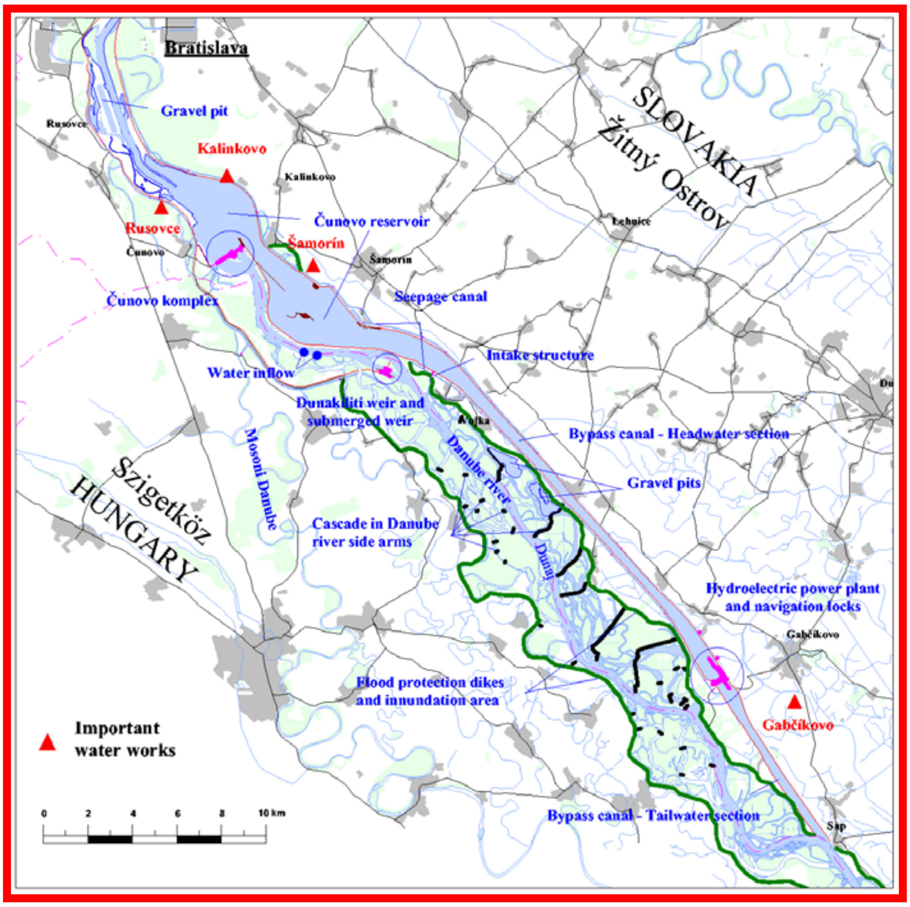
PLENIPOTENTIARY OF THE SLOVAK REPUBLIC
FOR CONSTRUCTION AND OPERATION
OF GABČÍKOVO - NAGYMAROS HYDROPOWER SCHEME

NOMINATED MONITORING AGENT OF THE SLOVAK REPUBLIC

Gabčíkovo Part of the Gabčíkovo-Nagymaros Hydropower Project

and

Joint Slovak-Hungarian Monitoring of Environmental Impact



Bratislava, October 2001

PREFACE

At present, benefiting from an extensive monitoring system that has been developed, providing as with high quality information as to the effects of the operation of the existing Gabčíkovo part of the Gabčíkovo Nagymaros Project on the environment, the situation is completely different from that which existed at the beginning of the projecting works. We have been witnesses to great progress made in knowledge, monitoring methods and technologies. The results of joint monitoring development on the basis of the Agreement between the Slovak and Hungarian Governments of April 1995 show that we are moving in the right direction - efficiently protecting and enhancing the environment at the same time that we make use of it for economic development of our countries.

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1. NATURAL CONDITIONS AND IMPORTANT STRUCTURES

1.1. DANUBE, DANUBIAN LOWLAND, GEOLOGY, HYDROELECTRIC POWER PROJECT

Danube, Donau, Dunaj, Duna, … a poetic river, reappearing in its untouched shape, accompanied by the nostalgic melody of Johann Strauss's *On the Beautiful Blue Danube* waltz. The natural evolution of the Danube and the changes resulting from a dynamic development of civilisation, along its banks contributed to the present character of the Danube, which seems to be as untouched as European nature in general.

