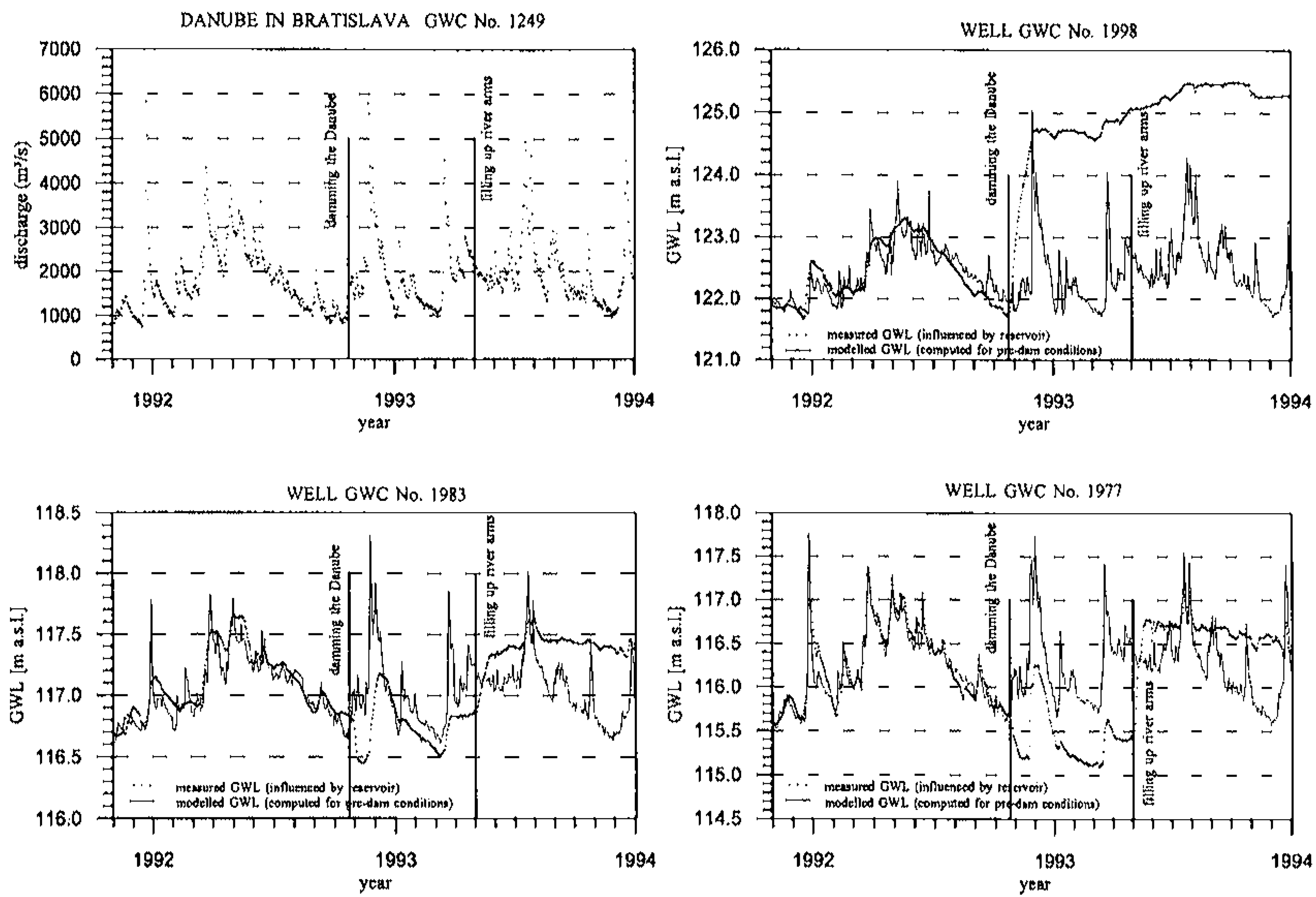


Fig. 9: The discharge in the Danube; measured ground water levels; computed ground water levels for pre-dam conditions

Based on SHMÚ data

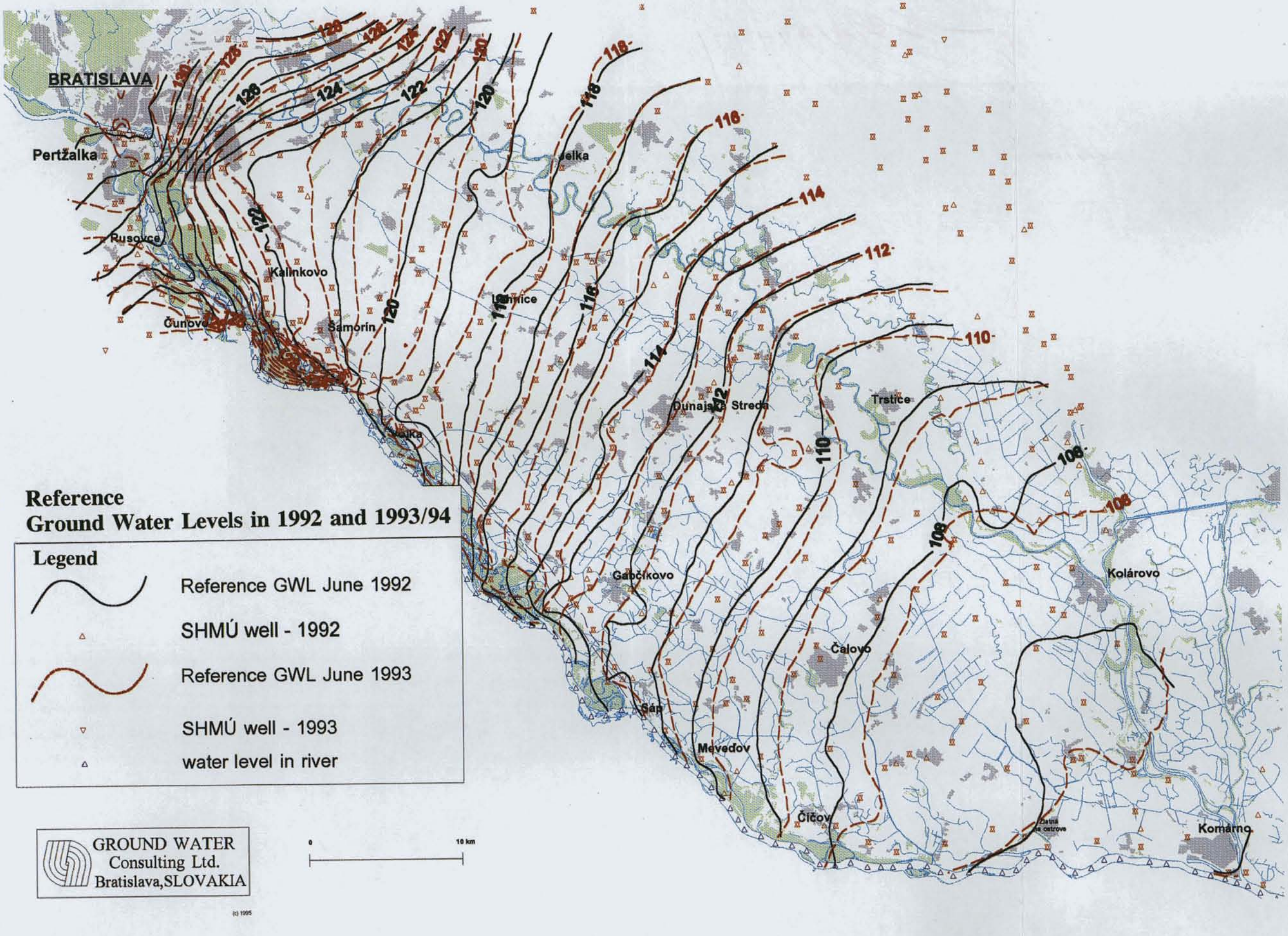


Fig.10: Reference Ground Water Levels in 1992 and 1993/94

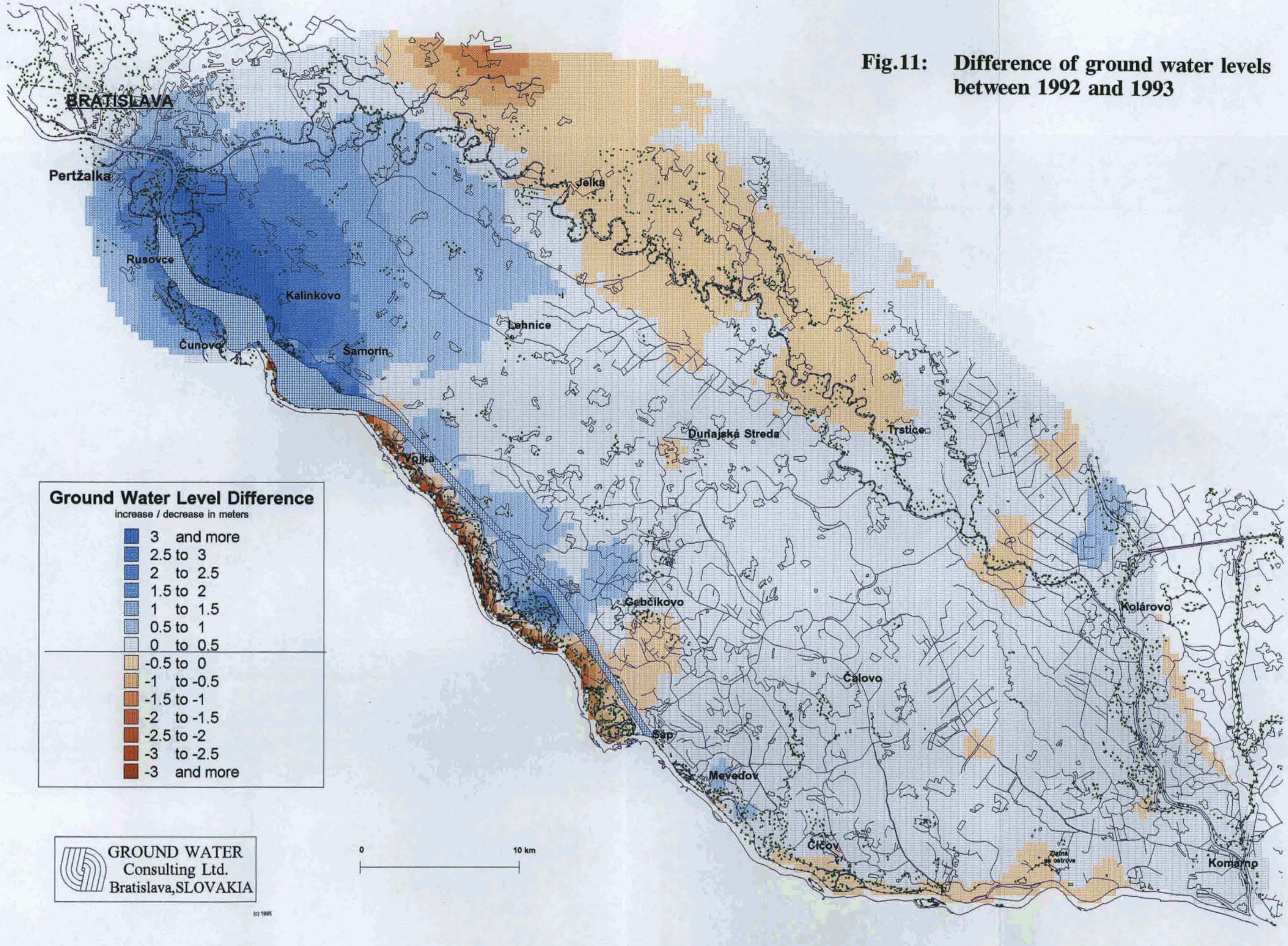


Fig.11: Difference of ground water levels between 1992 and 1993

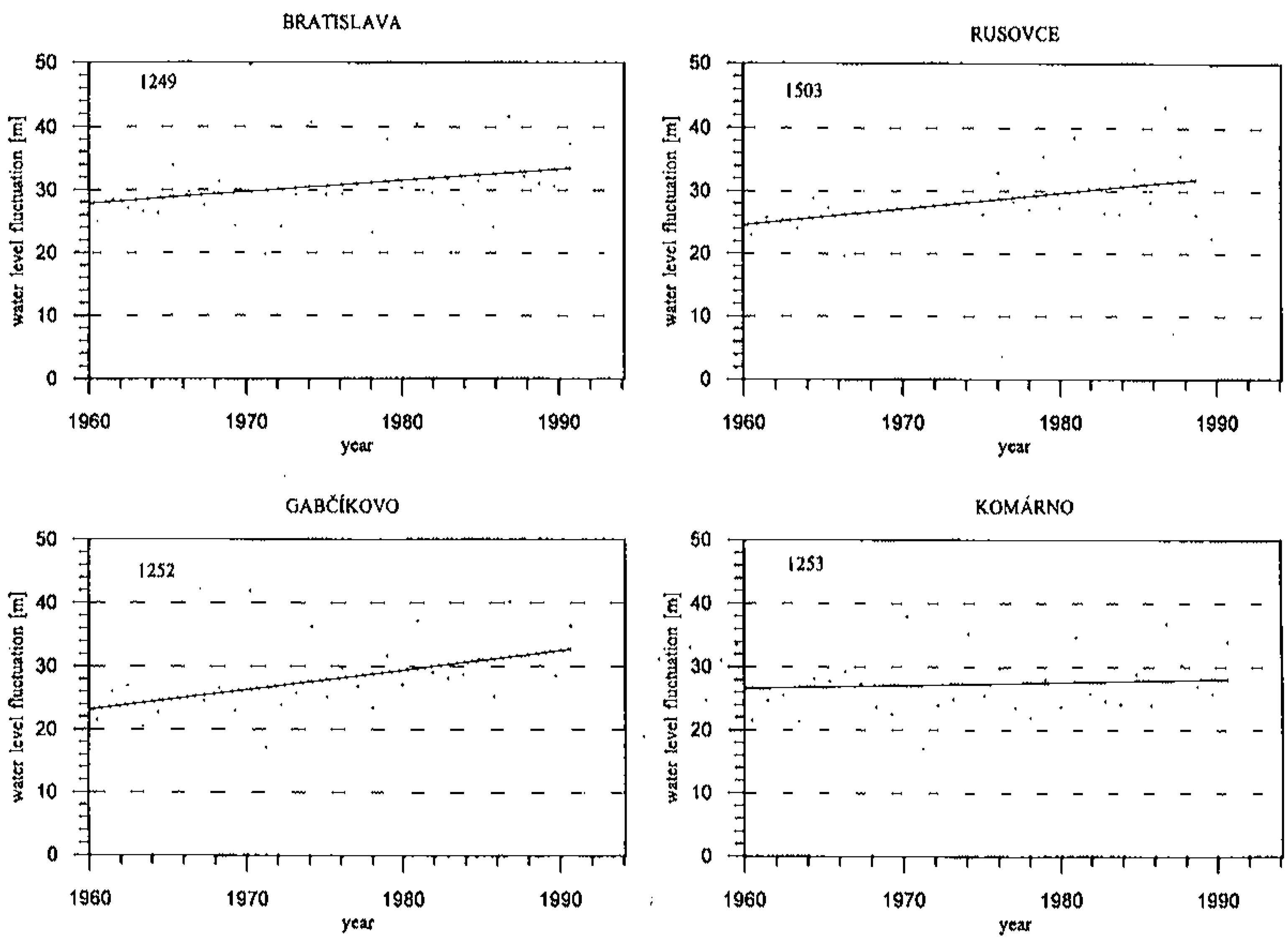


Fig. 12: Annual water level fluctuation at Bratislava, Rusovce, Gabčíkovo and Komárno

Based on SHMÚ data

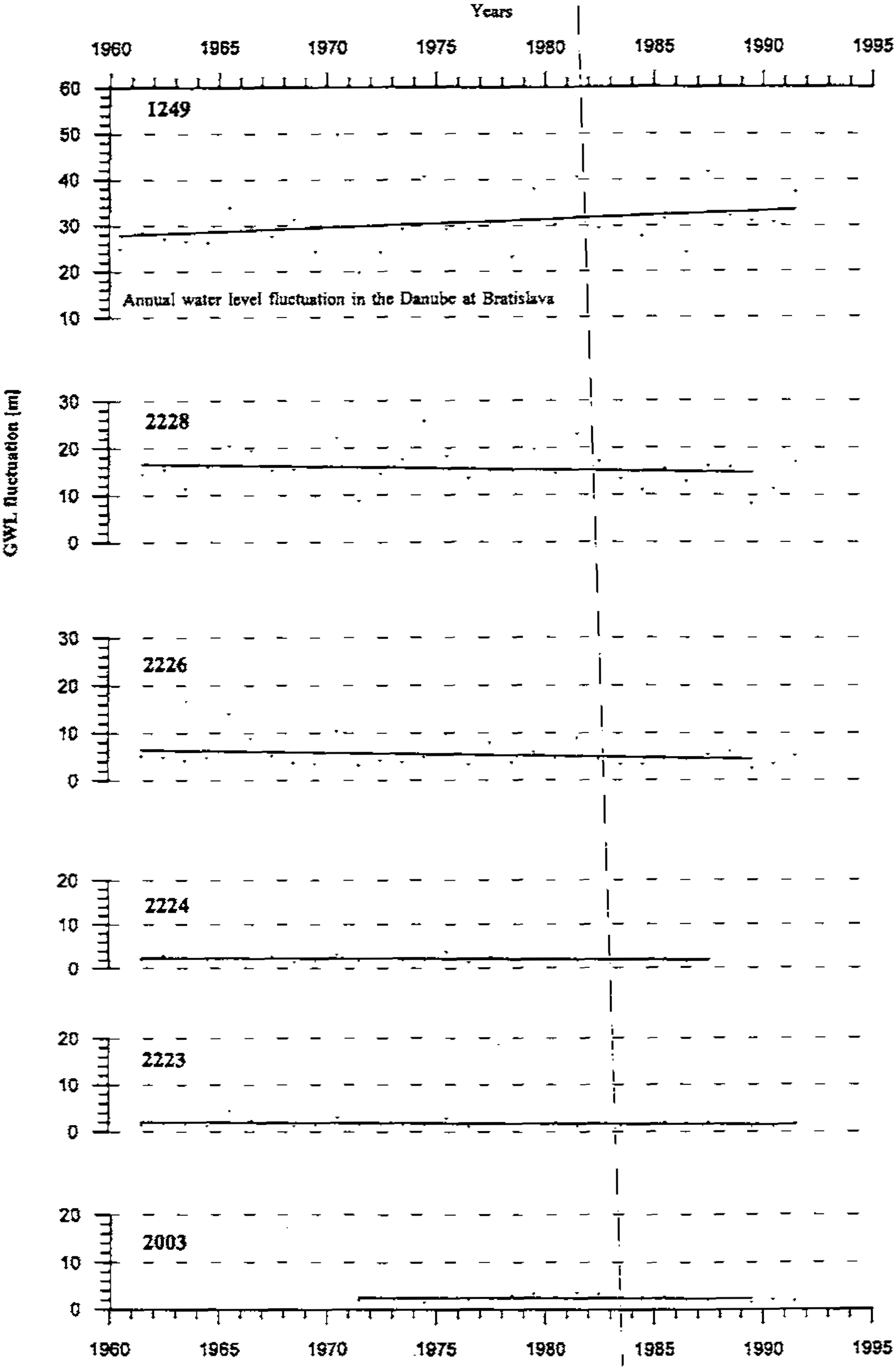


Fig.13a: Annual water and ground water level fluctuation in the Danube and in the wells across the area (upper part of Žitný ostrov)

Based on SHMÚ data

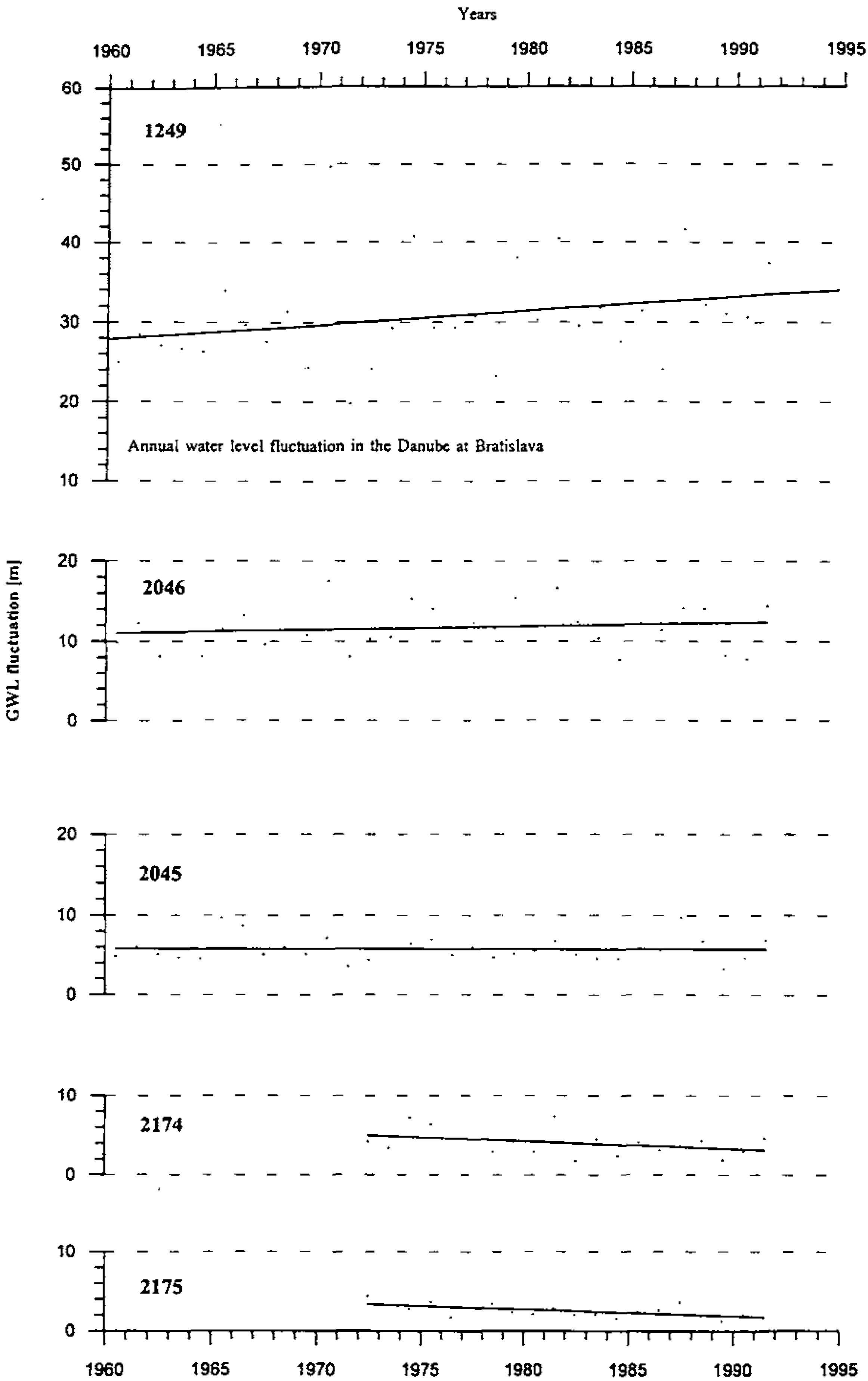


Fig 13b: Annual water and ground water level fluctuation in the Danube and in the wells across the area (right side of the Danube)

Based on SHMÚ data

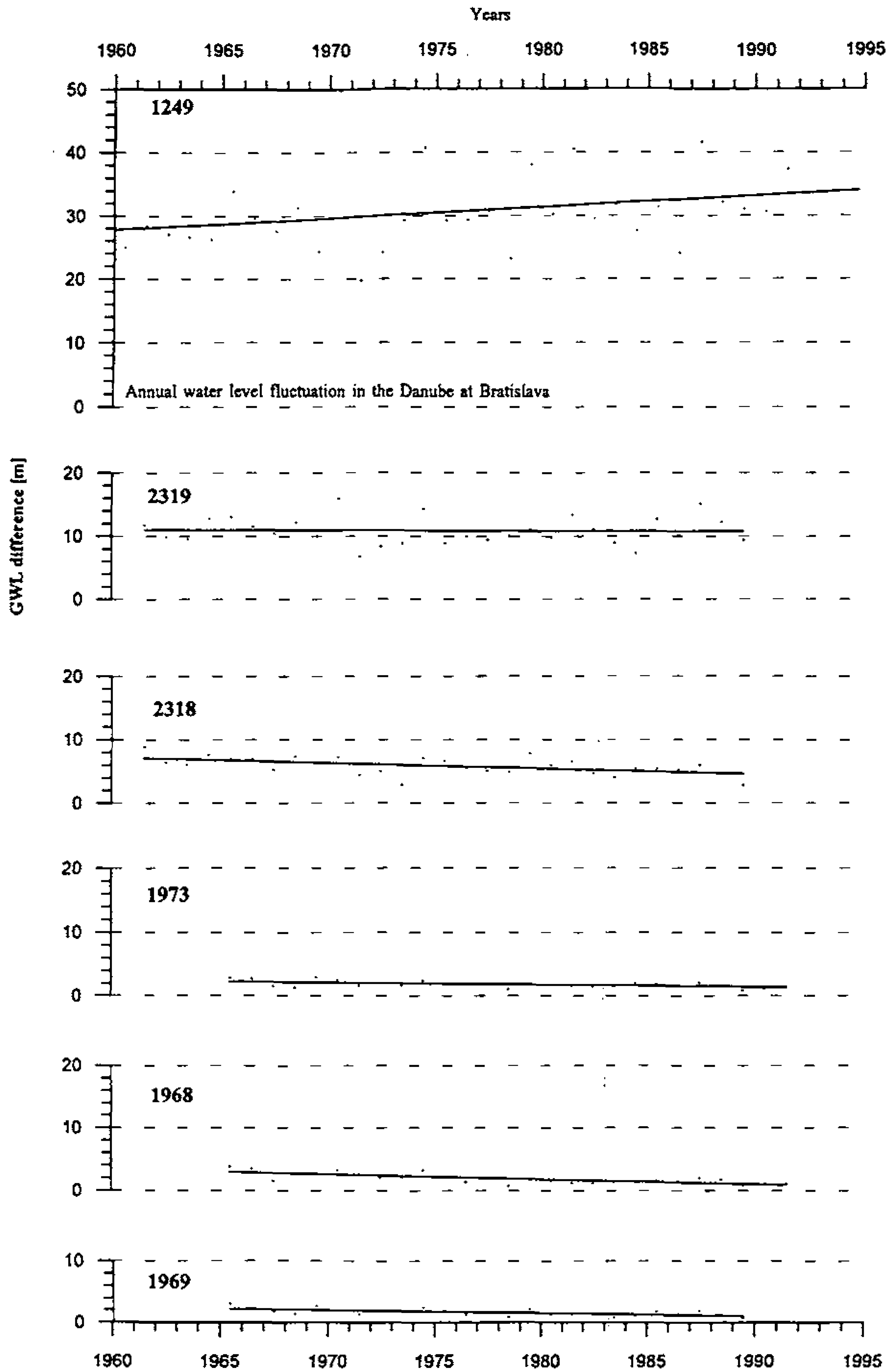
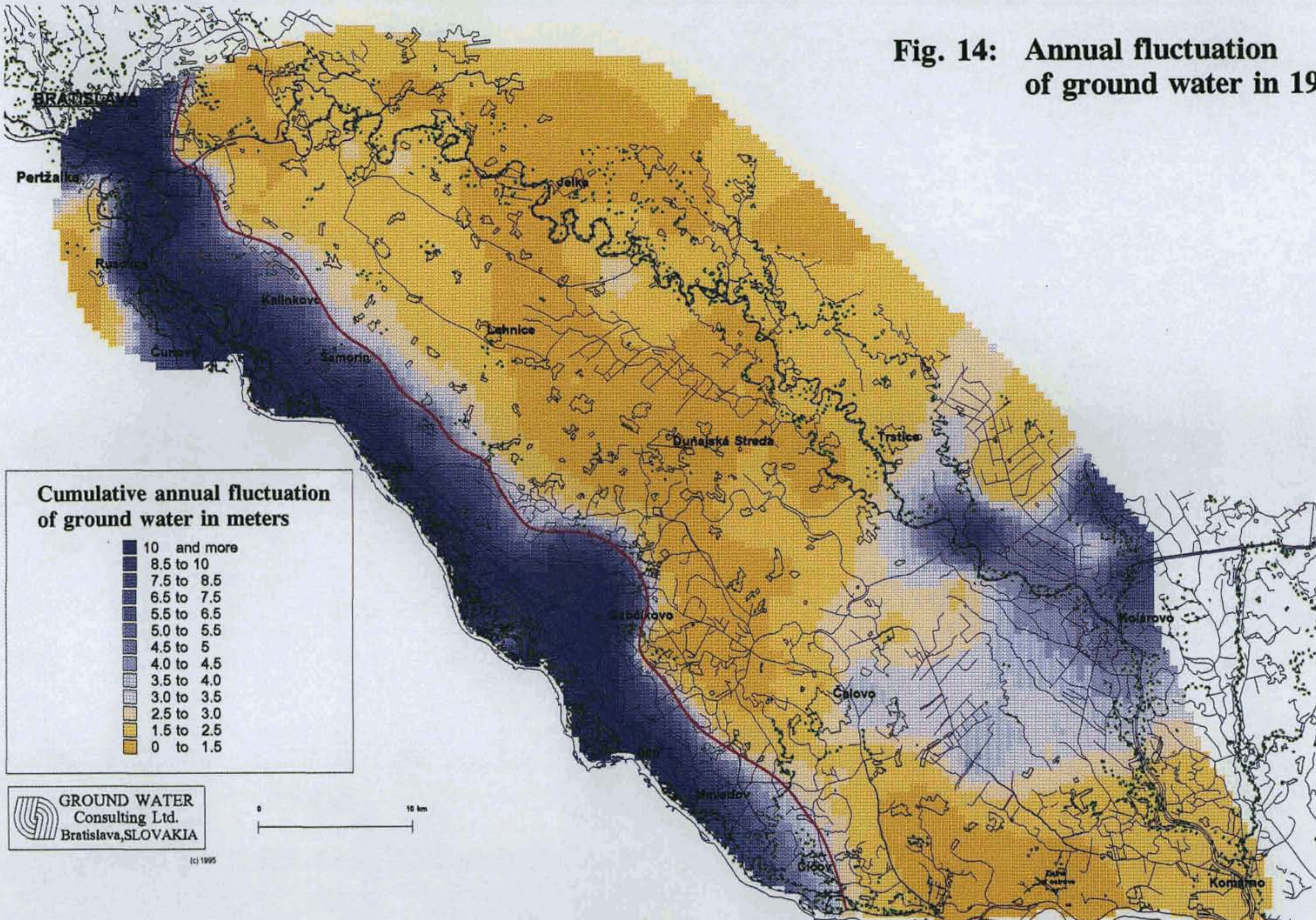


Fig.13c: Annual water and ground water level fluctuation in the Danube and the wells across the area (middle part of Žitný ostrov)

Based on SHMÚ data

Fig. 14: Annual fluctuation of ground water in 1991



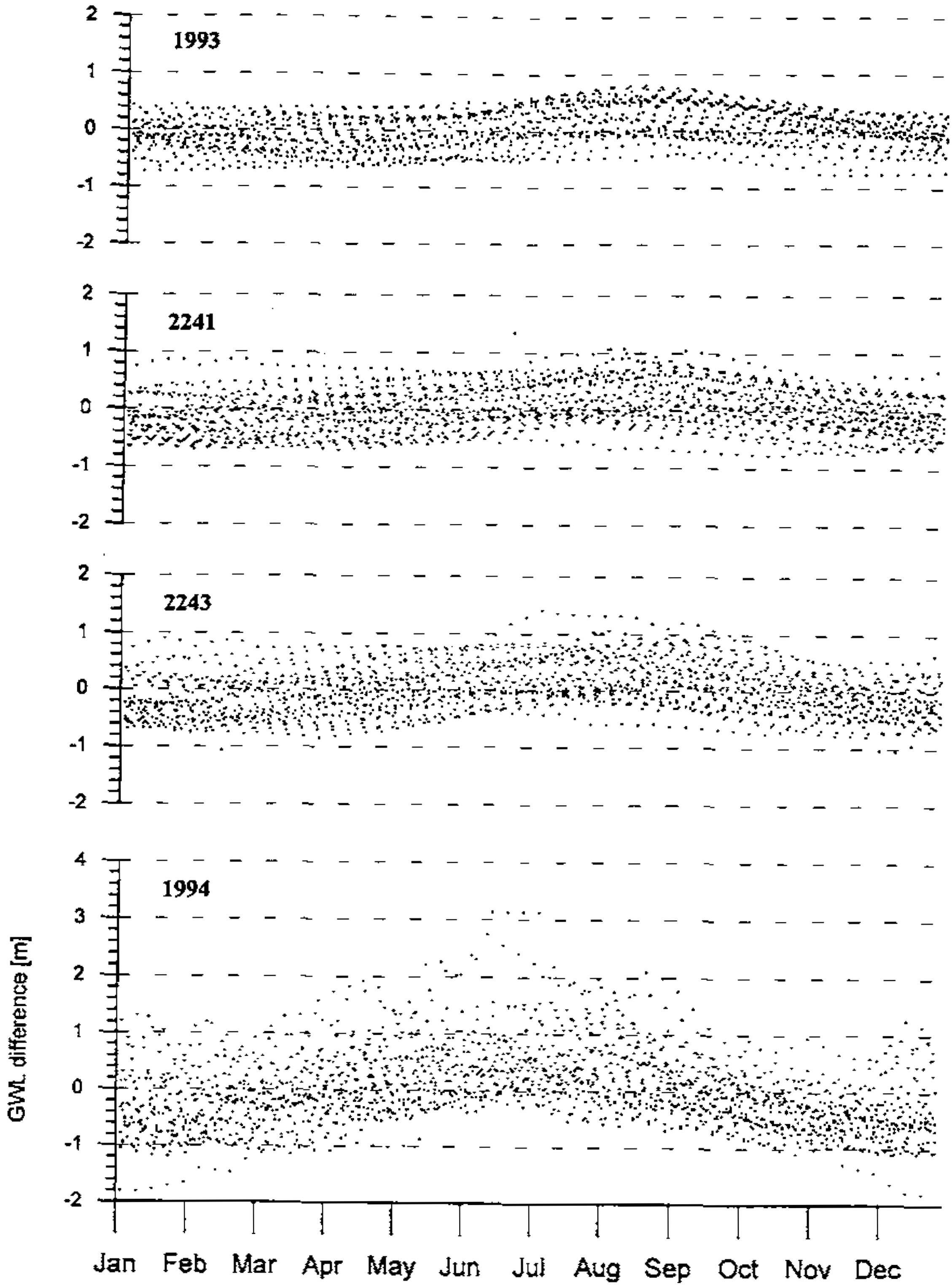


Fig. 15a: Seasonal ground water level fluctuation
(before damming the Danube, 1953 - 1992)

Based on SHMÚ data

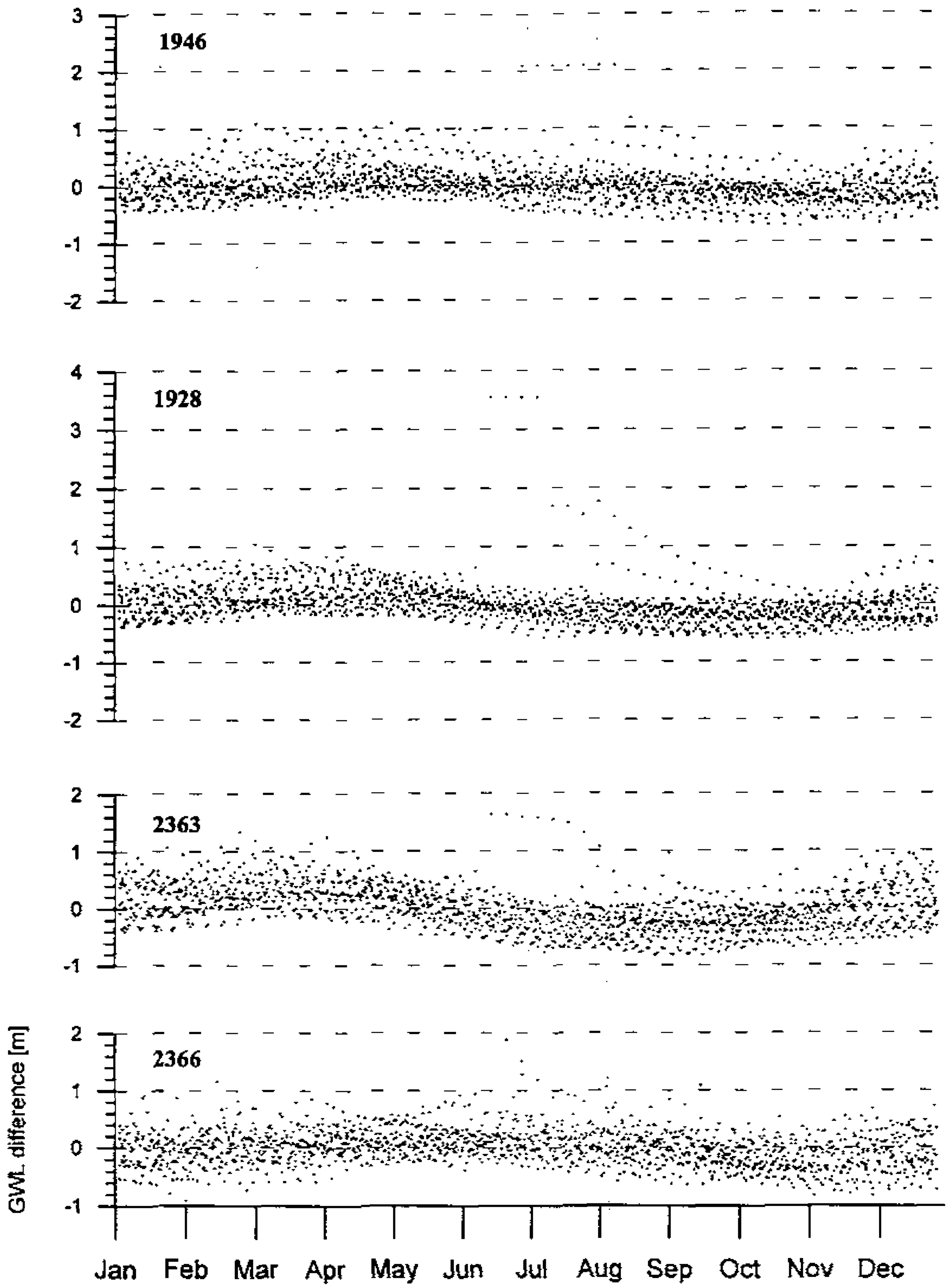


Fig. 15b: Seasonal ground water level fluctuation (before damming the Danube, 1953 - 1992)

Based on SHMÚ data

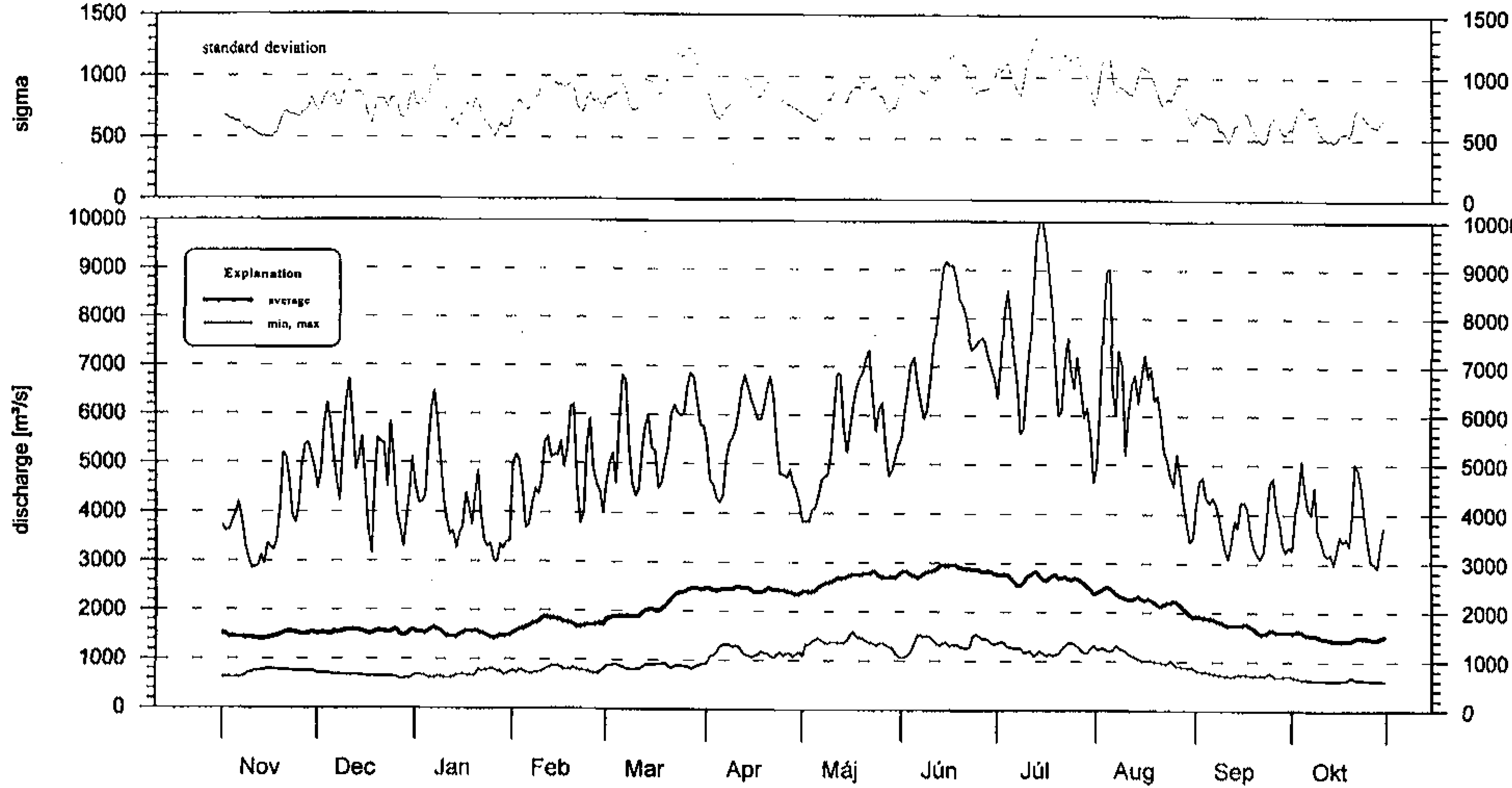


Fig. 16: Long - term seasonal discharge in Danube (Bratislava) (min, max, st.deviation) 1930 - 1992

Based on SHMÚ data

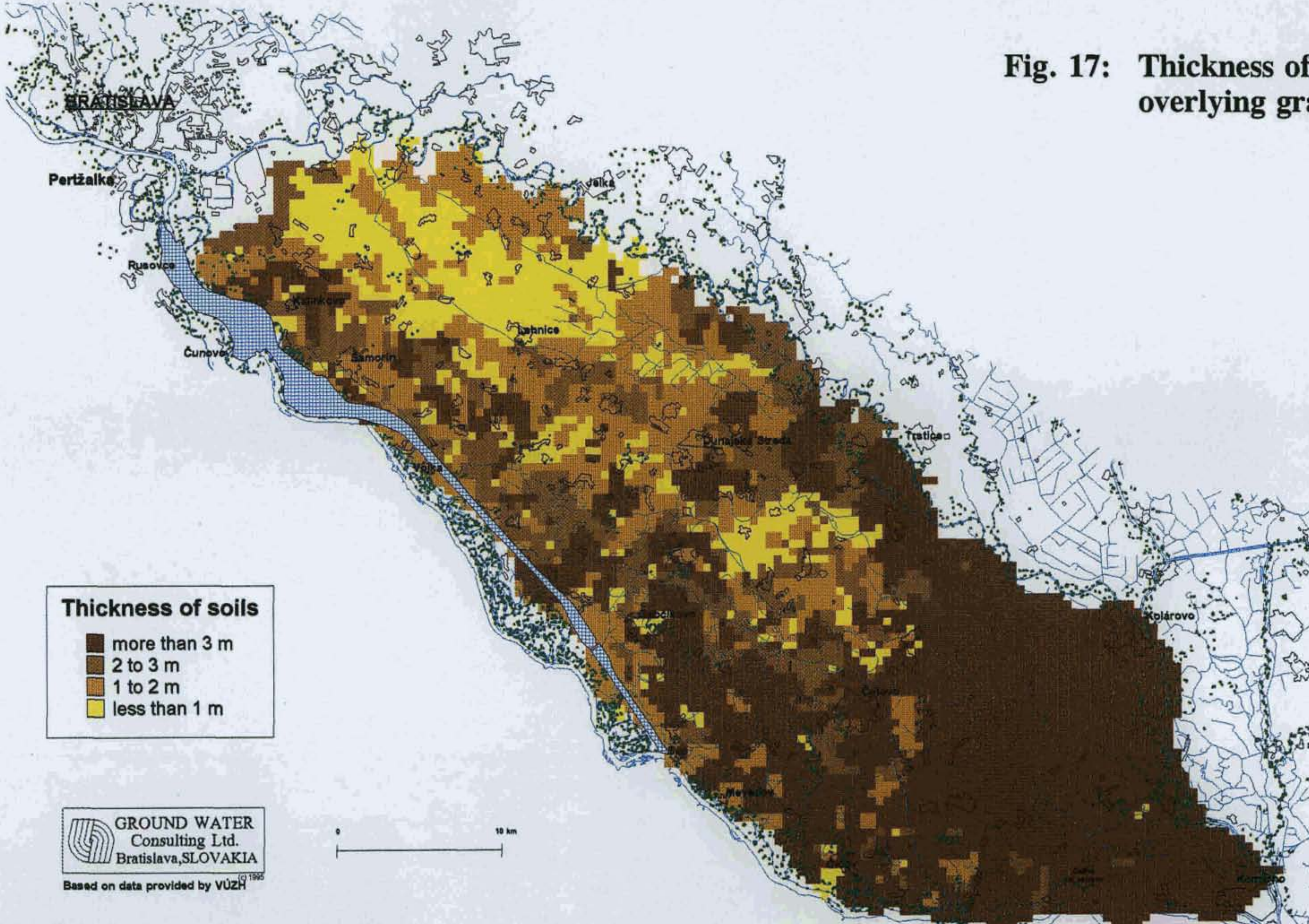


Fig. 17: Thickness of soils overlying gravel

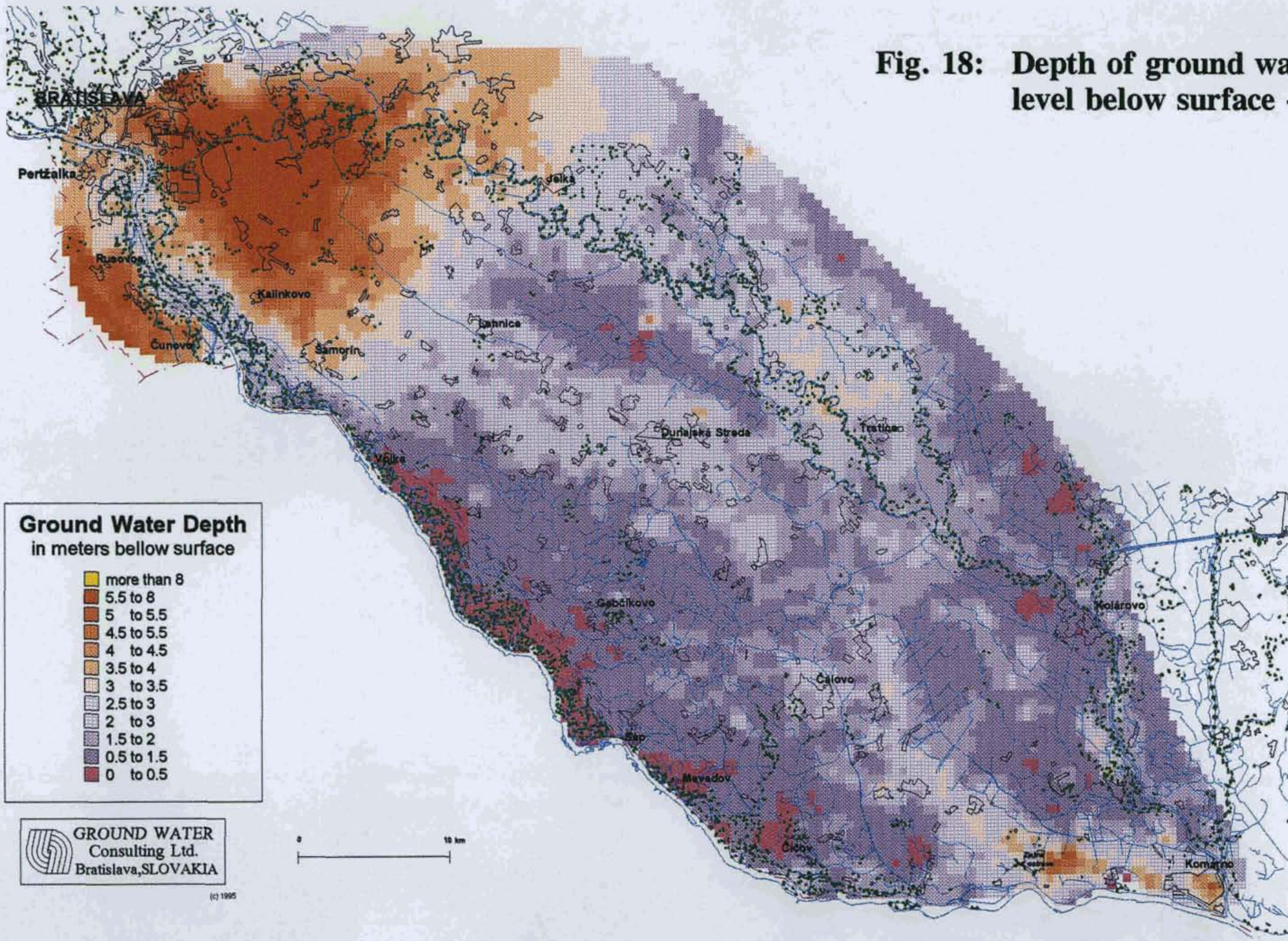


Fig. 18: Depth of ground water level below surface - 1962

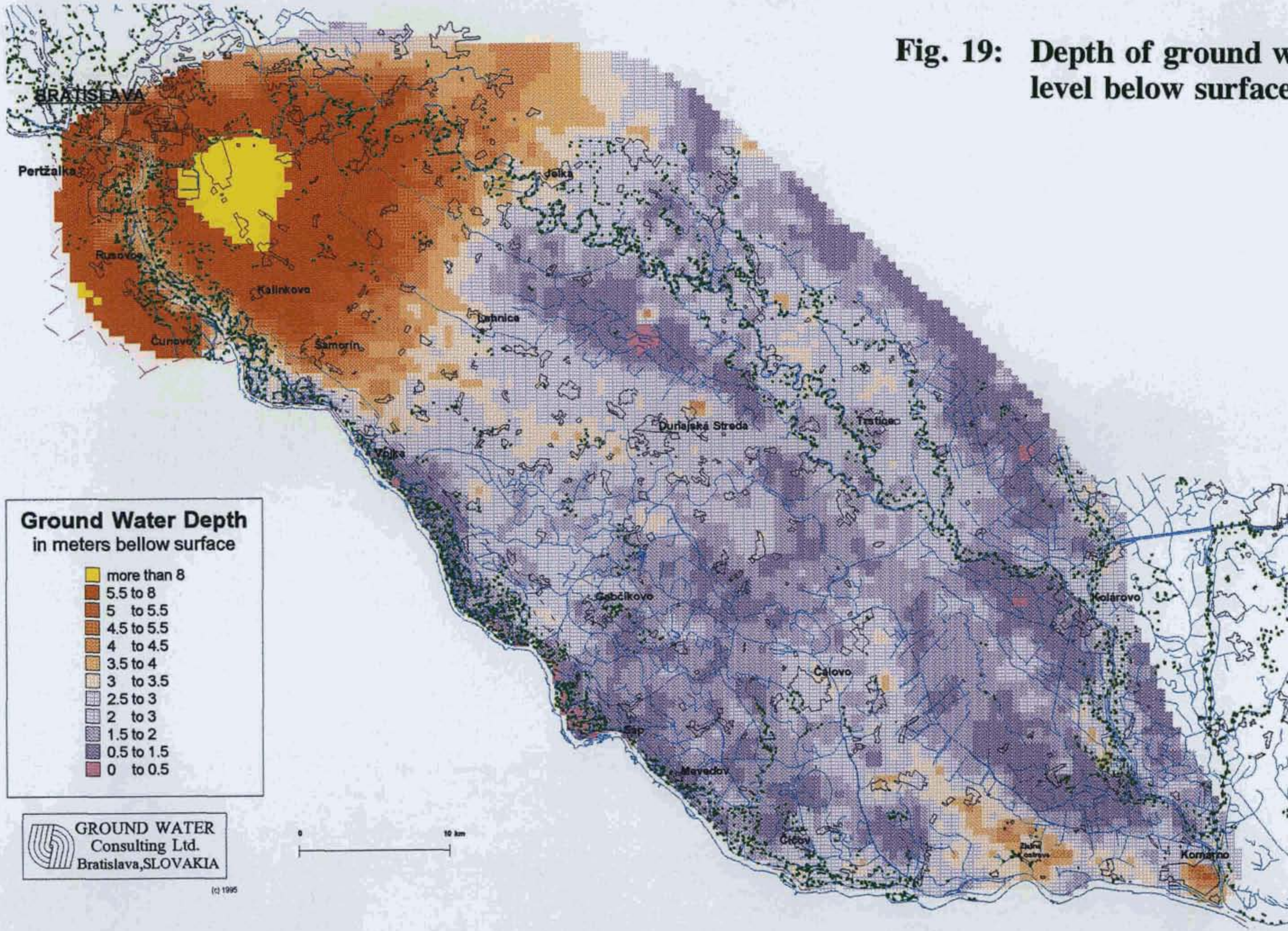
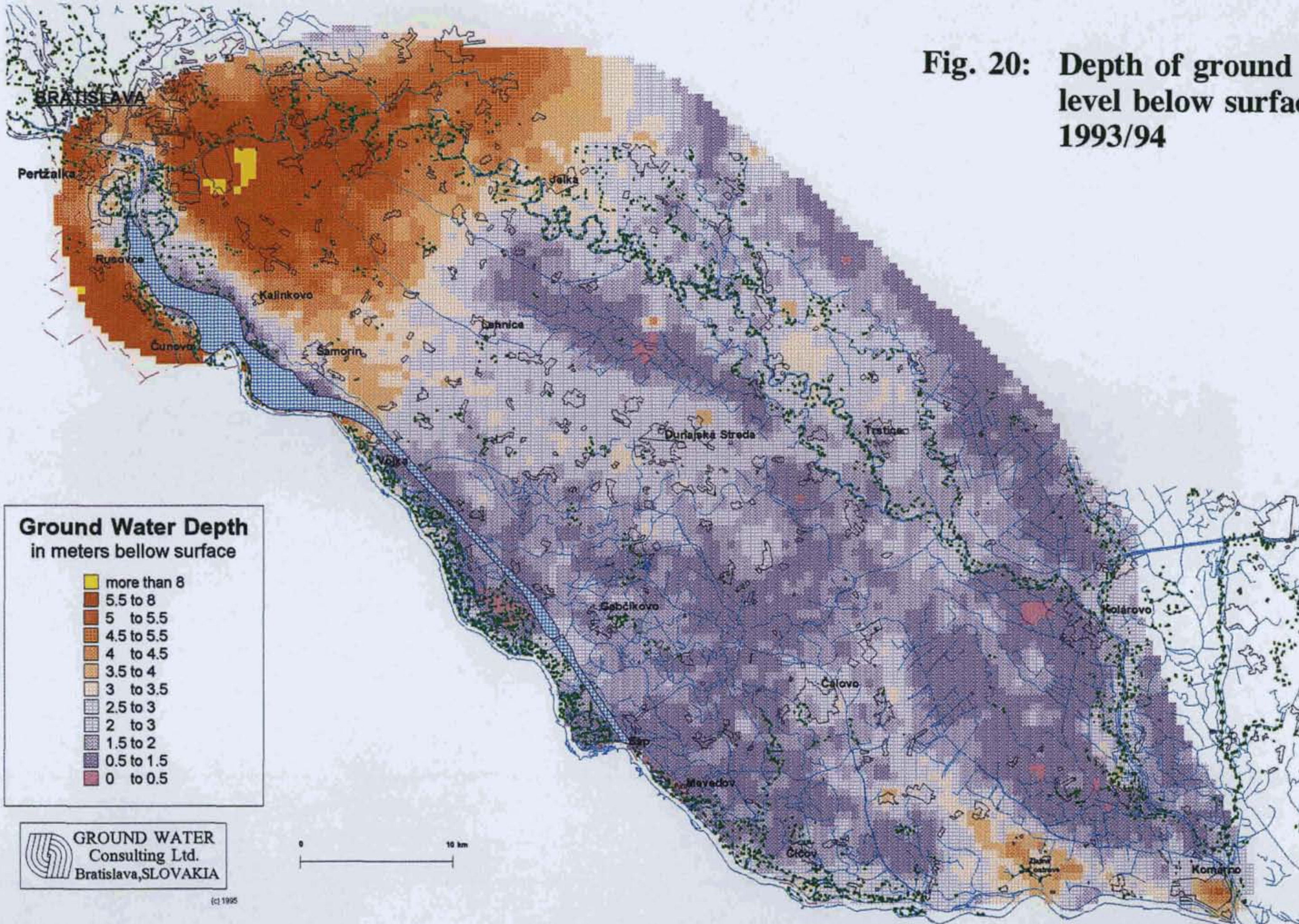


Fig. 19: Depth of ground water level below surface - 1992

Fig. 20: Depth of ground water level below surface 1993/94



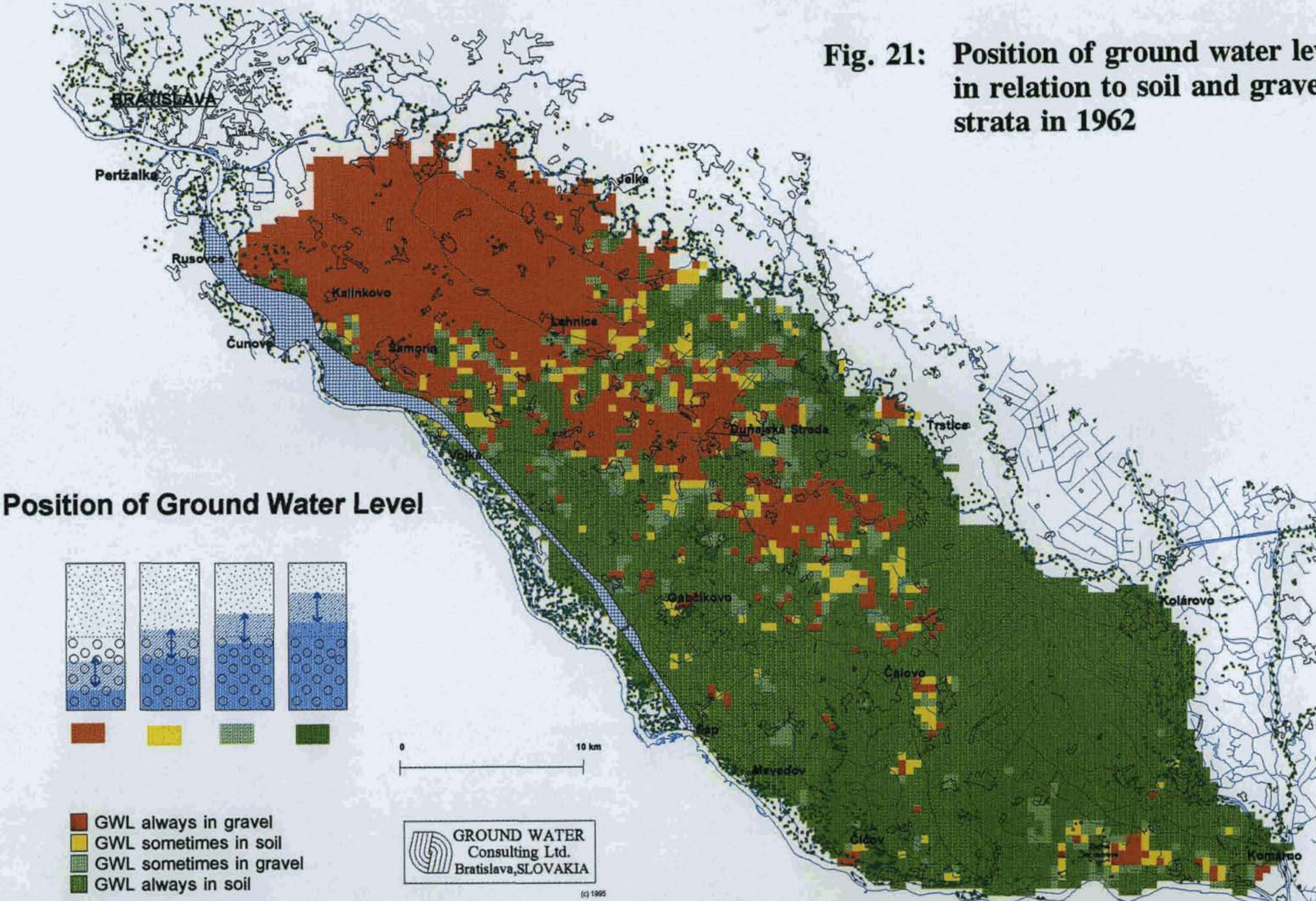


Fig. 21: Position of ground water level in relation to soil and gravel strata in 1962

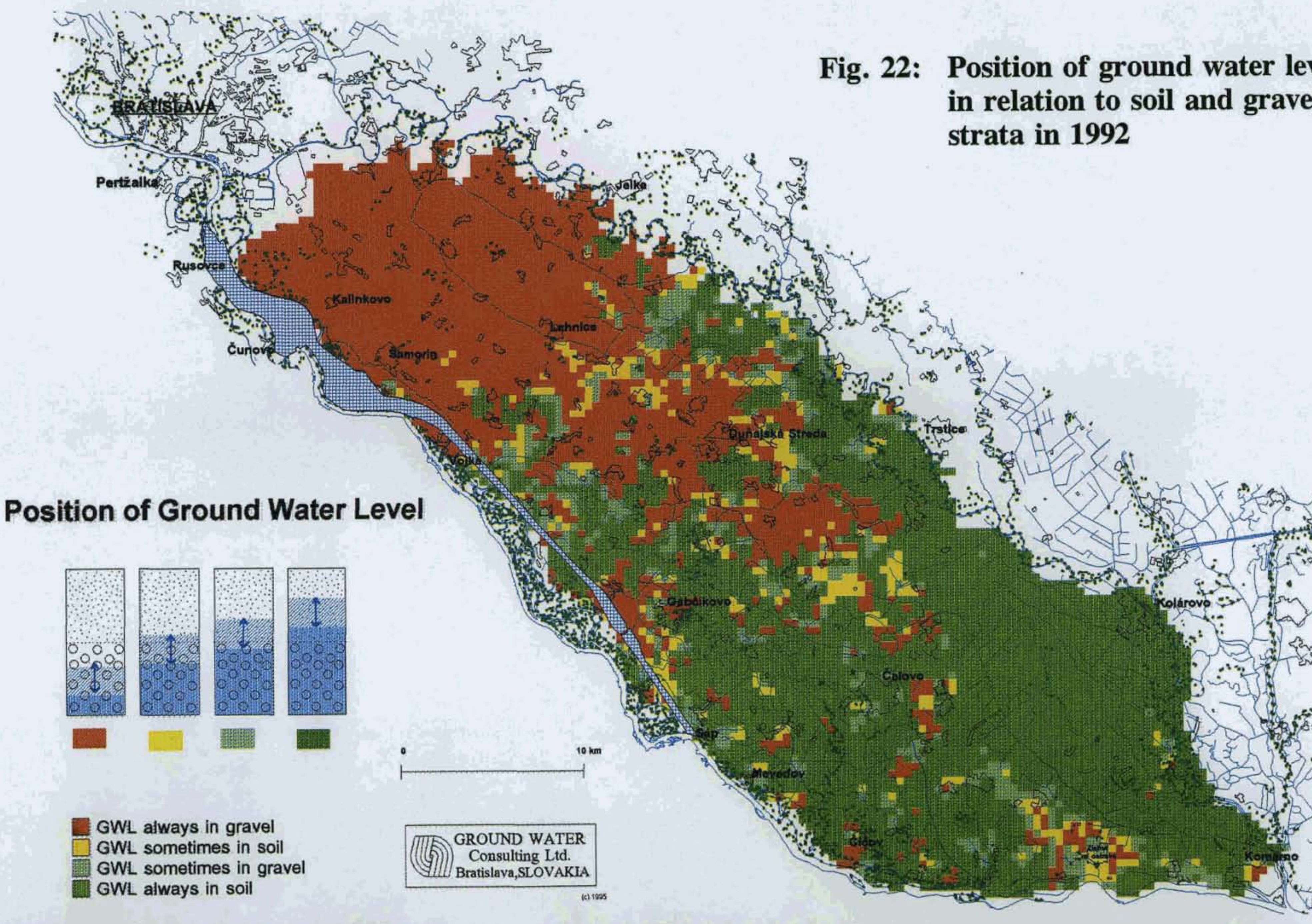
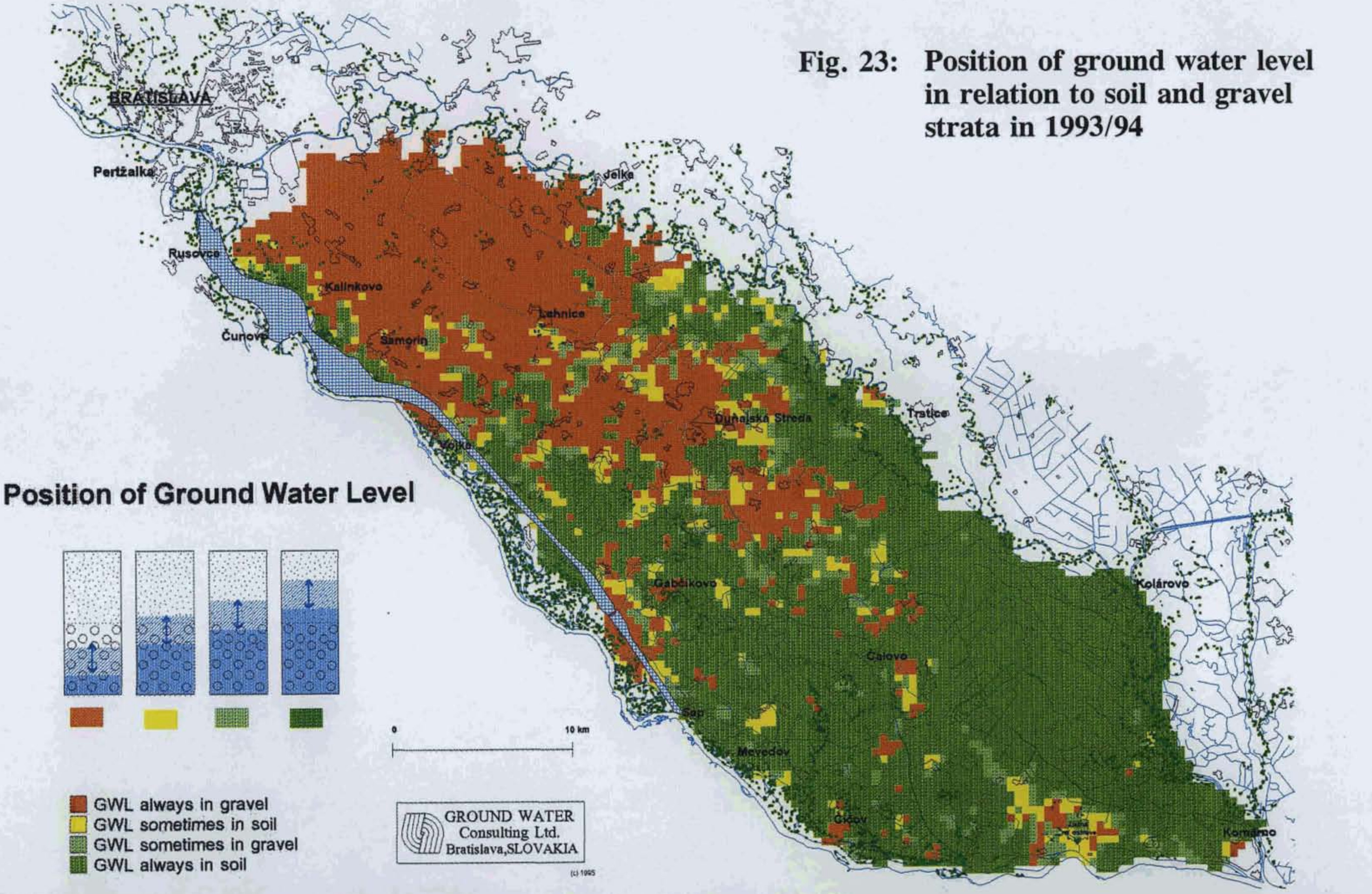


Fig. 22: Position of ground water level in relation to soil and gravel strata in 1992

Fig. 23: Position of ground water level in relation to soil and gravel strata in 1993/94



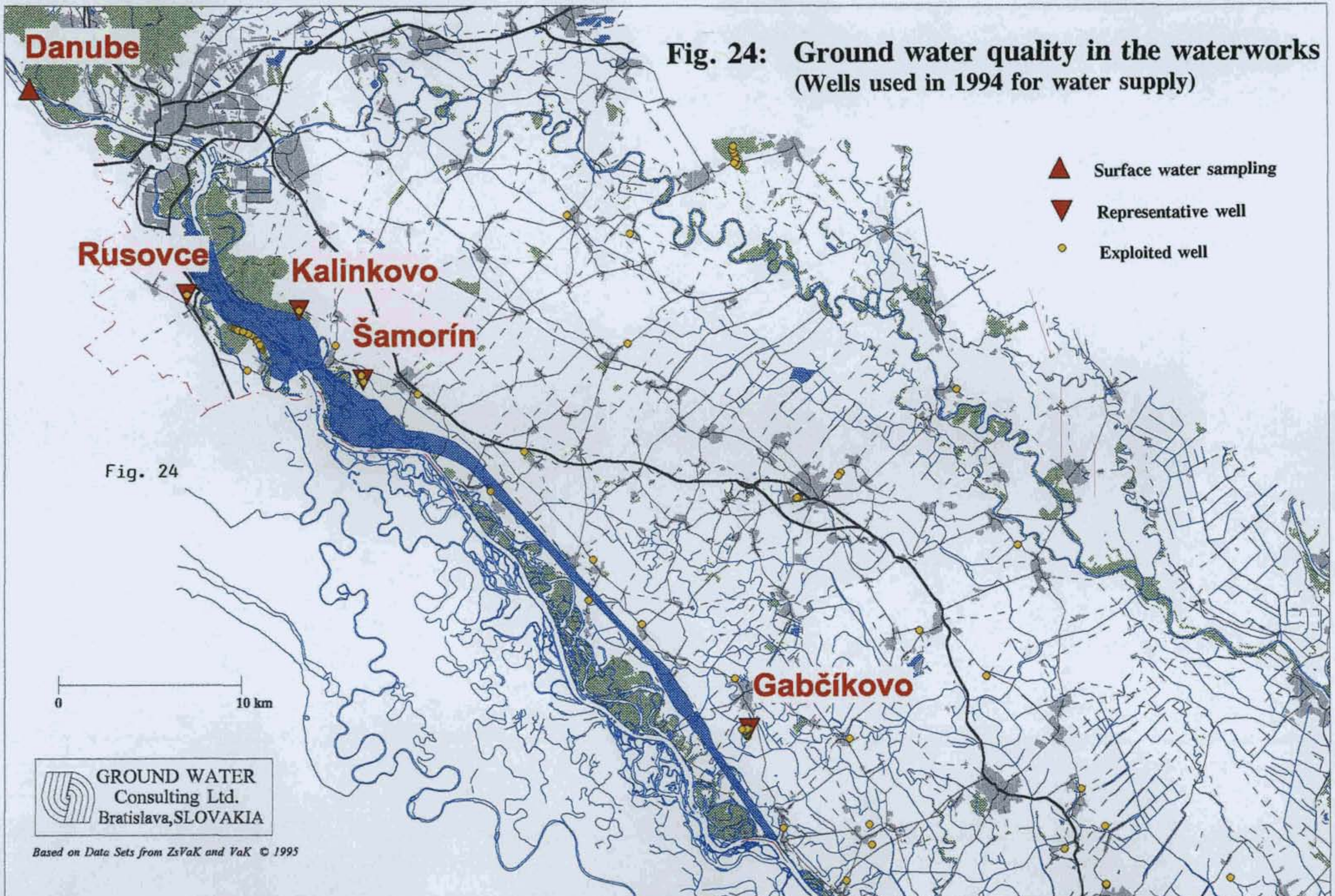


Fig. 24: Ground water quality in the waterworks
(Wells used in 1994 for water supply)
Danube
Rusovce
Kalinkovo
Šamorín
Gabčíkovo
Surface water sampling
Representative well
Exploited well
Fig. 24
0
10 km
GROUND WATER
Consulting Ltd.
Bratislava, SLOVAKIA
Based on Data Sets from ZsVaK and VaK © 1995

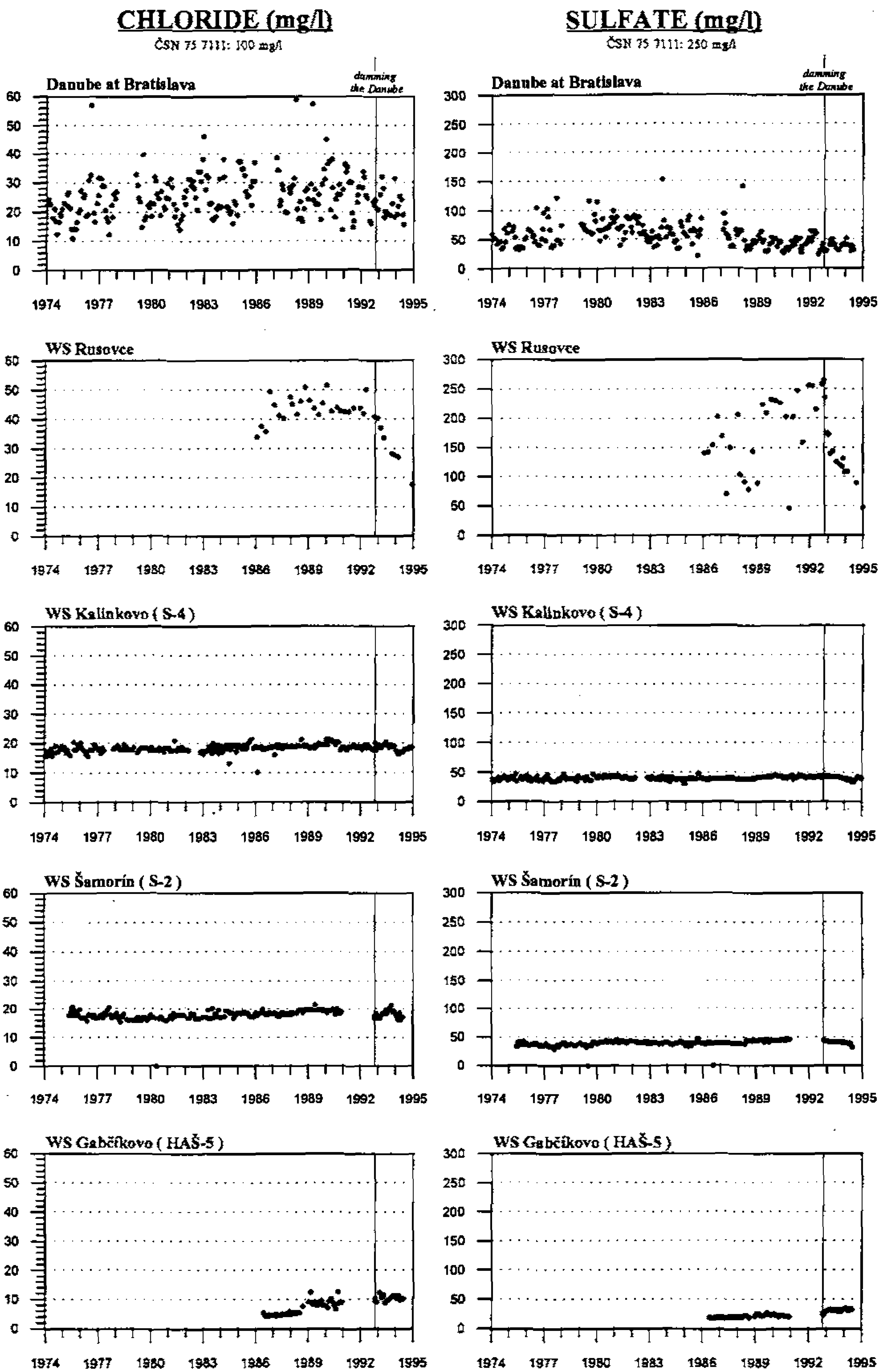


Fig. 25

Based on data sets from
ZsVaK, VaK, SHMÚ Bratislava

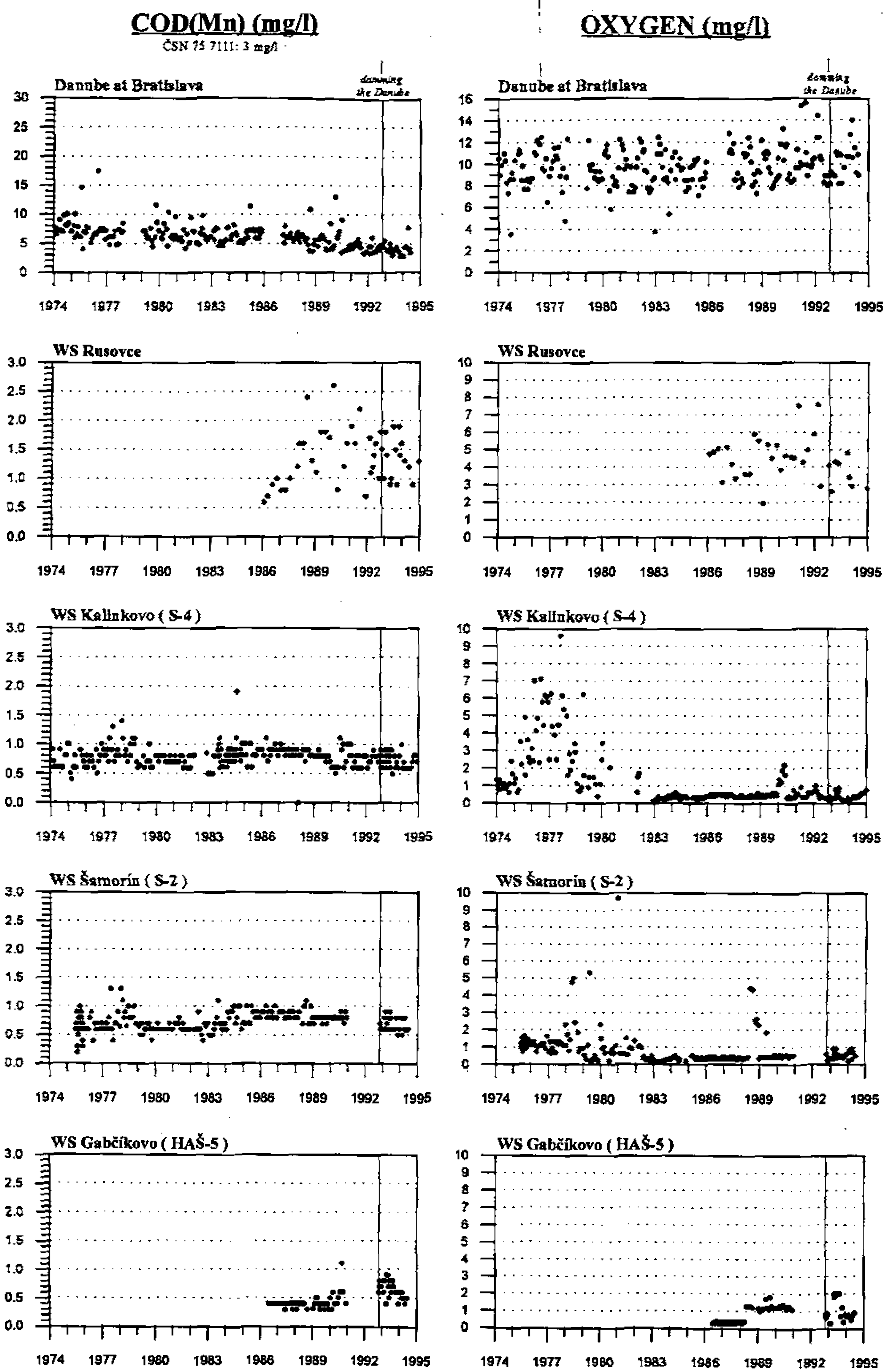


Fig. 26

Based on data sets from
ZsVaK,VaK,SHMÚ Bratislava

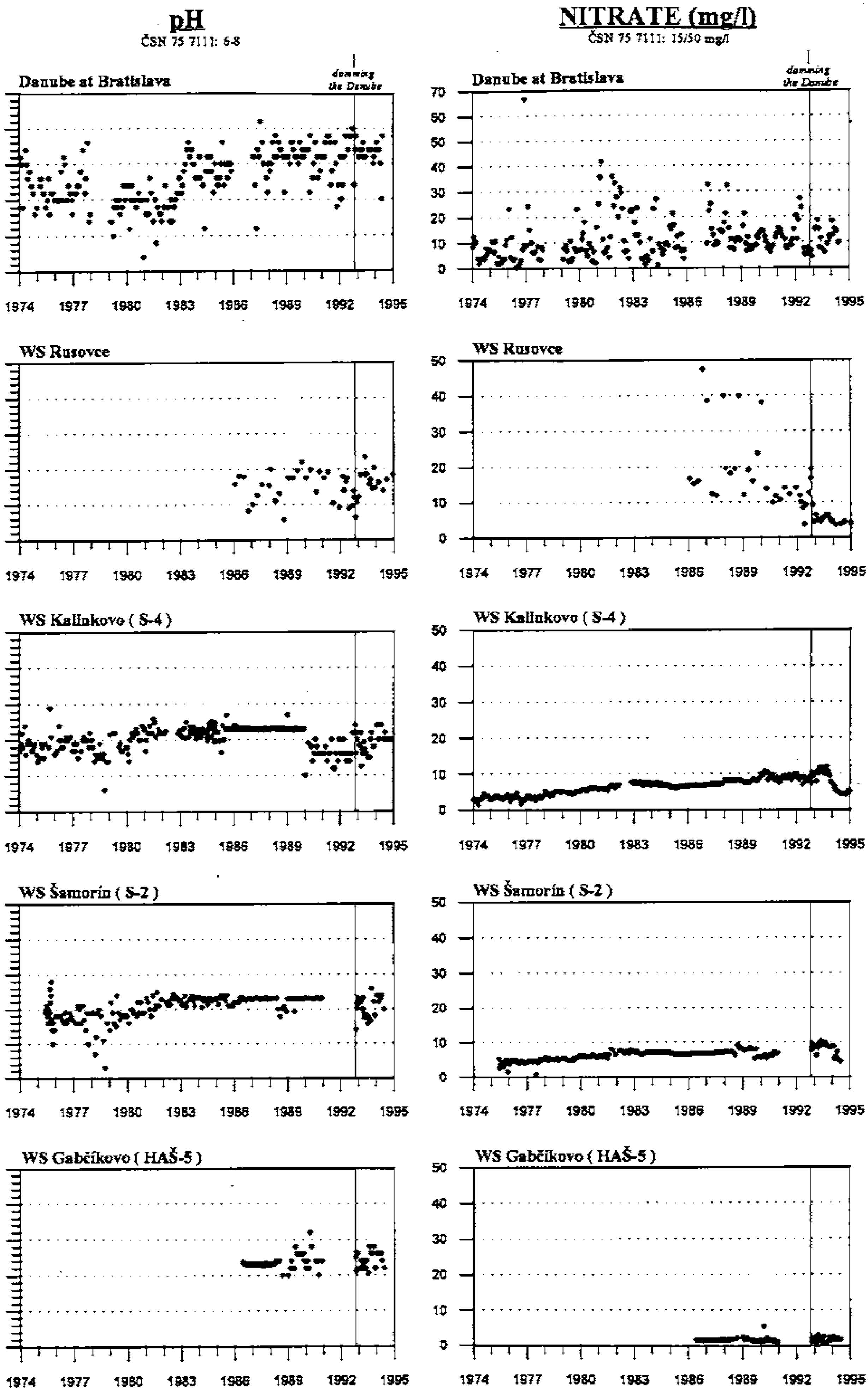


Fig. 27

Based on data sets from
ZsVaK,VaK,SHMÚ Bratislava

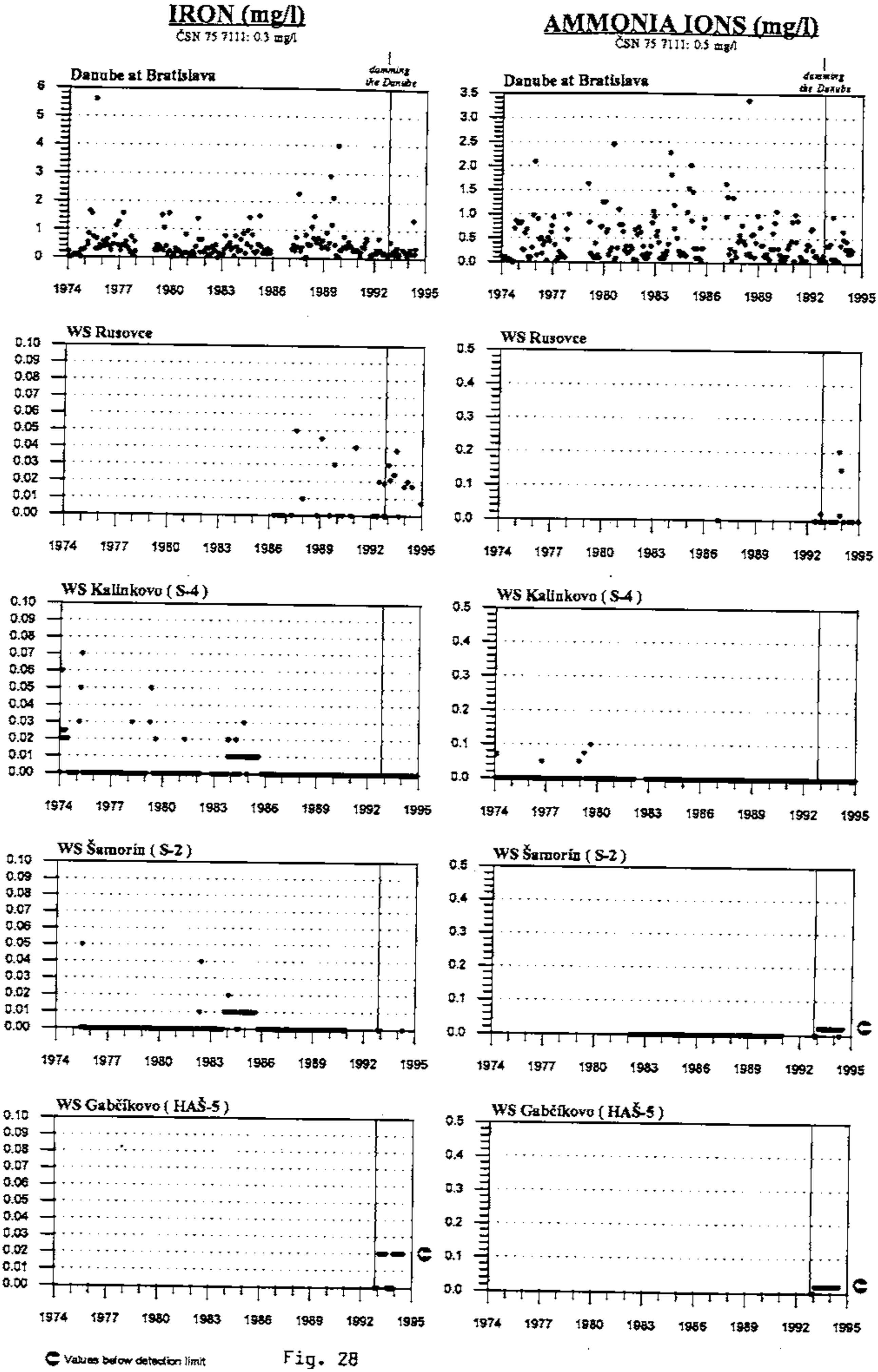


Fig. 28

Based on data sets from
ZsVaK,VaK,SHMÚ Bratislava

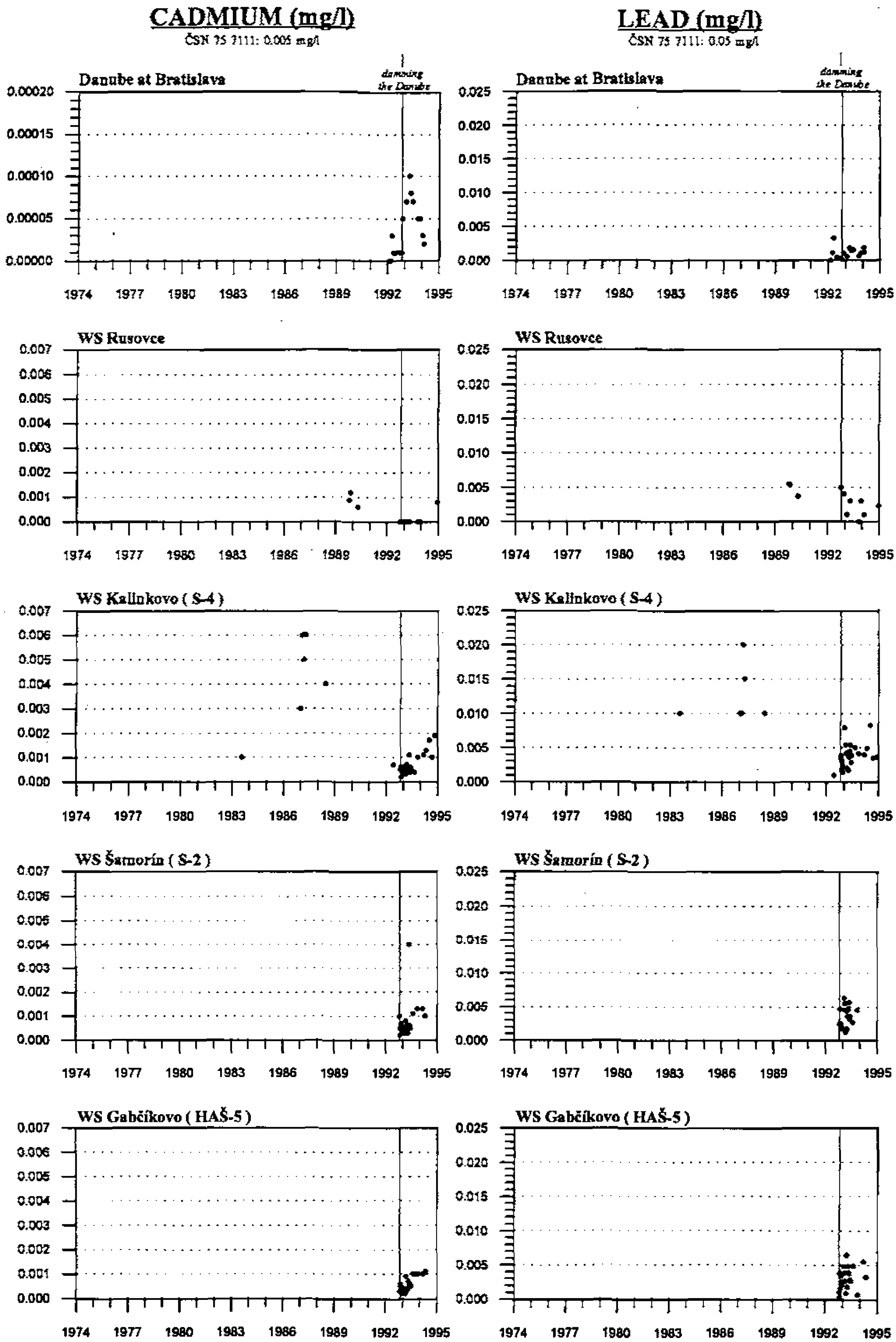


Fig. 29

Based on data sets from
ZsVaK,VaK,SHMÚ Bratislava

CHAPTER 2. WATER QUALITY, EUTROPHICATION AND SEDIMENTS (MONITORING REPORT)

J. Makovinská
M. Holobradá
P. Hucko

March 1995

This report deals with water and sediment quality in the Danube river, the reservoir, the headwater canal of the Gabčíkovo Section of the G/N Project and the branch system of the Danube floodplain. The monitoring profiles are indicated on Fig. 1.0 as follows:

D1 - the Danube at Bratislava (rkm 1869)
D2 - the Danube at Rajka (rkm 1842)
D3 - the Danube at Medveďov (rkm 1806)
D4 - the Danube at Komárno (rkm 1768)
R1 - the reservoir, the upper part, the right side
R2 - the reservoir, the upper part, the cunette
R3 - the reservoir, the upper part, the left side
R4 - the reservoir, the lower part, the right side
R5 - the reservoir, the lower part, the cunette
R6 - the reservoir, the lower part, the left side
C1 - the headwater canal, the upper part (at the ferry)
C2 - the headwater canal of, the lower part (at navigation locks)
B1 - the Vojka branch (rkm 2.9)
B2 - the Baka branch (rkm 3.0)

1. Water Quality

1.1 Water quality in the Danube prior to the putting of the Gabčíkovo section of the G/N Project into operation

The water quality in the Danube has been observed for more than forty years, the first joint extended Slovak-Hungarian program of water quality monitoring in the Danube being realised from April 1989. The joint monitoring is realised in agreed sampling points and periods and based on agreed parameters of the measurement and methodologies, with the results jointly evaluated.

For the evaluation of the Danube (surface) water quality, an agreed classification based on six water quality classes has been applied (ref. 13). The classification of respective parameters into the water quality classes is realised on the basis of comparison of their calculated characteristic values with the scheme of limit values in each water quality class. The characteristic value of water quality parameters is calculated on the basis of all measured values and expressed by statistical value C_{90} and, with regard to dissolved oxygen, C_{10}.

The studied reach of the Danube between Bratislava and Medveďov had, in the period from 1 January 1991 to 13 October 1992, prior to the putting of the Gabčíkovo Project into operation, favourable oxygen conditions. Characteristic values of dissolved oxygen concentration (C_{10}) were in the range from 8.2 $mg.l^{-1}$ at Bratislava to 8.4 $mg.l^{-1}$ at Medveďov, i.e., in the first quality class. The minimum oxygen concentration was measured in all measuring profiles early in September 1992, at the value 7.4 $mg.l^{-1}$ at both Bratislava and Medveďov profiles.

The characteristic values (C_{90}) for BOD_5 at Bratislava were between 3.2 $mg.l^{-1}$ and 4.0 $mg.l^{-1}$, at Medveďov 3.7 $mg.l^{-1}$, i.e., corresponded to the second water quality class.

The chemical oxygen demand values (C_{90}) (COD Mn) were in all profiles in the range from 5.1 $mg.l^{-1}$ to 6.1 $mg.l^{-1}$ and characteristic values (C_{90}) (COD Cr) were over the whole reach in the range from 13.7 $mg.l^{-1}$ to 21.1 $mg.l^{-1}$, i.e., both parameters corresponded to the second quality class.

From the hydrobiological point of view the Danube in the profiles Bratislava and Medveďov had, prior to the putting of the Gabčíkovo Project into operation, the betamesosaprobic character, showing a trend towards alphamesosaprobity during the winter season.

As far as the indicators of organic industrial pollution are concerned the concentrations of phenols, anionactive tensides and non-polar extractable substances in this Danube reach corresponded to the second quality class.

The values of the heavy metals concentrations were low. Cadmium, total chromium, arsenic, and nickel corresponded to the first quality class, lead and zinc to the first - second quality class, and mercury to the second - third class of water quality.

From among the specific organic micropollutants 13 selected indicators were monitored in groups of chlorinated pesticides, triazine pesticides, volatile chlorinated hydrocarbons, and polychlorinated biphenyls. The values of these organic micropollutants were low, meeting also the requirements for drinking water quality (refs. 1,2).

1.2 Water quality in the Danube after the putting of the Gabčíkovo section of the G/N Project into operation

1.2.1 Oxygen regime

During the period from 26 October 1992 to December 1994 the monitored reach of the Danube belonged to the first quality class according to characteristic values parameters of the oxygen regime. The values (C_{10}) of the dissolved oxygen were over the whole reach in the range from 8.0 $mg.l^{-1}$ to 8.7 $mg.l^{-1}$. The lowest oxygen content (7.1 $mg.l^{-1}$) was measured at Bratislava early in August 1994.

The characteristic values (C_{90}) for BOD5 in the monitored reach were in the range from 2.8 to 3.8 $mg.l^{-1}$, i.e., corresponded to the second class of water quality.

The values (C_{90}) for COD Mn were in the range 5.0 to 6.3 $mg.l^{-1}$, and values of (C_{90}) COD Cr were in the range from 13.5 to 16.0 $mg.l^{-1}$. On the basis of comparison of characteristic and average values of these parameters of oxygen regime from the period prior to the putting of the Project into operation and afterwards a slight increase of dissolved oxygen content within the range of the first class of water quality, and small decrease of BOD5, COD Mn, and COD Cr values in the range of the second class of water quality has been observed.

1.2.2 General evaluation of the quality

According to the oxygen regime parameters good oxygen conditions (first class) existed in the monitored Danube reach.

The average and characteristic values (C_{90} or C_{10}) of these parameters in profiles Bratislava (upstream of the Gabčíkovo Project) and Medveďov (downstream of the Project) are shown on graphs (Figs. 1.1 - 1.4).

Concentrations of physical and chemical parameters in the basic group corresponded to the second - third quality class, except for nitrogenous substances.

In the group of supplementing chemical parameters the content of phenols, tensides, and non-polar extractable substances corresponded to the second quality class.

From the hydrobiological point of view the betamesosaprobic character of the Danube has been preserved even after the putting of the Gabčíkovo Project into operation.

Concentrations of the majority of heavy metals were low. According to (C_{90}) values cadmium, lead, arsenic, copper, total chromium and nickel met the criteria of the first quality class. Zinc corresponded to the second quality class and mercury to the third quality class (ref. 16).

Concerning the group of organic micropollutants the content of chlorinated pesticides, volatile chlorinated hydrocarbons, and polychlorinated biphenyls was predominantly below the detection limit of determination. Sporadic and low concentrations of polycyclic aromatic hydrocarbons and of chloroform were identified on the whole reach during the years 1993 - 1994. The total content of organic micropollutants mentioned above was generally low and satisfactory also with regard to drinking water requirements (Standard norm 75 7111).

On the basis of the overall comparison of monitoring results from the period prior to and after the putting of the Gabčíkovo section into operation, it may be stated that no significant changes in water quality occurred. The recorded trend has shown a slight improvement in some parameters.

1.2.3 Water quality in the reservoir

The survey and evaluation of the water quality in the reservoir was carried out within the scope of the program of the monitoring of the reservoir's water quality (ref. 15).

The monitoring of the water quality development in the reservoir has revealed that with regard to chemical composition the Danube water has not changed as a result of its passage through the Projects structures. Not even indications of forecasted phenomena, characterised by the release of organic micropollutants and heavy metals from the reservoir sediments in the course of infiltration, were recorded.

The oxygen regime and the primary phytoplantkon production in the reservoir had been surveyed over the summer season 1994 (July-November) (ref. 17). The monitoring was realised at a lower operation water level in the reservoir and in very hot climatic conditions, representing rather extreme circumstances. The average oxygen content in both parts of the reservoir during this period was in the range from 8,0 to 8,5 $mg.l^{-1}$ (first class quality). No significant differences in the values of dissolved oxygen were identified within the stratification (surface-centre-bottom). The average BOD 5 content in the reservoir and in the headwater canal was from 2.0 to 2.3 $mg.l^{-1}$ (second class) and COD Mn was in the range 3.2 - 3.45 $mg.l^{-1}$ (first class).