The historical changes of the Danube system are a consequence of geological development and the often changed climatic relations during Quaternary time. One has to include the changes in the volume and movement of gravel and fine sand in the Danube, a deepening, increasing and meandering of the riverbed, sedimentation and erosion, and frequent floods. The nature has also been affected through intensive felling of forests, preparation of new agricultural land, intensive draining measures, and the construction off irrigation systems and river dikes. At the same time, the changes caused by urbanisation, industrialisation, population growth, transportation and communication systems development, transformation to a modern agriculture based on chemicals, as well as the overall chemical contamination, all have to be taken into consideration.

It is beyond question that **the current condition of the Danube and its flood plain is the result of centuries of human intervention.** It is a river that has contributed greatly to the development of the States sharing the Danube basin. It is a river that has been extensively utilised for navigation, water supply, fishing, and more recently, for hydroelectric power production and other purposes. I is equally beyond question that whenever measures are taken to modify the flow of a river, as contemplated by the Gabčíkovo – Nagymaros hydroelectric power project, there will be environmental effects, some adverse. This is true of all projects. The same modern technology that has made possible complex river projects has also led to techniques to measure the environmental impacts and to avoid, offset, mitigate, or remedy them. In the EC Fact Finding Mission report [2] it was concluded, "the environmental impacts of reducing the discharge in the Danube are negative, unless proper remedial actions are taken". As will be shown below, such impacts were dealt with and with a great deal of success.

Independent EU experts [1] in November 23, 1992 outlined the state and trends in the area, "Before the 18th century the Danube split downstream from Bratislava into two almost identical arms. Near Bratislava it was partly a braided river with many small islands, as a result of progressive sedimentation where the Danube entered into the plain. Both arms were however meandering river systems and the Little Danube (Malý Dunaj) still is. Large changes occurred during the 19th century, when the first regulation works started. Within several decades the system changed into a braided river. Some of the older branches are still present in the landscape".

"With the past endikements, especially during the last century, flood peaks became steeper and higher, flooding more frequent but in general with a shorter duration. The original zoning in vegetation towards higher grounds and associated forests was largely 'diked' out of the system. Most of the higher, no longer flooded soils were converted into agricultural lands" [1].

"These river regulation works led to a deliberate and natural cutting off and bundling of river branches into one main, straightened and heavily fortified channel for navigation. This remaining channel is characterised by rapid water level fluctuations and very large stream velocities. The cut off branches, behind the fortified riverbanks, are only activated at higher discharges. Within the river branches many small weirs and dams were built, so most of them behave like cascade systems at low discharges. The interaction with the side arms so created became limited." According to the experts of the Commission of the European Communities [1], flow in almost all river arms in pre-dam condition existed on an average of only 17 days per year.

The Gabčíkovo – Nagymaros Project consists of two parts, or steps, the Gabčíkovo part of the Project and the Nagymaros part of the Project. The Gabčíkovo part of the Project is situated in the central part of an intermountain depression, the Danube basin, called in Slovakia "Podunajská nížina" (Danubian Lowland). The Danube basin is filled by Late Tertiary (marine and lacustrine sand, fine sand, clay, sandstone, shales) and Quaternary sediments (river Danube sand and gravel settled in fluvial or lacustrine conditions). The total depth of the Quaternary and Tertiary sediments is 8000 m, with the uppermost Danube River sediments creating a main **aquifer of high permeable gravel and sand.** The thickness of the river Danube sediments, or the Danubian aquifer, ranges from a few metres at Bratislava to more than 450 m at Gabčíkovo, and goes back to a few metres downstream of Sap in the direction towards Komárno. Beneath this, a system of substantially less permeable aquifers and aquitards exist.

The important factors in the Danube transport and sedimentation processes are the existence of a **granite threshold connecting the Alps and the Carpathians in the area of Bratislava, with an outcrop of granites in the Danube River bed. A similar hard rock river threshold, predominantly of andesite rock is situated at Nagymaros (between the cities of Štúrovo-Estergom and Visegrád-Nagymaros), some 160 km downstream from Bratislava. Both thresholds are natural geological hydraulic barriers, steps or thresholds, in the riverbed. These are the upstream and downstream geological boundaries of the aquifers and the hydrological barriers naturally damming the Danube River bottom.**

Typical for such thresholds are a high gradient of the riverbed, high water-flow velocities and therefore lower navigation water depth, higher erosion downstream of such a threshold, moving fords, meandering of river and river arms, etc. The part of the river at Bratislava, just downstream from such a threshold, is a typical example. The flow velocity is high, the aquifer is shallow but with an extremely high hydraulic conductivity (permeability). Two municipal waterworks are situated at the granite threshold one on each side of the river. The Bratislava waterworks is on the Danube left side, Sihoť Island, and is more than 100 years old. The second waterworks at Pečniansky les is on the Danube right side. These waterworks supply Bratislava with drinking water of some 1500 and 600 l/s, respectively. Both riverbanks in front of these waterworks are natural. And this is the place where the impact of the Gabčíkovo step starts, with a slight increase of the Danube water level.

Just downstream from Bratislava the Danube forms **two branches, the Malý Danube in Slovakia and the Mosoni Danube in Hungary.** These branches create two analogous islands, **"Žitný ostrov"** in Slovakia and **"Szigetkőz"** in Hungary. In the Gabčíkovo part of the Project, between Bratislava and Medveďov, the Danube formed an **"inland delta"** region, **in geological literature expressed as an alluvial fan**, through which it once meandered. This “inland delta” has its original typical morphology, i.e. meandering river, coarse sediment accumulation and erosion, changes in riverbed gradient, etc. This large alluvial fan consists of a highly permeable extensive aquifer, capable of carrying and transferring high volumes of ground water. The Danube flows on the top of this “fan”. Water from the Danube infiltrates into the fan sediments and flows downward as ground water through the Danubian Lowland, nearly in parallel with the Danube River. In the lower part, where the slope of the river and the surrounding area **suddenly decrease to the one quarter of its gradient** at Bratislava, the ground water flows back into the Danube river via its own river arms, the Danube tributaries, and the drainage canals. All this occurs because of the lowered permeability, and lowered aquifer thickness downstream from Gabčíkovo, which is a result of changed sedimentation conditions upstream of the andesite hard rock threshold barrier at Nagymaros.

The hard rock granite threshold and the andesite threshold, which naturally dam the Danube river bottom and the places where the alluvial fan ends, a sudden decrease of river gradient from 40 to 10 cm per kilometre, are also important from the viewpoint of decision-making. At these places there have been proposals to situate the hydropower stations known as Wolfstal, Nagymaros, and Gabčíkovo, respectively.

According to the mutually agreed plan and **Treaty 1977** [5] between Hungary and Slovakia, the Gabčíkovo-Nagymaros project is hydrologically connected to the previously planned Slovak - Austrian hydroelectric power plant at Wolfsthal, upstream from Bratislava, and to the project Adony, downstream in Hungary (river kilometre - rkm 1601). The technical proposal is in accordance with the concept of the Rhine-Main-Danube and Danube-Oder-Elbe navigation system and with all hydropower stations and dams on the Danube.

In the German sector of the Danube, some 26 hydroelectric power projects have been completed. In Austria, ten hydroelectric power plants with navigational locks are in operation on the Danube. A chart listing these Austrian plants and the year of construction appears bellow.

Tab. 1.1. List of Austrian hydroelectric power plants on the Danube

Power plant	Year
Jochenstein – with Germany	1956
Ybbs – Persenbeug	1959
Aschach	1964
Wallsee – Mitterkirchen	1969
Ottensheim – Wilhering	1974

Power plant	Year
Altenwörth	1978
Abwinden – Asten	1980
Melk	1983
Greifenstein	1985
Freudenau (Vienna)	1997

1.2. THE GABČÍKOVO PART OF THE GABČÍKOVO – NAGYMAROS PROJECT

The Gabčíkovo part of the hydroelectric power project Gabčíkovo-Nagymaros was based on a combination of flood control, navigational improvements, production of electrical energy and protection of nature. In their working group report [1] independent experts of the Commission of the European Communities, stated on November 23, 1992: **"In the past, the measures taken for navigation constrained the possibilities for the development of the Danube and the flood-plain area. Assuming that navigation will no longer use the main river over a length of 40 km, a unique situation has arisen. Supported by technical measures, the river and flood-plain can develop more naturally".**

It emerges from the report of the Commission of the European Communities tripartite fact-finding mission [2], dated 31 October 1992, that **“not using the system would have led to considerable financial losses, and that it could have given rise to serious problems for the environment”.**

1.3. THE MAIN STRUCTURES OF THE GABČÍKOVO STEP

The hydroelectric power station, consisting of four blocks in which eight turbines and generators have been installed. They are all vertical Kaplan turbines, with runners 9.3 m in diameter and a maximum capacity of 90 MW each. The total installed capacity of the hydropower station is 720 MW with an operational discharge of 4000 m^3/s. Minimal and maximal discharges are 413 and 636 m^3/s per turbine, inversely related to water level differences of 24.0 and 12.88 m, respectively.

Two navigation locks serve passing ships and barges sailing along the Danube. Each lock is 275 m long and 34 m wide. The difference in water levels between the upstream and downstream canal varies from 16 to 23.3 m.

The **bypass canal,** consist of the headwater section upstream from the navigation locks, a hydroelectric power station, and a tail-race section (outlet canal) downstream from the power station.