The comparison of water temperature values within the respective zones did not show any significant changes. This state was characteristic for discharges with short water retention, during which the thermal and chemical stratification in the direction from the water surface down to the bottom does not occur.

2. <u>Eutrophication</u>

Eutrophication means an enrichment of a water system with nutrients, especially with nitrogen and phosphorus, resulting in increased phytoplankton biomass production.

The research and monitoring program of the phytoplankton development realised in the framework of the evaluation of impacts of the construction and operation of the Gabčíkovo Project on the environment focused mainly on conditions for the primary phytoplankton production in the reservoir and in the inlet section of the headwater canal. Both prognosis and analysis of available data confirm that, at current heights of the water column and retention time of water in the reservoir, the increase of the algae biomass during the water flow through the reservoir will not exceed the tolerable limit (refs. 4, 6, 7, 18, 17). In the evaluation of the impacts of the Gabčíkovo Project attention was also paid to the changes in concentration of the algae biomass in the headwater canal, and in the old Danube riverbed.

This report contains the evaluation of monitoring results in the reservoir of the Gabčíkovo Project, in the Danube during the period prior to and after the completion of the Gabčíkovo Project as well as in the branch system near to Gabčíkovo.

2.1 Eutrophication in the reservoir and in the headwater canal

The phytoplankton biomass, nutrient content, and oxygen regime, especially at the reservoir's bottom, can be considered as the main indicators and evidence of eutrophication. Eutrophication processes have been evaluated on the basis of the results of monitoring carried out in 1993 and 1994 (refs. 1, 2, 5, 15, 18).

Phytoplankton development in the reservoir is mainly dependent upon the amount of phytoplankton in the water flowing into the reservoir at Bratislava (profile D1). The increase of the phytoplankton biomass, expressed as chlorophyll a in the longitudinal profile of the Gabčíkovo Project is variable - usually with a moderate chlorophyll a increase in the direction Danube - reservoir - canal (Fig. 2.1). During the period of usual spring phytoplankton maximum in the Danube a decrease of biomass in the direction towards the canal was observed. Even under extreme conditions during the summer 1994 (lower water level and high temperatures) the trend towards the increase of phytoplankton was not obvious (Fig. 2.2).

The phytoplankton biomass in the reservoir attained the maximum values of 74.1 $\mu g.l^{-1}$ of chlorophyll a early in August 1994. These values are lower by half than the maximum biomass values in the Danube upstream of Budapest registered in 1991 - 1993 (ref. 10). At Budapest, in 1991, the spring and summer maximum was greater than 160 $\mu g.l^{-1}$ chlorophyll a, in 1992 the maximum was greater than 170 $\mu g.l^{-1}$ chlorophyll a, and in 1993 it was around 130 $\mu g.l^{-1}$ chlorophyll a. The differences in living organisms development in different parts of the reservoir were observed in this period. The amounts of phytoplankton identified in the right-side profiles of the reservoir (R1 and R4) were substantially higher than those in the stream-line (cunette) and in the left part of the reservoir (near Kalinkovo and Šamorín). In the first half of August, similar differences in the areal distribution were observed only in the upper part of the reservoir (Fig. 2.3). The differences were less evident in the lower part of the reservoir, the lowest phytoplankton biomass values being observed in the left part of the reservoir and slightly increased concentrations of chlorophyll a in the right part (Fig. 2.4). During the last sampling in October the areal differences were similar to those registered in August.

The vertical stratification of phytoplankton showed some differences; however, on the basis of just four measurements, these cannot be generalised. It may nevertheless be definitely concluded that in all monitored sampling profiles of the upper part (profiles R1, R3), and also of the lower part of the reservoir (profiles R4, R6), the phytoplankton biomass decreases towards the bottom. The decrease of phytoplankton in relation to the increase of water depth was most apparent in the deepest parts of the reservoir near to the "Birds island" in the profile R4. The differences between the maximum biomasss in the water column was 6-25 $\mu g.l^{-1}$ of chlorophyll a. Early in August 62%, in October 59.5% of maximum values found in the water column occurred at the bottom. Thus certain zonal stratification of phytoplankton in vertical direction occurs in the deepest parts of the reservoir, but for the general evaluation of production conditions this is practically without any significance.

The vertical phytoplankton stratification is dependent upon the intensity of the photosynthesis related active radiation (PHAR). At PHAR values higher than 800 $\mu E.s^{-1}.m^{-2}$ algae show a tendency to move from the surface into deeper horizons. During the period of our measurements the PHAR value below the water level was often higher than 800 $\mu E.s^{-1}.m^{-2}$. However, already in depths of 1.5-2.5 m it dropped to the value below 20 $\mu E.s^{-1}.m^{-2}$, (below 1% of the surface activity) considered to be a utility limit for algae. The values of gross primary phytoplankton production correspond to the above light conditions in the reservoir. The highest values of gross phytoplankton production were identified usually in the horizons of 1-2 m. The gross primary phytoplankton production ranged between 0-11.8 $mg.l^{-1}\ day^{-1} O_2$, the highest values being measured in the profile R4 early in August, similarly as in the case of biomass production.

On the basis of vertical measurements of changes of temperature, oxygen content, conductivity and pH, the reservoir may be characterised as an aquatic environment without thermal stratification, with small differences in O_2 concentrations on the water surface and at the bottom (max.2.4 mg. l^{-1}) and with minimum changes of conductivity and pH. The water temperature on the surface of different parts of the reservoir was more or less uniform. In summer months, in June - August, a slight increase of water temperature was recorded in the longitudinal profile of the reservoir, as well as in the direction towards the dykes. Although the vertical zonal water temperature stratification was minimum, a trace of a temperature curve typical for stratified reservoirs was observed in the deeper parts of the reservoir. Similarly, the horizontal and vertical oxygen stratification was minimum; however, a typical trend of oxygen drop in summer months in the direction towards the bottom was observed (Fig. 2.5).

Simultaneously with the monitoring of phytoplankton development in the reservoir, macronutrients (phosphorus and nitrogen) which are important substances stimulating or limiting the phytoplankton development, have also been analysed. Total phosphorus content (total P) in the longitudinal profile ranged in respective months from 0.05 to 0.10 mg.l^{-1} (Fig. 2.6), the highest concentrations being recorded in autumn, similarly as in the Danube. Low concentrations occurred in August 1994 in the streamline in the lower part. A similar trend was observed in the case of total nitrogen content (total N), with highest concentrations occurring in autumn (Fig. 2.7). With regard to the large area of the reservoir the nutrient content in its different parts has been compared. Higher total P concentrations were identified in the left part of the reservoir. On the contrary the highest concentrations of total N occurred in the right-side parts.

The total phosphorus content, total P, in the longitudinal profile (in the streamline) was in July - November in the range from 0.06 to 0.27 mg.l^{-1}, the highest values being observed in the profile D1 (Bratislava) in October (Fig. 2.6). As far as the total N is concerned, values from 1.76 mg. l^{-1} in the upstream part (streamline) to 3.68 mg. l^{-1} in the downstream part (streamline) were measured in the longitudinal profile of the reservoir between the profile D1 and the headwater canal. Gradual increasing of total N content occurs from August to November. No significant changes among respective profiles were recorded during the year. In other parts of the reservoir total P concentrations oscillate around the value 0.1 mg.l^{-1}. Lowest values in the streamline of all profiles were measured in August 1994 (Fig. 2.7).

Total P in respective parts of the reservoir has similar values as those measured in the streamline. Highest values were measured in July and October. (Fig. 2.8). The lowest determined concentrations were in the right part of the reservoir. However, fluctuation of total P values occur in respective months. The content of total N in various parts of the reservoir corresponds to the values measured in the streamline. The highest values were recorded in July and November, a gradually total N increase occurs till November. There are no significant variations in identified values between respective sides of the reservoirs.

Generally the content of total P and total N in the reservoir may be summarised as follows: total P occurred in the range from 0.05 to 0.27 $mg.l^{-1}$ with average values about 0.1 mg. 1-^{1}, and total N occurred in the range from 1.73 to 3.73 $mg.l^{-1}$, the prevailing values being in the range from 2 to 3 $mg.l^{-1}$.

According to observations realised hitherto the differences in longitudinal and areal distribution of phytoplankton were not, in general, so important as to influence significantly the increase of the phytoplankton biomass in the Danube downstream of the Gabčíkovo Project. The maximum difference was recorded early in August 1994, when chlorophyll a concentration in the upstream right side was 3.7 higher than in the streamline. Similar differences were found in the downstream left part of the reservoir. Even in the marginal shallow zones of the reservoir an extensive development of water bloom forming cyanobacteria was not observed. Different biocenosis development with prevailing filamentous green algae was recorded only in the narrow marginal shallow zone (up to 0.5 m) in the upstream part near Kalinkovo. Nutrient content, similar to the Danube, is also high in the reservoir - N and P values being sufficient for unlimited phytoplankton growth. Vertical stratification of nutrients, temperature, and oxygen was not apparent even in the deepest parts of the reservoir. Relatively high oxygen content was identified even at the bottom, in the deepest parts of the reservoir (6.4 $mg.l^{-1}$ O_2).

The water in the reservoir (similarly as the Danube water at Bratislava), may be characterised on the basis of maximum chlorophyll a and total P values as eutrophic water.

2.2 Evaluation of the Gabčíkovo Project impact on the Danube eutrophication

The Gabčíkovo Project's impact on the Danube river have been studied in three representative profiles

- the Danube at Bratislava (comparative profile to evaluate water flowing into the reservoir)

- the Danube at Rajka (profile where the direct impact of the upper part of the reservoir on water quality in the old riverbed is observed)

- the Danube at Medveďov (profile enabling evaluation of the impact of the whole Gabčíkovo Project on the Danube downstream).

During the period 1989 - 1994 variations in phytoplankton biomass (chlorophyll a), occurrence of algae and content of respective nutrient components were evaluated on the basis of average seasonal values (spring, summer, autumn, winter), percentage growth and growth analysis or analysis of decreasing selected parameters, comparing Bratislava-Hrušov and Hrušov-Medveďov profiles, the first profile being relative.

During the years 1989 - 1992, prior to the filling of the reservoir and the putting of the Project into operation, the phytoplankton biomass growth between Bratislava and Hrušov was 4.1 - 23.4%. In the first year of Project operation, in 1993, the biomass growth was 21.0%, in the second year of operation, in 1994 it was 22.1%. Average annual absolute biomass growth in the Hrušov profile in 1989-1992 ranged from 0.7 to 4.86 $\mu g.l^{-1}$ of chlorophyll a, in 1993 and 1994 it was 2.87 and 2.24 $\mu g.l^{-1}$ respectively. The average annual growth between the profiles Hrušov and Medveďov prior to the operation was 9.0 - 16-1%, in the year 1993 it was 45.4% and in the year 1994 the biomass decreased by 0.49%. The relatively high percentage growth in 1993 occurred in the period of low concentrations of chlorophyll a; increase of absolute values was, however, low in this period. The average absolute biomass growth prior to the filling of the reservoir was 0.13 - 4.16 $\mu g.l^{-1}$, in the years after the construction it amounted to 0.56 - 4.6 $\mu g.l^{-1}$ (Fig. 2.10).

The phytoplankton of the Danube is characterised by the seasonal dynamics of respective algae groups. *Chrysophyceae, Cryptophyceae, Odinephyceae, Bacilariophyceae* and *Volvocales* occur in spring. *Chlorophyceae, Bacillariophyceae, Cyanophyta and Euglenophyta* are predominant in summer. In autumn the same types occur as in spring and in winter only *Bacillariophyceae* are present. The most frequent phytoplankton are *Aphanocapsa, Microcystic, Oscilatoria.* In general it may be stated that four groups are dominant, namely *Bacillariophyceae*, Blue-green algae and *Cyanophyta.* No apparent difference in qualitative occurrence of phytoplankton between the periods prior to and after the Project operation has been defined.

On the basis of the comparison of absolute values of the difference in nutrients in the pair of profiles Bratislava - Hrušov, and Hrušov - Medveďov in years 1989-1994 it may be stated that in the pair of profiles Bratislava - Hrušov (the upper part of the reservoir), the values of the total N changed from positive values of difference in 1989 to negative ones in the following years. In the years after the filling of the reservoir the N-total values further gradually decreased. The P-PO_4 values gradually decrease since 1990 (+354.31%), similarly as P-PO_4 values have changed from positive differences to negative ones in years 1992-1994.

In the second pair of profiles Hrušov- Medveďov the differences in N-total are in the range from -54.41% (1989) to +46.75% (1992). A growth occurred in 1994 as compared with 1993, when a drop was observed as compared with 1992. It is interesting to note that negative and positive values alternate in respective years. Concerning the N-NO_2 indicator, all values are lower than in the relative profile Hrušov. In 1994 the defined values were lower than in the years before putting the Project into operation. As far as N-NO_3 is concerned the lowest values were measured in 1993 (-55.03%) and the highest in 1994 (+126.52%). Except for the year 1993, all values are higher than in the comparative profile. After the successive growth until 1991 a decrease occurred until 1993 and then again an increase in 1994. The N-NH_4 indicator has undergone changes over the years 1989-1994 from negative (1989-1992) to positive values, from 1993 showing a successive decreasing trend. P-PO_4 after the increase in 1990, (+509.87%) gradually decreased, reaching negative values in 1993 (-156.74%), and then again increased to positive values in 1994 (+113.52%).

The comparison of annual average values of P-PO_4 in the profile Bratislava (profile D1) during the period 1987 - 1994 has shown, that on average a gradual decrease of values occurs. The same trend of P-PO_4 concentrations decrease has been observed in the Hrušov profile. N-NO_3, after the previous drop in this profile, has slightly increased since 1993. The indicators N-NO_2 and N-NH_4 showed an increase by 1991 - 1992, and then a decrease.

The indicator P-PO_4 in the profile Hrušov gradually decreased until 1994. Total N was decreasing from 1991 to 1993, and then slightly increased in 1994. Inorganic forms of nitrogen (N-NO_3, N-NO_2, and N-NH_4): N-NO_3 were gradually decreasing from 1990 to 1993, a slight increase occurred in 1994. N-NO_2 gradually decreased since 1990, similarly as N-NH_4. Inorganic nitrogen showed decreasing values till 1994.

P-PO_4 values in the profile Medveďov gradually decreased in 1989 - 1993. A slight increase has been observed in 1994 back to the level reached in 1992. Total N, after an increase in 1990, was gradually decreasing by 1993 and in 1994 increased to the level of 1992. N-NO_2 concentrations, after an increase by 1991, decreased by 1994. N-NH_4 values increased by 1991 and then decreased by 1994.

On the basis of the evaluation of results of the analysis of monitored indicators, it may be stated in general that the balancing out of values takes place in the monitored profiles and that the general decrease of values occurs after the putting of the Project into operation, as compared with the period prior to the operation. The first two years of monitoring of the phytoplantkon in the reservoir and of the impact of the Project on the Danube water quality indicate that, in accordance with the prognosis, water impoundment in the reservoir does not result in significant phytoplankton biomass increase in the Danube.

2.3 Branch system in the area of Gabčíkovo

Phytoplankton biomass of two monitored branches in the floodplain, i.e., Baka and Vojka branch, expressed in chlorophyll content, was in 1991-1993 in the range 0.79 -75.8 $\mu g.l^{-1}$ in the Vojka branch (profile B1), and 2.37 - 90.1 $\mu g.l^{-1}$ in the Baka branch (profile B2). Maximum values were measured in the period of spring growth of *Bacilloriophyceae* at low water levels. After the implementation of the water recharge for the branch system the differences between two localities were reduced. The net primary phytoplankton production in the Baka branch was in the range 0.74 -3.79 $mgC.m^2.day^{-1}$, in the Vojka branch 0.1 -5.94 $mgC.m^2.day^{-1}$. Differences in net primary phytoplankton production in the branches and in the Danube (0.04 - 5.18 $mgC.m^2.day^{-1}$)

are negligible (ref. 11). The diversity of phytoplankton genera (species) in the monitored branches is lower than the diversity in the Danube, four groups being dominant (*Bacillariophyceae, Chlamydomonadales, Clorococcales and Cyanophyta*).

Maximum biomass values (36.8 μg.1-1 of chlorophyll a and abundant phytoplankton occurrence (49040 cells in 1 ml) defined within the scope of an experiment under extreme conditions (water temperature 30.5°C, water stagnation in the branch during the experiment) did not show significant phytoplankton growth even under these extreme conditions.

Generally it may be stated that diversity of phytoplankton in the branches in the Danube floodplain is rich, however lower than in the Danube. The defined values of net primary biomass production and phytoplankton abundance are comparable with the Danube. Taking into account the discharge through the intake structure to the branch system (refs. 1, 2), the impact of the water in the side arm system on the main channel of the Danube, with regard to eutrophication, is minimal.

3. Quality of Sediments

3.1 Quality of sediments in the reservoir

The quality of sediments in the reservoir had been assessed within the scope of the research program undertaken in 1994 (ref. 4).

Sediment sampling was carried out in fixed monitoring profiles and in profiles where an increased sedimentation was assumed (Fig. 1.0). The granulometric sediment composition and its organic proportion were determined from samples. The sampling was realised in accordance with the methodic recommendations of the World Meteorological Organization (ref. 21). The sediment quality evaluation was performed on the basis of criteria applied in the Netherlands: the General environmental quality standards (GEQ -Standards) (quality objective 2000), test values and warning values for fresh, surface water, and sediment (ref. 20). They have been recently proposed for application in ventures within the scope of the Environmental Program for the Danube River Basin. On the basis of this criteria the sediments are classified, according to the content of respective substances, into three value groups indicating the basic, limiting and warning value.

In the nutrients assessment we have focused on determination of total nitrogen, total phosphorus, potassium, and of the organic share.

The total nitrogen occurred in the range from 170 to 779 mg/kg, the average value being 486.7 mg/kg. The total phosphorus ranged from 7.6 to 101.1 mg/kg, with the average value of 29.48 mg/kg. Potassium was in the range from 8418 to 13958 mg/kg, the average value being 11201 mg/kg. The organic part in the sediment samples was determined in the range from 2.7% to 9.0%.

The results of heavy metals analyses revealed that values of cadmium, chromium, mercury, and lead were lower than the basic values of the GEQ - Standards. Values of copper were higher than the basic values, nevertheless they did not exceed the limiting values. In view of the results of the geological subsoil research of the Danube river basin, it may be said that these elements are part of the rock-forming minerals.

The determined value of methoxychlor and fluoranthene were below the basic value. In case of PCB, lindane, heptachlor, DDT, hexachlorbenzene, benzo (a) pyrene and phenantrene the determined values were higher than basic values but the limiting values were not exceeded, which illustrates the low loading with specific organic micropollutants.

The comparison of present results with the results from 1991 (ref. 8) showed that in the group PAH (fluoranthene, phenantrene, benzo (a) pyrene) the determined average values were identical. The same results were obtained also in case of HCB, lindane and methoxychlor. In the PCB group lower values were ascertained in average than in 1991. Values of DDT were in average higher than in 1991. The measurements showed residual presence of DDT.

Radiochemical analyses of sediment samples in the profiles in the reservoir focused on the determination of the total specific alpha activity and total specific beta activity (which are orientation indicators of the radioactivity) and on determination of some natural and artificial gamma emitters. The ascertained values in the reservoir showed higher specific alpha activity, in comparison with average values determined in other Slovak watercourses. The specific beta activity was approximately identical with values determined in other watercourses (ref. 9).

Also some natural gamma emitters from the transformation series of uranium-238 (Ra-226, Bp-214, Bi-214) and transformation series of thorium-232 (Ac-228, Pb-212, Bi-212, Tl-208) were monitored. All these gamma emitters are usual components of the environment and the measured values did not exceed the natural values of the background.

The comparison with the results of works carried out in 1991 (ref. 8) for the purpose of analysis of rock formation characteristics in the riverine zone of the Danube in the area of the Gabčíkovo Project showed approximately the same values of Ac-228, Bi-214, Pb-212 and Tl-208.

The specific activity of potassium-40, in the group of primordial gamma emitters, corresponded to higher values determined in 1991. The results correspond to the values determined in other Slovak watercourses.

Among the antropogenous radionuclides, important from the radiobiological point of view, cesium-137 was monitored because of its long half-life, as well as Cs-134. The measured values of Cs-134 were very low. Highest values of Cs-137 were determined in one half of the sediment samples. The determined values were higher than in 1991, probably due to the residual activity caused by the collaps of the Chernobyl nuclear power plant.

The results of granulometric analyses revealed that more than 90% of particles ranged between clayey and silty particles of sediment. The majority of sediment samples had a silty character.

An investigation of sediments in the area of Gabčíkovo was carried out in 1993 by Rodák et al. (ref. 19). The sampling was realised 6 months after the filling of the reservoir. The research results show that the sediments are not significantly polluted and that they are not polluted by organic contaminants. In spite of higher contents of some heavy metals in sediments, analysed by means of the method of total disintegration, the authors do not classify the concerned territory as contaminated, because the major part of heavy metals forms a part of stable rock-formation minerals.

3.2 Quality of Danube sediments

The quality of sediments in the Danube has been monitored within the scope of the joint extended Hungarian-Slovak monitoring since 1993 in profiles Bratislava (left and right bank), Komárno (left and right bank), and Szob (left and right bank). For the purpose of the Gabčíkovo Project impact assessment, two profiles are decisive and enable the estimation of sediment quality, namely Bratislava and Komárno profiles. The profile Komárno is, however, influenced by right-side tributaries from the Hungarian territory, mainly by the Mosoni Danube carrying pollution from the Györ.

Heavy metals have been monitored in the profile Bratislava and Komárno since 1994. The estimation of results based on the mentioned GEQ Standard (1991) showed that all identified heavy metals occurrence is below the basic value. Many of them are just one half of the basic value. In the Bratislava profile the values of determined heavy metals are higher than those in the Komárno profile.

As far as organic matters are concerned, the data from 1993 and 1994 are available for both profiles. The majority of values of polychlorinated biphenyl's in both profiles was close to the detection limit (5.0 µg./kg). In four cases PCP (Delor-106) the basic value of the GEQ Standard was exceeded. However, the limit value was not exceeded.

The group PAH, involving fluoranthene, phenantrene, and benzo (a) pyrene was established in 1993 and 1994. The comparison of values measured in Bratislava and Komárno in 1993 showed, that the values of respective PAH in Komárno are lower by one or two orders than in the Bratislava profile. All determined values in the Komárno profile are lower than the basic values of the GEQ Standard (20). The basic values for above mentioned parameters are exceeded in Bratislava, however the limiting values are not exceeded. The basic values of phenantrene and fluoranthene were exceeded only in one sample in 1994.

In addition to the mentioned organic matter, lindane, heptachlor, DDT, metaoxychlor, hexachlorbenzene were also detected in both profiles. In 1993 lindane, heptachlor and hexachlorbenzene were determined in values below the detection limit, which is 2.5 µg./kg. In 1993 lindane exceeded the basic value in Bratislava and Komárno in one sampling. In case of heptachlor the basic value was exceeded in both profiles, but it was not significant. The basic value for DDT was exceeded three times (but the limiting value was not surpassed). Hexachlorbenzene occurred in concentrations below the detection limit (2.5 μg./kg).

Radiological parameters - total specific alpha activity, total specific beta activity, and gamma-spectrum - have also been continuously monitored over the years 1993 and 1994. Specific beta activity identified in the Komárno profile in 1994 were lower than in 1993. The parameters Cs-134 and Cs-137 show similar results. In Bratislava profile the specific beta activity values in 1994 corresponded in average to those determined in 1993, the values of Cs-134 and Cs-137 were in average lower. Comparing Bratislava and Komárno profiles, all parameters showed higher values in the Bratislava profile in both years.

Average values of selected heavy metals, organic micropollutants, and radioactivity parameters determined in the Danube sediments and in the reservoir are presented in respective diagrams (Figs. 3.1-3.8). In conclusion, it may be stated that the quality of sediments in the reservoir and in the Danube oscillated within the range of concentrations which corresponded to or were lower than the basic values. The limiting values were attained only in exceptional cases.

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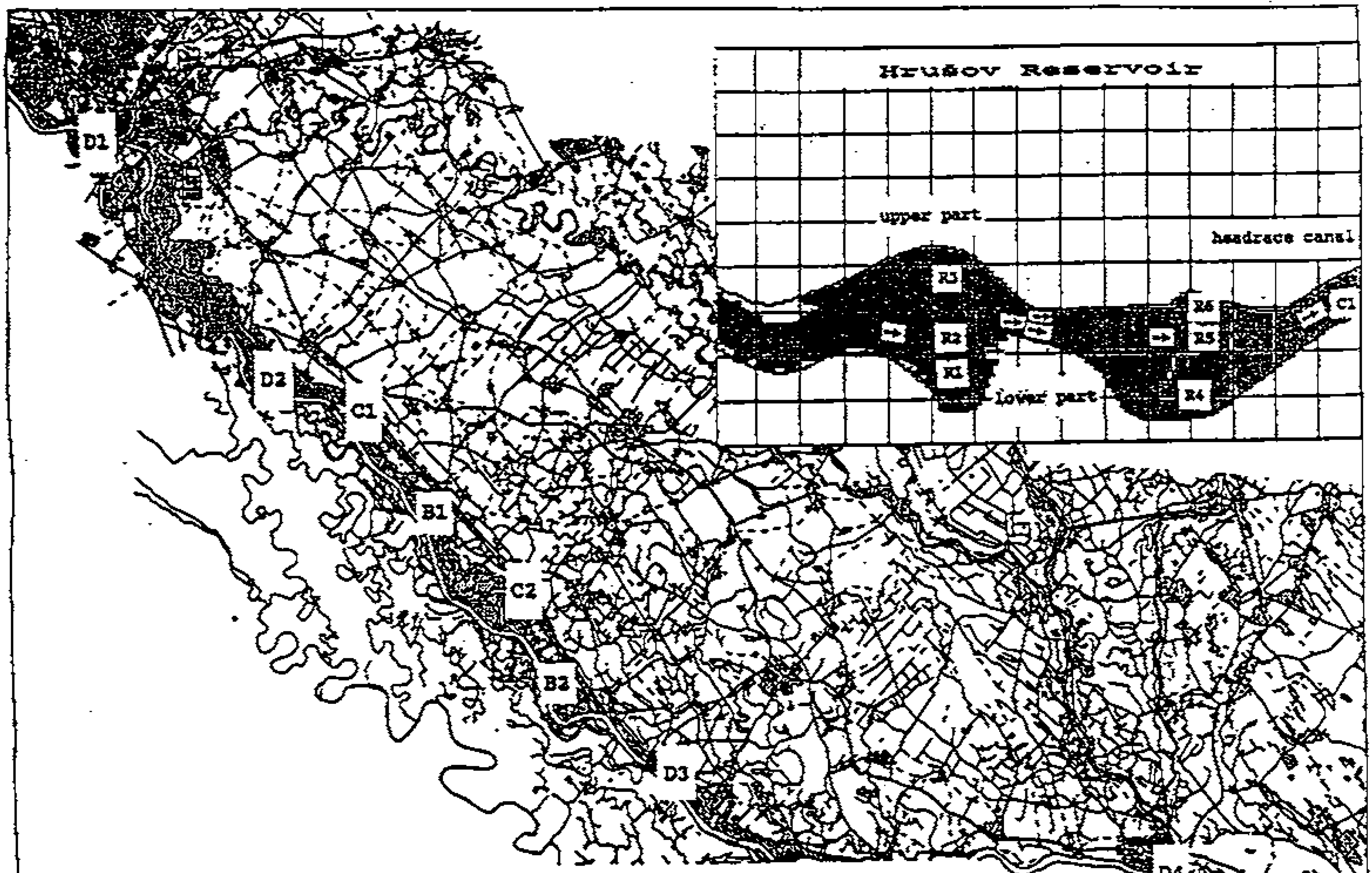
Fig. 1.0



Monitoring profiles

Fig. 1.1. Dissolved oxygen in the Danube

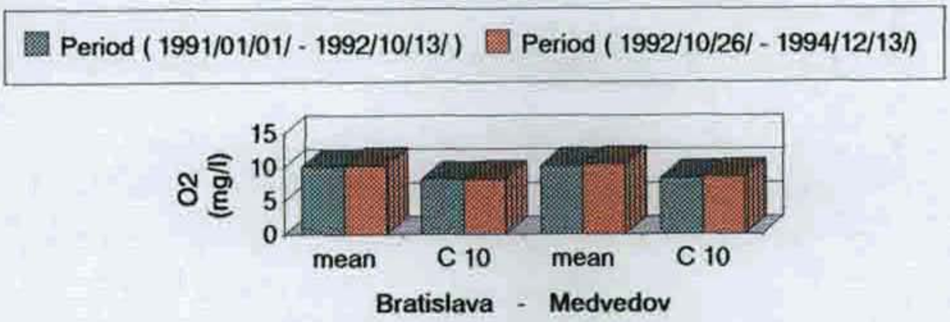


Fig. 1.2. Biochemical oxygen demand in the Danube

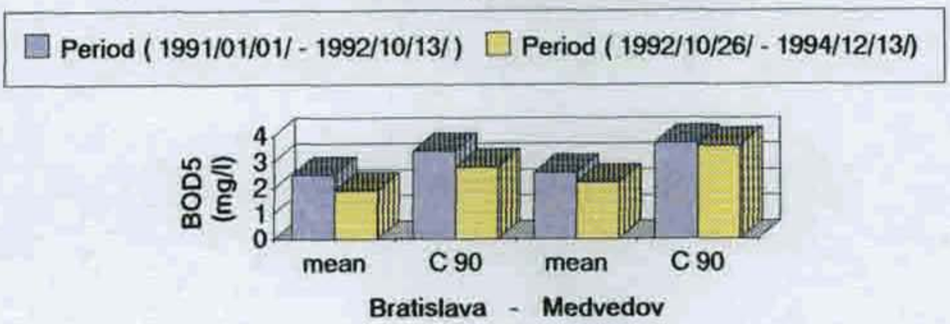


Fig. 1.3. Chemical oxygen demand (COD-Mn) in the Danube

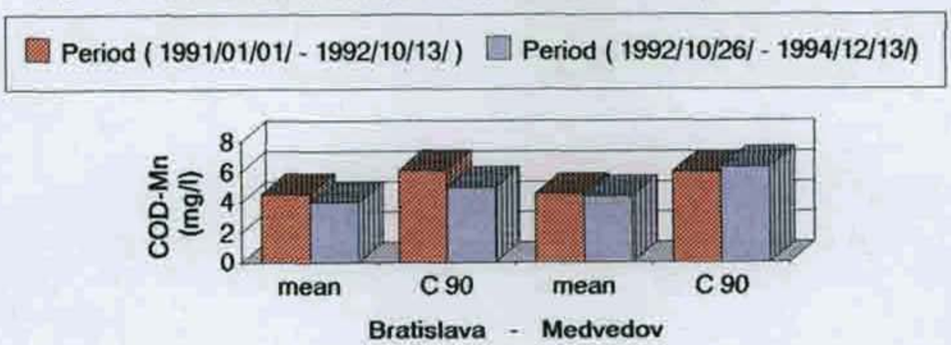


Fig. 1.4. Chemical oxygen demand (COD-Cr) in the Danube

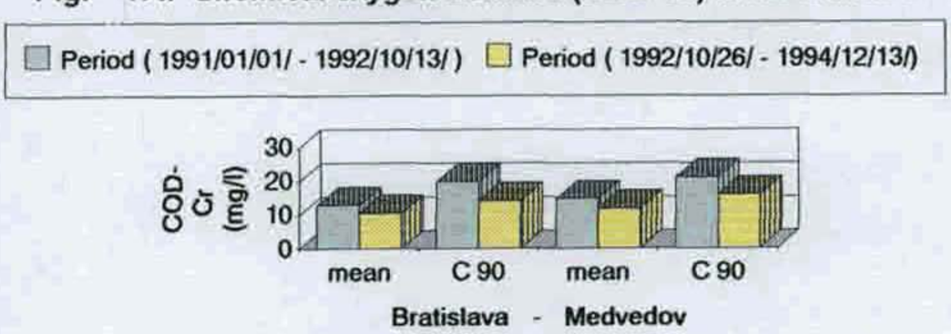


Fig. 2-1

Phytoplankton biomass
in the longitudinal profile of the Gabčíkovo project

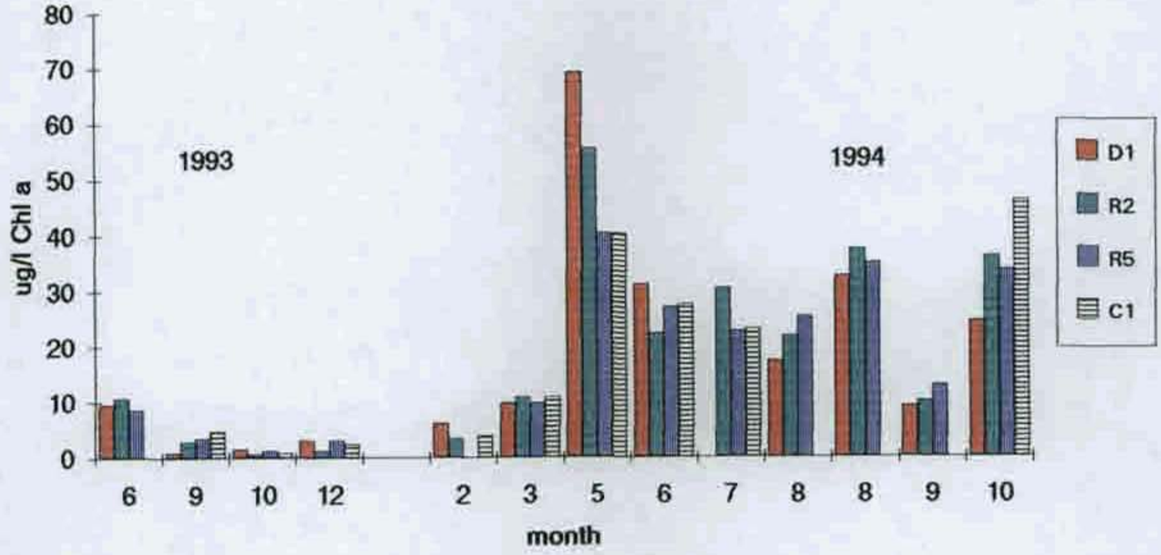


Fig. 2-2

Phytoplankton biomass
in the longitudinal profile of the Gabčíkovo project

summer 1994

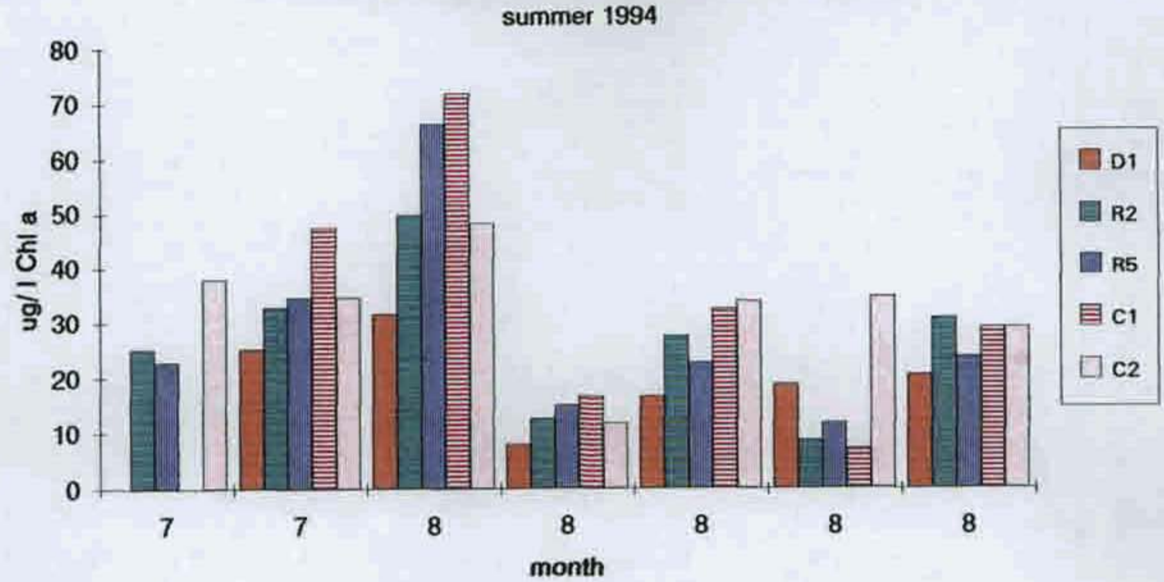


Fig. 2-3 **Phytoplankton biomass in the upper part of the reservoir**

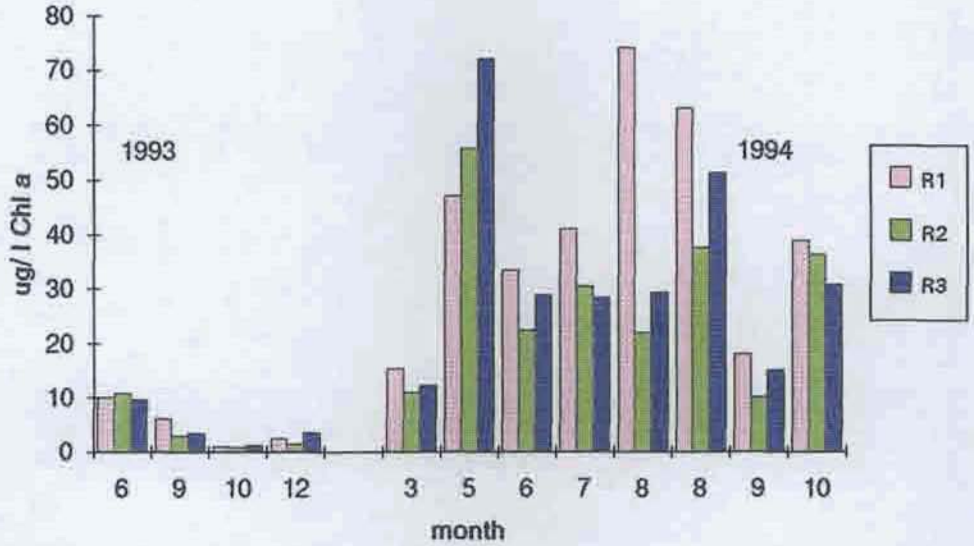


Fig. 2-4 **Phytoplankton biomass in the lower part of the reservoir**

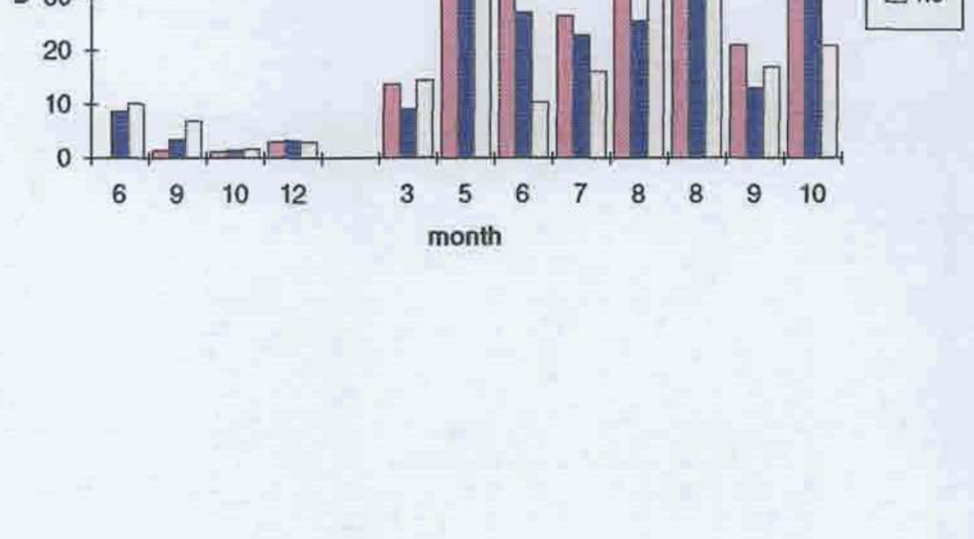


Fig. 2-5 **Water temperature and oxygen stratification in summer 1994 (profile R4)**

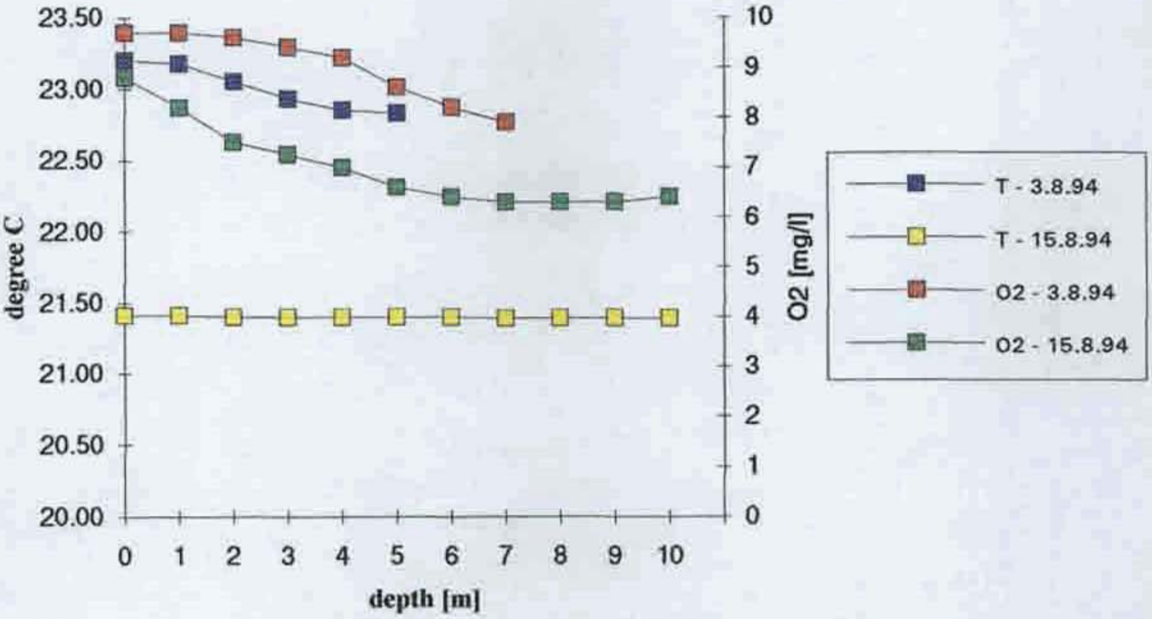


Fig. 2-6

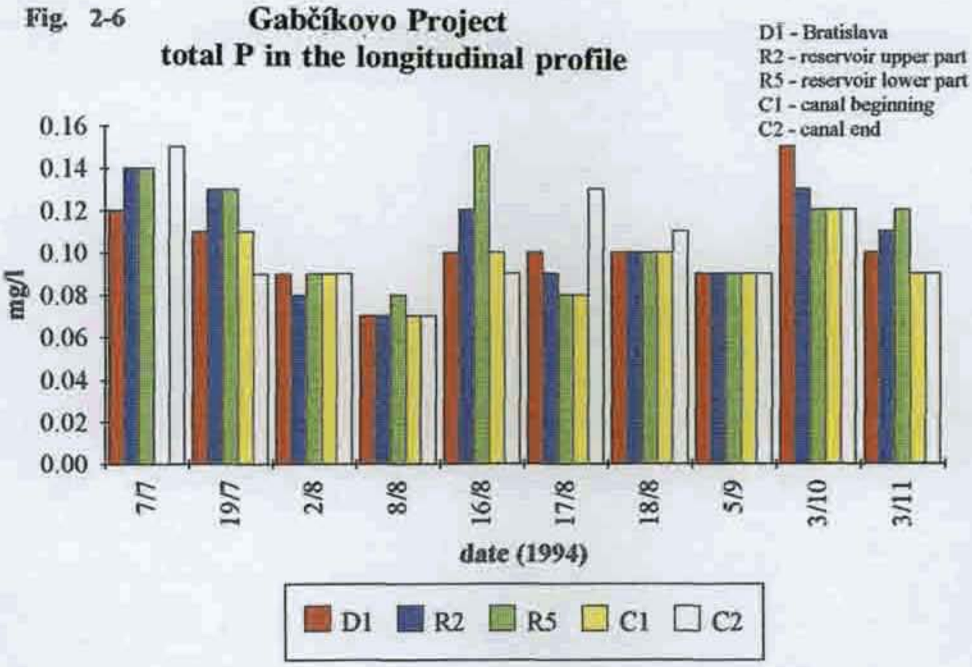

Gabčíkovo Project
total P in the longitudinal profile
DI - Bratislava
R2 - reservoir upper part
R5 - reservoir lower part
C1 - canal beginning
C2 - canal end
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
mg/l
7/7
19/7
2/8
8/8
16/8
17/8
18/8
5/9
3/10
3/11
date (1994)
D1
R2
R5
C1
C2

Fig. 2-7

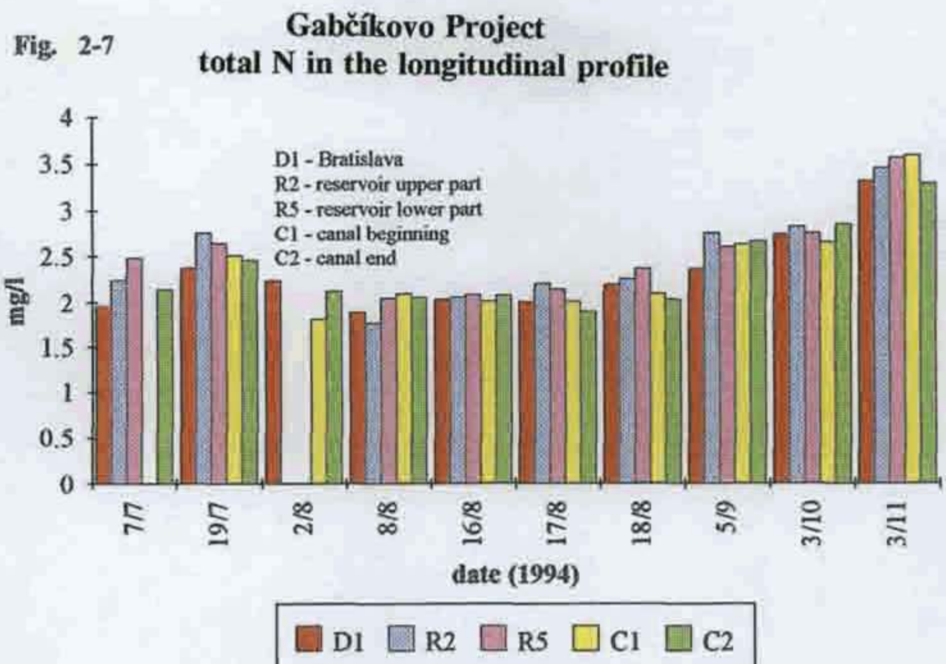

Gabčíkovo Project
total N in the longitudinal profile
4
3.5
3
2.5
2
1.5
1
0.5
0
mg/l
D1 - Bratislava
R2 - reservoir upper part
R5 - reservoir lower part
C1 - canal beginning
C2 - canal end
7/7
19/7
2/8
8/8
16/8
17/8
18/8
5/9
3/10
3/11
date (1994)
D1
R2
R5
C1
C2

Fig. 2-8

Long-term trend of total P in the longitudinal Danube profile

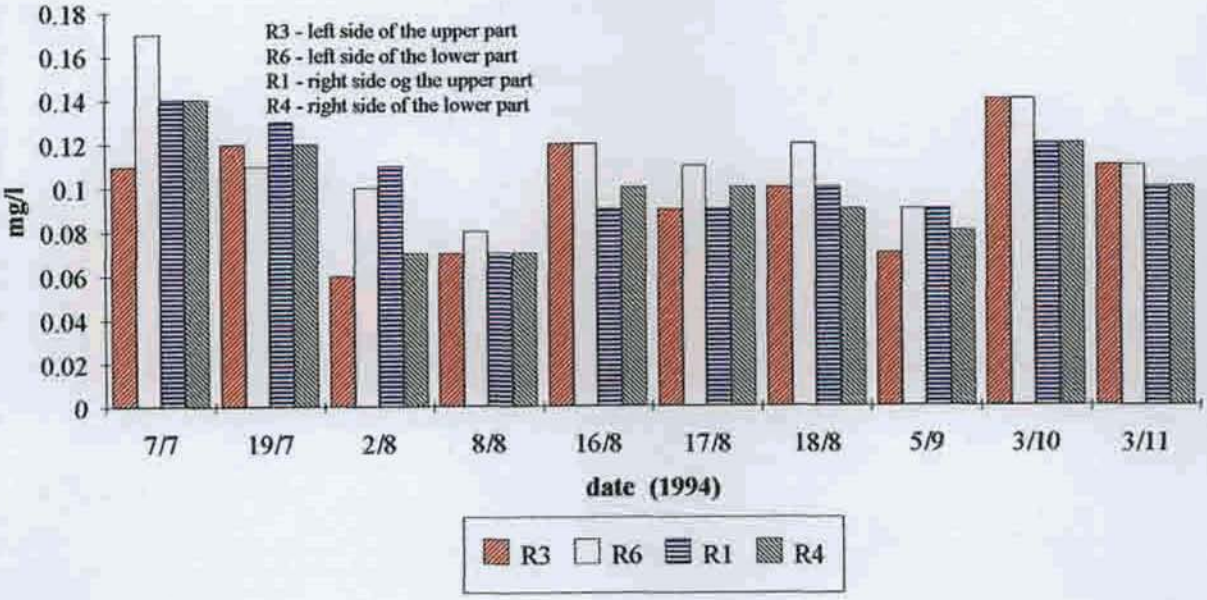


Fig. 2-9 **Long-term trend of changes of phytoplankton biomass**

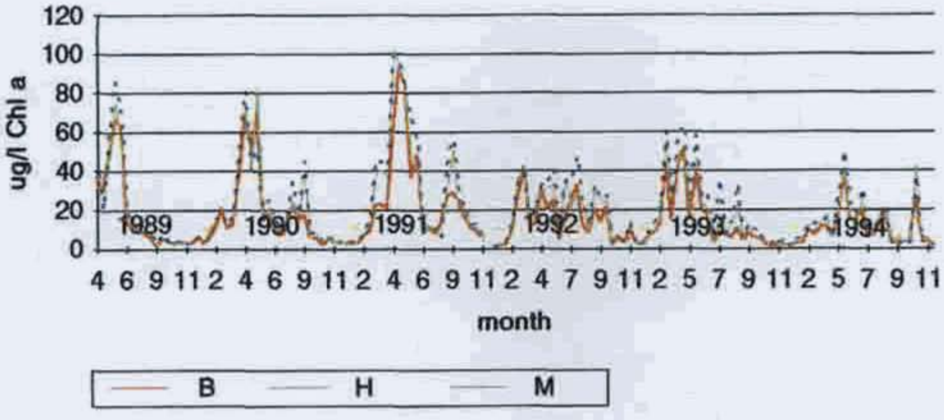


Fig. 2-9a **Increase of phytoplankton biomass [%] between Bratislava and Hrušov**

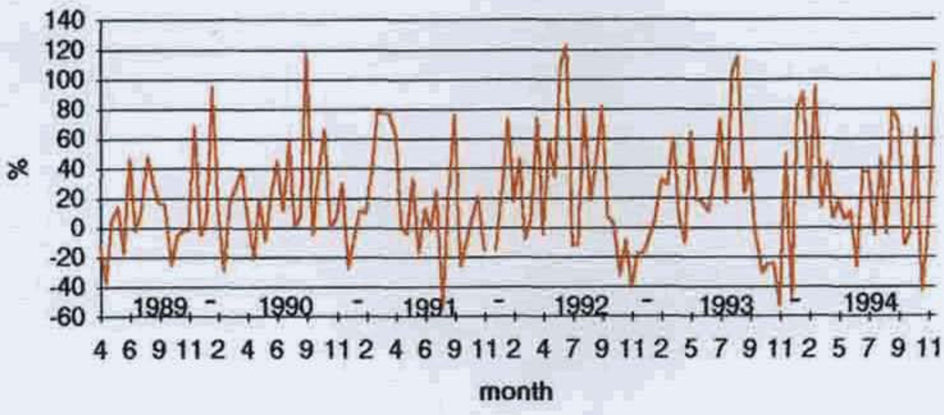


Fig. 2-9b Increase of phytoplankton biomass [%] between Hrušov and Medvedov

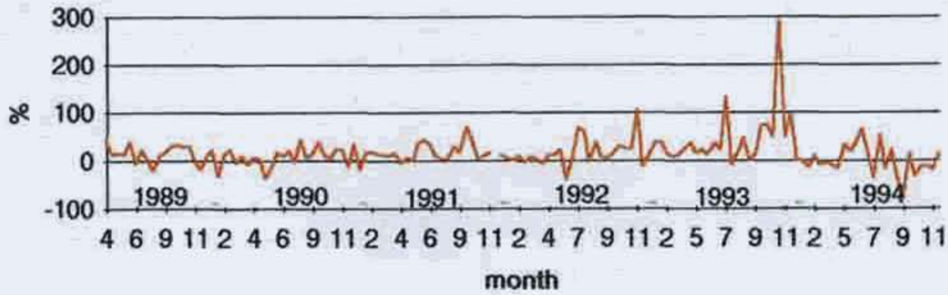


Fig. 2-10

Long-term trend of P- total in the longitudinal Danube profile

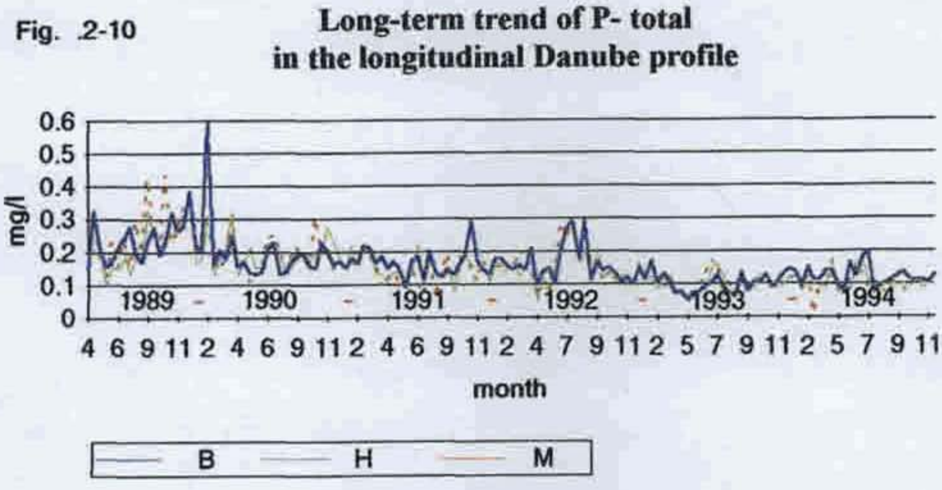


Fig. 2-10a

Increase of total P [%] between Bratislava and Hrušov

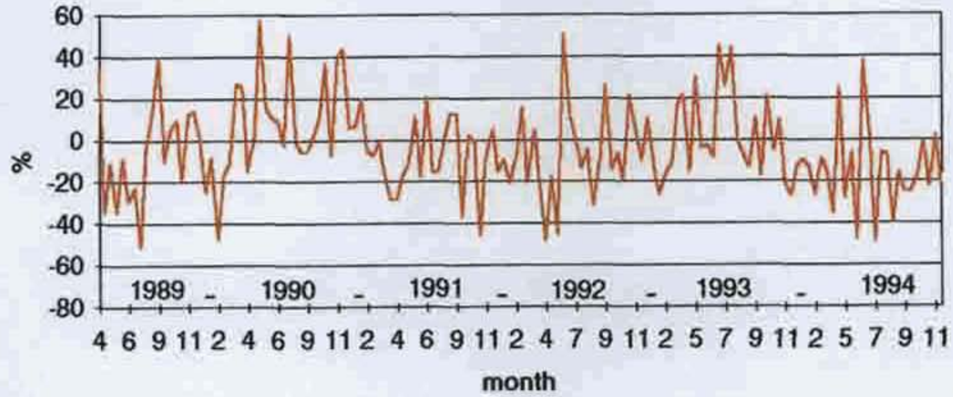


Fig. 2-10b

Increase of total P [%] between Hrušov and Medveďov

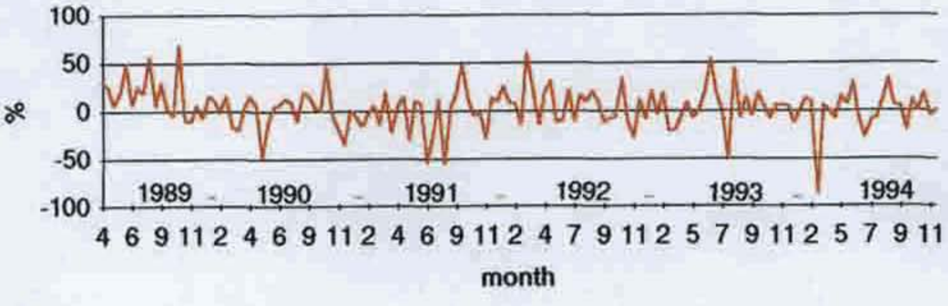


Fig. 2-11

Long-term trend of total N in the longitudinal Danube profile

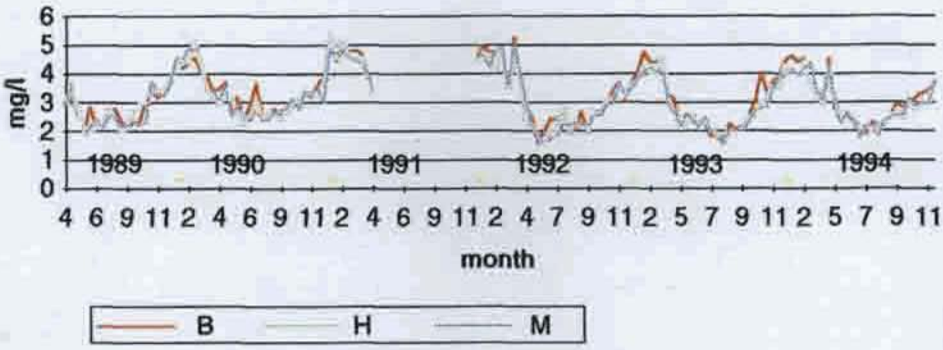


Fig. 2-11a

Increase of total N [%] between Bratislava and Hrušov

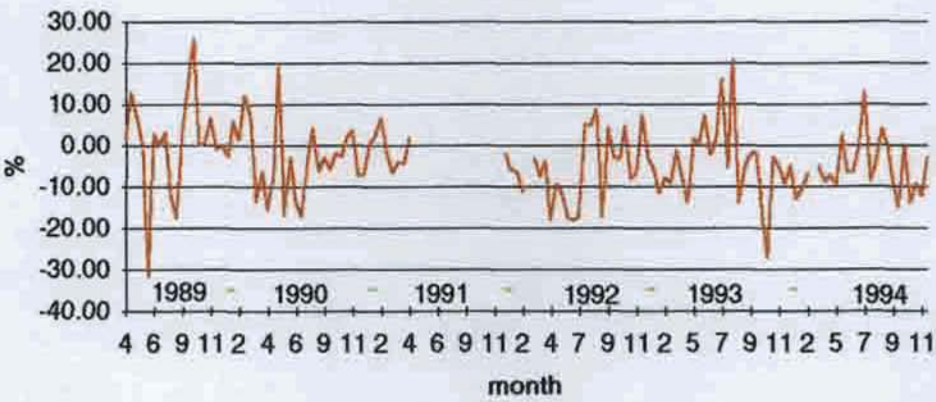


Fig. 2-11b

Increase of total N [%] between Hrušov and Medveďov

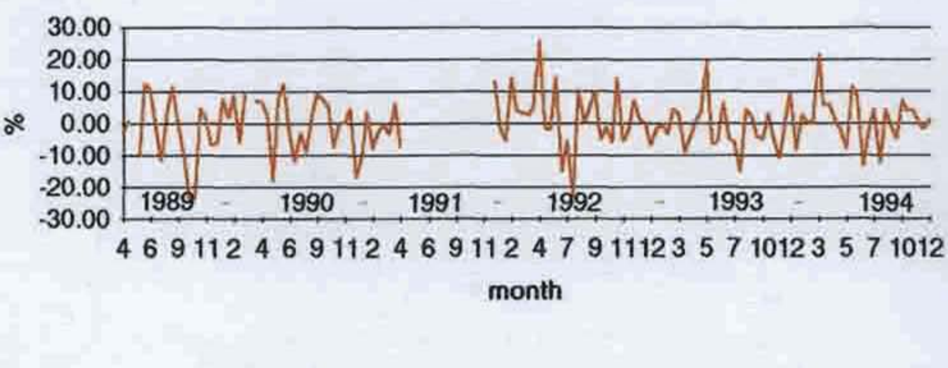


Fig. 3.1. **Mean annual values of heavy metals (Cr,Cu,Ni) in the Danube and the Reservoir in 1994**

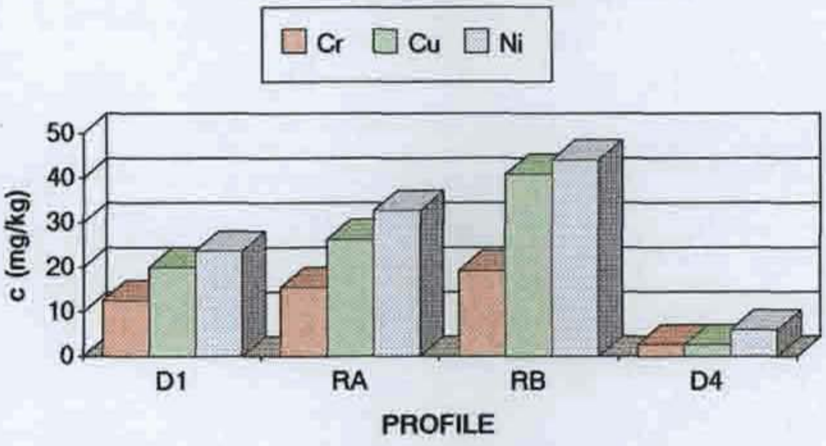


Fig. 3.2. **Mean annual values of heavy metals (Hg,Cd) in the Danube and the Reservoir in 1994**

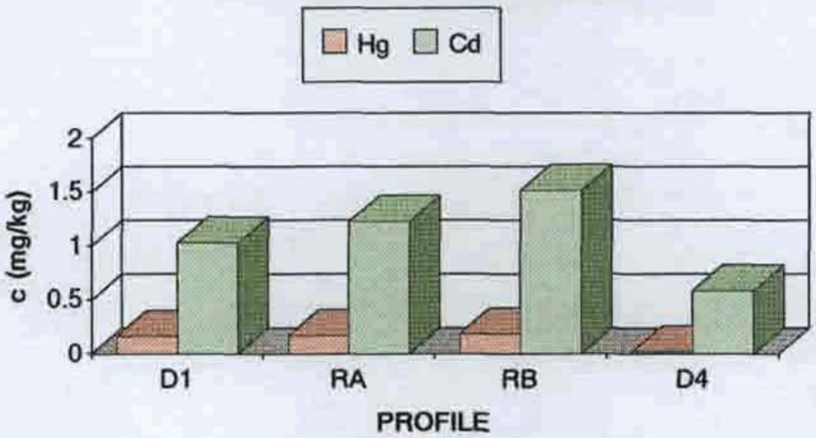


Fig. 3.3. **Mean annual values of heavy metals (Pb,Zn) in the Danube and the Reservoir in 1994**

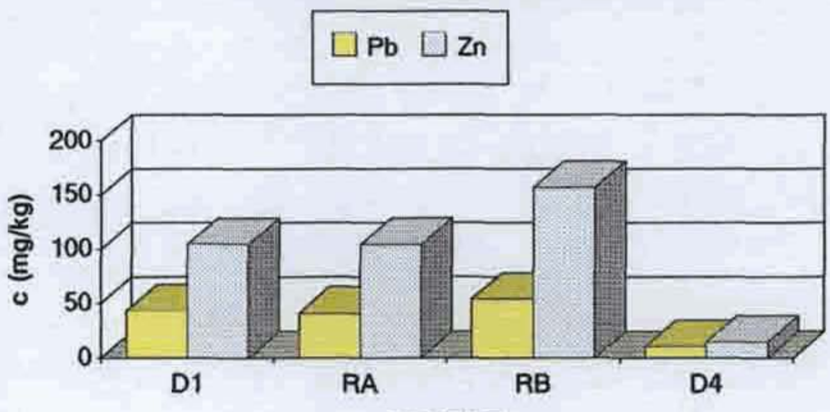


Fig. 3.4. **Mean annual values of PCBs in the Danube and the Reservoir**

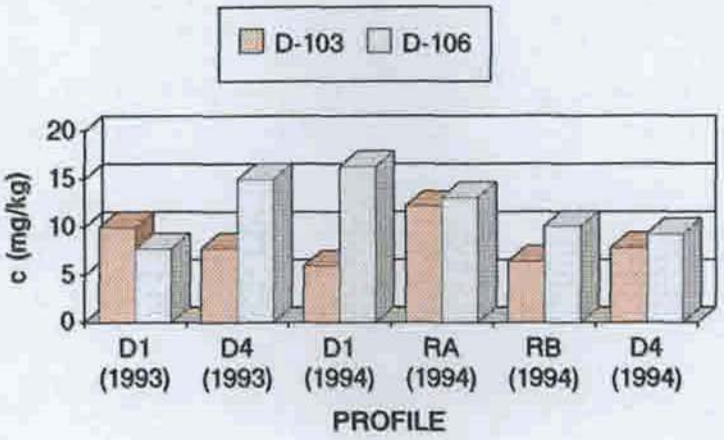


Fig. 3.5. **Mean annual values of chlorinated hydrocarbons in the Danube and the Reservoir**

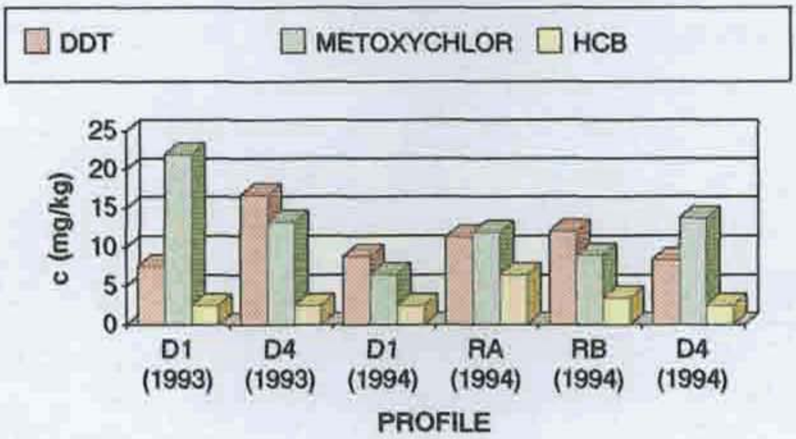


Fig. 3.6. **Mean annual values of PAH in the Danube and the Reservoir**

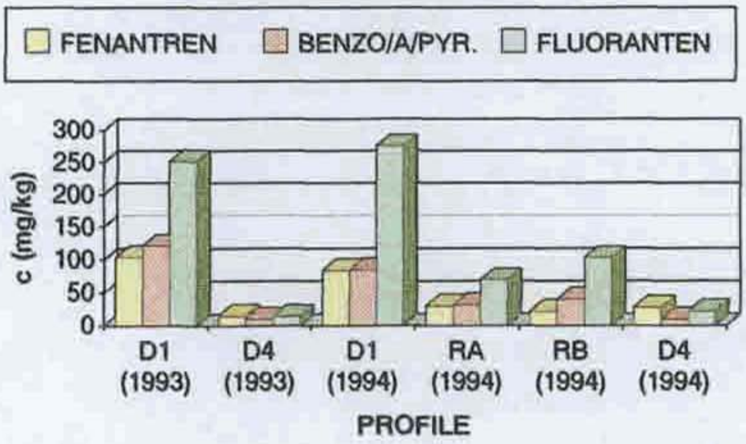


Fig. 3.7. **Mean annual values of radiological parameters in the Danube and the Reservoir**

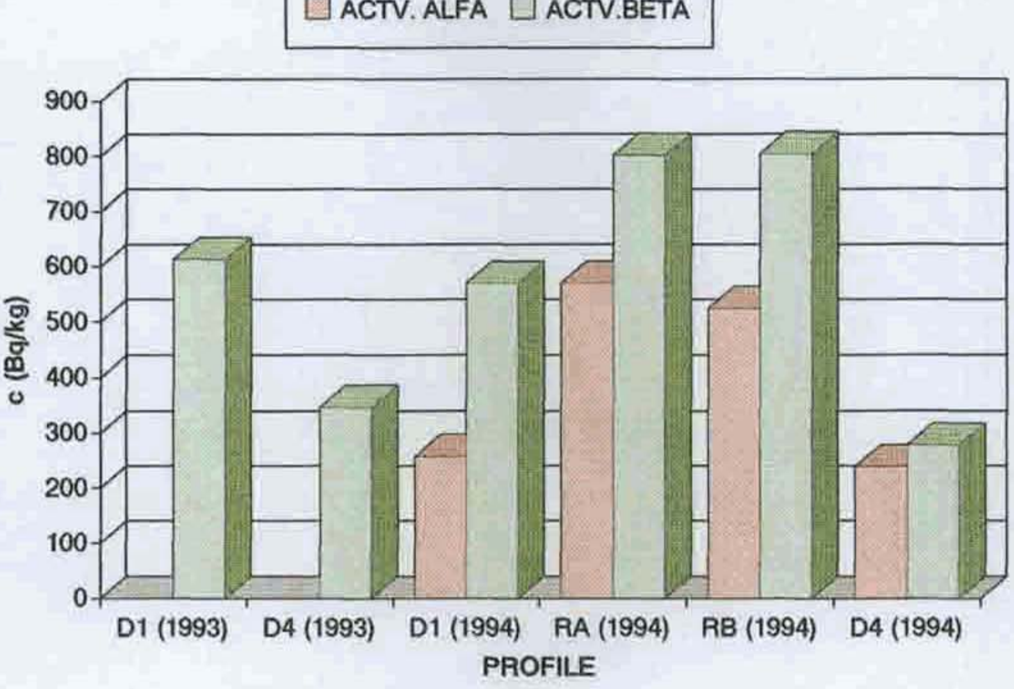
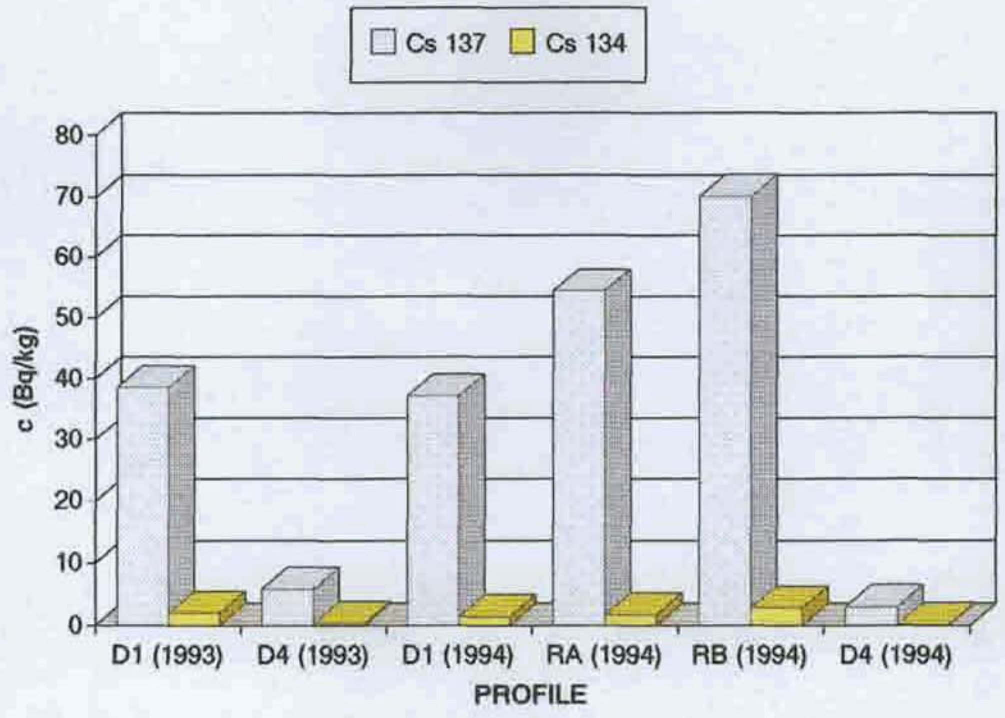


Fig. 3.8. **Mean annual values of radionuclides in the Danube and the Reservoir**



CHAPTER 3. UNSATURATED ZONE, SOIL, AGRICULTURE AND FORESTS

Section 1: **Unsaturated zone by J. Šútor**

Section 2: **Soil and agriculture by E. Fulajtár**

Section 3: **Forests by K. Csölle, J. Oszlányi, L. Molnár and I. Mészároš**

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1. Unsaturated Zone

1.1 Water in the Zone of Aeration - Water Source for the Biosphere

The part of the lithosphere between the soil surface and the first ground water horizon has the features of a three phase system. It consists of a solid phase of various granular composition, which constitutes the structure of the porous media. In the pores, water in various phases occurs according to its state and its bond to the solid phase. The gaseous phase fills up the pores together with the water up to the full porosity, i.e., it fills up that part of the pores which is not saturated by the water. For this reason this part of the lithosphere is called the unsaturated zone, or the zone of aeration. It is a part of the hydrological cycle which connects the surface and subsurface waters. Its depth in the natural conditions of Žitný Ostrov is 0.4 to about 7 m and, according to the definition of the zone of aeration, it varies due to ground water level movements.

The water in the zone of aeration is a water source for the biosphere in the region. This volume of water is not of a free water character. Its energetic bond with the solid state is expressed by the moisture retention curve. Its characteristic points are the point of field water capacity (FWC), the point of the decreased availability (PDA) and the wilting point (WP). The root system of the plant cover respectively its suction force overcomes without any problem the energetic bond of the water in the zone of aeration between the FWC and WP. Water in the zone of aeration as a water source for the biosphere can be defined as follows (Šútor, 1991):

MP12 Čilizska Radvaň

- The third group of localities are sites numbered from N0 to N10 and selected on agricultural soils where irrigation is current and where the penetration of the water through the zone of aeration to the ground water level is expected.

For the quantification of the changes of water storage dynamics in the zone of aeration of Žitný Ostrov after the putting of the Gabčíkovo Project structures into operation, we take account of the ground water levels as elaborated by Mucha and Pavlíková (1993), Chalúpka and Popelková (1994) as well as of the results published by these authors in this Volume in Chapter 1. It is evident that in the upper part of Žitný Ostrov (the sites Lehnice and Kalinkovská horáreò as indicators) the ground water levels rose after the filling of the reservoir, whereas a decrease was observed from the reservoir downstream to Gabčíkovo and almost no change or a very slight rise occurred in the surroundings of Čalovec. Further changes occurred after the water supply of river branches was put in operation - this led to the ground water rise also in the left-side area of Žitný Ostrov close to the bypass canal.

As mentioned above, the Gabčíkovo Project structures influence the dynamics of the water storage in the zone of aeration of the surface layer through the changes and variability of the ground water levels. The quantification of this impact with respect to monitoring can be divided into three temporal periods which can be defined as follows:

- starting-point state (includes the monitoring of the water content in the zone of aeration before the operation of the Project, i.e., before October 1992),

- transition state (determined by the Danube's damming and the putting into operation of the water supply system with the intake structure at Dobrohošť supplying the left side river branches) which continues through the whole year 1993,

- operation state (this means stable operation conditions when the water is divided between the old riverbed of the Danube and the bypass canal, when the water supply system for the inundation zone is operated and the dates of artificial flooding of the inundation zone are set up, and the water level regime for the old riverbed simulating the ground water level variations known from the period before the start of the operation of the Project is established). This operation state has not yet been fully introduced. It depends on the optimalisation with respect to the phenomena included.

For the quantification of the ground water level changes and variability on the dynamics of the water storage in the zone of aeration three characteristics were selected:

- the courses of the integral water content in the zone of aeration during 1990 to 1994,
- the mean values of the water content in the zone of aeration in individual seasons of the years 1990 to 1994,
- the quantification of the participation of the individual soil horizons on the cumulative content of water in the zone of aeration in defined intersects of the time series.

The complete material from all the monitoring sites and the years mentioned is very extensive and was published in detail by Šútor (1993,1994), Rehák (1991, 1992, 1993), Petrovič- Džupová (1992, 1993, 1994), Pristachová (1989), Šoltész (1991,1993).

1.2 Course of the water content in the zone of aeration on monitoring sites in the years 1990 to 1994

The courses of the integral water content in the zone of aeration in the years 1990 to 1994 - with the exception of the Kráľovská Lúka site where the monitored series cover 9 years (1986 - 1994) - indicate the influence of the ground water level changes and variability. These time series cover all three analysed time periods of Žitný Ostrov's pre-dam environment state with respect to the impact of the Project structures: starting-point state, transition state and operation state, the optimalisation of which still continues. The graphical interpretation of these courses together with the trend of development for individual sites is expressed as follows in Table 1:

Kalinkovská horáreň	Fig.1.1	MUZ 14	represents the upper part of Žitný ostrov
Lehnice M7	Fig.1.2	MUZL 7	
Lehnice M9	Fig.1.3	MUZL 9	
Báč	Fig.1.4	MUZ 12	represents the central part of Žitný ostrov
Mliečno	Fig.1.5	MUZ 13	
Zlatná na Ostrove	Fig.1.6	MUZ 5	represents the situation downstream of Gabčíkovo
Kráľovská Lúka	Fig.1.7	MUZ 19	represents the inundation area of the old riverbed of the Danube
Dobrohošť	Fig.1.8	MUZ 17	
Bodíky	Fig.1.9	MUZ 18	
Dekan	Fig.1.10	MUZ 20	

The influence of the long-term trend of ground water levels decrease before the operation of the Gabčíkovo dam as noted by Mucha (1994) and the unfavourable changes after the operation of the structure prognosticated by some authors are not evidenced during the balanced monitoring period (two years before the operation, one year of transition and two years after the damming). No negative changes of the water content in the zone of aeration occurred. On the contrary, the monitored courses of the water content in the zone of aeration in the upper Žitný Ostrov sites, on the left-side area of the bypass canal and downstream of Gabčíkovo are showing the increasing trend.

In Kráľovská Lúka (inundation zone) the last two years 1993 and 1994 are changing the decreasing trend before these two years to one slightly increasing. The same can be expected in other two localities in the inundation area, i.e., in Bodíky and in Dekan. The most important is the decreasing trend of water content in the zone of aeration in Dobrohošť where the decrease of the ground water levels is supported by the structure of the surface layer. The ground water level fell to the gravel strata, and thereby the hydraulic contact between the ground water level and zone of aeration is disturbed, i.e., the capillary supply of the zone of aeration was interrupted. This phenomena was not caused by important decrease of the ground water level but by the structure of the porous media. It is the only case from the whole territory influenced by the Gabčíkovo Project.

The monitored courses of the water content in the zone of aeration depicted on Figs. 1.1-1.10 are sensitive to the change of the ground water level which confirms their important role in the water balance of the surface layer and also the possibility of its regulation by optimised operation of the Project.

1.3 Mean values of the water content in the zone of aeration in individual seasons in the years 1990 to 1994

The vegetation cover of the area is being supplied by water from the zone of aeration during the vegetation season (in respect of Žitný Ostrov, in April-October). The water storage is limited by its development during the winter season. At the beginning and during the whole vegetation period it is possible to evaluate the storage, its use and formation using the courses of the integral water content in the zone of aeration during this period. The autumn season illustrates the exhaustion of the water storage during the vegetation season and its renewal by the end of year due to precipitation. Therefore the evaluation of the monitored water storage in the zone of aeration is elaborated in individual seasons of the year, i.e., January-March (first quarter of the year), April-June, July-September, and October-December for the years 1990-1994, i.e., in a 5 year period.

The results of such analysis, i.e., the mean values of the water content in the zone of aeration in individual seasons, are shown on Figs. 1.11-1.14. The Y-axis represents the values of the water content in the zone of aeration and the X-axis the individual sites in which the evaluation was done. To the displayed mean values of the water content, in each locality there is joined the mean values for the season and the value of the water content corresponding to the wilting point (for the soil of the monitoring site).

On the basis of these results we can state that after the putting of the Gabčíkovo Project into operation, the mean values of the water content in the zone of aeration did not fall down in any of the seasons permanently below the value corresponding to the wilting point. The monitored integral values of the water content in the upper Žitný Ostrov area, in its central area and downstream of Gabčíkovo are higher than the mean values; this statement is valid also for the Kráľovská Lúka site in the inundation area.

1.4 Participation of the individual soil horizons on the cumulative water content

The cumulative water content in the zone of aeration represents its total storage. With respect to the vegetation cover it is important to know also the structure of its distribution with the depth of the zone of aeration. Besides this the distribution expresses the stability of the storage in individual horizons and mutual relationship with the ground water levels.

The non-uniform exhaustion of the individual horizons of the zone of aeration results from the different distribution in the root system of the vegetation cover, respectively reflecting the structure of its porous media. Therefore the analysis of the monitored values of the water content in individual horizons was done to evaluate the dynamics of the water storage in the zone of aeration in the conditions of the individual sites. In this way, the participation of the individual horizons of the zone of aeration on its cumulative water content was elaborated.

The method of the water content monitoring in the zone of aeration is based on its evaluation in 10 cm layers, i.e., from the soil surface to the selected depth. As can be seen from Figs. 1.11-1.14 the chosen depth was between 100 and 200 cm in the individual sites. The obtained data can be used for the analysis of the share of individual horizons on the cumulative water content in the whole monitored depth.

This type of analysis for the Kráľovská Lúka site is shown on Figs. 1.15-1.19. The Y-axis represents the water content in the aeration zone and X-axis number of the monitoring day. The water content in individual layers is from the chosen depth (in Kráľovská Lúka conditions from 200 cm depth) is added step by step to the previous value up to the surface of the soil. Adding the water content of the last layer we obtain the integral water content of the aeration zone of the whole monitored horizon. The depth of the added water content in individual layers is expressed in mm of the water column. Therefore the individual contents directly characterise the retention properties of the individual layers in space and time.

The analysis of the individual horizons of the aeration zone on the cumulative water content for the year 1990 (Fig. 1.15) in Kráľovská Lúka documents the whole year water supply from the ground water level. The same can be stated for 1991 (Fig. 1.16). The decrease of the integral water content to almost 260 mm in 1992 was caused by low discharges in the Danube during the summer season, prior to damming. The gradual water storage exhaustion of the aeration zone was analysed in 1993 (Fig. 1.18) where the beginning of the water supply through the intake structure at Dobrohošť to the inundation area can be seen. Year 1994 (Fig. 1.19) shows the highest values of water content in the spring and early summer seasons. The end of 1994 clearly indicates the level regime of the Danube river.

The application of a similar analysis as for Kráľovská Lúka on other monitoring sites is of real meaning only for the year 1993. The analysis for Lehnice is shown on Fig. 1.20, for Hamuľiakovo on Fig. 1.21, for Čilistov on Fig. 1.22, for Baka on Fig. 1.23, for Dekan on Fig. 1.24 and for Dobrohošť on Fig. 1.25.

These analyses illustrate the sensitivity of the reaction of the water storage in the zone of aeration to the ground water level change, the inertness at sudden changes, the possibility of optimalisation of the water regime of the surface layer in the inundation area by ground water level changes in the frame of the operation regime being prepared.

Three elaborated characteristics, i.e., the integral water content courses, the mean water content values and the quantification of the individual soil horizons participation on the cumulative water content in the zone of aeration of the surface layer in the natural environment of Žitný Ostrov give us the objective basis for the evaluation of the Gabčíkovo Project's impact on the water content in the aeration zone as a water source for the biosphere in this region.

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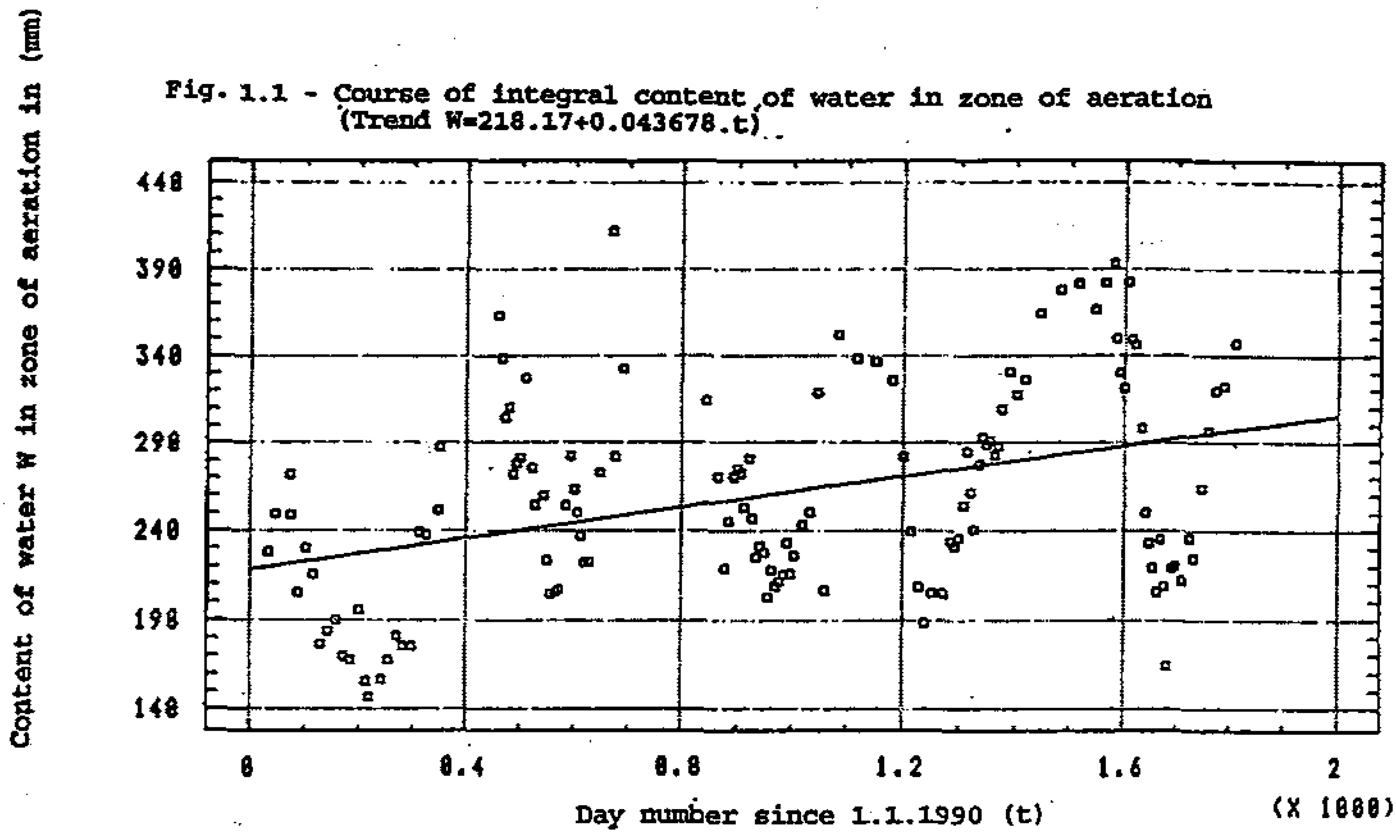
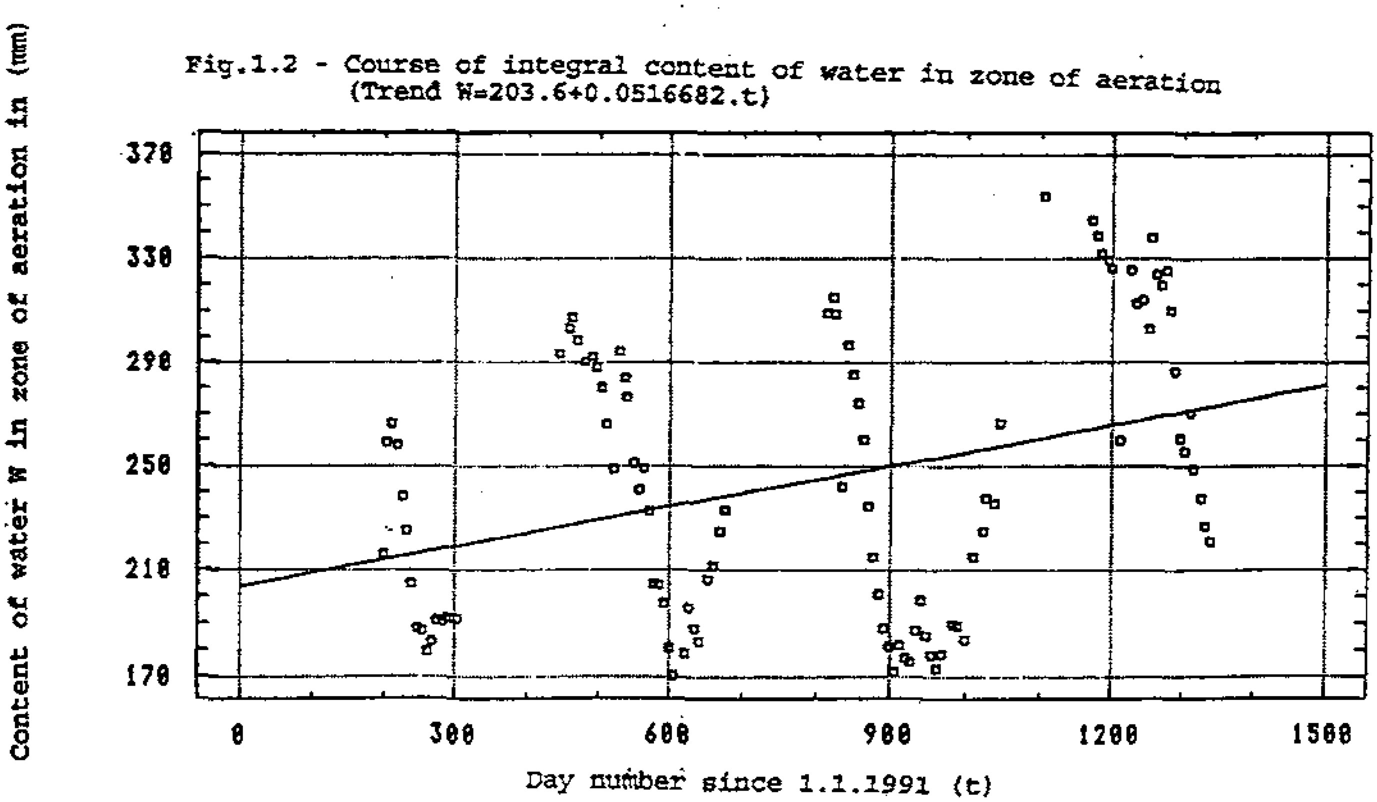
Fig. 1.1 - Course of integral content of water in zone of aeration
(Trend W=218.17+0.043678.t)



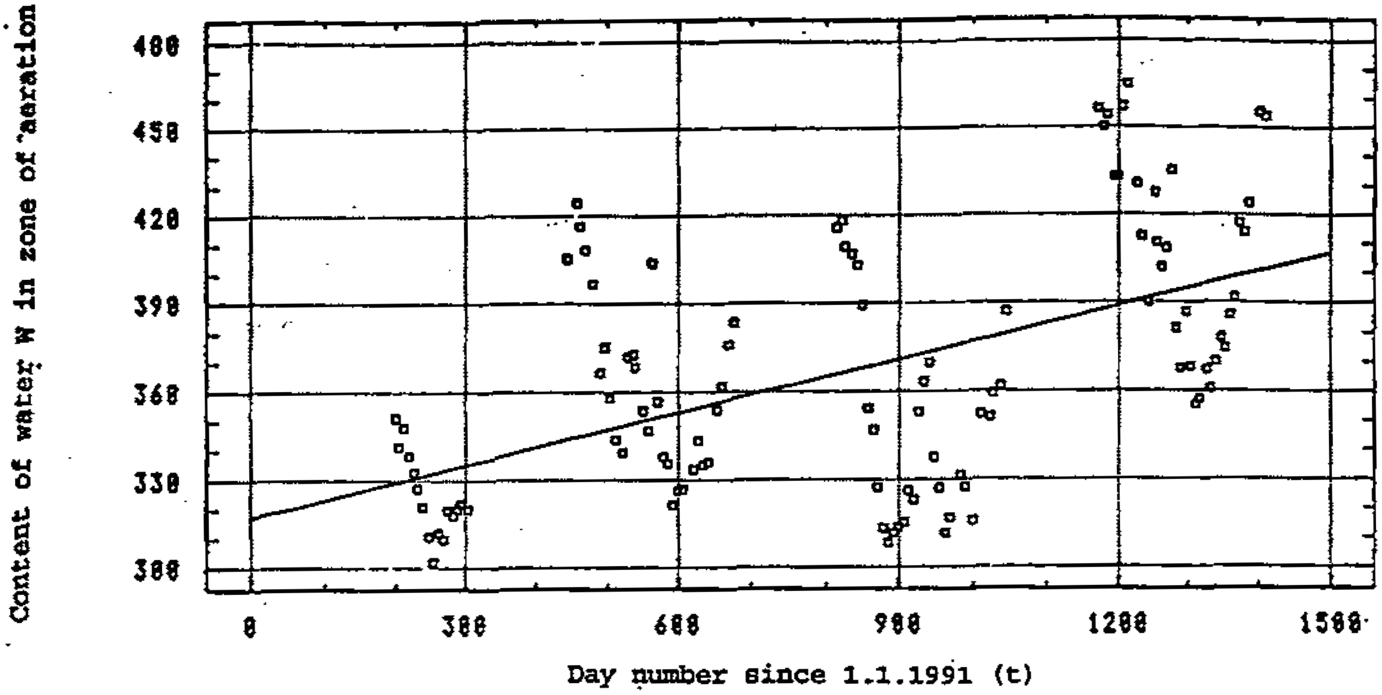
Locality: Kalinkovská forester's house - 1990/94

Fig.1.2 - Course of integral content of water in zone of aeration
(Trend W=203.6+0.0516682.t)



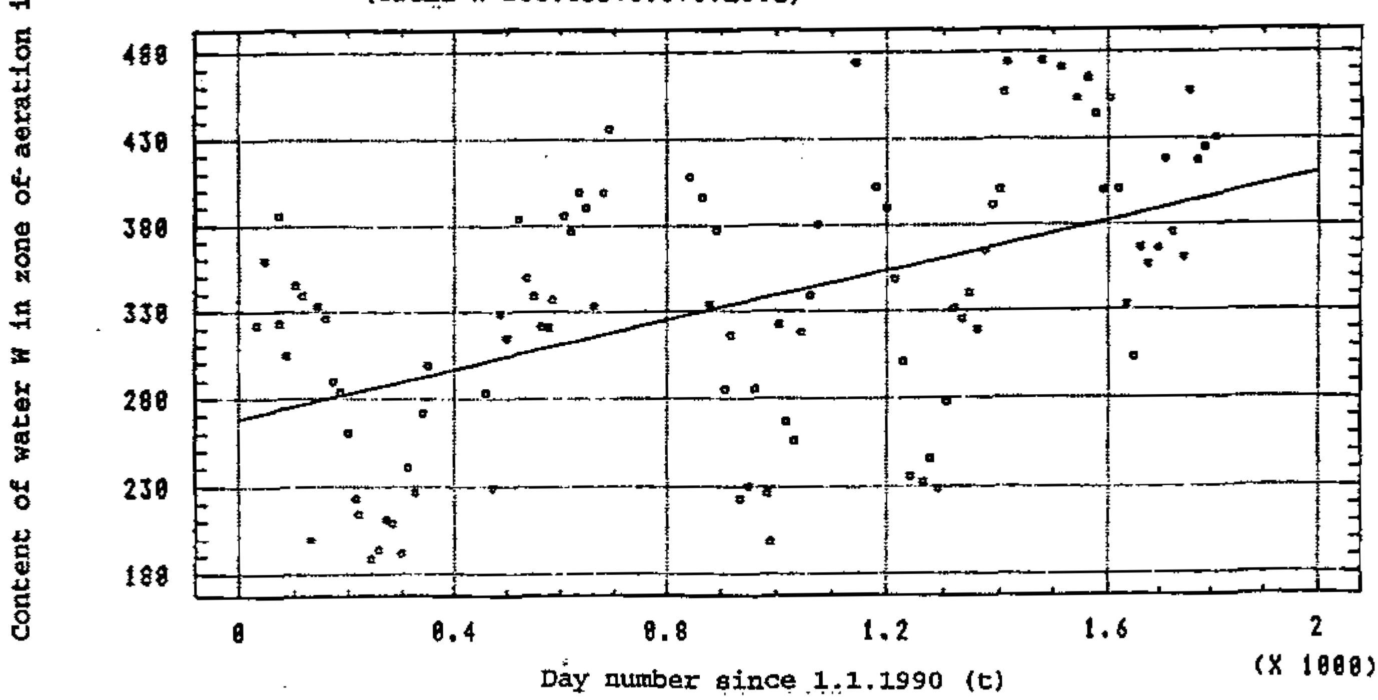
Locality: Lehnice (7) - 1991/94

Fig.1.3 - Course of integral content of water in zone of aeration
(Trend W=317.128+0.059796.t)



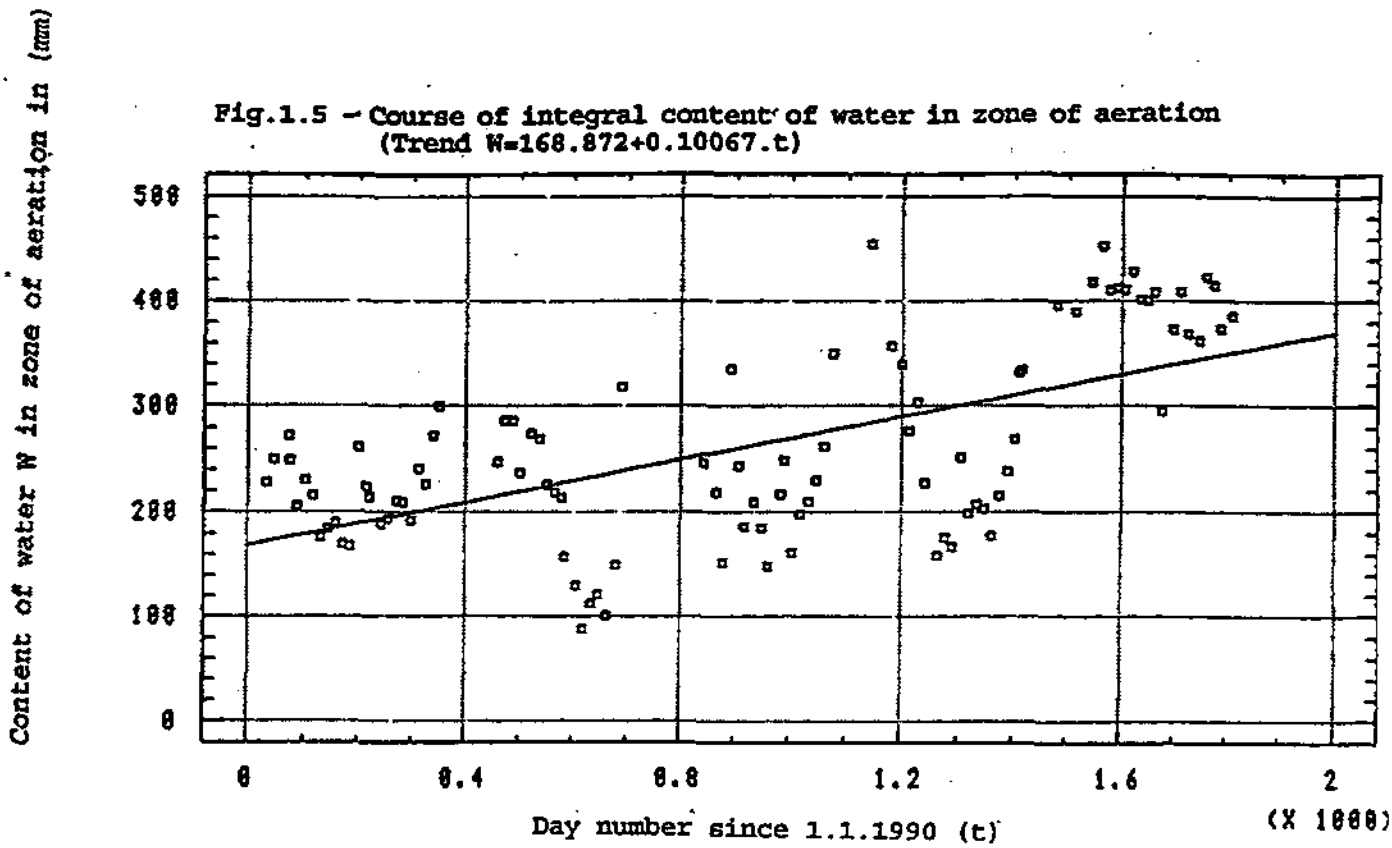
Locality: Lehnice (9) - 1991/94

Fig.1.4 - Course of integral content of water in zone of aeration
(Trend W=268.655+0.070710.t)



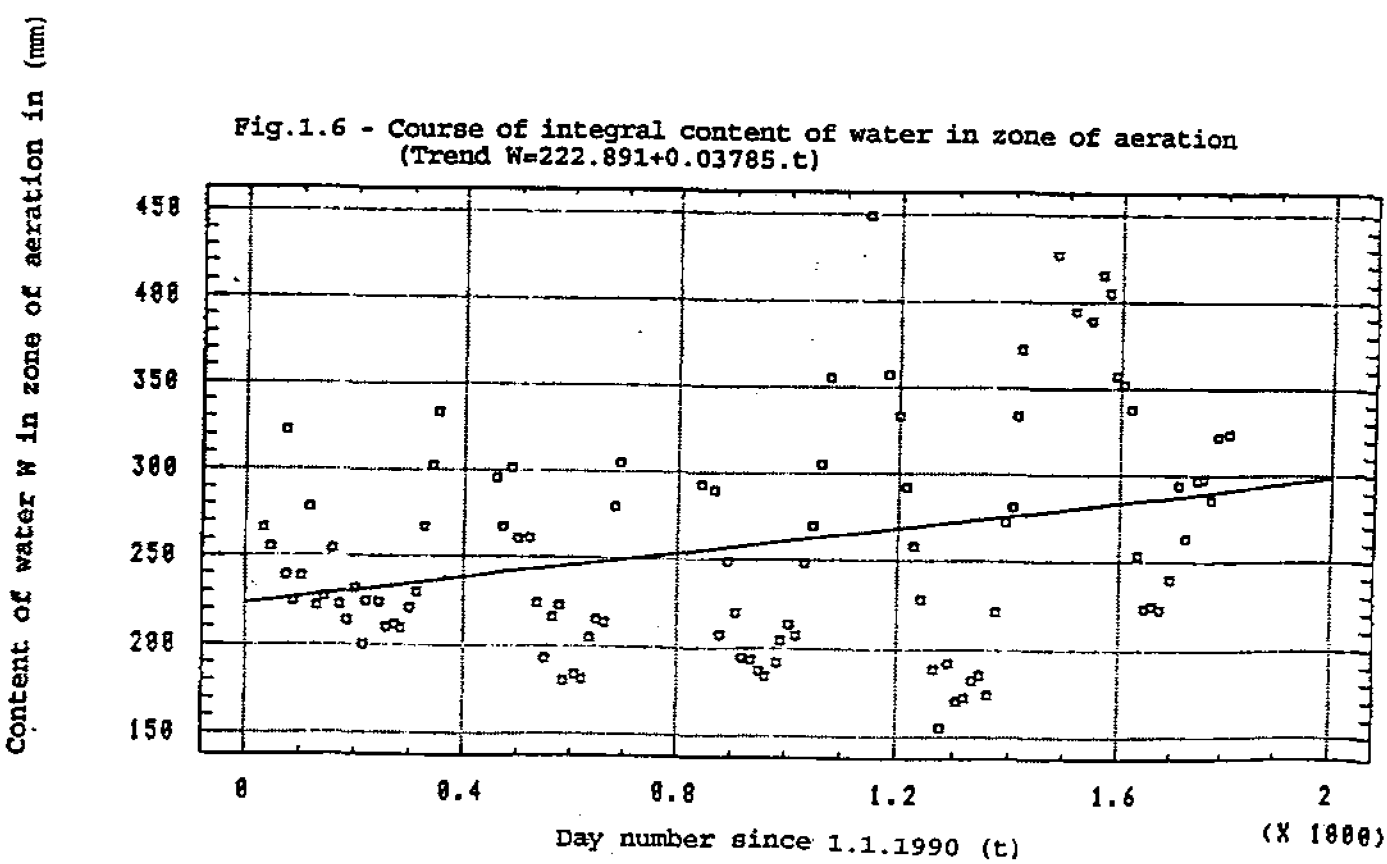
Locality: Báč - 1990/94

Fig.1.5 - Course of integral content of water in zone of aeration (Trend W=168.872+0.10067.t)



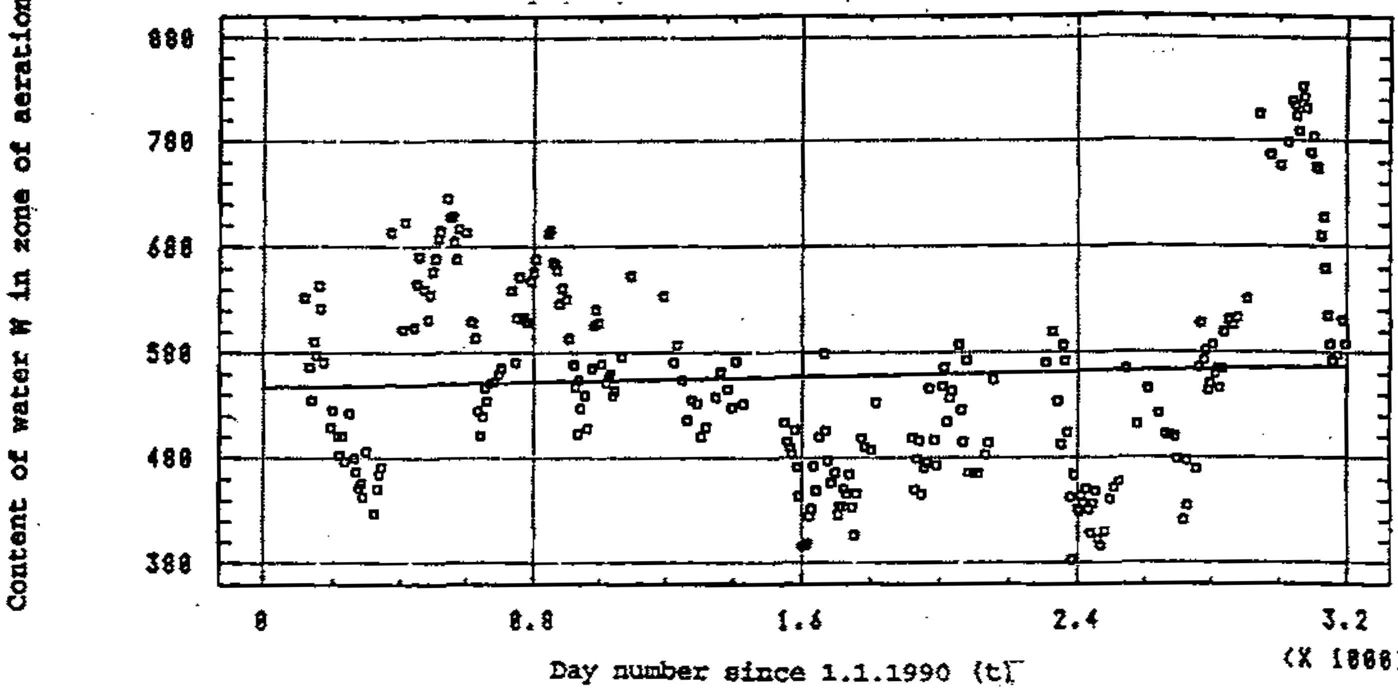
Locality: Mliečno - 1990/94

Fig.1.6 - Course of integral content of water in zone of aeration (Trend W=222.891+0.03785.t)



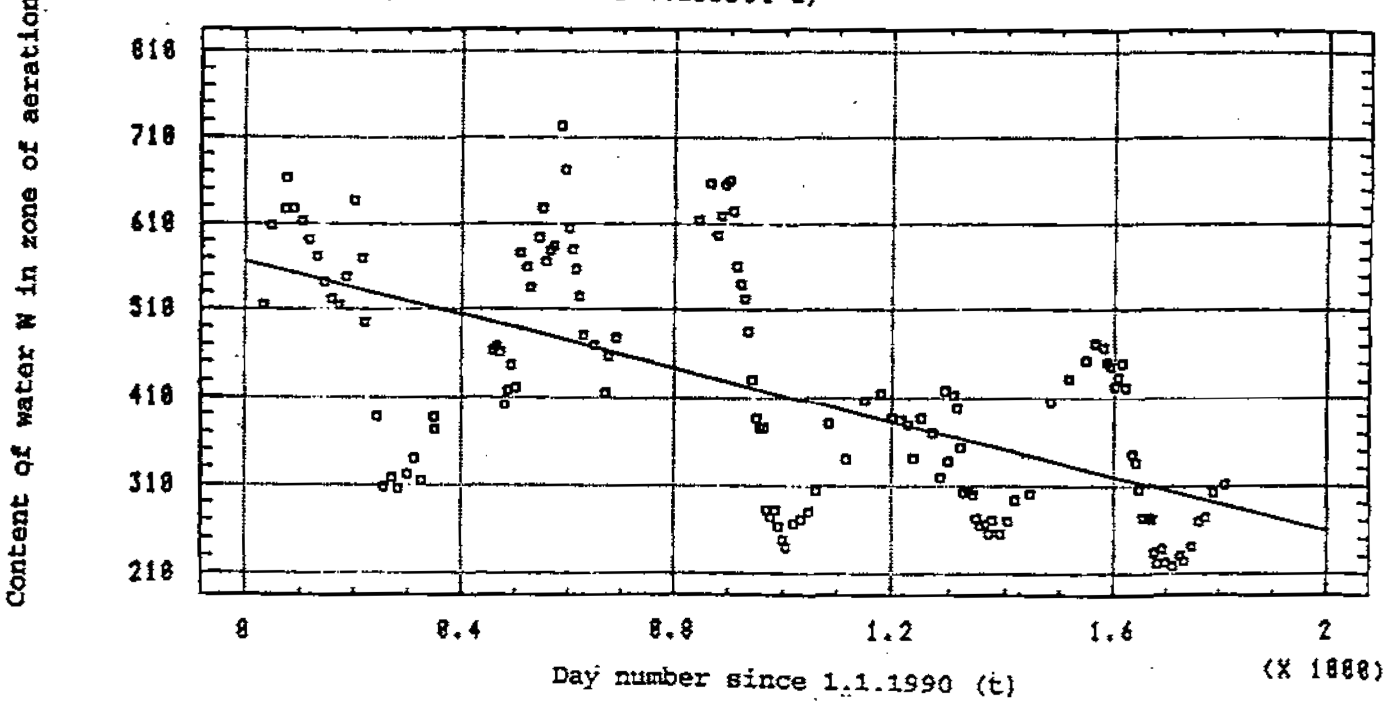
Locality: Zlatná na Ostrove - 1990/94

Fig.1.7 - Course of integral content of water in zone of aeration
(Trend W=546.811-6.19848E-3t)



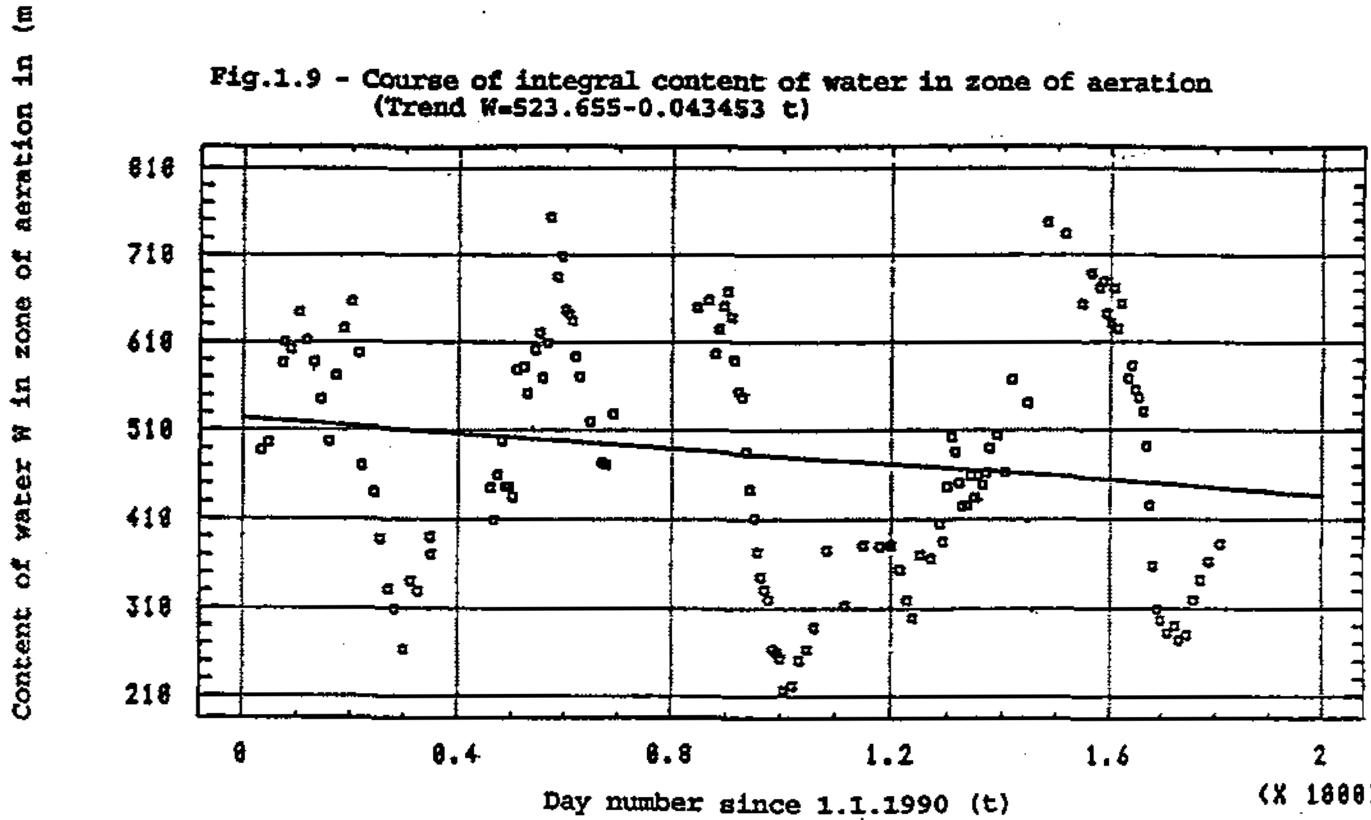
Locality: Kráľovská lúka - 1990/94

Fig.1.8 - Course of integral content of water in zone of aeration
(Trend W=565.925-0.153364 t)



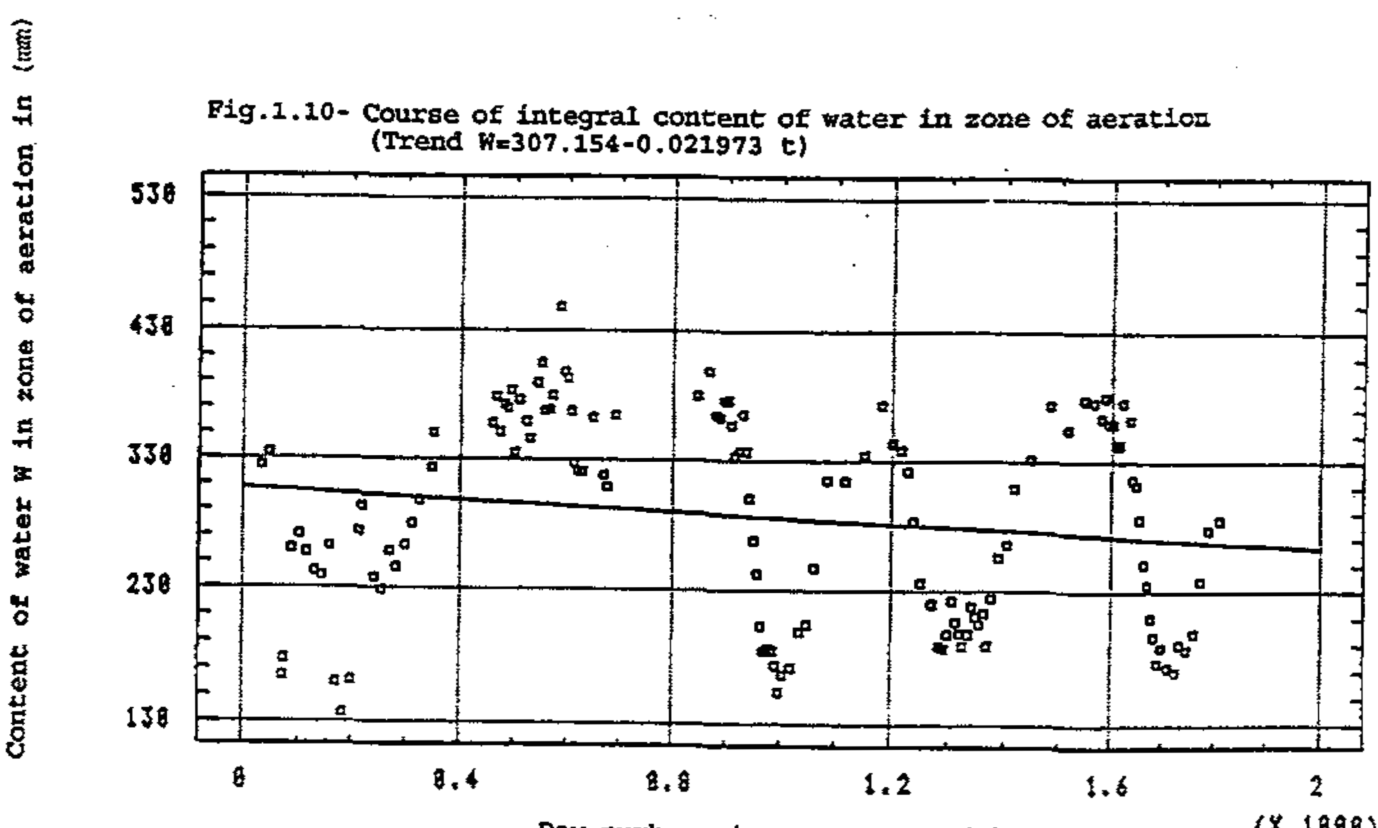
Locality: Dobrohošť - 1990/94

Fig.1.9 - Course of integral content of water in zone of aeration
(Trend W=523.655-0.043453 t)



Locality: Bodíky - 1990/94

Fig.1.10- Course of integral content of water in zone of aeration
(Trend W=307.154-0.021973 t)



Locality: Dekan - 1990/94

Mean water content in unsaturated zone during the first quarter of 1990-1994

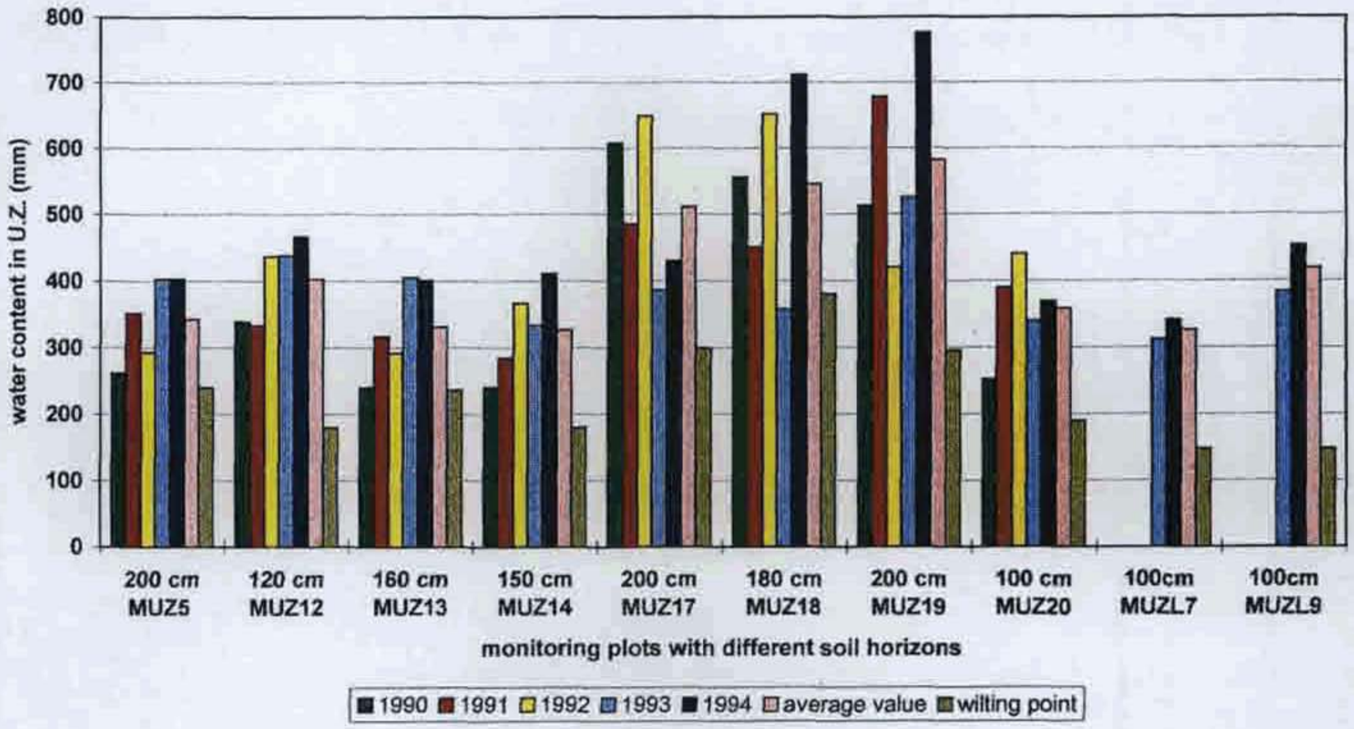


Fig. 1.11 Institute of Hydrology SAS

Mean water content in unsaturated zone during the second quarter of 1990-1994

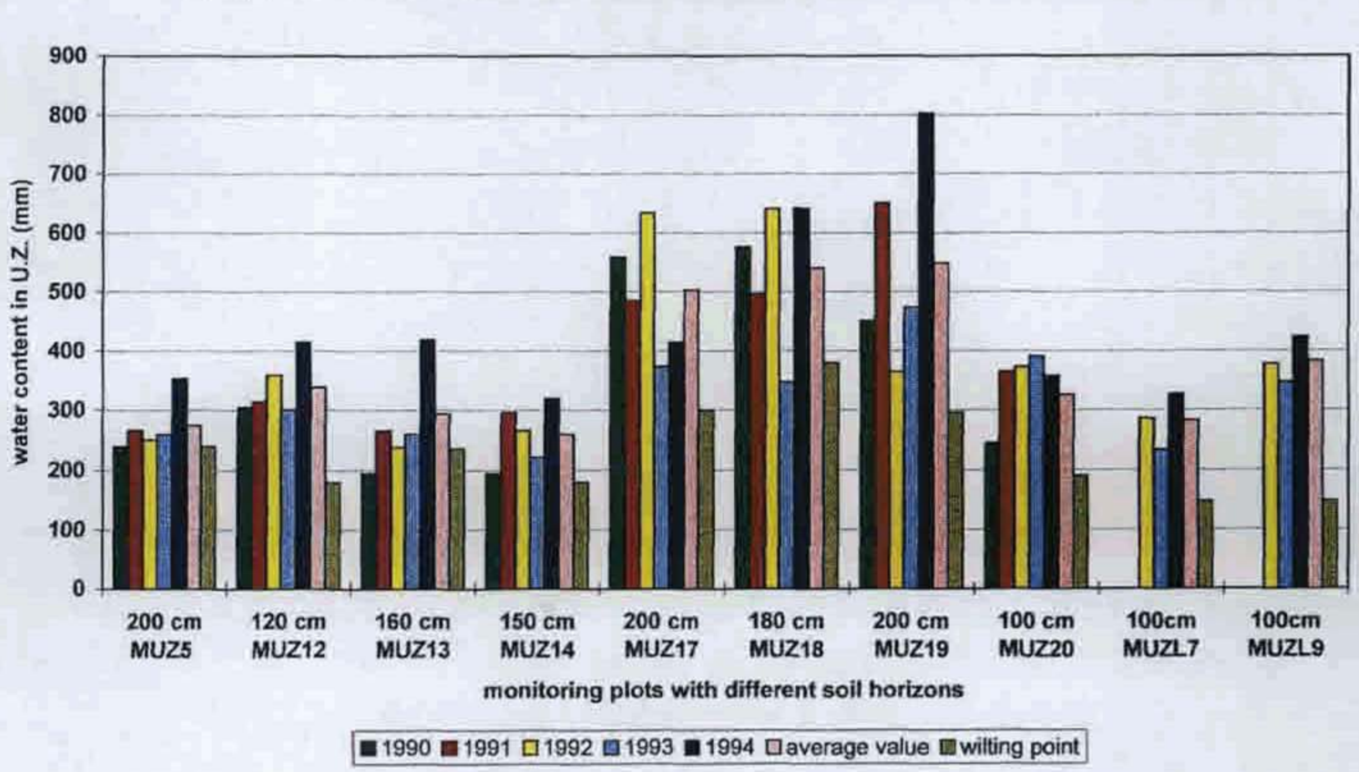


Fig. 1.12 Institute of Hydrology SAS

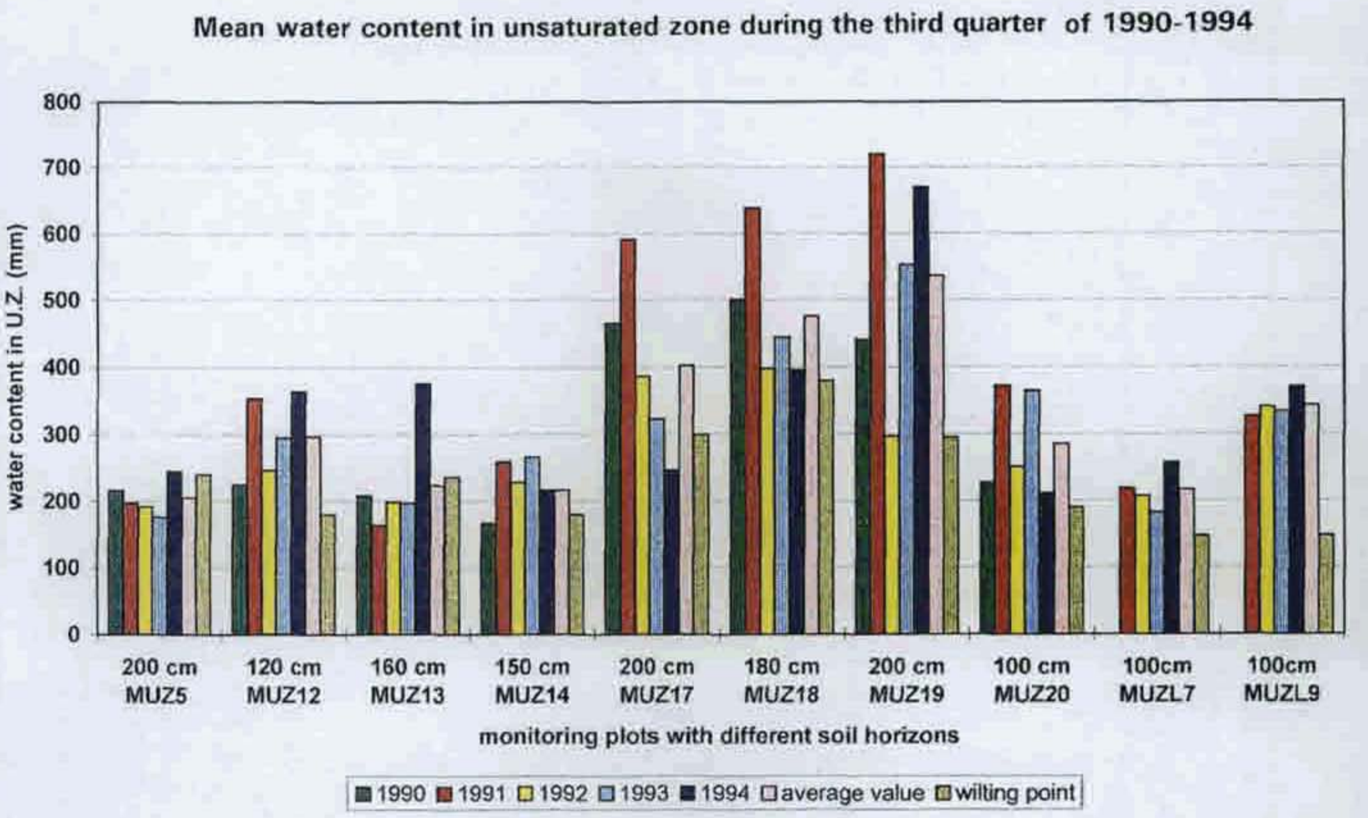


Fig. 1.13

Institute of Hydrology SAS

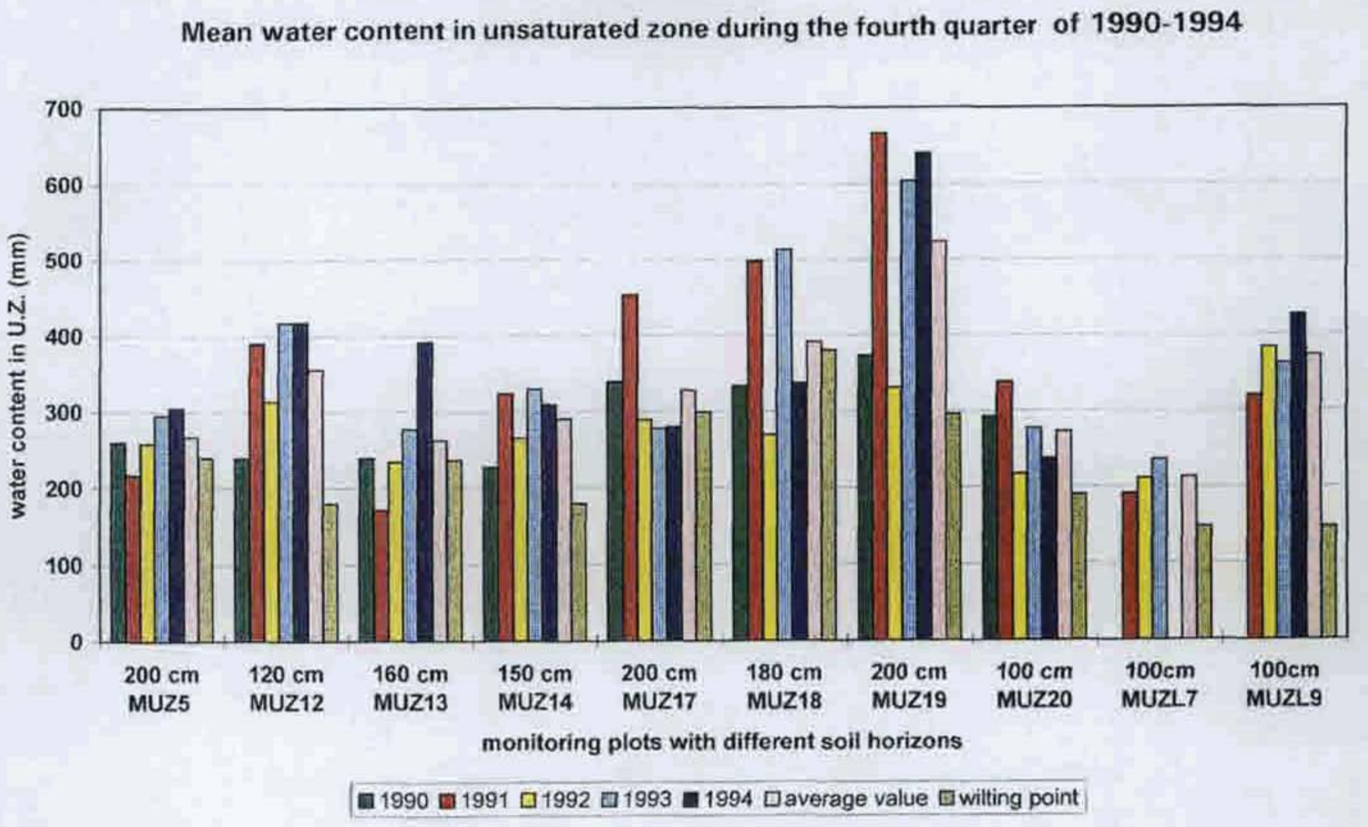
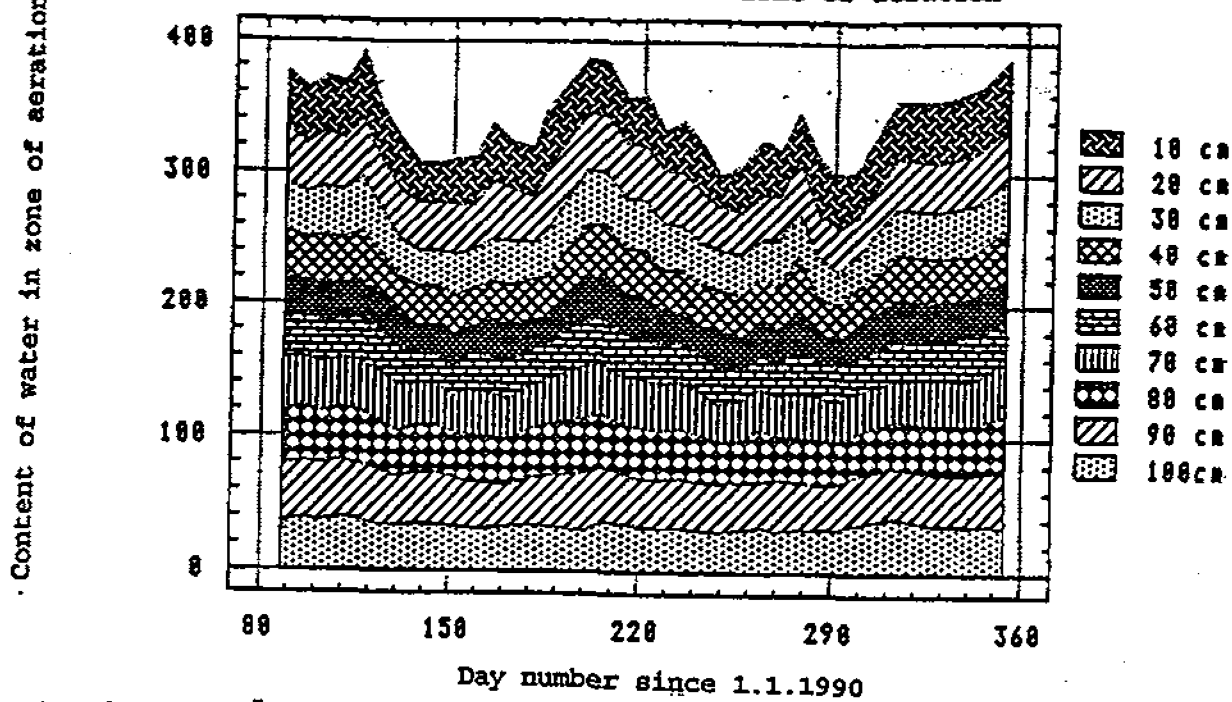


Fig. 1.14

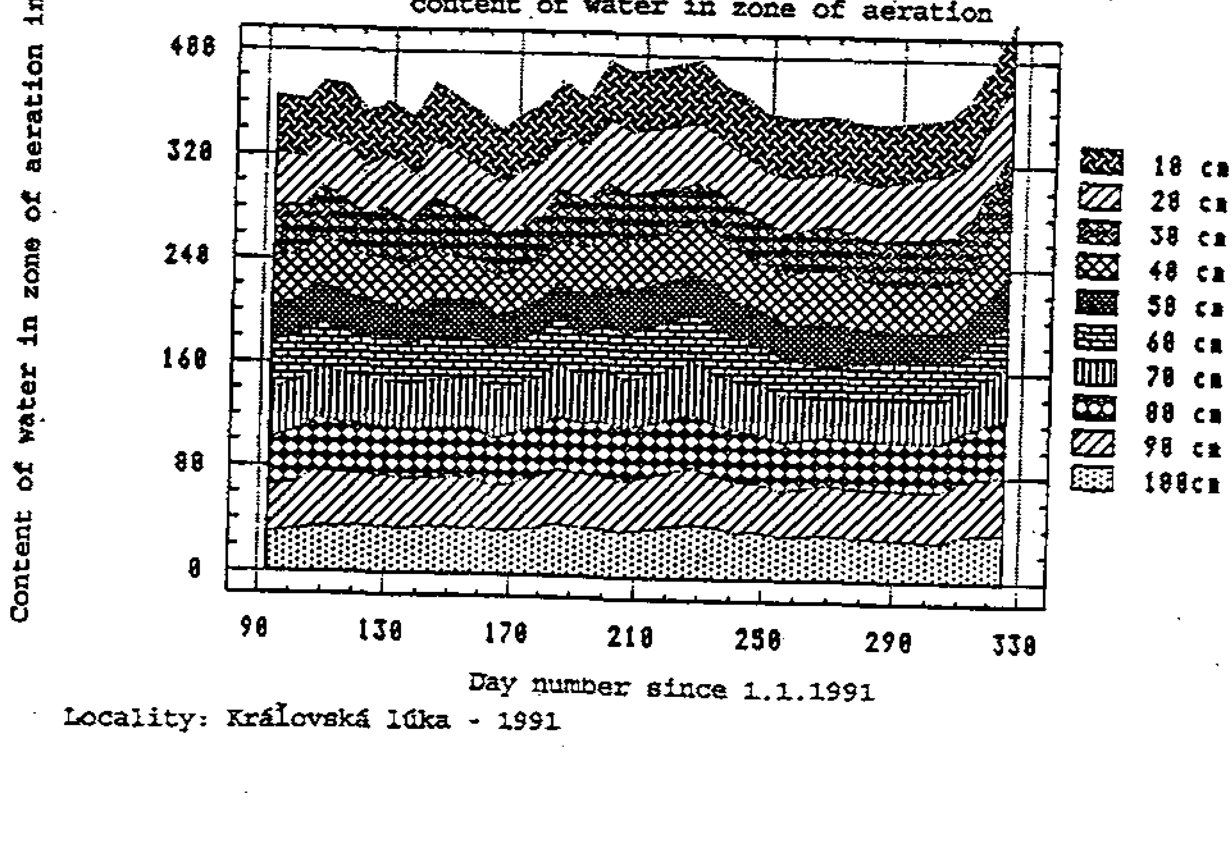
Institute of Hydrology SAS

Fig. 1.15 - Participation of soil horizons on cumulative content of water in zone of aeration



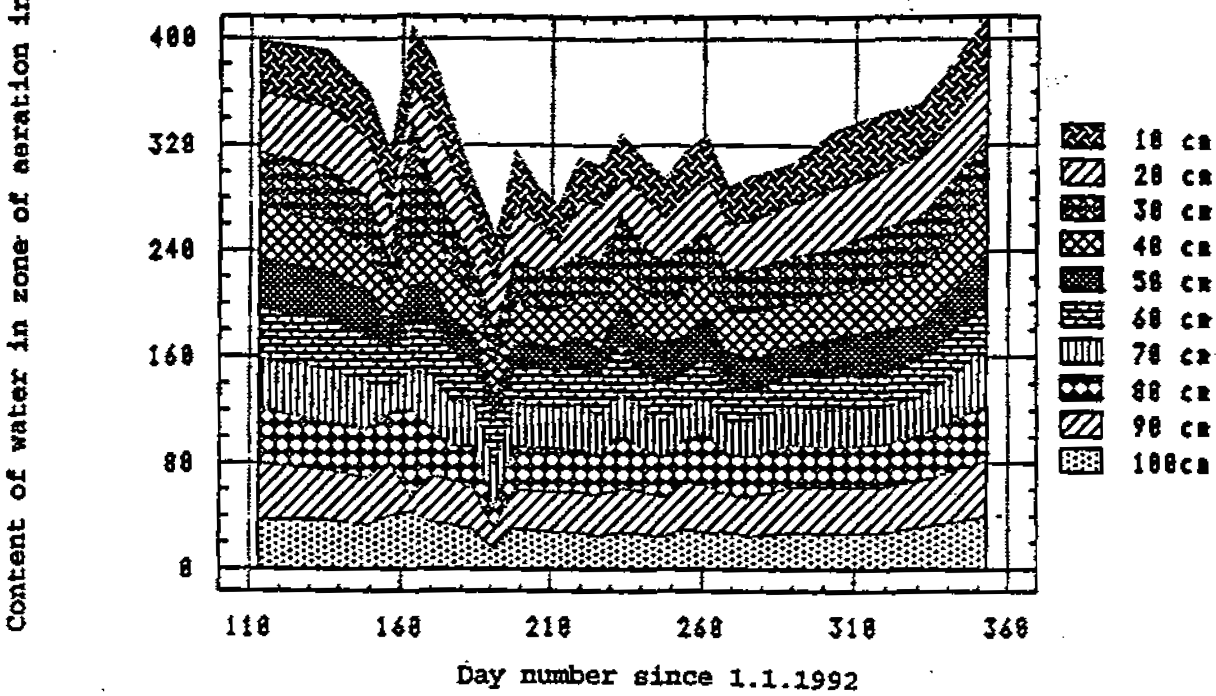
Locality: Královská lúka - 1990

Fig. 1.16 - Participation of soil horizons on cumulative content of water in zone of aeration



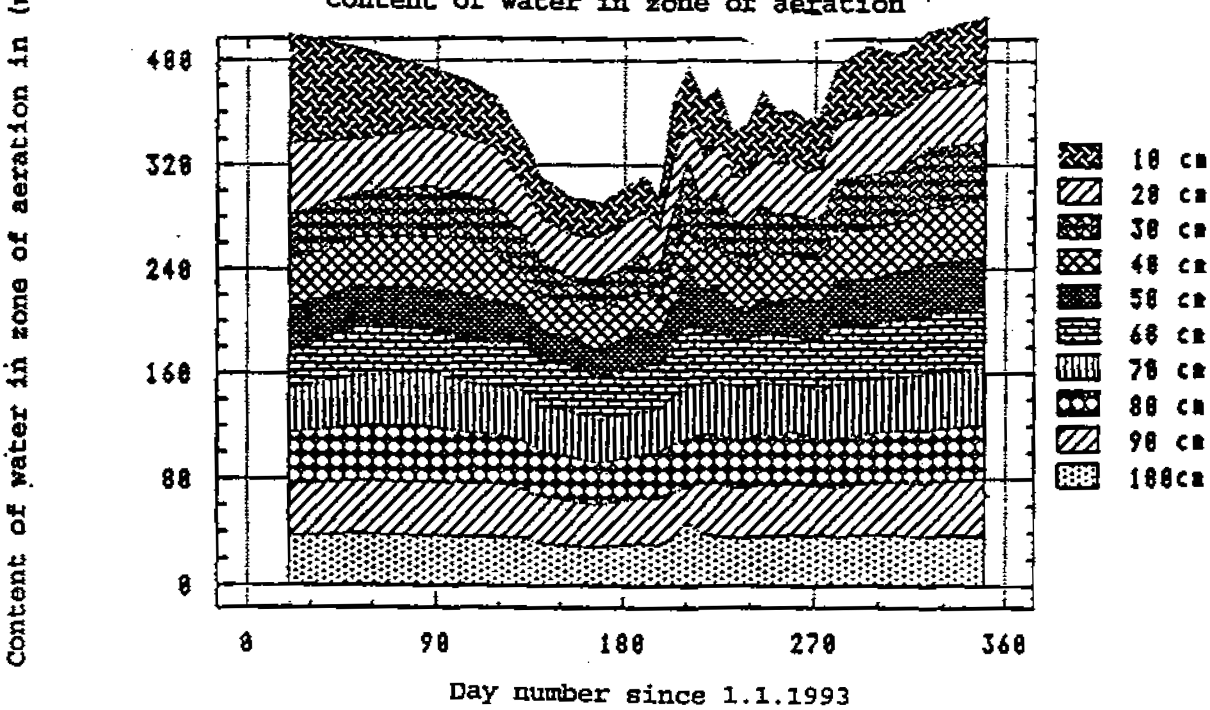
Locality: Královská lúka - 1991

Fig. 1.17 - Participation of soil horizons on cumulative content of water in zone of aeration



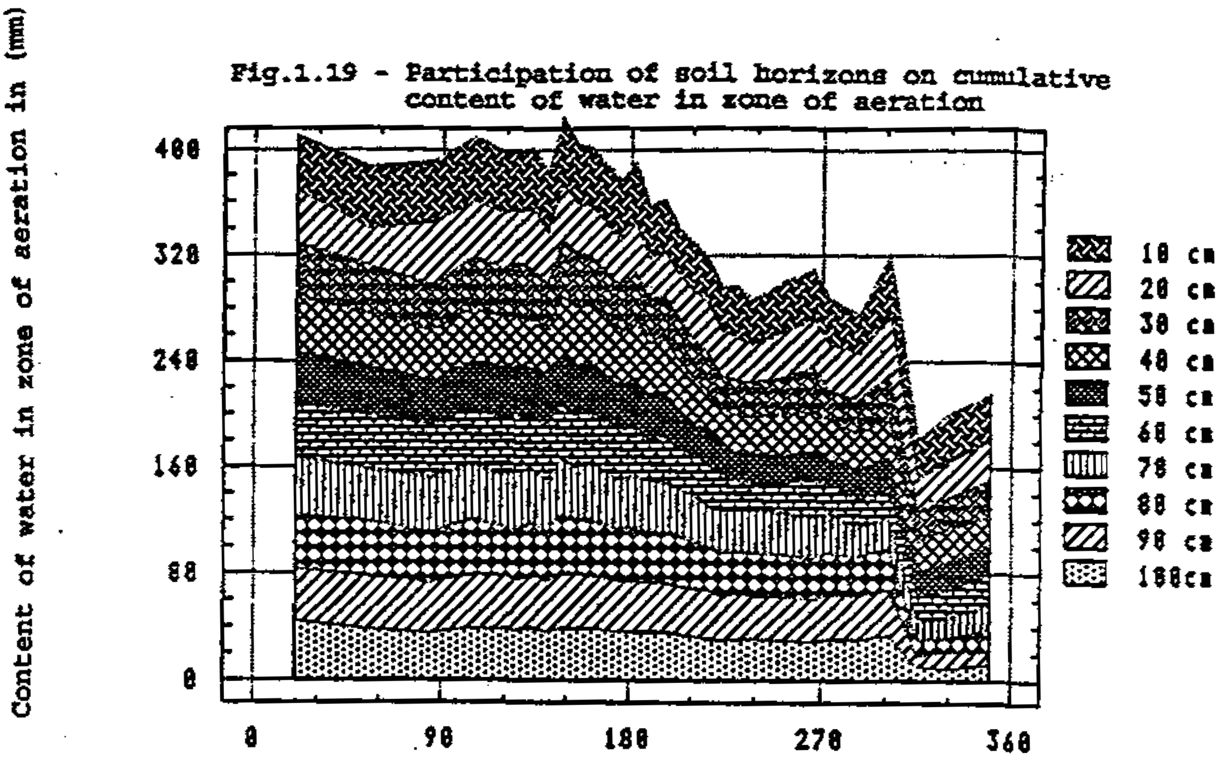
Locality: Kráľovská lúka - 1992

Fig. 1.18 - Participation of soil horizons on cumulative content of water in zone of aeration



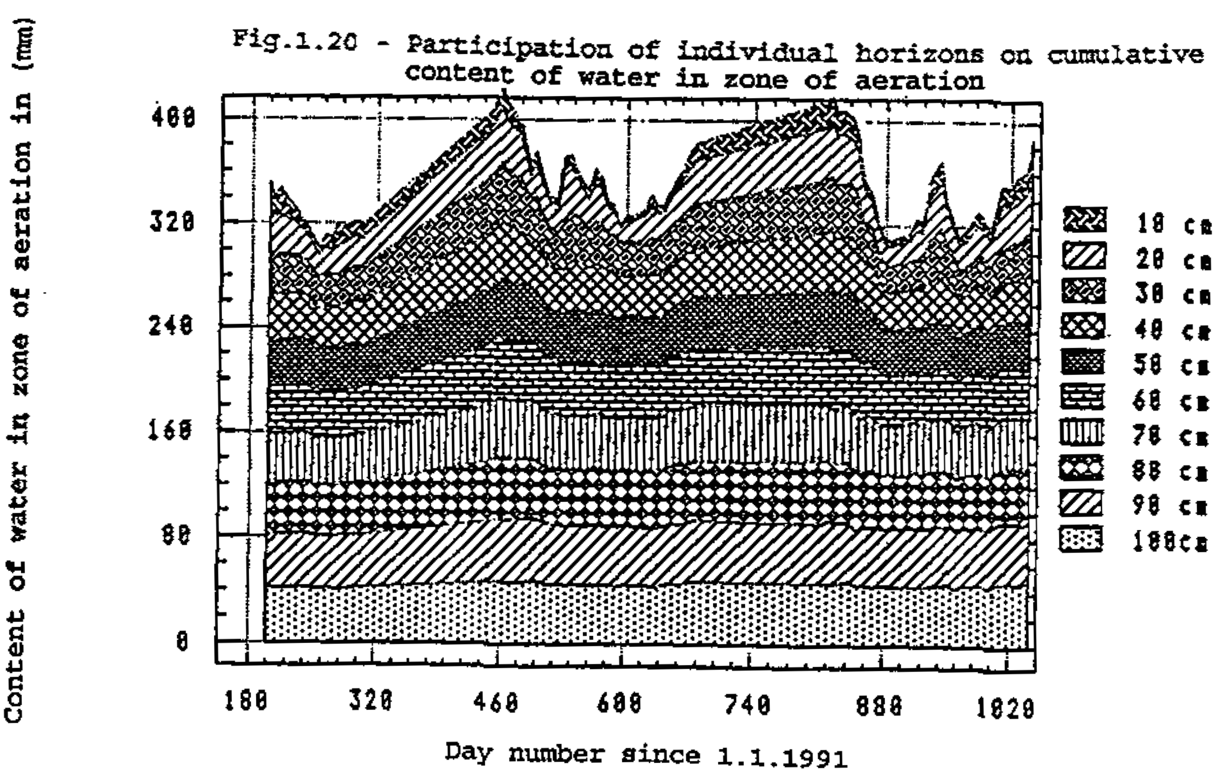
Locality: Kráľovská lúka - 1993

Fig.1.19 - Participation of soil horizons on cumulative content of water in zone of aeration



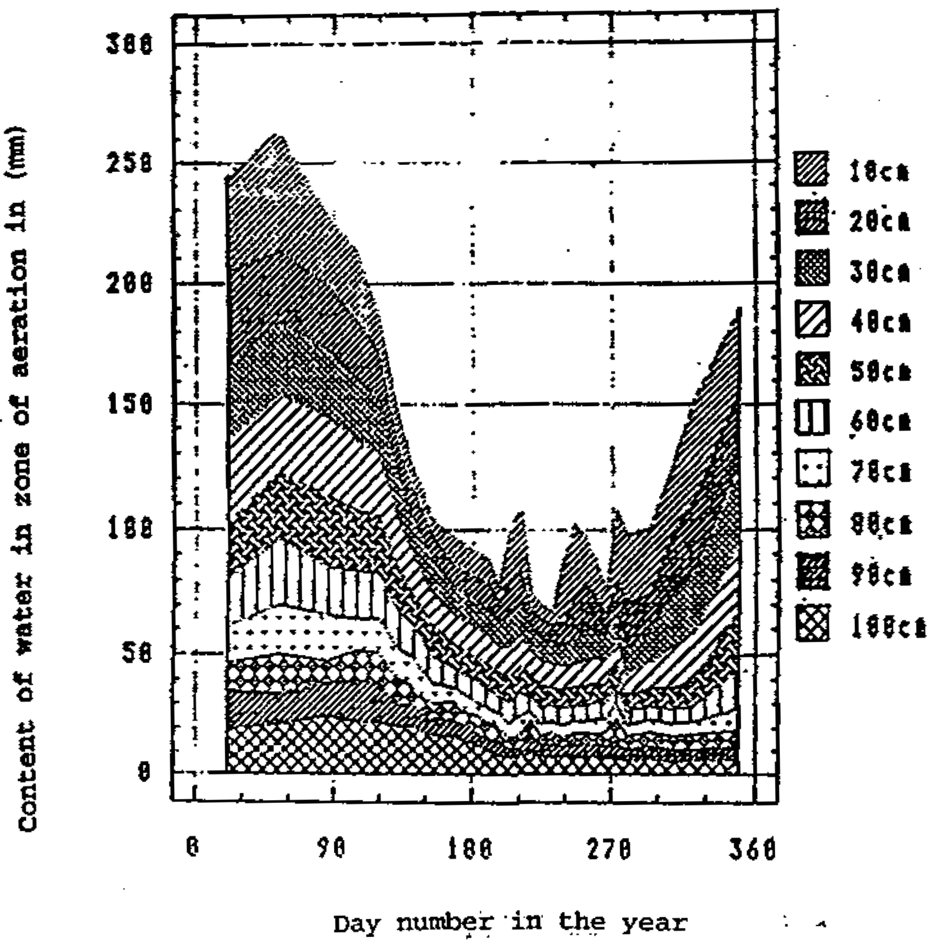
Locality: Králǒvská lúka - 1994

Fig.1.20 - Participation of individual horizons on cumulative content of water in zone of aeration



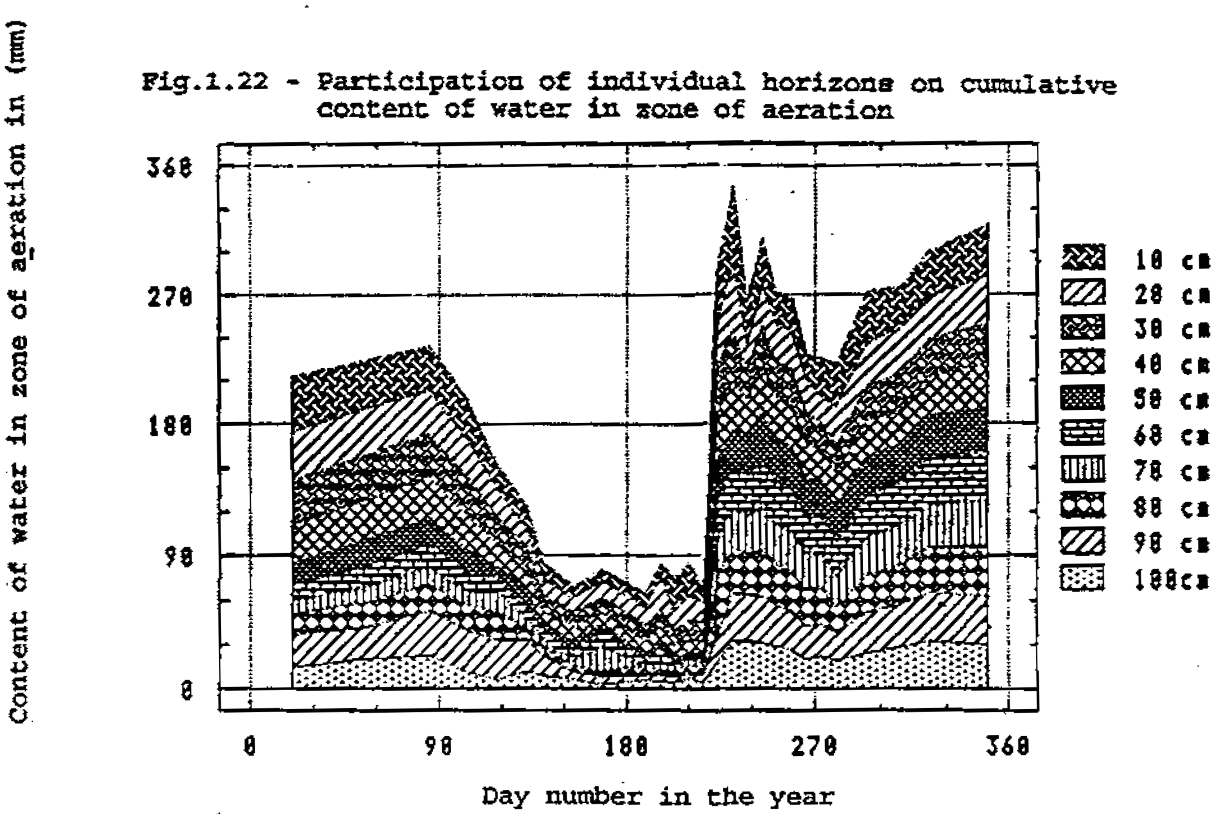
Locality: Lehnice (9) - 1991/93

Fig.1.21 - Participation of individual horizons on cumulative content of water in zone of aeration



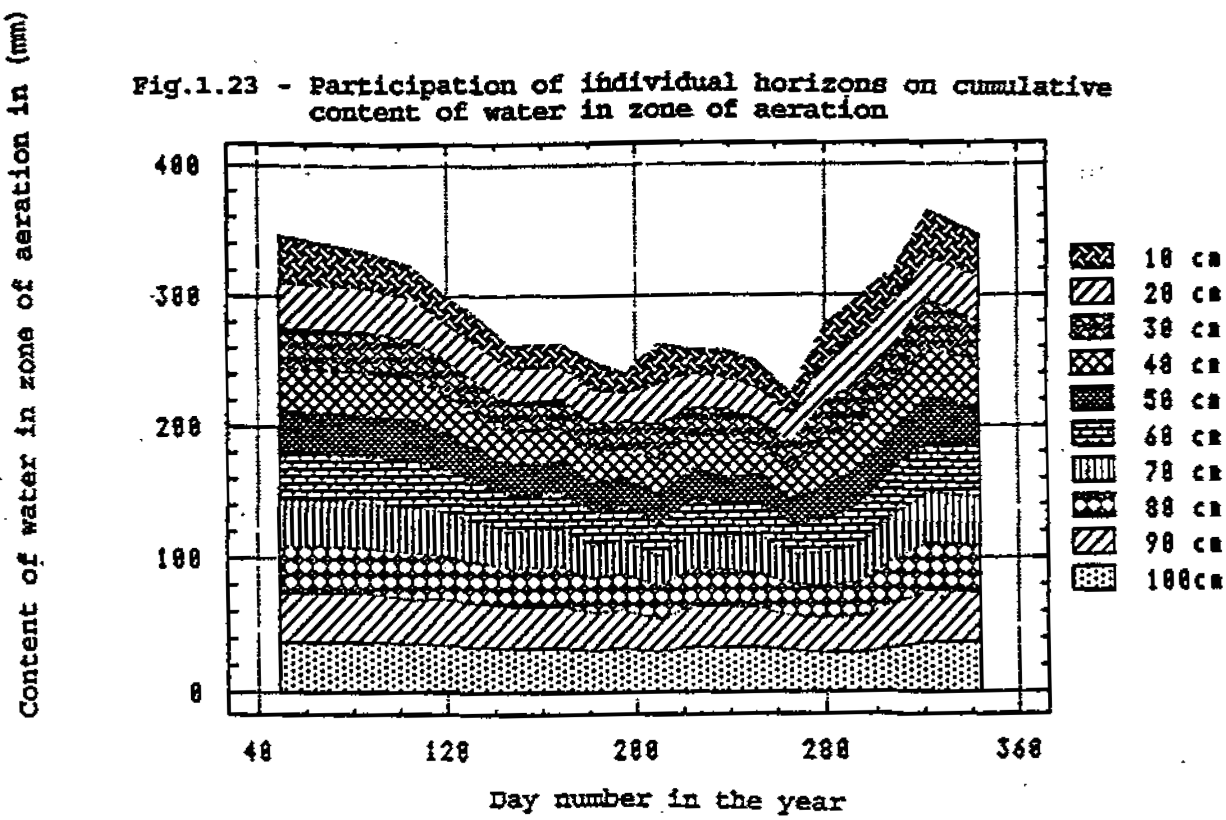
Locality: Hamuliakovo -1993

Fig.1.22 - Participation of individual horizons on cumulative content of water in zone of aeration



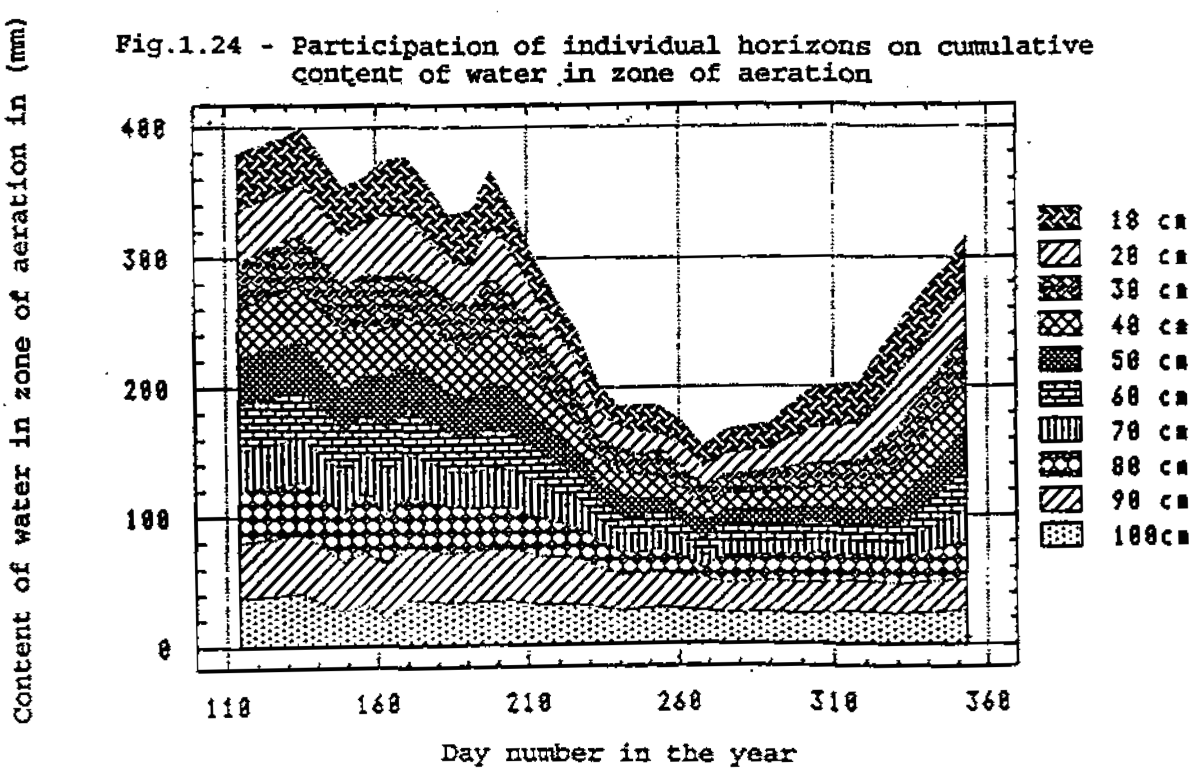
Locality: Čilistov -1993

Fig.1.23 - Participation of individual horizons on cumulative content of water in zone of aeration



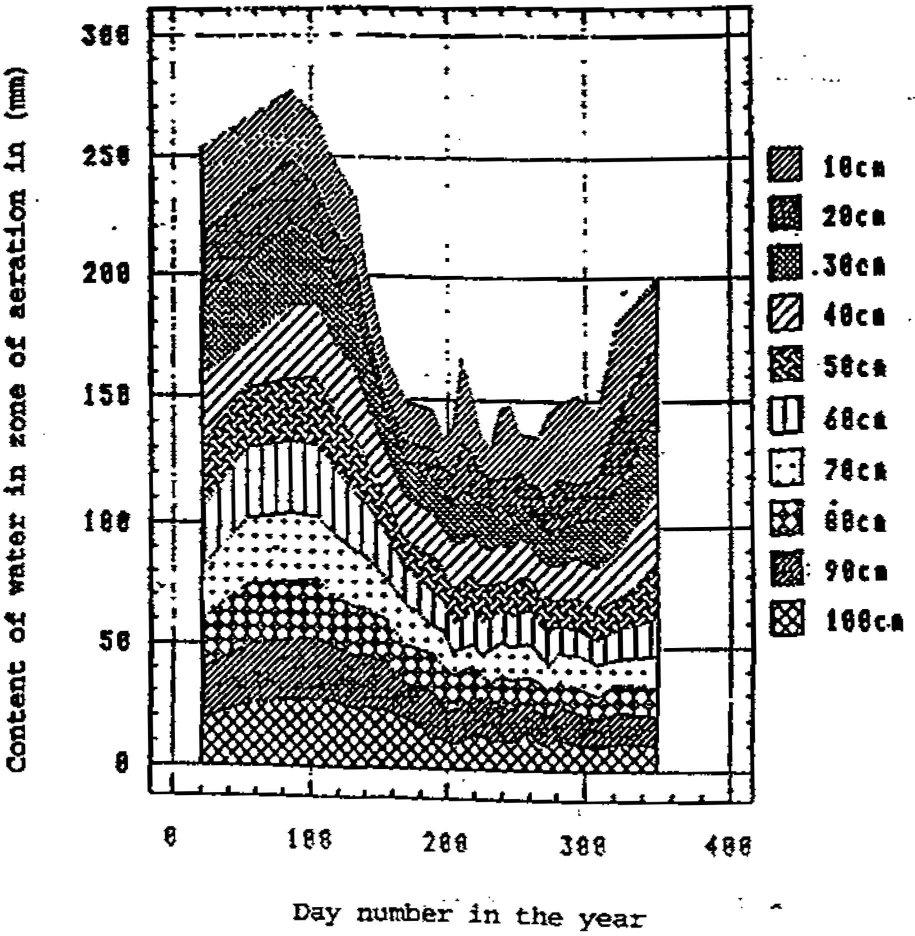
Locality: Bàka -1993

Fig.1.24 - Participation of individual horizons on cumulative content of water in zone of aeration



Locality: Dekan -1993

Fig.1.25 - Participation of individual horizons on cumulative content of water in zone of aeration



Locality: Dobrohošť -1993

2. Soil Monitoring

Soil monitoring constitutes the monitoring and evaluation of the selected set of soil properties and ground water characteristics in Žitný Ostrov. These might change both qualitatively and quantitatively due to ground water table increase or decrease and can also influence the soil fertility.

The soil monitoring relates to two phases. The first one, prior to 1992, characterises the so-called starting point (or zero level) soil properties and processes, i.e., the situation before the Gabčíkovo Project was put into operation. A large set of basic, physical and chemical soil properties is evaluated, including recent pedogenetic processes and ground water chemical composition related to soil chemistry.

The second phase, after 1992, characterises the situation after the putting of the Gabčíkovo Project in operation. It monitors the influences of the water construction, namely the change of ground water levels on soil properties.

The soil monitoring started in 1989. A network of 20 stationary monitoring sites is being operated for soil properties data collection. This includes pedologic, soil moisture and hydrogeologic gauges as well as rain gauges. This equipment is used for soil and ground water sampling for chemical analyses, soil moisture, ground water levels, precipitation, and irrigation measurements.

The selection and location of individual gauging sites was oriented on areas with important forecasted ground water level changes (Gažovič, 1988) and possible changes of salt concentration in ground water after construction of the Gabčíkovo project. Other factors accounted by the monitoring sites selection are as follows: morphogenetic-stratigraphic composition of the soil profile, texture, upper layer depth, gravel strata depth, ground water level, ground water mineralisation, etc.

2.1 The evaluation and interpretation of the obtained results

The extensive data obtained during the monitoring are summarised and evaluated in a report characterising the starting-point soil properties and agriculture development (Fulajtár et al., 1991) as well as in further report which evaluates the situation after the putting of the Project in operation (Fulajtár et al., 1995).

In this report we present the recent results of the soil monitoring concerning those soil characteristics which are decisive for the soil fertility in the given area and which are the most correlated with the possible water structure influence on the following soil properties development. It concerns mainly the soil moisture, humus content and quality, salting processes and ground water chemical composition.

2.1.1 Soil moisture

The soil moisture is being monitored as the most important soil parameter with respect to the Gabčíkovo Project's infuence upon the soils and agriculture. Long-term changes would consequently cause qualitative changes of the whole set of soil properties and processes, including soil fertility. Therefore, the soil moisture is being monitored very frequently, i.e., every 10 days (since 1994 every 15 days) in 10 cm layers up to 3 m depth or to ground water level. During the winter months (December-February) the soil moisture is monitored once per month. Simultaneously with soil moisture also the ground water levels and precipitation depths are measured.

From the point of view of the prognosticated and recent ground water levels the territory of Žitný Ostrov is divided into 3 regions:

- the region influenced by the reservoir (upper Žitný Ostrov);
- the region influenced by the bypass and tailrace canals (middle Žitný Ostrov);
- the region without significant influence of the Project structures (lower Žitný Ostrov).

a) The region influenced by the reservoir (upper Žitný Ostrov)

The soil moisture and ground water regimes of this region are monitored on the sites Mp 1-3. The ground water levels in this area, before the filling of the reservoir with water, were in the depth of about 5-7 m . After filling of the reservoir (October 1992) the ground water levels increased to 3-2 m and stayed on this level throughout 1993. In 1994, due to lower water level in the reservoir, the ground water levels decreased to 3-4 m below the surface of the terrain.

The soil moisture and its dynamics in the decisive, 1 m deep surficial soil layer did not change. The sandy-gravel layers situated here in the depth of 2 and more metres do not allow the capillary rise from the relatively deep ground water level into the root zone. Therefore the original soil moisture conditions were preserved here. The dynamics of the water content oscillate here between so-called semiuvidic and semiarid moisture intervals, i.e., between the hydrolimits of field capacity and wilting point (FC-WP). Within the topsoil layer (0-30 cm), the water content falls even slightly below the wilting point during the summer season.

The results of the soil monitoring allow us to conclude that the original soil moisture regime has beeen preserved in the region influenced by the reservoir. Neither the soil water mobility and its accessibility for plants, nor the prognosticated soil water logging in depressions have occurred.

From the point of view of the global conditions for agricultural production, the changed situation (the increase of the ground water levels to 2-3 m below the surface) should be considered as positive. It has resulted in a significant increase in the high quality ground water storage available for irrigation and the recently increased ground water level (3-2 m) is already accessible for deep-root plants. This new situation in the soil water regime overall in this region creates more favourable conditions for harvest stabilisation.

b) The region influenced by the bypass canal (middle Žitný Ostrov)

In the region adjacent to the bypass canal, the significant decrease of the ground water levels (3-4 m) was predicted in some studies for the period after the completion of the Gabčikovo Project. Due to the Project modifications (higher discharges in the old bed, water supply to the river branches and irrigation canals), the original ground water levels situation was in general preserved.

Soil water and ground water regimes in this region are being monitored on sites Mp 4-13. It follows from the figures in these appendices that the predicted decrease in ground water levels did not occur. Their original depth (1-3 m) remains, as does the original soil moisture regime. In both topsoil (0-30 cm) and subsoil (30-100 cm) horizons the soil moisture varies mostly within the optimum semiuvidic moistures interval, i.e. between the hydrolimits of field capacity and the point of decreased availability (FC-PDA). From the point of view of field plant demands, this moisture interval secures their fluent supply by abundance of accessible water with sufficient aeration. During the dry summer season the soil moisture decreases to semiarid interval, i.e., under the hydrolimit of the point of decreased availability.

The prediction of adverse impacts, i.e., the substantial drying of the soil, high mineralisation of the organic matter, humus content decrease, nitrate formation and their wash out due to the ground water level decrease was proved inaccurate.

c) The region without significant influence of the Project's structures (lower part of Žitný Ostrov)

On the territory of the lower part of Žitný Ostrov, where the interrupted underground diaphragm walls have been built along the Danube river (as part of protective measures related to the Nagymaros Project), the original regimes of both ground water levels and soil water were preserved.

Both soil moisture regime and ground water levels regime are monitored on sites Mp 16, 18, 20. In these sites the ground water levels are in the depth of about 2 m. The soil moisture of the topsoil is mostly semiarid and soil moisture of subsoil is in optimum semiuvidic interval, i.e., between the hydrolimits of field capacity and the point of decreased availability (FC-PDA).

2.1.2 Humus content and quality

Humus content and quality are important soil properties influencing soil fertility. They are monitored because the permanent change of the soil moisture regime would cause also the change in humus content and quality.

These changes were expected mainly in the area influenced by the headwater and tailrace sections of the bypass canal, due to important ground water levels and soil moisture decrease.

As the original ground water levels and soil moisture regime did not substantially change after the completion of the Project, the conditions for the prognosticated humus decrease did not occur and it is not realistic to expect them in the future.

Recent results of the humus monitoring in the area of the bypass canal are in Table 2.1. It follows from the table that both the content and quality of the humus have been preserved.

2.1.3 Soil salting processes

The soil salting processes have taken place on Žitný Ostrov for many years. They are known from Kyntera (1932), Červenka (1960), and Hraško (1969,1971). These processes do not have any relation to the Gabčíkovo Project. The results of the monitoring of these phenomena confirm that they are still taking place on the impact area today. They occur under the form of salinisation, i.e., increase of the content of free water soluble salts in the soil water, or alkalinisation, i.e., a sodium bonding to colloid complex.

The process of salinisation is very weak as confirmed by low electric conductivity (ECe) in range of 2-4 mS cm^{-1}.

The process of alkalinisation is more distinct. The content of the sodium bonded to soil colloid complex (ESP), in the range of 5-10%, indicates the low salting of the soil, but it occurs in most of the monitored soils both before and after Project completion.

The main reason for these phenomena are the mineralised ground waters. They transport soluble salts into the soil profile where they accumulate and bond to the soil complex. The concrete data on the salting of the monitored soils are summarised in Table 2.2.

2.1.4 Groundwater chemical composition

Within the monitoring of the ground water chemical composition as related to the soil chemistry, stress is given to soluble salts content, the so-called mineralisation, which is the main reason of the soil salting.

The results of the monitoring confirm that the Žitný Ostrov ground water is mostly medium mineralised, i.e., one litre of water contains 500-1000 mg of salts. From the course of the ground water mineralisation in individual sites, a slight increasing trend in mineralisation can be observed since 1991-1992. This trend continues even after the putting of the Project into operation. The increasing mineralisation of the ground water is understood as the consequence of extreme climatic influences of the last 5 years (very hot and dry summers, mild winters, high evapotranspiration) and also as a consequence of the gradual technogenic metamorphisation of the water with increasing constituents of anthropogenic origin.

2.2 Conclusions

The results of the ground water and soil monitoring of Žitný Ostrov confirmed that, after putting the Gabčíkovo Project into operation, no changes of the ground water levels which would cause the negative changes of the soil water regime did occur.

At all monitoring sites the original soil moisture regime was preserved. Due to this the original state of other soil properties and processes is being preserved, too, including their evolution trends. It is confirmed also by the results of the monitoring of soil salting and ground water mineralisation.

The overall conditions for agricultural production on Žitný Ostrov have been preserved and in the area of the reservoir's influence they are even slightly improved.

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Tab. 2.1 Humus content and quality

Sonde	Depth	Humus content			Humus quality		
	(m)	(%)			C_{HK}/C_{FK}		
		x*	x_1	x_2	x*	x_1	x_2
			1993	1994		1993	1994
Mp 4	0.10-0.20	1.78	2.16	1.31	1.11	1.51	1.08
	0.40-0.45	0.71	0.93	1.06			
	0.45-0.60	0.33	0.43	0.40			
	0.60-0.80	0.19	0.24	0.32			
	1.00-1.20	0.16	0.22	1.12			
Mp 5	0.10-0.20	2.74	2.40	2.27	1.68	1.66	0.82
	0.35-0.55	2.05	2.16	1.54	1.00	1.46	1.03
	0.65-0.75	0.69	1.34	0.68			
	0.75-0.90	0.40	0.62	0.43			
	1.00-1.20	0.50	0.77	0.58			
Mp 6	0.10-0.20	2.76	2.98	2.31	1.08	1.44	1.24
	0.30-0.40	1.98	2.98	1.94	1.09	1.59	1.13
	0.60-0.70	0.73	1.86	0.98			
	0.80-0.90	0.45	0.83	0.47			
	1.10-1.30	0.26		0.39			
Mp 7	0.10-0.20	3.83	2.98	3.51	1.74	1.44	1.47
	0.35-0.45	2.87	2.65	2.65	1.03	1.50	1.42
	0.65-0.75	1.41	1.91	1.27			
	0.85-0.95	1.00	1.62	0.86			
Mp 8	0.10-0.20	2.55	2.78	2.13	1.20	0.98	0.90
	0.40-0.50	1.81	2.38	1.61	1.06	1.46	0.88
Mp 9	0.10-0.20	3.69	4.56	3.51	1.11	1.42	1.12
	0.40-0.50	1.29	2.67	1.44	1.19	1.22	1.26
	0.65-0.75	0.60	1.53				
	0.90-1.00	0.38	1.33	0.41			

continuation of Table 2.1

Sonde	Depth	Humus content			Humus quality		
	(m)	(%)			C_{HK}/C_{FK}		
		x*	x_1	x_2	x*	x_1	x_2
			1993	1994		1993	1994
Mp 10	0.10-0.20	3.31	3.57	2.94	1.30	1.61	1.52
	0.30-0.40	2.54	2.38	2.40	1.29	1.36	1.35
	0.70-0.75	0.67	0.69	0.89			
	0.90-0.95	0.24	0.33	0.43			
Mp 11	0.10-0.20	3.21	3.65	2.81	1.55	2.06	1.23
	0.30-0.40	0.71	3.05	1.80			
	0.40-0.50	0.69	1.29				
	0.90-1.00	0.40	0.62	0.60			
Mp 12	0.10-0.20	3.79	4.03	3.52	1.14	1.63	1.75
	0.35-0.45	2.12	2.45	2.16	1.49	1.40	1.88
	0.55-0.65	0.88	1.02	0.96			
	0.90-1.00	0.48	0.38	0.53			
Mp 13	0.10-0.20	4.55	4.72	3.81	1.01	1.30	1.07
	0.40-0.50	3.38	3.52	1.99	1.01	1.30	0.97
	0.80-0.90	1.26	1.31	1.14	0.84	1.87	0.93
	1.10-1.20	1.16	1.03	0.78			
Mp 14	0.10-0.20	2.66	2.14	2.24	1.04	1.07	0.91
	0.60-0.70	0.40	0.19	0.51			
	1.10-1.20	0.26	0.17	0.39			

Notes :

x* - Starting point state - mean values for 1989-1992

x_1 - Actual values in 1993

x_2 - Actual values in 1994

Table 2.2 Soil salinity

Sonde	Depth (m)	ESP (%) x*	x1 1993	x2 1994
Mp 1	0.10-0.20	3.0	1.3	0.3
	0.25-0.35	2.5	1.5	3.7
	0.45-0.55	1.9	1.1	2.1
	0.75-0.85	2.3	4.4	2.1
	1.10-1.20	4.3	2.5	3.3
Mp 2	0.10-0.20	4.3	1.6	2.0
	0.30-0.40	2.2	3.8	2.3
	0.55-0.70	3.3	4.9	4.6
	0.85-1.00	5.4	5.2	5.4
Mp 3	0.10-0.20	4.7	4.3	2.6
	0.40-0.50	5.2	7.7	5.1
	0.60-0.70	4.5	6.2	4.8
	0.80-0.90	5.4	8.6	4.9
Mp 4	0.10-0.20	2.2	2.0	2.0
	0.40-0.45	4.6	3.2	3.0
	0.45-0.60	6.1	3.6	4.2
	0.60-0.80	6.3	3.1	5.7
	0.80-0.90	5.4	3.6	3.7
	1.00-1.20	4.6	3.4	2.9
Mp 5	0.10-0.20	3.0	4.2	1.0
	0.35-0.55	3.4	4.5	4.9
	0.65-0.70	4.4	3.5	4.4
	0.80-0.90	4.8	3.9	5.8
	1.00-1.20	3.1	3.1	7.7
Mp 6	0.10-0.20	1.4	4.1	1.9
	0.30-0.40	1.4	3.2	2.2
	0.60-0.70	2.2	4.0	3.5
	0.80-0.90	4.2	5.0	4.3
	1.10-1.30	4.4	-	4.6
Mp 7	0.10-0.20	2.0	1.9	2.0
	0.35-0.45	2.1	2.3	3.3
	0.65-0.75	2.6	1.9	3.0
	0.85-0.95	3.4	3.2	3.1
	1.10-1.20	4.9	-	4.2
Mp 8	0.10-0.20	2.2	2.1	1.7
	0.40-0.50	2.8	3.0	3.1
	0.90-1.00	3.3	5.2	-
Mp 9	0.10-0.20	2.4	3.3	1.2
	0.40-0.50	3.1	3.9	4.0
	0.65-0.75	3.9	3.8	5.0
	0.90-1.00	4.0	5.6	5.3
	1.20-1.30	4.5	-	-
Mp 10	0.10-0.20	1.5	0.8	1.2
	0.35-0.45	2.6	8.0	1.1
	0.70-0.75	3.4	5.0	2.0
	0.85-0.95	3.2	6.5	2.9
	1.10-1.20	2.3	-	4.1
Mp 11	0.10-0.20	4.3	8.9	1.3
	0.30-0.40	3.6	8.0	2.8
	0.40-0.50	3.8	6.6	3.0
	0.60-0.80	4.4	6.2	3.0
	0.90-1.00	5.2	7.6	3.5
	1.10-1.20	5.0	-	6.1
Mp 12	0.10-0.20	5.2	8.7	1.9
	0.35-0.45	4.0	8.3	3.4
	0.55-0.65	2.3	8.8	4.1
	0.90-1.00	2.8	7.2	4.0
Mp 13	0.10-0.20	2.1	2.4	1.3
	0.45-0.50	4.4	4.7	4.0
	0.80-0.90	5.6	5.2	4.8
	1.10-1.20	5.8	5.5	5.2
Mp 14	0.10-0.20	5.4	4.3	1.6

	0.60-0.70	8.5	8.4	7.5
	1.10-1.20	6.5	7.6	8.2
Mp 15	0.10-0.20	2.7	2.6	1.1
	0.30-0.35	2.5	2.9	1.3
	0.50-0.60	3.4	5.0	5.0
	1.10-1.20	5.4	6.0	4.1
Mp 16	0.10-0.20	3.4	3.1	1.7
	0.40-0.45	7.0	7.8	3.6
	0.50-0.65	8.2	8.8	7.2
	1.00-1.10	9.2	-	7.8
Mp 17	0.10-0.20	5.2	3.7	2.2
	0.30-0.40	3.7	2.5	2.1
	0.45-0.50	5.4	3.6	2.4
	0.60-0.70	6.7	6.2	5.2
	1.00-1.10	8.4	10.2	9.8
Mp 18	0.10-0.20	4.6	6.0	4.9
	0.40-0.50	-	3.3	5.6
	0.55-0.60	7.2	3.4	8.9
	0.70-0.80	6.0	3.5	9.8
	1.00-1.20	6.0	4.6	9.4
Mp 19	0.10-0.20	2.9	2.3	1.9
	0.35-0.45	3.0	2.3	1.7
	0.60-0.80	2.1	2.2	3.4
Mp 20	0.10-0.20	4.0	4.6	1.2
	0.30-0.40	4.0	3.6	2.5
	0.60-0.70	3.4	4.3	4.1
	1.10-1.20	5.0	-	3.5

Notes : x^* - Starting point state - mean values for 1989-1992

x_1 - Actual values in 1993

x_2 - Actual values in 1994

3. Forests

3.1. The situation before 1992 and in 1993-1994

The forests in the Danube inundation area had been strongly influenced by man in the years prior to the date when the Gabčíkovo hydropower plant was put into operation. Growing conditions had been determined by existence of the system of flood protection levees completed on both sides of the Danube in the last century. Originally, the floods used to cover larger territories, but the floodwater was shallow. At that time, excellent conditions existed for tree species of hardwood floodplain forests (such as Quercus robur L., Fraxinus excelsior L. and Ulmus sp.). After completion of the dyke system the floods became more frequent and intensive and the growing conditions for the hardwood tree species deteriorated to such an extent that hardwood tree species disappeared from this area. On the other hand, very good growing conditions were created for the fast-growing poplar clones (demanding good nutrient and moisture conditions).

The change of the tree species composition occured mainly after 1939. The silviculture became concentrated on monocultures of poplar clones with high wood production (the highest wood production in Slovakia) and short cutting cycle. The poplar clones monocultures now cover 80 % (in certain localities even more) of the stand area; their existence depends on the permanent intervention of the forester - no natural afforestation or regeneration is possible. From the ecological point of view, the shrub storey is the only stable component of these forest ecosystems; the shrub storey composition is usually natural and autochtonous species prevail.

The forest ecosystems of the original tree species composition (Populus alba L., P. nigra L., Salix sp. etc.) now occur rarely in the area. These tree species are also sensitive to growing condition changes (less sensitive is P. alba L.).

Monitoring parameters commented on in the following text are based on direct measurements of tree species on the permanent monitoring plants of the forest and biota partial monitoring systems. Monitoring was performed in the vegetation periods in 1990, 1991, 1992, 1993 and 1994 (Oszlányi; Pišút; Csölle et al.). The forest stands structure has been evaluated in September and October, the leaf area index in the time of its maximum (June, July) and the loss of leaves by August 15 (the date of the forest health monitoring accepted by all European countries).

According to the results of the tree species monitoring (both tree and shrub storeys), the area within the impact area of the Gabčíkovo hydropower Project (on the Slovak territory) can be divided into two parts:

1. Upper part, i.e., the territory influenced by the reservoir where the ground water level was raised. Before the putting of the Gabčíkovo hydropower Project into operation, the forest stands here depended only on precipitations. The ground water level was situated in the gravel layer and therefore not accessible for vegetation. After 1992, because of the return to the more natural state of the hydrological soil conditions in the area, the growing conditions for tree species became much better. Tree species have reacted to better conditions by revival, there have been obvious positive changes in the vitality of both tree and shrub storeys in comparison with the situation in the years before the filling of the reservoir. The prognosis is optimistic (see, permanent monitoring plots MB02b, MB03, L19).

2. Lower part, i. e., the territory between the old riverbed and the bypass canal. The ground water level here is in contact with the root production space of forest stands even now, during the operation of the Gabčíkovo hydropower plant. On the greatest part of this territory no obvious changes on tree and shrub layers could be observed after the putting of the hydropower plant into operation. The greatest part of permanent monitoring plots and of the forest stands in general is stable from the production - ecological point of view; no significant changes have occured in a single one of the monitored parameters. (Permanent monitoring plots MB10, L06, MB14, MB15).

In the so-called dry triangle (territory between the old riverbed, the headwater canal and the left side branch system supplied with water from the by-pass canal by means of the intake structure near Dobrohošť), on the 50-100 m wide belt along the old riverbed but seldom elsewhere, there have been indications which point as a possible result to the partial destruction of the forest (based on results of 1993, 1994 at permanent monitoring plots L11, L12, MB06, MB09).

3.2 Monitored production - ecological parameters and their evaluation

3.2.1 Structure of tree and shrub layer

On the absolute majority of permanent monitoring plots no significant changes in tree and shrub storey structure could be observed in the years 1993 and 1994. Species composition, biosociological, thickness and height structure have changed only very slightly in harmony with the growth laws of the respective forest ecosystem. In the tree stock, dying off of a tree with less good or bad biosociological position could be observed only very rarely; this phenomenon is fully in harmony with the natural selection of tree inventory (Oszlányi, 1993, 1994; Csölle et al. 1993, 1994; Rovný, B. et al., 1993; Matečný, I. (ed.), 1993).

On the permanent monitoring plot L19 (upper part), there was a more intensive pressure mainly in the canopy space, but also in the total production space of tree and shrub storeys as a result of the ecosystem revival. These changes have a positive character. Only in the case of the permanent monitoring plot MB06 (in the dry triangle) was there a negative quantifiable shift in the ecosystem structure. This indicates the tendency to partial destruction of tree and shrub storeys as a result of the worse hydrological conditions (sinking of ground water level). In 1994, in comparison with the state in 1992, changes in biosociological, height and thickness structure of tree stock were observed as a result of the extinction of some Populus alba L. trees with the worst position in the ecosystem. The partial drying-up of the crowns, to changes in their architecture and in the canopy closure have occured. In the shrub storey the stock reduction of the dominant tree species Swida sanguinea (L.) Opiz and Wiburnum opulus L. has occured. This reduction affected the lowest individuals with the worst biosociological position in the shrub storey.

3.2.2 Leaf area index (LAI)

Leaf area index (surface area of leaves in hectare per 1 hectare stand area) is a very good and significant indicator of forest stand production capacity, its vitality and its state of health. The leaf area index of the absolute majority of the permanent monitoring plots is acceptable (4.12-5.75 $ha.ha^{-1}$ in one-layer willow ecosystems and 5.96 -7.73 $ha.ha^{-1}$ in one- and two-layer poplar and oak monocultures and in forest stands of autochtonous poplars as main standsforming tree species). These values of leaf area indices document the apropriate health state of the forests and the high production capacity and vitality of the monitored forest ecosystems (Tab. 3.1).

Tab. 3.1 *Leaf area indices of tree species (both tree and shrub layers) at some permanent monitoring plots (leaf surface area in ha per 1 ha of forest stand area), (1993, 1994 - vegetation period after filling the dam)*

	Lower part	Year	LAI ($ha.ha^{-1}$)
X (close to MB10)	Mature poplar monoculture with shrub undergrowth	1988	7.53
L06	Close-to-mature poplar monoculture	1991	6.96
		1994	6.07
MB10	Mature willow stand with poplars	1991	4.12
MB14	Mature willow stand	1991	4.95
L01	Close-to-mature oak monoculture with shrub layer	1992	7.73
MB06	Close-to-mature domestic poplar stand with shrub layer IN THE DRY TRIANGEL	1992	6.2
		1994	4.74
MB09	Young willow monoculture (pole stage stand) ON THE RIVERBANK	1992	4.79
		1994	4.12
MB15	Mature willowstand	1993	5.66
L03	Mature willowstand	1993	5.08
		1994	5.22
L12	Mature poplar monoculture with shrub layer IN THE DRY TRIANGEL	1994	2.72
	Upper part		
L19	Young oak monoculture (pole stage stand)	1991	1.71
		1993	3.02
		1994	3.18
MB02b	Multi - storeyed stand (Populus alba, Fraxinus excelsior, Negundo aceroides)	1993	4.91
MB03	Close-to-mature willow stand	1993	4.94
		1994	4.90

The greatest part of the area is represented by the permanent monitoring plots, where no significant changes in the leaf area index have occured (re-measurements taken after the hydropower plant was put into operation). This is the case for permanent monitoring plots L06, L03. Approximately the same values of leaf area indices equal to those evaluated before the putting of the Project into operation can be predicted on the greatest part of other localities in the lower part of the territory (MB10, MB14, MB15) after the the hydropower plant has been put into operation

On the other hand, the leaf area index has grown very significantly at the permanent monitoring plot L19 (upper part within the impact area of the reservoir - here the underground water level is now higher than before the filling up of the reservoir). Here the leaf area index in 1994 is 185 % of leaf area index registered in 1991. High values of the leaf area indices in the upper part of the territory are represented by the permanent monitoring plots MB02b and MB03 (1993, 1994). The prognosis here is optimal.

3.2.3 Loss of leaves

As a result of bad or worse growing conditions (and of other facts) the loss of leaves is observed in Europe by August 15, each year. The loss of leaves is evaluated in % ranging between 0 % loss of leaves (a perfectly leaved and absolutely healthy tree) and 100 % loss of leaves (a completely dry, dead tree).

The following results in the Project impact area are based on uninterrupted observations in 1991, 1992, 1993 and 1994:

On permanent monitoring plots which represent the majority of the territory (MB10, MB14, MB15, MB18, MB23 - Fig. 3. 1, Pišút 1994, 1994 and L02, L05, L06, L03 - Fig. 3.2, CSölle et al., 1993, 1994, the loss of leaves is relatively small and the differences between the respective years are not significant. The loss of leaves here is 10 - 15 % and only very seldom is higher than 20 % (L11, L12). This parameter documents also the stable, unchanged healthy state of trees on the majority of the permanent monitoring plots, as well as the stable state of trees, physiological activities.

Despite the small number of observations (4 vegetation periods), the positive trend in loss of leaves can be documented on permanent monitoring plots MB02b and MB03 in the years 1993 and 1994. This is without any doubt the result of the better growing conditions in the area caused by the increase of the ground water level in the locality (Pišút, 1994).

Decrease of the loss of leaves, which is, however, still relatively high, can be observed on other permanent monitoring plots in the upper part (where there has been the raising up of the ground water level); especially on MB04 and MB05. Here the values in 1993 and 1994 document the significant improvement of the health state of trees (Fig. 3.3).

Positive changes, i. e., obvious tendency towards the decrease of leaf loss have been registered on the following permanent monitoring plots in the upper part: L14, L15, L16, L18, L19, L20, L21, L23, Fig. 3.4. An exception are lots L24 and L13, where the loss of leaves is still getting higher. Tendency towards the leaves loss increase has been recorded also on MB09 (willow) which lies directly in the neighbourhood of the old riverbank.

3.2.4 Biomass production

Changes in the biomass production today, two years after the putting into operation of the Gabčíkovo Project, can not yet be exactly assessed and evaluated. Height thickness and volume increment, resp. biomass increment can be recorded with sufficient accuracy only after longer period of measurements (at least 4 - 5 years).

3.2.5 Transpiration of water through the forest ecosystems

Direct measurement of transpiration by floodplain forest was needed for monitoring of the water requirements of vegetation cover under natural and later also the human hydrological regimes of the inundation area. The importance of direct and continuous measurements of transpiration depends upon the immediate assessment of water consumption by vegetation and on the evaluation of disposable soil water resources.

Testing of the equipment started during the second half of the vegetation season in 1990 on two representative plots in Gabčíkovo (L01) and Královská lúka (L06). Measurements of the selected trees (oak-Quercus robur L. in Gabčíkovo and poplar-Populus in Královská lúka) continued till August 1991, when a flood damaged most of the equipment installed. The results obtained so far are contained in the report (Molnár et al., 1991).

The monitoring of the transpiration continued during the vegetation season in 1992 on the same sites and selected trees. Results have been published in the report (Molnár, Mészároš, 1992). In 1993, after the reservoir was filled and the hydropower plant was put into operation, the monitoring of the transpiration continued in Královská lúka (L06) and was furthermore located next to the reservoir in Podunajské Biskupice (L19). The location of the station in Gabčíkovo (L01), just below the hydraulic structure, did not reflect impacts of the hydropower plant operation, as was already indicated by measurements during the dry season in 1992 (see Figures 3.5 and 3.6). Results obtained in 1993 were published in the report (Molnár, Mészároš, 1993).

3.3 Method of measurements and equipment

The continuous measurement of transpiration within the stem of the selected tree is based on the heat balance method by Čermák, Deml and Penka (1973). This non-destructive method depends on accurate measurements of the heat conductivity in the active xylem of a plant. For constant heating 5 electrodes are used. The electrodes are placed into the measured segment of a stem, so that the whole cambial profile is heated. Temperature of the hydroactive xylem is measured by 8 thermometers arranged in two rows just below and over the electrodes. Recorded difference in temperature (up to 3 degrees of Celsius) or so called cooling effect is related to the speed of flow in the hydroactive xylem, which allows to account the amount of water consumpted for transpiration.

The described method of transpiration measurement has been tested, calibrated and used on different tree species and under different hydrological and/or morphological conditions. The flatland features of the Danubian floodplain forest are favourable for the use of this method. The special comparative calibration is required only by the poplar tree.

3.4 Interpretation of monitored data

Transpiration through the forest is the end product of the interrelation of different phenomena. The dominant diurnal course of transpiration with daily maxima between 12.00 and 15.00 hrs., is mainly determined by physiological processes of vegetation and considerably reduced by occasional rainfall. The transpiration intensity within a day also depends on solar radiation, air temperature, humidity and wind speed. All these meteorological characteristics have not been measured on all the sites selected for monitoring of transpiration, and therefore, one of the most related and easy measurable, the air temperature over the canopy was recorded. The close relationship between the diurnal course of transpiration and air temperature over the canopy proved by Molnár and Mészároš (1990) is also documented on data from Podunajské Biskupice (L19), see Fig. 3.9.

In the case of floodplain forest, the most significant influence on transpiration are changes of disposable soil water resources. Results obtained since 1991 show that the basic seasonal course of transpiration is determined by the vegetation cycle of deciduous forest, but substantially depends on the limiting soil water resources. Fig. 3.6 documents the impact of insufficient soil moisture on measured transpiration by the poplar tree in Kráľovská lúka (L06) at the end of August 1992, when the gradual decline of the ground water levels caused the sudden interruption of water supply into the root system of the subject tree. This phenomenon did not occur in the same period in 1993, after the Gabčíkovo hydropower plant and water distribution system were put into operation. The results of monitoring on two permanent representative plots in Královská lúka (L06) and Podunajské Biskupice (L19) are shown on Figs. 3.7 and 3.8. Both graphs illustrate the natural seasonal course of transpiration in 1993, after the operation of the Gabčíkovo water distribution system. The diurnal course of transpiration, naturally remained dependent on the meteorological conditions and rainfall in every particular day of the season.

Finally, the monitored data allows us to conclude that the proper knowledge of the diurnal and seasonal courses of transpiration by selected representative trees gives us a unique opportunity to define the actual state of the studied forest ecosystem. The presented quantified informations have the authentic value for optimalisation of the Gabčíkovo water management regime immediately, and not only after some damage on floodplain forests is visible.

The significant ecological and also water resources management parameters are reflected as the daily sums of transpiration of the selected tree species. As stated, the daily sums of transpiration vary due to the characteristics of studied trees, as well as due to meteorological characteristics, rainfall and disposable soil water resources. Table 3.2 shows the daily transpiration of the selected trees, including the measured variability of daily transpiration for a given period of time.

Table 3.2

Station	Species	Characteristics girth(cm)/height(m)	Daily transpiration ($l.day^{-1}$)			Obs. period
			Min.	Max.	Mean	
L 01	Oak	77.5 / 10.5	2.3	34.4	13.8	V-IX 1992
L 06	Poplar	98.0 / 31.5	290.3	1 029.8	699.1	VII-VIII 1992
L 06	Poplar	98.0 / 31.5	95.1	417.0	232.3	IX.1992
L 06	Ash	128.0 / 35.0	72.3	736.6	318.2	VII-X 1993
L 19	Oak	70.0 / 9.0	0.9	21.6	7.5	VIII-X 1993

The values presented in figures and/or the table confirm rather stable moisture conditions on permanent monitoring plot in Gabčíkovo (L01) and improved conditions in the middle of inundation area in Královská lúka (L06) due to the water supply into the river branch system. The selected oak in Podunajské Biskupice (L19) which is close to the reservoir, despite rising ground water levels in 1993 (1.95 - 2.10 m from the ground surface), has not indicated a considerable improvement of its vitality so far. Further improvement of the situation in the area of Podunajské Biskupice is expected. Additional data from 1994 are being processed.