The **Čunovo reservoir** is a part of the original Hrušov-Dunakiliti reservoir, which is situated exclusively on Slovak territory. The area of the originally designed Hrušov-Dunakiliti reservoir is 6000 hectares, and of the Čunovo reservoir approximately 4000 hectares, depending on water level. The operational water level at Čunovo is about 131.1 m a.s.l. (Above the Baltic Sea level); the minimal and maximal operational levels are 129 and 131.5 m a.s.l., respectively. Ensured navigational depth is 3.5 m, according to requirement of the Danube Commission.

The **intake structure** at Dobrohošť supplies the inundation river branch system with water and it enables flood simulations for forestry and ecological purposes. The discharge capacity is up to 240 m^3/s.

The **original function of the Dunakiliti weir** in the Gabčíkovo part of the Project is fully substituted by the **Čunovo weir** constructed on the Slovak territory and inside of the original reservoir area, upstream from the Dunakiliti weir.

Because at present the construction of the Nagymaros part of the Project on the Hungarian territory has not been built, the Gabčíkovo power station is operated as a run-of-the-river plant in a "water-level regime", meaning that the head water level is fixed and the allowed water level fluctuation $\pm$ 4 cm at a low flow discharge of up to 1500 m^3/s, and $\pm$ 15 cm at a higher flow discharge.

1.4. ECOLOGICALLY AND SOCIAL IMPORTANT STRUCTURES AND AREAS

The main parts of the area and of the Gabčíkovo hydroelectric complex having ecological importance and importance to the regional development are:

1. **The Čunovo reservoir** is a new biotope incorporating typical conditions of river and flood-plain ecotopes as, for example, the slowly- and fast-flowing main river beds, through-flowing deep and shallow river branches, flooded areas, and through-flowing lakes with variable depths and diverse flow velocities. The Čunovo reservoir is raising the surrounding ground water level to the level known 30 years ago, before bundling of river branches into one main, straightened and heavily fortified channel for navigation. .
2. **Upper part of the Čunovo reservoir** includes the original Danube riverbed, suitable for rheophilous species, a long shallow bay, suitable for limnic species, and numerous islands with diverse banks, suitable for macrophytes and waterfowl.
3. **Lower part of the Čunovo reservoir** includes a deep water area with linear and S shaped hydraulic structures, a waterfowl island, and an area for storing mud and fine sediments in the future.
4. At the ancient city of Šamorín there is projected **harbour for yachts and sport vessels**.
5. **Linear hydraulic structure** is designed to ensure sufficiently high flow velocities in front of the waterworks at Šamorín and to maintain high reservoir bed permeability without the deposition of fine sediments at places where ground water recharge towards the waterworks' wells takes place.
6. **S-shaped hydraulic structure** ensures a partially rotational flow and force sedimentation where it is harmless or advantageous. A function of this structure is also to minimise algae eutrophication.
7. **Protected nature areas:**

- Protected Landscape: CHKO Dunajský luh (Danube flood-plain), established on the May 1, 1998, as a response to the new hydrological conditions.
- Nature reserve localities: Ostrov Kopáč, Topoľove hony, Gajc, Hetméň, Jurovský les, Ostrovné lúčky.
- Protected sites: Bajdel, Poľovnícky les, Dolný hon, Park v Báči, Park v Rohovciach, Park v Kraľovičových Kračanoch, Park vo Vrakúni, Park v Gabčíkove.
- National nature reserves: Ostrov Orliaka morského, Číčovské mŕtve rameno.
- Nature monuments: Pánsky diel, Kráľovská lúka.