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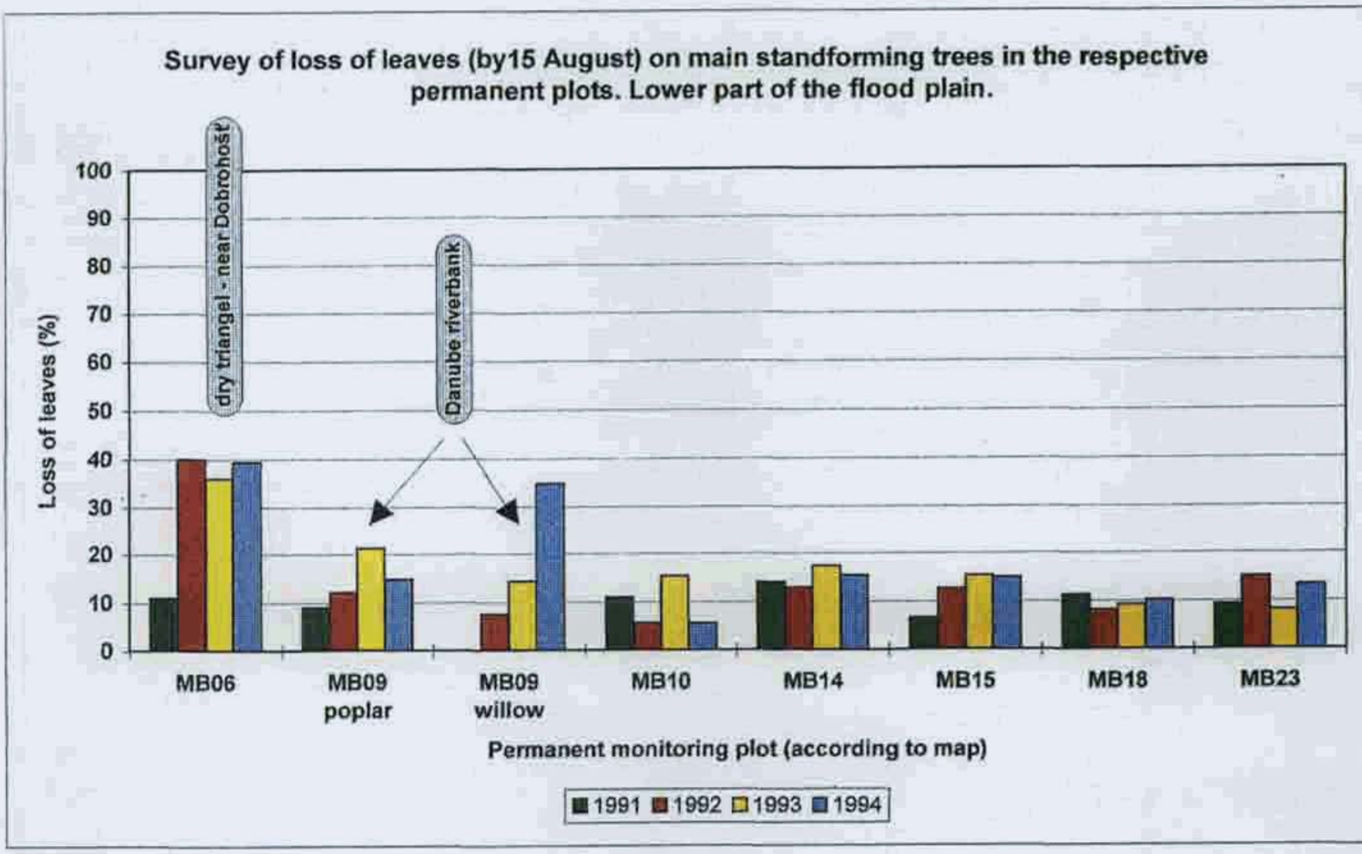
Survey of loss of leaves (by15 August) on main standforming trees in the respective permanent plots. Lower part of the flood plain.
Loss of leaves (%)
dry triangel - near Dobrohošť
Danube riverbank
MB06
MB09 poplar
MB09 willow
MB10
MB14
MB15
MB18
MB23
Permanent monitoring plot (according to map)
1991 1992 1993 1994

Fig. 3.1

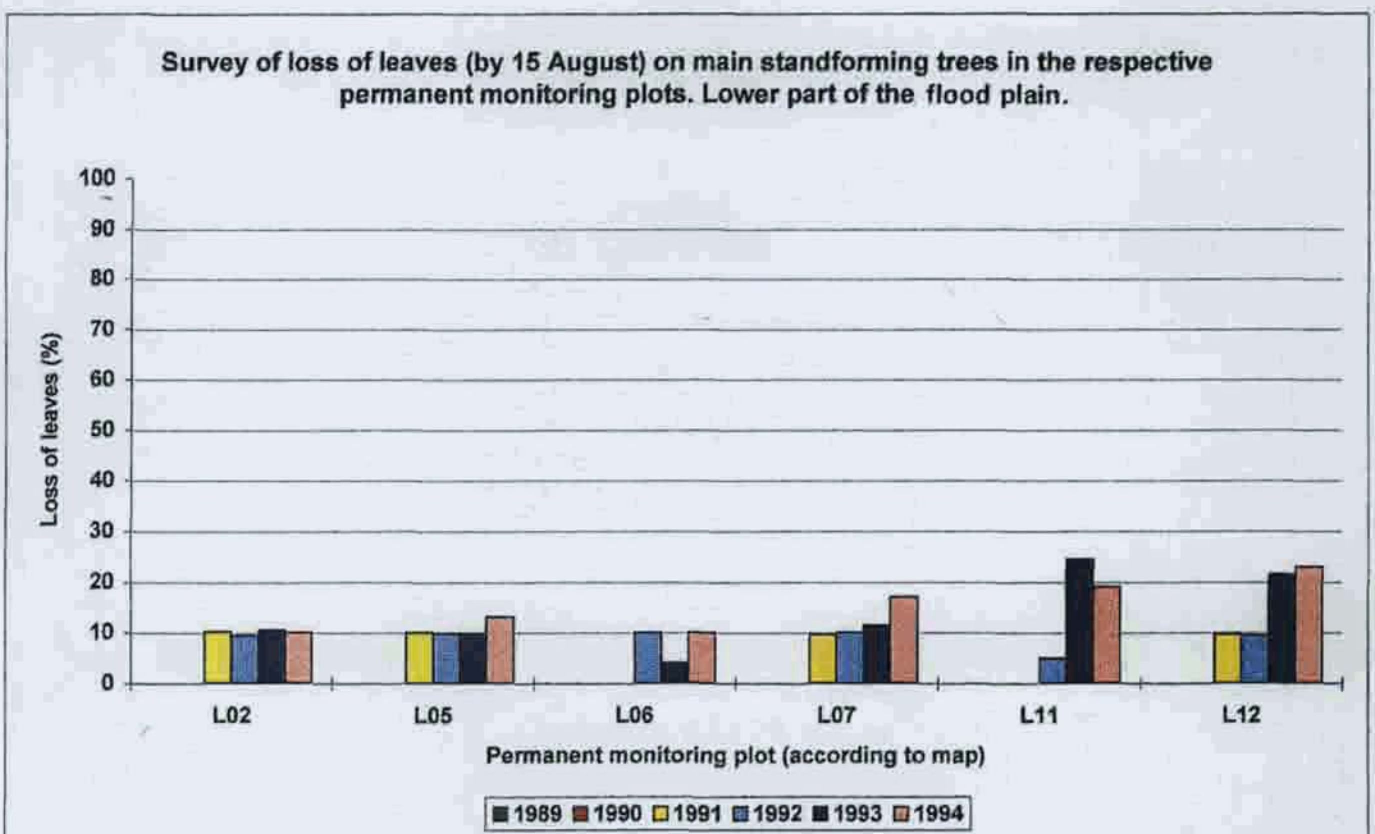
Survey of loss of leaves (by 15 August) on main standforming trees in the respective permanent monitoring plots. Lower part of the flood plain.
Loss of leaves (%)
L02
L05
L06
L07
L11
L12
Permanent monitoring plot (according to map)
1989 1990 1991 1992 1993 1994

Fig. 3.2

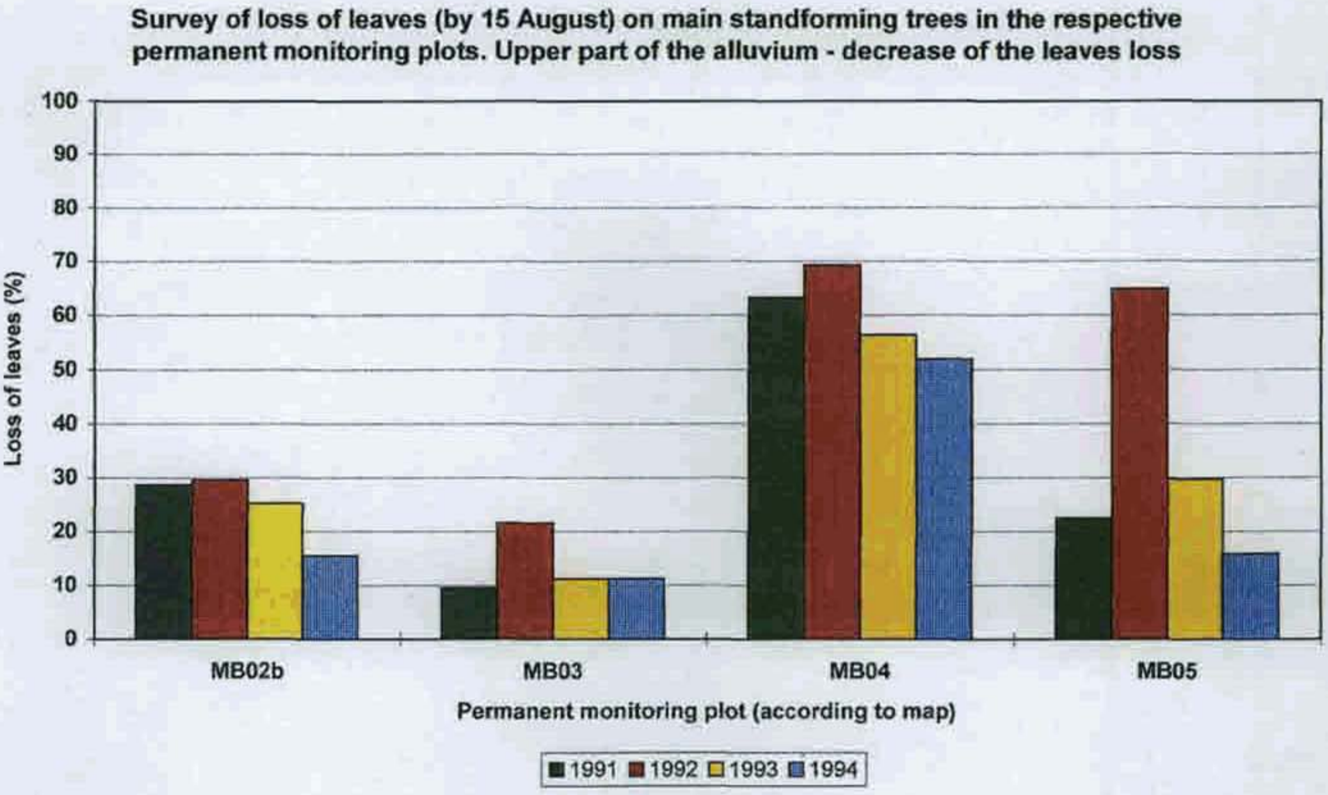
Survey of loss of leaves (by 15 August) on main standforming trees in the respective permanent monitoring plots. Upper part of the alluvium - decrease of the leaves loss
100
90
80
70
60
50
40
30
20
10
0
Loss of leaves (%)
MB02b
MB03
MB04
MB05
Permanent monitoring plot (according to map)
1991 1992 1993 1994

Fig. 3.3

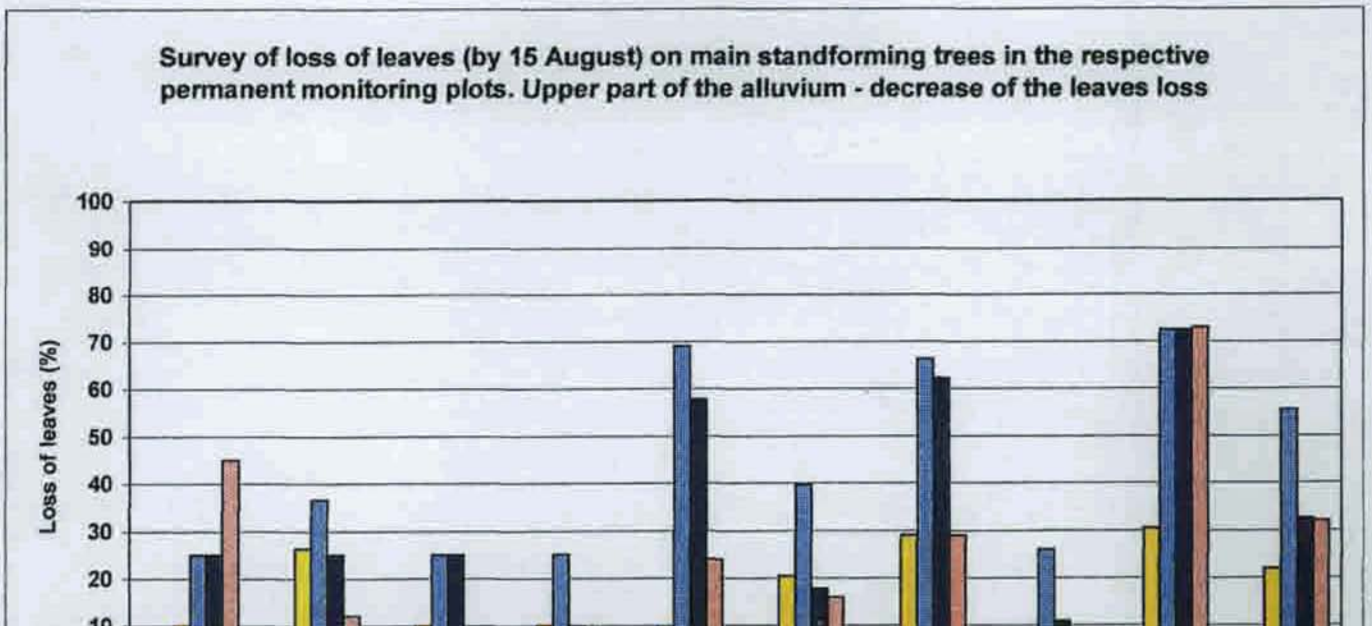
Survey of loss of leaves (by 15 August) on main standforming trees in the respective permanent monitoring plots. Upper part of the alluvium - decrease of the leaves loss
100
90
80
70
60
50
40
30
20
10
0
Loss of leaves (%)
L13
L14
L15
L16
L18
L19
L20
L21
L22
L23
Permanent monitoring plot (according to map)
1989 1990 1991 1992 1993 1994

Fig. 3.4

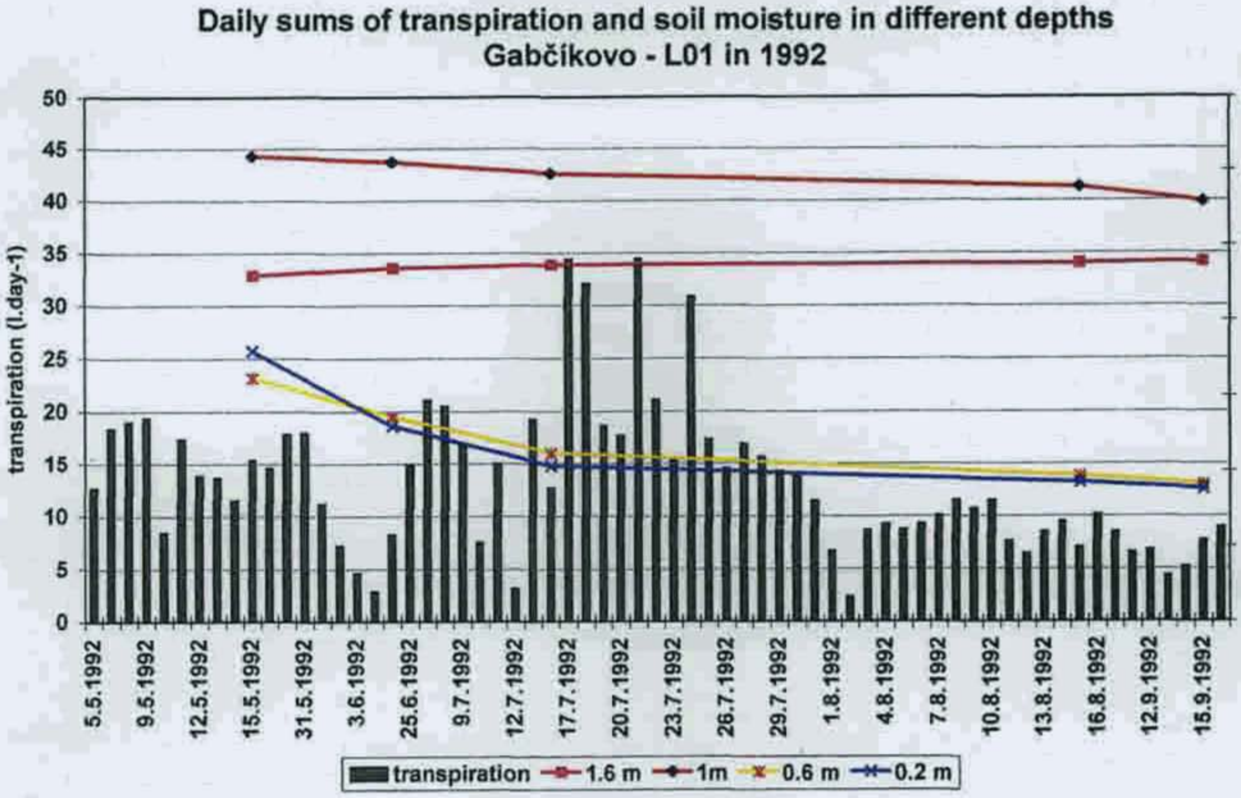

Fig. 3.5

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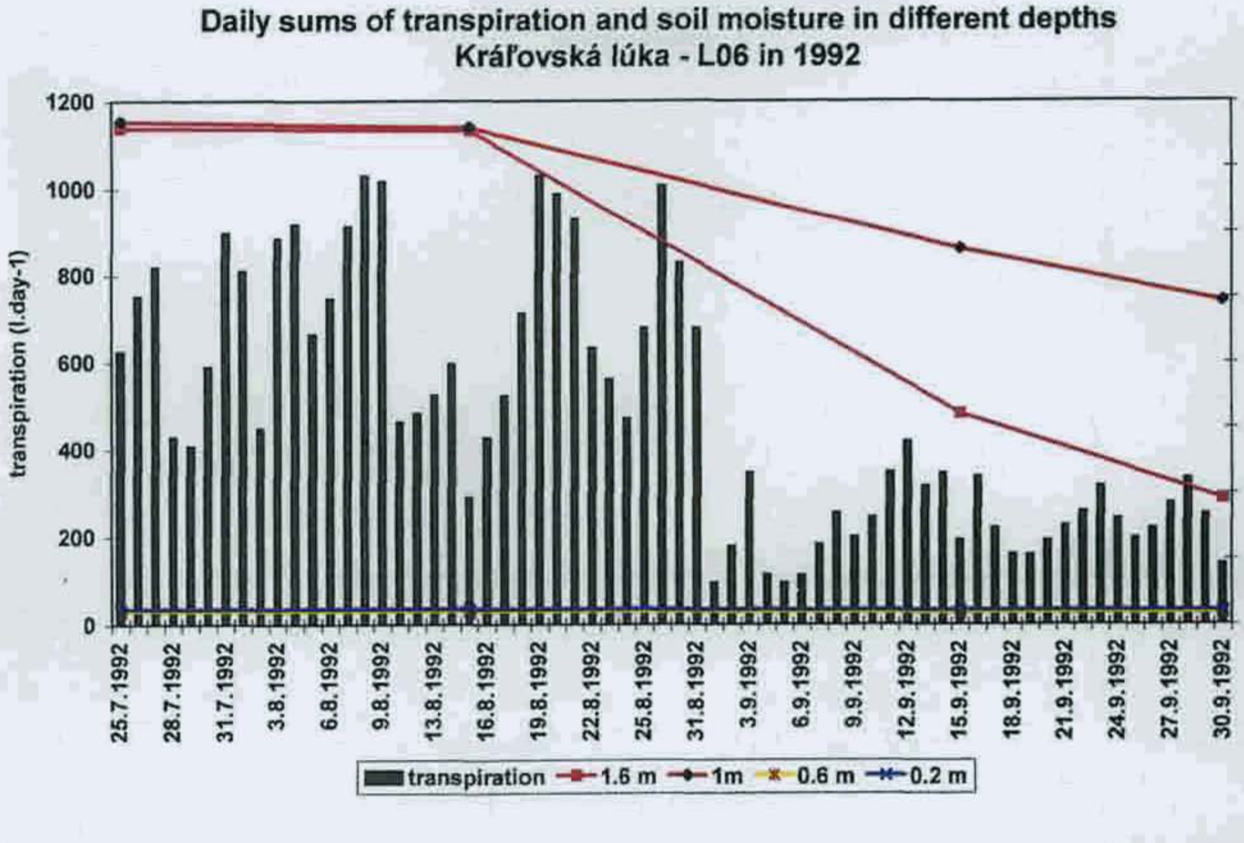

Fig. 3.6

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Daily sums of transpiration by ash tree and groundwater levels
Kráľovská lúka - L06 in 1993

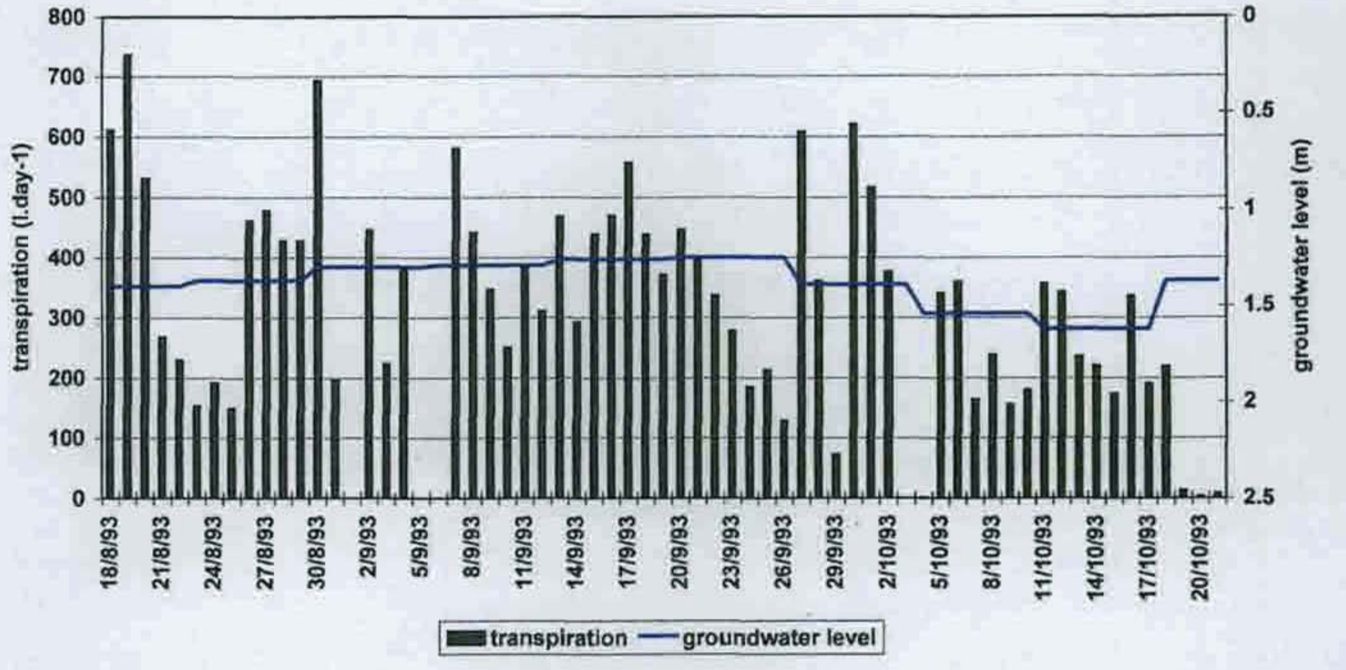

Fig. 3.7

Institute of Hydrology SAS

Daily sums of transpiratin by oak tree and groundwater levels
Biskupice - L19 in 1993

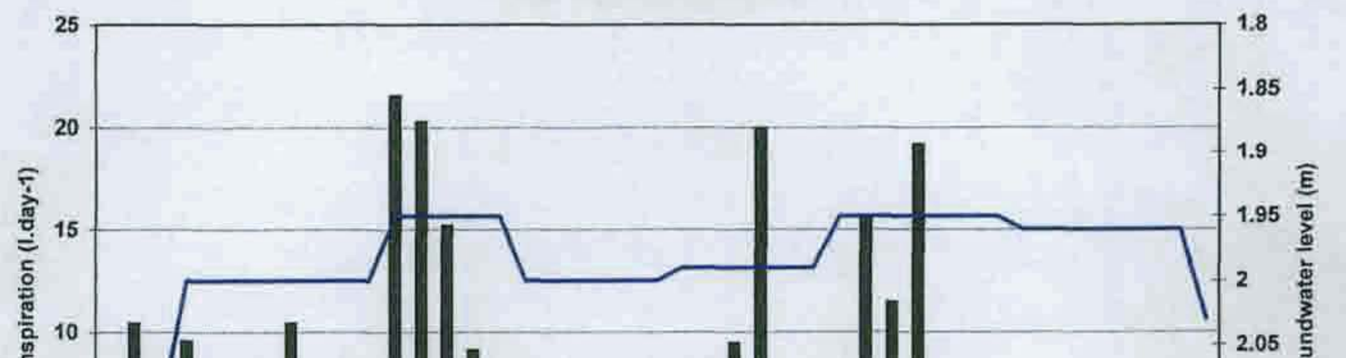

Fig. 3.8

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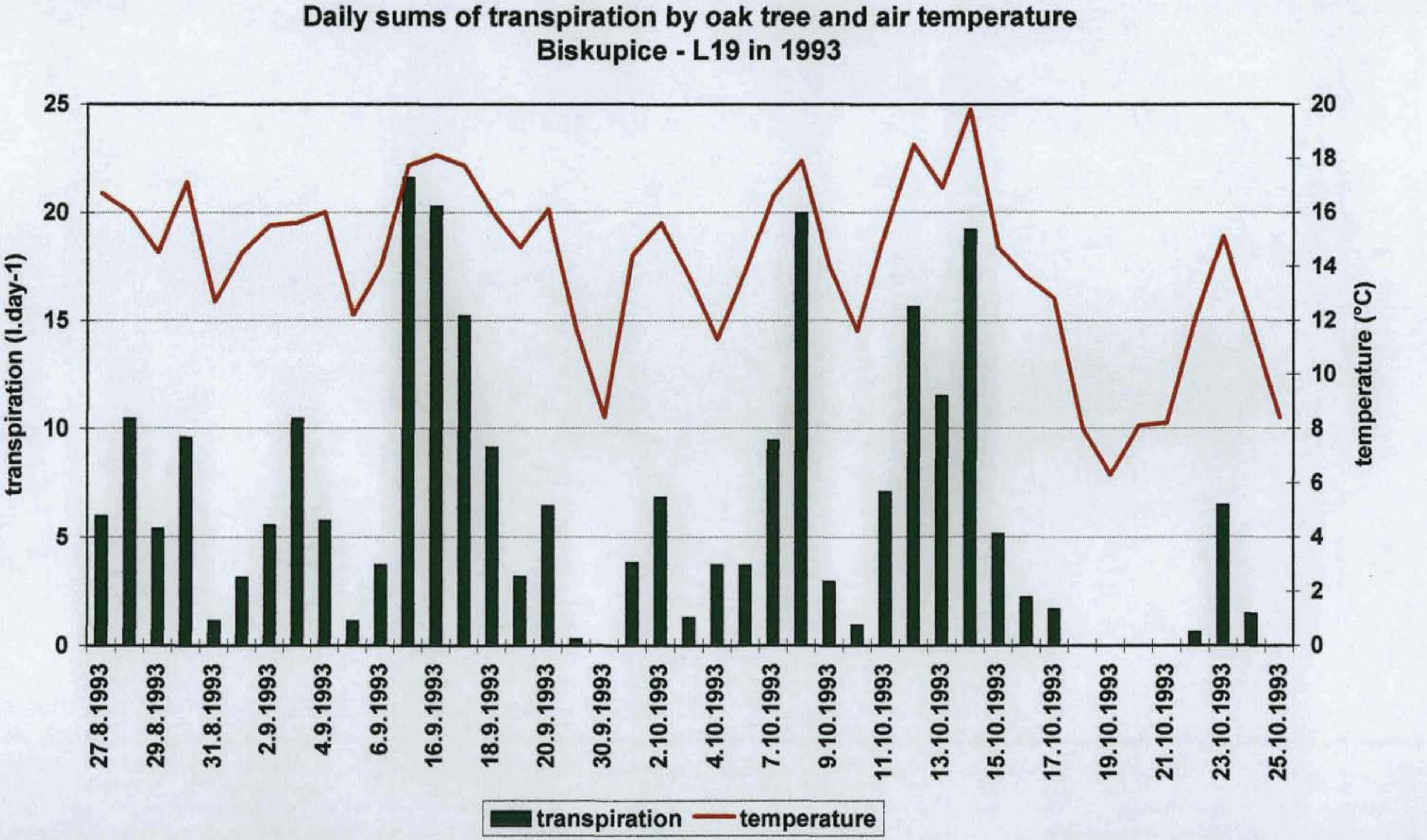

Fig. 3.9

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CHAPTER 4. FLORA AND VEGETATION OF THE DANUBE LOWLAND WITHIN THE IMPACT AREA OF THE GABČÍKOVO PROJECT

L. Šomšák & F. Kubíček

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1. Introduction

This study deals with the flora and vegetation of the Danube lowland in relation to the Gabčíkovo/Nagymaros barrage system including Variant "C". Because floodplain forests cover a significant area of the region influenced by the Gabčíkovo Project, the main attention will be paid to their development and future.

Floodplain forests of the Danube lowland have been the object of a number of botanical studies. A privileged place in this respect belongs to Jurko who greatly contibuted to our knowledge in this area (1958). He studied (in 1954-1957) in a most detailed manner the soil-ecological conditions of floodplain forests and the water regime of the Danube in relation to vegetation and their syntaxonomic value. Thus he depicted their more or less original state, corresponding to the former hydro-pedological regime of the Danube.

Part of these forests under Bratislava (Vlčie hrdlo-Kalinkovo) was depicted on a detailed phytocoenological map in scale 1:10,000 (Jurko et Šomšák, 1959). This map provides even today valuable basic material for comparison of all changes. The authoritative work of Jurko (1958) was followed by a number of studies concerning other Slovak floodplain forests, mainly along the Morava river (Šomšák, 1959), in the Tisa river lowland (Berta, 1970), in the downstream part of the Hron river (Šomšák, 1976), in the middle part of the Váh river (Kontriš, 1981) and attention was simultaneously paid to submountain floodplain forests (Jurko et Májovský, 1956; Jurko, 1961; Šomšák, 1961 and others).

A detail study of floodplain forests in the northern part of the Danube lowland, in relation to soil conditions, was produced by Džatko (1972). The vegetation of stagnant waters and dead arms of the Danube was depicted in detail by Otáhelová (1977, 1978). The phytocoenoses of bank ecotopes of the floodplains of Slovak rivers were in depth studied by Šomšák (1972), Šmihulová (1967) and others. Kubíček and Šomšák (1985), and Kubíček et al. (1989) devoted great attention to synecological conditions and primary productivity of floodplain forests. Also the reaction of trees composing floodplain ecosystems to changes in groundwater levels by variation of leaf area and leaf litter (Oszlányi, 1994) was carefully studied and is very well known.

Šomšák (1964) and Jurko (1976) first tried to predict changes in the floodplain ecosystems in connection with the planning for the Gabčikovo/Nagymaros Project. Complete documentation and inventory of flora in the Danube lowland on the Slovak side was completed in 1986 by Bertová et al., (1986). All changes of the floodplain ecosystem's biota in the Slovak side of the Danube lowland have been carefully monitored since 1991 (Lisický et al., 1991, 1993, Matečný et al., 1994).

Thus the flora of the Slovak floodplain ecosystems, including the Danube inundation area, can be considered as one of the best defined and best known of Europe. The Slovak scientists have therefore always had and now have a potential to evaluate correctly and objectively the influence of the Gabčíkovo/Nagymaros Project, including its Variant "C", on flora and forests in particular.

2. Floodplain Forests Prior to Construction of the Gabčíkovo/Nagymaros Project

The period prior to construction of the Gabčíkovo/Nagymaros Project can be divided into three stages:

- (i) the period prior to the construction of protection dykes along the Danube
- (ii) the period since completion of the major regulation works in 1890-1900 until 1960, and
- (iii) the period of the decrease of the water level in the Danube since 1960 until the damming of the Danube in 1992.

(i) The first period is known from maps, the first of them dating from the 4th Century B.C. (Jakubec, 1993). It was characterised by the flow of the main mass of waters in the lines of today's Malý Danube (Little Danube) and Čierna voda (the Black water river) with smaller current turning to the right from the river, approximately along the line of today's Rusovecké branch, continuing further to Komárno. The northern stream represented the main navigation route and was regularly adapted for this purpose.

Only after floods in the 18th Century and after long lasting drying up at the beginning of the 19th Century were the waters diverted to the present main riverbed. A number of arms on the maps from that period (Jakubec, 1993) lead us to suppose that a considerable part of Žitný Ostrov was regularly flooded. But there were several elevated areas which were not flooded even during catastrophic floods. It is supposed that the willow-poplar floodplain forests, best adapted to repeated floods, prevailed.

The completion of construction of anti-flood dykes on both sides of the Danube, some 100 years ago, represented the first serious interference into the original floodplain ecosystems. The creation of the inter-dyke area provoked substantial change in the hydrological and hydropedological regime of the territory. Floods, which prior to the erection of dykes irregularly extended to the whole Danube lowland, became strictly limited to the inter-dyke area. They became more severe and more frequent with occurrence even several times per year.

(ii) This led to the change of the original conditions, to which biota on both sides of dykes had to adapt (adaptive succession). The major changes were as follows:

- loss of communication of surface water in the side arms in the protected area with water in main channel
- disappearance of direct flooding of the inland part of Žitný Ostrov
- the conversion of reophile types of arms into dead arms with stagnant water
- destruction of litoral communities of reophile arms on the inland side and a rise of stagnant water phytocoenoses (Lemnetea, Potametea, Phragmito-Magnocaricetea and others)

- changes in oscillation of ground water levels in the inland part of Žitný Ostrov in relation to the rhythm of water fluctuation in the Danube, or in the inter-dyke area

- floristic, phytocoenological and synecological re-building of azonal floodplain forests in the inland part of the lowland into climazonal forests (Ulmo-Quercetum)

- areal re-building of the floodplain forests in the inter-dyke area into willow-poplar communities

- increase of number (area) of reophile arms in inter-dyke area

- increase of erosion-aggradation activity of the Danube and its arms in inter-dyke area and multiplication of primary succession (repeated settlement of new deposits).

One hundred years (since the erection of protection dykes) is a very short period for the development of vegetation. Nevertheless, this was sufficient for the floodplain ecosystem to create an equilibrium in changed conditions. However, floodplain forests which adapted in this area do not represent the type of original forest. They represent successive adaptations of nature to important changes of conditions caused already twice by man.

The classification of these forests corresponding to their state at the end of the 1950s (Jurko, 1958; Jurko et Šomšák, 1959) was as follows:

- Willow-poplar floodplain forests (Salici-Populetum):

  These occupied all low plots with the position closer to the ground water level (further from the river), but also higher aggregated ramparts with light soils. Floods occurred at these places several times per year, mainly in June-July.

- Ash-poplar floodplain forests (Fraxino angustifoliae-Populetume albae) as a transitional type between willow-poplar and ash-elm floodplain forests: Floods influenced localities of this ecosystem at least once a year. These communities are dependent on ground water level.

- Ash-elm floodplain forests (Fraxino-Ulmetum):

  These forests are common on higher, rarely flooded terraces. In addition to the ground water levels the rainfall water has a function here.

- Elm-oak floodplain forests (Ulmo-Quercetum):

  This is the driest type of forests, developed on gravel or sandy terraces of the Danube. Ground water level enters into play here only at times of catastrophic floods; they are otherwise influenced by condensated moisture and precipitations.

- Xerophillous Danubian forest-steppes (Crataegetum danubiale):

  These communities are represented by shrub habitats of hawthorns and low oaks with xero-thermophillous vegetation. Their occurrence is bound on gravel benches with partial cover of sand. Because of the absence of capillary rise they are clearly a climazonal type of vegetation.

At the end of the 1950s the following from among secondary forests could be found here:

- Poplar monocultures - at the end of fifities these were planted only on clear-cuttings, without surface preparation of soil. These were planted almost on all localities of natural floodplain forests, but mostly to places of earlier willow-poplar stands. Their extent was in that time about 1,200 ha (8.5 % of the total extent of floodplain forests).

- Black locust stands (Chelidonio-Robinietum, Bromo-Robinietum). These habitats were mostly scattered as small woods out of the inter-dyke area. In the inundation area they appeared only as associated trees.

- Plantations of Junglans regia, rarely Junglans nigra, cultivated for commercial puposes, mainly in the upper part of Žitný Ostrov.

- Stands of Ailanthus altissima, unimportant as to their extent, scattered on the whole territory, mainly outside the inundation area.

The major part of the floodplain forests, by the end of the 1950s, did not yet manifest signs of structural changes in connection with the decrease of ground water levels (which had already started at that time, mainly in the upper stretch of the Danube). Nevertheless the whole region was marked by the sudden drying of elm (Ulmus minor), which was affected by an expansion of graphiosis.

The characteristics of such state of floodplain ecosystems, even if created during less than 100 years, can be accepted as a starting point in evaluating all further changes.

(iii) The decrease of the Danube water level and subsequent decrease of ground water levels characterises the period between the end of the 1950s and the damming of the Danube at the end of 1992. This was a result of the lowering of the riverbed caused by a number of factors starting with regulation works, anti-flood measures, excavation of gravel and the construction of dams on the Austrian and German stretch of the Danube (Danišovič, 1993).

The decrease of water level in the Danube by about 1.5 to 2 m during the last 30 years resulted in a corresponding decrease of ground water levels (Mucha et al., 1993). Such a decrease led in many places to the loss of contact between the ground water and the soil profile. The root system of trees and herbs in some types of floodplain forest (Fraxino angustifoliae-Populetum albae, Ulmo-Fraxinetum, the direst types of Salici-Populetum) became exclusively dependent on rainfall water.

The characteristics of the evolution during the last 30 years can be summed up as follows:

- Loss of communication between the side arms and the Danube in the uppper part of Žitný Ostrov (stretch between Bratislava-Čunovo).

- Seasonal reduction of flow through the side arm system in the inter-dyke area in the stretch Hrušov-Palkovičov (Sap).

- Drying off of dead arms bed and their gradual settlement by shrub, often even by xero-thermophillous vegetation (Cornus sanguinea, Crataegus oxyacantha, Salix purpurea, Salix alba). Typical examples were mainly in the stretch Bratislava - Hrušov.

- Areal destruction of water and marsh vegetation in favour of a littoral one due to loss of communication between the water in the side arms and in the main channel, in particular in the second half of the vegetation season. This was typical for the side arm system in the inter-dyke area.

- Re-building of soft floodplain forests by means of regressive succession from the most humid and humid types (Salicipopuletum myosotidetosum and typicum) towards more xerophyllous types (Salici-Populetum variant with Cornus sanguinea) in the upper part of the territory.

- Re-building of elm-ash (Ulmo-Fraxinetum) and ash-poplar (Fraxino angustifoliae-Populetum albae) phytocoenoses into climax types of elm-oak forests (Ulmo-Quercetum), sometimes even into forest steppe shrub communities (Crataegetum danubiale) on the whole territory but mainly in the upper part of Žitný Ostrov.

- Drying off of upper part of crowns of Populus alsba, Fraxinus angustifolia, Quercus robur on elevated places of soft but even hard floodplain forest, gradual destruction of the tree layer and rise of shrub blocking stadia with Cornus sanguinea and Cornus mas. between Hrušov end Bratislava.

- Decrease of circumference increment of timber, mainly of Populus nigra, Populus alba, Salix alba in the upper part of Žitný Ostrov.

- Loss of leaves of willows on aggregated gravel and sandy ramparts along the whole Danube, ending with dying off of trees.

The decrease of increment and loss of leaves often ended in the destruction of willow-poplar forest, forced forest management to expand plantation of cultivar poplar monocultures. In addition to the originally planted euro-american clones (Populus robusta, Populus monilifera), the plantation on places of the inter-dyke area (Hrušov - Komárno) of clone "I 214", which showed to be more resistant to the changes in groundwater levels, started. The extent of these planted lignicultures was about 8,000 ha by the end of 1992, which was about 80% of the total extent of floodplain forests in the inundation area (Šomšák et al., 1993).

The huge extent of cultivar poplar monocultures in the lower part of the floodplain, but also below Bratislava caused an enormous spread of neophyte species, mainly populations of Aster novi-belgii, Solifdago gigantea and in recent years also Impatiens glandulifera. Moreover, areas of lignicultures were affected by expansion of numerous synanthropic species (Cirsium arvense, Arctium lappa, Arctium nemorosus, Calamagrostis epigeios etc.).

The decrease of ground water levels since the end of fifties required the plantation of monocultures of other trees as Acer pseudoplatanus, Fraxinus excelsior, Tilia cordata, Robinia pseudoacacia, Pinus sylvestris, Pinus nigra and others. Similarly, as poplar plantations, they are alien elements in floodplain areas and have considerably changed the natural potential of ecosystems and species biodiversity.

Similar consequences appeared also in the right-side, Hungarian part of floodplain forests near to Čunovo, Dunakiliti and on the whole Szigetköz.

3. Forest Ecosystems after the Damming of the Danube (1992)

The damming of the Danube river generated basic changes in hydrological and hydropedological regime as far as the area between Bratislava and Palkovičovo (Sap) is concerned. From the point of view of hydrological changes, but mainly its impact on vegetation, the whole territory can be divided as follows:

- floodplain ecosystems below Bratislava
- floodplain forests south of the village Hrušov
- the drained part of floodplain forests
- the inundation area (Dobrohošť Palkovičovo)
- littoral zone of the reservoir

3.1 Floodplain ecosystems below Bratislava

This area includes vegetation of the island Kopáč and remnants of forests between Petržalka and Rusovce. Ground water levels in this area were raised, as a consequence of the damming, back to the values from the end of the 1950s (Mucha et al., 1993, Chalupka, 1993). The side arms, having no direct connection with the Danube, were filled up with the rising groundwater. The increase of ground water levels influenced the vegetation of this area as follows:

- The shrub formations (mainly Cornus sanguinea) on the dead arms bottom, which settled there during previous years when the groundwater level was low, have been submerged and are dying, for this vegetation does not bear the whole-year flooding. A similar situation exists in the arms between villages Rusovce and Čunovo.

- The renovation of stagnant water vegetation (Lemnetea, Potametea, Phragmitti-Magnocaricetea) has begun in the re-filled side arms (Biskupické rameno, Horné Rusovské rameno, Rusovské rameno).

- The renovation of the most humid type of willow-poplar forests (Salici-Populetum phragmiti-caricetosum) has begun by snatching of willows in limozic eco-phase (the Biskupické rameno).

- Abundant natural reforestation of poplar (Populus alba) from seeds now occurs (previously rare in this area).

- The leaf loss decreased by about 4% in some floodplain trees in comparison with 1991, in shrub species Cornus sanguinea by up to 50% and in neophyte species Negundo aceroides by up to 85% (Oszlányi, 1994).

- Slight increase of the thickness increment at poplar (Populus alba) was ascertained, by 3 mm in 1994 in comparison with previous years (Šomšák, mscr.).

3.2 Floodplain forests south of the village Hrušov

This area includes a polder; the proximity of the reservoir causes certain fluctuation of the ground water levels.

In this area the return of original vegetation conditions existing some 40 years ago is most easily visible. Continuous biomonitoring (Uherčíková, 1994, Oszlányi, 1994, Pišút, 1994) confirms the revitalisation mainly of ash-poplar (Fraxino-Populetum), but also elm-ash (Ulmo-Fraxinetum) types of floodplain forest.

3.3 The drained part of the foodplain forest

The area of floodplain ecosystems with the most significant decrease of ground water levels occurs in a triangle between the reservoir, head water canal and intake structure near Dorbrohošť (the so-called dry triangle). The decrease of ground water levels, which is now almost 4 m under the surface, made the floodplain forest dependent on precipitation.

A similar situation exists on the aggregated rampart along the riverbed of the Danube from the reservoir up to the confluence of the tailrace canal with the old Danube. This synecological situation excludes the possibility of natural reforestation of original floodplain trees. It could adapt only to cultivated poplars planted by "deep drought" method. This territory has been monitored since 1991. From the obtained results a course of regressive succession can be seen (Uherčiková, 1994, Oszlányi, 1994, Pišút, 1994). This succession tends towards the disintegration of the forest ecosystem and to its replacement with shrub formations. It is evidenced by such processes as:

- increase of number of individuals from synanthropic species and decrease of number of those from hydro-hygrophillous species

- loss of leaves of willow species up to 80% and, on the contrary, an ideal state of leaves at shrub species Cornus sanguinea

- dying off trees, which were earlier damaged by an extreme defoliation, in particular Salix alba and Salix fragilis.

At present, this area is also the object of a dendrochronological research. Preliminary results from balance of thickness increments show that the process of increment decrease began long ago, approximately since the beginning of the 1970s, and was the result of the sinking of the Danube's water level (Šomšák et Gazdík, mscr.).

3.4 Inundation area (Dobrohošť - Palkovičovo)

The decrease of the discharges and the drop of ground water levels in the inundation area (left side of the Danube) have been remedied by means of a managed water supply through the intake structure near Dobrohošť. A system of weirs and permanent water supply from the by-pass canal provides sufficient water level and flow in the branches. It was ascertained (Sumbal and Sikora, 1993) that the level of ground water extrapolated from branches is on the major part of the territory less than 1.5 m under terrain, and thus within the reach of tree roots. This water supply covers about 75% of the inundation area. The increase of the discharge through the intake structure up to 234 m^3/s would enable flooding of the whole inundation area (Sumbal et Sikora, 1993).

A more or less constant discharge (28 m^3/s) could have a negative impact on the vitality of trees (mainly that of original trees), which are adapted to frequent fluctuation of ground water levels. But this problem is technically easy to solve.

In spite of the fact that there are seven monitoring sites in the inundation area (Lisický, 1991), only one is suitable for the observation of impacts of the water supply in the branch system (monitoring site No. 10 - Královská lúka). The other monitoring sites are all localised in the drained part along the old riverbed, or in the area affected by backwater, upstream from the confluence of the tailrace canal with the Danube. This is due to the fact that the monitoring areas were selected for the whole Gabčikovo/Nagymaros Project and not for Variant "C".

The larger part of the inundation area was in the past reversed into lignicultures of cultivar poplars, which have relatively wide valency to hydropedological conditions.

The results of monitoring of reactions of flora to existing situation indicate the following:

- excellent healthy state of trees in the tree layer, without traces of decline
- occurrence of natural reforestation of tree species Fraxinus angustifolia from seed, which was not earlier observed
- increase of population of protected humid species Leucojum sativum due to ground water levels increase
- almost no changes in the thickness increment of poplar clone "I 214" (the most prevalent tree of the inundation area).

Due to the insufficient number of monitoring sites in the area of simulated discharge, supplementary measurements, including dendro-ecological measurements by the Pressler borer, were realised in 1994. Preliminary results are for the present of a limited significance; however they do not indicate any apparent changes since the damming. Undoubtedly, longer term observations are needed.

The qualitative composition of biodiversity in the Danube's floodplain between Dobrohošť and Palkovičovo (Sap), especially vascular plants, deserve special attention. There are species of the following eco-phases (Hejný, 1960):

- hydro-phase (plants of stagnant or slowly flowing waters -Lemnetea, Potametea)

- littoral phase (plants of shallow waters with oscillating water level - part of the class Phragmito-Magnocaricetea)

- limozic eco-phase (soil surface is saturated by water, often drying off - drier part of the class Phragmito-Magnocaricetea, communities of shore lawns and seasonal phytocoeneoses-Bidentetea, Plantaginetea majori, Littoreletea, isoeto-Nanojuncetea)

- terrestric eco-phase (water as the main factor retreats and appear as soil humidity - Salicetea purpureae, Ulmenion, alluvial meadows etc.).

These four eco-phases represent in the Dobrohošť-Palkovičovo (Sap) area about 32% (321 taxons) of the total number of 1000 vascular plants in the concerned territory (Gabčíkovo-Nagymaros) - Bertová et al., 1986. From the above-mentioned taxons about 200 are terrestric, 11 growing in littoral eco-phase, 55 in limozic eco-phase and 52 species in hydro-phase. It means that shifting/re-colonisation induced by appearance or disappearance of stands in connection with function of simulated water discharge in the branches will affect approximately 118 taxons of vascular plants. This number includes plants, which very rapidly settle substrates created by water, as genus Polygonum, Bidens, Phalaris, Phragmites,Caltha, Cyperus, Limosella, Agrostis and others.

Two years of observation (1993-1994) of the water supply into the branch system show enlargement of the area of limozic and littoral eco-phase. New biotopes arose also for plants requiring relatively calm waters as Nymphaea, Nuphar, Sagitaria, Butomus, Certophyllum, Potemogeton and others, mainly in the side branches of arms with flowing water, where sedimentation of flooded material prevails.

According to observations no single species of vascular plants disappeared; on the contrary an increase of population of protected species Leucojum aestivum resulting from the raise of ground water levels has been ascertained.

Also in the reservoir an increase of limozic and littoral eco-phase biodiversity is taking place. The northern shallow part of the reservoir constitutes a huge area of shallow water and semi-terrestric conditions.

3.5 Littoral zone of the reservoir

There is a several tens of metres wide belt of shallow water on the northern margin of the reservoir. This belt is, following different water levels in the reservoir, for distinct periods only submoistened (limozic eco-phase), or covered with shallow layer of water (littoral eco-phase). On numerous places the bottom can emerge on to the surface for longer time (terrestric eco-phase). These habitat conditions representing periodical waters are an ideal biotope for the spread of such species as are Persicarla amphibian, Equisetum fluviatile, Ranunculus lungua, Ranunculus sceleratus, Ranunculus sardous, species of genus Batrichium, Persicaria lapathifolia, species of genus Myriophyllum, Hipuris vulgaris, Nymphoides peltata, Hottonia palustris, Butomus umbellatus, Najas marina, species of genus Potamogeton, species of genus Eleochoris and numerous others. Some of the above-mentioned species were already ascertained in 1994.

Detritus from these highly productive ecosystems will enrich water in the reservoir with organic materials, which, under suitable management, can be transported to the floodplain area - the branch system between Dobrohošť and Palkovičovo.

4. Conclusions

This study is aimed at an assessment of the long term development of the flora and vegetation of the floodplain ecosystems in the Danube lowland. It focuses on the actual conditions both prior to and after construction and implementation of the Gabčíkovo section of the G/N Project through Variant "C" and the reaction of vegetation to the changed hydropedological conditions. The given data are related to the Slovak side of the ecosystems, but in the case of the realisation of the proposed measures in Hungary (direct recharge into the Hungarian side arms, construction of underwater weirs in the old Danube riverbed, etc.), the conclusions would be valid (after certain corrections) also for the right bank of the Danube river.

The authors of this study do not deny the negative consequences of the Gabčíkovo-Nagymaros Project, such as the removal of floodplain and other forest to the extent of 3,267 hectares on the Slovak side, the synecological changes in the draining section under the Hrušov reservoir and in the narrow stretch alongside the Danube riverbed. But these may be solved by suitable management (e.g., by plantation of cultivar poplars by depth planting).

As to plant biodiversity, there is no proof as to the lowering of the phytogenofund from the experience of two or more years since the damming. To the contrary, new biotopes may appear as a result of the water recharge into the side arm system in the inundation area (Dobrohošť - Palkovičovo) and in the huge limozic and littoral zone around the Hrušov reservoir, leading to a presumption in the favour of increased biodiversity.

In connection with the prediction of expected changes, it is possible to turn to the past 100 years of the Danube river. For, during this period of construction of the protection dykes, all ecosystems became adapted to the changed conditions. It is therefore possible to predict a similar adaptation to these new conditions.

Our experience since the end of the 1950s leads us to conclude that due to the decrease of water flows in the side arm system following the regulation of the Danube riverbed, the retention of sediments in the Austrian and German stretch of the Danube and the continuing trend of the Danube riverbed towards erosion, the floodplain forests would eventually have disappeared on the Slovak side of the Danube river. The Gabčíkovo Project and Variant "C" have prevented this regression.

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CHAPTER 5. FAUNA IN THE GABČíKOVO PROJECT IMPACT AREA: SURVEY OF RESULTS OF MONITORING DURING 1990-1994

D. Matis
I. Országh
V. Košel
I. Krno
E. Tirjaková

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1. Historical Development

The development of the fauna of the Danubian lowland lasted several million years and was influenced by geological and climatic changes which had determined the overall character of the region (with the Danube river as a decisive factor in the formation of the geomorphological profile of the territory as we know it today). The river had developed an extensive system of side arms surrounded with abundant floodplain forests and with water related animal communities. Annual floods, caused by the position of the river meandering on the top of the alluvial cone above the surrounding terrain, supplied these ecosystems with moisture and nutrients, changing at the same time the river flow and the whole pattern of the branch system.

The surrounding landscape, however, gradually obtained a different, more xerophillous character. The extensive farming, for which the fertile soil and mild climate provided good conditions, steadily led to the reduction of forests, to adaptations of the river flow and aridation of moistened areas. Both the Žitný Ostrov on the north (between the Danube and Malý Danube) and the Szigetköz on the south (between the Danube and Mosoni Danube) became economically extensively utilised. An extensive system of canals, weirs and dykes was built for water supply and drainage.

The main river channel was created by man, enclosed by dykes and regulated for the purpose of navigation, thus separating the original inland delta into two parts. The concentration of the main flow into a single riverbed led to the gradual drying of the branches and their disappearance. Thus the floodplain became narrower and branches together with their typical habitat became restricted to the inter-dykes area.

The change in the flow velocities of the river towards relatively fast flowing water led to the appearance of animal communities bringing the fauna nearer to that of submountain character. The original fauna was preserved only in the branch system.

The erosion of the Danube riverbed during the last decades and loss of the interconnection between the river and the branches led to their further degradation, and the drop of ground water levels caused the aridisation of the region, which together with pollution of waters had as a consequence the decrease of the original fauna during recent decades. The change of communities occurred in different parts of the Danube river as well as in the branch system.

These changes are well documented in several studies devoted to the fauna on the Slovak side of the Danube river: Brtek (1953), Brtek, Rotschein (1964), Ertl (1970, 1974, 1976, 1985), Ertlová (1963, 1968,1970), Holčík et al. (1981), Onderlíková (1958) and Vranovský (1974, 1975, 1995) and others.

The basic work dealing with the fauna of the Slovak stretch of the Danube is that of Brtek and Rotschein (1964) containing the inventory established by the time of its publication. The authors mention especially the invasion of pontocaspian elements.

The plankton in different biotopes of the Danube has been documented by Ertl (1962, 1966, 1970, 1974, 1976, 1985). He reports relative scarcity of plankton in the Danube. Plankton production is positively influenced especially by the branch system. The organisms are washed therefrom into the river (see, also, Vranovský, 1974a, 1974b, 1975).

The benthos of the branch system was studied by Ertlová (1963, 1970, 1973). Her works mention a high biomass of benthic organisms in the branch system and their relative scarcity in the main channel (Ertlová, 1968).

The work of Holčík, Bastl, Ertl and Vranovský (1981) contains a survey of possible ecological impact of the Gabčíkovo - Nagymaros Project. It takes for its basis a technical solution which was later altered and therefore the results of this work are not relevant for the actual situation.

2. Changes of Fauna after the Putting of the Gabčíkovo Project into Operation

2.1 Water communities

Various types of water biotopes can be found on the concerned territory: those typical for flowing water as well as those typical for different types of branches. The aquatic fauna of this reach of the Danube is unique from the European point of view. Unlike other rivers in Central and western Europe, the fauna of this reach of the Danube is characterised by the occurence of animal species originating from the Parathetis Sea (Neogene). Due to immigration of Pont-Caspic species, unique communities with a specific biodiversity have developed (An der Lan, 1967).

2.1.1 Plankton

Plankton represents a mixture of organisms passively carried by water flow, or floating in stationary water. These organisms are of different origin, they may live permanently in a water column and reproduce in it, or they originate from a substrate as, for example, larvae of *Chyronomidae, Diatomacae* and others do. Optimal conditions for development of plankton exist in stagnant waters; in flowing waters, plankton is carried and washed away.

In the main channel plankton represents a relatively small part of organisms production. Usually the largest share of zooplankton biomass represent protozoans (40-80 %), then rotifers (11-16 %) and crustaceans (2-6 %) (Vranovský, 1974, 1985). Among phytoplankton, algae prevail. According to recent measurements, no significant changes in the composition of plankton occurred during the construction and after putting into operation of the Gabčíkovo section of the G/N Project. The analyses of phytoplankton (biomass, number, primary production) confirm that a distinct horizontal zonation can be observed in the reservoir and in the headwater canal.

An important part of zooplankton is represented by water fleas (*Cladocera)*. The number of determined species of this group decreased in the main channel after the Danube's damming at the end of 1992 and increased again in 1993 and 1994 when the situation became stabilised. Due to the decrease of water level in the old riverbed an increase of benthic species (living at the bottom) and decrease of planktonic species took place.

At the same time the number of water fleas (*Cladocera)* decreased almost by a half in the branches with flowing water, and this situation lasted through 1993. Some species were even absent. As in the main channel, an increase of benthic and litoral species has also been observed here. No apparent changes in the number of determined species were recorded in branches with stationary water, which corresponds to the monitoring results concerning other animal groups living in water. This type of side arm, except the locality Královská lúka, has not been more substantially affected by the construction of the Project.

2.1.2 Benthos

The monitoring also covered fauna living on the bottom (benthos). Special attention was paid to microzoobenthos groups, in particular to ciliated protozoa and quantitatively also to flagellates, rhizopods and schmall metazoans.

During the years 1989 - 1994, 256 species of ciliated protozoa were determined in the monitored localities. The number of species for different years are presented on Fig. 1. From the point of view of the whole spectrum of species, the Danube system in this part is most abundant (Matis, 1961, Tirjaková, 1992, Szentivány, Tirjaková, 1994). In previous years, attention was paid mainly to the dead branch Lyon near Čičov, where 158 species have been ascertained all together (Matis, Tirjaková, 1992). Thus this branch serves as a main basis for evaluation of changes in the Danube river system. The analysis of omnivore/bacteriovore/predator communities is shown on Fig. 2.

2.1.2.1 The Danube

Changes of benthic fauna in the Danube riverbed have been monitored in four profiles since 1989. Three of them (Dobrohošť - rkm 1841, Bodíky - rkm 1830 and Gabčíkovo - rkm 1817) are in the sector of the river where, since November 1992 (after damming of the Danube), a decrease of water level occurred. One profile (Kľúčovec -rkm 1804) is downstream of the confluence of the tailrace canal and the Danube, where hydrological conditions are similar to those before putting of the Gabčíkovo Project into operation.

Microzoobenthos

Microzoobenthos (including periphyton) consist from several groups of microorganisms (*Flagellata, Rhizopoda, Ciliophora* and microscopic metazoans such as rotifers, nematods, gastrotrichs, tardigrads and turbellarians flashworms). Ciliated protozoa are dominant. Sudden changes in these communities in the main riverbed occurred already in 1993 (see Fig. 3 and 4) without, however affecting the total number of species. Preliminary results of monitoring in 1994 confirm this conclusion. Significant changes towards stabilisation and enrichment of the main channel fauna are taking place.

Our research leads to the conclusion, that during the construction of the Gabčíkovo Project a number of suitable refuges of aquatic fauna were preserved, later providing the basis for regeneration of aquatic communities.

Their abundance has increased 2-10 times on most of the monitored localities in the main riverbed. The locality Istragov (Fig. 4) is a typical example. It is presumably caused also by an increase of algae growth (Šporka, Krno, 1994).

Gradual establishment of natural food relations leads to an increase of the spectrum of species and ratio of omnivores in the main channel (stretch from Dobrohošť to Istragov). There is significant decrease of bacteriovores (for the water purity is higher). This is most evident in the locality

Istragov (Fig. 6). The ratio of bacteriovores species in the main channel increases again downstream of the confluence with the tailrace canal (Klúčovec) (Fig. 5).

Macrozoobenthos

26 species of benthos (not including insects) permanently living in water have been registred on four sampling points in the main channel in 1989 - 1994. Prior to the putting of the Project into operation there were 23 species and after (1993 and 1994) there were 26 species. Two new species were from the group *Mollusca* and one from the group *Crustacea - Isopoda*. No single one from among species occurring in this area before the damming disappeared. Newly identified species occurred in the stretch with the decreased water level (Dobrohošť - Gabčíkovo). Thus it can be said that the diversity of species, as far as permanent hydrobiontes are concerned, remained unchanged downstream of the confluence with the tailrace canal, and slightly increased in the stretch where the discharge decreased (three new species).

The situation is different as far as water insects are concerned. There were 10 species of *Ephemeroptera* and 9 species of *Trichoptera* known before 1992. In 1993-1994 only 5 species of *Ephemeroptera* were ascertained, from which 4 bellonged to earlier determined species while one was new. In the same period 8 species of *Trichoptera* were ascertained; four from previously determined species disappeared while three new species appeared (Fig. 10-13.).

Table 1. Numbers of ascertained species (Danube)

Group	1989-1992	1993-1994
Porifera	1	1
Turbellaria	2	2
Polychaeta	1	1
Hirudinea	2	2
Gastropoda	6	8
Bivalvia	4	4
Crustacea		
-Amphipoda	4	4
-Isopoda	1	2

Bryozoa	2	2
Ephemeroptera	10	5
Plecoptera	-	1
Trichoptera	9	8
Total	42	40

Changes in quantity of zoobenthos were more important. They are illustrated on three profiles: two of them - Dobrohošť and Gabčíkovo - are situated on the Danube's stretch where the discharge decreased since November 1992. The third profile (Klúčovec) is downstream of the confluence with the tailrace canal where the hydrological conditions are similar to those before the damming of the Danube. Quantitative conditions of benthic fauna have been ascertained separetely on natural bottom of the Danube river and on bank stones. The abundance of benthic fauna is expressed in number of individuals per 1 m^2 of the substrate. Dynamics of changes in these profiles during the period 1991 - 1994 are shown on Fig.7.

The abundance of permanent zoobenthos in all profiles, in 1991 and 1992 (in pre-dam conditions), was in total lower, but with considerable oscillation. Since 1993 the abundance of zoobenthos started to increase considerably on the river bank stones, but only in the Danube stretch Dobrohošť- Gabčíkovo (the old riverbed). In 1994 these values were even higher (Fig. 7). *Mollusca* showed the largest increase. A similar increase of abundance did not occur in the profile Klúčovec downstream of the confluence with the tailrace canal where the values corresponded to those from previous years. The abundance of insects decreased in the first half of 1993, but then gradually increased, and in 1994 reached higher values than prior to the putting of the Project into operation. The quantity of larvae of parasitic black flies (*Simuliidae, Diptera)* considerably decreased in the stretch Dobrohošť- Gabčíkovo.

2.1.2.2 Branch system

Microzoobenthos

The character of changes is illustrated on the example of the locality Královská lúka (Fig. 8). The graph shows a stabilised situation in 1991 and 1992. The change came in 1993 when a decrease of species numbers occurred. The gradual restoration of the community took place in 1994. The changes in abundance underwent similar development. While in 1991 and 1992 this branch was receiving water only sporadically from the main channel, where the discharge decreased after the damming, or from the rainfall, in 1993 and 1994 springs of ground water occurred as a result of filling of neighbouring branches with water. Thus relatively stable abiotic conditions for formation of communities have been created. This led to an increase of number of species and their abundance. While in 1993 the abundance decreased 2-10 %, depending on seasonal dynamics, in 1994 it became stabilised and approaches the original state (Fig. 9).

The microzoobenthos situation in other branches did not change, the branches Opátske rameno, Starý les and Lyon had stabilised communities of microzoobenthos during the whole observed period.

Macrozoobenthos

The impact of the Project on the branch system depends on their locality. There are three types of change:

- the increase of water level and permanent presence of water in branches,
- the increase of water level and permanent water flow through branches,
- drying off in some parts of branches

a) The increase of water level and permanent presence of water occurred in arms on both sides of the Danube below Bratislava, between rkm 1850 and 1865. After an increase of water level in the monitored branch (locality Biskupické rameno), earlier periodically drying off, the renewal of fauna of hydrobiontes, mainly *Mollusca* (8 species) has been observed. Positive changes occurred also in the settlement of these waters by insects. A number of species previously not present in this locality, mainly mayflies (*Ephemeroptera*), dragonflies and damselflies *(Odonata)* appeared. Some of these species are classified as rare or threatened (*Caenis lactea, Coenagrion mercuriale, Somatoclora metallica).* Development of fauna in this locality probably tends towards the increase of species diversity.

b) In the largest territory, in the length of 20 km between Dobrohošť and Gabčíkovo, the arms started to recieve permanent discharge (continuous flow of water). Immediately after the damming of the Danube in October 1992, there was no discharge and the water level dropped in these branches. This situation lasted until March 1993, when the intake structure near Dobrohošť was put in operation.

The monitoring revealed 27 species of pernanent hydrobiontes (Table 2) on sampling area at Bodícke rameno between 1989 and 1992. Shortly after beginning the water supply into branches (1993), a certain retreat of species in all groups was observed. In 1994 the number of species started slowly to increase. In the first period the fauna came from refuges or it was transported by water from upstream sections. E.g., the quantity of Lymnaea stagnalis at Bodíky was higher than before the putting of the Project into operation.

According to observations, the majority of species in this area has been preserved. Some of them were not ascertained because of the method used (influenced by rise of water level). From among the water insects *(Odonata)*, several rarer species appeared. No essential changes in species composition, in comparison with the pre-dam situation, are expected in the near future.

On the quantitative level some important changes have occurred. They were most evident in 1993 as far as leeches (*Hirudinae)*, snails and slugs (*Gastropoda*) are concerned. A clear decrease of *Hirudinea* and *Crustacea-Amphipoda* was recorded. The abundance of 2 species of *Gastropoda* decreased, but the abundance of 5 species of this group was already in the second half of 1993 higher than before the beginning of water supply. Further growth of abundance in 1994 was recorded only in the case of two species. The quantity of troublesome mosquitos such as *Aedes vexans* and *A. sticticus* considerably decreased in this area. It can be supposed that the quantitative situation will be stabilised during 1-2 years.

Table 2. Number of species at the branch locality Bodicke rameno prior to and after the beginning of water supply

	1989-1992	1993	1994
sponges (Porifera)	2		1
turbellarian flatworms (Turbellaria)	3	1	2
leeches (Hirudinea)	5	2	1
snails (Gastropoda)	10	8	8
clams (Bivalvia)	3	1	1
crustaceans (Crustacea)			
- amphipods (Amphipoda)	4	2	2
- mysids (Mysidacea)			1
Total	27	14	16

c) In the remnants of arms upstream of Dobrohošť (in the triangle between the bypass canal, old riverbed and water supply canal) and downstream of the Gabčíkovo step between the tailrace canal and the old riverbed (locality Istragov) a long lasting loss of water and drying of marsh communities occurred. It is due to the fact that - in the first case - the water supply from Dobrohošť can not reach the locality situated upstream, and - in the second case - the locality (Istragov) is beyond the reach of water from the tailrace canal. An alternative recharge program has not yet been implemented. These wetlands used to dry off sporadically even before the putting of the Project into operation, nevertheless relatively rich fauna of *Mollusca* existed here (Dobrohošť, 12 species).

A significant change of fauna in the branches cannot be expected due to the existence of variable flowing conditions. There is an ongoing progressive regeneration of original species. Different species can, however have another quantitative occurrence as compared to the pre-dam situation.

2.2 Terrestrial communities

Within the framework of the monitoring of biota on the territory influenced by the Gabčíkovo project several selected groups of terrestric animals were observed, such as *Mollusca - Gastropoda, Isopoda - Oniscidea, Chilopoda, Colembolla, Heteroptera - Pentatomorpha, Coleoptera Carabidae, Staphylinidae, Curculionidae,* butterflies *(Lepidoptera),* birds *(Aves), Mammalia* and others known as sensitive to any change of the environment, e.g., change in soil humidity or in plant cover. Prior to the damming of the Danube these studies had a character of fauna-inventory collection. They had as a goal the establishment of the quantitative and qualitative representation of species of the above-mentioned groups.

Despite the fact that the period after the putting of the Gabčíkovo section of the G/N Project into operation (1993-1994) is too short for a more detailed evaluation of ongoing changes, the results of monitoring can reveal some changes.

2.2.1 Monitoring areas between Bratislava and the reservoir

Monitoring areas on both sides of the Danube between Bratislava and the beginning of the headwater canal - the island Kopáč, the locality Ostrovské lúčky and islands Rusovské ostrovy - have not undergone major changes. The increase of ground water levels in this area is most significant on the island Kopáč and in the locality Ostrovné lúčky, where the ground water level rose in the lowest places by 40 cm. The branch Biskupické rameno was in the past nearly dry, whereas now it is filled up with water.

Monitoring sites in this area, despite the increase of gound water level since 1993, retained their drier, forest-steppe character with a rare dry-thermophilous fauna.

The islands Rusovské ostrovy resemble floodplain forests known from other monitoring sites. They represent well-preserved relics of transitional floodplain forests as the study of their *Mollusca* communities confirm.

Dry and warm areas have preserved their character from the past, they did not undergo major changes in comparison with previous years. This is confirmed by monitoring based studies of terrestrial *Oniscidea*, *Chilopoda*, epigeic *Heteroptera* and butterflies *(Lepidoptera)*, which were not influenced by an increase of humidity on the island Kopáč, nor in the locality Ostrovné lúčky.

From among the monitored groups, only *Curculionidae* reacted more sensitively to the increase of humidity. The originally ascertained spectrum of this species decreased by one third in 1993. The xerophilous species (those adapted to dry conditions) started gradually to disappear.

Also hydrophilous species (species adapted to moist conditions) of *Gastropoda*, concentrated up to now in some humid refuges in this locality, started to react to the change of humidity conditions. Their gradual spreading can be expected.

The ascertained presence of several other species, such as *Cochlicopa lubricella*, *Henia illirica*, *Thyreocoris fulvipennis*, *Vilpianus gallii*, which are indicators of dry and warm biotopes and deserve strict protection confirm, that both localities - the island Kopáč, as well as Ostrovné Lúčky constitute valuable reserves of rare *Mollusca*, *Chilopoda*, *Heteroptera* and butterflies (*Lepidoptera)*.

2.2.2 Monitoring sites in the area of the diversion (between localities Dunajské Kriviny and Istragov)

The changes on monitoring sites in the area of the Danube diversion have been more apparent than in the upstream areas or in the area downstream of the tailrace canal. The evaluation of these changes, based on the results of studies of different groups of animals, is not without ambiguities. The observed changes in communities of selected groups are linked, in the majority of cases, with the process of aridisation at the monitoring sites. This process is most advanced on monitoring sites in the localities Dunajské Kriviny and Královská lúka. As confirmed by results of studies of *Colembolla*, there is a retreat of hydrophilous species and penetration of more tolerant, rather thermo - and xerophillious species.

On the contrary, a certain increase of humidity was recorded on monitoring site Bodícka brána, as manifested by increased occurrence of ecomorphoses of *Hypogastrura* *engadinensis.* It is confirmed also by the occurrence of two species of hydrophilous butterflies *Apatura ilia* and *Lycaena dispar*, never seen here before 1993.

The difference in qualitative and quantitative occurrence of *Heteroptera - Pentatomorpha* was recorded on monitoring sites Dunajské Kriviny and Istragov. On the first site there is a visible decrease of quality and quantity of species characteristic for leaf-litter of soft floodplain forest, in comparison with the years 1991 and 1992. This is related to aridisation on both sites. From among these species, on both localities, only one - *Drymus brunneus* - occurred in 1993, other hydrophilous species were not ascertained.

The monitoring site Istragov was not suitable for epigeic hydrophilous *Heteroptera* in previous years (1991, 1992), because of the high degree of humidity exceeding the optimal limit for their existence. In 1993 the humidity in this area decreased as a consequence of water level drops in the Danube and due to selective cutting of the poplar monoculture. The degree of humidity dropped to a level suitable for the occurrence of epigeic hydrophilous *Heteroptera*, which showed, in 1993, the highest qualitative and quantitative presence. The study of butterflies (*Lepidoptera)* confirms the decrease of humidity in the three above-mentioned areas.

Also the results of a study of *Carabidae* on above-mentioned monitoring sites show the retreat of species requiring humidity and an increase of abundance of humidity less requiring eurytopic species. Species typical for the so-called cultural steppe started to penetrate this area, even if for the moment in small numbers.

These changes can be considered as the beginning of a phase leading to drier types of floodplain ecosystems.

The decrease of humidity at the locality Královská lúka is confirmed by the absence of humid-soil-philous *Curculionidae*, which were ascertained here in 1990-1992. In 1993 more tolerant species from the genus *Dorytomus* started to appear here.

Changes have occurred also in the composition of *Chilopoda*. A retreat of hydrophilous species ascertained here during previous years, started to occur in 1993. The most visible changes in the species spectrum of this group occurred on the monitoring site Dunajské Kriviny. On the other hand, the number of eurytopic specie *Lithobius forficatus* increased considerably (8 times).

The study of terrestric *Gastropoda* in the area of diversion confirmed the supposed retreat of forest species (*Semilimax semilimax, Trichia striolata* and others) mainly at the Bodíky site, where the number of species requiring floodplain forest conditions decreased by about 40% in 1993 in comparison with previous years. On the monitoring site Istragov there is a visible increase of species more or less alien to floodplain forest as *Punctum pigmaeum, Trichia hispida* and others. On the monitoring site Dunajské Kriviny, the number of forest hydrophilous and shore-settled species slightly decreased. No changes were ascertained in the locality Kraľovská lúka.

Studies of small mammals reveal that no changes occurred on the monitoring sites in 1993 and that the species composition is the same as in previous years.

2.2.3 Monitoring sites downstream of the tailrace canal confluence with the Danube

From among monitoring sites in the area downstream of the confluence of the tailrace canal with the Danube, only the locality Sporná Sihot allows different interpretations. The community of *Colembolla* in this area is variable and changes of dominant species are taking place. It can be explained by an excessive lightening of the vegetation cover (cutting of poplars), similar to that in the location Istragov.

Also the studies of butterflies *(Lepidoptera)* indicate the ongoing process of aridisation. This is confirmed by occurrence of some xero- and thermophilous species not ascertained here during previous years. *Melitaea phoebe*, which did not occur here earlier, was for the first time noted in 1993. It is a species indicating dry and warm biotopes. Probably due to cutting of poplars at Sporná Sihot, an increase in abundance of more xerophilous *Gastropoda* was observed. By now a relatively well preserved floodplain forest exists on the monitoring sites Čičov - Starý les (Old forest), with rich communities of observed animal groups, belonging, within the studied areas, among the most valuable ones.

There is no indication that the operation of the Gabčíkovo section of the G/N Project could harm this unique area which deserves most vigorous protection. The timber harvesting as well as all other activities in this area should be carefully regulated.

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Fig. 1: General number of Ciliophora species in different years

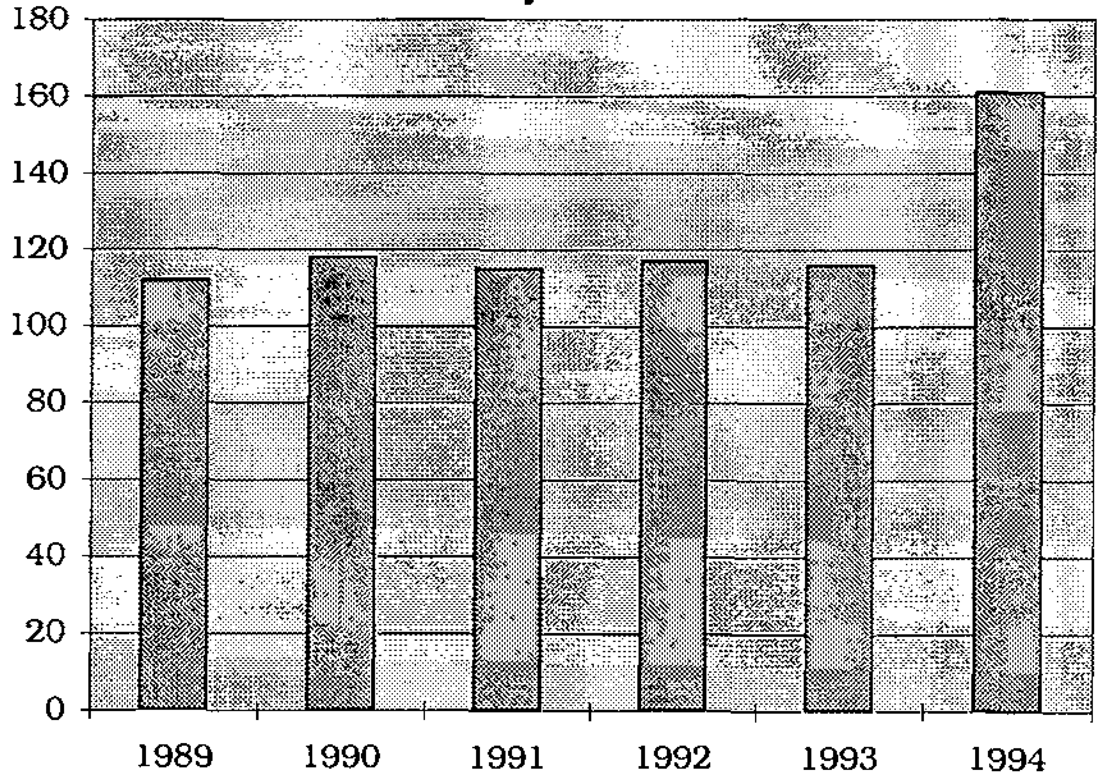


Fig. 2: General percentages of Ciliophora trophic groups in different years

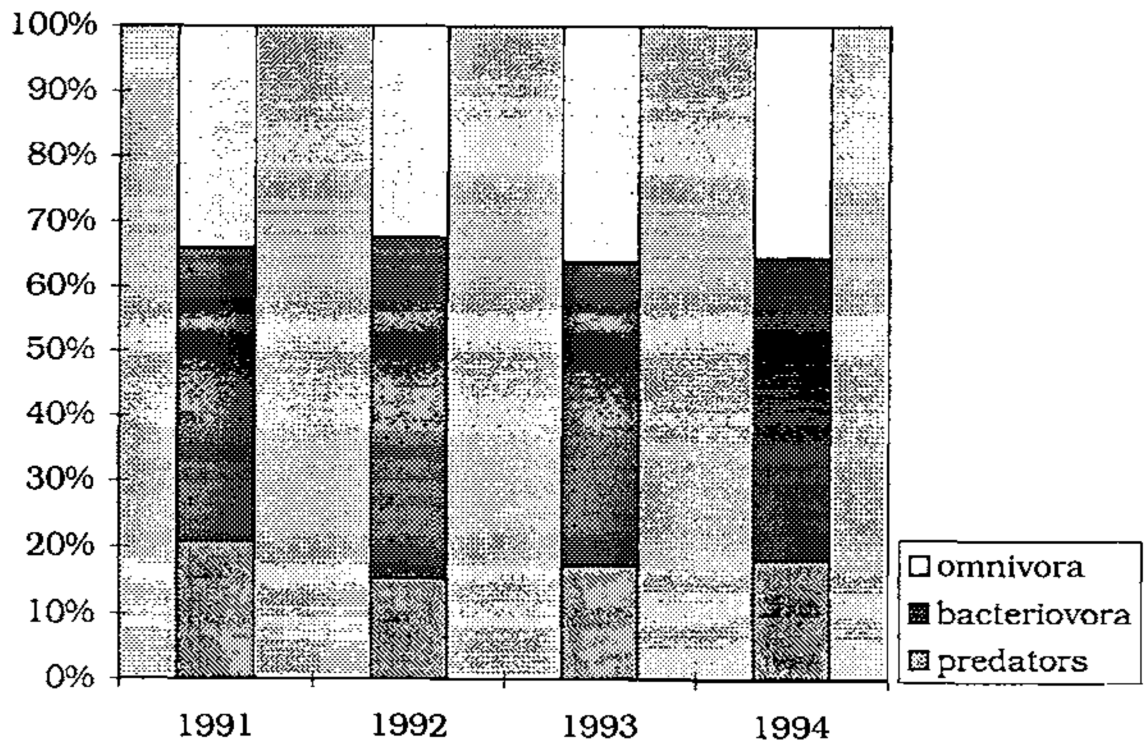


Fig. 3: Mean number of Ciliophora species indifferent years (Istragov-Dunaj)

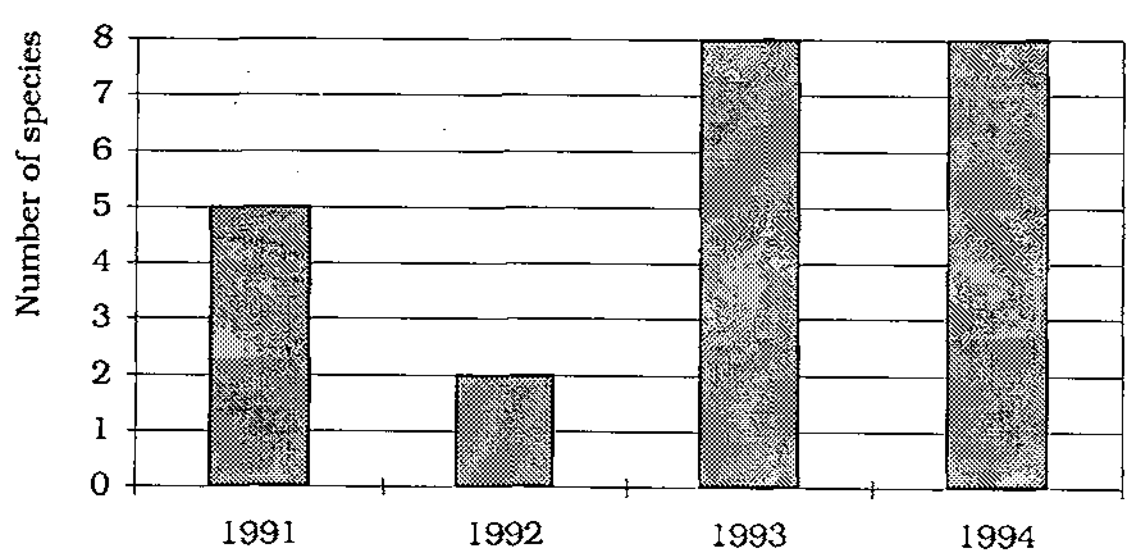


Fig. 4: Mean Ciliophora abundance in different years (Istragov-Dunaj)

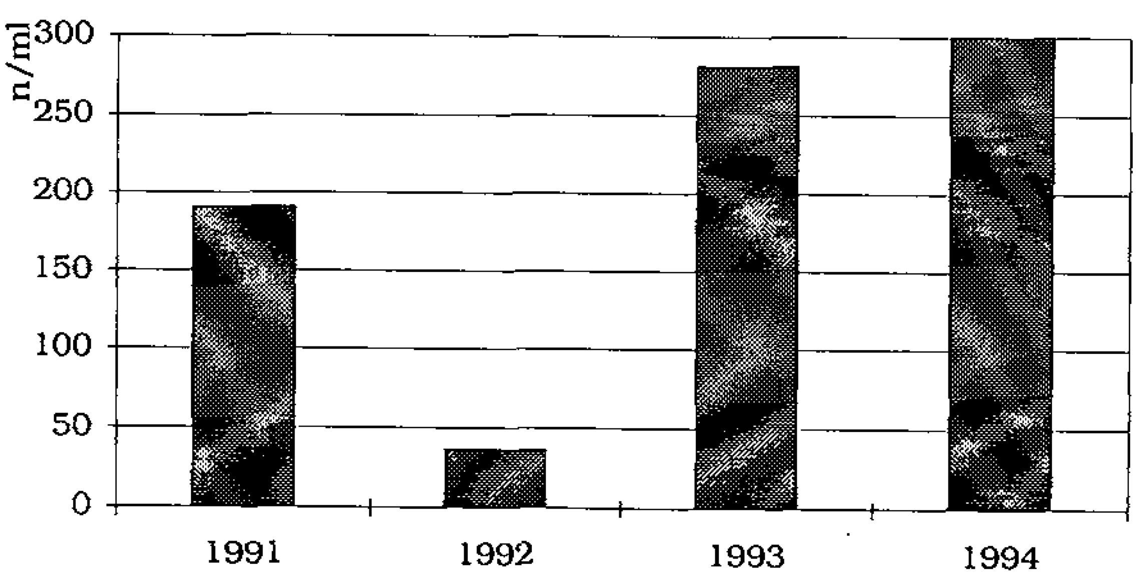


Fig. 5: Percentages of Ciliophora trophic groups in different years (Sporná Sihoť)

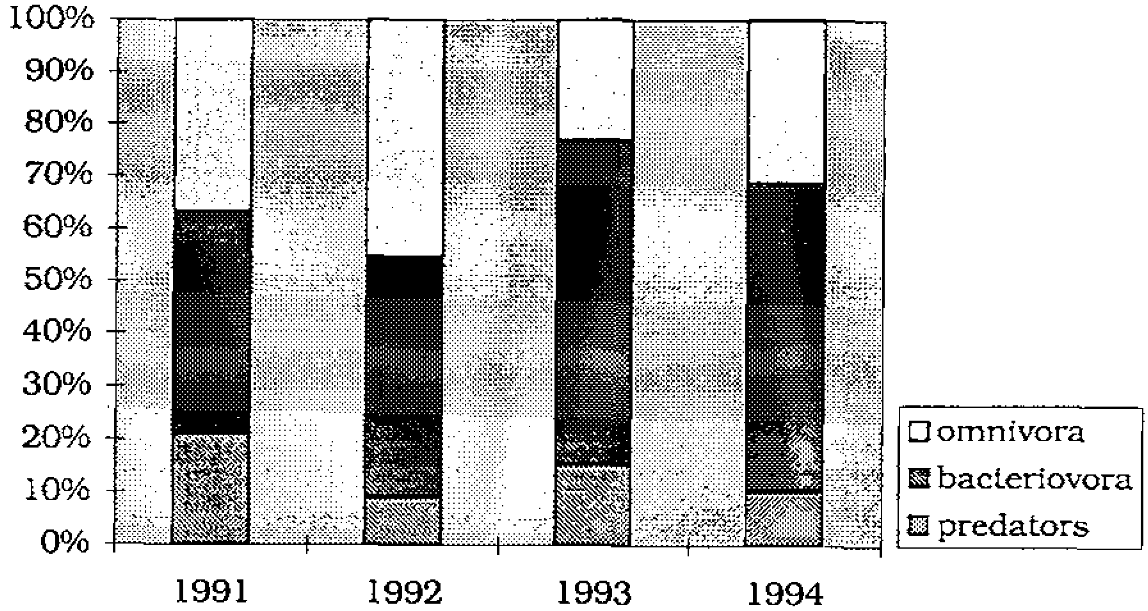


Fig. 6: Percentages of Ciliophora trophic groups in different years (Istragov-Dunaj)

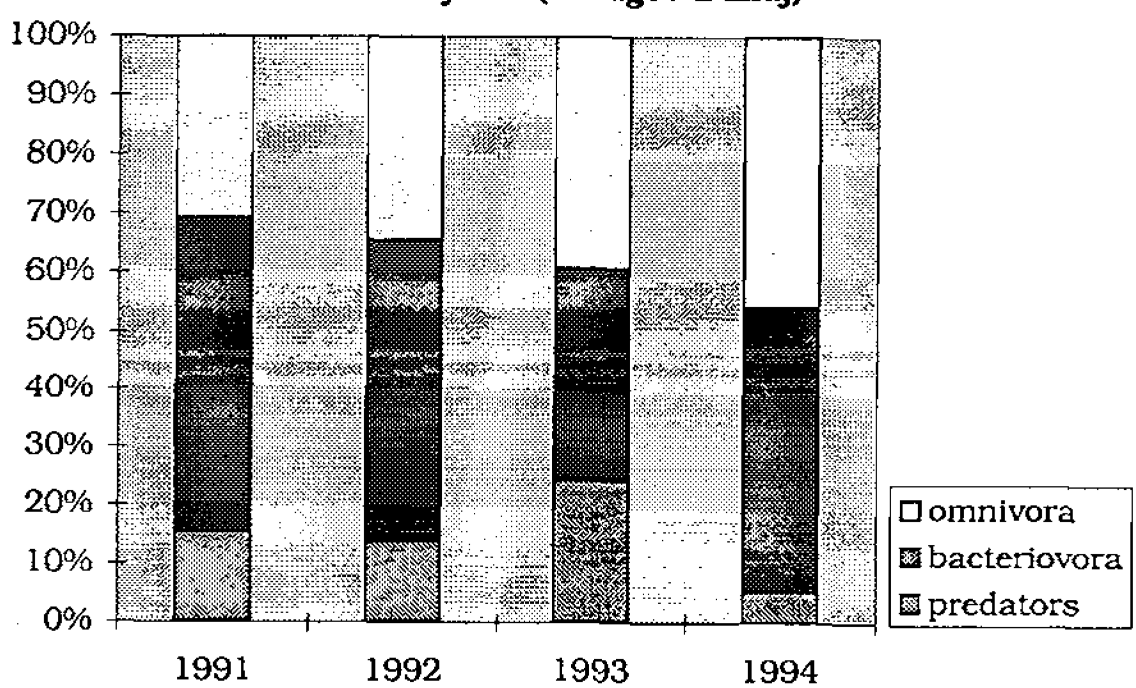


Fig. 7: Abundance of bentic permanent fauna on the main flow bank stones

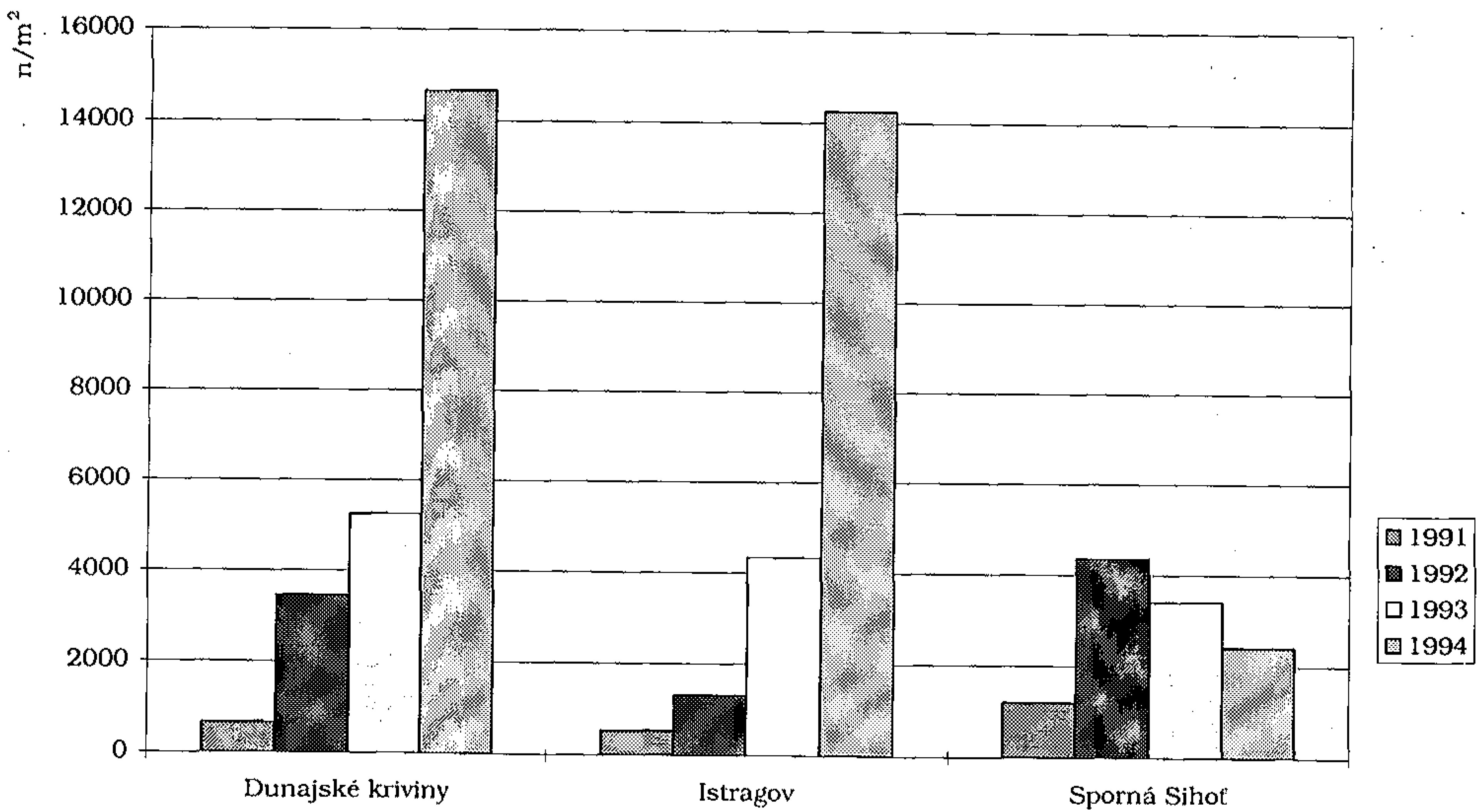


Fig. 8: Mean number of Ciliophora species in different years (Kráľovská lúka)

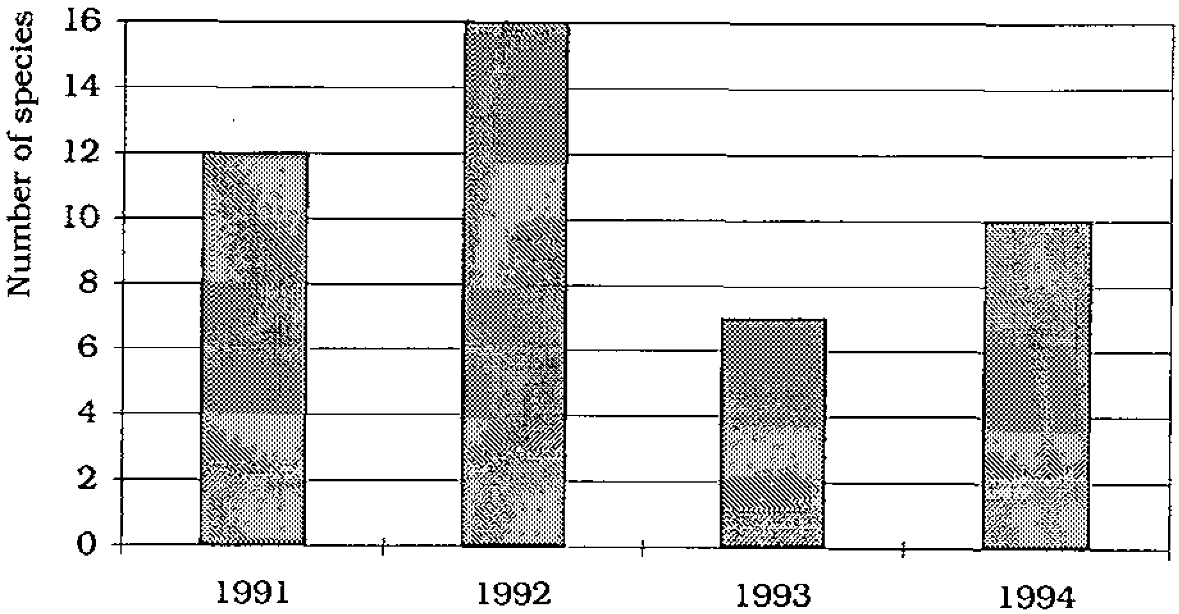


Fig. 9: Mean Ciliophora abundance in different years (Kráľovská lúka)

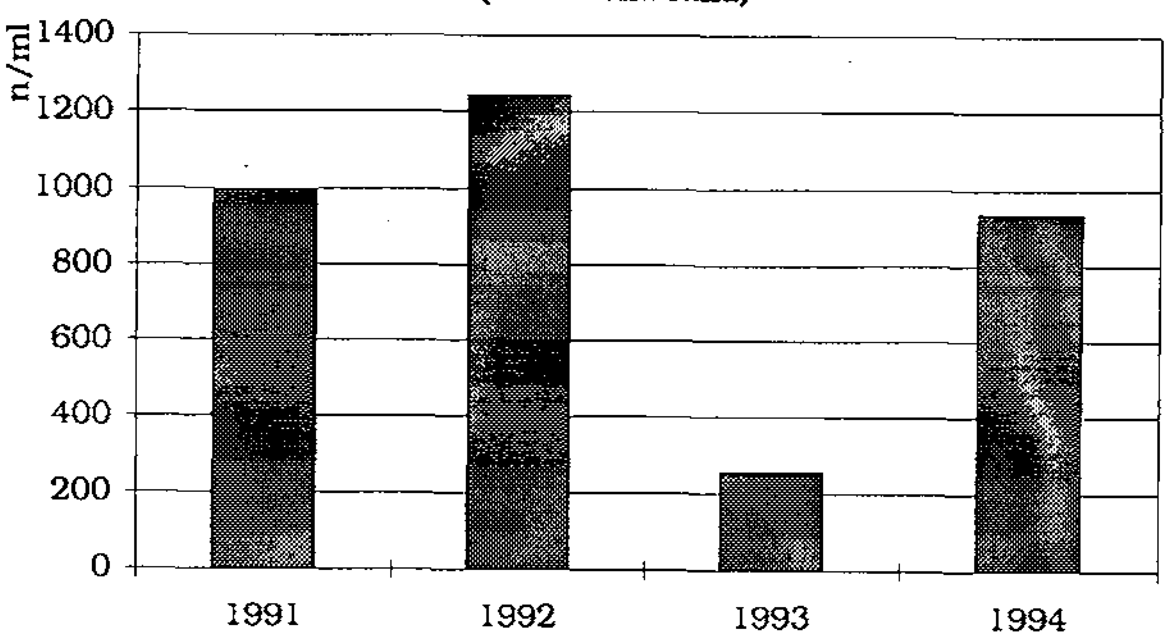


Fig.10. Changes in abundance of trophic guilds of macrozoobenthos (Ephemeroptera, Trichoptera) of the Danube (Dunajské kriviny)

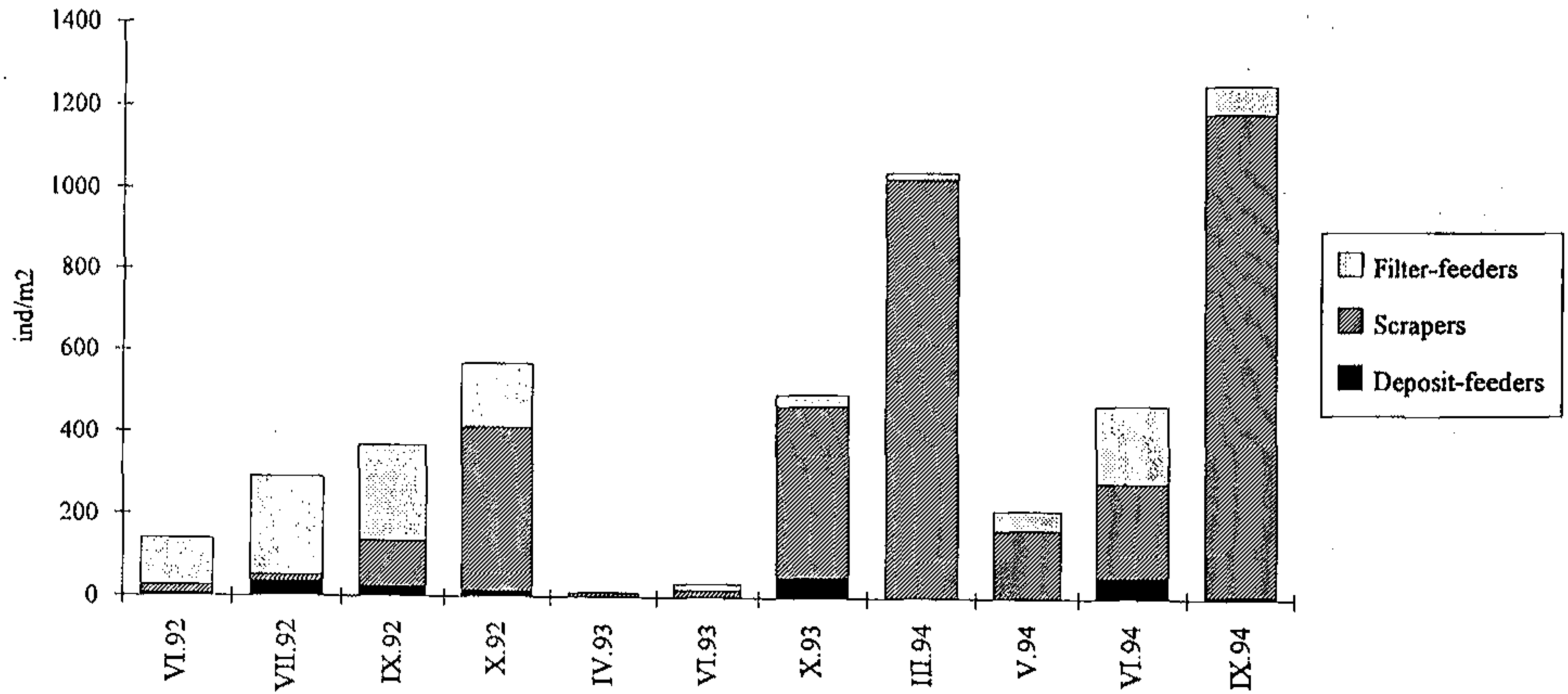


Fig. 11. Changes in abundance of trophic guilds of macrozoobenthos (Ephemeroptera, Trichoptera) of the Danube (Istragov)

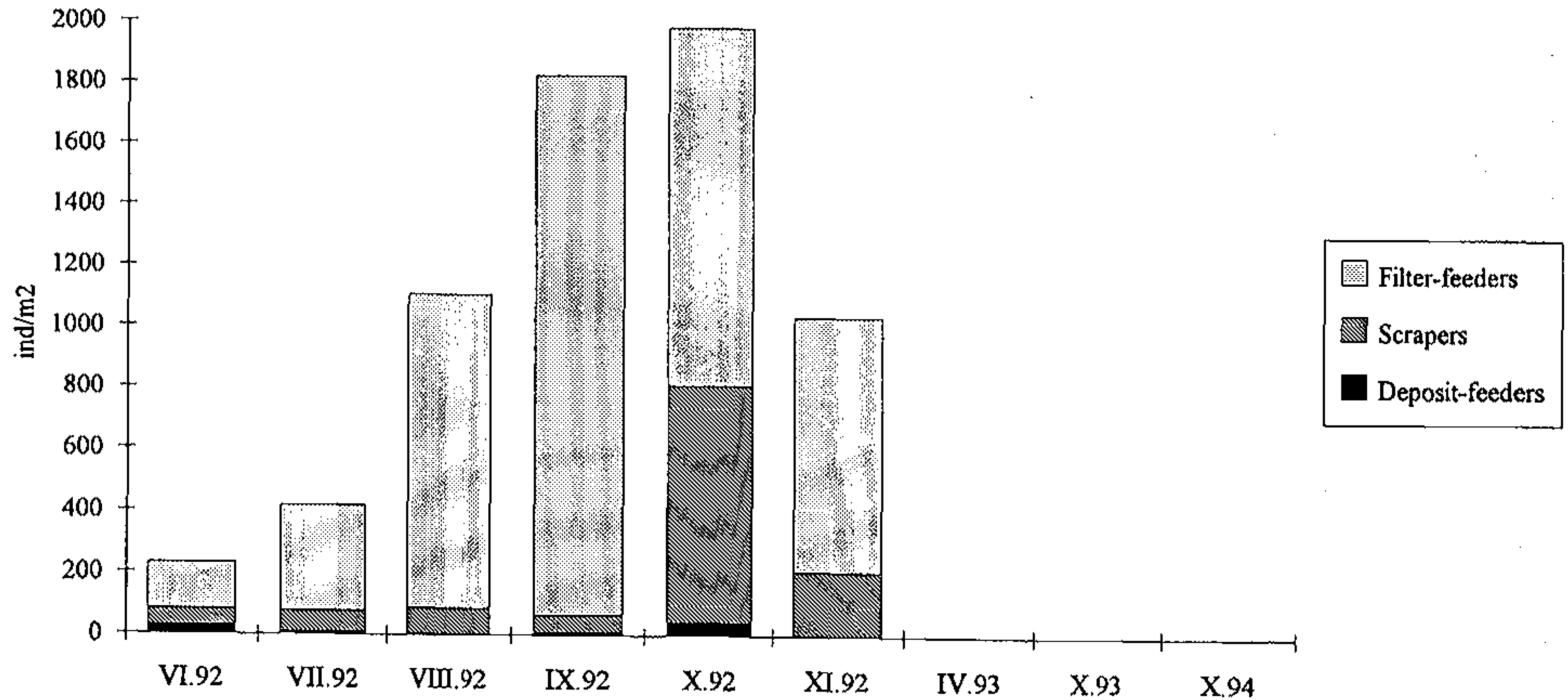


Fig. 12. Changes in relative composition of caddisflies (Trichoptera) taxocenoses of the Danube (Dunajské kriviny - Bodíky)

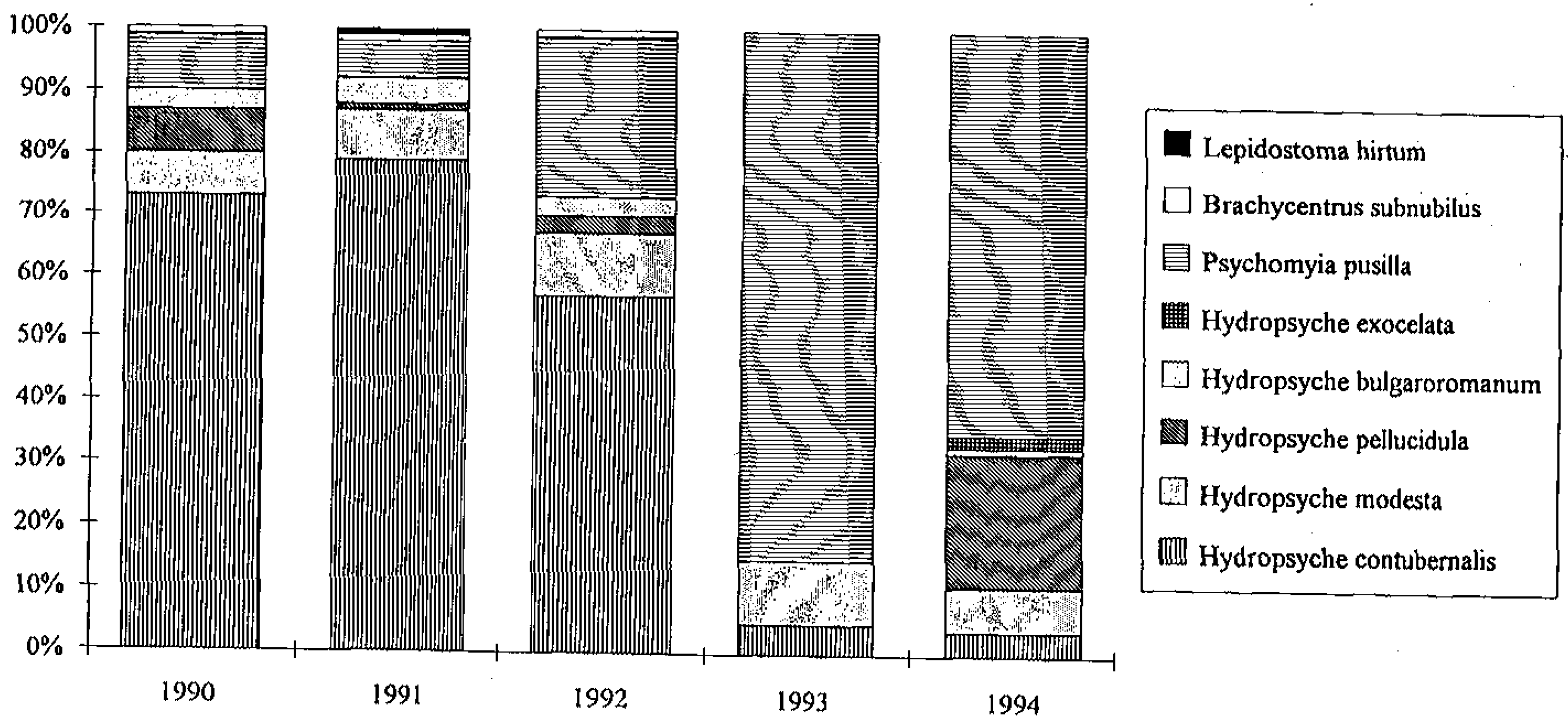
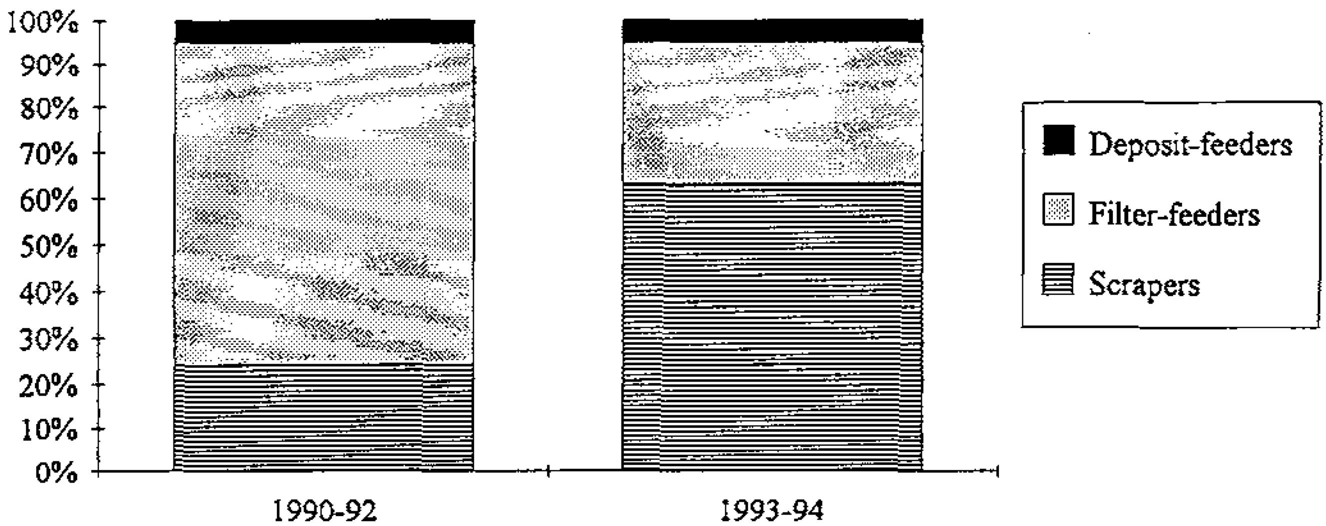


Fig. 13. Changes in relative composition of trophic guilds of macrozoobenthos, based on some water insect groups - mayflies (Ephemeroptera and caddisflies (Trichoptera) of the Danube (Dunajské kriviny - Bodíky)



CHAPTER 6. ICHTHYOFAUNA AND FISHERIES

A. Kirka

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1. The Pre-Dam Situation on the Danube

The regulation of the Danube for navigation purposes had already taken place by the end of the last century. The flow of water from the main channel into the branches was forcibly interrupted.

The changes in hydrological regime had an adverse impact on the Danube fishery, as registered already by Heckel (1851) and Kornhuber (1863).

The construction of the barrages on the submountain part of the Danube and the deepening of the Danube riverbed for navigation purposes changed considerably the hydrological regime of the Slovak section of the river. The substantial changes in transport of bedload and its deposition occurred over a major part of the river causing the progressive sinking of the riverbed.

In the section between Bratislava and Hrušov, during periods of low discharges, the branches used to drain totally and dry up. In the middle and lower part, branches got smaller during the periods of drought. Only at discharges of 2 300 m^3/s and higher, did water flow into branches. At discharges 5000 - 6000 m^3/s, the branches were filled up to the banks (3 - 5 days/year) and only at discharges over 6000 m^3/s was the whole inundation area between the dykes flooded (2 days in average).

This had a negative impact on the water level in the branch system and subsequently on fisheries, whose output decreased progressively. Later a significant deterioration of water quality resulting from extensive industrialisation occurred as well. In 1973, the water quality at the river inlet on the Slovak territory reached 4th degree in quality (alfamezosaprobia). Besides the above-mentioned factors, there was an excessive catch of some fish species.

1.1 Ichthyofauna

According to literature (Balon, 1967), the ichthyofauna of the Danube in general and especially in the Slovak section was already considerably affected in the 1960s. The decrease of rheophilous, litophilous and economically preferred species was registered. The species Huso huso, Acipenser stellatus, A. nudiventris progressively disappeared from the ichthyofauna of the Slovak-Hungarian sector of the Danube, the species Acipenser ruthenus and A.güldenstädti, Cyprinus carpio, Silurus glanis, Esox lucius, Stizostedion lucioperca, Aspius aspius, Barbus barbus, Hucho hucho and Salmo trutta m. fario occurred more rarely. This was a consequence of man's activities manifested by permanently high catch, river regulation and pollution.

On the other hand, intentionally or accidentally new species, previously unknown, were introduced or appeared in the Danube, such as Oncorhynchus mykiss, Coregonus lavaretus, Ctenopharyngodon idella, Aristichtys nobilis, Hypophtalmichthys molitrix, Ictalurus nebulosus, Gasterosteus aculeatus, Micropterus salmoides, Lepomis gibbosus. Thus in the 1970s there were 61 species belonging to 15 families in the Slovak-Hungarian sector of the Danube (Holčík et al.1973, Kirka, 1994).

1.2 Fisheries

On the basis of studies performed during a period of 30 years by the former Institute of Fishery Research and Hydrobiology in Bratislava, reliable data on the number and biomass and partial data on fish production in this section of the Danube have been collected. In stationary, periodic waters, the ichthyomass reached an average of 260 kg per hectare, in the branches of the parapotamal type, it reached 400 kg per hectare and in the branches of plesiopotomal type, following a reduction in water area, up to 1200 kg. In similar branches near the source of pollution, there were only 60 kg and in the main channel only 35 kg of ichthyomass per hectare. The low ichthyomass of the main channel was caused by high flow velocity, shifting bottom, high turbidity and low density of food organisms.

The annual fish production could be characterised similarly. In the main channel, its average value was 18 $kg.ha^{-1}$. In the branches it was about 200 kg. The three most numerous species were Alburnus alburnus (bleak), Rutilus rutilus (roach) and Gymnocephalus cernuus. Their ratio was 89.10 % of the total abundance and 80.66% of the total ichthyomass, respectively. The ratio of economically preferred species was 0.49 - 0.55% of the total number and 3.15 up to 3.30% of the mass of the whole ichthyocenosis. The secondary species represented 0.88 - 6.27% of the total number and 6.89 - 11.54% of the whole ichthyomass. The accompanying species represented 98.63 - 93.18% of the number and 89.96 - 85.16% of the mass. The number of species varied between 19 and 29.

The ichthyocenoses were in an unbalanced state with a predominance of non-predator species over predator species in a very unfavourable ratio. This had negative consequences such as the decrease in production, progressive decrease of valuable species, and decreases in economic value of ichthyocenosis and total catch (Bastl, Holčík, 1972).

2. Situation After Damming of the Danube (Variant "C")

The Gabčíkovo part of the G/N Project, as implemented under Variant "C", consists of the reservoir which was created behind the weir built up near Čunovo, the headwater canal leading to the hydroelectric power plant in Gabčíkovo, seepage canals, the tailwater canal, the old riverbed of the Danube between the villages Čunovo and Palkovičovo and the branch systems.

2.1 Ichthyofauna

2.1.1 Reservoir

The reservoir which has been created behind the Čunovo weir is, in comparison with the original Project, shorter and, in the lower part, narrower. The daily fluctuation of water level is minimal with the water level at 130 m a.s.l. The hydroelectrical power plant is being operated in constant mode. This means that there is relatively short retention time of water and fast exchange of its volume. The reservoir represents, in essence, a several times enlarged riverbed of the Danube. Due to the lower velocity of flow, some sedimentation of suspended load and bedload occurs in certain parts of the reservoir. The water temperature shows some differences, but in principle, it corresponds to original values. No temperature stratification occurs.

The species composition and biomass of zooplankton are similar in most parts of the reservoir, and higher than in the main channel of the Danube. The biomass of phytoplankton increases especially in lenitic places.

As far as the quantitative composition of macrozoobenthos is concerned, the research confirms the realism of prognoses made by some ecologists (Rothschein, 1976) in the period before the construction of the system of water works on the basis of experience from reservoirs on the German and Austrian sectors of the Danube. The abundance of macrozoobenthos have reached in average 22,563 specimen on m^2 in the upper part of the reservoir and even 76,368 specimen on m^2 in the lower part of the reservoir. The biomass reached in the upper part of the reservoir in average 167.9 $g.m^2$ and 335.1 $g.m^2$ in the lower part of the reservoir. These values of biomass confirm high productivity of the Danube in the area of the reservoir (Nagy, Šipoš, 1994).

No great changes have occurred in the species of ichthyofauna of the reservoir as compared to the main river flow (Tab.1). It is supposed that the occurence of typical rheophilous species, e.g., Rutilus pigus virgo, Pelecus culturatus, Zingel zingel, Zingel streber and Cottus gobio will decrease. Populations of such species as Barbus barbus, Vimba vimba, Chondorostoma nasus, Stizostedion lucioperca and others will appear. In parts of the reservoir where the flow is lower, increase in population of phytolitophilus species, e.g., Perca fluviatilis, Alburnus alburnus, Rutilus rutilus, Abramis bjoerkna, Abramis brama, Gymnocephalus cernuus can be expected.

The occurrence of economically preferred species such as Stizostedion lucioperca and Silurus glanis will increase. The species Esox lucius, Cyprinus carpio and Tinca tinca will be dependent on water purity and the stability of the water level, especially during the spawning, early development and growing periods. An increase in the number of Acipenser ruthenus can be expected, too. Most likely, the predominant fishes will be the species Leuciscus cephalus, Abramis brama, Vimba vimba and Chondrostoma nasus (Kirka, 1994).

Due to the construction of the weir and bypass canal, the reservoir becomes practically an isolated ecosystem from below, with ichthyocenoses dependent on their own reproduction, on the system of their control and seasonal migration from the upper situated sections of the Danube and the lower part of the river Morava.

2.1.2 Headwater Canal

It is not expected that large amounts of important sustainable ichthyocenoses will be formed in the headwater canal. The bottom and banks of the canal are smooth, and do not provide necessary hiding places for fish. On the other side, there are some places where, in particular, salmonids and other rheophilous species are concentrated. The negative impact of the headwater canal on the ichthyofauna of the reservoir consists of the above mentioned features.

2.1.3 Seepage Canals

The thermal regime of the water of seepage canals is different from the thermal regime of the Danube and it is distinguished by greater uniformity of temperature, which does not fall below 4 ^{0}C in winter, and does not rise above 15 ^{0}C in summer. The water quality is classified in the IA and IB classes. Both canals were relatively quickly grown over with submersed vegetation. Good living conditions led to the creation of a rich benthic zoocenosis and, subsequently, an ichthyocenosis composed of about 25 species, including salmonids as predicted in earlier studies (Kirka, 1988).

2.1.4 Tailrace Canal

A steady hydrocenosis is formed successively with the predominance of species seeking for a lotic environment as the flow speed and water volume is greater here than in the old riverbed. After putting the Gabčíkovo waterwork into operation, conditions similar to those in the main channel were created here. Already during the winter months of 1994, species like Abramis sapa, Abramis ballerus, Abramis bjoerkna, Abramis brama, Vimba vimba, Chondrostoma nasus, but also Stizestedion lucioperca, S. volgense and Esox lucius were caught here, together with such species as Acipenser ruthenus and Pelecus cultratus.

The tailrace canal provides acceptable conditions for spawning of majority of litophil potamophils. This ichthyofauna is in continuous formation. The number of fish species confirmed to date is 24 (Tab.1), (Kirka, 1994).

2.1.5 Old Riverbed of the Danube

After the damming of the Danube, the old riverbed between Čunovo and Palkovičovo has smaller discharge, lower flow velocity, and higher water purity as a consequence of partial sedimentation in the reservoir. Its bottom has become more stable during the season and consequently the fauna of macrozoobenthos is now richer. The food base for fish is also richer, although the structure of benthos is being gradually rebuilt.

An intensive sedimentation of drifted components occurs in certain areas in the lower part of the old channel due to the broad and shallow riverbed and slower flow. Due to this fact, the ratio of oligochets increased, and the number of amphipods and trichopters decreased.

During monitoring in 1993, the presence of 35 fish species in the old riverbed was confirmed, including rheophilous species: Oncorhynchus mykiss, Salmo trutta m.fario, Coregonus lavaretus, Abramis sapa, A.ballerus, Chondrostoma nasus, Leuciscus cephallus, L. idus, Vimba vimba, Silurus glanis, Lota lota, Gymnocephalus baloni, Gymnocephalus schraetser, Stizostedion lucioperca, S. volgense. Zingel streber, Z. zingel, Proterorhinus marmoratus, Cottus gobio and other species (Kirka, 1994), (Table 1).

Changes in the ichthyofauna concern only some habitats of the littoral zone of the old riverbed.

2.1.6 Branch Systems

Under original conditions, the branch systems fulfilled very important functions. During long lasting and high discharges, the area of fish production increased. Nutrients found in soils were transferred into the water and contributed to the dynamic development of phyto-and zooplankton.

This complicated, but effective, mechanism began to be affected in the 1950s and was later disrupted. Since the end of the 1950s, fish eggs deposited on submersed plants at the bank line have often dried up because of sudden water falls. Moreover, although inundation occurred and continued to occur periodically, the periods of inundation did not correspond to spawning periods from a thermal point of view. This means that the spawning of the fish did not occur during optimal conditions of inundation.

Despite the fact that it is not yet possible to assure the interconnection between the old riverbed and the branch systems on both sides of the Danube (which could partially contribute to the restoration of conditions similar to natural conditions), the implementation of measures aimed at the water supply of the branch system on the Slovak side has made it possible to eliminate several negative factors from the past by enabling:

a) free entry of migrating fishes into the branch system from the downstream sector,

b) realisation of at least 2 floodings of inundation area around the branch system:

- in the first period, at water temperature of 5-7°C, the water level should be increased for the period of 4 weeks, to enable reproduction and breeding of main predatory phytophilous species,
- in the second period, at the temperature of 14-17° C, water level should be increased also for the period of 4 weeks, to enable reproduction and breeding of carp and other phytophilous species. Recurrence of fresh floodings will prevent excessive oxido-reduction processes in the branches and destruction of fish species.

c) maintenance of optimum water level in the winter period: this will guarantee minimal mortality during fish hibernation,

d) temporary decrease of water levels in autumn period: this will make possible realisation of intensive catch of economically preferred species (with large eye nets),

e) elimination of rescue catch of young fish during the periods of drought.

Moreover, the flow in the main branches will improve the composition of ichthyocenoses to the benefit of potamophils belonging to secondary and economically preferred species.

Due to certain sedimentation in the reservoir, the transparency of water flowing into the branch system has increased moderately. Turbidity caused by anorganic particles (suspended load) decreased substantially. Water has some vegetation turbidity due to mild phytoplankton. The growth of higher water plants will be prevented by higher vegetation turbidity and by deepening of the branch system. The number of predatory phitophilous fishes will increase. The danger of eutrophication, anaerobic conditions and fish destruction is lower, the water flow being guaranteed.

Monitoring in 1993 has confirmed the presence of 29 fish species occurring in the system, despite the short period of monitoring and limited number of monitored localities. The regular occurrence of 55 fish species is supposed (Table 1).

2.2 Fisheries

The prognosis of the development of ichthyocenoses after the construction of water works on the Danube was prepared in the framework of the "Research of composition and catch of fishes in reservoirs and rivers (flowing waters)". It was stated that:

> "by realizing the by-pass variant, instead of one system of biotopes (river, system of branches, inundation area), new biotopes will originate (reservoir, by-pass canal, old riverbed and system of branches). From them only system of branches and reservoir are of importance for fishery. But only under condition that the system of branches would be supplied with seepage or gravitation water, (...). If the existence of branches is preserved, then their importance from the point of view of fisheries will substantially rise. Instead of today's total ichthyomass of 291 tonnes, available production of 146 tonnes and possible catch of 49 tonnes, due to constant hydrological regime and improved temperature conditions the ichthyomass could reach 485-679 tonnes, available production could be 243-320 tonnes and real annual catch 78-107 tonnes. All this requires to pass since the beginning on the half-intensive fish production" (Holčík, et al. 1973)

The conclusions of this research report, it is true, underestimated the importance of reservoir, and in particular of the filling with water of already dried branches near Podunajské Biskupice and Rusovce as well as the creation of extensive spawning and feeding areas in the upper part of the reservoir. Nevertheless - and this is decisive - it did not focus solely on the conservation of already substantially changed conditions of the river in the whole area of inland delta but recommended a half-intensive system of fishery production in the branches.

The recent results of the direct water recharge in the left side inundation area confirms the view that existing technical equipment makes possible the solution of all problems connected with the derivation of the river. The water discharge into the branch system has enabled the revitalisation of dead branches of the parapotamal and plesiopotamal type and maintains these filled up with water, according to needs and their character, during the whole year.

The intake structure of the branch system makes it possible to control water levels in the branches, i.e., to control the flow and length of time (according to water temperature), during which the spawning and early development of young specimens and their nutrition can take place. This is important from the point of view of the phylogenetic adaptation of fishes, in that it develops their food basis and reduces mortality of young specimens especially in the winter period. Thus the conditions of fishery will be improved in this section of the river.

The new solution of the system of branches thus offers the possibility of effective investment into fishery and fish production through the controlled application of appropriate fish fries and catch at the end of the season. The value of production and possible catch will increase at least three times due to the change of species composition of ichthyofauna in favour of economically preferred species and they will become comparable with the fish production in ponds of second class.

3. Comments on Fishery Losses in the Szigetköz Area

3.1 General Comments

As follows from the above mentioned data concerning ichthyocenosis of the joint Slovak-Hungarian section of the Danube, there has been a substantial predominance of non-predatory species over predatory species in an unfavourable ratio. It resulted in a more intense food competition among non-predatory species due to their overpopulation, decrease of growth and production, progressive reduction of precious species and thus decrease of economic value of ichthyocenosis and catch.

These facts inspired the Danube countries in 1958 in creating the Mixed Commission for application of the Convention concerning fishing in the waters of the Danube. The countries committed all parties to respect the rules of fishing and maintenance of fish basis as well as to increase intensive production of fish of economic importance. There is a rule that for each 1 tonne of economically preferred species caught there must be the stocking of 1000 small fish of a mass less than 250g per individual.

No exact measurements were made by Hungary in the concerned area of the Danube during the last years that would allow an acceptance the relative values of losses of available production of fish, claimed by Hungary. The decrease of density of ichthyocenosis occured in autumn 1992 at low water level, when a substantial part of the ichthyocenosis emigrated from the branch system. The washing out of the substantial remaining part of ichthyocenosis from the branch system occurred during the diversion of the Danube. Parts of the ichthyocenosis were partially caught and partially kept in terrain depressions.

The real causes of the worsening of fish production began much earlier and were more complicated than mentioned in the Hungarian Counter-Memorial.

As stated in para. 3 of the protocol of 29th session of the Mixed Commission for application of the Convention concerning fishing in the waters of the Danube (3-10.4.1989):

> "The hydro-meteorological conditions were generally unfavourable in the mentioned period (1987 and 1988). They were characterized by a strong and long winter 1987, short period of inundation with maximum in the last part of April 1988. These unfavourable conditions together with higher pollution influenced negatively reproduction and growth of fish, especially economically important sorts of fishes.
>
> The Mixed Commission stated that less fish was caught in the Panonian basin, especially in the joint Czechoslovak-Hungarian section of the river due to worsened ecological conditions."

The protocol of the 30th session of the Mixed Commission for application of the Convention concerning fishing in the waters of the Danube (2.-6.4.1991), para. 3 states:

> "The hydrological conditions were especially unfavourable in the mentioned period (1989 and 1990). They were characterized by low water level and higher pollution,

what influenced reproduction and growth of preferred fish species. The Mixed Commission stated that due to ecological situation, the catch substantially decreased for most state parties".

Further, in para. 5.1., it stated:

"The Mixed Commission listened to the reports of the Hungarian, Czechoslovak and Yugoslav sides on results of fisheries in the Panonian basin and stated that the catch of majority fishes in 1989 and 1990 decreased due to the low water level in the Danube which caused the isolation of branches." ...

"The Hungarian side informed the Mixed Commission that the worsening of conditions for fishes in the Danube was not connected only with worsening of hydrological conditions, but also with the construction of river projects on the Danube in Germany and Austria what limited the migration and development of higher number of economically preferred species."

In paras 2 of both protocols, it is stated that:

"It follows from the reports of state parties that the total catch was in 1987 12 849,5 tonnes and in 1988 13 406,1 tonnes. In comparison with the average catch in the years 1985 - 1986, i.e. 14 219,0 tonnes, the catch in 1987 and 1988 was lower of 1 370,2 tonnes, respectively 813,6 tonnes". ...

"It ensues from the reports of state parties that the total catch of fish in 1989 was 9 983,8 tonnes and in 1990 8 850,1 tonnes. It is 3 134,6 tonnes, respectively 4 268,4 tonnes less than in 1988. This decrease was caused by unfavourable hydrological conditions".

On the basis of the official data of the Mixed Commission for application of the Convention concerning fishing in the waters of the Danube, the calculations presented by Hungary at pp. 189 - 192 of vol. 2 of its Counter-Memorial cannot be considered as correct:

a) The total catch of fish in the Danube represented in 1987 90% of the average catch in the years 1985 - 1986, 94% in 1988, 70% in 1989 and only 62% in 1991.

This important decrease of the fish catch was evidently caused by bad climatic and hydrological conditions together and not by local changes of topography of the river in the area of the Project.

b) The situation in the years 1989 - 1990 was the basis of the decrease of fish catch in the years 1991 - 1992 and it also influenced following years. This fact must be taken into consideration.

c) The estimations of abundance, ichthyomass and available production do not take this fact into consideration for the period after damming of the Danube and therefore they would have to be lowered by 30-50%.

d) No account is taken of the statement of Hungarian experts in the Mixed Commission for application of concerning fishing in the waters of the Danube concerning the negative impact of the barrages in Germany and Austria on fishery in the Hungarian-Slovak section of the river.

4. The Alleged Fish Destruction on 30 July 1994

At the end of July 1994, the following values, characterising actual conditions, were registered in the lower part of the reservoir:

Water temperature:

The Danube in Devín (25.7.1994): 21.0°C.
The Danube in Gabčíkovo 18.8°C.
By-pass canal in Dobrohošť: 22.5°C.
Branch system in Vojka: 22.7°C.

The Danube in Devín (1.8.1994): 22.4°C.
The Danube in Gabčíkovo 19.4°C.
By-pass canal in Dobrohošť: 22.6°C.
Branch system in Vojka: 24.6°C.

Water discharge:

The Danube in Devin (29.7.1994): 1381 m^3/s.

The old riverbed of the Danube: 210 m^3/s.

Intake into the Mosoni Danube: 19 m^3/s

Intake into the left-side system: 18 m^3/s.

The content of dissolved oxygen: (Makovinská, J., Luther, S.,1994: The oxygen regime and primary production of phytoplankton of the Hrušov reservoir. Final report, VÚVH, Bratislava.)

Reservoir at Čunovo

L = level

M = middle

B = bottom

Date	Time (hour)	Depth (m)	O_2 (mg/l)	Temperature (0C)	Sat. (%)
19.7	5.15	L 0.5	8.2	21.8	94.3
		M 2.5	8.2	21.8	94.3
		B 5.0	8.1	21.8	93.1
	11.58	L 0.5	7.9	21.4	90.1
		M 2.5	8.2	21.3	93.3
		B 5.1	8.1	21.2	91.9
2.8.	5.05	L 0.5	8.8	23.7	105.0
		M 2.3	8.5	23.7	101.4
		B 4.8	8.5	23.6	101.2
	12.00	L 0.5	7.9	23.1	93.2
		M 2.5	8.3	23.1	97.9
		B 5.0	8.3	23.2	98.1

Water level in the reservoir: in metres above sea level

29.7.1994: 129.17 m, 30.7.1994: 129.15 m,

31.7.1994: 129.11 m, 1.8.1994: 129.03 m

On the basis of these values it can be concluded :

a) The water level in the reservoir on 30 July 1994, as well as before and after this date, was stabilised on the quota 129.03 - 129.17 m a.s.l.

b) The water discharge into the old riverbed was stabilised at 210 m^3/s

c) The water temperature corresponded to temperature determined in the main water flow at Devín and it was still normal.

d) The quantity of dissolved oxygen was higher than 8 mg/l which responded to 90 - 94% of saturation at actual water temperature.

On 4 January 1995 Ing. A.Kirka and Ing. Ján Vincent determined in the main riverbed, in the section of Dunakiliti weir groups of thousands of 0+ and 1+ young fish. The determination - + of species is being done today.

These facts evidently contradict the so-called considerable fish destruction of 30 July 1994.

With regard to these values and to the fact that the Slovak side did not register any fish mortality and the Hungarian side did not report any fish mortality to the Slovak specialised institutions, the alleged "serious fish destruction" seems unlikely to have taken place. If no method of estimation of dead fish is indicated, the said ichthyomass is not reliable. Thus the whole claim cannot be accepted. There is no justification for attributing the alleged fish destruction to Variant "C" in any event.

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Table 1.

Actual state of ichthyofauna on the territory affected by the construction of Variant "C" (Slovak side).

(+) probable occurrence, (++) confirmed occurrence,
(-) the occurrence is not supposed, (?) uncertain occurrence

	Species	Reservoir	Tailrace canal	Orig. r.bed	Branch system
I. ACIPENSERIDAE					
1.	Acipenser ruthenus (Linnaeus, 1758)	+	++	+	+
II. SALMONIDAE					
2.	Hucho hucho (Linnaeus, 1758)	-	+	?	?
3.	Oncorhynchus mykiss (Walbaum, 1972)	+	++	++	+
4.	Salmo trutta morpha fario (Linnaeus, 1758)	+	++	++	+
5.	Salvelinus fontinalis (Mitchill, 1815)	-	+	?	-
III. COREGONIDAE					
6.	Coregonus Lavaretus (Linnaeus, 1758)	+	+	++	+
7.	Coregonus peled (Gmelin, 1788)	+	+	-	+
IV. ESOCIDAE					
8.	Esox lucius (Linnaeus, 1758)	+	++	++	++
V. UMBRIDAE					
9.	Umbra krameri (Walbaum, 1792)	-	-	-	+

VI. ANGUILLIDAE

10.	Anguilla anguilla (Linnaeus, 1758)	+	++	+	+

VII. CYPRINIDAE

11.	Abramis ballerus (Linnaeus, 1758)	+	-	++	+
12.	Abramis bjoerkna (Linnaeus, 1758)	+	-	++	++
13.	Abramis brama (Linnaeus, 1758)	+	-	++	++
14.	Abramis sapa (Pallas, 1811)	-	-	++	+
15.	Alburnoides bipunctatus (Bloch, 1782)	-	-	+	+
16.	Alburnus alburnus (Linnaeus, 1758)	+	++	++	++
17.	Aristichthys nobilis (Richardson, 1844)	+	+	+	+
18.	Aspius aspius (Linnaeus, 1758)	+	++	++	++
19.	Barbus barbus (Linnaeus, 1758)	+	++	++	++
20.	Carassius auratus (Linnaeus, 1758)	+	++	++	++
21.	Carassius carassius (Linnaeus, 1758)	+	-	?	+
22.	Chondrostoma nasus (Linnaeus, 1758)	+	++	++	++
23.	Ctenopharyngodon idella (Valencien. 1844	+	+	++	+
24.	Cyprinus carpio (Linnaeus, 1758)	+	+	++	++
25.	Gobio albipinnatus (Vladykovi Fang, 1943)	+	+	+	++

26.	Gobio gobio (Linnaeus, 1758)	+	+	+	+
27.	Gobio kessleri (Dybowski, 1862)	-	+	+	+
28.	Gobio uranoscopus friči (Vladykov, 1929)	-	+	+	+
29.	Hypophthalmichthys molitrix (Valen 1984)	+	+	++	+
30.	Leucaspius delineatus (Heckel, 1843)	+	-	-	+
31.	Leuciscus cephalus (Linnaeus, 1758)	+	++	++	++
32.	Leuciscus idus (Linnaeus, 1758)	+	++	++	++
33.	Leuciscus leuciscus (Linnaeus, 1758)	-	+	+	+
34.	Pelecus cultratus (Linnaeus, 1758)	?	++	++	+
35.	Pseudorasbora parva (Schlegel, 1842)	+	+	+	+
36.	Rhodeus sericeus (Pallas, 1776)	+	-	+	++
37.	Rutilus frisii meidingeri (Heckel, 1852)	?	+	+	-
38.	Rutilus pigus (Lacépede, 1804)	+	+	++	+
39.	Rutilus rutilus (Linnaeus, 1758)	+	++	++	++
40.	Scardinius erythrop. (Linnaeus, 1758)	+	+	+	++
41.	Tinca tinca (Linnaeus, 1758)	+	+	++	++
42.	Vimba vimba (Linnaeus, 1758)	+	++	++	++

VIII. COBITIDAE					
43.	Cobitis taenia (Linnaeus, 1758)	+	+	+	++
44.	Misgurnus fossilis (Linnaeus, 1758)	-	-	-	++
45.	Noemacheilus barbat. (Linnaeus, 1758)	+	+	+	++
46.	Sabanejewia aurata (Filippi, 1865)	-	-	?	?
IX. ICTALURIDAE					
47.	Ictalurus nebulosus (Le Sueur, 1819)	?	?	?	+
X. SILURIDAE					
48.	Silurus glanis (Linnaeus, 1758)	+	++	++	++
XI. GADIDAE					
49.	Lota lota (Linnaeus, 1758)	+	+	++	++
XII. GASTEROSTEIDAE					
50.	Gasterosteus aculeatus (Linnaeus, 1758)	+	+	-	+
XIII. CENTRARCHIDAE					
51.	Lepomis gibbosus (Linnaeus, 1758)	+	?	++	++
XIV. PERCIDAE					
52.	Gymnpcephalus baloni (Holčík et H.1974)	+	+	++	++
53.	Gymnocephalus cernuus (Linnaeus, 1758)	+	+	+	++
54.	Gymnocephalus schraetser (Linna, 1758)	-	+	++	+

55.	Perca fluviatilis (Linnaeus, 1758)	+	++	++	++
56.	Stizostedion lucioperca (Linns, 1758)	+	++	++	++
57.	Stizostedion volgense (Gmelin, 1788)	?	++	++	++
58.	Zingel streber (Siebold, 1863)	-	++	++	+
59.	Zingel zingel (Linnaeus, 1758)	-	+	++	-

XV. GOBIIDAE

60.	Proterorhinus marmoratus (Pallas, 1811)	+	+	++	++

XVI. COTTIDAE

61.	Cottus gobio (Linnaeus, 1758)	+	+	++	++

CHAPTER 7. AVIFAUNA

PART I CHANGES OF SPACIAL RELATIONS OF SELECTED BIRD SPECIES IN THE BYPASS CANAL AND IN THE DANUBE'S INUNDATION AREA AFTER THE PUTTING OF THE GABČIKOVO PROJECT INTO OPERATION (EXCERPT)

Peter Áč & Mirko Bohuš

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1. Introduction and Aim

Downstream of the Devín gate, the Danube river created in the past on the top of its sediments a dynamic system of side arms undergoing permanent changes. Due to its sedimentation and erosion activities, the river used to create new active branches, while in the old ones, without discharges, the gradual process of their filling up was taking place. (...) In the seemingly monotonous plain a varied mosaic of aquatic, terrestric and transitional types of biotopes existed. Their diversity and food-capacity found their expression also in a diversity of forms of organisms occurring in this ecosystem and in its own productivity. At the same time this ecosystem served as an important migration corridor and gathering area of migrating animals, among which birds have a primordial place. For its unique character and lasting importance this territory was included among important bird areas of the Slovak Republic and since 1993 has been on the list of wetlands under the Ramsar Convention.

Birds represent one of the important parts of the ecosystem. Thanks to their mobility enabling them to react immediately to current changes, relatively easy identification in the terrain and other properties, birds represent an important indicator of the state and changes of the environment. (...)

From the chronological point of view the last immense anthropogenous interference into the territory concerned was the construction of the Gabčíkovo Project, damming of the original main channel of the Danube followed by the diversion of its flow and the operation of the Gabčíkovo

Project with related activities. This has been the most significant intervention into the concerned territory since the very beginning of its exploitation by man. There are available data on previous state of biota and first of all on its most apparent representatives from the period before the construction of the Gabčíkovo Project. It is possible then to compare the new state with the past one, even if the existing data base does not allow us to include in such an analysis the population trends of the majority of species. The aim of this work is to assertain and to evaluate changes of the environment as manifested through selected groups of birds dependent on the aquatic environment. As indicators, there were selected representants of orders *Pelecaniformes, Ciconiiformes, Lariformes, Ralliformes, Accipitriformes* and *Anseriformes*, taking into account mostly long observation distances on open areas. The observations focused on spatial relations and habitat preferences with respect to the newly created technical landscape. In parallel with these observations an inventory research of avifauna has been implemented.(...)

The selection of localities had as an aim to include sectors of biotopes that most closely represent the original landscape as well as the newly created technical landscape. In this case the sectors of the main Danube channel, branch system and the bypass canal of the Gabčíkovo Project have been selected. (...)

The observed stretch of the main channel was limited to rkm 1821 - 1835, where there occurs parts of river banks adapted with quarry stone as well as gravel benches. Observations in the branch system were carried out from newly built cross-dykes named in technical terms lines A to G. (...) Observations on the bypass canal were taking place from the right-side dyke of the bypass canal along its whole length.

Results:

During 17 observation days in the months January - August 1994 a total number of 52 bird species dependent on water were observed.

Survey of determined species:

1. *Gavia stellatta* (Pontopp.)
One exemplar was observed on April 15, 1994 at the beginning of the bypass canal.

2. *Podiceps nigricollis* Brehm
This species was observed isolately during spring passage in March - 6 exemplars.

3. *Podiceps cristatus* (L.)
This species is an abundant hibernant in the bypass canal, in the main Danube river it wintered only individually. Nidification in the branch system was proved by finding the nest.

4. *Podiceps ruficollis* (Pall.)
This species was regularly observed on all studied localities, where it is regularly wintering. The highest number (32) was observed on April 8, 1994 in the bypass canal. Nesting was assertained by observation of just hatching fledglings in the branch system.

5. *Phalacrocorax carbo* (L.)
Cormorants regularly occurred in the main Danube channel and in the branch system during the whole year, but were not observed in the bypass canal. Estimation of the total number of night-passing cormorants on the newly created night-ground in the branch system was estimated to be 1,500-2,000 exemplars.

6. *Ardea cinerea* (L.)
Grey herons regularly occurred in all observed localities. The occurrence in the bypass canal was limited only to single scattered individuals. In the branch system gathering of grey herons occured on suitable fishing places at suitable water table. For example in August 8, 1994 a flock of 72 individuals was observed.

7. *Ardea purpurea* L.
Purple heron is regularly observed since the beginning of water supply into the Slovak branch system in May 1993. The first observation was on April 22, 1994. The number increased after bringing off fledglings from nesting-ground in Hungary; in one locality in the branch system system 6 exemplars were observed at once and the flight of a flock of 15-20 individuals in August. This species was only infrequently observed in the main Danube channel and not at all in the bypass canal.

8. *Egretta alba* (L.)
This species occurred regularly and during the whole year in the branch system and in the Danube channel, but was not observed in the bypass canal. Maximal numbers occur in August (last years during the whole autumn). Flocks gather in suitable places with suitable food offer. In August 10, 1994 a flock of 142 exemplars was observed.

9. *Egretta garzetta* (L.)
This species occurred rarely, except during summer period when it occurred regularly, separately or several individuals, on shallow places of the Danube channel and in the

branch system. On August 10, 1994, 3 exemplars together with *Egretta alba were observed.*

10. *Nycticorax nycticorax* (L.)
This species occurred in the main Danube channel and also in the branch system, separately or in groups of several individuals, but does not nest on the Slovak side of the floodplain; it was not observed in the bypass canal.

11. *Ixobrychus minutus* (L.)
A young bird flying out was observed in reeds of the branch system during the first ten days of August, where nesting can be supposed due to suitable topic conditions. This species was not observed in the bypass canal.

12. *Platalea leucorodia* (L.)
Two exemplars were observed flying over in the second ten days of August 1994. This species was not observed in the bypass canal.

13. *Ciconia ciconia* (L.)
White storks regularly occur in the side arm system and also in the main Danube channel, the bypass canal does not provide trophical possibilities.

14. *Ciconia nigra* (L.)
This species occurs in the branch system as well as in the main Danube channel, where during post-nidification moves the gathering of large numbers of individuals take place on trophically attractive localities. In the branch system a flock of 68 individuals was observed. This species is nesting in the inundation area.

15. *Cygnus olor* (Gm.)
This species regularly occurred on all three localities during the whole observed period. The largest gathering in a single flock was observed in the main Danube channel on August 10, 1994. Nesting was not observed.

16. *Anser* sp. Briss.
Three species of goose *Anser anser*, *Anser fabalis* and *Anser albifrons* were regularly observed during the winter period in the main Danube channel.

17. *Anas platyrhynchos* L.
This species occurred during the whole year in all three localities. It nests only in the main Danube channel and in the branch system, where a concentrated occurrence was observed even during nesting period. As a wintering ground it uses mainly the bypass canal, where a considerable number of ducks are gathering. E.g. about 1,500 ducks gathered in the stretch about 600 m from the hydropower plant on February 3, 1994. Smaller numbers (about hundreds) are staying mainly in the part of the branch system under the line G until freezing of the branches and broods of ducks of tens or hundreds individuals stay in the main Danube channel.

18. *Anas penelope* (L.)
This species occurs rarely in the branch system during migration and nesting was not observed.

19. *Anas strepera* L.
Rare, probable nester in the branch system.

20. *Anas acuta* (L.)
Occurrence was confirmed in the main Danube channel during spring passage (two pairs during the last ten days of March 1994).

21. *Anas querquedula* (L.)
This species was observed together with the following one in the main riverbed and in the bypass canal, tens of individuals were wintering there together with wild ducks.

22. *Anas crecca* L.

23. *Aythya ferina* (L.)
This species is a hibernator in the branch system and also in the upper stretch of the bypass canal neighbouring with the reservoir.

24. *Aythia nyroca* (Güld.)
A pair was observed in the branch system at the end of August 1994.

25. *Aythia fuligula* (L.)
This species is a common hibernator (hundreds of exemplars) clearly preferring the bypass canal, mainly its part bordering with the reservoir. In the main Danube channel it was occurring only in a small number during winter months.

26. *Bucephala clangula* (L.)
Regularly wintering species during observed period, clearly preferring the main Danube channel to the bypass canal. On the main river it occurred in flocks, most often counting tens of individuals.

27. *Clangula hyemalis* (L.)
The occurrence of 22 individuals was recorded on April 15, 1994 at the beginning of the bypass canal.

28. *Mergus albellus* L.
This species occurred in pairs or in flocks of several individuals in the main Danube channel, occasionally also in the branch system, during winter months till February 26, 1994.

29. *Mergus merganser* (L.)
7 exemplars were observed on the main river in February 19, 1994. It was not observed in the branch system, nor in the bypass canal.

30. *Somateria mollisima* (L.)
One exemplar was observed in the bypass canal during the second decade of March 1994.

31. *Circus aeruginosus* (L.)
One exemplar flying from Hungary was observed during nidification period.

32. *Milvus migrans* (Bodd.)
This species regularly occurrs in the main Danube channel and in the branch system, where it nests. On the bypass canal only flights over were observed.

33. *Haliaeetus albicilla* (L.)
This species wintered in the main Danube channel and in the branch system (12 exemplars). The most concentrated occurrence of 7 individuals was observed in the branch system on February 26, 1994. It was not observed in the bypass canal. In addition to winter occurrence also summer occurrence of two adult exemplars and one juvenile was observed.

34. *Pandion haliaetus* (L.)
This species was sporadically present and individually in the branch system and in the main Danube flow during the whole observed period.

35. *Fulica atra* (L.)
This species was observed as a relatively common hibernator in the bypass canal; in the branch system and in the main flow its abundance was smaller. During the nesting period and afterwards the situation changed. This species nested in the branch system (observation of non-flying fledglings in August 1994).

36. *Gallinula cloropus* (L.)
This species was present and nested in the branch system, but was not present in the main river or in the bypass canal.

37. *Charadrius dubius* (Scop.)
A common nester on gravel benches in the main Danube channel, it was present in the branches only at low water table (August 1994). It was not observed in the bypass canal.

38. *Numenius arquata* (L.)
Only one hiberning exemplar was observed in the main Danube channel.

39. *Actitis hypoleucos* (L.)
This species was present on the main river (confirmed nesting) and in the branch system during the whole nidification period; it was not observed in the bypass canal.

40. *Tringa ochropus* (L.)
This species occurred in the main river and in the branch system during move (March 24, 1994) and during post-nesting moves (August 1994). It was not observed in the bypass canal.

41. *Tringa nebularia* (Gunn.)
A flock of about 20 individuals was observed in the branch system in August 1994.

42. *Tringa totanus* (L.)
This species was observed during the spring passage move.

43. *Philomachus pugnax* (L.)
Four individuals of this species were observed in the main channel on April 4, 1994.

44. *Vanellus vanellus* (L.)
A nester of gravel benches of the main Danube channel, it did not occur in the branch system, nor in the bypass canal.

45. *Recurvirostra avosetta* (L.)
Four exemplars were observed in the Danube's main channel during May 1994. In previous years some pairs of this species were nesting in the non-operational bypass canal.

46. *Larus canus* L.
This species and the following two ones were present during the observation period on all three localities.

47. *Larus argentatus* Pontopp.

48. *Larus ridibundus* (L.)

49 *Larus minutus* (Pall.)
A transmigrant species, observed in the Danube's main channel in three exemplars in April, 29, 1994.

50. *Sterna hirundo* (L.)
A likely nester on gravel benches in the Danube's channel, observed also in the branch system.

51. *Chlidonias nigra* (L.)
A transmigrant in the Danube's channel. Three exemplars were observed in the main river in April - May.

52. *Alcedo atthis* (L.)
This species occurred in the main channel and in the branch system during the whole observation period; it did not occur in the bypass canal.

For the purpose mentionned above we have selected eight from among the above-mentioned species, considered as typical ones for the original Danubian avifauna. These species are easily recognisable in the terrain. Their minimal and maximal absolute numbers in the Danube's main channel, in the branch system and in the bypass canal are on Table 1.1.

Table 1.1. Occurrence of selected bird species in the Danube's main channel (D) and branches and in the bypass canal (C):

Species		Months I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Phalacrocorax	D	7-21	6-348	20-70	69-175	75-184	6-500	12-36	120-510
carbo	C	0	0	0	0	0	0	0	0
Ardea	D	3-22	2-10	2-10	15-29	2-25	3-30	2-5	18-75
cinerea	C	5	0	0	2	2-15	0	0	2-6
Egretta	D	34-41	22-37	15-25	21-47	5-10	1-2	1-3	42-131
alba	C	0	0	0	0	0	0	0	0
Anas	D	236-750	218-400	80-300	6-122	16-101	8-25	16-85	196-297
platyrhynchos	C	950-491	30-1500	54-76	3-22	3-12	36-220	12-42	120-230
Cygnus	D	2-10	2-28	22-55	25-55	6-10	2-6	1-3	2-6
olor	C	0-14	0	6-15	0-6	0	0	0	0
Larus sp.	D	6-26	0-35	3-6	4-10	12-37	12-122	12-40	19-81
	C	6-96	0-60	14-92	17-20	3-9	8-85	2-12	12-96
Fulica	D	0-32	6-80	6-50	0-6	0-2	0	2-6	12-15
atra	C	6-174	0-6	10-60	0-4	0	0	1-3	0
Haliaeetus	D	1-8	1-7	2-4	0-2	0-1	0	0	0
albicilla	C	0	0	0	0	0	0	0	0

minimal and maximal number of birds in month

The occurrence of species *Phalacrocorax carbo* (L.) *Egretta alba* (L.) *Haliaeetus albicilla* (L.) was exclusively bound to the Danube's channel and branch system. A clear preference for the bypass canal, its unfrozen water surface and asphalt banks, was manifested by genus *Anas* and species *Fulica atra* (L.) during the winter season. These species gradually moved to the branch system for nesting period until bringing off fledglings. An increased number of ducks were already observed in the bypass canal in August. As can be seen from the results, the bypass canal is chosen by birds mainly during the winter season as a rest area, while during the nesting period almost the whole bird population concentrates in the branch system and in the Danube's main channel, where possibilities for nesting exist. The absence or rarer occurrence of some species (*Phalacrocorax carbo* (L.).), representants of family *Ardeidae* in the bypass canal is due to unsuitable food and rest conditions. Species *Cygnus olor* (Gm.) preferred, even if not exclusively, the environment of the Danube´s main channel. Representants of genus *Larus* except species *Larus minutus* Pall. were occurring on all three localities without any distinct differentiation.

Significant differences resulted from observation of escape-distances in different localities as far as species *Anas platyrhynchos* L., *Cygnus olor* (Gm.), *Fulica atra* L. and genus *Larus* are concerned (Table 1.2).

Table 1.2. Average escape-distances of selected species in various types of environment

Species	Danube´s channel and branch system	Bypass canal
Anas platyrhynchos	150-200	10-50
Gygnus olor	10-20	3-5
Fulica atra	40-50	20-50
Larus sp.	50-100	3-10

Obtained data show considerable adaptation of birds to the environment typical for water areas of urban agglomerations.

2. <u>Discussion and Selected Ecosozological Aspects</u>

The change in water regime and construction of communication net with reinforced surface appears to be the most important factor of the environment as far as birds dependent on water habitats are concerned.

The shallow parts of the branch system (mainly along the Danube river in the downstream direction), from which the most important was the locality Istragov, had a function of trophical bases for ichtyophagous bird species. They had a function of gathering grounds of birds during post-nesting flights and migration, mainly for species *Ardea cinerea* L., *Egretta alba*(L.) and *Ciconia nigra* (L.) and also for wintering (first two species) (Áč, 1990 Bohuš, unpublished data).

The water supply regime into the branch system from the intake structure at Dobrohošť, which followed the earlier drying of the center of this locality, did not provide conditions for this important function of the locality. Only after the drop of water supply resulting from the extremely low discharge in the Danube during the summer of 1994 were suitable trophic conditions created in this less frequently visited part of the branch system. This resulted in an increased concentration of the above mentioned species, reaching earlier known values from these localities. In the second ten days of August, 1994 a gathering was observed in which there were 142 individuals of *Egretta alba* (L.) 72 individuals of *Ardea cinerea* (L.) and 68 of *Ciconia nigra* (L.). For assuring this important function of the branch system it is desirable to regulate water supply in the branch system while respecting, at the same time other requirements of the ecosystem.

During our observations we have revealed a significant increase of aquatic bird species in the branch system, the causes of which vary for different species. During the summer perid 1994, but also 1993, adult individuals of *Ardea purpurea* L. (6 of them) later joined by some young birds, were regularly observed in the Slovak branch system. During the last decade this species occurred in our part of the branch system only in individual numbers and rather rarely (Áč, Bohuš, unpublished data). In the not so distant past, this species nested on the Slovak side of the Danube (Balát, 1963, Rác, in verb.) but original nesting localities either lost their original character, or were destroyed. According to available data (Rác, in verb.) from the whole area concerned, this species nests at present only in Hungary and after the extreme decrease of water levels in the Hungarian part of the branch system it uses our side only as trophical base. Due to absence of suitable sites and its high trophical requirements this species does not nest here. In comparison with our own unpublished data from the last decade before the putting of the Gabčíkovo Project into operation, there is an increase, in the branch system, of numbers and nesting of species *Fulica atra* L., including branches originally with the flowing water. This phenomenon can result from population trends of this species, but the more probable cause seems to be the stabilised water level enabling successful nesting and development of submersed macrophytes thanks to nearly stationary water. A similar situation was observed also in the case of species *Gallinula chloropus* (L.) and *Podiceps ruficollis* (Pall.).

The construction of crossing weirs connected by communications with reinforced surface opened the whole inundation area to cars, which has a negative effect on species sensitive to any disturbance. General coverage of the area with communications reduced the possibilities of escape from this interference. In the case of species *Haliaeetus albicilla* (L.) nearly exclusive preference for localities in the stretch of the Danube's main channel was observed. At present there is no communication with the reinforced surface along the Danube which would enable increase of visits in this territory. After the opening of a large part of the area to access by cars, the attempts of this species to nest here were oriented towards other localities, situated in a still relatively quiet area. This species is in the centre of the conservation efforts, and in order to provide conditions for the creation of a nesting population we consider it necessary to assure sufficient isolation of at least some parts of the inundation area and their protection against visits relating to different human activities.

In the lower part of the branch system, in the stretch corresponding to rkm 1821 - 1825 of the river, a number of winter gathering places was created (mainly by all *Anas platyrhynchos* L., *Aythia ferina* (L.), *Fulica atra* L., *Ardea cinerea* L., and *Egretta alba* (L.)). In this area the villages Trstená na Ostrove and Baka had been separated from the inundation area by the bypass canal, which led to a considerable decrease in visits. The effect was visible already during the last years of the construction of the Gabčikovo Project (Bohuš M., unpublished data).

During the observation period an unusual increase of number of species *Cygnus olor (Gm)*, in comparison with the 1980s and the begining of the 1990s, was observed. In earlier years this species was observed in the branch system and in the Danube's channel only rarely and individually, possibly in small flocks. It is possible to ascertain the gradual increasing of occurence and abundance of this species (Áč, Bohuš, unpublished data). In earlier years (the 1950s) this species was not even considered to be a part of the avifauna of Žitný Ostrov (Balát, 1963, Bališ, 1952), whose southern part is the monitored territory. The increase in the number of swans is related to general expansion of this species, its synanthropisation and population trends. The fact that after the putting of the Gabčikovo Project into operation a sudden increase in swan number occured indicates such plausible dependence.

We have observed apparent changes in spatial relations in the case of the species *Phalacrocorax carbo* (L.). After the fundamantal change in the hydrological regime of the branch system and the main riverbed, resulting from the damming of the Danube, this species, directly dependent on aquatic environment, concentrated itself during the winter 1992 - 1993 in the Danube's channel. With all probability it was due to easier access to food in the decreased water level in the Danube's main channel. A similar concentration was not observed in the first months of 1994. We have recorded the transfer of night-ground from the Hungarian side (at approximately rkm 1821 - Bohuš, unpublished data) to our side, to the places known as being night-grounds in earlier periods (Áč, 1983). Up to the present time the exact causes of this event are not known and its explanation remains an open question for a further stage of research.

When evaluating the function of the bypass canal we consider it necessary to draw attention to a mass winter occurrence of birds, mainly from order *Anseriformes*. The birds use the asphalt banks of the bypass canal for rest. According to our working hypothesis there is a local increase of temperature due to the absorption of the sun shine energy in the dark asphalt layer, which provides a warm comfort to the resting birds in winter months. This hypothesis, will be verified in a further stage of the research.

An apparent shortening of escape-distances of indicative species occurring in the bypass canal has been ascertained. Occasional traffic, usually without stopping, on the top of the dyke of this artificial water course, as well as absence of hunting in this locality, allowed the habituation mainly of all representants of order *Anseriformes* (in particular *Anas platyrhynchos* L.), in lesser degree also of representants of other observed orders. In the area of the Danube's main channel, and in the branch system, birds, up to present, stand by escape distances known from the period before the putting of the Gabčíkovo Project into operation. This phenomenon is known from urban agglomerations. Its entire significance for organic functions and relations which developed together with individual species during their evolution, can not yet be unequivocally stated. We suppose, that further stages of reasearch will bring answers to at least part of the questions in relation to the preservation of the whole scale of etological manifestations of organisms existing in systems functioning according to the natural scheme undisturbed by man. (...)

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PART II. OUTLINE OF CHANGES IN COMPOSITION OF AVIFAUNA RESULTING FROM THE CONSTRUCTION OF THE GABČIKOVO BARRAGE (EXCERPT)

Pavel Kovačovský & Ivo Rychlík

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Because this work contains only results of field observations for months March - August 1994, its findings should be understood as being preliminary in character. A more reliable picture of changes in composition of the avifauna can be submitted only after completion of the whole-year cycle of observations. In spite of this it may be stated, that even the results obtained up to now provide a number of valuable information about the impact of the construction of the Gabčíkovo water Project on the composition of the avifauna in the affected stretch of the Danube river.

During observations in the terrain we have recorded on the monitored territory the occurrence of 52 aquatic species of birds, birds depending by their way of life on water and predators.

The survey of determined species is as follows:

Gavia stellata, Gavia arctica, Podiceps cistatus, Podiceps nigricollis, Podiceps griseigena, Tachybaptus ruficollis, Phalacrocorax carbo, Ardea cinerea, Ardea purpurea, Egretta alba, Ciconia ciconia, Ciconia nigra, Cygnus olor, Cygnus atratus, Anser fabalis, Anas platyrhynchos, Anas strepera, Anas, querquedula, Spatula clypeata, Netta rufina, Aythia ferina, Aythia fuligula, Aythia marila, Bucephala clangula, Clangula hyemalis, Mergus albellus, Mergus serrator, Milvus migrans, Haliaetus albicilla, Bueto bueto, Circus aeruginosus, Falco subbuteo, Falco tinnunculus, Pandion haliaetus, Gallinula chloropus, Fulica atra, Vanellus vanellus, Charadrius dubius, Philomachus pugnax, Tringa nebularia, Tringa totanus, Tringa hypoleucos, Numenius arquatus, Capella gallinago, Recurvirostra avosetta, Larus argentatus/cacinans, Larus ridibundus, Chlidonas nigra, Sterna hirundo, Riparia riparia, Motacilla alba, Motacilla flava.

The minimum assertained numbers varied between 1,400 - 1, 800 individuals in March, the maximum state having been ascertained in August, when total numbers reached approximately 17,000 individuals.

The impact of the construction of the water project can be evaluated on the basis of comparison of total numbers of birds on the monitored territory prior and after the damming of the Danube. We have recorded a distinct increase of the total number of individuals and at the same time their decrease on the old Danube. This can be demonstrated by the example of changes in numbers of wild duck *(Anas platyrhynchos)* determined during regular (January) international counting of aquatic birds on the Danube river (Table 2.1). It confims that the creation of a huge water area in the intimate proximity of the old Danube's flow caused a shift of a part of birds from the old channel to the reservoir. The high number of birds settling in the reservoir indicates that this newly created water area is very attractive for aquatic birds, which find here suitable conditions for wintering, for food finding and, several species also for nesting.

Table 2.1. Results of January counting of wild duck *(Anas platyrhynchos)*

Year	1991	1992	1993
Number of ducks in the Danube stretch from rkm 1842 to 1851.75	653	539	168

Until now the results of observations showed that the water level has a considerable influence on the number of individuals and their distribution in the observed territory. This impact is most distinctly manifested in the Hrušov reservoir, mainly in its upper part (approximately from the place corresponding to rkm 1846 of the former Danube bed). A decrease of water level (for example in July and August) causes the emerging of a number of small islands of different size and even rise of a large dry areas, often with isolated water patches. A retreat of continuous water area from the dykes reaches, in such a case, in the reservoir near to the village Kalinkovo, 100-300 m. Large numbers of ducks *(Anas platyrhynchos)*, gulls *(Larus ridibundus* and *Larus argentatus/cachinnans)* and cormorants *(Phalacrocorax carbo)* gathered on such emerged areas. The numbers of species, which are looking for food on the banks, eventually in rather shallow water (for example *Charadrius dubius, Tringa nebularia, Philomachus pugnax* and others) increases. On the contrary, at considerably increased water level (for example in the first half of April 1994, when the water level in the Danube river culminated in Bratislava at about 700 cm) the above-mentioned species practically disappeared. At the same time major part of nests of teal (*Fulica atra)* and diver (*Podiceps crist*atus), and to a smaller extent also nests of wild dug *(Anas platyrhynchos*) were destroyed by the flood. Nevertheless, we have recorded a substitute nesting of the above-mentioned species, from where the fledglings were brought off approximately 2-3 weeks later.

In addition to the above-mentioned species we have recorded nesting (in some cases only by observing young birds together with adult individuals) of other species as follows: *Aythia fuligula, Larus ridibundus, Larus argentatus/cachinnans, Sterna hirundo, Tachybaptus ruficollis, Gallinula chloropus, Recurvirostra avosetta* and *Riparia riparia.*

Among the most abundant species in the monitored territory are *Phalacrocorax carbo, Cygnus olor, Anas platyrhynchos, Aythia fuligula, Fulica atra, Larus argentatus* and *Riparia riparia.*

It is possible to observe a clear preference of some species for a certain type of biotope. The most obvious examples are species *Podiceps cristatus* and *Fulica atra*, which clearly prefer the huge water area of the reservoir. Seasonal dynamics of selected species based on comparison of numbers assertained on the old riverbed and on the reservoir are shown on Table 2.2.

Table 2.2. Numbers of selected species determined on the old Danube and on the Hrušov reservoir in 1994 (R)

Species		determined numbers (min-max)					
		March	April	May	June	July	August
Pediceps	D	0	0	0	0	0	0
cristatus	R	14-27	26-110	8-67	47-61	76	44
Phalacrocorax	D	2-188	64-99	173	3-11	117	6
carbo	R	63-131	45-472	28-389	143-198	1086	810
Cygnus	D	58-107	0-64	0-71	18-19	12	4
olor	R	4-21	12-57	80-168	113-275	384	604
Anas	D	122-150	6-208	22-31	23-233	22	250
platyrhynchos	R	104-127	87-201	14-155	141-300	174	4679
Aythia	D	0	0	0	0	1	0
fuligula	R	435-656	58-1605	15-18	10-183	555	0
Fulica	D	0	0	0	0	0	0
atra	R	235-477	72-354	32-85	52-92	660	3290
Larus	D	10-33	215-370	348-520	210-295	167	196
ridibundus	R	129-499	1037-2017	610-2218	734-1588	4405	536

Rare and faunistically important species are mainly: *Gavia stellata, Gavia arctica, Podiceps griseigena, Ardea purpurea, Netta rufina, Aythia marila, Clangula hyemalis, Mergus serrator, Haliaetus albicilla, Pandion haliaetus, Falco subbuteo, Numenius arquatus* and *Recurvirostra avosetta*. The occurrence of the species *Cygnus atratus* can be explain only by its escape from some zoological garden, because this species has its origins in Australia.

Discussion and conclusion

The total number of birds on the monitored territory is influenced mainly by wintering species (e.g. *Bucephala clangula)*, by rearing the fledglings of nesting species (e.g., *Anas platyrhynchos, Larus ridibundus, Riparia riparia)*, eventually by an apparent increase of number of individuals at the end of summer, resulting from birds gathering on the large water surface of the Hrušov reservoir where they come from smaller water areas in the neighbourhood after they have reared their offspring (e.g., *Anas platyrhynchos, Fulica atra*).

We consider as important observations confirming the gradual adaptation of species *Larus argentatus/cachinnans* in our territory. Štollmann (1970) mentions this species as occurring on our territory mainly in the summer and autumn months. At present its occurrence on our territory is over the whole year and for the first time during our observations we have recorded its nesting on the Hrušov reservoir.

Similarly, we also have also recorded the nesting of several pairs of the species *Recurvirostra avosetta* in the proximity of the old Danube channel. Our observations confirm earlier published data concerning the occurrence and nesting of this species on the monitored area (Darolová, 1992).

Recent results of our work confirm that in the area of the Gabčíkovo Project new ecological conditions are being formed, which are manifested also through changes in qualitative and quantitative composition of avifauna on the monitored area. The total number of individuals as well as a number of determined species has increased, together with the occurrence and even nesting of some rare species. Due to the fact that the Gabčíkovo Project has been put into operation only quite recently, it has been possible to use it as a model territory for the research of formation of new animal communities resulting from the radical interference of man into the environment.

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CHAPTER 8. CLIMATE IN THE IMPACT AREA OF THE GABČIKOVO SECTION OF THE G/N PROJECT

P. Petrovič

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1. Introduction

The climatic conditions of the region where the hydroelectric power project Gabčíkovo is situated had already been studied within the scope of the research undertaken in connection with the preparation of the G/N Project. This region was characterised in several climatologic studies as being on the boundary between the maritime and continental climate (refs. 1-4), in the moderate zone on the transition from the Atlantic-continental to the European-continental zone (ref. 5), with mild winter, increased precipitation late in the spring and early in the summer, the second part of the summer being dryer. While in the warmest month the average temperature does not reach 22^{0}C, at least 4 months have the average air temperature higher than 10^{0}C (ref. 6).

Under such conditions, evaporation from the water surface and potential evapotranspiration are higher than the total precipitation. This determines also the structure of vegetation cover and crops (together with actual hydrologic conditions - ground water level and capillary rise).

When the monitoring of the hydroelectric power project Gabčíkovo was suggested, potential microclimatic phenomena and impacts of the project on the adjacent territory had been analysed (refs. 7-8), various possibilities of evaluation of the evapotranspiration from plant growth in the concerned territory were processed including mathematic modelling (ref. 9) and evaluation of the observations used by Dr. Lapin (ref. 10).

This study focuses on three most significant elements with respect to ecological conditions of the region determined by the hydrological cycle: the air temperature, precipitations and potential evapotranspiration. Further it deals with the potential microclimatic phenomena of the hydropower project, above all under vertically stable meteorological situations.

2. Climatic Characteristics of the Period 1961-1990

The nearest meteorological station which has carried out the long-term observations of the concerned region is located at the airport Bratislava-Ivánka (48^0 10'N, 17^0 12'E h=133m). It is about 11 km from the Čunovo reservoir (see, Fig. 7). The difference between the altitudes of the station and the reservoir's water level is about 5 m. The climatic characteristics of the region have been established on the basis of data available in the Slovak Hydrometeorological Institute (SHMI).

The annual course of the air temperature in Bratislava is presented on Fig. 1 where MAXMAX and MINMIN mean the momentaneous extreme temperatures over the whole considered period 1961-1990, the values ranging between -24.6^{0}C and 36.5^{0}C. The maximum registered during this period was exceeded on August 19, 1992 when the value 37.9^{0}C was registered. Thus, the absolute amplitude of temperatures is 62.5^{0}C. The daily average temperatures in respective months range between MINMEAN and MAXMEAN. The observed extremes of the daily average temperatures in the concerned period were -19.6^{0}C and 29.2^{0}C. However, this extreme temperature has already been exceeded twice, in August 1992, by the value 29.7^{0}C. The yearly course of the average air temperature is expressed by the curve MEAN, in the range from -1.4^{0}C to 20.1^{0}C. The mean temperature above 10^{0}C occurred in 6 months. This determines the growing season. On the basis of the yearly air temperature course the region can be classified as a region with a warm climate.

The yearly precipitation course (Fig. 2) shows that the average monthly MEAN totals are in the range from the minimum of 34.0 mm to the maximum of 65.6 mm. The average yearly total is 575.8 mm. The monthly precipitation totals are in the range from the minimum MIN (the lowest value being 1.7 mm) to the maximum MAX (the highest value being 197.4 mm).

The yearly evapotranspiration course is illustrated on Fig. 3. The average MEANs are in the range from 9.5 mm in January to 131.6 mm in July. The highest potential evapotranspiration (158 mm) during the considered period was registered in July 1983. It was exceeded in August 1992 (164 mm).

It is obvious from the comparison of yearly evapotranspiration totals ranging from 654 mm to 895 mm (938 mm in 1992) that the region suffers from moisture deficiency.

3. **The Possibilities of Influencing the Microclimate of the Area**

After the beginning of Project construction, the vegetation was removed from part of the construction site and local changes, limited in time and space, could be observed. This provisory period ended in October 1992 with the damming of the Danube without leaving behind it any visible signs.

The new reservoir created upstream of the Čunovo weir has at the maximum water level the surface of 2,518 hectares and, at the considered evaporation values of about 800 mm per year, the evaporation from the reservoir amounts to about 20 mil. m^3. This represents an average water transfer into the atmosphere of about 0.6 m^3/s (in July 1.25 m^3/s). During the three summer months, 45% of the annual volume of the evaporation occurs. This water evaporation from the reservoir in July is comparable with the water evaporation from the cooling tower of the nuclear power plant Bohunice. The amount of the water evaporated during the summer months, as in the case of the nuclear power plant Bohunice, cannot cause detectable microclimatic changes, even if during hot summer days the increase of the humidity would be desirable.

Another discussed problem of possible microclimatic change resulting from the construction of the Project is its impact on the temperature regime of the lower layer of the atmosphere. On the basis of the original concept of the monitoring (ref. 7) and its modification (ref. 10) a new meteorological station has been established in the Gabčíkovo area. The observations are recorded and a continuous series of values have been started. However, at present, the evaluation of the possible thermal impact can be done (due to the short time of observations) only through qualified assumption.

Due to the general lay-out of the Project structures, the body of the dam as well as the body of the hydropower plant are exposed to the sunshine mostly during the morning hours. Later the sun shines either in line with the body of the dam and hydropower plant, or from the water side. Thus the thermal accumulation on the dam body is not very significant. If there is any influence at all, then it is limited to the closest neighbourhood of the dam. The left-side dyke of the headwater canal is exposed during almost the whole day to the sunshine. Part of its insulation is covered with reflexive-protective coating, and it is cooled by the flowing water.

A part of the floodplain forests was replaced by the reservoir water surface. There is a low probability of and until now no evidenced microclimatic impact.

Specific short-term microclimatic variations could occur at stable situations and at a weak wind activity, or eventually under windless conditions. At longer-lasting stable situations, the effect of the large water surface could result in a relative increase of the air humidity, in the occurrence of fog or other phenomena such as dew and hoar frost.

4. Comparison of the Fog Occurrence and Air Humidity in Bratislava and Žihárec

Due to the fluctuating character of the climatic phenomena in the long-term view it is necessary, in identifying local changes, to compare the measurements from the station located in the impact area with the measurements from the station outside of this area. In another study (ref. 11) we have demonstrated that the VUVH experimental station at Žihárec (48° 04'N, 17°54'E, h=111m) can be considered as adequately reliable and not influenced by the construction of the G/N Project and thus suitable for such comparison. We have been comparing situations of fog occurrence and situations when relative air humidity exceeded 90%. When the changes recorded in both stations were approximately equal, we did not consider them as locally conditioned.

Because fog occurrence is recorded at the Žihárec station only since 1965, we have considered the same period (1965 - 1993) in both stations. The number of foggy days in respective years at both stations can be seen on Fig. 4. The number of days with fog occurrence varies, but in general decreases at Žihárec and increases in Bratislava. While some change had already occurred in Bratislava in 1989, the increase in Žihárec which occurred in 1993 was higher than in Bratislava. Obviously this change has no relation to the damming of the Danube and may be explained as a result of industrial air pollution in Bratislava.

More detailed analysis of the occurrence (in ⁰/oo) of wind, fog and high relative air humidity (RAH) has been worked out on the basis of wind directions and velocities, separately for Bratislava (BA) and Žihárec (ZI). It covers the period 1965 - 1993 (black lines), as well as the period from October 1992 to September 1994 (red lines), i.e. the period after the damming of the Danube (Fig. 5). The occurrence of a calm (windless) situation and fog/humidity conditions related to this situation is explained in the legend (CALM).

The comparison of results shows that at Žiharec wind from the NE occurred less frequently in the last two years and wind from E to S occurred more often. No changes in wind distribution between the two periods has been recorded in Bratislava. Since the pattern at higher wind velocities is similar, the causes of the recorded changes cannot be of a local character and interpreted as the impact of the reservoir.

The occurrence of fog and high relative air humidity during to periods registered at both stations is presented on Table 1.

Tab. 1. Relative occurrence of fog and high relative humidity over the year at stations Bratislava

	fog		relative humidity	
period	65-93	92-94	65-93	92-94
station				
Bratislava	13.3	18.1	22.6	19.6
Žihárec	10.1	8.8	32.2	29.5

The table shows that the 5% increase of the fog occurrence took place in Bratislava in the last period, mainly at wind directions from the NE and SE. However, it can be seen from Fig. 4 that these changes had already appeared in 1989. The increase takes place particularly in November. The comparison of the fog occurrence under calm conditions and at wind velocities up to 2 ms-1 for Bratislava and Žihárec appears on Fig. 6.

The fog occurrence at Žihárec slightly increased, but only at wind direction from the SE and W. The fog occurrence in Bratislava has increased in the whole half-circle from NE to SW. It follows from the geographical situation that the air is moving towards the meteorological station in Bratislava - Ivánka from the Čunovo reservoir area under the wind from the SE to SSW directions.

Similarly, the frequency of occurrence of other phenomena, such as hoarfrost, soft rime and supercooled fog has been studied. The yearly course of frequency of occurrence of these phenomena showed the 10% increase in Bratislava during the period 1992 - 94 as compared with the long-term average. This increase has occurred mainly in the winter period. It may be explained by the same reasons as the increased fog occurrence. No change has been recorded at Žihárec.

The increased fog occurrence and related phenomena in Bratislava cannot be attributed to the effects of the Čunovo reservoir. The highest number of days with fog occurred in 1990, i.e. prior to the damming of the Danube. Taking into account that the frequency of the occurrence of high relative air humidity did not change, it is probable that the increased fog development in Bratislava is due mainly to increasing air pollution by aerosols.

5. Conclusions

The analysis of existing monitored data of the concerned territory influenced by the construction of the Gabčíkovo Project did not reveal any ascertainable microclimatic variations attributable to the two-year operation of the Gabčíkovo Project. The general development of climatic characteristics and potential microclimatic phenomena have been and continue to be monitored and a data basis which will enable the analysis of these problems on the background of a longer period is being developed. By means of comparison with the measurements at the station Žihárec it will be possible to study in a more detailed way the manifestations of microclimatic changes which could result from the influence of the Gabčíkovo Project.

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Fig. 1. Yearly course of air temperature in Bratislava (1961 - 90)

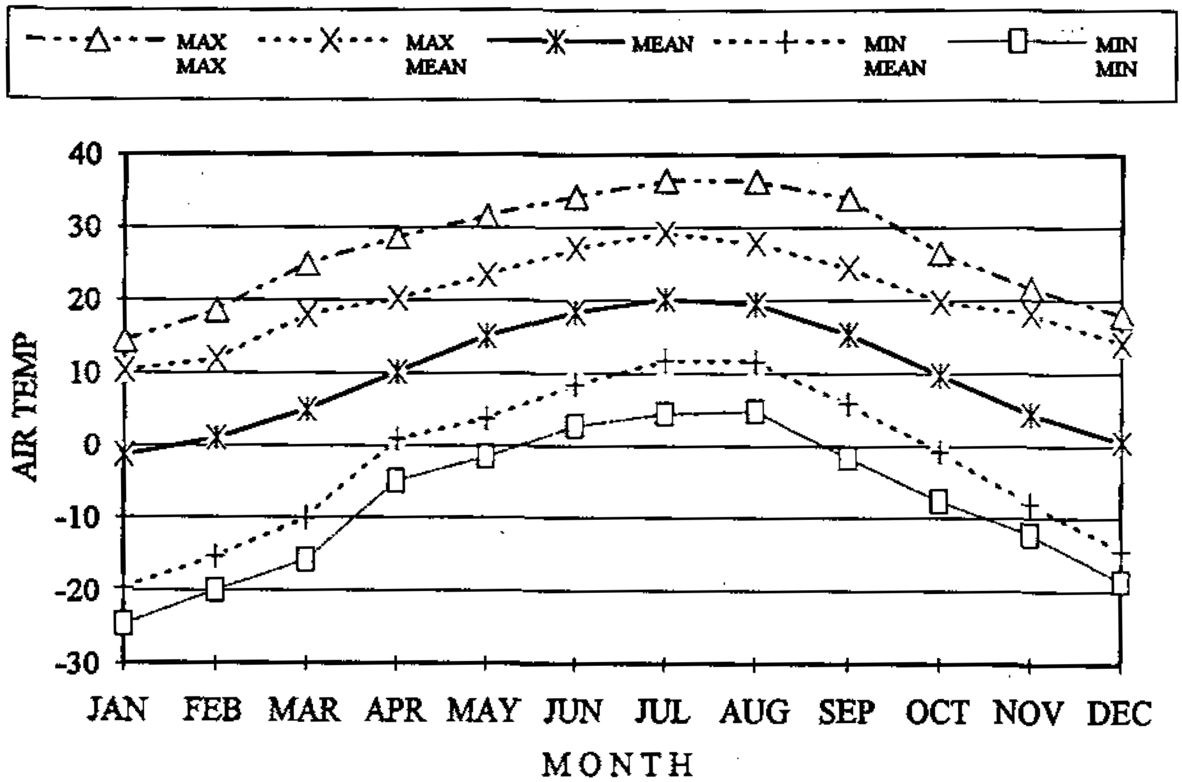


Fig. 2. Yearly course of precipitation in Bratislava (1961 - 90)

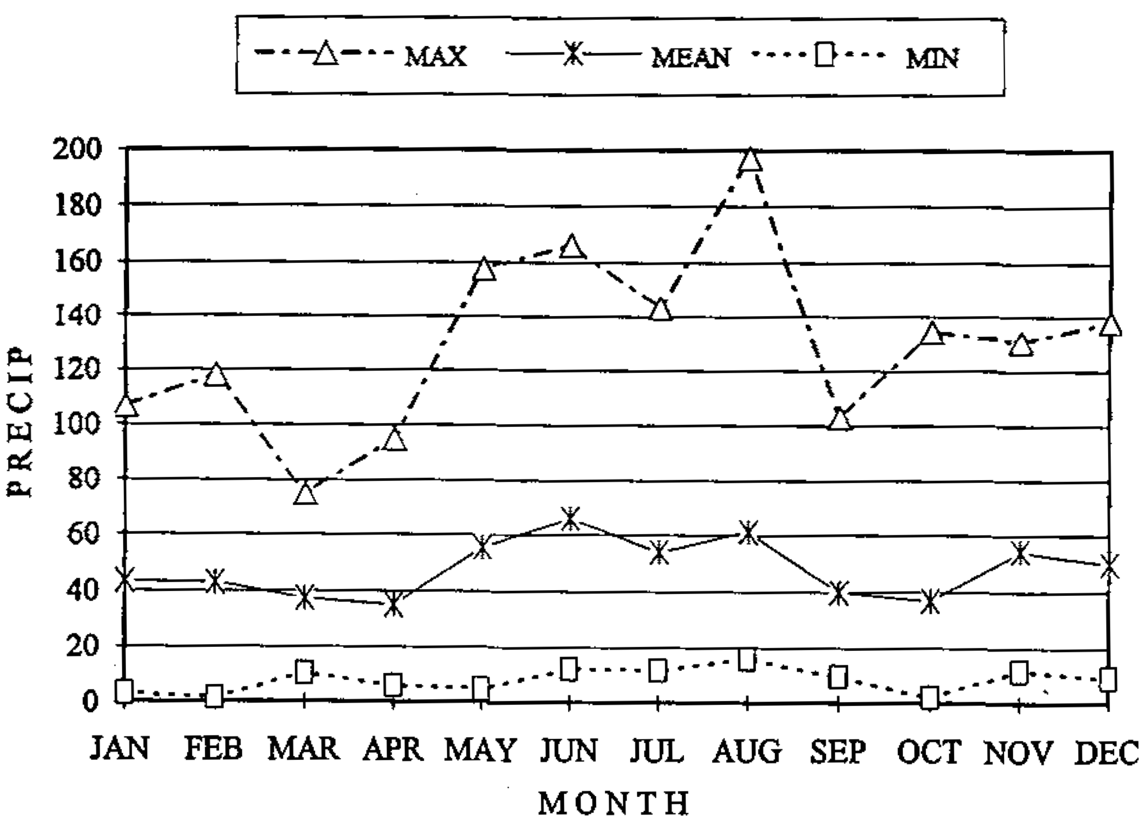


Fig. 3. Yearly course of potential evapotranspiration in Bratislava (1961 - 1990)

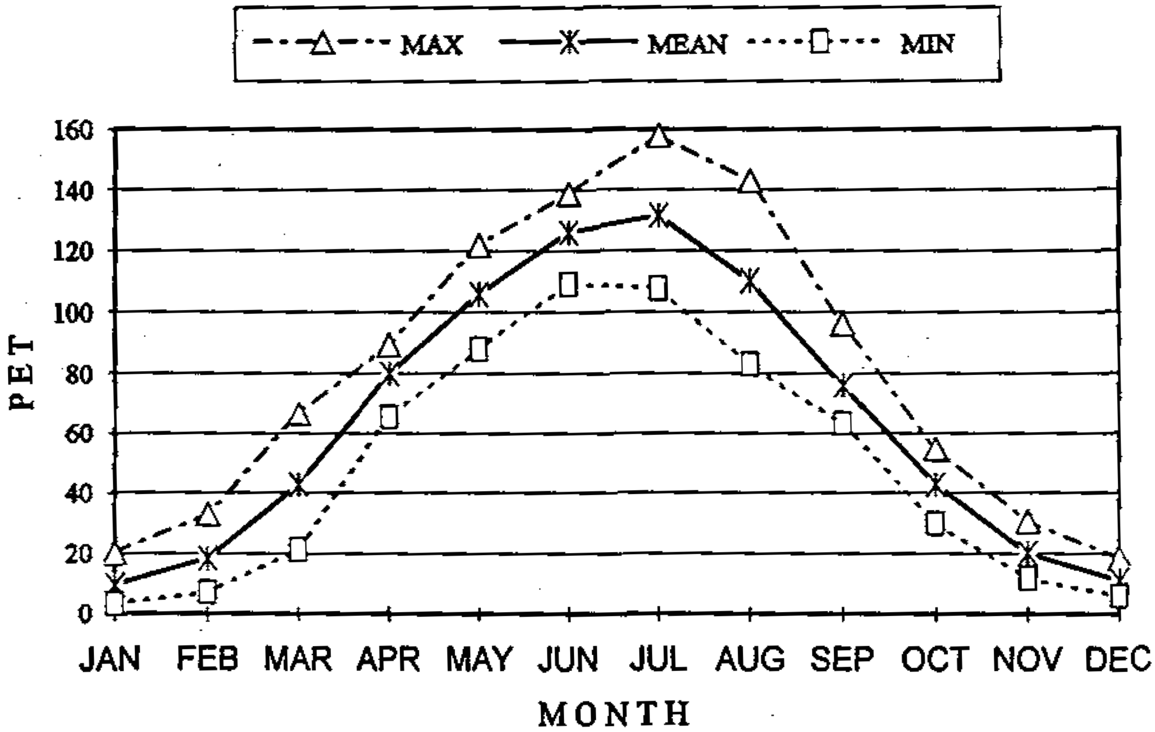
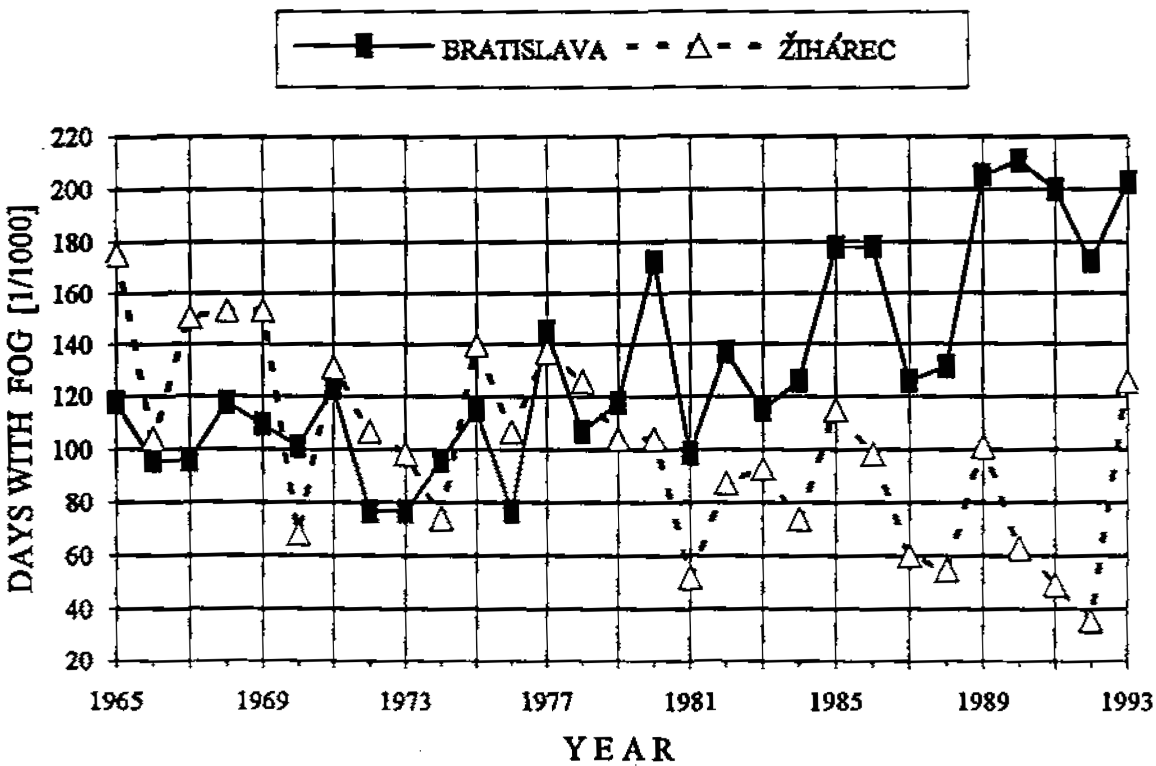


Fig. 4. Number of days with fog occurrence per year in Bratislava and Žihárec



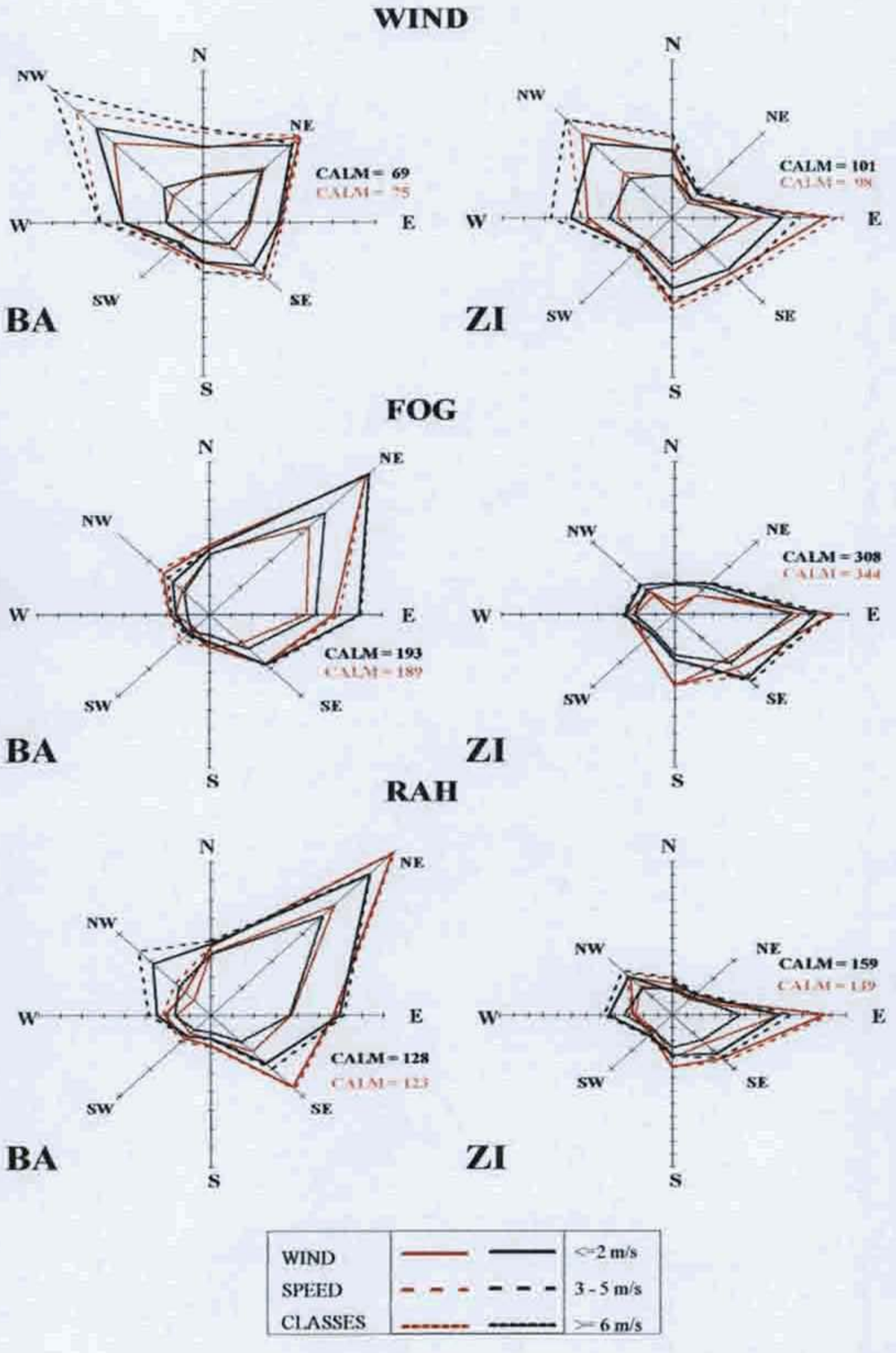


Fig. 5 Comparison of wind, fog and relative air humidity occurrence at stations Bratislava (BA) and Žihárec (ZI) over the periods 1965-93 and 1992-1994

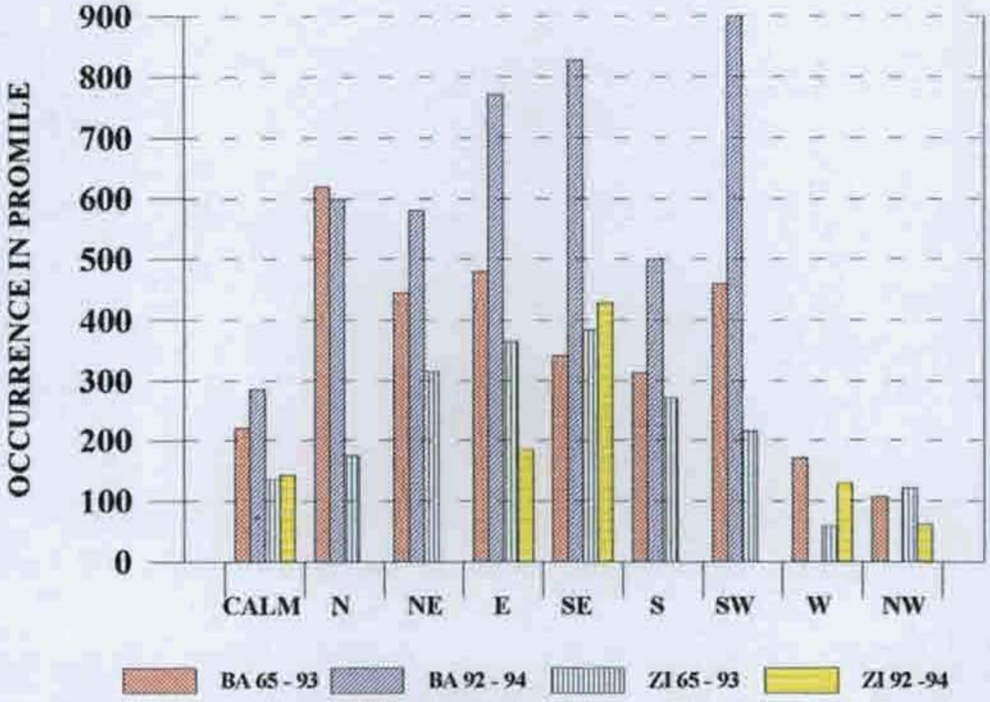
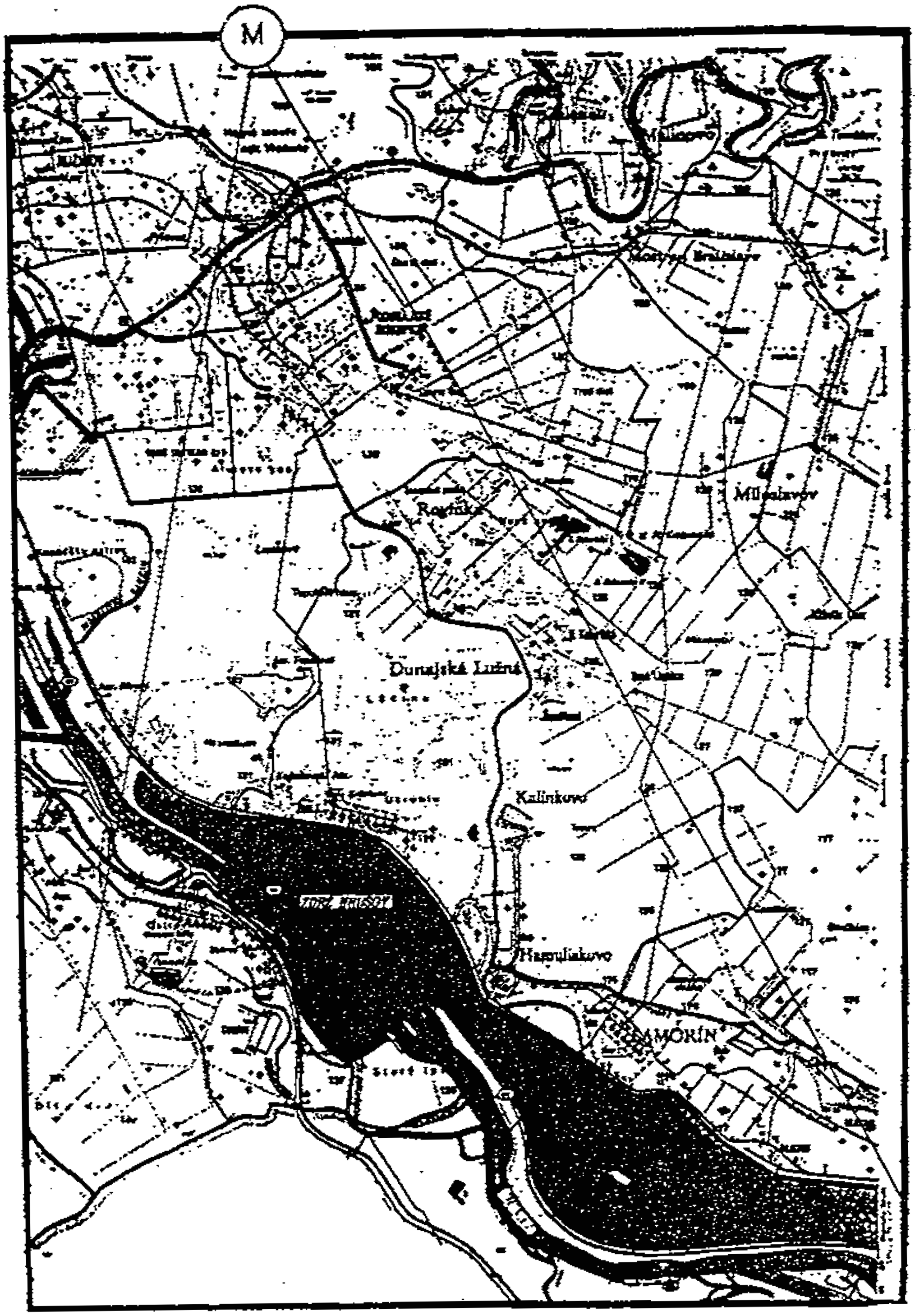


Fig. 6. Comparison of fog occurence in November in the years 1965-93 and 1992-94 in Bratislava (BA) and Žihárec (ZI)

Fig. 7



Map scheme: Meteorological station Bratislava - Ivánka (airport)
and reservoir above Čuňovo

folding of the sedimentary expanse of the Tethys, which followed the collision of the North European and the Carpathian Orogenies. The Western Carpathians belong to the northern branch of the Alpine Orogeny, which stretches from the Pyrenees, and runs through the Western and Eastern Alps, Western, Eastern and Southern Carpathians, to Balcanides, Taurides and farther eastward to the Himalayas.

The geographic boundary of the Western Carpathians is placed: in the west, in the Danube River valley; in the east, in the Uh River valley; in the north, the erosional margin of the Flysch nappes of the Outer Carpathians; in the south, by the Great Hungarian Plain.

3. Geological Division of the Western Carpathians

The Western Carpathians are a mountaineous range with a nappe structure and a distinctive polarity of orogenetic processes, migrating through time from south to north. In terms of the rock filling, the age of structuring of units and their mutual relations, we divide the Western Carpathians into two basic units: the Externides and the Internides (Mišík, et al., 1985). Structuring (folding) of the Internides was completed prior to the Upper Cretaceous, during the Mediterranean phase (some 65 million years ago); the Externides were folded during the Tertiary times (30 - 12 million years ago).

Table 1. Division of West Carpathians (Mišík, et al., 1985, modified)

Externides	Outer Western Carpathians	1. 2. 3.	Fore-deep Flysche zone - outer Krosno zone - inner Magura zone Klippen-zone
Internides	Central Western Carpathians	4. 5.	Core mountain zone (Tatricum+subtatric nappes) Veporicum Unit (Veporicum+ Choč + Muráň nappes)
	Inner Western Carpathians	6.	Gemericum Unit (Gemericum + Silica nappe)

Externides

3.1 Fore-deep

It was formed in the fore-land of the Flysch belt. It is made of the Neogene sediments, overlying partly its genuine basement - the European Platform, represented by the Bohemian Massif, consolidated during the Hercynian stage (Mahel' and Buday 1968).

3.2 Flysch belt

It forms an enormous accretional wedge of the Flysch belt with a nappe structure, composed of Cretaceous and mainly Paleogene formations in a Flysch-type development (alternations of clayey shales and sandstones). Two zones are distinguished in the Flysch belt: the Outer Krosno zone and the Inner Magura zone. The more inner (southern) units were thrusted over the more external ones, which agrees with overall structural pattern of the Western Carpathians.

3.3 Klippen-belt and Sub-klippen zone

It represents a narrow zone (max. 30 km wide) of extreme spatial shortening with an extraordinarily complicated structure. It stretches from Vienna and runs via the Central Váh River Basin and Orava, further to Eastern Slovakia, Carpathian Ukraine, ending in Romania.

Internides

3.4 Central Western Carpathians

These are made of a belt of Core mountains (e.g. Malé Karpaty Mts., and the Tribeč Mts.) and of the Veporic belt (e.g. the eastern part of the Nízke Tatry Mts. and the Veporské vrchy hills), which differ from each other by the presence and development of the Mesozoic units. As far as the structural-tectonic position is concerned, the Tatricum and the Veporicum Units can be correlated to the Lower and Middle Austroalpinicum of the Eastern Alps (Mahel' 1986).

3.4.1 The <u>belt of Core mountains</u> is represented by the Tatricum Unit, the Krížía nappe and the overlying Choč nappe.

- The Tatricum Units are made of crystalline rocks (containing granitoids, and lesser crystalline schists) and sub-authochthonous Mesozoic rock cover.

- The Krížía nappe, like the Choč nappe, is underlain almost exclusively by Mesozoic formations.

3.4.2 The <u>Veporic Unit</u> is made predominantly of granitoids and crystalline schists, the Upper Paleozoic, the Mesozoic cover (Veporicum) and the Choč and Muráň nappes. The Veporicum Unit is thrusted subhorizontally upon the Tatricum Unit. The projection of this thrust at the surface is called the Čertovica line.

3.5 Inner Western Carpathians

The tectonic boundary between the Central and Inner Western Carpathians forms a subhorizontal thrust - the Margecany - Ľubenik line, which separates, at the same time, the Veporicum from the Gemericum Units.

3.5.1 The <u>Gemericum Unit</u> is floored by low metamorphosed Paleozoic of the Gemericum, overlain by the Meliata Unit and by the Silicicum nappe, both being of Mesozoic age. The Gemeric Unit is a structural-tectonic equivalent of the Oberaustroalpin Unit.

3.6 Tertiary basins

The Mediterranean (Pre-Upper Cretaceous) was the main orogenic phase within the Central Western Carpathians and the post-tectonic basins contain the relics of the Upper Cretaceous sediments, but mainly the sediments of Paleogene and Neogene age. The Paleogene sediments are divided into two basic lithological types - the Budin sequence and the Subtatric group (Gross, <u>et</u> <u>al</u>., 1984). The Neogene basins are located within the tectonic depressions, formed due to the development of the Western Carpathian arc. <u>The Danube Basin also belongs here</u>.

3.7 Neovolcanics

These are found mainly within the Internides and represent the products of Neogene (Miocene) back-arc volcanism (Lexa, et al., 1993) and Plio-Pleistocene basic mantle volcanism, predominanting in the region of southern Slovakia. They are found in two extensive regions: central and eastern Slovakia. In the central Slovakian region the central Slovakian neovolcanics occupy the Kremnické and the Štiavnické vrchy hills, the Vtáčnik Mts., the Pohronský Inovec Mts., the Javorie Mts. and the Krupina plain. The eastern Slovakian region is represented by the Slanské vrchy hills and the Vihorlat Mts. Products of the Upper Miocene-Pleistocene basic mantle volcanism are found also in southern Slovakia and northern Hungary.

4. Geological Structure of the Danube Basin

The Gabčíkovo Project is situated in the central part of an intra-mountain depression, called in Slovakia the Podunajská nížia (Danubian lowland) and in Hungary the Small Hungarian Lowland. It is bordered: in the north, by the following core mountains: Malé Karpaty, Považský Inovec and Tríbeč; in the east, by the Central Slovakian neovolcanics and southeastern complexes of the Hungarian Midmountains; in the north and northwest, by the Eastern Alps and Litava Mts. (Vass, et al., 1988, 1990). In geological terms, the Danube Basin is filled by Late Tertiary and Quaternary sediments, reaching the thickness in its central part of up to 8 000 m (Seneš 1960,1962, Kilényi and Šefara 1989).

The Slovak part of the Danube Basin has been divided into the following partial depressions: the Blatné depression, between the Malé Karpaty Mts. and Považský Inovec Mts., the Rišňovce depression, between the Považský Inovec and Tríbeč Mts., the Komjatice depression, between the Tríbeč and the Levice horst and the Želiezovce depression between the Levice horst and northern slopes of the Transdanubian Range (Vass, et al., 1988, 1990). The deepest central part is called the Gabčíkovo depression.

The basement of the Danube Basin is formed mainly by the Tatricum and Veporicum tectonic units, the latter being thrusted subhorizontally over the former, along the Čertovica line. In the north, there occur Mesozoic nappe units; in the southeastern part, the basement is made of the Budin Paleogene sediments. The contact between the Tatricum and the

Veporicum Units can be defined in the northeastern section of the Tríbeč Mts.,(Hók, et al., 1994); however, toward the central part of the basin, it is overlain by Neogene sediments and it runs roughly through the central part of the Komjatice depression, toward the southwest (Fusan, et al., 1987). The course of the Čertovica line in the central part of the Danube Basin and toward the Small Hungarian Lowland is uncertain.

The wells drilled in the areas of Kolárovo (K-2, K- 3, K-4), Dubník (D-1), Šurany (Š-1) and Podhájska (P-2) intersected the Veporicum Unit in this part of the Basin's basement (Biela, 1978a). The wells drilled in the area of Ivánka (I-1, I-2) and Mojmírovce (M-1, M-7, M-8, M-29, M-30) intersected the Tatricum rocks. Within the central part of the Basin no well reached the basement of the sedimentary filling. However, the position of rocks, belonging to the Transdanubian Range, south of the Hurbanovo-Diósjenö fault, intersected in a number of wells (Biela, 1978a, Fülop and Dank, 1987, Dank and Fülop, 1990).

The most recent findings (Horváth, 1993) indicate a flat thrusting of the Transdanubian Range units over its basement, which is, in the area north of the Hurbanovo-Diosjenö fault, made of the Veporicum rocks. This would indicate a similar structural-tectonic position of the Transdanubian Range as is the case of the Gemericum Unit versus the Veporicum Unit. The Rába and Hurbanovo-Diosjenö line represents a structural-tectonic equivalent of the Margecany-Žňubeník line, or, according to Balla (1994), of the Rožňava line. These lines were reactivated during the Tertiary times as faults with normal slip (Horváth, 1993, Tari, et al., 1991, Hók, et al., 1993) or strike slip component of the movements, whereas the youngest movements had but extensional character (Fodor,1992,Vass, et al., 1993).

In the southeastern part of the basin - in the Želiezovce depression, there are Paleogene sediments of the Budin development cropping out at the surface, which are however, in terms of tectonic development, of no prime importance.

5. Geotectonic Development of the Danube Basin and its Sedimentary Filling

The Danube Basin is composed of several structural-tectonic horizons, differing in duration and mechanism of formation (Čepek, 1938, Adam and Dlabač 1961, Janáček, 1971, Bergerat, 1989).

The oldest, pre-rifting development stage (Bergerat, 1989) is characterized by structures that formed under transtensional/transpressional conditions prevailing during the collision of the Carpathian orogeny with the European Platform 24-16 million years ago (Jiríček, 1979, Royden, 1988, Kováč et al., 1993a, Nemčok 1993, Nemčok et al., 1993). Structural-tectonic activity of the pre-rifting stage influences primarily the structure of marginal parts of the Danube Basin.

The following structural elements of the Lower Miocene (Egerian to Ottnangian) age may be considered exceptional: dextral shear zones striking ENE - WSW, situated in the north in the regions of Malé and Čachtické Karpaty, Považie Považský Inovec, Bánovská kotlina basin, up to the Upper Nitra area (Kováč et al., 1993, Kováč, et al., 1994, Hók et al., in press). The shear zones in the south display many features in common with those in the Budin vrchy hills, in the area of the Transdanubian Range (Fodor, 1992, Fodor, et al., 1992).

At the close of this time (Karpatian) the activity of sinistral faults striking NE-SW predominated, accompanying an escape of the Western Carpathian crustal fragment in a northeastern direction (Ratschbacher 1991, Nemčok, 1993). The most apparent faults that had formed during this period are the Litava faults at the NW margin of the Malé Karpaty Mts. (Lankreijer et al., in press, Kováč et al., 1993). A similar role of a sinistral fault may however be assumed along the Rába fault, which delineates the Transdanubian Range to the northeast (Balla, 1990).

The pre-rifting stage represents relatively little distributed sediments of the Lower Miocene (Eggenburgian-Karpatian) age. They occur as relatively thin layers (50-300 m) at the margins of the recent Danube Basin (Biela, 1978). At the western margin, there are predominantly occurrences in the area of Šoproň and in the Blatné depression (Kováč et al., 1986, 1989, 1993). In the east, they follow the slopes of the Transdanubian Range (Tari, et al., 1992).

The oldest confirmed Middle Miocene sediments of the Danube Basin are of Lower Badenian age and occur in the Želiezovce depression. Distribution of these sediments, documented in the drill holes (Biela, 1978a) delineates the axis of the sedimentation space of the Lower Badenian, striking WNW-ESE to NW-SE. This orientation of the basin is in good agreement with the results of measurements of the paleostress field (Nemčok et al., 1993), with the orientation of extension striking generally NW-SE during the Lower Badenian time. At the same time it demonstrates the extensional activity of the NW-SE striking faults, that delimit the sedimentary space of the Lower Badenian within the Želiezovce depression, as well as within other regions of the Western Carpathians (Hornonitrianska kotlina basin). It substantiates the transtensional activity of the Middle Slovakian fault zone, which mediated a communication with the Lower Badenian sea during this period through a system of grabens and horsts, oriented oblique (NW-SE) to the north-southern course of the Middle Slovakian fault zone (Hók, et al., in press). The faults, striking NW-SE, did not take part in the later development of the Danube Basin.

The rifting stage in the Slovak part of the Danube Basin is represented first of all by sediments of the Middle Badenian and Sarmatian, which attain significant thicknesses mostly within the depressions in the northern part of the Danube Basin (Blatné, Komjatice and Rišňovce depressions).

During the Middle Miocene times a structural recontruction of the Basin and changes in regimes from transtensional to extensional had taken place due to the roll-back effect of the fading Karpatian subduction, which generated an opening of the Danube Basin as a whole during the time span ranging from 16 to 12 million years ago (Kováč, et al., 1989, Horváth, 1993). The extensional regime of the rifting stage activated decollements at the boundary between the plastic and brittle zones of the upper crust (Horváth, 1993, Tari 1992, 1993) accompanied by a distinctive subsidence, especially along listric slip faults, predominantly in the central part of the Danube Basin, where the upper crustal extension was accompanied by an ascension of mantle materials. At the northern margin of the Danube Basin there were also activated left hand side faults, striking ENE-WSW (Kováč et al., 1993b).

Considerable thicknesses of the Middle Badenian sediments are accumulated within the Blatná depression, where they reach up to 2200 m (wells šp-5, šp-3 - Biela, 1978). The sedimentation within this space was controlled by a mechanism of rapidly subsiding basin of the pull-apart type (Kováč, et al., 1993), limited by faults striking NE-SW.

A crucial role in the development of the basin, since the Middle Badenian, was played by the extensional movements oriented NE-SW, whose activity reflected itself in the geomorphology of the area. The fault systems such as the Veľké Záluže, Mojmírovce and Šurany faults, striking NE-SW, controlled the sedimentation in the area of the Rižňovce and Komjatice depressions. The direction of the extension of paleostress field rotates into the NW-SE direction (Nemčok and Lexa 1991, Kováč and Hók, 1993, Nemčok, et al., 1993).

The period of post-rifting stage is characterized by an extension with but local compressional event during which, apart from normal slip listric faults oriented NE-SW (Mojmírovce fault), also the N-S striking dextral strike-slip faults were activated at the eastern limits of the Danube Basin (Kováč and Hók, 1993). Subsidence of the area in the last stage was due to the collapse of a thermic diapir and it manifests itself mostly in the central part of the basin (Tari, et al., 1992, Šefara, et al., 1993).

The post rifting stage is represented by the Pannonian and Pontian and partially also Pliocene sediments, deposited predominantly within the central and southeasten parts of the basin. The youngest Plio-Quaternary sediments reach in the area of the Gabčíkovo depression the maximum thickness of 400 m (Pristaš, et al., 1993).

Based on available data, the activation of Quaternary faults may characterize the stress field, whose extensional component is oriented in agreement with the course of the orogeny (Gerner, 1992, Kováč and Kováč, in press). In the morphology of the area (drainage courses, orientation of valleys) accessible to direct study (Kováč, et al., 1994), apart from the above mentioned, the E-W and N-S extensional faults play an important role (Priechodská and Harčar, 1988).

6. Courses of the Main Fault Lines in the Danube Basin

To evaluate the activities and functions of faults in the area under study we have used the Structural-Geologic Map of Czechoslovakia (its construction was based on satellite photograph interpretation) at a scale 1:500 000 (Reichwalder 1984), the Geologic Map of

Czechoslovakia at a scale of 1:500 000 (Fusan, et al., 1967) and the Tectonic Map of the Basement of Tertiary of the Inner Western Carpathians (Fusan, et al., 1987). We have also taken into account the courses of faults shown in the published maps of the Austrian and Hungarian territories (Dank and Fülop, 1990). The more detailed data we have gleaned from the papers of Marko (1986), Maheľ (1986), Elečko et al., (1993) and Maglay, et al., (1993).

The Danubian fault system (Koutek and Zoubek 1936, Čepek, 1938) runs in a NW-SE direction and limits the southernmost end of the Malé Karpaty Mts. (Matula, 1957).

The Malé Karpaty Mts fault limits the Malé Karpaty Mts. horst from the southeast. It was formed during the Badenian time and later accentuated and renewed (Magdolen, et al., 1979). At present it is seismically active (Čepek, 1938). The majority of authors hold that the Malé Karpaty Mts. fault is a normal slip fault dipping to the southeast and separating the Malé Karpaty Mts. from the Danubian Basin Neogene (Cambel, Valach, 1956, Janáček, 1971, Fusan, et al., 1971).

The Ludince fault (or Ölved-Dobrá Voda fault sensu, Elečko, et al., 1993) runs through the Brezovo depression and continues along the southern slopes of Považský Inovec and Tribeč Mts. The Považský Inovec horst progressively subsides toward the south along this fault and plunges below the Neogene of the Danubian lowland (Fusan, et al., 1971). Manifestations of this NW-SE oriented fault may be observed during the Lower Miocene times to extend up to the Štúrovo area.

The Váh River fault system (Hynie, 1927, Maheľ, 1950, 1951, Putiš 1981) runs along the western side of the Považský Inovec Mts. and influences morphologically the Váh valley. Along this system the western margin of the Považský Inovec Mts. subsides in a stepwise fashion.

The Tribeč Mts. are limited on their southeastern side by the Mojmírovce fault. Geophysical research and exploration drilling indicate its continuation towards the SW, to the Danube Basin (Fusan, et al., 1987, Eleçko, et al., 1993). During the Middle and Upper Miocene times the faults striking NE-SW provoked a subsidence of the Danube Basin and deepening of the basin in a SE direction. The Žitava and the Šurany faults display features similar to the Mojmírovce fault.

The Middle Slovakian fault zone (Kováč, Hók, 1993) is another important fault system in this area. It forms a fault system striking N-S, whose width is approximately 20 to 25 km. The western part runs along the contact of the Malá Fatra Mts. with the Turčianska kotlina basin and the margin of the Žiarska kotlina basin further south. The eastern margin runs in the area of Hronská Breznica, through the Banská Štiavnica as far as the Hurbanovo-Diosjenö fault. It is partially represented by the Hont fault system. An analysis of inferred gravimetric maps and the results of seismic measurements along regional sections have shown that the western margin of the fault zone between the Turčianska and Žiarska kotlina basins down to the Hurbanovo fault reaches down to the Moho-discontinuity, whereas the other faults reach even the lower parts of the crust (Kvitkovič, Plančár 1977).

Within the area of the southern Slovakian basins an important regional fault belt, called the Plešivec-Rapovce fault system (Plančár, et al., 1977, Vass, et al., 1993), had been revitalized during the Neogene times. In the area of Balasagyarmat this system splits off from the Hurbanovo-Diósjenö fault and, passing the Balasagyarmat and Rapovce area, it continues to Čoltovo, south of Plešivec. It manifests itself in the gravimetric maps as a distinctive gravity gradient, reflecting the density differences of the rock complexes at greater depths. Southward of the fault belt there are dispersed intense magnetic anomalies (Plančár, et al., 1977).

Parallel and northward from the above, there runs the Šahy-Lysec fault system. According to Vass, et al., (1993) it is a volcani-tectonic zone, reactivated during the Lower Badenian. At sites of its intersection with the faults of the NNW system it mediated the dilation of ascending conduits for the andesite volcanism.

7. Geologic - Seismic Features of the Danube Basin

On the basis of the structural - geologic and geophysical properties, it is possible to draw within the discrete regions of the Western Carpathians several geologic - seismic domains (shown on Fig. 1.1), with an approximately identical degree of potential seismic hazard (after Kováč, et al., 1994):

7.1 Outer Carpathian belt

In geological terms it represents an immense complex of folded sediments of the Tertiary accretional wedge. A geophysically characteristic feature of this domain is a belt of magnetic anomalies. The depth of their emplacement ranges from 4 to 20 km. Another feature is the Karpatian gravity minimum, bound to the change in the composition and thickness of the Earth crust in the frontal part of the Western Carpathians.

7.2 Eastern Alpine and Central Western Carpathian belt

In terms of seismoactivity this is relatively consolidated. From the structural-geologic as well as geophysical point of view, this domain may be divided into several regions:

a) Region of the Danube Basin, represented by a young basinal structure, that had formed under conditions of extensional regime. From a geophysicist's point of view, the whole region is characterized by the decrease, from west to east, of the thickness of lithosphere from 90 to 60 km. The thickness of the crust in the Danube Basin is 28 km.

b) The Core mountain belt was segmented during the Tertiary times into blocks, separated by normal slip faults, listric faults and strike slip faults. The transtension was succeeded by an extension during the Miocene, which has been well documented by both the geologic data (Marko, et al., 1990,1991, Kováč, et al., 1993, Kováč and Hók, 1993, Hók, et al., in press, Nemčok and Lexa 1991) and geophysical data. Tectonic distortion of the core mountain belt along fault zones reaches generally down to the upper - or even to mid - crustal levels. The thickness of the lithosphere is in this area 28-33 km.

The divide between the Outer Carpathian belt and the Central Eastern Alps belt is represented at the surface by the Klippen-belt. It is characterized by shear-thrust-like reworking, effected under compressional conditions. The lower part is marked by the course of the Peripieniny lineament. Southern continuation of the Peripieniny lineament at the surface is represented by the Vienna thermal line

(Mur Leitha), which continues down to the lower crust. It is represented at the surface by the Litava faults.

c) The Region of Middle Slovakian neovolcanics is floored predominantly by the Upper Badenian - Lower Sarmatian volcanic rocks. The latest manifestations of volcanic activity are vocanic and volcani-sedimantary complexes of Pliocene age (between 0.53 and 0.16 million years ago, Burian, et al., 1985). Volcanic activity is bound to the active fault belts, which extend down to middle - or lower - crustal levels. Recent postvolcanic activity establishes increased values of geothermic gradient (35 - 70 °C) in this area (Biela, 1978a,b). The thickness of the lithosphere is here 70 80 km. The thickness of the crust ranges between 28 and 33 km.

7.3 The Transdanubian Range Region

In geological terms, there are crustal fragments here that have in respect of their development much in common with the southernmost units of the Northern Kalk Alps and Southern Alps. The thickness of the crust decreases toward the Danube Basin to 26 km. In the region of the Transdanubian Range it attains 32 km. The earthquake epicentres are concentrated mostly at the northern margin of the Transdanubian Range, as well as along north-southern zones in central and eastern parts of the Central Range.

8. Upper Miocene - Quaternary Development in Areas Close to the Gabčíkovo Project

The Gabčíkovo Project is situated in the central part of the Gabčíkovo depression, where the depth of the basement reaches some 8 000 m (Kilényi and Šefara, 1989). The Pre-Neogene basement is made of the Lower and Middle Austroalpinicum units and their equivalents - the Western Carpathian basement, represented by the Tatricum and the Veporicum Units (Fusan, et al., 1971, Fusan, et al., 1987, Vozár, et al., 1994, Balla 1994) that contact the rocks of the Transdanubian Range along flat lying thrusts (Tari, et al., 1992, Horváth, 1993). In the northwest, they are represented by the Rába line; in the north, by the Hurbanovo-Diósjenö line.

Sedimentary filling of the basin, in its central part, is probably formed at its base by pre-rifting and rifting Karpatian and Badenian sediments (not certified by drilling). The filling proper is mainly made of Upper Miocene sediments (Sarmatian to Pontian Pliocene) and Quaternary sediments.

The onset of distinctive subsidence in the central part of the Danube Basin took place in the Upper Miocene. Pannonian sediments stratigraphically overlie the Sarmatian sediments; however, in the vicinity of Komárno, they transgress the Mesozoic basement of the Transdanubian Range, and in the area of Trnava they sediment directly on the Lower Paleozoic rocks (Buday and Špička, 1967). The maximum thickness of the Pannonian sediments was intersected in the drill hole K-2 at Kolárovo (1355 m), while the minimum in the drill hole Sb-1 near Patince (93.8 m) (Biela, 1978a). Based on the extrapolation of drilling data and interpretation of seismic sections, the thicknesses of Pannonian sediments in the centre of the Gabčíkovo basin depression reach the depth of 2 200 m (Nagy and Tkáčová, 1992, 1994). The lithological filling of the Pannonian is composed of the two basic developments: marginal development with predominating coarse clastic sediments of coarse-grained conglomerate type gravels and sandstones. In the basinal development there predominate pelitic sediments of silty, clayey or coal/clay types. This development is typical for the Gabčíkovo depression and extends up to the Komjatice depression (the Ivanka formation, Priechodská and Harčár, 1988).

The sediments of Pontian through Pliocene age were deposited in an alluvial and lacustrine environment and their lithologic character is much more variable compared to those of the Pannonian age. The fine-grained sediments predominate in Pontian (clays, coal/clays and silts), whereas the coarse clastic (gravels ,sands) predominate in Pliocene. The distribution of Pontian through Pliocene sediments (Volkovce formation - Prechodská and Harčár,1988) coincides roughly with the distribution of Pannonian sediments. Their thickness in the Gabčíkovo depression attains 2 800 m (Nagy and Tkáčová, 1994).

Quaternary subsidence represents a 500 m thick group of sedimentary beds, which may be divided into two complexes (Pristaš, et al., 1994). The lower, considered to be of Lower Pleistocene age, consists of fine-grained sandy gravel, with frequent beds of sandy and clayey sediments. It is a result of sedimentation in a discharging lake environment. The bottom of the lower group of beds lies in the middle of the depression, at a depth of some 500 m and its thickness reaches 330 m.

The Middle Pleistocene is represented by medium to coarse-grained sandy gravels with scarce intercalations of finer grained sediments. In the centre of the depression, which remains identical to the centre during the Pliocene and Lower Pleitocene periods, the thickness of this group of beds attains 170 m. However, it decreases at the margins to 50 - 30 m.

As regards the youngest tectonic activity, which influenced vertical movements in this region and controlled the subsidence and the deposition of sediments, several stages can be distinguished:

- Pannonian - in which, besides of the Gabčíkovo depression, the Komjatice depression had formed under conditions of NW-SE striking extension (Kováč, et al., 1994). Apart from NE-SW normal slip faults (Mojmírovce and Šurany faults), which controlled the Pannonian sedimentation within the Komjatice depression, the faults striking N-S were activated, displaying dextral transtensional movement - the Middle Slovakian fault zone (Kováč and Hók, 1993).

- Pontian-Pliocene - the regions of the Gabčíkovo and Komjatice depressions were controlled by faults striking NE-SW, which were gradually succeeded by E-W striking fault structures, forming under extensional conditions. These faults facilitated an accumulation of alluvial fans of the Volkovce group of beds, a material transported from the NE part of the basin towards the SW (Harčár and Priechodská, 1988).

- Quaternary tectonics exhibit a stress field, with the main compression directed within the area of Danubian lowland NW-SE (Gerner, 1994). The activity of vertical movements (Joo, et al., 1989, Šefara, 1993, Maglay, et al., 1993) indicates the sustained subsidence of the central part of the Danube Basin. Under these extensional conditions mainly the W-E to NE-SW striking faults have formed, thus causing a tilting of Plio-Quaternary blocks at the margin of subsiding region, whereby the base of movement may be assigned to Pontian and Pannonan pelitic complexes (Kováč, et al., 1994).

9. Geophysical Evaluation of Tectonic Activity in the Central Part of the Danube Basin

9.1 Interpretation of detailed gravimetric section

To appraise the hitherto active faults in the area of Bratislava (Hricko, et al., 1994), the following geophysical methods were used: seismics, gravimetry, geoelectric methods, atmogeochemistry, radon emanations and gamma spectrometry. Application of these methods was a follow up to construction of geological maps, measurements of markers of stress conditions, including the DPZ analysis and seismology (earthquakes). Faults and fault zones with potential to sustain the differential processes, many of them with probable discontinuous movement and dependent upon inevitable accumulation and ensuing release of strain in the form of earthquakes, were delineated. The zone of inversion, in which the change of geotectonic conditions takes place (Malé Karpaty horst versus the Gabčíkovo depression) has been defined.

The detailed gravimetric profile with the pace of measurement 50 m (Fig.1.2) intersects the two presumed neotectonic fault lines: the Šamorín and the Dobrohošť faults. The gravimetric section proper forms a curve with a very transitional continuous field with small undulations. Anomalous features in the curve indicate in summary all the inhomogeneities at depth (relief of the basement, structure of deep seated and abyssal features). The smooth course of the curve indicates the effects of these deep seated and abyssal structures.

Theoretical effects of the fault structures were calculated for fault throws of A-50 m and B-100 m. The models are inferred from local density relations, measured in a number of wells within the Danube Basin.

Appraisal of the measured curve at the site of the courses of inferred faults results in finding that its course differs from the modelled effects. An addition of certain regional influences (infuence of deep seated structures) will not allow to juxtapose (to overlap) these two gravitational effects at any site. This should mean that the location of faults at the mentioned sites must be placed in serious doubt and that the differences at the geologically confirmed deep levels would then be explained by a mechanism other than fault-forming (different compaction of underlying rocks due to sorting of the material during the sedimentation, wandering of sedimentation depocentres etc.).

This kind of mechanism of geological motion does not imply a potential shearing deformation of any part of the Gabčíkovo Project.

The recent role played by the faults has been determined in the surroundings of Bratislava, using the results of radon emanations (Hricko, et al., 1984). Provisional outcome of the radon survey (radon map of Slovakia - Daniel - pers. comm) resulted in finding the radon emanations in the area of Komárno township, which agrees with the assumed relation of tectonics and seismicity. No other sites of increased radon emanations were found within the Danube Basin.

9.2 Interpretation of seismic profiles in the area of the Gabčíkovo Project

The interpretation of seismic profiles (appearing as Figs. 2-9 hereto) in this study is an addition and the corollary to the report "Geodynamic model of Danube Basin in the area of the Gabčíkovo Project", which in turn is part and parcel of the report "Comparison of older and recent aspects of geologic-tectonic structure of the Danube Basin in relation to the seismicity of the Gabčíkovo Project" (Mahel', et al., 1995). This comprised Annex 26 to the Slovak Counter-Memorial.

Some 700 sq. km. of seismic profiles have been made using the SRB method, in the broader surroundings of the Gabčíkovo Project (Fig. 1.3). The measurements in profiles were made during 1973, 1977, 1981, 1882, 1983 and 1992. As the measurents made in 1973, 1977, 1981, 1982 and 1983 were of lower quality and numeric processing of the field seismic data experienced since then distinct qualitative progress, the seismic profiles made during the above years were submitted to reprocessing in 1991. Thus, a relatively satisfactory set of seismic information has been gathered to allow for provisional evaluation of geologic-tectonic features of the central part of the Danube Basin, in which the Gabčíkovo Project is located.

The following factors influence the character and the quality of the wave image in the seismic profiles:

- Unfavourable influences of geomorphologic nature interfere and distort the useful information on the seismic signal values. There are marshy grounds and bogs as well as a dense network of channels in the area under study, which hamper primary field measurements.

- The majority of geophysical methods or seismic surveys, respectively, suffer from unfavorable influences of loose beds, or less consolidated cover units, composed mainly of the Quaternary sediments. Such beds are called, using a seismic survey vocabulary, the beds of low velocity of propagation of elastic waves, and they negatively affect the quality of measurements (they distinctly weaken the signal). Such beds attain in this area thicknesses of up to several tens of metres and add significantly to illegibility of the record, especially at frequencies of approx. 0.2 to 0.4 sec.

- Formation of distinct reflexive waves takes place when there are relatively flat and straight bedding planes. Undulations of bedding planes and frequent facial changes cause the energy dispersion and inhibit the formation of a continuous reflex. In geophysical terms the thin and the thick beds can be recognized. The thin bed is the one whose thickness is less than two times the length of the seismic wave through which it passes. In such case the interference of waves, reflected from both the hanging wall and the foot wall of a thin bed takes place, which complicates again the interpretation of the wave image. It is the Upper Pannonian through Quaternary (see Tab.1, above), i.e., the deltaic or lacustrine - fluviatile sediments, that exhibit in the region under study the above mentioned properties, in seismics terms unfavourable.

- Fault planes cause fading and dispersion of relevant energy, formation of diffracted waves, dissipation and deformation of reflexes, interruption of continuous correlation, different dips of physical boundaries within discrete slabs, occurrence of the so called pre-thrusted anticline etc. This should mean that the indication of faults in the time-bound sections relies on a series of signs whose interpretation cannot be arrived at separately but only in correlation.

The structure of the Danube Basin is characterized by quick subsidence during the Lower and Middle Miocene (16 to 12 million years ago) and much slower subsidence during subsequent times.

During the first stage a part of the lithosphere becomes dilated, proportionally thinned and, at the same time, hot asthenosphere upbulges. Dilation of the lithosphere on the continents almost always necessitates crustal subsidence (Roberts-Yielding, 1994). During such processes the upper part of the lithosphere breaks due to normal downslip, often synsedimentary and earlier horizontal sedimentary beds dip opposite to the strike of downslip in faults. (Figs. 6 and 7).

Lithospheric dilation is generally associated with the formation of trough-like rift, reaching several 10 to 100 m along the strike of faults. Depending on the strike of lateral displacement and on spatial emplacement of discrete faults there form sometimes dilational and folded structures. At selected sections of seismic profiles is this stage associated with tectonic lines, which fade in a vertical sense in time spans 2 to 1.5 second, i.e., at the boundary between the Middle and Upper Miocene.

During the second stage the initial subsidence (rifting stage) is followed by a slower, passive (post-rifting), the so called thermic subsidence. In this case the deposited sediments are less disrupted and are more widespread. Gradual cooling causes the asthenosphere to change into heavier lithosphere - dilation or horizontal tensional stress is gradually smoothed and is followed by the contraction. As the heat transfer slowly decreases, the thermic subsidence becomes too sluggish.

At this stage there predominate the compensational (contractional) faults, which display in part listric features, small vertical throw (of an order of metres to tens of metres), whilst the horizontal component is negligible. At selected sections of seismic profiles is this stage associated with tectonic lines, which fade in vertical sense in time spans 2 to 1.5 second, i.e., they reach the boundary between the Middle and Upper Miocene. However, a majority of them are the compensating downslip faults, which smoothed the strain; their repeated activity is not plausible, provided the conditions did not change. Manifestation of these faults during the Quaternary is difficult to be identified, because the upper part of the seismic record (0.2 to 0.4 second) has, in a number of sections, poor legibility.

In conclusion, it can be stated that, from the geodynamic point of view, the formation of the Danube Basin evolved during two stages of tectonic activity.

The first stage (rifting stage) took place during the Lower to Middle Miocene, whereas the second stage (post-rifting stage) during the Upper Miocene, Pliocene and Quaternary. The rifting stage is characterized by distinct faulting activity throughout the Danube Basin, while the faulting activity associated with the post-rifting stage is bound predominantly to marginal portions of the basin. The recent times are dominated by thermic stabilization of the basin, associated with low activity along faults, which is still concentrated within the marginal parts of the Danube Basin.

Table 2 Lithological - stratigraphic section through central part of the Danubian Basin (Nagy and Tkáčová, 1994)

Stage	Lithology	Sedimentary environment	m
Quaternary	predominantly gravels, coarse grained sands, scarce clays	fluviatile	500
Rumanian	fine polymictic gravel with layers of sandy variegated clays	fluviatile-lacustrine	500
Dakian	variegated clay stones with beds of sandstones	fluviatile-lacustrine	1000
Pontian	limy claystones with beds of sandstones	lacustrine	1300
Pannonian	limy claystones with beds of sandstones	lacustrine-very fresh brackish	2200
Sarmatian	limy claystones with beds of sandstones locally with tuffs	brackish-shallow water marine	500
Badenian	limy claystones sandy limy siltstones beds of sandstones, locally tuffite	shallow water marine, locally deeper water	1500

10. Conclusions

The Gabčikovo Project is situated within the central part of the Danube lowland. In geological terms this structure is represented by the Danube Basin, filled in by the Late Tertiary and Quaternary sediments, reaching the thickness in the central part of up to 8 000 m (Seneš, 1960, 1962, Kilényi and Šefara, 1989).

The basement of the Danube Basin is formed by the Tatricum and Veporicum tectonic units, the latter thrusted over the former along the Čertovice line and by complexes of the

Hungarian Midmountains, in nappe position.

During the Lower Miocene the tectonic activity of the pre-rifting stage of the Danube Basin influenced mainly the structure of its marginal portions.

During the Middle Miocene the central part of the Danube Basin became a subject of transformation due to tectonic activity that took place under conditions of extensional regime of the rifting stage. Downthrow and listric faults, bound to decollements at the boundary between plastic and brittle crust, were activated (Horváth 1993, Tari 1992, 1993), accompanied by distinct subsidence, predominant in the marginal parts of the basin.

During the Upper Miocene, in the course of the post-rifting stage, the development of the basin was characterized by an extension with limited activity along faults and local compressional events, which provoked both downthrow and listric faults striking NE-SW and N-S striking dextral strike slips at the eastern limits of the Danube Basin (the Middle Slovakian fault zone).

In the field morphology there distinctly appear Quaternary tetonics (courses of streams, orientation of valleys), accessible to naked eye observation (Kováč, et al., 1994). Manifestations of the Quaternary tectonics indicate that continuous subsidence in the central part of the Danube Basin have taken place (Joo, et al., 1989, Šefara, 1993, Maglay, et al., 1993). Within the frame of this extensional regime, predominantly the W-E to NESW striking listric downthrow faults take place, which cause tilting of the Plio-Quaternary blocks in the central part of the Danube Basin, whereby the base of the movement may be assigned to the Pontian and Pannonian clayey complexes (Kováč, et al., 1994). By no means, however, are the earthquake centres bound to these fault disruptions.

The following important fault systems run within the broader area of the Danube Basin: the Danubian fault system, the Malé Karpaty fault, the Ludince fault, the Považie fault system, the Mojmírovce and the Šurany faults, the Middle Slovakian fault zone and the Plešivec - Rapovce fault system. None of them runs in proximity of the Project. Out of the above important fault lines, the Middle Slovakian fault system only reaches the Moho-discontinuity level. We have no evidence that these faults would disrupt the uppermost portions of the sedimentary filling in the area immediately surrounding the Project.

Based on structural - geologic and geophysical properties it is possible to delineate within the region of the Western Carpathians the geological domains with a roughly similar degree of seismic hazard (Kováč et al., 1994).

We rank the Danube Basin region in the geologic - seismic domain of the Eastern Alps and Central Carpathians, which are in terms of seismic activity consolidated. From the geophysical point of view the whole region is characterized by diminishing thickness of the lithosphere from west to east, from 90 to 60 km. The thickness of the crust within the Danube basin region reaches 28 km. No distinct earthquake centres are found there. Distinct earthquake cenrtes are situated in the geologic-seismic domain of the Hungarian Midmountain and in the southern branch of the Peripieniny lineament, along the western margins of the Leitha and the Malé Karpaty Mts. (Kováč, et al., 1994).

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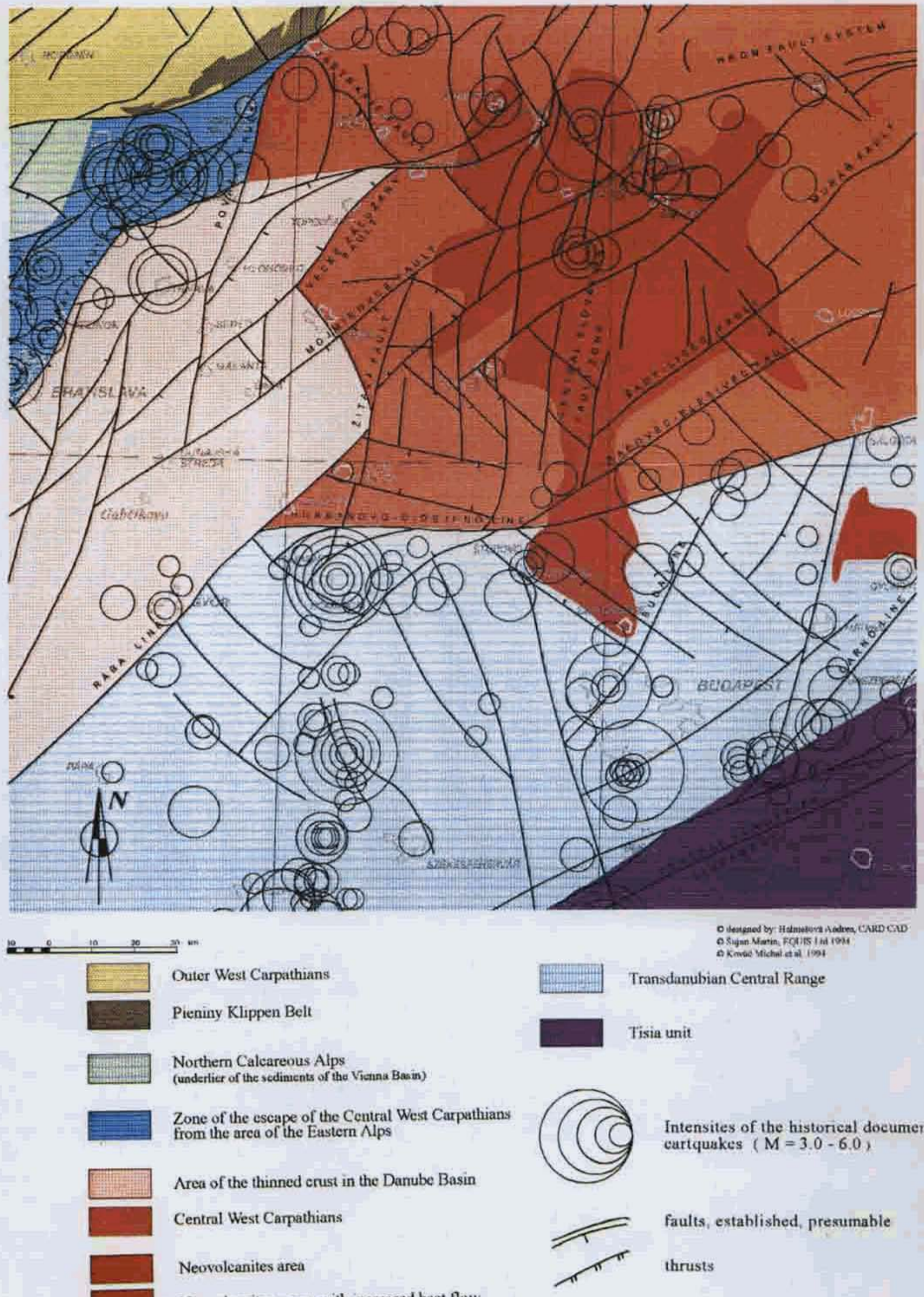
Fig. 1.1 MAP OF THE GEOLOGICAL-SEISMIC DOMAINS



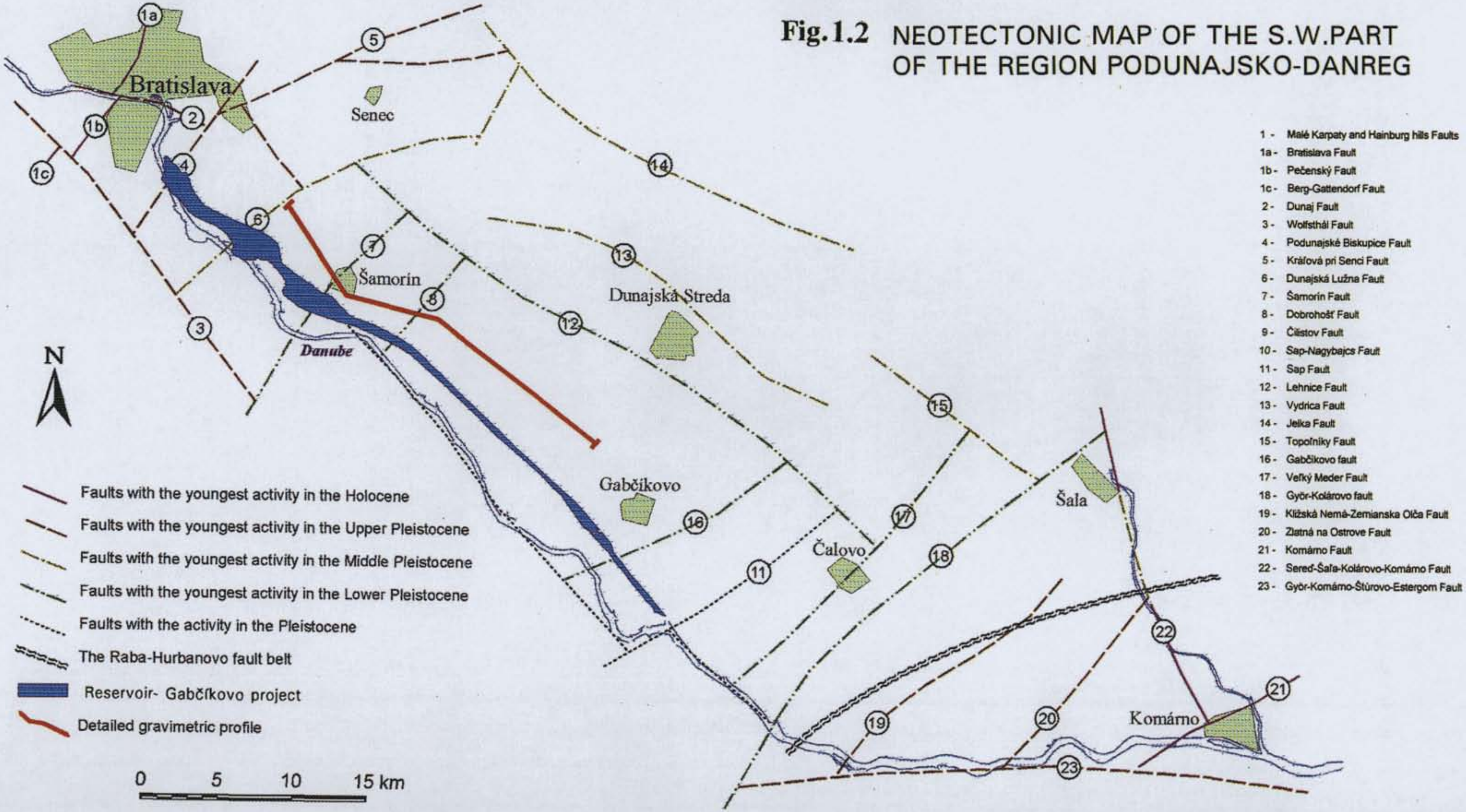
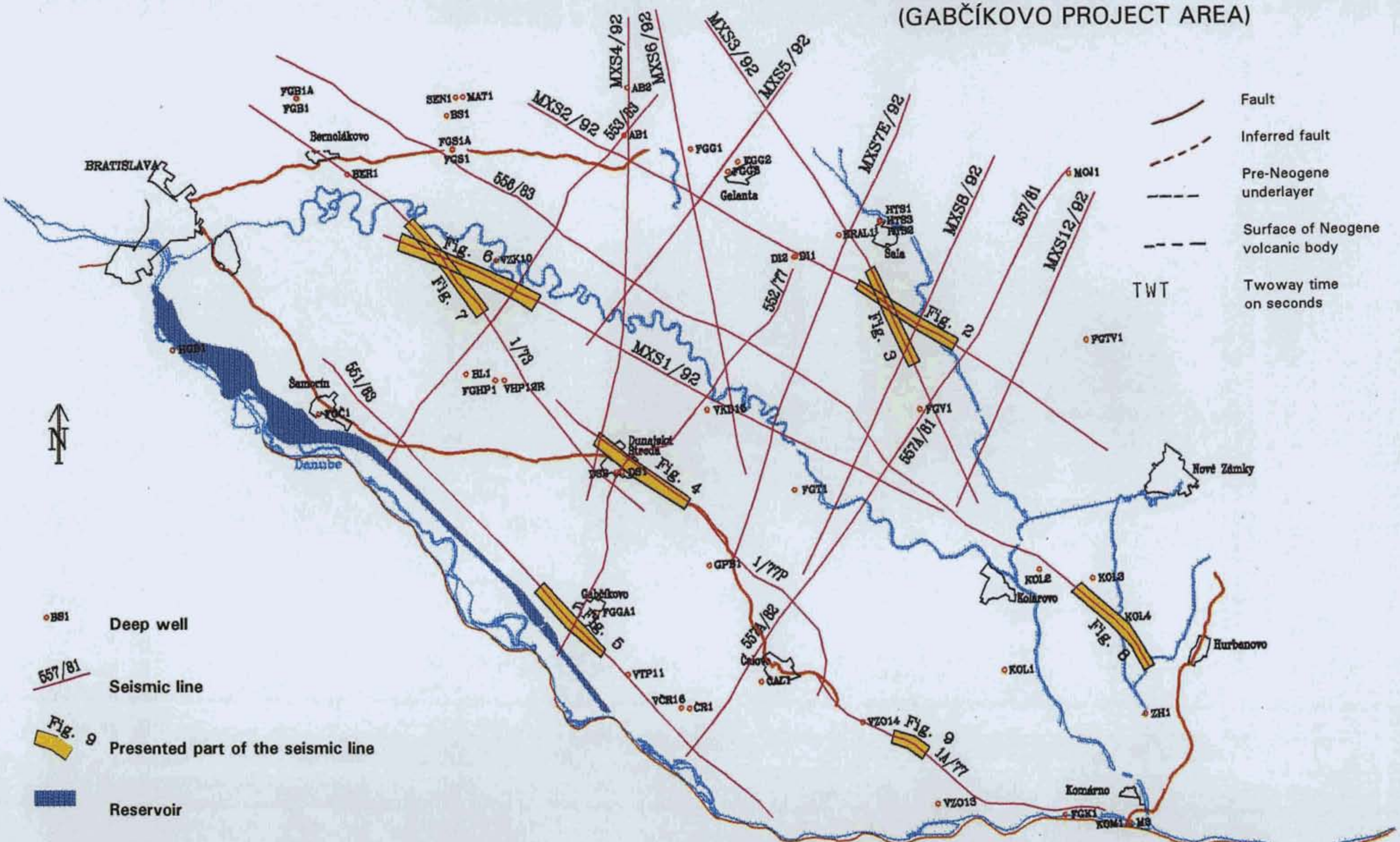


Fig.1.2 NEOTECTONIC MAP OF THE S.W.PART OF THE REGION PODUNAJSKO-DANREG

Fig. 1.3 SITUATION MAP OF SEISMIC LINES (CDP) AND DEEP WELLS (GABČÍKOVO PROJECT AREA)



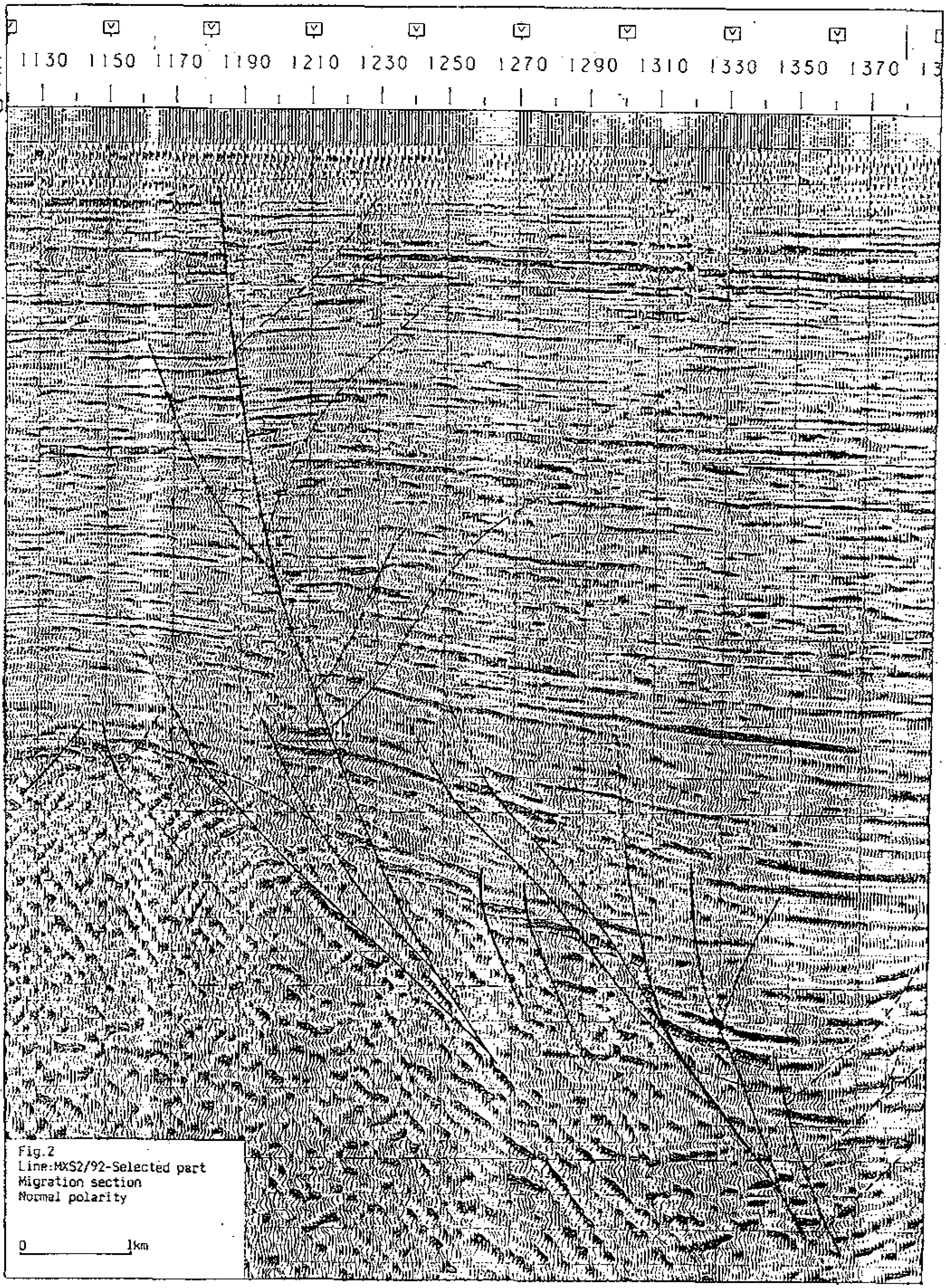


Fig.2
Line:MXS2/92-Selected part
Migration section
Normal polarity

0 1km

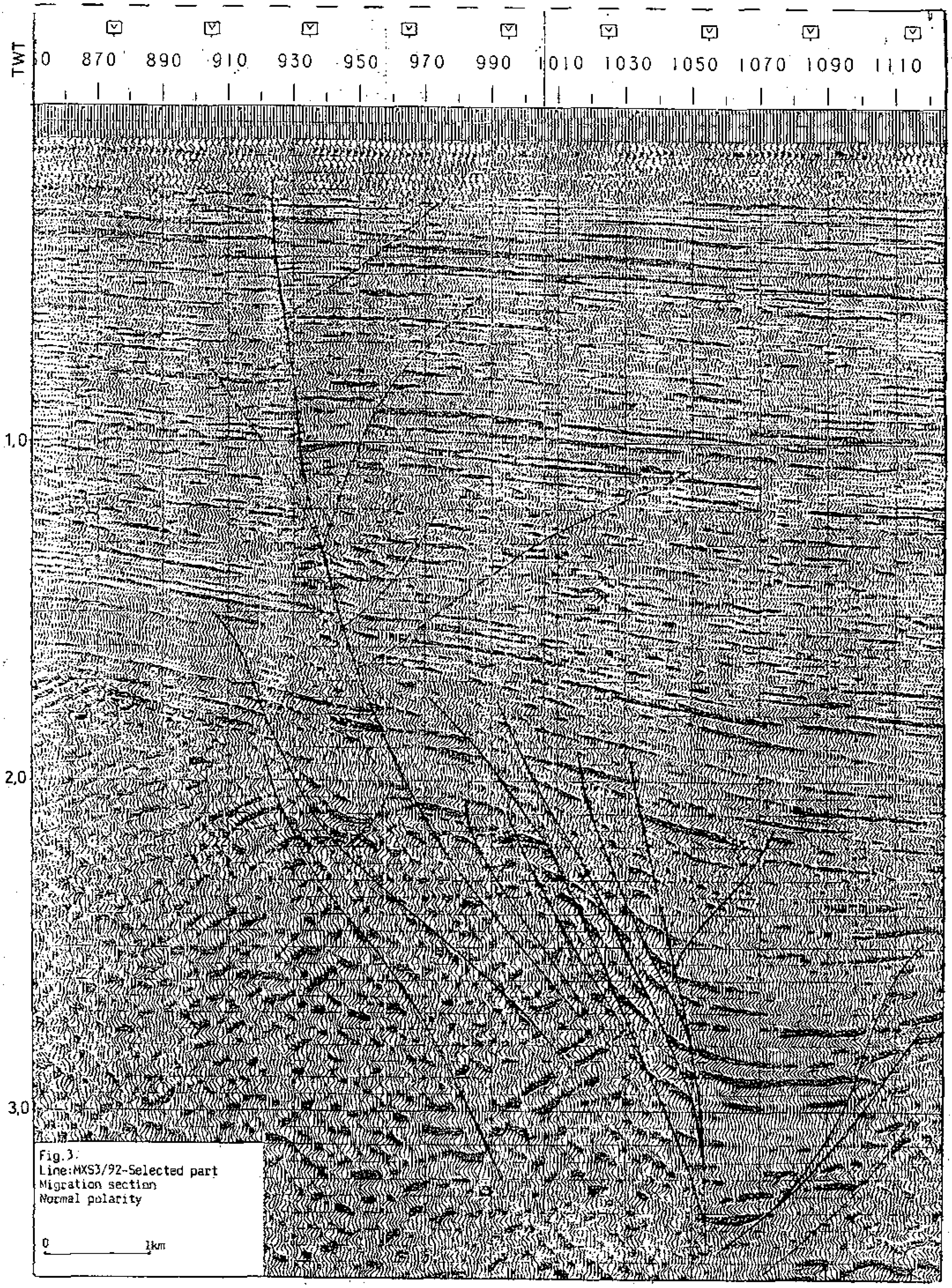


Fig.3:
Line:MXS3/92-Selected part
Migration section
Normal polarity

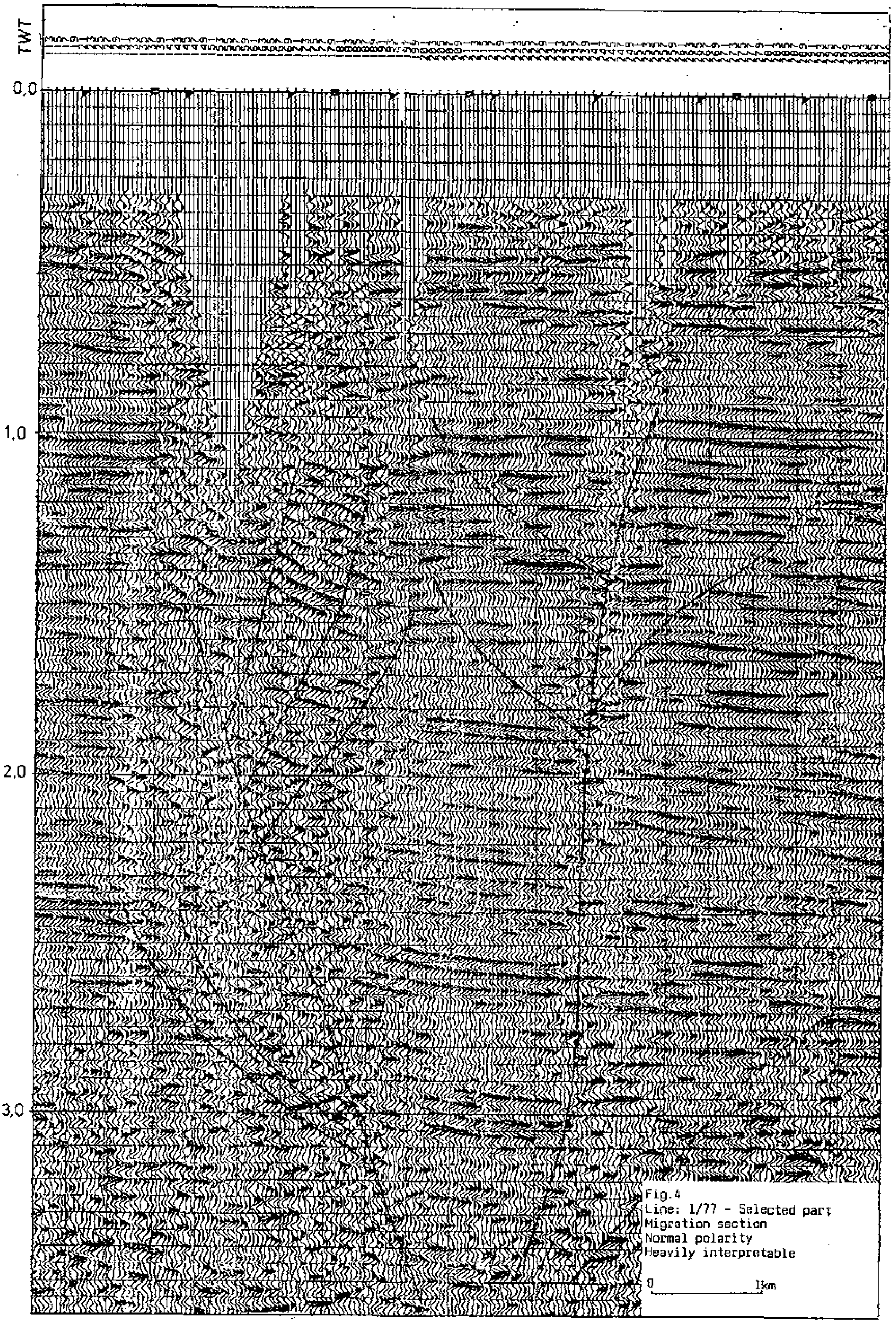


Fig.4
Line: 1/77 - Selected part
Migration section
Normal polarity
Heavily interpretable

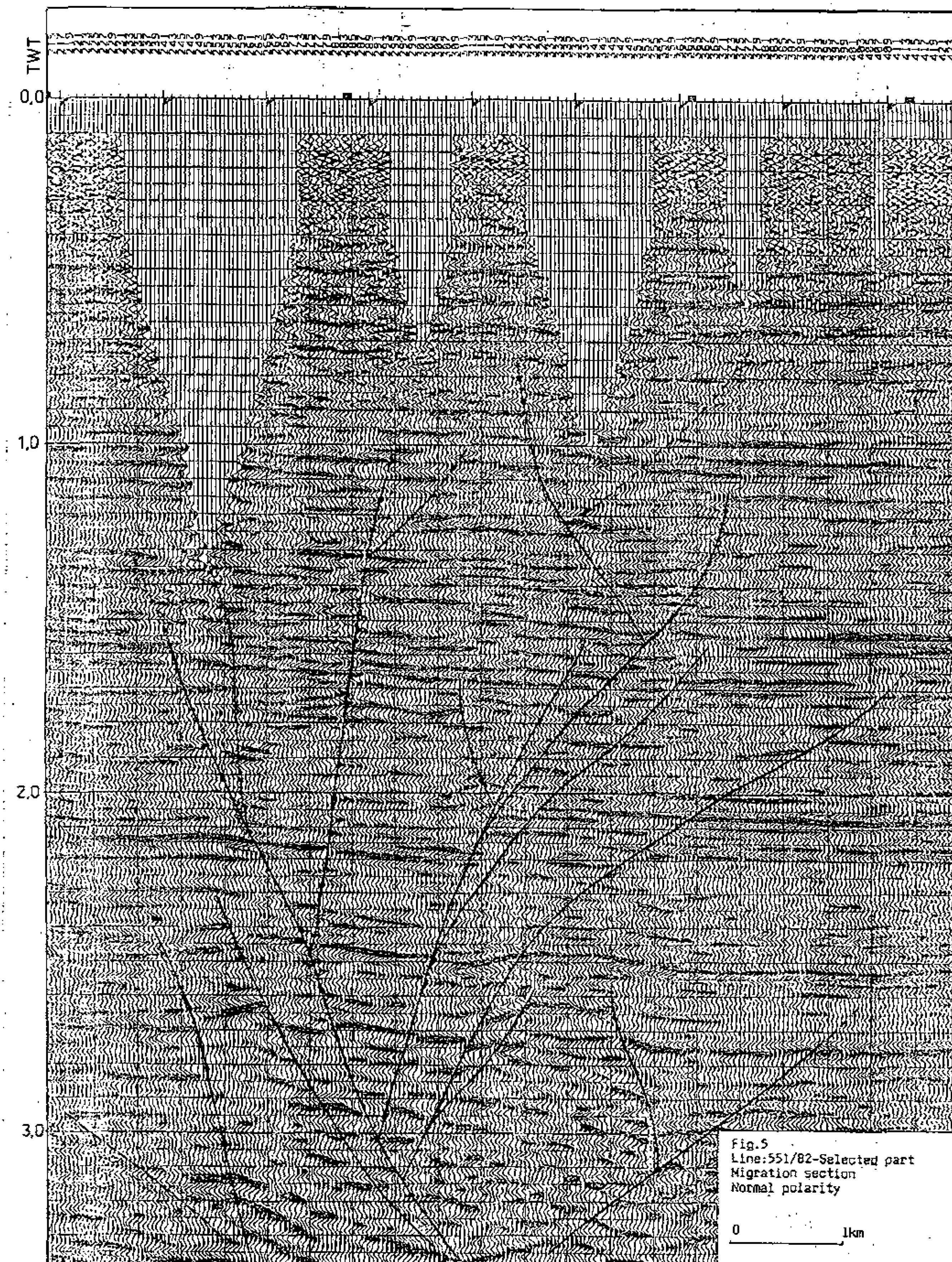


Fig.5
Line:551/82-Selected part
Migration section
Normal polarity

0 1km

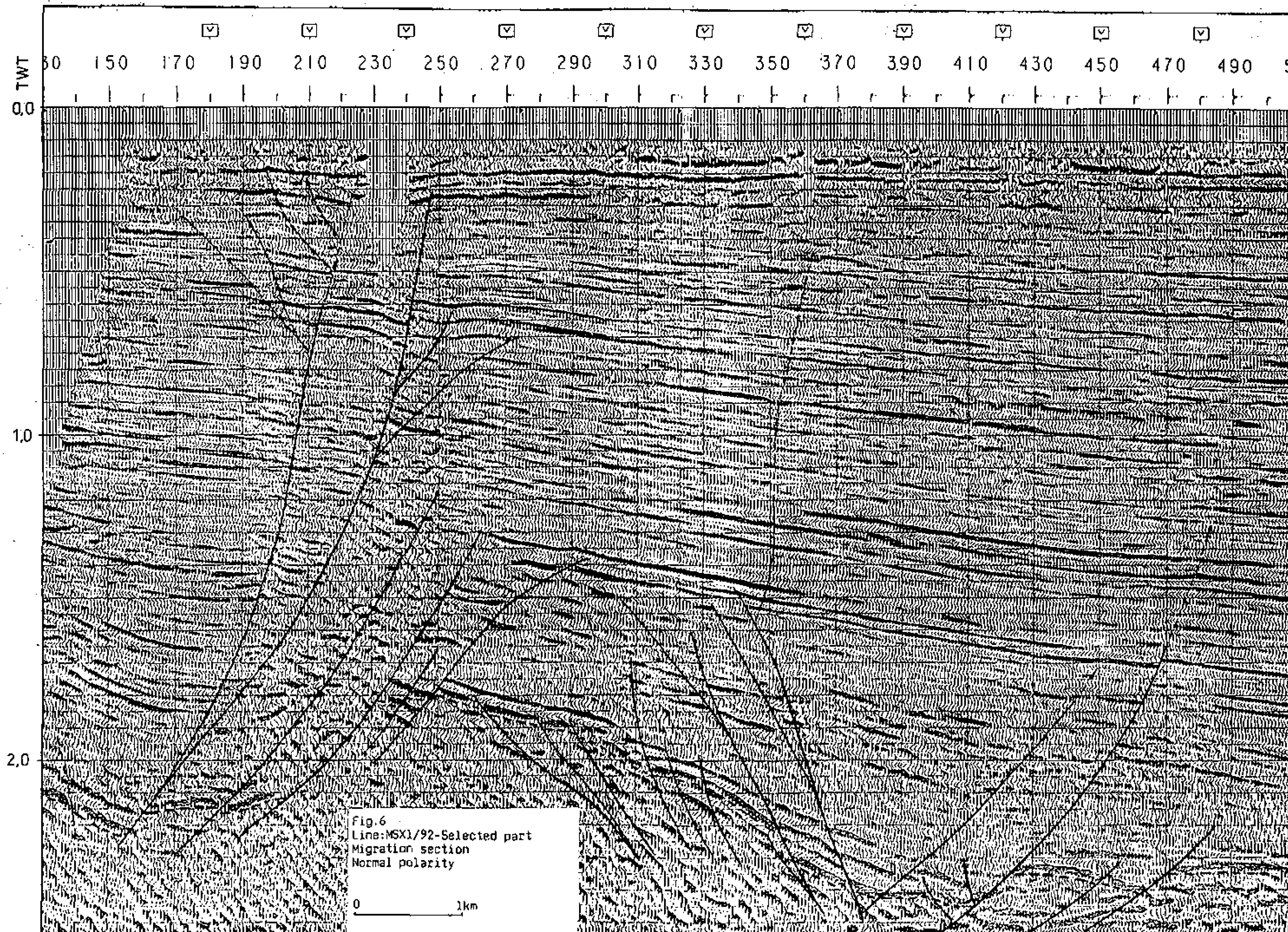


Fig.6
Line:MSX1/92-Selected part
Migration section
Normal polarity

0 1km

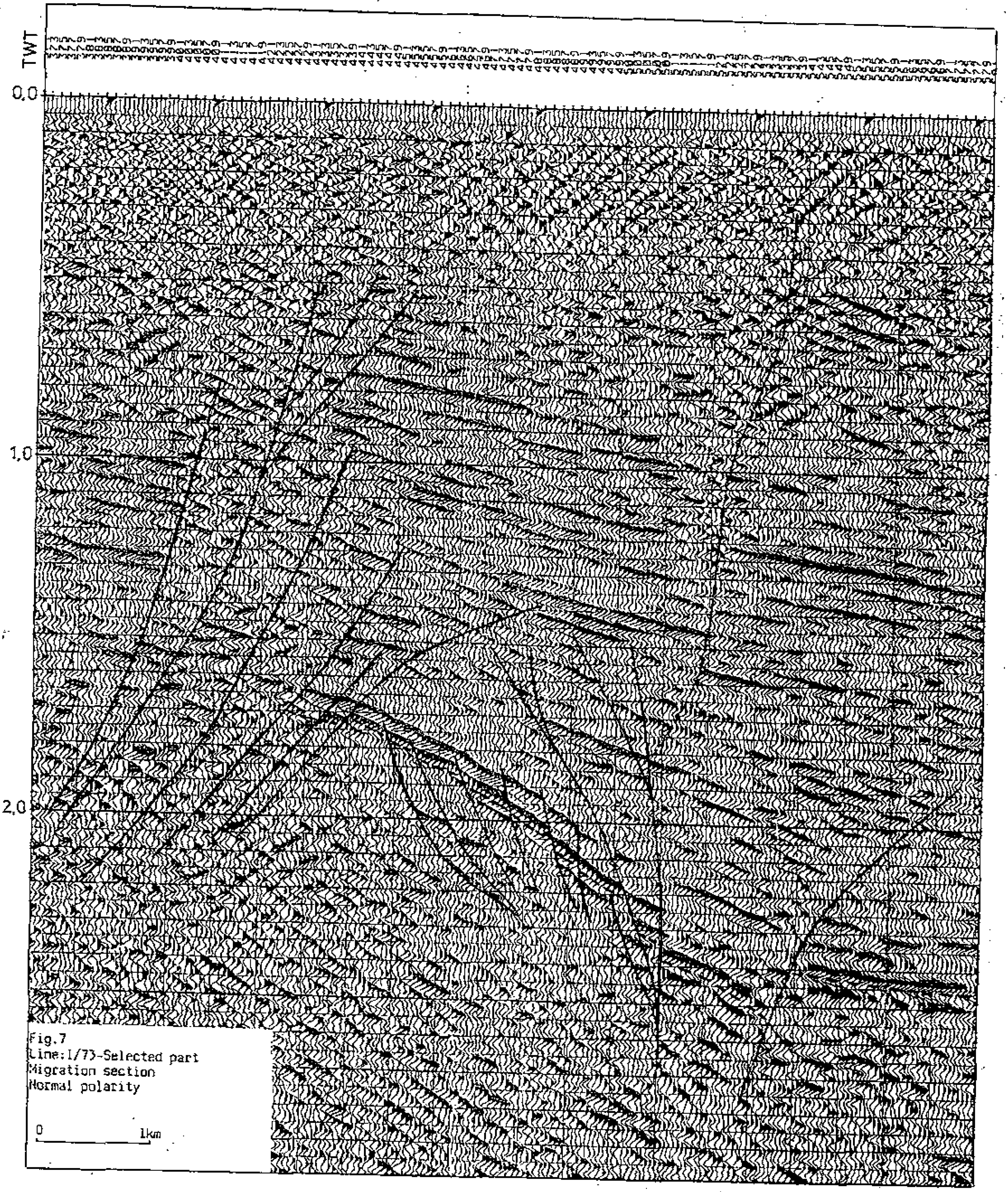


Fig.7
Line:I/73-Selected part
Migration section
Normal polarity

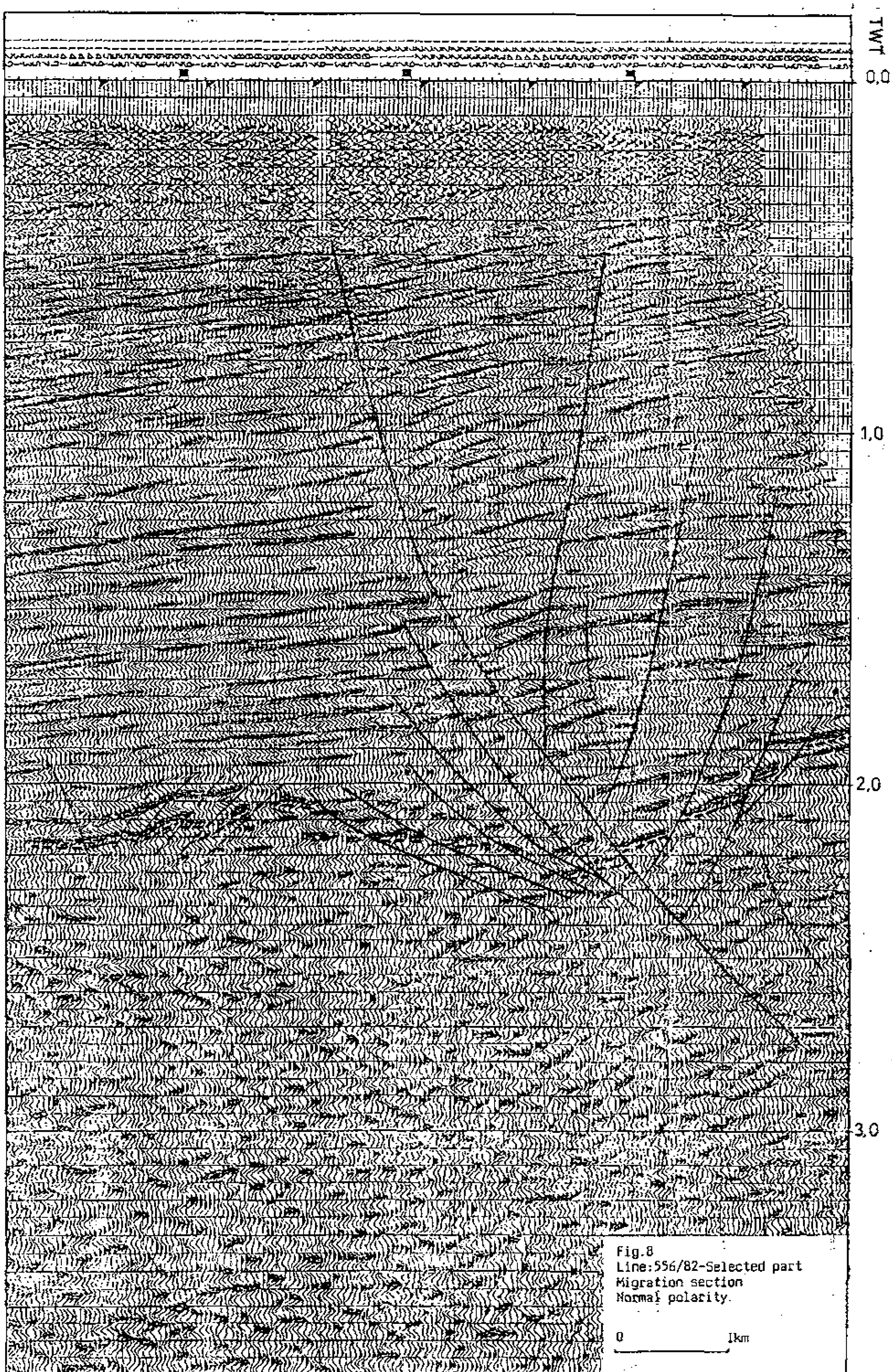


Fig.8
Line:556/82-Selected part
Migration section
Normal polarity.

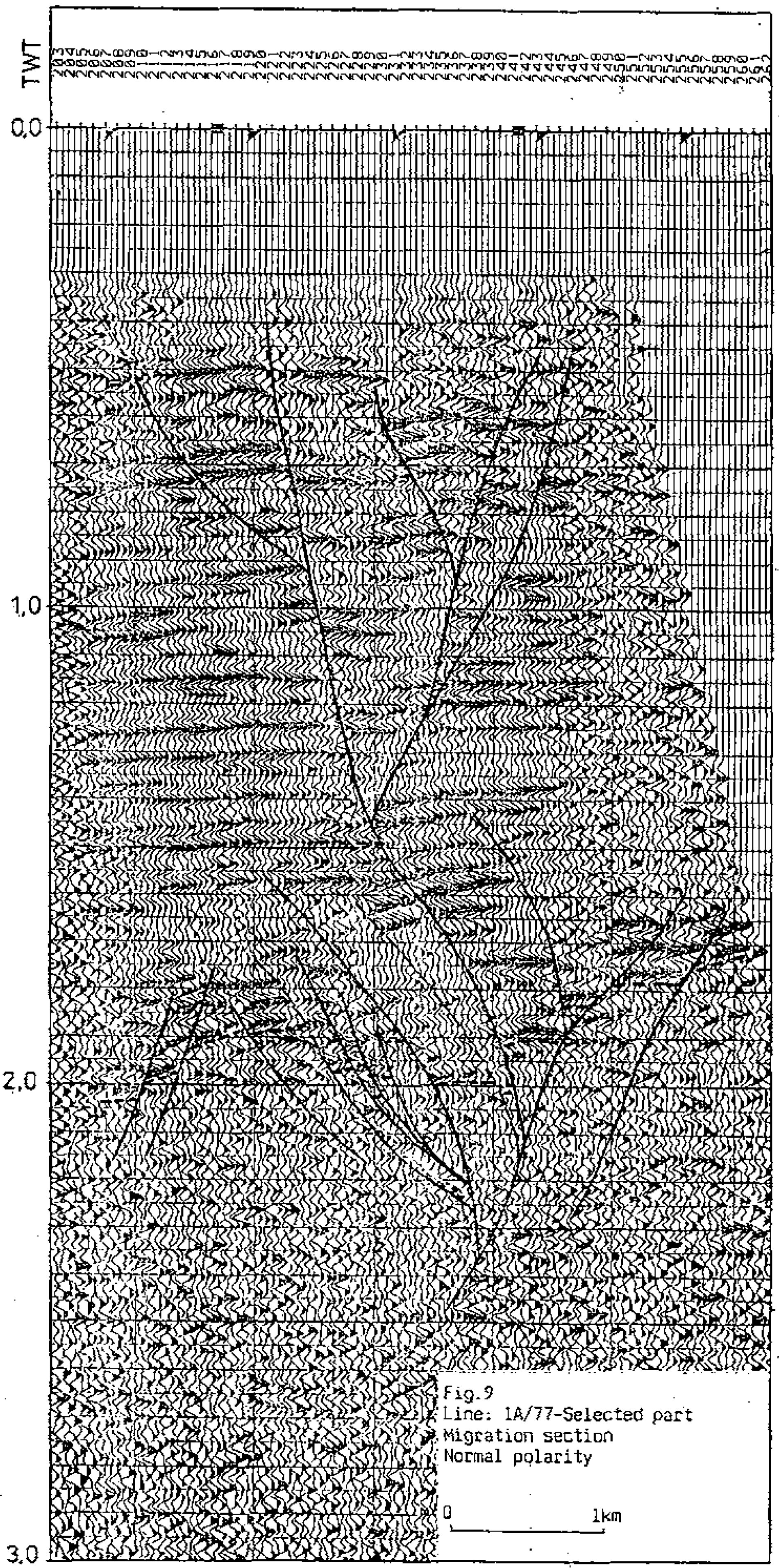


Fig.9
Line: 1A/77-Selected part
Migration section
Normal polarity

CHAPTER 10. SEISMICITY AND SEISMIC HAZARD

PART I. AN APPRAISAL OF SEISMICITY OF THE AREA OF THE G/N PROJECT

V.Janotka
J.Viskup

February 1995

1. Introduction

As a basis for designing the G/N Project, the Czechoslovak and Hunagrian experts agreed in 1965 on so-called Unified regulations which were compatible with or even stricter than both Czechoslovak and Hungarian state norms for designing dams. This was also the case in calculating the seismic load. Czechoslovak designers applied the norm ON 73 6503 entitled the Load of water management constructions by water pressure (1963), ČSN 73 6503 Load of water management constructions by water pressure (1972), ON 73 6503 Load of constructions of hydrotechnical buildings, ČSN 73 6850 (1975) Earth dams, P= 12-526-266 (1982), and Instructions for designing hydrotechnical constructions in seismic regions (Klapatek, Bratislava, 1982).

In 1980 a seismic microzoning of the area of the G/N Project structures on the Slovak territory was carried out by the authors of this study and their institution (Dept. of Applied and Environmental Geophysics, Faculty of Natural Sciences, Comenius University) and in 1982 it was followed by an independent expertise for the Gabčíkovo part of the Project made by experts from the then Soviet Union.

In all stages of designing and preparation of the Project all questions were the subject of continuous consultation between Slovak and Hungarian specialists. Thus, for instance, the calculation of seismic load was discussed between Ing. Polka and Ing. Mistéthy. It should be noted that until June 1989 the Hungarian side did not have any objections as to the calculation of seismic load and the entries used for calculation. The objections were raised for the first time by Academician Varga in 1989 at a common meeting of Slovak and Hungarian specialists. At this meeting the Hungarian side expressed objections that in calculating the seismic load for the G/N

Project the seismotectonic situation in the Hungarian territory was not taken duly into consideration.

2. Calculation of Seismic Load

The calculation of seismic load was based on the seismicity data of the area in which the G/N Project was to be situated. The process of its assessment was carried out in accordance with existing methodological regulations used in Czechoslovakia as well as in the USSR. These methodological regulations were updated to match the actual level of know-how in Czechoslovakia, Hungary and USSR. They relied on calculation of the seismic coefficient from the macroseismic earthquake intensity and then on the use of this parameter as one of the entries to calculate the seismic load. This seismic coefficient sensu stricto is the value of maximum expected acceleration, divided by gravitational acceleration. Later on, a direct assessment of the acceleration value was carried out from the earthquake intensity and this value was used to calculate the seismic load.

3. Seismic Microzoning

The results of observations of earthquake effect in this region have shown that the macroseismic effects of an earthquake are also influenced by local changes in the geologic situation. These intensity changes, resulting from the local geologic situation, can be assessed with the use of the seismic microzoning method. This method was applied in the area of the G/N Project in 1977. Since no sufficient practice in applying this method was available in Czechoslovakia at that time, the methodological procedure used in the then USSR (SNiP - II - A. 12-69 - Gosstroy, Moscow, 1977) was applied.

The results of seismic microzoning indicated that the sediments, which possess low velocity to propagate seismic vibration (e.g., Holocene sediments filling the oxbow lakes of the Danube), could increase the intensity of the earthquake. On the basis of this information the decision was taken to remove such low velocity sediments.

4. Actual Seismologic and Geologic-Tectonic Information on the Area

To assess the stability of the Gabčíkovo part of the Project the most recent knowledge on the geologic-structure of the area is available. This knowledge was gathered from the results of the reflexive seismic exploration, realized along the seismic profile 551/82 551/83 during 1982-1983. The results of reflexive seismic measurements have been reprocessed by the American company Maxus and reinterpreted in cooperation with the VVNP (Oil and Gas Research and Exploration State Enterprise) Bratislava (Hrušecký, et al., 1994). The depth extent of this exploration reached some 15 km.

The latest methodologic techniques used in the USA and Japan to assess the acceleration and seismic load are also at our disposal, and both the software and hardware equipment is available. Seismic calculations, until then carried out using "hall fashion" computers, can now be made using PCs, which facilitate computations on site and the application of various models. Thus it is logical that some of the methods used 30 years ago can be considered obsolete now and the results achieved at that time should be regarded with caution.

Development cannot be stopped however. Thus, considering the dynamics in the development of new technologies and know-how, it may well be anticipated that within a few years new evidence will come to light. These will add to accuracy and to the state of knowledge.

5. Magnitude and Intensities of Earthquakes

In order to facilitate the understanding of this study, we shall explain shortly the categories of earthquake magnitude and intensities.

The magnitude of an earthquake is a parameter, referred to (among the first) when the character of the earthquake is to be described. This parameter is associated with the energy released during an earthquake, and instrumental measurements are used to determine it. Its value is rated using the Richter scale. Thus, if the magnitude of a given earthquake was rated at 5.7 on the scale, we refer to an earthquake magnitude of 5.7 degrees on the Richter scale. The value is reported with precision to one decimal. If the instrumental measurements are not available, earthquake magnitude is determined by calculating it from its intensity, which is the second earthquake parameter. This method is usually applied to estimate the magnitude of historic earthquakes where no instrumental measurements were carried out. Since regular measurements did not commence in our territory earlier than after World War II, this situation applied to the Komárno earthquake. However, the calculation of magnitude from intensity is not reliable and can be, to some degree, subject to mistakes.

Macroseismic intensity of an earthquake (called simply intensity) can also be expressed in degrees. It is established using macroseismic observations, i.e., the observations of eye-witnesses, the manifestations inflicted on buildings and on the Earth's surface. Based on the degree of disruption, or observed effects, the appropriate degree of intensity scale can be established and is given as a full, or a half of a degree.

To understand the importance of the acceleration parameter (which is the third earthquake parameter) in seismological practice and its relation to macroseismic intensity, we present here a concise review of the most utilised macroseismic scales.

Various intensity scales have been in use all over the world. However, the 12 degree scale is the most preferred. In Slovakia, the ČSN 73 0036 Seismic load of buildings from 1973 and the MCS (Mercali Cancani Sieberg) scale, is applied. This scale has also been used by seismic engineers and construction designers in designing the G/N Project.

Slovak seismologists as well as the seismologists from other Eastern European States use the MSK scale (Medvedev-Sponhayer-Kárník). This scale has various modifications (MSK-64, MSS-73, MSK-78, MMSK-84). The one most frequently used is the MSK-64. The European Commision issued in 1993 the MSK-92 scale, which bears the same designation. In the US the MM scale (Mercali Modified) is in use. All the three scales are 12 degree scales, and any macroseismic effects corresponding to a given degree are, regardless of which one of the above scales has been used, roughly identical. Therefore an earthquake whose macroseismic effects would correspond to 8.0 MSK-64 should match 8.0 MCS as well as 8.0 MM.

Each degree of intensity in the MCS, MSK-64 and MM scale is given a certain value of acceleration. It is important to mention that the acceleration value differs considerably for each degree as between the three above mentioned scales. Thus, the macroseismic effect ratings using the three scales are similar on one hand, but on the other, the acceleration value, which is used for practical calculations, differs for each scale.

We note with regret that this fact has been exploited by Hungary in its calculations, it having applied whichever of the two scales best fits the purposes of its argumentation. If, for instance, in the norm used in designing the G/N Project, the MCS scale has been used, the same norm should then be used to assess the acceleration from the intensity - one cannot then switch to the MSK-64 scale. As the relation between intensity and acceleration is not straightforward, it is not referred to in the newly proposed version of the MSK-92 scale, and the acceleration value must be determined using another operation, i.e., basing on the calculation of accelerograms of expected earthquakes.

Hungary also supports its assertions as to the seismic risk of the area by using magnitude values published by various authors. From these, Hungary derives their macroseismic intensities on the MSK scale and ultimately the accelerations too. These are then used as essential arguments to support its arguments. All these procedures, apart from the above mentioned serious ambiguity between the intensity and acceleration, fail to provide any information on the accuracy of entry parameters, which served as entries for calculations. The seismologic analysis presented in the Hungarian Counter-Memorial (HC-M) also includes the ancient earthquakes (Vol. 2, page 210, Chapter 6, HC-M), in which case the accuracy of the entry data can be doubted. The degree of accuracy is decisive, regardless of the versatility and brilliance of any given interpreting method.

Other terms which will be explained below are the maximum expected macroseismic intensity (Imax) and the maximum magnitude (Mmax).

In seismologic terms, the Imax and Mmax can be determined using various techniques - from the frequency diagram, from the oscillations in Benioff diagram, from the correlation of Imax and Mmax with the seismic activity using the Riznitchenko method, or using the theory of extreme values, or the correlation of the length of active fault with magnitude.

The majority of the above mentioned methods do not take into consideration possible oscillation of tremor activity in the future, or possible manifestations of new epicentres.

6. Tectonics and Calculation of Magnitudes in Relation to the G/N Project

The geologic structure of the region, in this area of the Danube basin, is part and parcel of any seismologic analysis. From this, it is mainly the tectonics that are determinant for both the accumulation and the release of energy. Sudden release of energy is very often accompanied by earthquake effects. It is generally accepted (and in fact incorrectly used in the HC-M as will be shown later) that any point of an active fault, any part of which became an epicentre of an earthquake in the past, may become the epicentre of a would-be earthquake in the future. The most probable sites are considered to be those (if such sites exist) at the intersections of faults.

The empirical relation between the length of an active fault line (km) and maximum magnitude Mmax is reported by various authors, and the range is large. This is why the use of any one of the relations without prior correlation with known data from the area under study may lead to considerable deviations from reality. It is evident that in regions for which such an analysis cannot be carried out due to lack of information it is necessary to apply a generalised relation. The Komárno earthquake should be taken as such, as no measured instrumental data exist to indicate the strength of motions within this region.

For the above reason we present here (Table 1) the relations given by several authors to calculate the maximum magnitude of the Komárno earthquake. An 80 km length of the fault has been assumed in making the calculation, as in HC-M, Vol. 2, Fig. 6.2.

Table 1. Calculation of Mmax based on the length of fault (80 km) according to different authors.

Author	M max
Schebalin (1974)	5.806
Drimmel (1979)	5.506
Anderson and Whitcomb (1975)	5.550

It is obvious that the Hungarian side could produce higher magnitude values based on calculations by other authors. We nevertheless wish to emphasise that the relation given by Drimmel was obtained from 40 calculations of fault lines in the Alps and Western Carpathians and was accepted at the 16th Assembly of the European Seismological Commision in Strasbourg in 1978 as applicable for shallow depth epicentres.

Even if the magnitude value were derived from the maximum observed intensity values and assuming an epicentral intensity Io=8.5°, then, using relations of different authors, the results of the magnitude of the Komárno earthquake calculated from the intensity would be as follows:

Table.2. Calculation of Mmax based on maximum observed intensities

Author	M max
Czomor and Kiss (1959)	5.4
Kárník (1966)	5.72
Kárník (1968) h=6km	5.539
Kárník (1968) h=8km	5.655

On the basis of the above, we can conclude that it is sufficient to consider the maximum magnitude of an earthquake in the region as Mmax = 5.7, and the maximum epicentral intensity as Io = 8.5° MSK-64. These values also correspond to the newest published data (Bune, Szeidowitz, Brouček, 1991) describing the Komárno earthquake.

Furthermore, Hungary's earthquake analysis misinterprets certain facts and is misleading. This is the case, for instance, as to the assertion on pages 78 and 79 of Vol. 1 of the HC-M, which refers to a paper written by Kárník in 1971 and states that the magnitude value of 6.0 was assigned to this area in 1978. In the next sentence there is a statement saying that an earthquake of Richter magnitude ranging from 6 to 6.5 can be expected, whilst on the following page there is yet another note stating that the intensity of the Komárno earthquake ranged from 8.5 to 9.5 degrees and that its Richter magnitude was 6.2.

One cannot avoid the impression that decimals have no essential meaning. In reality, however, this is not so, because the relation between the acceleration and magnitude follows a logarithmic course, and in this case the decimals are of great importance.

The following should also be noted: in the publication of Kárník (1971), referred to at page 78 (HC-M, Vol. 1), the intensity of the Komárno earthquake, which took place on 28 June 1763, conformed to the 9th degree; however, neither the scale used was specified (page 186) nor its magnitude. This magnitude can however be immediately calculated from the relation, given on page 69 of Kárník (1971) for the area 21 (Carpathian region): the resulting value is M = 5.73 and not 6.2. If the relation used to calculate the magnitude were also to include the thickness of the epicentre, given on the page 65 of Kárník, then M = 5.87; and if the relation given by Csomor and Kiss on page 64 were applied, then M = 5.7; and if the thickness of the epicentre were also taken into calculation, then M = 5.62.

Nevertheless, Hungary comes forward with the value 6.5, which has been derived from the intensity of the 9th degree of the Komárno earthquake, and it proposes to apply the same value for Györ and finally for Gabčikovo, too.

Furthermore, at note 316 to page 78 of Vol. 1, HC-M, it is stated that Kárník assigned to this seismogenic zone in 1978 the magnitudo M = 6.0, and the map shown as Fig. 6.3 in HC-M, Vol. 2, also uses the same value. In the paper of Kárník, Schenk and Schenková entitled: "Seismologic assessment of epicentre areas" (in Czech), there also appears a scheme of earthquake provinces, which in the area of Gabčíkovo takes a substantially different course. Gabčíkovo is situated at the boundary of the two seismotectonic units, namely the PB1 tectonic unit, with a maximum magnitude M = 6.0 and the CW7 tectonic unit, with a maximum magnitude of M = 4.5.

The latest assesment of the Komárno earthquake of 28 June 1763, published in 1991 by Bune (Russia), Bouček (Slovakia) and Szeidowitz (Hungary) unequivocally contradicts the Hungarian assertion in its Counter-Memorial that the values of magnitude of 6.0 to 6.5 should be considered for the Komárno earthquake. We can refer here to the following data associated with the Komárno earthquake given in this 1991 paper: Magnitude M = 5.7, epicentral intensity Io = 8.5°, the depth of epicentre 8 km and 6 km, (depending on parameters used in calculation). This publication also mentions estimates on the depth of the epicentre of this earthquake given by other authors which vary widely depending on the entry parametres used and the method of calculation.

This parameter, moreover, refers to the Komárno earhquake alone and absolutely does not mean that the magnitude and the intensity of this earthquake can be expected at any point along a line such as the supposed Györ - Becske fault line that Hungary has postulated (which is examined below in Part II of this Chapter).

Once the earthquake takes place at the intersection of the two earthquake zones, in calculating the seismic hazard the epicentral area cannot be included into each zone. Were this to happen, then in analysing the hazards it would be considered twice, which would result in overestimating of the effects. The experiments conducted abroad (Prof. Keilis-Boroka, Moscow) have shown that at the intersection of two seismogenic zones there can develop tremors, whose energy is up to 30 % higher, compared to what is expected to happen in but one such zone.

We reiterate that the magnitude value, which the Hungarian side proposes to use in calculations (6.0, and even 6.5) is not trustworthy.

7. Acceleration in Relation to Intensity and Magnitude

To calculate seismic load it is important to know the peak value acceleration.

We consider it misleading to infer this value from the intensity, as it leads to a disproportionate increase in the acceleration value, which enters into calculations of load. Presented macroseismic intensities are but supporting values, with but an empirical relation to acceleration. Furthermore, they differ according to the author relied on and the macroseismic scales used. This is why the acceleration value must be known. The acceleration value can be determined exactly using accelerogram calculations for a given magnitude, depth of epicentre, development mechanism of an earthquake, epicentral distance and environmental parameters.

The HC-M relies mainly on the ICOLD norm and the calculation of maximum credible earthquake (MCE), which according to the author of Chapter 6 of Vol. 2 of the HC-M has not been done by Slovakia in spite of the fact that the International norm, he says, recommends such a calculation be made in connection with large water works. The seismic hazard is deduced by Hungary from M value supported by empiric relations (I acceleration in g. and historical data on earthquakes in this region) as well as from the newest geological, geophysical and seismological investigations. The degree of hazard is purposefully supplemented by allegedly unsatisfactory geotechnical and mechanic properties of materials used in construction of the barrages of the G/N Project. The author presumes their possible liquefaction and solidification under influence of tremors during the earthquake. He also pays attention to the high degree of tectonisation of andesitic rocks, which participate in the geological structures in the surroundings of Gabčíkovo, as they were intersected by the Hungarian side in the construction pit dug at the Nagymaros barrage site. This author declares that this tectonisation is due to strong tectonic activity, although he does not explain the role they played at different stages of formation of the basin, and no detailed neotectonic analysis of the area mostly during Post-Pannonian period is given.

The acceleration values arrived at in the HC-M are based on the results of Bondár's calculations for which a 400 m thick model of gravely sands, with properties similar to the Danunbian gravels, was used. This modelling, according to the HC-M, resulted in a finding that the peak acceleration value of 0.25g gradually increases to reach at Gabčíkovo up to 0.3g. Hungary asserts that similar calculations have not been undertaken by the Slovak side even though the ICOLD norm 1989 says that they should have been calculated. The HC-M states (on page 80 of Vol. 1) that eventual application of the MCE could result in a "worst case scenario", with an estimated value of peak acceleration approaching 0.3g.

It is surprising to note that this peak acceleration value, presented as a corollary to the concept derived from Kárník's published magnitude value of 6.0 to 6.5, and consequently inferred macroseismic intensity 9° MSK, agrees exactly with that subsequently calculated by Bondár using the mentioned model. Empirically obtained peak acceleration value does not differ in the slightest from the one calculated by Bondár using up-to-date methods and software.

Hungary's objections to the absence of an MCE by Slovakia of the Danube Basin are groundless. Such modelling (MCEA for G/N 1994) has been carried out by authors of this study on hundreds of real models, using various marginal values of entry parameters. The results of this modelling, presented in the form of Maximum Credible Earthquake Accelerograms, absolutely contradict Hungary's assertions in the HC-M. A more detailed analysis of these results is provided below in this study.

8. Accelerograms and Analysis of Calculated Accelerations

Essential variables influencing the magnitude of manifestation of an earthquake are the acceleration value (peak acceleration value is used occasionally, sometimes the term acceleration is interpreted generally, as an "effective value"), the duration of vibration, and predominant period of vibration. To calculate the seismic load we are usually satisfied with the peak acceleration value within certain frequentional range (within certain period area), and this is used directly to compute the seismic coefficients.

The peak acceleration value, the predominating period of vibration and the duration of vibrations are determined by means of the calculation of accelerograms of expected earthquakes. On the basis of these accelerograms the other parameters, too, can be determined, such as vibration spectra (Fourier's spectra), amplification, seismic response spectra, etc.

The earthquake accelerograms are calculated for all three components, the two horizontal and mutually perpendicular, labelled NS (North - South) and EW (East - West), and one vertical component, labelled UD (Up Down), so as to arrive at a calculation of the absolute magnitude of the acceleration vector or the deviation. Because the horizontal component is the most important, the greater of the two is usually referred to. The HC-M's assessment, which uses acceleration values, gives one value only, but without specifying which of the two components is being dealt with.

The above mentioned MCE accelerograms of expected earthquakes were calculated for the Gabčíkovo area using the Komárno, Dobrá Voda seismogenic zones and the local epicentre. Earthquake accelerograms were calculated to construct approximately 500 different models for discrete, previously selected sites of the barrage as well as for the Gabčíkovo locality. The earthquake accelerograms could be calculated very accurately in the case of the Gabčíkovo step area, as there is situated a 2582 m deep geothermal well FGGA1. Thus, the geological section and the thickness of beds and soils are known.

The deeper portions of the environment were modelled on the basis of the results of reflexive - seismic depth measurements, reprocessed by the US company Maxus for the sake of better legibility of interpreted geologic environments in both the basin filling and Pre-Neogene basement (I, Hrušecký 1994).

9. Results of Maximum Credible Earthquake (MCE) Interpretation

The following table shows the maximum peak acceleration values (in gravitational acceleration values) for discrete sites of the barrage, as well as for the well FGGA, applying various seismological models, seismogenic zones and finally for discrete components, as a result of extensive above mentioned modelling in the area of the Gabčíkovo Project.

Table.3

Site	Model	Seismogenic zone	Component	a_{max}
km 09275	VSM	Komárno	h2	0.0792g
VK 47	SM	Komárno Komárno	h1 h2	0.0665g 0.0656g
		Malé Karpaty Malé Karpaty	h1 h2	0.0518g 0.0517g
		Local Local	h1 h2	0.0285g 0.0245g
	DM	Komárno Komárno	h1 h2	0.0543g 0.0477g
		Malé Karpaty Malé Karpaty	h1 h2	0.0193g 0.0311g
		Local Local	h1 h2	0.0257g 0.0199g
km 15100 VK 82	SM	Komárno Komárno	h1 h2	0.0658g 0.0612g
		Malé Karpaty Malé Karpaty	h1 h2	0.0500g 0.0519g
		Local Local	h1 h2	0.0289g 0.0247g
	DM	Komárno Komárno	h1 h2	0.0372g 0.0350g
		Malé Karpaty Malé Karpaty	h1 h2	0.0168g 0.0238g
		Local Local	h1 h2	0.0220g 0.0149g
km 15250 VK 79	SM	Komárno Komárno	h1 h2	0.0662g 0.0602g
		Malé Karpaty Malé Karpaty	h1 h2	0.0461g 0.0545g

		Local Local	h1 h2	0.0277g 0.0255g
	DM	Komárno Komárno	h1 h2	0.0434g 0.0361g
		Malé Karpaty Malé Karpaty	h1 h2	0.0160g 0.0229g
		Local Local	h1 h2	0.0216g 0.0138g
km 15750	VSM	Komárno	h2	0.0796g
VOK 88	SM	Komárno Komárno	h1 h2	0.0672g 0.0602g
		Malé Karpaty Malé Karpaty	h1 h2	0.0474g 0.0520g
		Local Local	h1 h2	0.0282g 0.0236g
	DM	Komárno Komárno	h1 h2	0.0436g 0.0369g
		Malé Karpaty Malé Karpaty	h1 h2	0.0169g 0.0235g
		Local Local	h1 h2	0.0219g 0.0153g
well FGGA	SM	Komárno Komárno	h1 h2	0.0533g 0.0519g
		Malé Karpaty Malé Karpaty	h1 h2	0.0291g 0.0680g
		Local Local	h1 h2	0.0710g 0.0248g

The above Table shows that the maximum peak acceleration value for the Gabčíkovo locality reaches 0.0796g at the km 15.750 of the barrage, computed from the VSM (very shallow model - 200 m thickness of sediments) for the epicentre in Komárno and its EW component.

The "most dangerous" factors are in this respect the tremors from the epicentral Komárno area. However, the value of peak acceleration, modelled this way, represents only one third of the acceleration obtained by Bondár and adopted by Hungary in Vol. 2, HC-M.

As far as a comparison of the two models is concerned in relation to calculated acceleration value, these are highest in the case of the VSM model and lowest in the case of the DM (deep model). In Table 2 there are the EW components of all the three tested models for two testing sites, namely the km 9.275 and the km 15.750 of the intake channel barrage. The Table shows that the lowest accelerating values were calculated using DM, where the smothering properties of the environment of thick sediments take place, whereas in applying the shallower models (e.g., in Bondár's 400 m thick model) no such effects can be expected. In scientific terms, we are certain that in Hungary's analysis such a fact should have been at least mentioned. As is well known scientifically, considering the depths of epicentres, a thick sedimentary formation such as the one present here (the thickness of sediments reaches altogether some 8 - 8.5 km) must possess distinct absorbing abilities.

Table 4 contains a review of differences in acceleration (in percent) in using various models.

Table 4

Model	VSM-SM	VSM-DM	SM-DM
km 9.275	21%	66%	38%
km 15.750	32%	116%	63%

When considering the absorption of a thick sedimentary formation, i.e., the DM model, in which a 12 km thick formation is used as an entry parameter for modelling, the least favourable appeared in the barrage at km 9.275, with the acceleration value for NS (north-south) component of 0.0543g.

Spectral analysis of outcome seismic signal, shaped as Fourier spectra shows several distinct maxima in each curve. These maxima range generally from 0.5 to 8 Hz, whereby the envelope of these curves has in the case of shallow models 2 maxima, the first at 1.0 Hz and the second at 8 Hz. Owing to greater absorption in higher frequencies of the signal, the maximum in the deep model (DM) is shifted towards lower frequencies and several partial maxima are present at 0.5, 2.4 and 7 Hz. The environment influences the preceding signal as a differentiated filter.

The shift of spectral maxima is influenced not only by structures, but also by the spectral composition of entering accelerograms. However, the influence of the environment with various thicknesses is evident too. The spectra obtained from the VSM and DM look more compact and their spectral composition is more contrasting. From this point of view the SM seems to be a transitional environment, where the spectra decompose, shifting between the VSM and DM. In the case of SM the domains of low frequency spectra are characterized by several partial peaks and the spectral representation of VSM and DM is compact. Among discrete components of the same waves from various epicentral regions there is no shift of spectral characteristics, or it is but negligible.

Amplification of seismic signal within frequentional domain (i.e., relation between the exit amplitudes and entry amplitudes) is an important parameter in the relation to modelling abilities of a real environment, and it is logically dependent on the model for which it was calculated. In the case of the shallowest model (VSM) some of the frequencies are amplified approximately 1.5 times, in case of the shallow model, 3 times, and in case of the deepest model, up to 20 times. The higher frequencies are more absorbed and the amplification of higher frequencies is weaker compared to the lower ones.

To compare the empirical method (used in the HC-M) with the exact method, which lead to MCAA calculations, we have computed accelerations expectable at Gabčíkovo, using the calculation based on magnitude and distance parameters. To accomplish this, we have used the relations given by various seismologists and ascertained from empirical data. This procedure has been explained in detail at the beginning of this study. It was used by Bondár in modelling MCE and is the only procedure used by the Hungarian side, resulting in a calculation of the acceleration as 0.3g. We have made the calculation for the epicentral area of Komárno, using entries from the Komárno earthquake of 1763, the way they were published by Bune, Brouček, Szeidowitz, et al., (1991). The results are presented in Table 5.

Table 5. Acceleration values, calculated from the magnitude and the distance, according to relations of various authors.

Author	Acceleration
Papazochos (1993)	0.024 g
Chiaruttini (1981)	0.045 g
Tcheodulides (1988)	0.047 g
Štejberg (1982)	0.050 g
Davenport (1972)	0.052 g
Bufaliza (1986)	0.053 g
Joyner and Boore (1981)	0.054 g
Facioli and Agalbato (1976)	0.063 g
Thiel (1986)	0.068 g
Okamoto (1980)	0.074 g

We wish to point out that the above relations are not specified for dicrete seismic regions. For this reason, it is more appropriate to enter the values attained from the earthquake accelerograms, through modelling and calculation of the MCE.

Accordingly, it follows that the calculation of accelerograms should be privileged among all the other procedures and, keeping this assumption in mind, we realized the above extensive modelling, which analyses all the least favourable effects of various seismogenic zones at various sites of the Gabčikovo project. In spite of this fact, a review of the variables set out in Table 5 results in a finding that these acceleration values correspond to those values attained by calculation of accelerograms.

Determined acceleration values, calculated from relations given by various authors, serve to support the results of exact calculations. The relations of Faccioli and Agalbat (1976) and Chiaruttini (1981) in Table 5 are derived from the data obtained during the earthquake in Friuli (1976), whose model was used by Bondár in his modelling.

10. Conclusions

Extensive modelling and MCA calculations are the result of long term research of the seismic vibration parameters, realised within the framework of seismic zoning and the study of the latest procedures applied to solve seismic hazards. It represents a multidisciplinary approach in which the geotechnical entries, the geological and structural information as well as the results of geophysical synthesis and new seismologic research play, in relation to accuracy of obtained results, the most important role. Use of professional software, purchased for this reason to process them, multiplies the accuracy and credibility of obtained results.

This study was not a usual routine work, it rather had the character of a team research, and the contribution of all team members, be it direct or indirect, should be appreciated.

This research resulted in calculating the MCEA for various modelled environments, various epicentral areas and two horizontal components of vibrations. The results are summarised in the written text and in appendices, which represent a complete catalogue of accelerograms, their spectra and spectral responses of the Gabčíkovo Project structures, for which they were calculated. These results clearly refute the HC-M's "worst case scenario", based on acceleration values ranging from 0.25 to 0.3g.

Graphic representations show the whole range of parameter changes, including the interval of extreme acceleration changes. This set of accelerations (Table 3) enables to reject any assertion supporting most unfavourable acceleration values (in g). We present herewith the results of a complex analysis of accelerations and spectral parameters of wave motion, carried out within the whole area of the Gabčíkovo Project, using in the calculations a variety of parameters, epicentral areas and real geologic environments.

These results have shown that the maximum calculated acceleration applicable for the Gabčíkovo Project and obtained by means of calculation of the MCE equals the value 0.0796g, and not 0.3g, as asserted in the HC-M.

PART II. **SEISMIC HAZARD IN THE AREA OF THE G/N PROJECT WITH SPECIAL REGARD TO THE POSTULATED GYÖR-BECSKE SEISMOGENIC ZONE**

V. Janotka
J. Viskup

May, 1995

1. Introduction

This study is a sequel to Part I of this Chapter. It consists of an analysis of the most recent results of investigation of the geological-tectonic structure of the area of the Gabčíkovo section of the G/N Project as related specifically to the newly "discovered" Györ-Becske fault line, which is first mentioned by Balla (1994) in a paper that forms part of Hungary's "Scientific Evaluation" summarised in Vol. 2 of the HC-M. This study is based on the results of deep reflection-seismic research, magnetotelluric sounding measurements and gravimetric modelling. The seismological research has used new methods to re-evaluate the intensity I and the magnitude M parameters.

The research based on the above methods, together with seismic engineering methods and acceleration calculations, enables us to evaluate objectively and with the utmost accuracy, in accordance with the most up to date scientific achievements in this field, the following:

(a) The "Györ-Becske" hypothesis in relation to the geomorphology and tectonics of the area concerned;

(b) The susceptibility of any such fault line to accumulate and transfer seismic wave energy (with quantification of these properties);

(c) The possible interaction of the zone hypothesised on the basis of the postulated "Györ-Becske" fault with neighbouring or cross-cutting zones in order to quantify their combined effect; and

(d) The stability of the structures of the Gabčíkovo Project both individually and as a whole in the light of this evaluation.

The results of comprehensive modelling and acceleration calculations carried out by Slovak experts offer an exact and verifiable basis for assessing the speculative values presented by Hungary (in its Counter-Memorial).

2. The Origin of the So-called Györ-Becske Earthquake Zone in the Light of Present Geological-Tectonic, Seismologic and Geophysical Knowledge

Apart from the known and reliably ascertained earthquake zone in the area of the Danubian lowland, namely the zone based on the Komárno-Berhida fault, Hungary has now proposed another fault line, the "Györ-Becske" line and its resulting zone. Such a fault line or zone has not been documented outside of Hungary.

The "Györ-Becske" fault line makes its first appearance in Fig. 6.2, in Vol. 2 of the H-CM (at page 227), the authority cited for this Figure being "after Balla and Goal (1994)", a paper annexed to the HC-M and forming part of its "Scientific Evaluation". Fig. 6.2 does not indicate that the EW line identified as the "Györ-Becske" line is considered the earthquake zone. While Komárno - Berhida clearly appears on Fig. 6.2 as a seismogenic zone, the "Györ-Becske" line is identified in the legend as a "large topographic step".

In spite of this, on the basis of this topographic feature shown on Fig. 6.2, Hungary's Counter-Memorial hypothesises an earthquake zone capable of transfering distinct tremors reaching a magnitude of 6.5, with an acceleration exceeding 0.3 g. Should such an evaluation be accepted, such zone would far exceed the seismic risk of the clearly defined, scientifically accepted Komárno - Berhida zone.

It should be noted that the prominent Hungarian seismologist, Zsíros, who has proposed the framework of 14 zones of earthquake hazard in the Hungarian territory, refers to the Komárom-Berhida zone but not to any "Györ-Becske" zone (Zsíros, 1991).

Such a zone does not appear on the map of relief of the brittle structures of the Pre-Tertiary basement (Kováč, et al., 1994).

Such a zone has indeed been mentioned only by Balla (1994), but his conclusions, referred to in Chapter 6, Vol. 2, of the HC-M, are at best geological hypotheses. Even in 1992, Balla did not hint at the existence of such a source zone, where in characterising the "Raba line" he did not mention any other zone in its proximity (Balla 1992).

Taking into account the latest geological-tectonic and neotectonic knowledge and research, it should be recalled that the very existence of any such zone is subject to serious doubt (Kováč, et al., 1995). As Hungary's own illustration indicates, this feature is no more than a "large topographic step", which would imply either a topologic terrace (Varga, Nemesi and Džuppa, 1993) or a part of the Hungarian Midmountain, which is not organically linked to the consolidated basement of the Slovak part of the Danube basin - the Gabčíkovo depression. (This would also concur with the explanation for seismological features of the NW part of the Hungarian Midmountain according to which these are the result of the mechanical sliding of blocks, which is a response to the extensional regime of the area, rather than the classic accumulation of strain in the basement, characteristic for the source areas.)

In any event, neither earlier nor the most recent research substantiate the conclusion that there is a "Gyor-Becske" fault line, let alone an earthquake source area (Szeidovitz 1986, Zsíros 1995).

There is no geophysical information to support the existence of an earthquake source area, as shown by the results of interpretation of the deep reflexion seismic section K1 (Annual Report of the Eotvös Loránd Institute of Hungary, 1987). This section intersects the area of interest, along with the results of the magneto-telluric sounding (MTS) (Varga, Nemesi and Džuppa, 1991, Kilényi et al., 1991), provides the relevant information on the deep structure of this area. It is astonishing that Hungary, in introducing such a serious allegation, completely ignores the results of this very extensive, deep seismic profiling and the MTS.

Specialists working in this field know that the present chances of obtaining relevant information on the deep structure are limited due to the changing PT conditions. Considering the present level of knowledge, apart from the limited seismologic information, virtually only the results of the above mentioned reflexion seismic research, the deep magneto-telluric sounding and, in part, the gravimetric modelling can be used. Among these, especially the first two, are essential, although these methods are very expensive. Instead of relying on these, Hungary relies on a hypothesis which has not taken into consideration the relevant results of deep seismic research, or the MTS.

Thus, the assertion (at page 207, Vol. 2) of the HC-M, that the existence of the "Györ - Becske" zone has been substantiated by macroseismic, topographic and geophysical data must be rejected. The only relevant data is topographic data because this line is, in fact, nothing more than a topographical or geomorphologic terrace, as Fig. 6.2 indicates. The macroseismic data (Seidovitz, 1986, Zsíros, 1991) and the results of geophysical interpretation (Varga, et al., 1993, Kilényi, et al., 1991) do not substantiate the existence of any such zone.

Until the assertions concerning the existence of this zone are supported by results of stress measurements made in the bore holes drilled in this area, the assertions are nothing more than an hypothesis. As demonstrated above, it is an hypothesis that is not substantiated by the macroseismic data or by geophysical interpretation.

Even more surprising than Hungary's conclusions as to the existence of a "Gyor-Becske" fault line and zone are the alleged macroseismic effects attributed to it in the HC-M. As mentioned above, Hungary tries to attribute to this zone the properties of an earthquake zone capable of transfering distinct tremors reaching a magnitude of 6.5 with an acceleration exceeding 0.3 g.

3. The Present Seismological Capacities for Calculating the Magnitude Intensity and Acceleration for the Area of the so-called "Györ-Becske" Line

In order to analyse the present possibilities and methods of calculation of the seismological parameters of the postulated "Györ-Becske" line, the existence of such a fault line and earthquake zone is assumed regardless of the fact that the scientific data fails to support any such assumption.

Among the terms frequently used for this kind of discussion of earthquakes, the most important are the magnitude "M", the intensity "I" and the acceleration "a".

3.1 Magnitude

The earthquake magnitude is the parameter first referred to when an earthquake is to be characterised. It is a parameter assessed by instrumental measurements and depends on the energy released during the earthquake. Its value is rated according to the Richter scale, for example, an earthquake measuring 5.7 on the Richter scale. This value is usually given with accuracy to one decimal. If instrumental measurements are not available, then the magnitude can be assessed from the calculated earthquake intensity. This procedure is used mainly in cases of historic earthquakes, where no such measurements could be carried out.

3.1.1 Probability appraisal of magnitude

This assessement is based on a frequency diagram for occurrence of an earthquake log N(M). Several distributions, for instance the Gutenberg-Richter's, parabolic, exponential, logarithmic, Gumbel's and others are used. The selection of a certain distribution will depend on frequency occurrence. On the basis of this relation, assisted by Schenk we have determined the magnitude of an expected earthquake originating from the postulated "Györ-Becske" zone to 3.6 ± 0.2° on the Richter scale.

3.1.2 Deterministic assessment of magnitude

In this case, the maximum magnitude is determined on the basis of empirical relations between the magnitude and physical variables characteristic for an earthquake focus. The Drimmel's relation is the one most used for the Central European region. The following table shows the values calculated using this relation. As the length of the postulated "Györ-Becske" line has not been indicated in the hypothesis, the following table gives the range of magnitudes, applicable for various lengths of the fault line:

Table 1

Length of the fault line (in km)	40	45	50	55	60
Magnitude (in °)	4.9	5.0	5.1	5.18	5.26

3.1.3 Expert estimations

This method involves the assessment of magnitude for a given area by several experts and the results are then processed statistically. We do not know of the application of such a procedure either in the case of the Komárno earthquake or in the case of other seismogenic zones in the area surrounding Gabčíkovo.

3.2 Intensity

The macroseismic earthquake intensity (often referred to simply as intensity) is usually expressed in degrees. It is determined on the basis of macroseismic measurements, i.e., according to the effects felt by people, manifestations on buildings and the earth's surface. The appropriate degree of the intensity scale is to be determined according to the degree of damage or observed effects and is usually given in whole, or halves of a degree.

The earthquake intensity can be assessed as follows:

- On the basis of historic observations of earthquakes, using a frequency method. However, this method fails where there are only a small number of observed earthquakes, which was the case with the Gabčíkovo Project area, where only 5 observations were available.

- On the basis of geological structure. In this case the intensity (I) can be calculated from the length of a fault line. Several relations exist within quite a wide range, some of them also taking into account geological features of a given fault line.

- On the basis of macroseismic relations between the magnitude and the intensity. These scales have been discussed in Part I of this Chapter. Each degree of intensity is given a certain value of acceleration. This value differs considerably for each degree as between the mentioned scales.

Table 2: Accelerations, given in gravitational acceleration values g for discrete macroseismic scales utilised in Europe.

	MCS	MSK-64	MSSS-73	MMSK-84
6°	0.005-0.01	0.025-0.05	0.031-0.06	0.05±50%
7°	0.01-0.025	0.05-0.1	0.061-0.12	0.1±50%
8°	0.025-0.05	0.1-0.2	0.121-0.24	0.2±50%
9°	0.05-0.1	0.2-0.4	0.241-0.48	0.4±50%

4. Synthesis of Acceleration Values, Assessed by Various Methods for the So-called "Györ-Becske" Zone

A primary parameter which should be accurately assessed is the acceleration value, used in calculations of the seismic load. Although different authors use different classifications, the acceleration value used for the calculation of the seismic load can essentially be assessed on the basis of two methodological procedures:

(1) Assessment of the acceleration based on expected earthquake parameters - magnitude, depth of seismic focus, mechanism of earthquake generation, epicentral distance. The following calculations can be made:

(a) Calculation on the basis of macroseismic relations, which determine the relation between the acceleration with other parameters like magnitude, depth of seismic focus, mechanism of seismic focus, epicentral distance and, occasionally, with the local geological situation.

(b) Calculation based on accelerograms, calculated for the area under study. The calculation can be made in 1D, 2D or 3D modification, respectively (2D and 3D modifications enable to the taking into account of lateral changes in the calculations) to fit the specific geological situation in a given area. This procedure is more exact and reliable than the one described in (a), although it takes longer and is more expensive. It also calls for good quality entry data, i.e., no accelerograms can be calculated unless the geologic background and tectonics are well known.

(2) Inference of the acceleration from the earthquake macroseismic intensity. In this case there exist several relations, which were statistically analysed by Schenk and Schenková (1981). If we were to use the intensity as Schenk has advised the authors of this paper, referring to the entry parameter values to calculate accelerograms, then the acceleration values given in gravitational acceleration a (g), a ($cm.s^{-2}$), the speed of deviation v ($cm.s^{-1}$) and deviation d (cm) are as shown in the following table. The maximum acceleration, obtained by this statistical method is smaller, relative to values calculated from the MCEA, namely 0.112g versus 0.1238g.

Table 3: The a, v and d values, derived from I according to Schenk

Parameter	Unit	Györ-Becske source area with Komárno earthquake zone	Györ-Becske source area without Komárno earthquake zone
a	g	0.053	0.039
a	$cm.s^{-2}$	53.43	39.08
amax	g	0.112	0.078
amax	$cm.s^{-2}$	111.63	78.27
amax	g	0.025	0.019
amin	$cm.s^{-2}$	25.22	19.29
v	$cm.s^{-1}$	7.01	4.58
vmax	$cm.s^{-1}$	24.48	15.05
vmin	$cm.s^{-1}$	2.14	1.48
d	cm	0.98	0.55
dmax	cm	3.12	1.6
dmin	cm	0.36	0.22

(3) The acceleration value can be determined exactly using accelerogram calculations for a given magnitude, depth of epicentre, development mechanism of an earthquake, epicentral distance and rock environment parameters. For this reason we have carried out these calculations for the so-called "Györ-Becske" line, applying an earthquake magnitude of M=5.7 and epicentral distance of 25 km. We made these calculations in spite of our conviction that this zone does not represent an earthquake source area (Zsiros, 1991).

5. Analysis of Results of Modelling and MCEA Calculations

Section 7 and 8 of Part I of this Chapter have described how acceleration is calculated and have pointed out the defects in the HC-M's calculations.

The results of extensive modelling of the Gabčíkovo Project from the so-called "Györ-Becske" seismogenic zones, both with and without the Komárno earthquake seismic focal zone, are shown in the following table.

Table 4: Acceleration values from MCEA

km 09.275 (drillhole 47)	VSM	Györ-Becske	h1	0.0610
		Györ-Becske	h2	0.0497
		GB with Komárno	h1	0.0823
		GB with Komárno	h2	0.1105
	SM	Györ-Becske	h1	0.0521
		Györ-Becske	h2	0.0431
		GB with Komárno	h1	0.0751
		GB with Komárno	h2	0.1101
	DM	Györ-Becske	h1	0.0590
		Györ-Becske	h2	0.0536
		GB with Komárno	h1	0.0960
		GB with Komárno	h2	0.1228
km 15.100 (drillhole 82)	VSM	Györ-Becske	h1	0.0585
		Györ-Becske	h2	0.0476
		GB with Komárno	h1	0.0880
		GB with Komárno	h2	0.1231
	SM	Györ-Becske	h1	0.0523
		Györ-Becske	h2	0.0450
		GB with Komárno	h1	0.0751
		GB with Komárno	h2	0.1047
	DM	Györ-Becske	h1	0.0498
		Györ-Becske	h2	0.0426
		GB with Komárno	h1	0.0705
		GB with Komárno	h2	0.1008
km 15.250 (drillhole 79)	VSM	Györ-Becske	h1	0.0557
		Györ-Becske	h2	0.0450
		GB with Komárno	h1	0.0854

		GB with Komárno	h2	0.1238
	SM	Györ-Becske	h1	0.0515
		Györ-Becske	h2	0.0440
		GB with Komárno	h1	0.0738
		GB with Komárno	h2	0.1044
	DM	Györ-Becske	h1	0.0514
		Györ-Becske	h2	0.0416
		GB with Komárno	h1	0.0795
		GB with Komárno	h2	0.1059
km 17.500 (drillhole 88)	VSM	Györ-Becske	h1	0.0547
		Györ-Becske	h2	0.0461
		GB with Komárno	h1	0.0865
		GB with Komárno	h2	0.1232
	SM	Györ-Becske	h1	0.0514
		Györ-Becske	h2	0.0455
		GB with Komárno	h1	0.0773
		GB with Komárno	h2	0.1048
	DM	Györ-Becske	h1	0.0520
		Györ-Becske	h2	0.0418
		GB with Komárno	h1	0.0811
		GB with Komárno	h2	0.1071

The results of the modelling, the MCE calculations and the "peak acceleration values" obtained for three level models and the so-called "Györ-Becske" seismogenic zones, both with and without the influence of the Komárno earthquake seismic focal zone, represent, along with the previous research which has taken account of the seismogenic zones located on the Slovak side, a minute verification of the Gabčíkovo Project and unique information on the environment where the Project is situated. This information allows the most accurate evaluation of the region so far as the seismic hazard is concerned, modelled by means of scientific calculations. It totally refutes the catastrophic scenario presented in the HC-M.

The results are based on the consideration of all potential hazardous seismogenic zones surrounding the Project on both the Slovak and the Hungarian side. The corresponding accelerograms for both horizontal components, the NS and the EW, provide a review of potential MCE and, analysing their values, they demonstrate the stability of the Project.

The results of the MCEA modelling, which take into account the seismogenic zones on the Slovak side (Komárno, Dobrá Voda and a local focus) in relation to the stability of the Project, are contained in Part I of this Chapter. This report supplements them by the MCEA modelling for the above mentioned so-called seismogenic zones.

In spite of the fact that in the light of the results of various scientific disciplines the existence of an earthquake source area based on the so-called "Györ-Becske" line cannot be sustained, we have gone on to prove that the attributes that Hungary assigns to this area in terms of acceleration values are incompatible with the best scientific research.

Our decision to carry out the MCEA modelling was prompted by the existence of an intricacy associated with the occurrence of earthquakes on account of the so-called "Györ-Becske" zone, which cannot be overlooked in calculating the earthquake hazard for the Gabčíkovo Project. The point of this intricacy rests in the way the data pertaining to the intersection of the Komárno-Berhida zone with the so-called "Györ-Becske" zone are visualised. An inclusion of the area of the Komárno earthquake into each of the source zones would result in considering its effects and analysing the earthquake hazard twice. This is why we have considered, in modelling the hazard in respect of the Gabčíkovo Project, two variants of hazard calculation concerning the so-called "Györ-Becske" zone. The first variant includes the influence of the Komárno seismic focus; the second does not.

Although, in seismological terms (and also as recommended to the authors by V. Schenk), it is sufficient to use the parameters of the so-called "Györ-Becske" zone alone (i.e., without the influence of the Komárno seismic focus) in calculating the degree of hazard to the Gabčíkovo Project, we decided to model both cases and also to calculate the MCEA for both variants. This decision ensued from our wish to analyse this hazard in the most comprehensive manner, thus eliminating any further speculation as to the possible influence of other foci within any postulated "Györ-Becske" zone with the potential to increase the acceleration values.

The acceleration values obtained through both modelling and MCEA calculations represent even in the least favourable cases roughly one third of the values presented in the Hungarian Counter-Memorial. The highest is the acceleration value at km 15.250 (drill hole 79) for the h2 component of the so-called "Györ-Becske" zone with the Komárno earthquake influence included. It is characterised by a variable 0.1238g. The rest of the values are shown in Table 4 above to permit them to be compared.

The calculated acceleration values, including the zone characterised by the combination of the least favourable effects in relation to the Project (the so-called "Györ-Becske" with the influence of the Komárno earthquake) are below those used in tests by I. Polko (0.125g) as well as below to those used to construct both the main Project structures and dykes (Polko and Varga 1995).

6. Conclusions

With the HC-M, Hungary has advanced the brand-new hypothesis of a "Györ-Becske" fault line and very hazardous earthquake source zone which, it claims, represents, due to its epicentral distance (20 - 25 km), a real hazard to the Gabčíkovo Project. Hungary asserts this in spite of the fact that this thesis contradicts the research results of Hungary's own seismologists. Hungary's hypothesis and assertions must be rejected:

- On the basis of the latest results of seismologic interpretations (Zsíros 1991, 1995, Szeidovitz 1986, Brouček 1988);

- On the basis of the latest, newest geologic - tectonic and neotectonic research (Kováč P. et al., 1995, Kováč M. et al., 1994); and

- On the basis of the results of geophysical interpretation, supported mainly by seismic, magnetotelluric and gravimetric measurements (Kilényi 1991, Varga et al., 1993, Annual rep. 1987).

On the basis of the MCE calculations carried out as part of this study (made for environmental models typical for the Gabčíkovo Project) we demonstrate that in any event the catastrophic scenarios presented in the HC-M are groundless. None of the acceleration parameters shown in Table 4 reach the values presented by Hungary, even though we have modelled and calculated not only the accelerations for the so-called "Györ-Becske" zone, but also for the least favourable case in the "Györ-Becske" earthquake source zone, including the Komárno seismic focus. All this is in spite of the recommendation of V. Schenk, the eminent Czech specialist in seismology, who suggested that, in calculating seismic hazards for the Gabčíkovo locality, the parameters for the Györ - Becske zone without the influence of the Komárno seismic focus should be used.

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CHAPTER 11. THE SAFETY OF THE G/N PROJECT STRUCTURES

PART I THE RELIABILITY OF THE GEOLOGICAL SURVEYS

L. Varga

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1. Introduction

A very substantial amount of geological engineering and hydrogeological survey work was carried out at the sites of both sections of the Gabčíkovo - Nagymaros Project, both prior to as well as during the construction period.

The Treaty parties agreed to the scope of the surveys, the survey methods and evaluation techniques in the Joint Contractual Plan. The results of surveys carried out for the purpose of the Gabčíkovo and Nagymaros sections were exchanged at joint meetings of the experts. While for the Gabčíkovo section of the Project, surveys have continued according to the Joint Contractual Plan requirements, the surveying of the Nagymaros section, carried out under the responsibility of the Hungarian party, was gradually reduced and ultimately terminated in 1989.

A wide range of survey methods were used: geophysical, bore hole measurements, radionuclide measurements and others. In situ investigations were carried out on the location of the hydropower plant and its connection with the headwater canal.

For the drilling of geological samples in the Gabčíkovo section, two methods were employed: pounding-rotation drilling in gravel and core sample drilling in peat.

A wide range of laboratory techniques were used for the samples' evaluation: grain size analysis, tangential stress analysis and compound permeability analysis. The following is a review of the survey methods for the individual structures.

2. <u>The Gabčíkovo Section of the Project</u>

2.1 The Hrušov-Dunakiliti reservoir

(A linear hydrotechnical structure)

The surveys focused on:

(a) Review of the subsoil of the dyke line

(b) Review of the subsoil of adjacent dyke fields

(c) Review of the pre-existing levees and dykes

(d) Review of the quality of dyke construction material.

Reviews consisted of: drilling, sample collection and laboratory evaluation. Supplementary assessments were based on: geophysical (seismic) measurements, bore hole measurements, water level measurements, water quality and water flow measurements in drills, etc.

Various geological zones were specified as a result of these measurements and reviews. On the basis of mutually agreed criteria for subsoil evaluation, different subsoil zones in the Project area, including all dyke locations, were established. For this purpose different types of sediment development, sediment depth, soil mechanics, and hydrodynamic parameters were taken into account.

2.2 The Headwater canal

(Similar to a linear hydrotechnical structure, with different parameters and stricter criteria for depth of measurements, drilling requirements etc.).

The surveys included:

(a) Well investigation (network 50 x 100 m)

(b) Research of sealing characteristics of the subsoil and sediments

(c) A search for suitable soil types for sealing of the canal bottom

(d) Investigations aimed to determine the best method for compound creation

(e) Water pressure tests to determine the best waterproofing.

On the basis of these surveys and tests, maps were drawn up depicting the sites, the development and the depth of sediments along the whole length and width of the canal.

The survey conclusions:

(a) The pre-existing presence of considerable sediments was not suitable for the foundations of the canal dykes. Organic sediments, silt and peat existed up to a depth of nine meters. On the basis of a very comprehensive study of seismic zones in the Project area, it was decided to remove these sediments and replace them with a sand-gravel compound material. The quality of the compound was checked by rigorous tests.

(b) A shortage of natural sealing materials required the use of PVC sheets (see, fn. 2 to Part II, below).

2.3 The Gabčíkovo step

(The weir, hydropower plant and navigation locks)

In this location intense surveys were carried out including dense drilling, detailed study of the sand-gravel sediment and assessment of the deep-pit foundation of the Gabčíkovo weir. In situ investigations were carried out at the bottom of the construction pit.

The drilling at various depths was carried out for the purpose of the measurement of mechanical, geotechnical and hydraulic parameters of sediments across the whole area.

At a large network of measuring points, silt samples were collected up to a depth of 110 m for the evaluation of the settlement of the subsoil below the weir. The network of observation drill sites enabled measurements to be made of the changes in the chemical content of the ground water in the pit area resulting from the sealing technology used or from pollution by petrochemical products in the area of the construction pit.

The survey resulted in:

(a) The determination of the best materials for construction of pumping-wells
(b) The determination of hydraulic parameters of sand-gravel sediments
(c) The recommendation to equip the construction pit with underground sealing walls and an injected bottom
(d) The specification of deformation modules at greater depths (to 30 m).

2.4 The Tailrace canal

(A linear hydrotechnical structure)

The surveys focused on:

(a) Water level fluctuation in the tailrace canal and sufosis susceptibility.
(b) Sufosis stability (hydraulic model)
(c) Sediment formation (and underwater dredging needs)
(d) Stability of the proposed left dyke
(e) Construction of a release-well system.

The study of sufosis stability was verified through an in situ, large scale experiment at Medvedov (1970-72).

3. **The Nagymaros Section of the Project**

The survey (of structures on the Slovak territory) included:

(a) Elaboration of a new geology-engineering and hydro-geology zoning on the area of the backwater stretch of the Nagymaros section of the Project (circa 100 km).

(b) Evaluation of components of flood control such as dykes, underground walls, drainage wells and canals, pumping stations and related replacement of bridges, roads etc. It included survey of flood control on the Ipeľ River and Hron River (in the reaches affected by the backwater of the Nagymaros reservoir), as well as the flood control of Komárno City.

4. **Joint Assessments; Independent Expert Appraisal**

The joint Czechoslovak and Hungarian geological discussions (1972 - 1978) focused on the scope of drilling and survey methodology. Agreed results of these discussions are contained in a Summing-up Report on results of geological engineering surveys, Gabčíkovo - Nagymaros (1978) which became a part of the Joint Contractual Plan.

In 1990 the Hydro-Quebec International concluded, on the basis of an overall review of the geological engineering research undertaken in connection with the G/N Project, that the scope of geological engineering information surpassed information for similar projects usual in the world. These findings are also confirmed by more than two years of successful functioning of the Project.

PART II DYKE STABILITY

I. Polko

February 1995

1. The Seismic Safety of the Headwater Canal and the Variant "C" Dykes (with PVC sealing sheets)

The dyke subsoil was carefully investigated as a part of vast geological and soil mechanics surveys using deep drilling, supplemented by earth drilling in order to evaluate accurately holocene sediment content and its characteristics. Because the investigation revealed very diverse content and characteristics of sediments (mostly consisting of silt, sand and mud deposited in dead river arms), inappropriate sediments were carefully removed and replaced by gravel compounded with heavy slabs using the Menard Co. "heavy tamping" method.

Material was removed to a depth of 0.5 m below the bottom level of inappropriate sediments. Thus the gravel filled dykes are directly connected with the gravel subsoil as can be seen in the longitudinal profiles of the dyke axis depicted on design documentation (Figs. 1 - 4)[1].

The adequate removal of inappropriate subsoil has been verified and confirmed by the supervising body of Vodohospodarská výstavba (Bratislava) and the official reports are kept in the archives.

The same technology was followed during the construction of the dykes of Variant "C". Wherever the survey revealed the presence of subsoil materials susceptible to liquefaction, these materials were completely removed. Concerning the 10.7 km long dyke of Variant "C", the complete removal of inappropriate subsoil materials was carried out in the stretch from km 0 (Čunovo complex) to km 4.7 and in the stretch between km 5.2 and km 9.2 of the dyke. The subsoil removed was replaced by gravel compounded by vibrating rollers. The use of this technology was possible due to the relatively low level of the ground water table.

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[1] Because of the extensive volume of these documents it was not possible to annex them to this Reply. Nevertheless, two copies of each enclosure have been submitted to the Registry of the Court at the date of filing of this Reply.

In the remaining parts, from km 4.7 to km 5.2 and from km 9.2 to km 10.3 a deep rod vibration method was applied for compounding in a drilling network 2.5 x 2.5 m (the Keller vibro-replacement technique). This compounding was carried out on the basis of previous surveys aimed to specify the necessary depth and area of compoundment. The level of compression of the gravel was measured before and after compounding and checked by a heavy dynamic penetration set as well as by digging samples.

The bodies of the dykes were built of compounded gravel (using the vibrating roller technique) to the volume weight of dry sample 2100 kg m^3. This means a porosity of n=21.3%. The volume weight was systematically controlled and statistically evaluated. There is no real likelihood that the dykes could settle more significantly in the event of an earthquake.

Because the entire headwater canal is perfectly sealed the water has not risen in the dyke body. This is continuously proved by measurements (hydropedologic control points) at the dyke heads and dyke feet since the beginning of operation two years ago. There is no water in the dyke body of the headwater canal along its whole length.

2. Seismic Stability

The dykes seismic stability was assessed by the then most up-to-date mutually agreed pseudostatic methods but also dynamic methods recommended by international experts (Hydroproject Experts Reports, Moscow 1981, 1982) including the use of the finite element method (FEM) - advanced counting method recommended by e.g., ICOLD (Bulletin 30 "Finite Element Method in Analysis and Design of Dams").

The pseudostatic technique took into account dyke vibration (dynamic aspects) based also on foreign norms. A review of basic calculation schemes and seismic acceleration is depicted on Fig. 5.

It should also be noted, that despite the recommendation contained in the Report of the Czechoslovak and Hungarian experts (relating to seismic zoning specifications and mapping of the area of the joint Czechoslovak-Hungarian project on the Danube, meeting of 23-25 November 1965) to calculate, for magnitude of 6 and 7 degrees MCS, horizontal seismic acceleration 0.01g

(M=6 MCS) and 0.025g (M=7 MCS) we had calculated with values of 8 and 9 degrees MCS and accordingly with horizontal seismic acceleration 0.05g (M=8 MCS) and 0.1 (M=9 MCS), the second value being applied for the area of Komárno.

These calculated accelerations surpassed the original values recommended in 1965 by nearly four times. These calculations are graphically displayed on Fig. 5.

(a) The horizontal seismic acceleration profile is constant in both the subsoil and dyke body based on the following calculations:

$a = 0.025\ g,\ 0.05\ g,\ 0.1\ g,\ 0.15\ g$

which, at the time, corresponded to the norm CSN -736503 and which are higher than those recommended in the 1965 joint Report for the headwater canal (0.01 g - 0.025 g).

(b) The horizontal seismic acceleration profile:

$a = 0.05\ g$

is constant in the entire subsoil and increases linearly by 2.5 times to the value

$a_{max} = 0.125g$

These calculations are based on the methodology recommended by Napetravidze (Georgian Academy of Science), which follows a theory of earth-dyke vibration.

(c) The horizontal seismic acceleration profile is constant in the subsoil and increases in the dyke crown by 2.0 times. This calculation was based on the following acceleration values:

In Subsoil	In Dyke Crown	MCS Scale
a = 0.075g	0.15g	7
a = 0.10g	0.20g	-
a = 0.125g	0.25g	8

These calculations are based on the methodology recommended by the Research Institute for Engineering Constructions (VUIS), Bratislava (1982) - "Guide for Hydrotechnical Design in Seismic Regions". The use of this guide is envisaged also in the draft revision of seismic norms (1989) still waiting for approval.

(d) The horizontal seismic acceleration profile according to the Russian norm SNiP -II-A. 12-69 (1977) "Construction in Seismic Regions", recommends a methodology based on "Spectral Dynamic Analysis", which takes into account the formation characteristics of the dyke body and the subsoil. In conditions of a compressible subsoil the method is based on the first three types of vibration of a trapezoidal dyke, taking into account different deformation characteristics of the subsoil and the dyke, by using a co-efficient according to Fogt:

$$K_F = \frac{k\, E_{dyke}}{(2\,(1+8)\, E_{sub}}$$

Calculations were carried out for basic horizontal acceleration in the subsoil: a = 0.05g and for three Fogt co-efficients:

$$K_F = 0.5 - 1.0 - 2.0$$

The graphic presentation of accelerations is on Fig. 5.

According to the calculations based on the above methods (a) - (d) the dykes are stable and the safety factor is greater than or equal to F.S = 1.

Furthermore, independent assessments were made by Hydroproject Moscow in 1982. This review of dykes stability in operation as well as in seismic conditions, based on the most recent Russian norm SNiP-II-7-81, confirmed the satisfactory results. This assessment was supplemented by another assessment of seismic stability - earthquake accelerogram loading - according to real accelerogram of the Friuli (1976) earthquake, using the finite element method (FEM).

The assessment of the state of pressure of the dyke according to this accelerogram was conducted by adjusting the scale. The maximum acceleration magnitude was established at 0.2g. The calculations took into consideration a time interval of 20 seconds.

In advance of these calculations there had been discussions about the necessary level of removal of subsoil which conclusively confirmed the necessity of the removal of inappropriate subsoil and its replacement by gravel (see above). The resulting graphic display of the stress profiles σ_x, σ_y, τ_{xy} for this situation, with a seismic load, are displayed in Figs. 6 - 12.

On the basis of this assessment based on the FEM, Hydroproject Moscow confirmed the suitability of the design and supported construction of the headwater canal on the assumption of the total removal of inappropriate subsoil.

The headwater canal dykes were evaluated even for such an extraordinary event as an earthquake which would damage the asphalt-concrete sealing cover and allow water to percolate through the gravel body of the dykes. Such a situation would be stable only for a limited time. That is why after the warning signal from the monitoring system the decrease of water level through a rapid release of the water from the reservoir would follow.

For the event of water percolation, different situations were assessed for the spread of water level decrease, assuming the non-stationary flow of 0.3 m/ sec in the term $T_1 = 17$ hours and $T_2 = 24$ hours. The water side slope of the dyke would remain stable during this time, save for some limited percolation failures (erosion of a part of sand content).

Calculations of a maximum credible earthquake, given the existing geological and tectonic conditions in the Project area, based on recommendations of Bulletin 72 ICOLD-89, realised by the Faculty of Natural Sciences, Comenius University in Bratislava, (Janotka-Viskup, 1994-95), focused on selected localities of the headwater canal. Accelerograms have been calculated for stretches of the headwater canal at km 9.275 and km 15.75 where accelerographs at the foot and crown of the dyke are envisaged and in part already installed as a part of a monitoring system.

From among 500 models used for calculation, 11 structural models, representing the complete range of geological variation in the region, are presented in the final report. These are referred to as:

DM (deep model, with a depth of 12 km)

SM (shallow model, with a depth of 400 m)

VSM (very shallow model, with a depth of 200 m)

The maximum calculated accelerations at the above mentioned km points of the headwater canal for different models are as follows:

Model	VSN	SM	DM
km 9.275	0.0792	0.0656	0.0477
km 15.750	0.0796	0.0602	0.0369

According to these calculations, the dissipation effect of the geological environment reduces the maximum acceleration to a value of 0.0796g. The dyke safety is adequate even for this level of maximum horizontal acceleration. Pseudostatic assessments were carried out for even higher values of pseudostatic design acceleration co-efficients, i.e., for 0.125g linearly increased to the dyke crown to a value of 0.25g. The pseudostatic co-efficient of about 0.025g corresponding to the originally recommended 1965 values for the region, i.e., M=7 MCS, would be adequate to the maximum calculated value of acceleration which is 0.0796.

For the event of seismic movements, the stability of the covering layer of gravel, 1.5 m thick overlaying the PCV sheets on the dyke slopes on the water side was also carefully assessed[2]. The risk of its sliding was evaluated on the basis of so called "wedge method" (see Fig. 13). Taking into account the current data on maximum acceleration (Janotka-Viskup, 1994-95) in the event of an earthquake in the area of Komárno, which would result in the locality of the headwater canal on the terrain surface into maximum acceleration a = 0.0796g, this maximum acceleration has been used also to assess the slope stability by pseudostatic methods. The acceleration would increase linearly from 0.08g at the surface level to the value 0.16g at the dyke crown. The safety factor against the sliding of the gravel layer is 1.036.

In view of the accomplished engineering geology survey, quality of design works, stability evaluations and the high standard of construction works confirmed by rigorous control, it can be concluded that the safety of the Project's structures is guaranteed. This conclusion is supported by the results of safety monitoring during two years of operation of the Project.

2 The thickness of the PVC sheets used, being 1.5 mm, has a proven mechanical resistance to the compounding of gravel above. PVC sheets of 0.6 mm were used only for supplementary sealing of horizontal pre-laid carpets and were protected on both sides by silt layers.

The water–retaining dykes of the headrace canal of the G–N Project

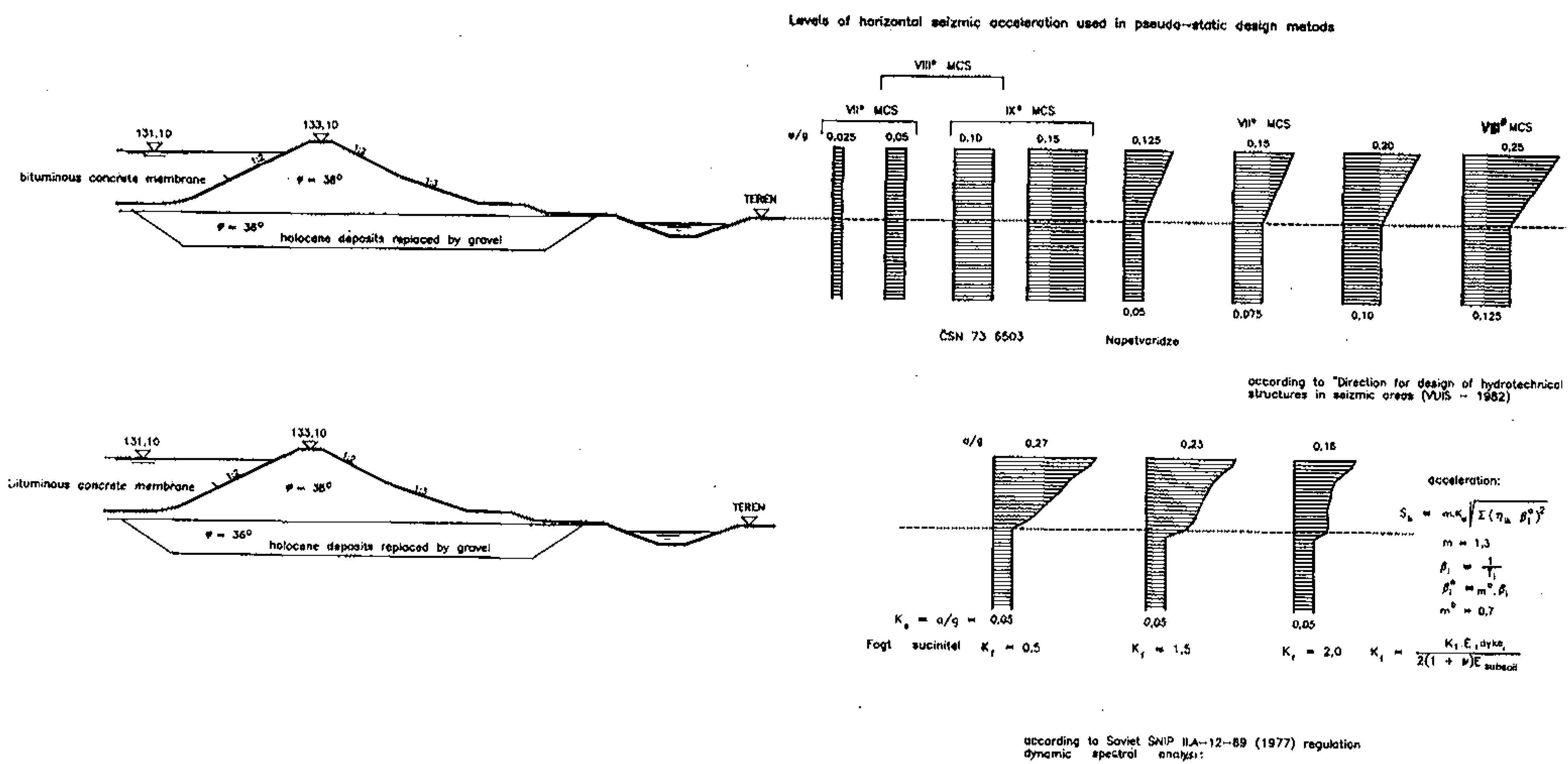


Fig. 5

PROFIL DISTRIBUTION SCHEME OF HEADRACE CANAL GABČÍKOVO

for Tension Evaluation by the Finit Element Method

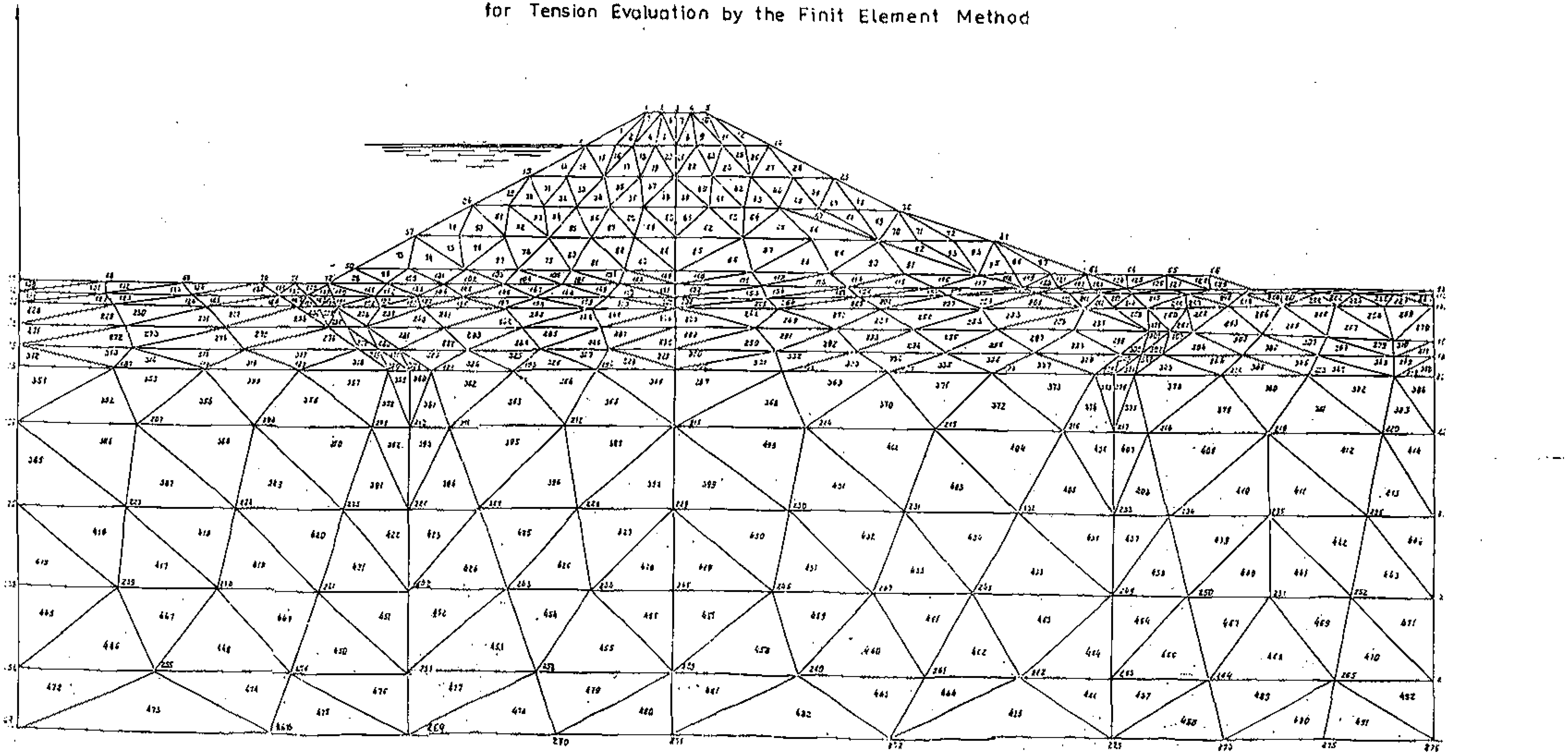
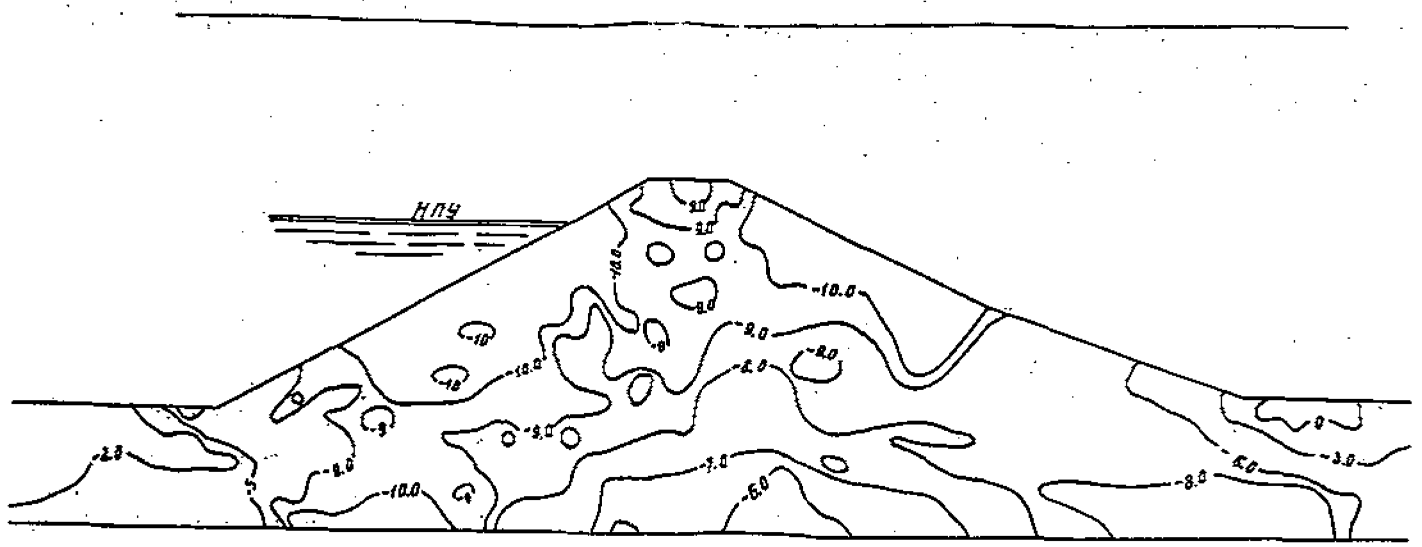


Fig. 6

STATIC STRESS DISTRIBUTION σ_x (t/m^2)

In the dyke and the subsoil

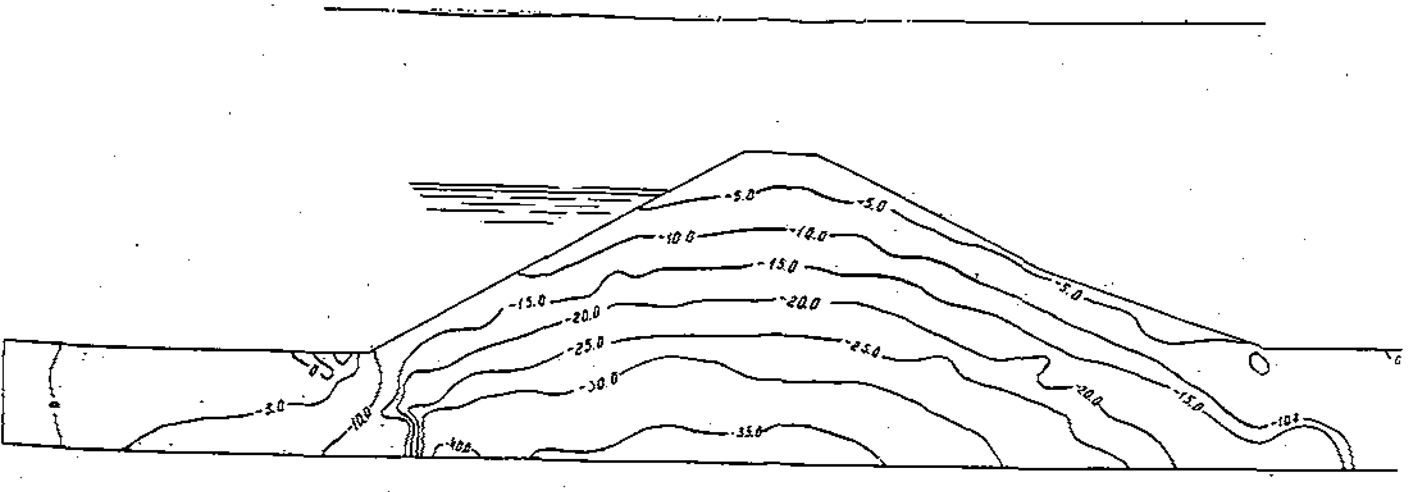


1st VARIANT

Fig. 7

STATIC STRESS DISTRIBUTION σ_y (t/m^2)

In the dyke and the subsoil

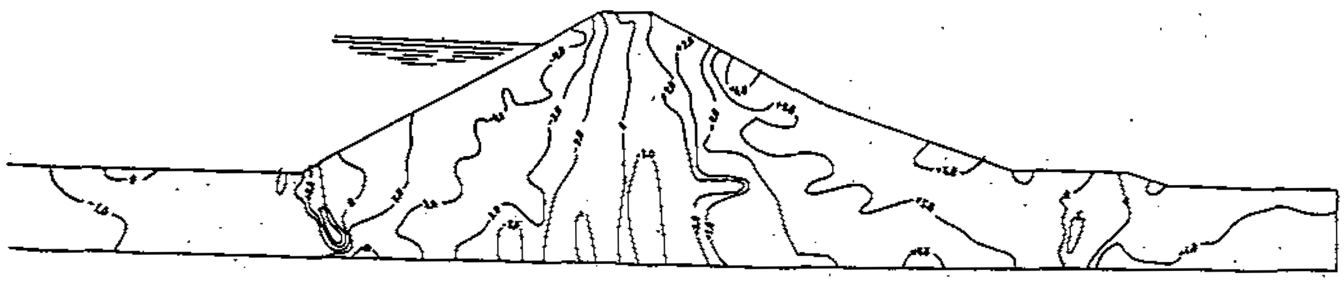


1st VARIANT

Fig. 8

STATIC STRESS DISTRIBUTION τxy (t/m²)

In the dyke and the subsoil



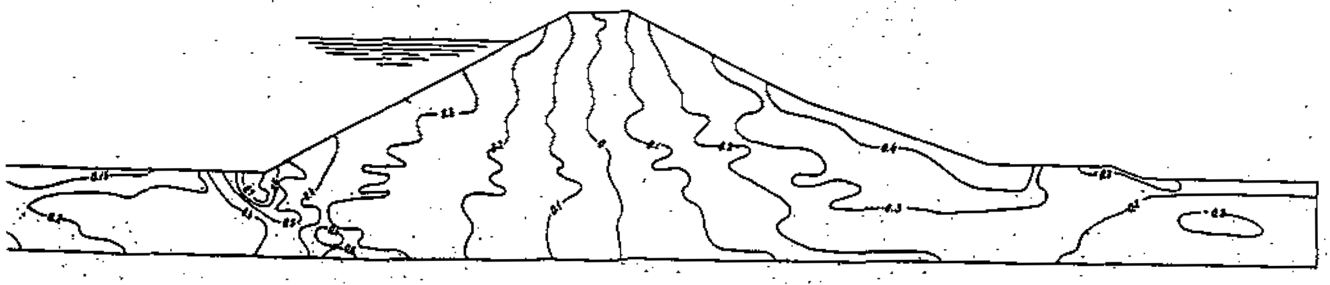
1st VARIANT

Fig. 9

DYNAMIC STRESS DISTRIBUTION σx (t/m²)

In the dyke and the subsoil

(horizontal seismic action)



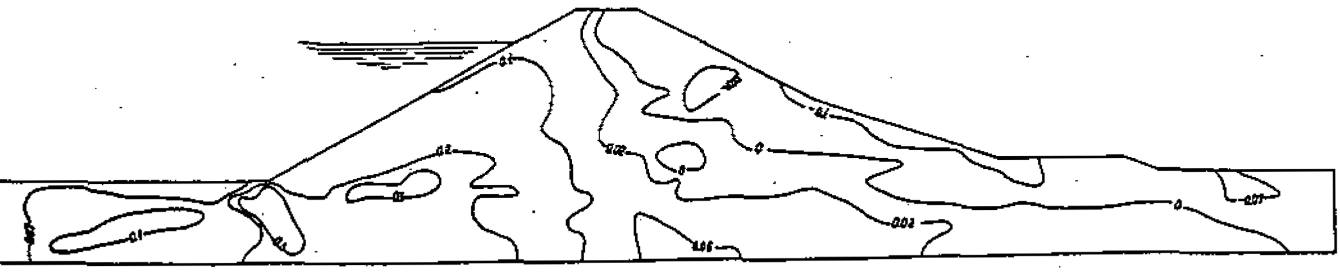
1st VARIANT

Fig. 10

DYNAMIC STRESS DISTRIBUTION σ_y (t/m²)

in the dyke and the subsoil

(horizontal seismic action)



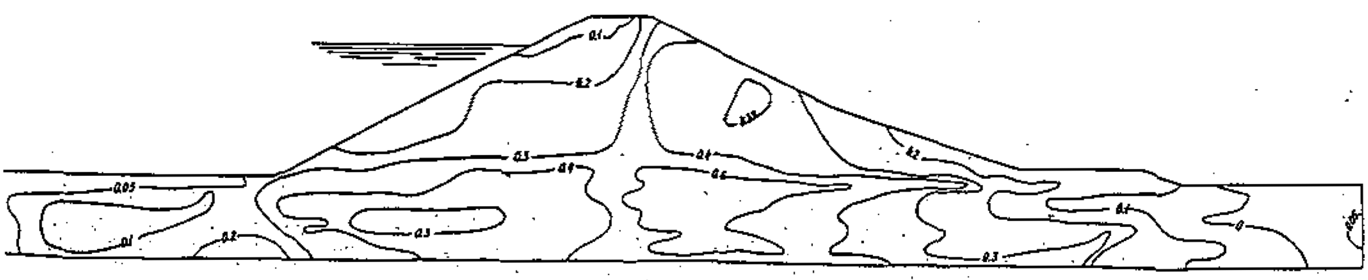
1st VARIANT

Fig. 11

DYNAMIC STRESS DISTRIBUTION τ_{xy} (t/m²)

in the dyke and the subsoil

(horizontal seismic action)



1st VARIANT

Fig. 12

Typical cross section of the dyke of the Variant C

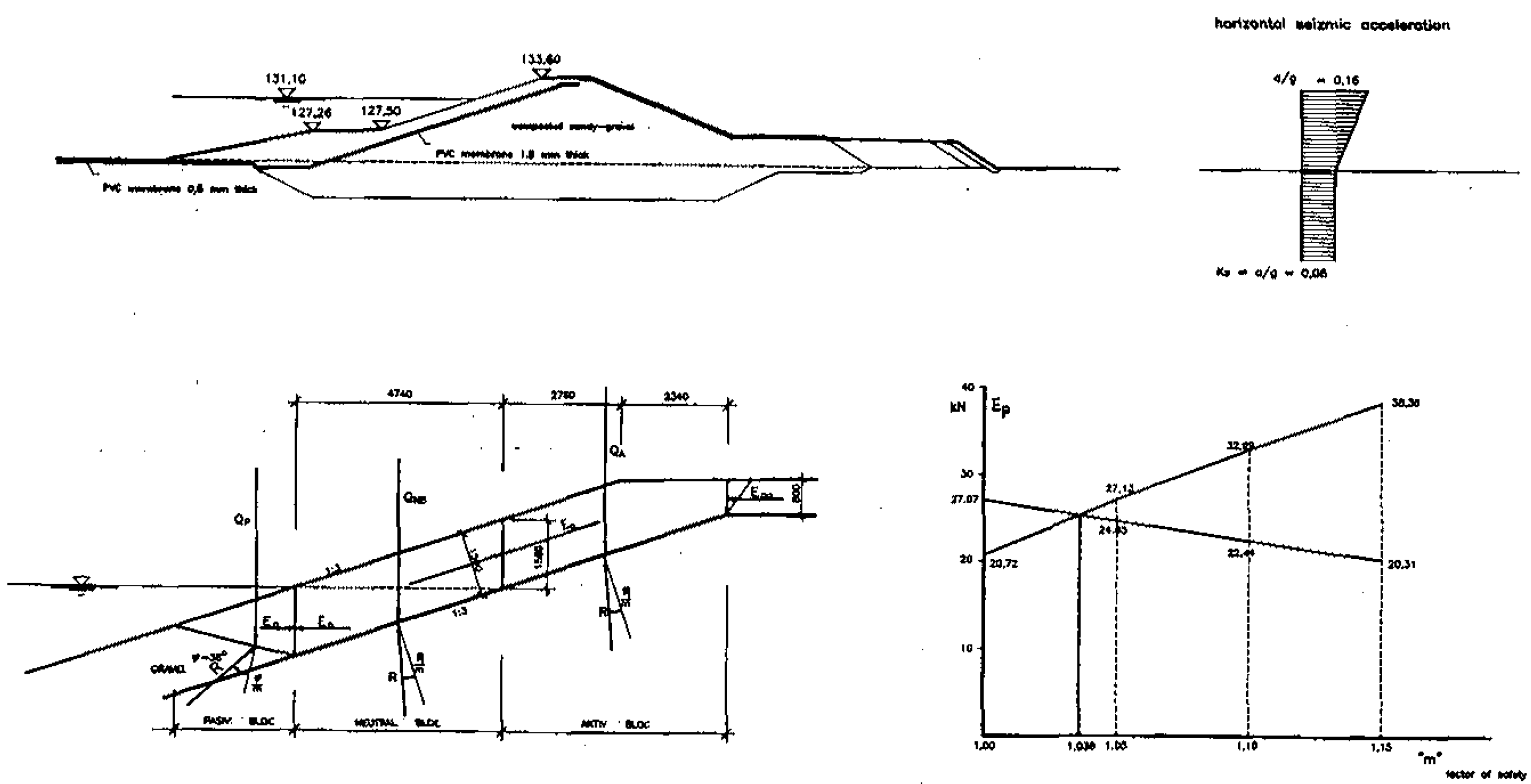


Fig. 13

CHAPTER 12. RIVER MORPHOLOGY AND HYDRAULICS, FLOOD CONTROL AND ICE REGIME

K. Holubová

A. Stančíková

April 1995

1. River Morphology and Hydraulics

1.1 The situation prior to the Danube damming

1.1.1 Riverbed development processes and their impacts on the Slovak-Austrian, Slovak, and Slovak-Hungarian reach of the Danube (rkm 1880-1708)

The characteristic traditional training works performed in the reaches of the German and Austrian Danube, realised in the last century and in the first thirty years of the 20th century, were intended to ensure flood control especially in places where the river left narrow valleys (Eferdinger Becken, Linzer Feld, Machland, Ybbstall, Tullner Feld, Marchfeld).

Subsequent training works aimed at concentrating low and mean discharges into a suitably shaped and adequate river channel, aimed also at the elimination of ice pack formation and the creation of ice barriers. However, their main objective was the improvement of river navigability, since navigation had been developing significantly since the second half of the last century.

The training works realised both positive and negative impacts. Due to the increasing erosion of the riverbed, the water level decreased and bottom grade line degradation occurred (Fig. 1.1). Alterations in the regime of surface waters resulted in alterations to the ground water regime within the riparian floodplain areas.

This process was taking place continuously on almost the whole Austrian reach of the river until the start of the construction of the hydro power project Ybbs-Persenbeurg and step-wise construction of the cascade of water engineering works. At present, the Danube bed degradation occurs in the reach between the river project Greifenstein (rkm 1949) and the mouth of the river Morava (rkm 1880).

Training works on the Austrian reach caused moderate instability of the longitudinal profile (river power projects create artificial erosion bases). Intensive erosion processes may be expected after completion of the Freudenau project (Vienna, rkm 1920), in the reach downstream of the project to the river Morava confluence with the Danube.

1.1.2 Riverbed development processes in the Danube reach between its confluence with rivers Morava (rkm 1880) and Ipeľ (rkm 1708) affected by the traditional training works

The aims of water management and training works in this reach of the river were practically identical with the aims of Austrian training works. However they were realised in different physical-geographical conditions, determined mainly by the following natural phenomena:

- The geological structure of the Danubian lowland (the Little Carpathians foothills to the Kravany fault) has a character of a very deep young tectonic depression, filled with strata of young tertiary marine, lake-riverine, and river sediments. Eastward from the said fault, from below relatively shallow quartenary sediments, older marine sediments of Palaeocene and Miocene rise up and almost reach the surface,

- The Danube's longitudinal profile is characterised by a prolonged gradient of the mountainous type 0.045% and 0.03% from the Austrian reach to Sáp (rkm 1810), and further downstream by slope conditions typical for lowland rivers 0.010% to 0.006%. Due to the fact that between Rajka and the mouth of the Mosoni Danube the river flows on the top of the alluvial cone, there is a risk of floods at high water levels and floods by internal (seepage) waters. There is an intensive interaction between ground and surface waters.

- The river meanders on the top of the alluvial cone (this phenomenon is often called an inland delta), delimited by the arms of Malý Danube and Mosoni Danube,

- There are changes in culmination of high discharges and duration of flood waves.

- There has been an unsteady discharge and bedload regime especially in the area of branch systems (between Bratislava and the Mosoni Danube), and the deformation of the longitudinal profile resulting from the decrease of bedload and suspended load sedimentation.

Training works had been executed in extraordinarily complicated hydromorphological conditions and did not bring expected results. This is evidenced by:

- the repeated, significant increase of the grade line and transverse dimensions of flood protective dykes, and

- continuous reconstruction and completion of the system of training structures for low water, to provide conditions for navigation.

There were serious problems in particular in the reach between Rajka (rkm 1848) and Gönyu (km 1790) for which the Belgrade Convention envisaged the establishment of the "River Administration" with the aim to ensure the maintenance of the navigable water way, having parameters recommended by the Danube Commission.

Due to the fact that Czechoslovakia and Hungary had already planned in the 1950s the construction of the cascades on this reach of the river, the traditional training of this reach was realised only to a limited extent. On the basis of the decision of the Czechoslovak-Hungarian "Joint Technical Commission" for boundary waters, the possibility of constructing the so-called "uniform riverbed" had also been investigated. The idea of the uniform riverbed had been partly realised:

- by means of training for improvement of navigation conditions and limitation of the interconnection between the main river channel and the branch systems,

- by dredging for river training, and also

- by industrial dredging (Fig. 1.2).

Industrial dredging, performed in a relatively large extent, further disturbed the already unsteady bedload regime, and influenced the bedload balance of the river. These changes resulted in a quickly advancing riverbed degradation extending also to the adjacent river sections (see Fig. 1.3 for the drop of the water level).

It is to be emphasised that the industrial dredging was not performed for only one purpose, the production of high-quality building material, but also for the flood protection of Bratislava. It occurred in the reaches of intensive sedimentation and previous disastrous floods at Medvedovo, Komárno, and Štúrovo. The localities of dredging as well as amounts of exploited gravel-sand were also selected always with the aim of contributing to the improvement of navigation conditions and were annually discussed between experts of the Czechoslovak-Hungarian and Czechoslovak-Austrian Commission for Boundary Waters.

The impacts of the "traditional" training works on the riverbed morphology had the following consequences:

(a) The drop of the water levels at the low regulation and navigation water in the area of Bratislava and in the section Nagybajcs (rkm 1804) - Zlatná na Ostrove (rkm 1780). Relatively balanced were the changes downstream of Komárno (rkm 1767) to the river Ipeľ mouth (rkm 1708). The riverbed degradation as well as water level drop resulted in the appearance of rocky sills in the reach of rkm 1734 - Nyergesújfalu and rkm 1711 - Chľaba (see Fig.1.3).

(b) The increase of the bank-full discharge capacity of the main channel, which was originally dimensioned for a discharge of 2886 m^3/s at the water level in Bratislava 500 cm (at present + 330 cm). Changes of the channel capacity were different in the respective sections and corresponded to the localities where more profound riverbed deformations had occurred.

(c) The water level drop led to a considerable reduction of the interaction of waters of the main river channel and river branches. Longitudinal weirs were constructed to enable, at certain discharges, the more intense interaction of surface waters and the supply of respective branch systems with water (autoregulation system).

(d) The construction of the system of groynes changed the flow conditions in the Danube main channel. The width of the trained channel for bank-full discharge capacity was reduced by 50 to 80 m on the average, thus contributing to the improvement of navigation conditions. In spite of that, the low regulation and navigation water levels determined by the Danube Commission were not met. Neither was it possible to remedy by means of those measures problems in ford sections and navigation straits. Neither training measures nor the excessive dredging were sufficient for development of a levelled, longitudinal profile, without the characteristic abrupt slope drop in the course of water levels in the area of Sáp. The longitudinal profile slope was not sufficient in this area to provide the force ensuring continual bedload transport.

The examination of the above mentioned problems revealed that due to continuously acting phenomena ensuing from the geological-tectonic, geomorphologic and potamologic processes, and in spite of long-term (more than one century) efforts it was not possible to maintain a balance: due to increasing demands for utilisation of the Danube river potential on one hand, and its environmental protection on the other hand, it was necessary to envisage a comprehensive solution to these problems.

1.2 River-morphologic processes during the operation of the Gabčíkovo Project (1993-1994)

1.2.1 Water level regime at the Čunovo weir with regard to river-morphologic processes

Under the current state of construction (phase 2 of construction of Variant "C") the determined maximum water levels at the Čunovo weir are as follows:

- up to the discharge of 10 600 m^3/s (the discharge with 1% probability of occurrence) - 131.5 m asl.,

- at a discharge higher than Q=1% - up to the elevation 132.00 m asl. (the structures of the Project will convey the discharge safetly),

- at a discharge of 13 000 m^3/s (the discharge with 0.1% probability of occurrence) the forecasted water level is 131.66 m asl. In rkm 1851.75 -

131.06 m asl. In the event of this extreme discharge the bypass weir should convey a discharge of 1400 m^3/s, the weir in inundation 6 280 m3/s, the hydropower plant 3 160 m^3/s, the navigation locks 1 840 m^3/s and the discharge of 320 m^3/s should be shared by other withdrawals and losses.

Under the winter regime (in the event of ice occurrence) the operation levels are defined as follows:

- maximum operation backwater level in rkm 1851.75:	131.10 m asl.
- minimum backwater operation level in rkm 1851.75:	130.10 m asl.
- minimum operation level in "exceptional situations"	128.20 m asl.

For international navigation, water level courses at minimum backwater level are relevant at the discharge Q 94%, and at minimum backwater level in case of "exceptional situations". The evaluation of the riverbed development carried out on the basis of measurements from February 1992 (section of rkm 1851.75 to rkm 1860), and October 1994 (section of rkm 1860 to 1880), revealed that these backwater water levels coincide with the course of low regulation and navigation water levels recommended by the Danube Commission:

- at the backwater elevation 131.10 m	in profile rkm 1880
- at the backwater elevation 130.10 m	in profile rkm 1878
- at the backwater elevation 128.20 m	in profile rkm 1874

At higher discharges Q > Q 94% the coincidence sites are shifted in the downstream direction.

After the damming of the Danube the proportion of duration of different water stages changed. The change in percentage values of exceeding different water stages, based on measurements at the gauging station Rusovce (rkm 1855,90, i.e. 4.15 km upstream of the Čunovo weir), is presented on Fig. 1.4, in relative and absolute altitudes above sea level. The study of the period 1989 - 1994 reveals that after the damming water levels in this profile raised up by about 4.6 m at 50% exceeding average daily water stages. The change in the regime of water levels and discharges resulted in a new hydromorphological regime of the Danube upstream as well as downstream of the Čunovo weir.

1.2.2 Morphologic changes in the Danube riverbed in the reach upstream of the Čunovo weir after putting into operation

After the damming of the Danube in rkm 1851.75 and filling of the reservoir the changes in the channel configuration occurred according to expectations.

The available data concerning cross-sections between rkm 1851,75 and rkm 1860 reflect first of all changes connected with earlier construction activities, which are not due to morphological processes. (In this profile the navigation route has been transferred and a new cunette has been dredged to ensure navigable route through the reservoir and other terrain adaptations were realised in the former inundation area to assure higher discharge capacity.)

After a two-year operation of the Gabčíkovo Project no significant changes, which would be due to bedload sedimentation, occurred in the reservoir. According to the prognostic mathematical model, the bedload retained in the reservoir will not reach the damming profile even after long-term operation of the Project (this conclusion was reached on the basis of model simulation of 50-year operation (ref. 1)).

Similarly, in the section between rkm 1860 -1880 no bedload sedimentation has occurred. The control monitoring of the navigable route showed that transverse material shifting on the riverbed took place and some change in the profile's configuration occurred, as a result of changed flow conditions after the damming of the Danube.

According to this prognosis the crucial points of bedload sedimentation should be the reach between rkm 1868.5 - 1864.5 after 10 and 20-year operation and rkm 1862.5 after 30-year operation (if no dredging occurs). Nevertheless, as a matter of example, it may be considered that, even after a 20-year operation of the Project, sediment bars may cause the increase of the water level in the profile of the water gauge station Bratislava (rkm 1868.75) only by + 0.38 m (at average long-term annual discharge of about 2000 m^3/s).

It can be however stated with certainty that such a situation will not occur, since the operator has at his disposal large-capacity dredges for the maintenance of the riverbed.

Within the area of Bratislava city the effective channel width at the high and means water levels is in some places almost the same (about 340 m as compared with 300 m). For this reason, in the interest of the flood protection of the low-lying quarters of the city, the predicted sedimentation must not be allowed in these places.

On the basis of comparison of courses at low regulation and navigation water levels in the section Bratislava-Devín, a water level decrease has occurred between rkm 1880 and 1878, while in the following section, down to rkm 1873.50 an increase of water level has been recorded as compared with the state in 1985 (ref. 18). In the section between rkm 1873.5 and rkm 1871.0 again a decrease has occurred, being afterwards followed by a slight increase of the course of the prescribed water level (Fig. 1.5).

It must be stated that these changes, with regard to Danube conditions, are not significant (being in the range max. -18 cm to +10 cm). These values correspond to usual changes of water levels at low discharges (see Tab. 1).

Tab. 1.

rkm	low flow 1985 m asl.	water level 1995 m asl.	diff. (2)-(3)	gauging station
1	2	3	4	
1880.000	134.31	134.13	-0.18	Devin
1879.760	134.19	134.07	-0.12	Devin port
1879.250	134.07	133.91	-0.16	Thebnerstrasse
1879.000	133.95	133.83	-0.12	
1878.000	133.47	133.46	-0.01	
1877.000	132.89	132.92	0.03	
1876.850	132.80	132.85	0.05	Devin quarry
1876.000	132.45	132.51	0.06	
1875.000	132.13	132.23	0.10	
1874.840	132.11	132.16	0.05	Wolfsthal
1874.000	131.74	131.75	0.01	
1873.500	131.55	131.60	0.05	Berg
1873.000	131.40	131.35	-0.05	
1872.000	130.84	130.69	-0.15	
1871.000	130.37	130.33	-0.04	
1870.000	129.86	129.91	0.05	
1869.000	129.40	129.43	0.03	
1868.750	129.25	129.17	-0.08	Bratislava

1.2.3 Alterations within the area of the reservoir

The main phenomenon determining the character and extent of reservoir sedimentation is, besides the character of the flow in the reservoir, the amount and granulometric composition of transported suspended load. The concentration and runoff amounts of suspended load in the Danube during last decades has relatively decreased as a result of hydro-technical measures, and of the construction of waste water treatment plants on the German, Austrian and Slovak territory.

Measurements performed by the Water Management Research Institute in Bratislava (VÚVH) in the 1950s showed an annual average suspended load runoff near Bratislava (rkm 1868.715) to be 6.9 mil.t/year. Austrian data from Bad Deutsch Altenburg (rkm 1886.240) from 1979 to 1989 showed values amounting to only 2.87 mil.t/year, and the recent measurements in Bratislava show only 2.17 mil.t/year (16).

The relationship between concentration and discharge of suspended load in the cross-section Bratislava (rkm 1868.715) are as follows:

$$C = 1{,}47396.10^{-5} \,.\, Q_{BA}^{\,1{,}88229}$$

$$Qpl = 1{,}47396.10^{-8} \,.\, Q_{BA}^{\,2{,}88229}$$

In the section downstream of the confluence of the tailrace canal with the Danube (Medveďov, rkm 1805) this relationship correspond to the formula:

$$C = 3{,}6884.10^{-3} \,.\, Q_{ME}^{\,1{,}16124}$$

$$Qpl = 3{,}6884.10^{-6} \,.\, Q_{ME}^{\,2{,}16124}$$

The difference between the runoff balances of the suspended load at stations Bratislava and Medveďov (2.1 mil.t - 1.5 mil.t = 0.6 mil.t) does not provide sufficient information on amounts of sedimented suspended load in the reservoir. Evaluation of sedimentation based on mathematical models ID and 2D indicates that from the inflow amount of suspended load about 60% to 40% was sedimented (1.38 to 0.84 mil.t = 1.1 to 0.67 mil.m^3) (ref. 8). Assuming linear distribution of sedimentation in the whole area of the reservoir, covering 2518 ha (at max. operating level), the average thickness of the sedimented layer amounts to 0.04 m, or 0.026 m/year.

The sedimentation process in the reservoir, as far as the areal distribution is concerned, does not evolve uniformly. However, despite varied bedload sedimentation in the reservoir, after a two-year operation of the Project, with non-stationary, flowing conditions in the reservoir, the sedimentation is not so apparent as to enable the determination of changes by means of modern electroacoustic equipment. That is why the method of deformations balancing with use of cross-sections in time intervals was not applied. The use of the areal-volume or spatial evaluation of changes in the configuration of the bottom of the reservoir can be considered only after several years of operation. On the basis of the experience gained during studies of sedimentation processes in 23 Slovak river power projects and their reservoirs we suppose that it will be possible to establish such balance after 5 - 7 years.

Amounts of suspended load in Medveďov, which are relatively higher then expected, have been caused by the fact that the tailrace canal is still being dredged. Thus especially at low discharges, higher suspended load concentrations occur in average in the tailrace canal than in Bratislava, especially when disturbance of fine bottom sediments happens (ref. 16). The concentration of suspended load at Medveďov increases also with the occasional increase of the discharge into the old riverbed , due to the existence of the sedimentation core in the Bagomer bend (rkm 1812).

The reservoir is at present in equalisation stage and the deformation processes occurring there are not significant. Thus the sedimentation processes do not influence the course of water levels in the reservoir.

1.2.4 Changes in the Danube channel downstream of the confluence of the tailrace canal with the Danube

The section of the Danube between Sáp (rkm 1811) and Kližská Nemá (rkm 1794) has been for many years at the centre of different efforts aimed at its regulation. The Joint Contractual Plan envisaged the solution by means of extensive deepening of the riverbed, for achieving:

- communication of the water levels of the Nagymaros Project and Gabčikovo Project without gradient losses, and

- decrease of water levels at extreme discharges, and increase of reliability of dykes in longitudinal direction.

For this reason the standard systematic river training for low water was not realised, neither was the reduction of the bank line width and stabilisation of conditions of flow by means of construction of one-sided, and in some places also both-sided, systems of groynes (solution used on the river Rhine and on the Austrian Danube).

This section was always a trouble spot as far as its navigability is concerned, and systematic interventions were needed (mostly dredging, see Fig. 1.2). Specific cost for training works in this section exceeded by several orders the budgets for other sections.

After completion of the Gabčíkovo part of the Project and without the Nagymaros Project this reach, from the morphological point of view, remained henceforth burdensome with regard to navigability (ref. 17), and even critical with respect to flood control (ref. 13). The causes lay in the fact that the training for low water had not been realised, neither was the general solution of the longitudinal channel profile designed within the scope of the Gabčíkovo-Nagymaros Project.

Forecasting analyses assumed significant morphological changes in the given reach (ref. 2) and therefore new measurements were performed in this area. The reach is at present without any training and problems of navigability are solved by means of local interventions, namely by dredging of the navigation cunette or fords.

The balance of changes of cross-sections from the years 1992/93 and 1994 (Fig. 1.6) in the reach Gabčíkovo (rkm 1820) to Kližská Nemá (rkm 1794) showed that:

- in the reach of the old channel from Gabčíkovo to Sáp (rkm 1811), i.e., to the confluence of the tailrace canal with the Danube, transfer of sediments occurred; they settled again in the Bagomer bend (rkm 1814 to 1811);

- immediately below the tailrace canal confluence with the Danube, significant riverbed deepening occurred (the transport of the material amounted to more than 550 000 m^3 on a several kilometres long reach);

- downstream of rkm 1806 the stream transporting capacity, i.e., conditions ensuring continual run of bedload are significantly reduced (abrupt slope decrease, wide, unstable channel, etc.); this causes relatively intensive sedimentation, resulting in unfavourable changes in the riverbed morphology with regard to navigation (changes in profiles in transverse direction, concaves are changed into convexes, ford profile is changed into inflex profile, etc.);

- as a result of training dredging the degradation of the channel in the flow direction prevails down to rkm 1801, while from rkm 1798 the aggradation and degradation occur approximately to the same extent.

Changes and especially trends of riverbed development had been observed not only in this reach, but also in the reach from Sap (rkm 1811) down to the river Ipeľ mouth (rkm 1708). They were based on comparison of the low regulation and navigation water recommended by the Danube Commission and focused on:

- global changes over the period from 1957 to 1994 (see Fig. 1.3, where the water level in 1957 represents a comparison basis and is represented by the horizontal line and water level decline by 1992 or 1994 is expressed in relation to it);

- the short period of the Gabčíkovo Project operation (1992-1994) (see Fig. 1.7, where the graphic expression is similar to that in the first case). The graph depicts only those sections which are not influenced by the impounded water - the short unimpounded reach upstream of Bratislava and the reach downstream of Sáp.

Fig. 1.7 reveals that the generally prevailing sinking of the levels of low regulation and navigation water in the period 1957-1994 had not substantially changed even after suspension of industrial dredging. The development in the last two years (1992-1994) indicates local increasing of the low regulation water levels and navigation water level, the grade line of the water level from 1957 not being reached in any locality.

Water level courses and new riverbed evolution conditions were encountered with navigation conditions recommended by the Danube Commission (ref. 17). The riverbed widths in the gabarit depth + marge (2.5 m + 0.2 m), i.e., in the depth of 2.7 m below the low regulation and navigation water are presented in Fig. 1.8, together with gabarit widths recommended by the Danube Commission, i.e., 180 m from Chľaba to the mouth of the Mosoni Danube, and 150 m in the reach upstream of the tributary mouth. Thus, it can be seen, that the river reach downstream of the tailrace canal confluence with the Danube down to the Mosoni Danube mouth does not meet prescribed gabarit conditions.

Conditions limiting navigation also occur on other reaches, such as for instance rocky protuberances in the riverbed at rkm 1734 (Nyergesújfalu) and, at rkm 1711, dangerous fords or straits in several localities.

Traditional training of the reach between the rkm 1811 and rkm 1794, as well as its maintenance, would be very demanding with respect to investment and operation, and from the point of view of flood control very problematic.

Within the scope of the Gabčíkovo-Nagymaros Project the flood protection on this reach consisted in the riverbed deepening and fortification of dykes. Since the Nagymaros Project has not been realised, the flood protection in this reach has become of topmost important.

In any case, the reach downstream of the tailrace canal mouth requires a complex solution, the most suitable one being the deepening of the riverbed and the impoundment of this reach, as envisaged by the Joint Contractual Plan.

1.2.5 Morphologic changes in the old Danube channel downstream of the Čunovo weir (rkm 1851,75 - 1810)

The passage of the flood wave through the Čunovo weir in November 1992, shortly after the damming of the Danube, caused deformations in the area downstream of the weir, in the right-side inundation and in the cut-off into the old Danube channel. This was due to the fact that the structures of the Čunovo complex were still under construction in part. The term of completion of these structures and their putting into operation was determined on the basis of the long-term hydrological regime of the Danube, based on the analysis of hydrological data for the period 1901-1985, with the aim to put the structures in to full operation in January 1993.

According to provisional operating regulations (elaborated within the scope of Project preparation in 1989, and updated at present), the monthly discharge Q 1% in October was determined to be 4100 m^3/s, in November and December 4300 m^3/s, and only in January 6000 m^3/s. Beginning on November 22, an unusual discharge wave was recorded (see Fig. 1.10) exceeding the mentioned values to a great extent, and culminating on November 25, 1992 at Bratislava at a water stage of 648 cm and discharge of 6078 m^3/s. The probability of the flood of this dimension in November - December, in the light of long term measurements (1901 - 1985) must be considered as extremely low.

The immediate consequences of the discharge wave were recorded in the inundation weir basin and the cut-off. Also a local outbreak into the Mosoni Danube occurred. These local deformations, nevertheless, had a temporary character and were remedied in the phase of completion of the inundation weir basin. The realised adaptations were properly ensured on the basis of hydraulic studies on physical models (refs. 7, 9).

During the operation of the Čunovo weir, seven discharge waves occurred with culmination discharges ranging between 6097 m^3/s (2.7 - year water) and 4616 m^3/s (on the limit of 1-year discharge). Under these conditions the discharge into the old riverbed was increased. The water flow at the bank-full discharge capacity was usually unsteady, unbalanced, according to the character of respective waves, the culmination level did not reach the height of the thresholds of lowered river bank sections aimed at assuring the direct water flow from the river to the branches. These weirs had been constructed as a part of the training of the uniform channel and they exist only on the right (Hungarian) river bank.

On the Slovak side in the reach Hrušov - Gabčíkovo, the mouth of Baka branch (rkm 1840 - 1821), the interaction possibilities were eliminated up to the bank level. Branches in the Slovak floodplain are supplied by means of an operable structure, built in the dyke of the headwater canal. The regime of the branch system is manageable, and up to the water level in the old channel corresponding to about Q = 3500 m^3/s, independent from the discharge in the Danube.

On the Hungarian side, as a substitute solution for supplying the Hungarian branch systems with water, openings in the right river bank were realised at rkm 1845.9 (40 m wide, overflow elevation 121.4 m asl.), and at rkm 1845.4 (30 m wide, overflow elevation 121.4 m). Later however, these openings were partly closed, because during water pumping into the branches at rkm 1845 (supply of 4.5 m^3/s) the water was returning though these openings back into the main channel. Further pumping of water into Hungarian branches from the Danube was realised at rkm 1832 (5.5 m^3/s). The branch system at Dunaremete (rkm 1826) was similarly supplied.

The discharges released through the Čunovo weir structures into the old channel meander on the bottom of the riverbed. Unflooded gravel bars are at present covered with fast spreading abundant plant growth. Plants increase channel resistance, and represent a stabilisation factor during the inevitable discharges of high water waves.

Evolution trends of morphological changes in the reach of the old channel between the Čunovo complex and Gabčikovo could not have been quantitatively estimated yet, because the Hungarian party did not make available the results of measurements of the riverbed configuration in 1993-1994. The Hungarian party had to submit these data to the Slovak party on the basis of the Protocol of the Slovak-Hungarian Commission for Boundary Waters. Exchange of materials had been taking place for years under mutual agreement, on the basis of annual rotation of monitoring works between Slovakia and Hungary.

On the basis of a visual evaluation of the configuration of the bare parts of the channel it may be stated that the material, washed off from the area of the inundation weir basin of the Čunovo weir during the flood in November 1992, sedimented on various places of the main channel, according to conditions of non-stationary regime of flow.

It can be expected that, in the event of larger discharge waves, further transport and re-deposition of a part of the sedimented material will take place. After completion of adjustment works in the area of the inundation weir basin and training of the river reach just below the Čunovo weir, the degradation of the riverbed in the flow direction will be limited. The water, rid of sediments during its passage through the reservoir, will be saturating itself with bedload from the alluvial riverbed subsoil, once the corresponding hydraulic-morphologic conditions are created. This process, according to the analysis of long-term discharge series (1900-1985), will be rather limited in time (ref. 15). Longer-lasting stationary conditions for continuous bedload transit in the old channel do not appear due to the division of discharges between the headwater canal and the old channel. However, the mixing of the bottom material and washing out of fine sediments will occur, which can be considered as a positive phenomenon.

Slightly different morphologic conditions will develop in the reach Gabčíkovo - Sáp (rkm 1820 - 1811), because this reach is already affected by the backwater and regime conditions of water levels determined by the tailrace canal in its mouth section. Morphologic changes in this reach have been evaluated by means of the balance of volume changes of the channel and are presented above.

It may be stated that, except for the exceptional situation which occurred in November 1992 when the Čunovo weir was still under construction, regime conditions, which would change significantly morphologic conditions in the old channel, have not developed. At most, a certain local sediment transport may have occurred during higher discharges.

Different morphologic conditions as well as water management and ecological conditions would occur, if the training of the old channel and branch system was resolved in a conceptual manner through the construction of underwater weirs (sills) (ref. 19) proposed in rkm 1814.2, 1818.6, 1821.3, 1824.4, 1828.3, 1831.7 and 1834.9, or eventually at rkm 1841 to 1843 (underwater weir planned by Hungary for enabling water supply in the branches through the Dunakiliti weir).

These structures would divide the section of the old channel into small retention areas, by means of which the following conditions would be achieved:

- more favourable conditions in the old channel for infiltration and re-infiltration (reduction of the ground water level drop in the riverine area),
- manageable interaction of the waters in the old channel and in the branches,

- conservation or, eventually, improvement of soil moisture conditions in the zone of capillary rise of the soil cover in the afforested floodplain,

- creation of more suitable conditions for inundation of the flood plain either by means of natural flooding, or controllable flooding by an increase of discharge through the intake structure,

- maintenance of conditions of dissipation (lowering) of high discharge waves, a basic condition for ensuring the efficiency of flood control function of dykes on the reach downstream of Sáp.

The system of underwater weirs in the Danube's old channel would create different conditions, as far as channel deformations are concerned, than the existing ones. These weirs would function as thresholds and have stabilising effects. Any increased sedimentation of fine sediments could be remedied by occasional flushing of the channel by higher discharge discharging through the Čunovo.(ref. 19)

As an alternative to the training by means of underwater weirs, solutions consisting in constructions of low barriers with controllable sluice gates (7m x 30m) located in rkm 1817.9 and 1828 have been worked out.

1.2.6 Morphologic changes in the branch system on the Slovak territory (rkm 1840 - rkm 1821)

The branch system on the Slovak side of the floodplain has been adapted in such a way that until the eventual occurrence of the discharge in the old riverbed exceeding the bankfull discharge capacity of the channel, it can be supplied with water independently, up to the discharge of 230 m^3/s, by means of a controllable intake structure near Dobrohošť.

This capacity of the intake structure provides not only adequate maintenance supply (at the discharge of 29 m^3/s), but enables complete filling of branches with water (at the discharge 50 m^3/s), and even flooding of the whole floodplain area (at the discharge 140 - 230 m^3/s).

Up to the present time the first two alternatives were employed in management of the discharge regime. Flood simulation is under preparation.

Despite the fact that the original branch sub-systems on the Slovak side have been interconnected (former systems: Hrušov, Vojka, Šuľany, Bodíky, Baka) and their only connection with the Danube is near Gabčíkovo (rkm 1820 - 1821), their regime and the rich ramification of the branches and cascade training of water levels on the edge of respective branch sections, may be controlled (10).

Operation regimes employed up to the present have not caused special morphologic changes on the bed of branches for the following reasons:

- Discharges up to 50 m^3/s do not cause transport of alluvial material on the branch bottom; moreover, the inflow discharges in respective sections gradually decrease with each section due to losses (ref. 4). Thus hydrologic and hydraulic conditions for deformation processes do not exist.

- Withdrawn water volumes from the canal are rid of a considerable part of suspended load; their concentration is decisively lower than at Bratislava, since waters have passed the upper and lower part of the Hrušov reservoir, where favourable hydraulic conditions for sedimentation exist.

Due to these circumstances colmatation has not occurred. This has been confirmed also by the amounts of water losses (infiltration into the aquifer) in the respective sections, which are significant. They were quantitatively determined within the scope of the research works of the PHARE Project (refs. 10, 11).

It is assumed that, during the simulated flooding of the territory, or its flooding from the old riverbed under the discharge conditions exceeding bank-full discharge capacity of the old channel, a partial washing out of fine sediments and local deformation in some branches could occur. However, after completion of the lateral canal the probability of the occurrence of such regime conditions is relatively small.

2. Flood Control

2.1 Flood control under the rules of operation of the Gabčíkovo Project

The provisional rules of operation (ref. 5) and the whole water-management regime based thereon are determined by the technical solution of Project structures, and the actual state of putting of different structures into operation. To the maximum possible extent, they utilise the characteristic parameters determined for the original variant of the Project. These were based on data from the last 50-year period. It is assumed that the rules of operation in their final form will be based on statistic data from the 90-year period.

The flood discharges were quantified as follows:

Table 2.

Probability %	N (years)	Q (m^3/s)
0,01	10 000	15 000
0,1	1 000	13 000
1	100	10 600
2	50	9 550
5	20	8 750
10	10	7 900

In addition to these parameters, the probabilities of occurrence and exceeding of discharges in respective months are also important, namely when certain construction phases are conditioned by the occurrence of discharges of a given probability. This was, for example, the case of timing for the Danube's damming and scheduling construction of the inundation wier of the Čunovo complex.

Flood handling under the conditions of the current stage of construction (2nd phase of the construction of Variant "C" is still under way) is realised according to the "General Flood Control Plan for the concerned territory of the Gabčíkovo-Nagymaros Project - Up-dating II" (November 1994, No. 27216).

Flood water handling depends on the water level regime in the reservoir and on the number of operating turbine-generator sets (TGS) of the hydropower plant. At Q = 1 (10 600 m^3/s) the discharges distribution is realised in accordance with Table 3.

Table 3

water levels - reservoir	130,50	130,50	130,50	131,10	131,10	131,10
No of TGS*	4	5	6	4	5	6
m3/s						
withdrawals and losses	320	320	320	320	320	320
bypass weir	1 200	1 200	1 200	1 200	1 200	1 200
inundation weir	5 830	5 830	5 780	5 830	5 830	5 750
hydro-power plant	2 260	2 830	3 300	2 260	2 800	3 330
navigation lock	990	420	-	990	450	-

* Legend: TGS - Turbine-Generator Set

Occurrence of a discharge higher than Q = 1% leads to water level increase exceeding 131.50 m above sea level. The prescribed safety of structures is assured up to the elevation of 132.0 m asl.

For handling the discharge Q = 0.1% (thousand year flood), the respective structures of the Project are to be utilised as follows:

Table 4

Structures	m3/s
by-pass weir	1 400
weir in innundation	6 280
hydro power plant	3 160
navigation lock	1 840
withdrawals, losses	320
total	13 000

location	water levels (m asl.)
rkm 1851, 75	131,66
hydro-power plant Gabčíkovo (head water)	131,06
hydro power plant Gabčíkovo (tailrace water)	118,00

The provisional rules of operation are not confined to the above mentioned critical stages and discharges. They regulate the regime of the Project operation within the whole range of discharges, taking into consideration the functions of all Project structures.

The protective structures (dykes and associated structures) in the impounded section upstream of Čunovo are adapted to new conditions resulting from the permanently increased water levels. At the same time (with prescribed freeboard allowance) they obey the demands for protection against extreme discharges determined in the provisional rules of operation. The existence of the Project as such influences the course of extreme discharge levels only in the closest proximity of the structures. Otherwise, during handling of high discharges, almost original water level regime conditions occur, since the capacity of the Project structures has been designed with this in mind.

Flood control in the reach of rkm 1851.75 to 1811.00 has, due to the ability to divide extreme discharges between the headwater canal and the old channel, increased. In a critical case of the discharge Q = 0,1% the discharge in the old channel would be only 7 680 m^3/s, and at the discharge Q = 1% even lower, i.e., 6 950 m^3/s. These amounts could not cause problems in the old channel as far as the water course is concerned, since the flood capacity of the channel is dimensioned for Q = 1%.

The method of discharge release in the provisional rules of operation is solved in a manner which excludes sudden water release from the reservoir and abrupt increase of water stages downstream of the Project and in the old channel which might result from the ill-timed manipulation of discharges.

In the reach downstream of the tailrace canal mouth, up to the confluence of the River Ipeľ with the Danube, the protective lines on the Slovak territory were reconstructed so as to meet the conditions ensuing from the operation of the planned project at Nagymaros. In the reach between Kližská Nemá and the Danube confluence with the tailrace canal, the planned Danube riverbed deepening was not realised. This was one of the pre-conditions for the increase of flood control of the adjacent territory. Thus, it is necessary to strengthen the protective measures in this reach.

After the completion of the 2nd stage of construction of Variant "C", the conditions for management of flood events will substantially improve, since higher flexibility will be introduced in discharge distribution and, at the same time, the specific loading of the respective structures of the Project will be lower, as will be the loading on the area close to the inundation weir basin and the following river reach.

2.1.2 Evaluation of the occurrence of higher discharge waves recorded during the Gabčíkovo Project operation

The Danube was dammed at the end of October 1992. The course of discharge hydrographs after this date is depicted on Fig. 1.11.

Over the period October 1992 to December 1994, the discharges exceeding at their culmination the discharge of the one-year flood were the following:

Table 5

dates	max. Q [m3s-1]
24.11.1992	6097 (2,7 year water)
18. 3.1993	4626 (near to 1 year water)
22. 7.1993	5228 (1,45 year water)
30. 7.1993	4616 (near to 1 year water)
27.12.1993	4674 (near to 1 year water)
15. 4.1994	5082 (1,21 year water)
19. 4.1994	5990 (2,55 year water)

According to the statistical criteria of culminations of flood discharges over the period of years 1876 - 1965, in absolute terms, these waves have been in general of little significance.

The situation was however different in the case of the flood wave, which culminated on 24 November 1992, due to the fact that some structures of the Čunovo complex were under construction. The inundation weir was not yet completed and neither was the rock chute in the lower profile of the bypass weir. This chute assures trouble-free discharge of water at a relatively great difference between water levels in the cut-off and in the old Danube channel. Works on both structures were scheduled to be completed by the end of 1992. It was assumed that increased discharge wave might occur only after December. This assumption was supported by statistical data.

According to the provisional rules of operation prepared in the framework documentation from 1989, the Q = 1% for concerned months was determined as follows:

October	4100 m3/s
November	4300 m3/s
December	4300 m3/s
January	6000 m3/s

The discharge wave, which began to develop from 22 November 1992, considerably exceeded these values. Over the period 1901 - 1985 the discharge in the class interval 5400-5500 m^3/s occurred in November only once and lasted only one day. The probability of exceeding this discharge was 0.039%. Similarly, on only one day in December, over this period, did the discharge in the interval 6600-6800 m^3/s occur, with the probability of exceeding being 0.038%. Thus it is obvious that occurrence of the above mentioned wave in November was an extraordinary phenomenon.

Under the given conditions, the substantial part of the discharge (more than 3000 m^3/s) had to be conveyed through the uncompleted inundation weir. The consequences were as follows:

- several segments prepared for mounting were moved by water, since the ropes holding them on the stocking place were severed;

- an erosion took place behind the cut-off, since the works on the rock-fill chute at the outlet into the Danube were in the initial stage. In connection with the bottom erosion downstream of the inundation weir, a further decrease of an already low water level occurred downstream of the weir. Finally, the breach of the right side of the cut-off into the Mosoni Danube occurred.

These facts lead to a partial re-design of the cut-off, its connection with the Danube, and the area close to the inundation weir basin of the Čunovo weir. New measures were studied on a physical model in the hydraulic laboratory of the Water Management Research Institute (refs. 7, 9).

Other discharge waves have now passed through the completed structures and no problems requiring special measures occurred.

The forecasting of water stages on the upper Danube and resulting training measures should reduce the unfavourable effects of wave discharging. However there is a problem in that due to the construction of several river projects on the Austrian Danube, the gauging stations, which in the past provided the basis for prognostic models, were gradually removed (Linz, Struden, Ybbs, Krems and partly also Wien-Reichsbrucke).

Furthermore, the canalisation of the watercourse and other anthropogenous activities within the river basin accelerated the reaction of the flow rate process on the storm rainfalls rush and on waters originating from snow melting. Over the last decade the discharge-travel times in the reach Linz-Bratislava were reduced by 25% to 40%. One of the best examples was the wave of August 1991, which passed the reach between Linz and Vienna in 20 hours, as compared with 40 hours in the past. In addition, also the speed of the wave limb rise was multiplied (ref. 12).

These circumstances complicate to a certain extent the discharge distribution at the Čunovo complex. Sometimes, also, the unreported discharging from the retention reservoirs of Austrian river projects contributes to these problems.

The new regime conditions in the section of the old channel are not only the result of the Čunovo weir operation. They are also due to other anthropogenous interventions, including those taking place outside the Slovak territory.

3. Evaluation of Ice Phenomena during the Operation of the Gabčikovo Project

3.1 Conditions of ice phenomena occurrence

Problems caused by ice phenomena occurrence on the Danube during the winter period may be divided into two groups:

- Occurrence of the ice cover in the reservoir of the Project. Experience from Austrian and German barrages on the Danube revealed that this phenomenon may be expected almost annually. The ice develops at the shore on the so called lake parts of the reservoirs and may quickly cover the whole reservoir. The velocity of freeze-up may be estimated by comparison with velocity of ice development on a free watercourse. Freeze-up on the Danube between Štúrovo and Dunaremete (about 100 km) during the extreme winter 1946-1947 occurred on one day. Over the winter periods 1900 to 1965 the velocity of ice cover spread ranged between the river Morava mouth and river Ipeľ mouth from 48 to 7 rkm per day. The occurrence of this phenomenon in the reservoir in itself does not create any hazard. It causes suspension of navigation; however it does not necessarily cause interruption of the hydropower plant operation and realisation of agreed water withdrawals.

- Occurrence of internal ice in form of frazil (drift-ice, pack-ice) and pans of frazil, which under favourable conditions developed in the free flowing water: flowing frazil or floes up to a certain degree do not necessarily present a hazard for navigation, hydropower production and water withdrawing. The frazil run can be, at the end of the winter period, accompanied by the run of ice released naturally or artificially from the upper reaches. It is well known that over some winter periods, due to climatic conditions, release and run of ice occurs on the Austrian reach of Danube sooner than on the Slovak reach, e.g., over winters 1955-1956, 1962-1963, 1963-1964, etc.

Problems occur when at the end of winter the slush ice run approaches the frizzed-up water level in the reservoir, and floes and slush balls drift under the ice cover, thus creating ice jamming and provoking the increase of water level up to flood stages. The risk of frazil development on the Danube is obvious from the amount of ice which can be created over the winter period in the river channel. Over the extreme winters 1949, 1956 and 1993, 3.6, 3.8 and 1.5 - 2.3 millions m^3 respectively of frazil having the intensity of 0.2 - 0.3 passed through the Bratislava cross-section.

However, occurrence of ice phenomena in the free, unimpounded reach of the Danube considerably decreased in the last years due to climatic and anthropogenous factors. This is evident from the statistical survey presented in Tab. 6, where variations in the ice phenomena occurrence over the period 1901-1990 are evaluated on gauging stations Vienna, Bratislava, and Komárno (ref. 14). It reflects changes after 30-year periods. The evaluation based on 15 and 10-year periods shows even more clearly the decrease of ice phenomena occurrence in the concerned reach. Thus also, the probability of hazardous ice jams occurrence, caused by slush ice running into the frozen water of the Čunovo reservoir and the potential risk of winter floods jeopardising Bratislava has decreased.

The solution of critical situations consists in providing successive ice run through the Čunovo complex of structures down to lower river sections while maintaining continuous ice cover in the reservoir and in the headwater canal. Ice breakers create an ice free trench, through which ice floes and balls of frazil are shifted, by means of manipulation of the Project structures, into the old Danube channel through the bypass weir and the inundation weir. Realisation of these operations is possible when adequate water velocities exist to ensure the ice transport into the headwater section close to the weirs, when optimum amounts of water necessary for conveying the accumulated ice are available and when there is sufficient water in the inundation weir basin.

Equally important is the full efficiency of Project structures. The Provisional Rules of Operation, Up-dating III define the operation control in winter period for the current state of completion of the Project. This is shown in Table 6.

Table 6

Y	period	Vienna			Bratislava			Komárno			
		ice	%	freeze -up	ice	%	freeze -up	ice	%	freeze - up	*
30	1900/01-1929/30	23	76	2	25	83	5	25	83	7	
	1930/31-1959/60	23	76	3	26	86	7	26	86	8	2
	1960/61-1989/90	16	53	1	15	50	1	20	67	2	7
15	1900/01-1914/15	12	80	1	13	86	3	13	86	4	
	1915/16-1929/30	11	73	1	12	80	2	12	80	3	
	1930/31-1944/45	14	93	2	14	93	4	14	93	5	
	1945/46-1959/60	9	60	1	12	80	3	12	80	3	2
	1960/61-1974/75	11	73	0	8	53	1	11	73	2	3
	1975/76-1989/90	5	33	1	7	46	0	9	60	0	4
10	1900/01-1909/10	8	80	1	8	80	3	8	80	3	
	1910/11-1919/20	8	80	0	9	90	0	9	90	2	
	1920/21-1929/30	7	70	1	8	80	2	8	80	2	
	1930/31-1939/40	10	100	1	10	100	3	10	100	2	
	1940/41-1949/50	8	80	2	8	80	2	8	80	4	
	1950/51-1959/60	5	50	0	8	80	2	8	80	2	2
	1960/61-1969/70	8	80	0	5	50	1	8	80	2	2
	1970/71-1979/80	4	40	0	5	50	0	6	60	0	3
	1980/81-1989/90	4	40	1	5	50	0	6	60	0	2

Legend:

Y	-	years
ice	-	number of winters, during the period, when any form of ice phenomena occurred
%	-	percentage of ice occurrence during the period
freeze-up	-	number of winters, during the period, when ice phenomena accompanied with freeze-up occurred
*	-	number of dams in operation in Austria

3.2 Principles of manipulation under winter regime

The rules of operation (ref. 5) envisage four possible scenarios for the winter operation of the Project.

The first scenario envisages manipulation in the situation where the reservoir and headwater canal are free of ice cover, but an ice run from the upper reach is expected. By means of manipulation of the structures, the water level is set up to the elevation 131.0 m asl. The inflow into the reservoir is continuously distributed between the bypass weir and the hydroelectric power plant Gabčíkovo. At the discharges in Bratislava Q > 1500 m^3/s also the weir in inundation is put into operation. When the ice enters the headwater canal and a continuous ice cover develops the navigation is suspended. Inflow discharges up to Q < 4000 m^3/s are utilised to the maximum extent in the hydroelectric power plant and discharged through the bypass weir; at higher Q, also through the weir in inundation. After ice run termination the navigable route is cleared in the reservoir and headwater canal, and then the navigation is restored.

The second scenario envisages the occurrence of frazil in the reservoir and headwater canal, and subsequent development of ice cover. The navigation is maintained by means of ice breakers or is eventually suspended. The distribution of the inflow discharge into the reservoir is similar as in the foregoing scenario. The navigation is restored after natural or artificial (by ice breakers) breaking of ice cover and ice clearing.

The third scenario assumes complete freeze-up in the reservoir and headwater canal, accompanied by the continuous transport of ice from the upper reach. Navigation is stopped. The ice float is directed by the ice cover towards the bypass weir and weir in inundation. The area upstream of the weirs is cleared by means of ice breakers and the ice floes are floated with interruptions. The inflow discharge up to 1500 m^3/s is divided between the hydroelectric power plant and the bypass weir, or, eventually, the weir in inundation. After the end of ice run and the ice cover breaking and ice clearing, the navigation is restored.

The fourth scenario assumes the most unfavourable situation, when an ice barrier develops at the end of backwater, downstream of Bratislava, as a result of ice jamming. Water level at the bypass weir is increased to maximum operation level and is maintained until the disintegration and releasing of the barrier. The water inflow into the reservoir is continuously distributed between the hydroelectric power plant and the bypass weir. At the discharge $Q > 1500$ m^3/s the weir in inundation is also put in operation. The release of water through the navigation locks is not envisaged. The navigation is restored after ice cover disintegration and ice clearing.

From the more than 50-year experience gained in operation of the Danube river projects in Austria and Germany, it follows that, if conditions allow, development of a continuous ice cover is accepted. As a principle, it is not broken by ice breakers, in order to prevent further ice formation. It is true that this leads to suspension of navigation; however it enables almost trouble-free operation of hydroelectric power plants and simultaneously reduces the risk of ice jam formation. Since on the whole German and Austrian stretch of the Danube this manner of operation is preferred to the artificial maintaining of navigation, there is no reason not to accept this principle also for the Gabčíkovo Project. That is why the Provisional Rules of Operation do envisage also the suspension of navigation as a normal part of a mode of winter operation.

3.3 Estimation of the winter operation over the period 1992-1994

Only two months after the putting of the Gabčíkovo Project into operation by means of the provisional solution, it was necessary to apply the manipulation mode under the winter regime. The winter season 1992/93 may be characterised as mild, with ice occurrence close to the banks and frazil run of low intensity during the first half of January 1993. This situation occurred again in the first half of February 1993, causing no problems on the free stretch of the river. Total duration of those phenomena was 13 and 17 days respectively. Situation on the Váh river (tributary) was similar. Continuous ice cover developed only far downstream, on the river Hron mouth, and on the river Morava, 30 rkm upstream of its confluence with the Danube. Breaking and drifting of the ice cover of the Hron and Morava rivers did not cause any difficulties in the Danube.

The situation on the Gabčíkovo Project developed as follows:

- The inflow discharge into the reservoir from the 1st to 7th January 1993 was in the range 958.0 to 1225 m^3/s . From 7th to 8th January it increased by 500 m^3/s, to 1627 m^3/s (+64 cm on the gauge station Bratislava-Devin). On the following day it had risen by 1000 m^3/s, to 2673 m^3/s (+121.0cm). The wave culminated on 9th January at 337 cm at the gauge station Bratislava, which corresponds to the discharge of 3029 m^3/s. After two days duration of a discharge exceeding 2500 m^3/s a drop by 600 m^3/s occurred and in the ensuing ten days the discharges remained in the range 1770 to 1397 m^3/s. On the last two days in January the discharge increased again by 600 m^3/s, and in the first 6 days in February, when ice phenomena occurred, the discharges were 1749 to 1407 m^3/s. The course of discharges and ice phenomena occurrence are presented in Fig. 1.10.

- Due to climatic and flow velocity conditions, ice began to develop in the reservoir and headwater canal on January 3rd, and successively continuous ice cover was formed. The ice occurred also on the left bank of the navigation cunette. The navigable route was maintained with an ice breaker till January 7th, when the ice continuously floating in created a barrier in the 13th rkm of the navigation cunette. The navigation was interrupted.

The situation corresponded more or less to that envisaged in the rules of operation under the third scenario. The operation of the hydropower plant continued, as well as ice floes discharging through the bypass weir, up to the value 610 m^3/s. When the discharge through the Bratislava cross-section exceeded 2500 m^3/s, 10 weir sluices of the weir in inundation were put into operation. The frazil ice float through the Bratislava cross-section was interrupted on January 9th but on 11th January the barrier was broken. Seven days later on 14th January the navigation was restored.

No ice phenomena occurred in the following winter 1993/94 in the free water course and the Project operation was trouble free. This has been the case also during the winter season 1994/95.

For the Project operation after the completion of the 2nd stage of construction of Variant "C", an up-dating of manipulation mode for the winter period is assumed on the basis of experience achieved hitherto and additional model studies (refs. 3, 6). Changes should deal with intensive frazil run requiring continuous discharge of frazil through the Čunovo complex of structures. In contrast with presently applied principles it has been recommended tó provide frazil discharge through a trench, almost as wide as the original Danube channel at a continuous cover having a thickness not more than 15 cm. For this mode of frazil discharging, it would be eventually required to open the weir gates during the whole period of ice and frazil run with corresponding reduction of the electrical production in Gabčíkovo power plant. The use of ice breakers is assumed for assuring the transport (shift) of broken ice from critical places (where low velocities exist). After successful completion of this operation the normal operation will be restored. The ice in the headwater canal, in the lower part of the reservoir, and in remaining parts of the reservoir upstream of Čunovo will gradually melt according to climatic conditions.

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Fig.1.1 Drop of low-flow (approx. 1000 m3/s) water level in the Danube between Greifenstein and Bratislava during period 1956 - 1985

(water level of the Danube Commission)

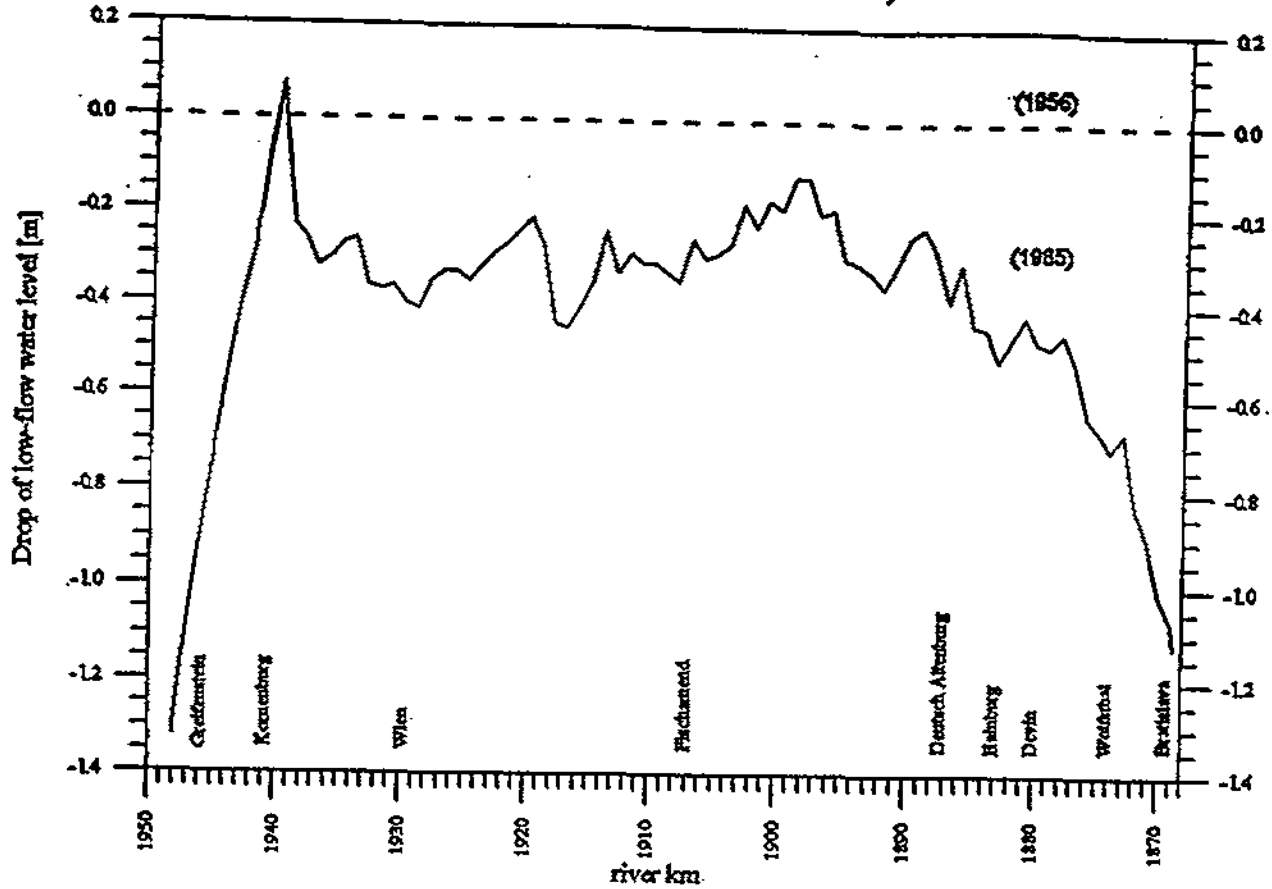


Fig.1.2 Global annual volume of dredged sediments from the Danube (ford dredging and industrial dredging)

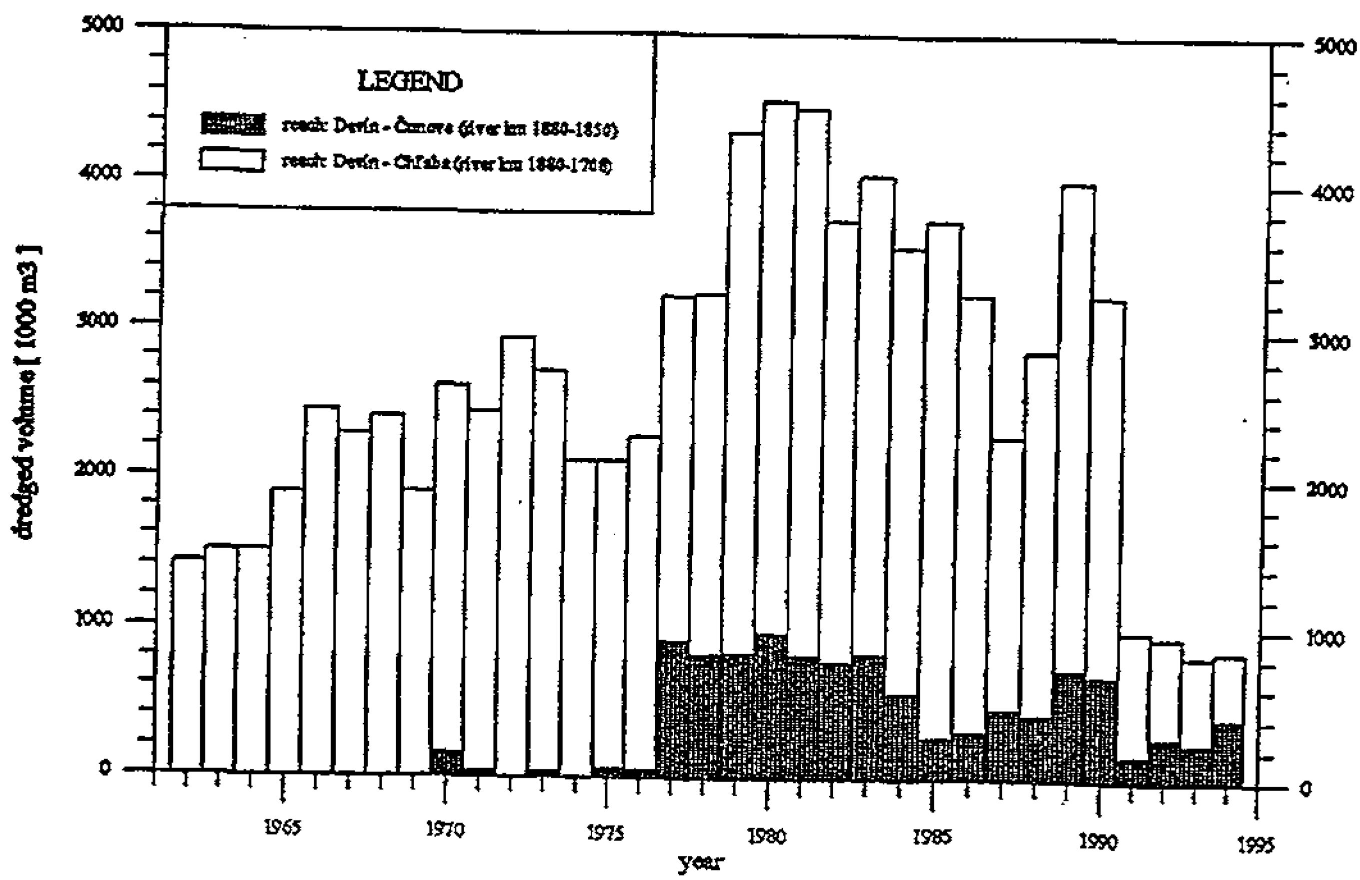


Fig.1.3 Drop of low-flow (approx. 1000 m3/s) water level in the Danube between Devín and Chľaba during the period 1957-1994

(water level of the Danube Commission)

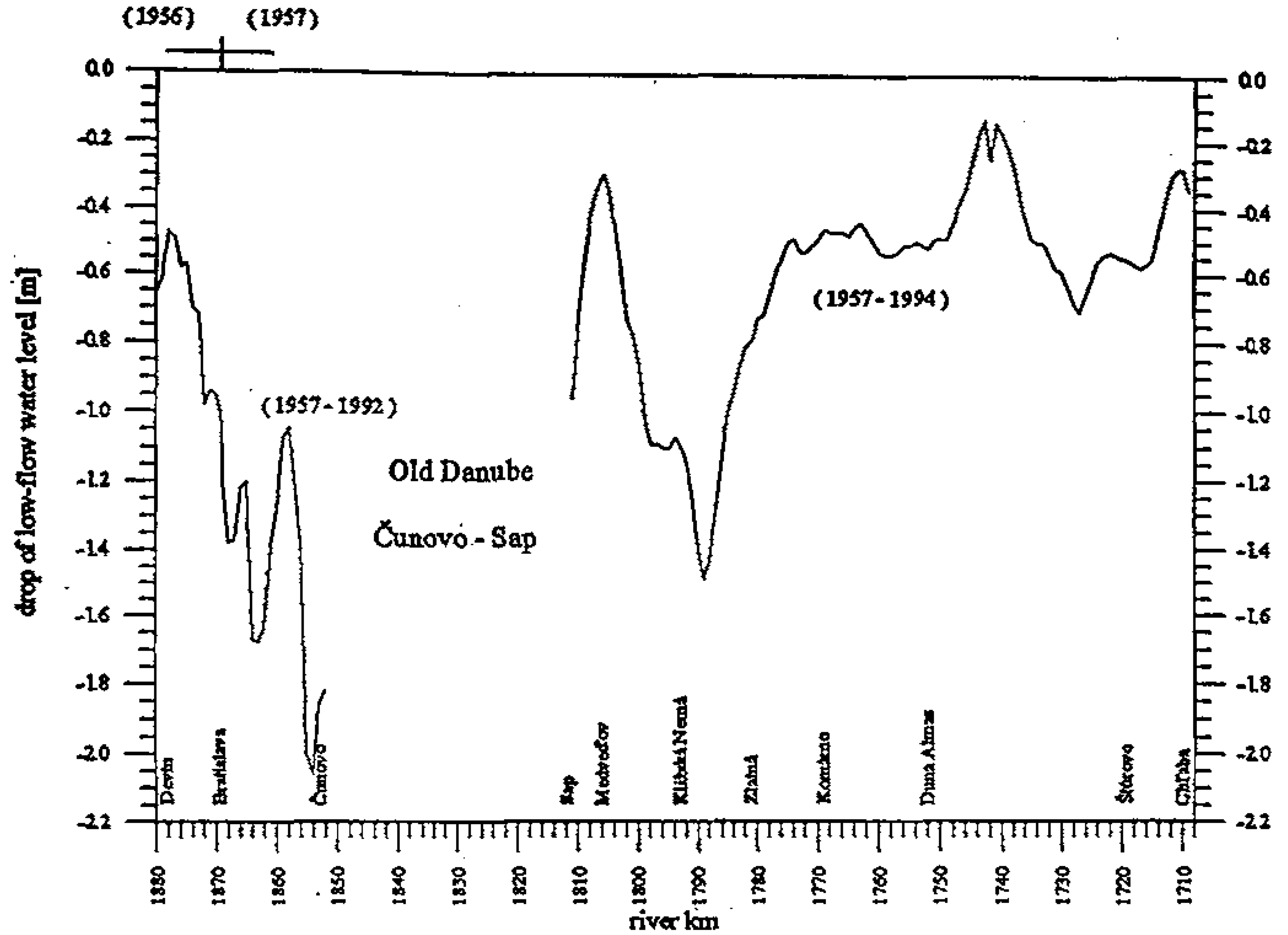


Fig.1.4 Probability curves of the Danube water stages in the Rusovce gauging station (river km 1855,90)

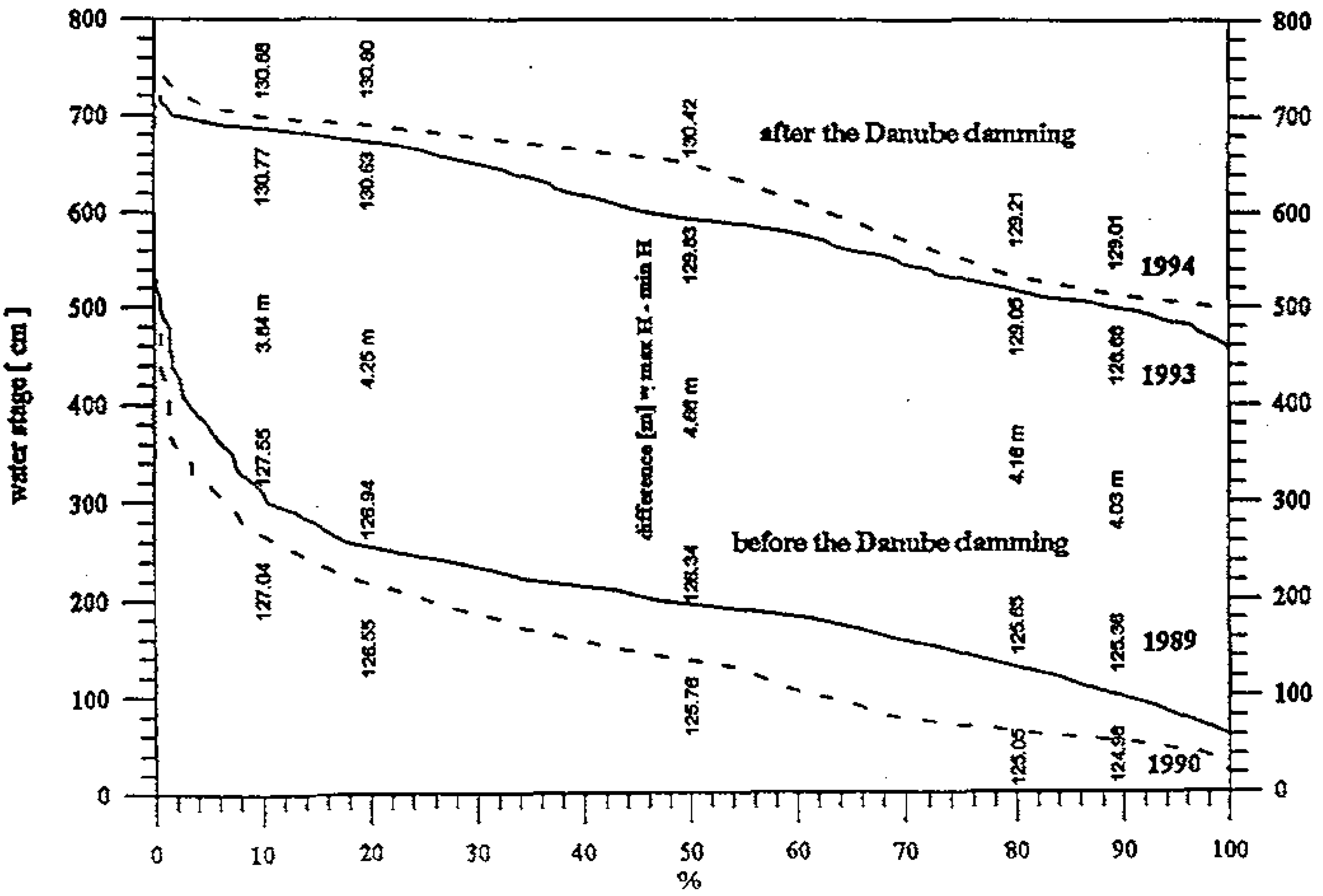


Fig.1.5 Deformations of the Danube river bed between Devín and Čunovo since 1991 - 1994

(under water level of the Danube Commission)

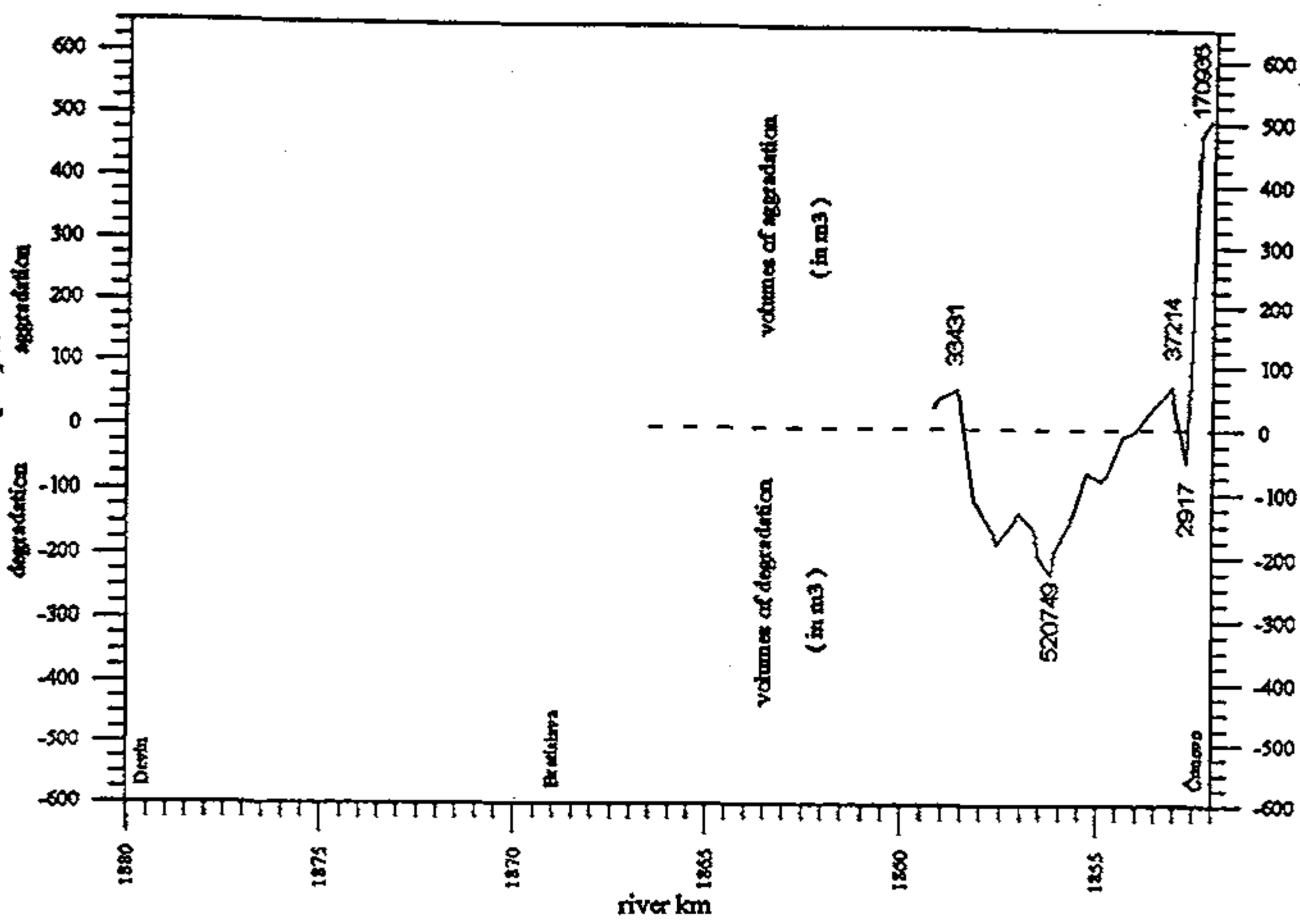


Fig.1.6 Deformations of the Danube river bed between Gabčíkovo and Klížská Nemá since 1992/93 - 1994

(under water level of the Danube Commission)

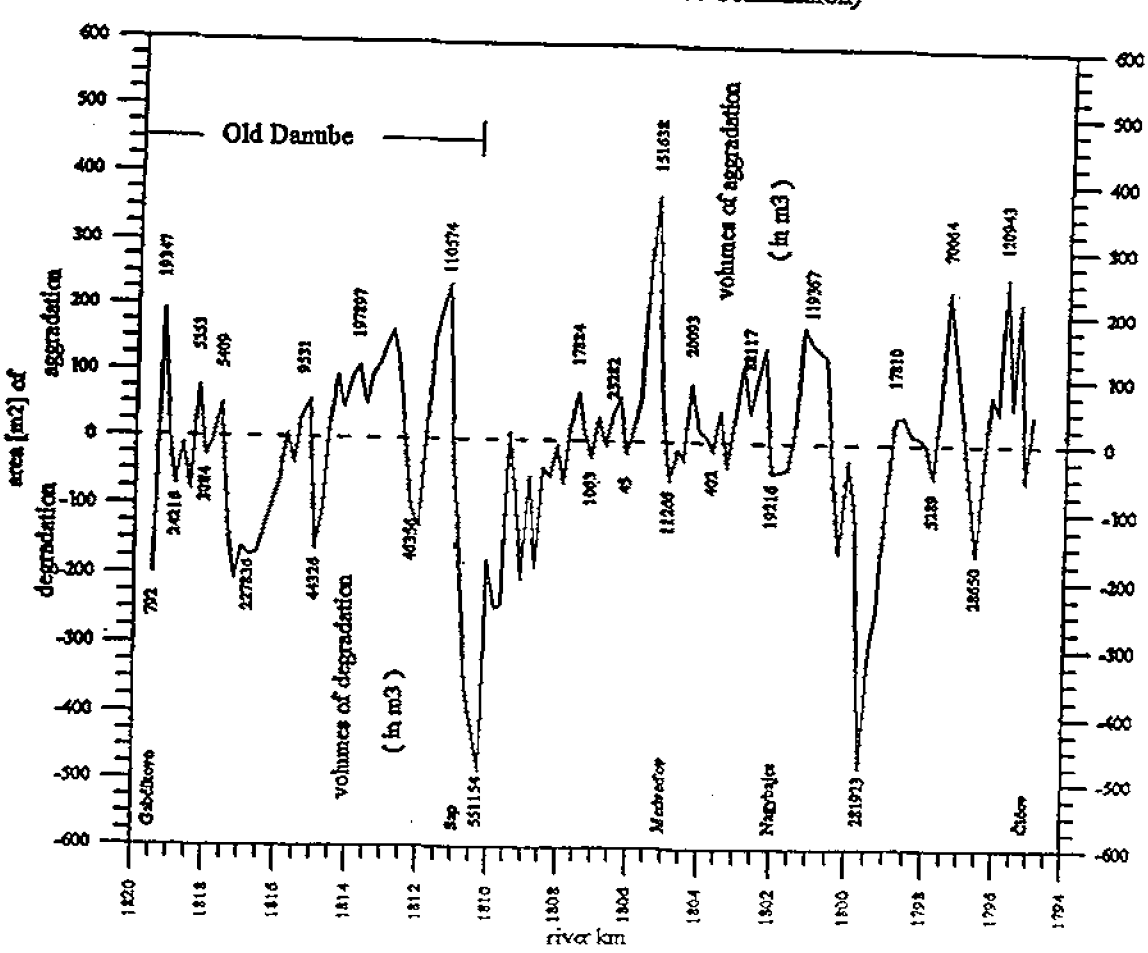


Fig.1.7 Change of low-flow (approx. 1000 m3/s) water level in the Danube between Devín and Chľaba during the period 1992-1994

(water level of the Danube Commission)

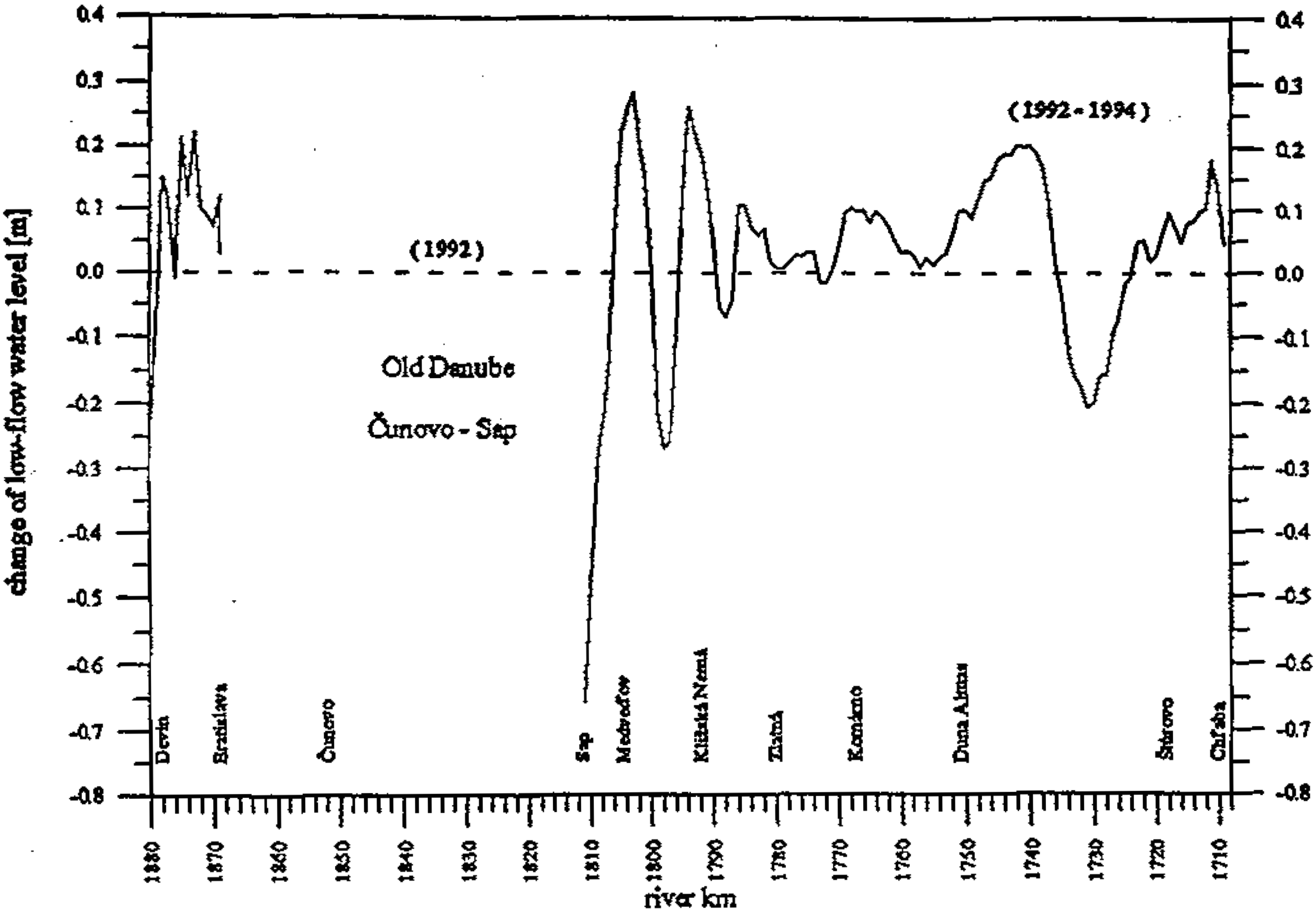


Fig.1.8 Width of the river bed 2.7 m under the water level of the Danube Commission (VUVH, 1993)

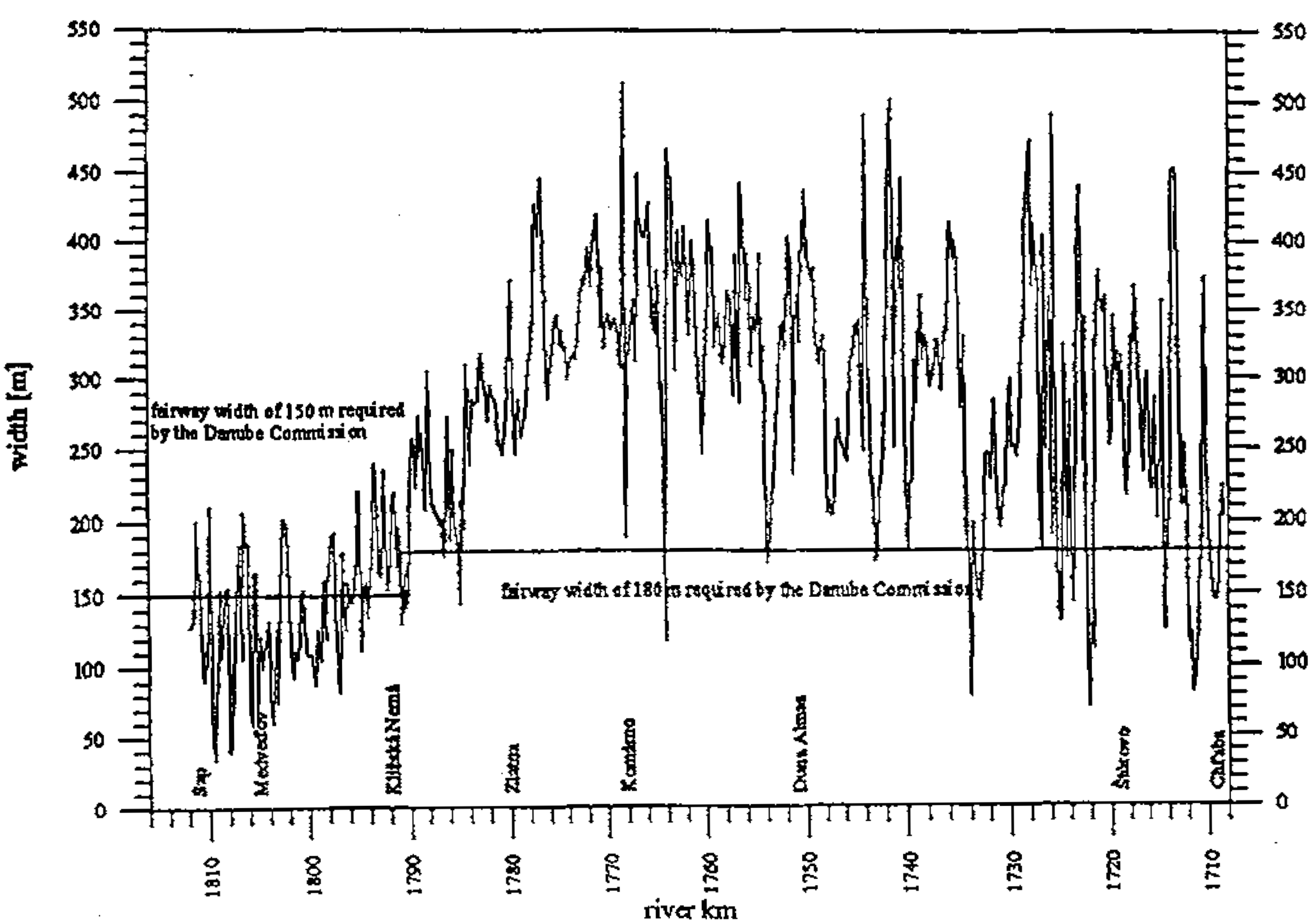
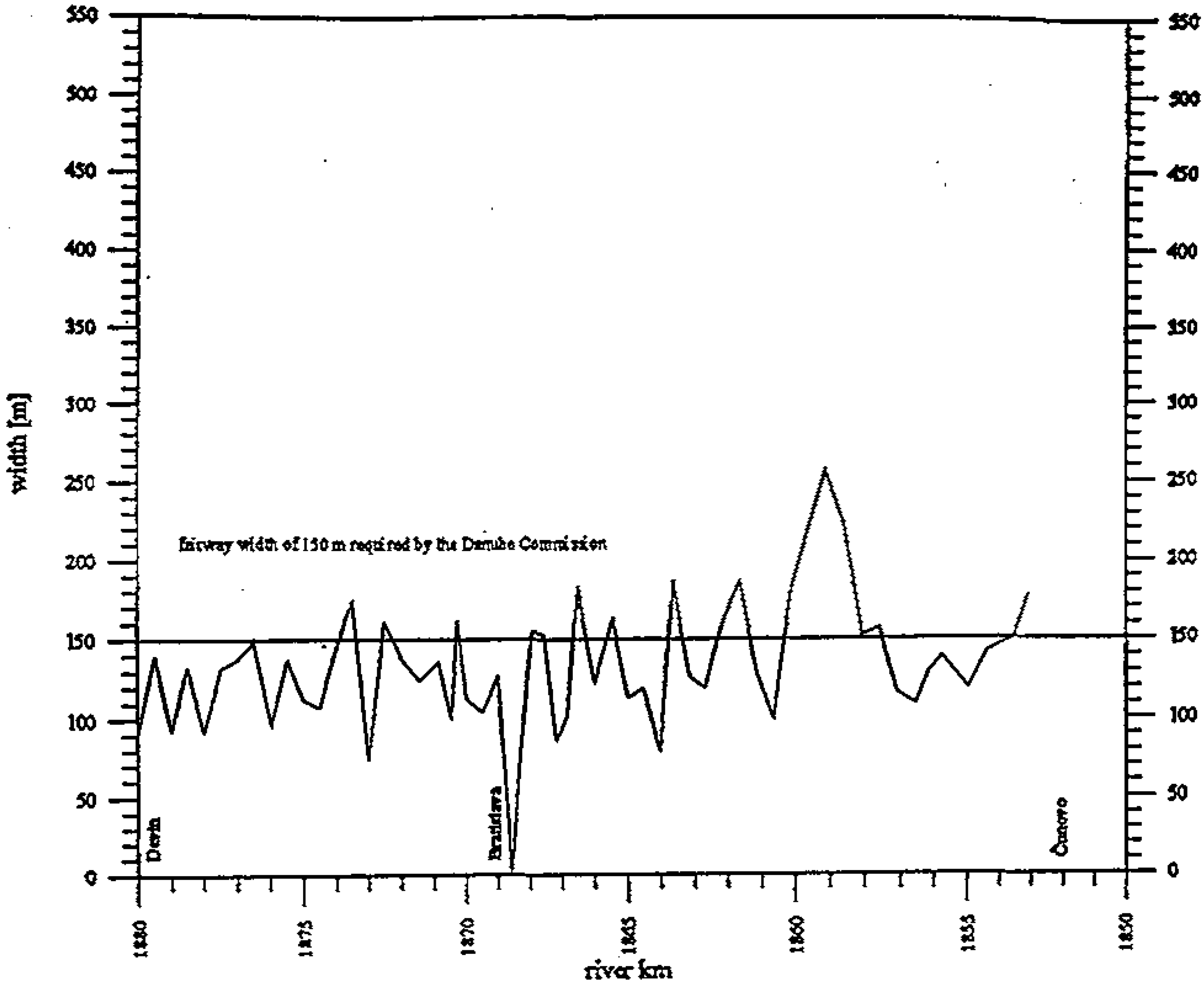


Fig.1.9 Width of the river bed-2.5 m under the water level of the Danube Commission (VUVH, 1992)



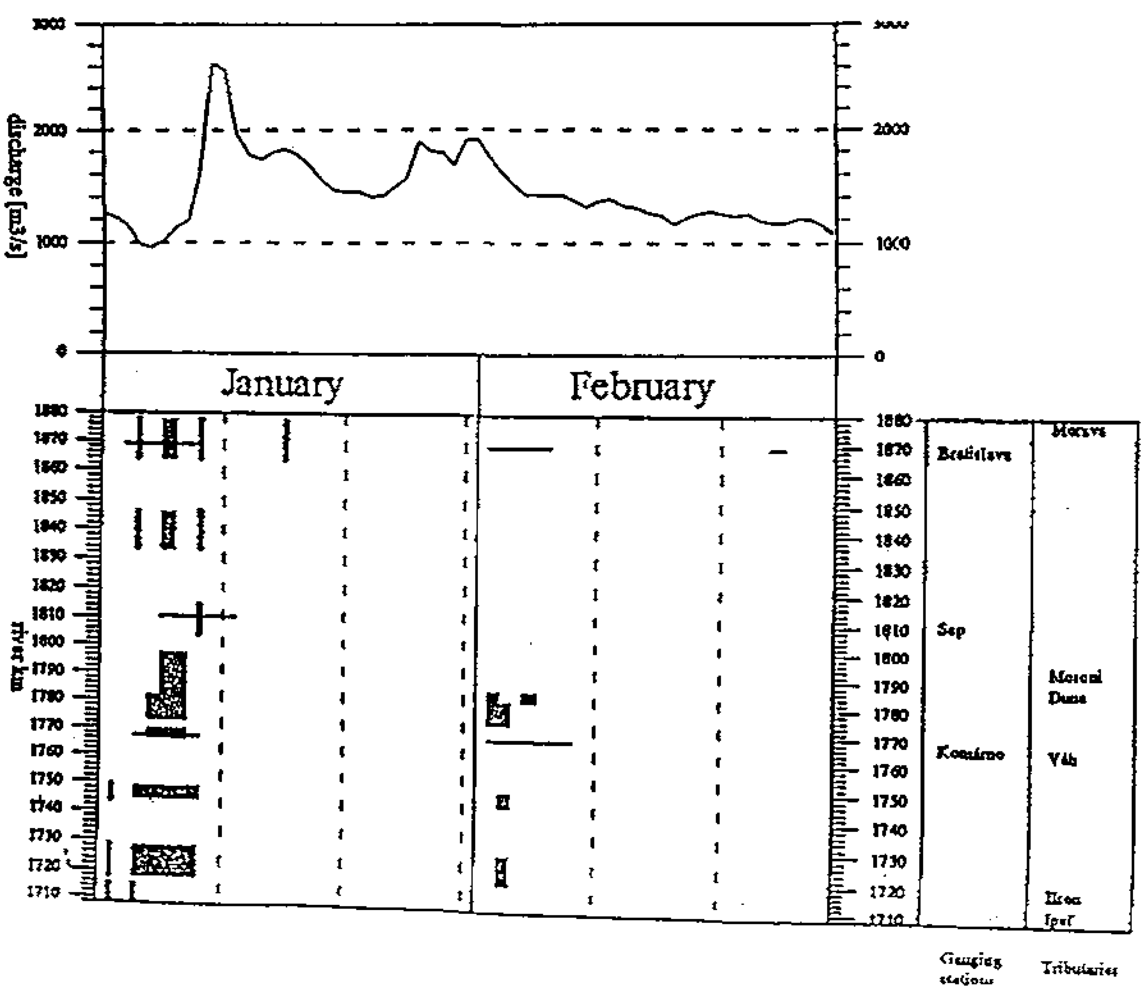
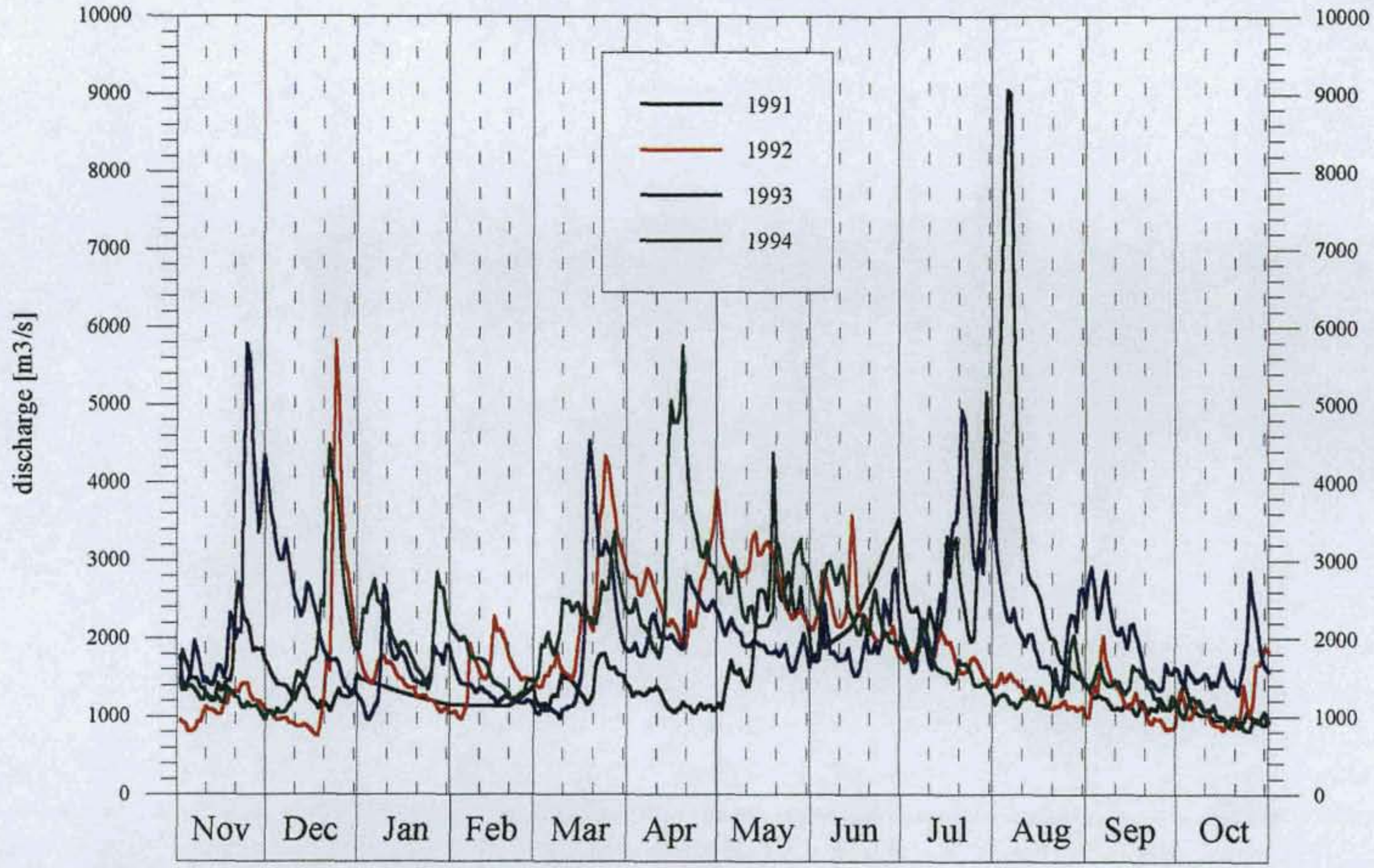


Fig.1.10 Ice regime of the Danube over the winter period 1993

Fig. 1.11 Danube river hydrograph

gauging station: Bratislava - Devín



CHAPTER 13. ELECTRICITY PRODUCTION : EVALUATION OF THE RESULTS OF THE OPERATION OF THE GABČIKOVO HYDROPOWER PLANT (1993 - 1994)

F. Čičik

April 1995

July 1990 was the date agreed by Czechoslovakia and Hungary for the commencement of the exploitation of the energy capacities of the G/N Project. Due to the suspension and following abandonment of works on the Project by Hungary, the first aggregate of the hydroelectric power plant in Gabčíkovo was put into test operation only in late October 1992. Thus a considerable loss of energy production planned for the electrical systems of both countries has occurred.

Due to the non-realisation of the Nagymaros step, 158 MW of installed output and delivery of 1025-1040 GWh has been lost from the energy balance. A further important impact consists in the fact that, due to the non-existence of the Nagymaros reservoir, the hydroelectric power plant Gabčíkovo cannot be operated in the peak mode. Thus around 1525 GWh/year of peak energy, and 810 GWh/year of semi-peak energy are lost, being replaced by the production of the base-energy.

The non-realisation of the Nagymaros part of the Project and the non-execution of the deepening of the Danube's river bed downstream of Sap/Palkovičovo result in a higher water level below the Gabčíkovo hydropower plant and, accordingly, in the decrease of the head (the distance by which the water falls) by about 1 m. Each metre of head lost (at an annual average discharge through the Gabčíkovo power plant equal to 1824 m^3/s) represents an annual production loss of around 140 GWh, which compares approximately with the production of an average hydropower plant on the river Váh (e.g., Kraľovany hydropower plant has an annual production of around 115 GWh).

The prolongation of the headwater canal, or rather the modification of the reservoir (under Variant "C"), causes further hydrodynamic losses in the headwater canal as compared to the agreed Project. There is a decrease of water slope in the headwater canal and also a limitation of manipulation possibilities of the hydropower plant.

The increase of the water discharge into the old Danube river bed from the reservoir as compared to the values agreed in the JCP represents, for every 100 m^3/s, the reduction of electricity production of about 150 GWh/year.

The actual mode of operation of the hydroelectric power plant Gabčíkovo, so-called "imposed operation" in the regime of the water level regulation, has also necessitated the alteration of the concept of the control room system of the power plant. The operation in the so-called "imposed regime" means that at every moment the whole flow of water must be used for energy generation, which complicates the functions of the control room of the electricity system. Unexpected changes in consumption (electricity demand) can coincide with sudden changes in discharge (the discharge in the Danube in Bratislava is affected also by the operation mode of the hydropower plant in Greifenstein - Austria). The safe operation of the electricity system requires, nevertheless, permanently balanced sources and consumption.

The change of operation mode of Gabčíkovo power plant resulting from the non-realisation of the Nagymaros part of the Project raised several problems which required consideration, among them the question of utilisation of all 8 generating sets of the Gabčíkovo hydropower plant. The experience gathered from operation, the actual stage of the generating equipment assembly/completion and the need of capacity for the evacuation of flood water through the Gabčíkovo step confirmed clearly the need for completion of all turbine-generator sets (TG-sets).

The test operation of sets TG8 - TG3 commenced on the following dates:

- TG 7 - 27.10.1992
- TG 4 - 6.11.1992
- TG 8 - 30.11.1992
- TG 5 - 11.01.1993
- TG 6 - 21.01.1993
- TG 3 - 13.01.1994

These TG-sets were put into "imposed operation" under the direction of the control room SEP-VET. Thus the installed capacity of the hydropower plant Gabčíkovo has reached 6 x 90 = 540 MW.

During the year 1994, following the decision to complete also remaining sets TG 1 and TG 2 whose assembly was earlier interrupted, the contract with ČKD Blansko was amended and the following dates for the termination of comprehensive operation tests are envisaged:

- TG 2 - 06/95
- TG 1 - 10/95

In 1994 the operation of the hydroelectric power plant has been unfavourably influenced by low water levels in the headwater canal (causing lower fall), which adversely affected the production of electrical energy (reduction of about 10-15%). The survey of production of the electrical energy in the years 1992-1994 is shown on Fig. 4.

The "imposed operation" of the Gabčíkovo plant alone cannot remedy several inconveniences resulting from the existing control room situation for the electrical energy system of Slovakia:

The G/N Project was planned to be an important source of capacity reserve for the operation of the energetic systems of both States - Czechoslovakia and Hungary, the source of readily available output in event of sudden failures in electricity systems, the source of regulation output. This function is even more important today because the electricity systems of both countries have been integrated in the Central Electricity System of Middle Europe (which includes the Czech Republic, Hungary, Poland and Slovakia) and intend to join the (European) Union for Coordination of Production and Transmission of Electricity (UCPTE), one of the pre-conditions for which is the attainment of the capability for national electricity systems to react promptly to breakdowns in the system.

The generating sets of the Gabčíkovo power plant are conceived in such a way which enables their rapid putting in or out of operation. The activation of a TG-set takes 50 seconds and after the next 20 seconds the set can reach full capacity. De-activation from full output takes 10 seconds. It was planned that the capacity of 180 MW would be available for the purpose of covering sudden demands in the system. The hydroelectric power plant Gabčíkovo is able to fulfil the functions of primary and secondary regulation required for connection with the UCPTE.

Thanks to their capability of flexible operation, the Slovak hydroelectric power plants, including the Gabčíkovo power plant, have proved, during tests in September 1993, their ability to fulfil the required functions. The connection of Slovakia with the UCPTE is expected to be realised by 1997.

Currently, Slovakia is connected with the Czech Republic through three 400 kW power lines and two 220 kW power lines, with Hungary through two power lines, and with Ukraine through one circuit. Connections with Poland and Austria are being prepared. The overall survey of transmissions of the electric energy in 1994 is shown on Figs. 1 and 2, and transmissions through the 400/100 kW Gabčíkovo transformation room are shown on Fig. 3.

The output of the Gabčíkovo hydropower plant is realised in two tension levels: through the 400 kW switchcontrol-room (from 6 generating sets) into two power lines of Podunajské Biskupice (Slovakia) and Györ (Hungary) and from two generating sets through external 110 kW switchcontrol-room into two power lines of Dunajská Streda. Both tension systems are interconnected with auto-transformation room of 400/100 kW 250 kVA, situated in the area of the 110 kV distribution room. The 400 kV distribution room fulfils the function of the frontier distribution room.

The flows of electrical energy shown on Fig. 3 confirm the important function that the power plant Gabčíkovo fulfils in supplying the region of Southern Slovakia with electricity, but also its important role in the international transfer of electric energy.

Fig. 1 - Import, export and transition of electrical energy of the Slovak Republic

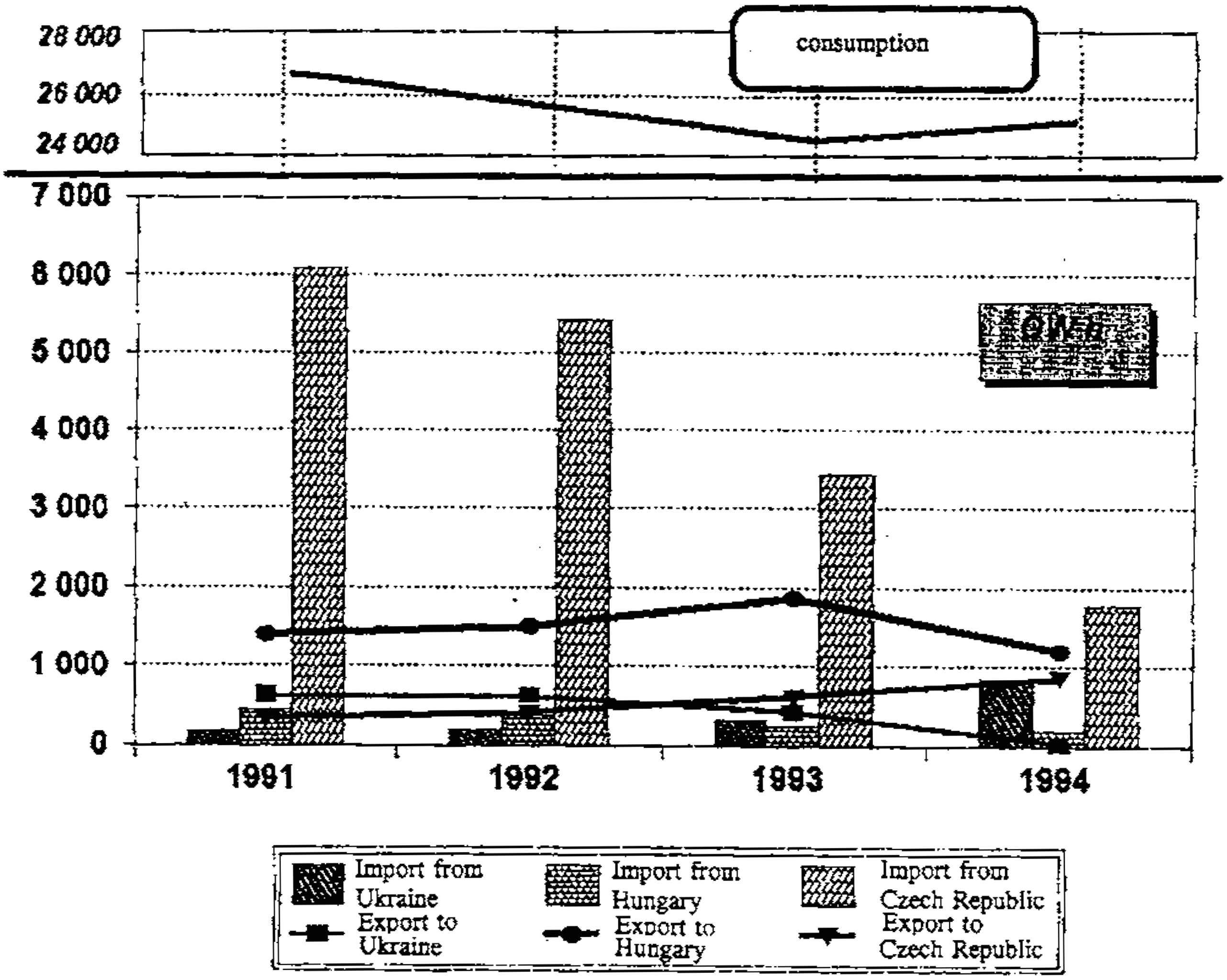


Fig. 2 - Import, export and transition of electrical energy of the Slovak Republic in 1994

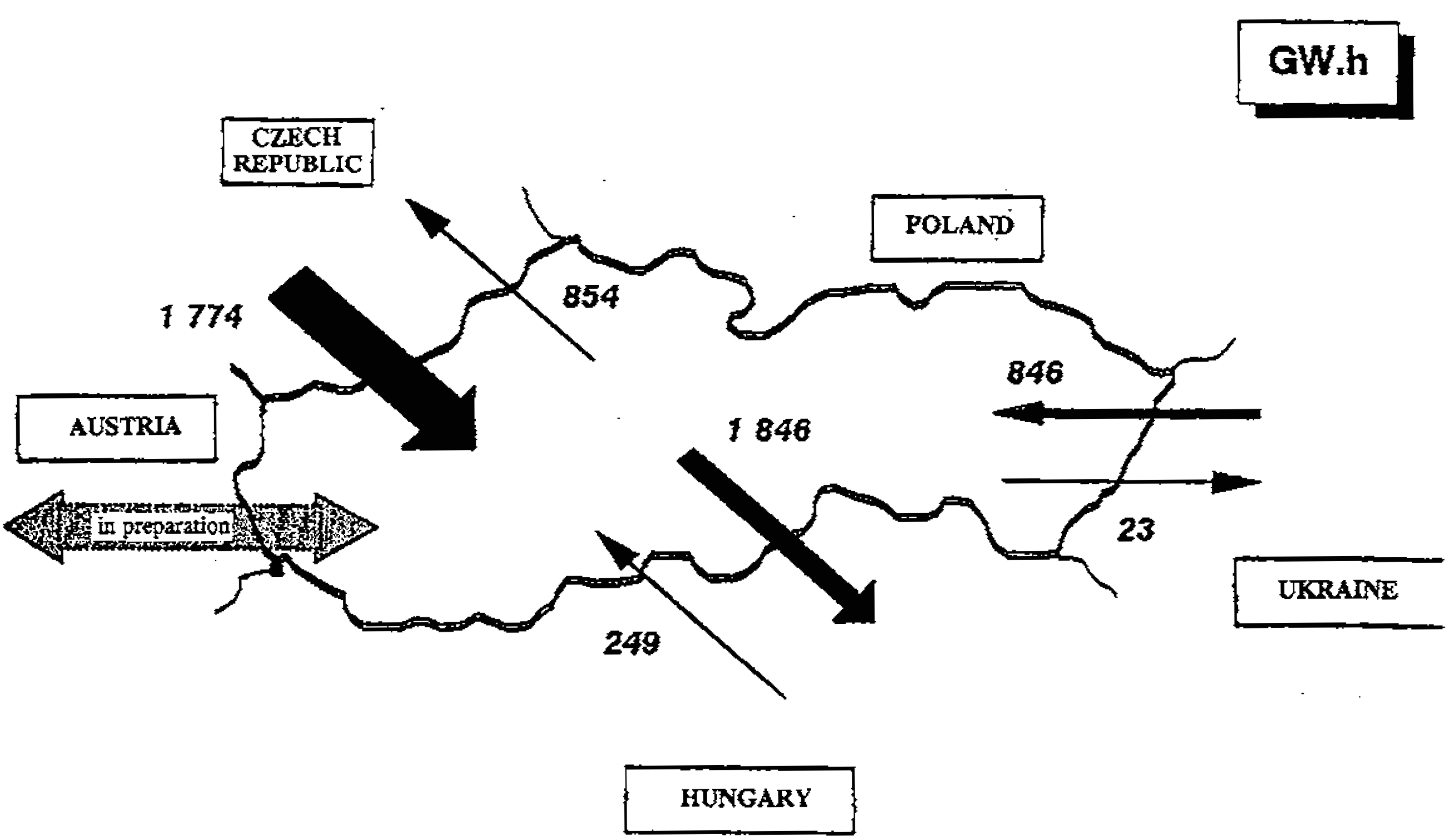


Fig. 3

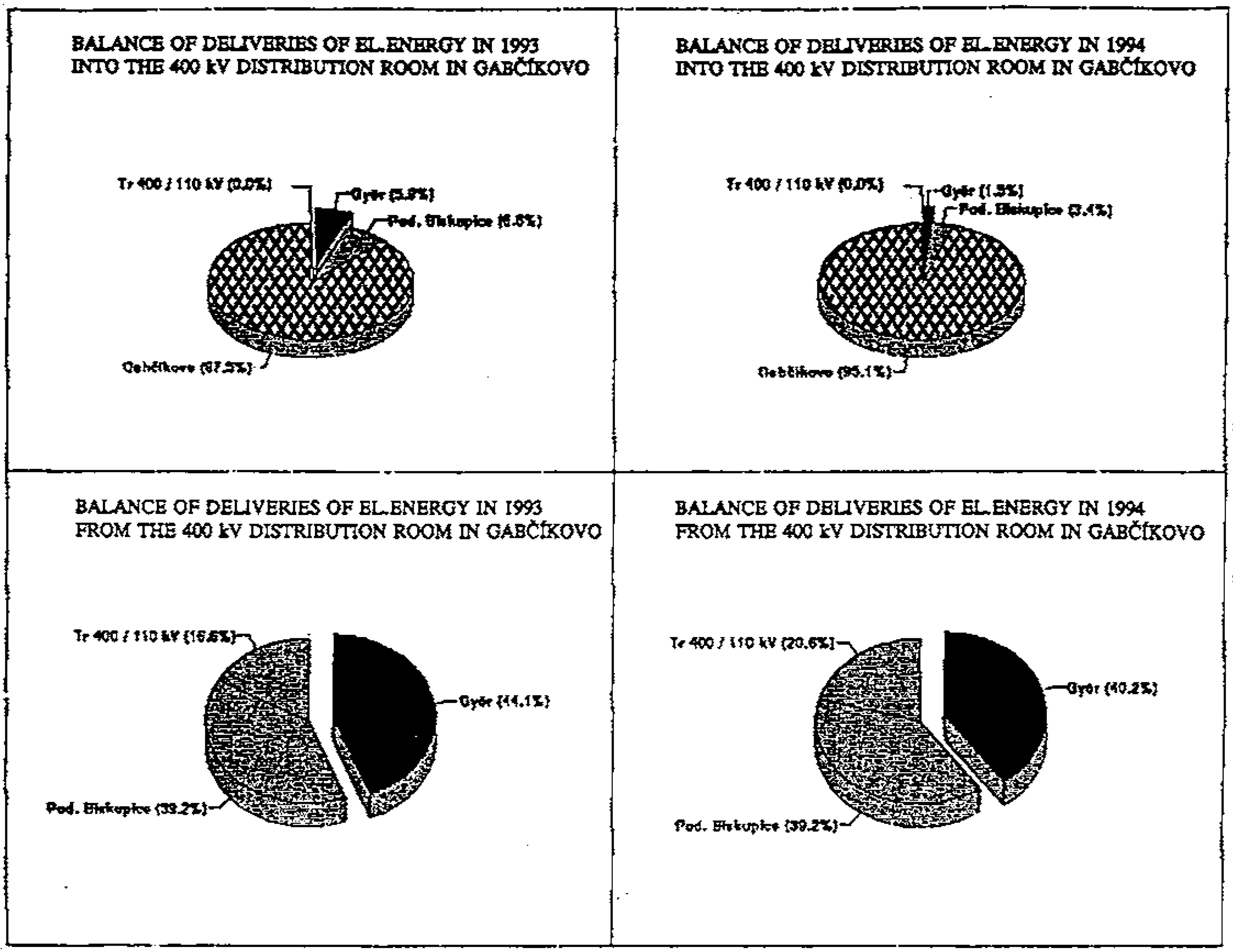
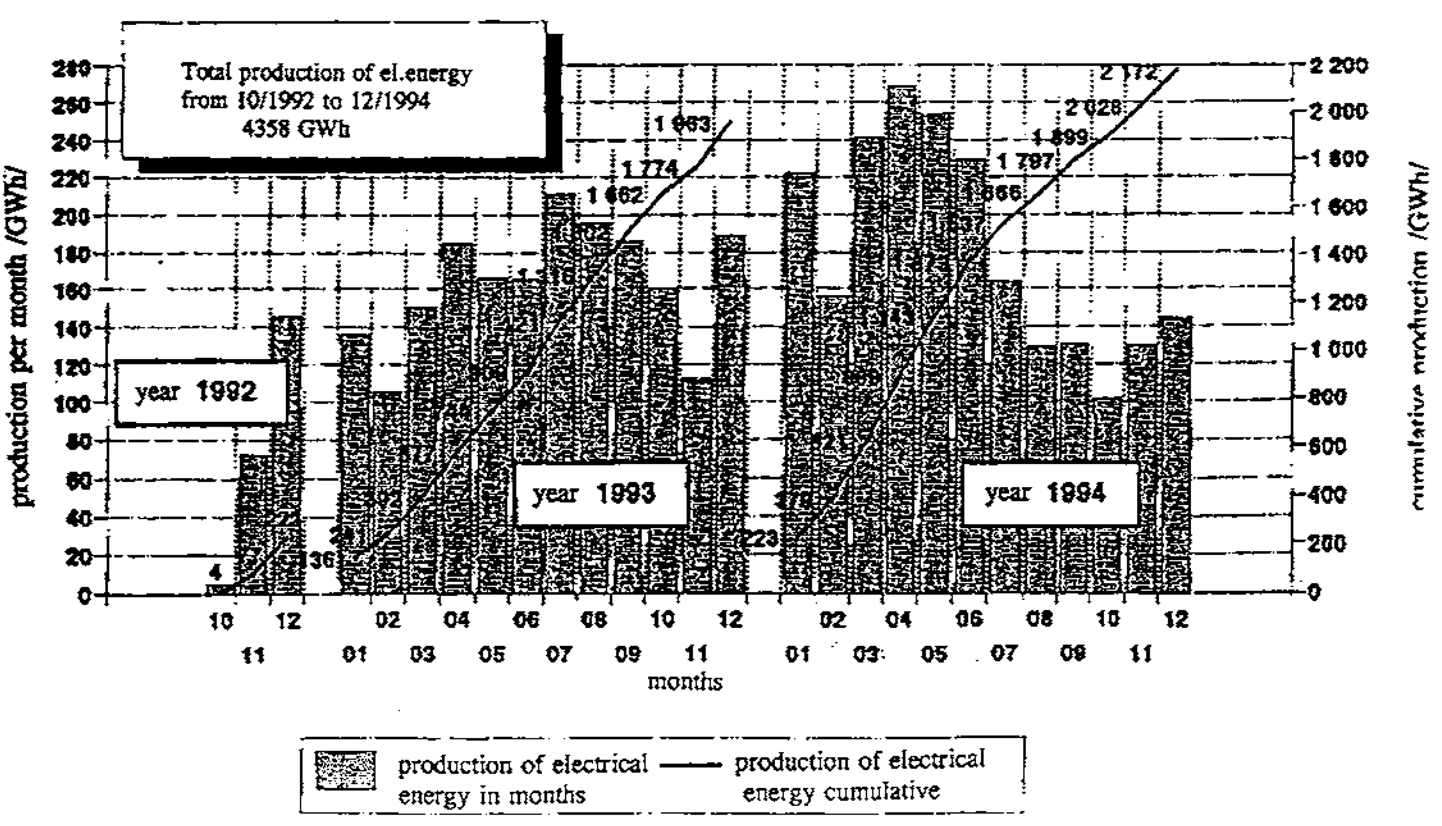


Fig. 4 Production of el.energy in hydroelectrical power plant Gabčíkovo



CHAPTER 14. NAVIGATION : TRANSPORT ON THE DANUBE AFTER THE PUTTING OF THE GABČIKOVO SECTION OF THE G/N PROJECT INTO OPERATION

P. Šesták

April 1995

At the time when the navigation locks of the Gabčikovo barrage were put into operation, Slovakia's State company for water transport, "Slovak Danube navigation", like many other Danube navigation companies, found itself in a serious situation resulting from the transformation of the economic system in the majority of the Danubian countries, which threatened its very existence. A number of national and international impacts, seemingly of a secondary character, have proved to be significant factors determining further development until the principal changes of the flows of commodity transport on the Danube take place.

It is clear from a brief inspection of the history of navigation conditions on the Slovak reach of the Danube that the date of the putting of the Gabčikovo navigation locks into operation represents the date of completion of the essential solution (optimisation) of navigation conditions in the critical sections between Bratislava and Gabčikovo (Table 1)

The statistical data on the development of ford sections on the Slovak reach of the Danube in the years 1991 - 1994, released by the Ministry of Agriculture of the Slovak Republic (Table 2) convincingly demonstrates the fact that the problem of seasonal navigation depth limitations in the section Bratislava-Gabčikovo have been solved, while the unfavourable depth conditions in the section Gabčikovo-Nagymaros, which were to be solved under the Gabčikovo-Nagymaros Project as originally planned, remain.

In order to explain the reasons why, immediately after the putting of the Gabčikovo navigation locks into operation, the volume of commodities transport in the said reach did not symmetrically increase, it is necessary to recall several important factors the result of which is the existing situation characterised by reduced load transport.

The following estimates are based on statistical data released by the Danube Commission and concern volumes of commodities reloaded in the Slovak and Hungarian ports on ships of the Danube navigation companies. This data illustrates the commodity flows from the ports through the Gabčíkovo locks, as well as the export and import of commodities through the Slovak and Hungarian ports from or to the ports on the lower Danube, or contrarily, from or to the upper Danube ports (Table 1).

The global figures of the volumes of commodities reloaded in the ports between 1987 - 1993 display the critical moments and events which have substantially influenced the development of commodities transport (Tables 3, 4 and 5).

Among the factors which have influenced the transport development in a negative sense the following must be mentioned:

- the collapse of the market of the former East-European organisation of economic integration - CMEA (COMECON), which drastically influenced the development of the commodities exchange after 1989;

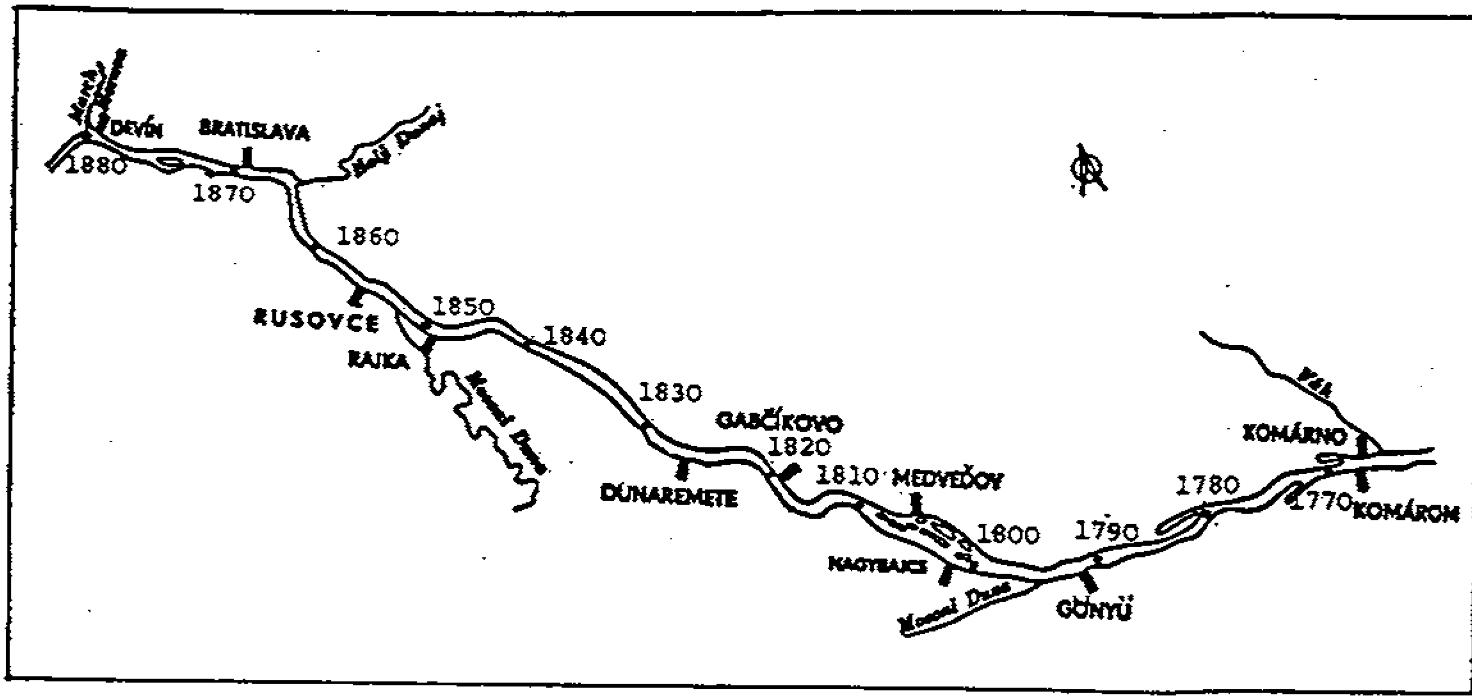
- the worldwide recession which manifested itself in its most apparent form in the former socialist countries, including Czechoslovakia, in the form of a considerable decrease of industrial production and subsequent decrease of transport demands;

- the military conflict in the Balkan region accompanied with the sanctions of the United Nations Security Council against Serbia and Montenegro (resolutions No.713/991, 757/1992 and 787/1992 and, in particular, the resolution No. 820 of April 1993) and retaliation measures by Serbia (introduction of fees on the navigation along the Serbian reach of the Danube), the result of which was a drastic decrease of the volume of commodities transport in direction towards the middle and lower Danube in the years 1992-1993.

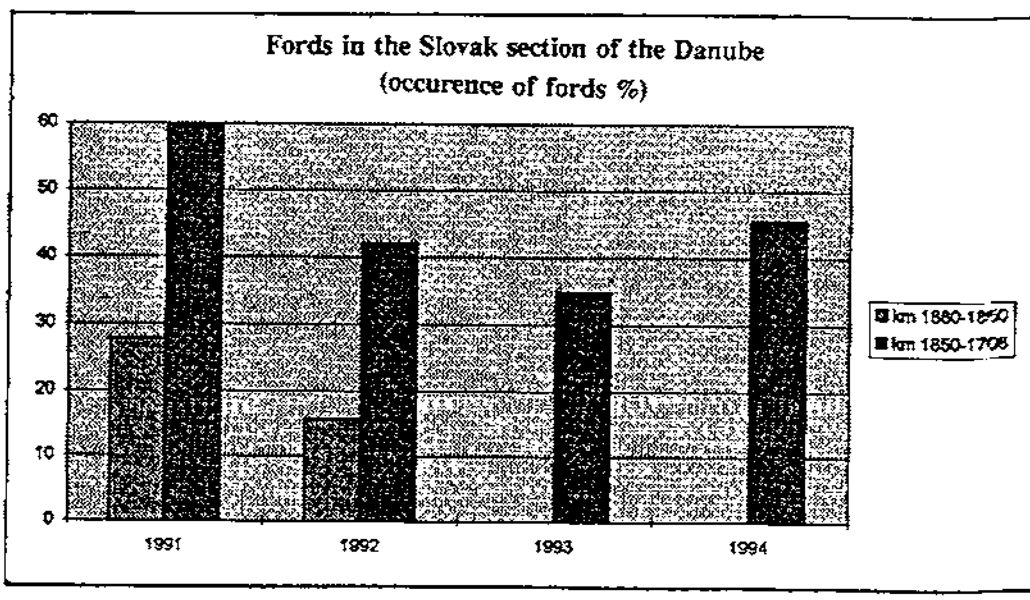
These factors resulted, among other things, in a continuous decrease of volumes of reloaded commodities registered in the years 1990-1993, apparent in particular in the Slovak ports.

By contrast, the opening of the Rhine-Main-Danube canal, at the end of 1992, represented a positive influence on the development of the volume of reloaded commodities. The connection of the Danube with the system of West-European water ways helped to stop, in the years 1993-1994, the decrease of commodities transport on the Danube. Due to the geographical position of the Slovak ports and to the composition of commodities passing through them, a gradual improvement of commodities transport was registered, in particular in the Bratislava port, and namely concerning the commodities transported from the upper Danube (without the use of Gabčíkovo locks) (Table 6).

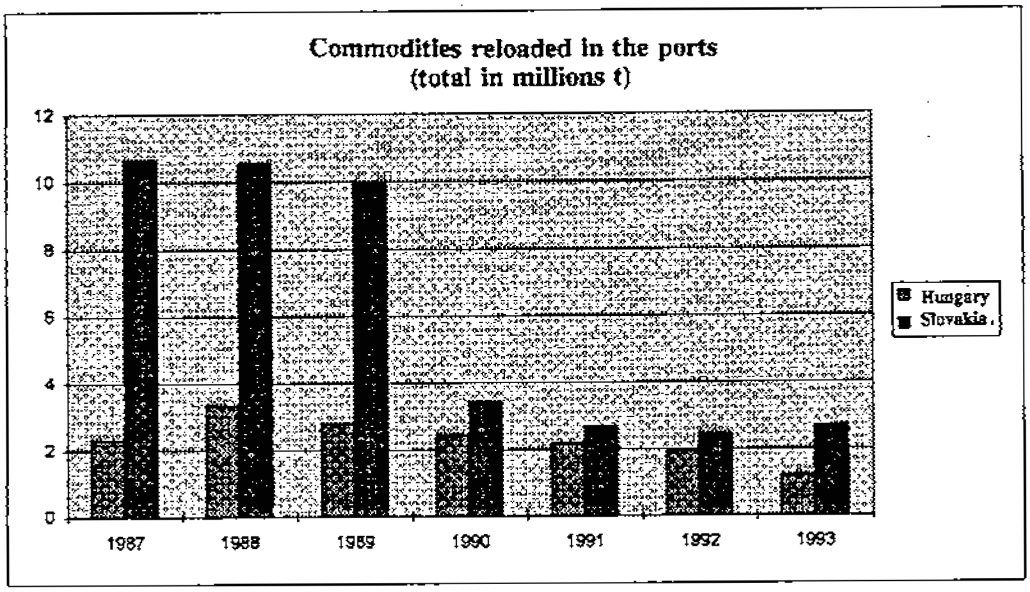
The continued deficiency of commodities transport from the lower Danube and resulting low demand for navigation through the Gabčíkovo locks is best demonstrated by the volume of commodities reloaded in the Komárno port (Table 7). At the present time, the lasting crisis in the former Yugoslavia may be recognised as the most important cause of reduced volumes of the commodities transport through the Gabčíkovo locks; its disturbing impact does not allow an optimum utilisation of the Gabčíkovo navigation facilities which are, since the partial completion of the Project, at the disposal of navigation companies of all European States.


DEVÍN
BRATISLAVA
1880
1870
1860
RUSOVCE
1850
RAJKA
1840
1830
GABČÍKOVO
1820
DUNAREMETE
1810
MEDVEĎOV
1800
NAGYBAJCS
1790
GÖNYÜ
1780
KOMÁRNO
Váh
1770
KOMÁROM

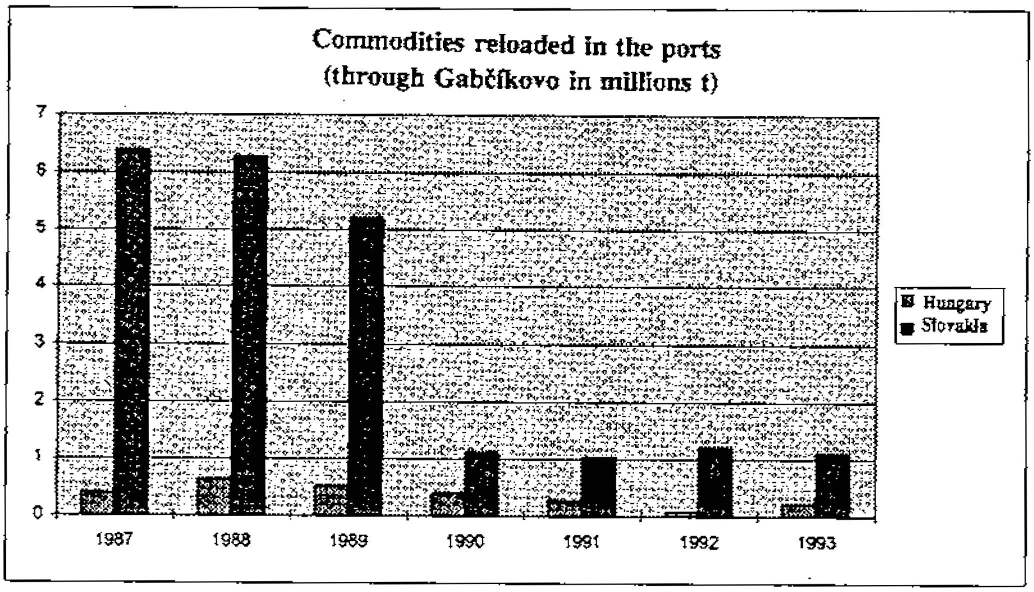
Tab. 1


Fords in the Slovak section of the Danube
(occurence of fords %)
60
50
40
30
20
10
0
1991
1992
1993
1994
km 1880-1850
km 1850-1708

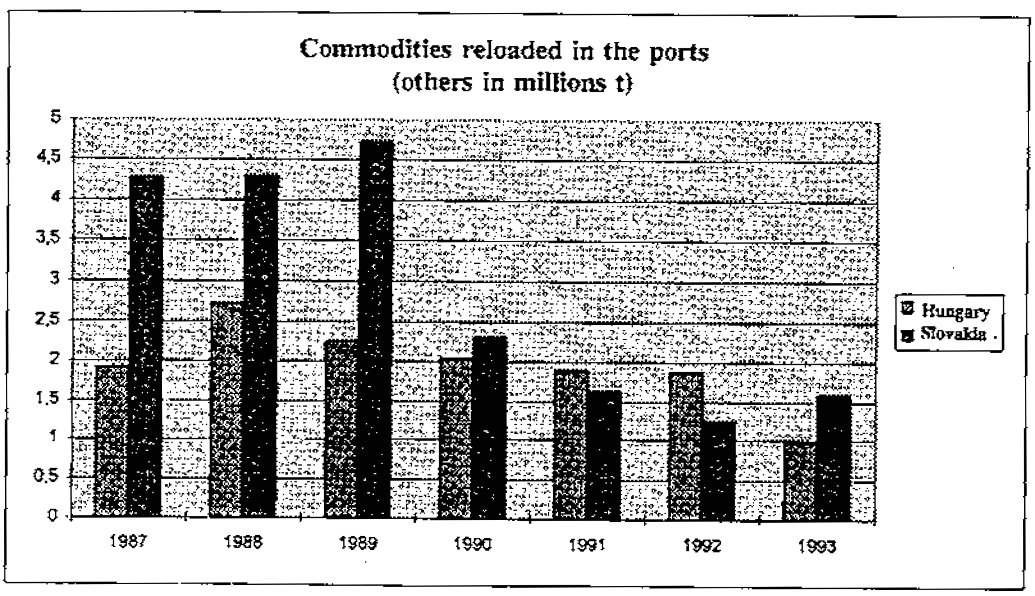
Tab. 2



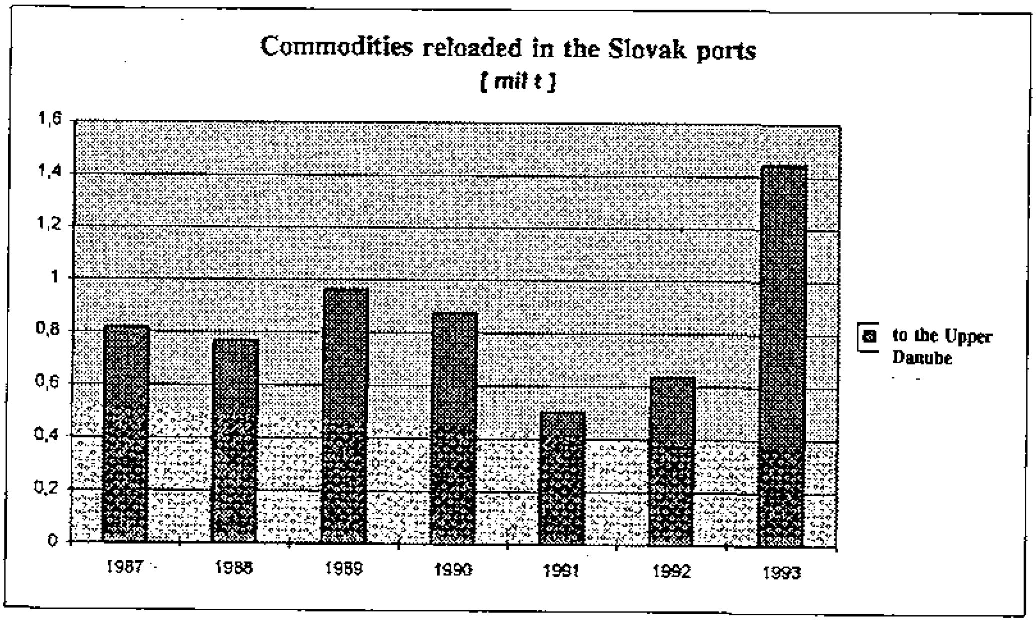
Tab. 3



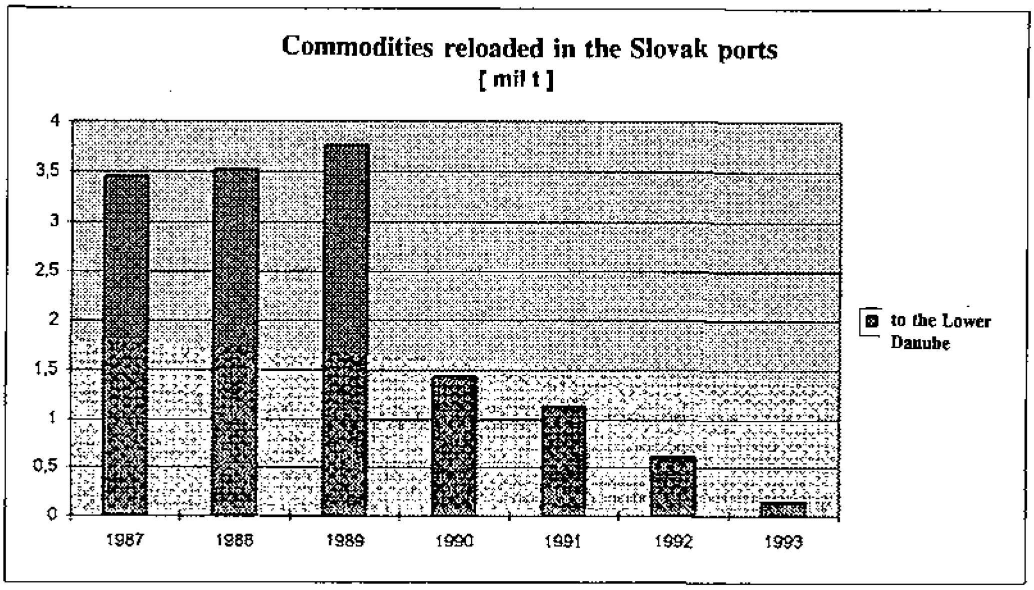
Tab. 4



Tab. 5


Commodities reloaded in the Slovak ports
[mil t]
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
1987
1988
1989
1990
1991
1992
1993
to the Upper Danube

Tab. 6


Commodities reloaded in the Slovak ports
[mil t]
4
3,5
3
2,5
2
1,5
1
0,5
0
1987
1988
1989
1990
1991
1992
1993
to the Lower Danube

Tab. 7