8. After damming the Danube its **original river bed** has a lower discharge (at present, according to the Agreement between Republic of Hungary and Slovak Republic signed in 1995, discharges are between 250 and 600 m^3/s), a lower but more variable and more suitable flow velocities, cleaner water, a narrower river bed and more natural river banks. The river bottom is more stable and more suitable for lithophilous species. There are excellent conditions for nesting and the wintering of waterfowls, especially in severe winters, because the Danube is recharged by warmer ground water infiltrating during the summer from the reservoir. The riverbed resembles a large river arm, similar to the earlier original state before the heavy stony bank stabilisation of the Danube. The abundance of aquatic organisms, mainly the littoral organisms is much increased and the food variety and amount available is much larger than under pre-dam conditions.
9. The **seepage canals** with on both sides of the reservoir and by-pass canal were designed to channel excess seepage water from the reservoir, to regulate the reservoir-evoked raising of ground water level, and to control the ground water level fluctuation. Water level can be regulated by gates to within some 2 m amplitude. Seepage canals with nearly drinking water quality are suitable new biotopes for some waterfowl, aquatic flora and fauna, and amphibians.
10. The **waterworks at Šamorín,** under present conditions of increased ground water recharge and raised ground water level, have the discharge capacity of 1200 l/s. Ground water quality was not changed.
11. The **Waterworks at Kalinkovo,** under present conditions of raised ground water level, have the discharge capacity of 600 l/s. Ground water quality was not significantly changed.
12. **Perspective water sources locality "Na pieskoch"** is an excellent reserve for the future.
13. **Waterworks at Rusovce** is situated in the area where the ground water level was significantly raised. The ground water quality was, by some parameters, significantly improved, on the area of the waterworks hygiene protection zone, and the discharge capacity is at present at least 2480 l/s.
14. The **area of water sports** at Čunovo is constructed mainly for wild water sports and the transport of small sport boats between the reservoir and the Danube. It also serves partly as the fish passage between the Danube and reservoir.
15. A **polder** was filled with gravel to take off the stagnant water body from the area of the waterworks at Rusovce.
16. **A bay** was filled by gravel, to hinder the concentration of waterborne (and floating rubbish) pollution in front of the Mosoni Danube intake structure.
17. The **intake structure for the Mosoni Danube** and the small hydropower station was originally designed to provide a permanent and to some extent variable water supply of 20 m^3/s into the Mosoni Danube, Zátonyi Danube and Hungarian river branches the whole year. At present it yields up to 40 - 50 m^3/s. It is possible to regulate the discharge. In pre-dam conditions the Mosoni Danube was directly supplied with water from the Danube only about 50 days a year, by discharges in the Danube over 3000 m^3/s.
18. The raised water level in the Danube improved the discharge control via the **intake structure for the Malý Danube.**
19. An **intake structure at Dobrohošť** designed to supply water to the Danube side arms on the Slovak territory takes water from the by-pass canal. The discharge capacity is 240 m3/s. The intake structure supplies the inundation area and river branches with water, and simulates water level fluctuation and floods for forestry and ecological purposes, e.g. the period needed for laying fish eggs.
20. An **intake structure to supply side arms on Hungarian territory** is situated directly in the Dunakiliti weir is at present not in use. The discharge capacity is up to 200 m^3/s.
21. There exist a **system of intake structures supplying irrigation canals.**
22. Partly **sealed bottom of the reservoir** serves to diminish the infiltration of surface water directly in front of the waterworks at Kalinkovo.
23. **The underwater weir at Dunakiliti**, constructed by Hungary in the framework of the Agreement between the Republic of Hungary and Slovak Republic signed in 1995, is designed to raise the Danube water level and to allow direct water connection and flow from the Danube into Hungarian river branches via openings in the river bank. Discharge into branches is regulated by the water level regulation at the Dunakiliti weir. The discharge capacity is over 200 m^3/s, according to the riverbank opening shape, underwater crest level and water level regulated by Dunakiliti weir.
24. The **inundation weir** may be used to direct a part of the floodwaters into the Danube riverbed and inundation area downstream from the damming of the Danube at Čunovo, usually, if the Danube discharge is over 6000 m^3/s.
25. The **bypass weir** was designed to channel and regulate flow discharge into the Danube, and to channel ice floes during construction of the Čunovo structures including hydropower station, ship lock and weir.

The long term capacity of the weir is 600 m^3/s. At present the weir is used as an auxiliary weir, regulating discharge into the Danube downstream of the damming, and partly as a fish passage. In the future it can be fully adapted as a suitable fish-passage.

26. **The Čunovo weir** is designed to regulate the discharge into the Danube riverbed, the water level in the reservoir, and to release ice floes and reservoir sediments.
27. An **auxiliary navigation lock at Čunovo**, connecting the reservoir with the Danube, can be used for navigation, for technical purposes, and for smaller and tourist ships.
28. **The small hydropower station at Čunovo** uses up to 400 m^3/s of the discharge from the reservoir into the Danube riverbed.
29. The **bypass canal** (diversion, power canal), which is a continuation of the Čunovo reservoir, directs the water to the power station and serves as a navigation canal. The bypass canal can handle a flood discharge of up to 5300 m3/s. The maximum flow velocity will not exceed 1.5 m/s during flood situations. The main ecological advantage of the bypass canal is that the navigation will no longer use the main river over a length of 40 km. A flood discharge of 5300 m^3/s in the bypass canal lowers the discharge in the Danube during a flood situation and protects the Szigetköz area. The bypass canal and the Gabčíkovo navigation locks are the main structures allowing a transfer of navigation away from the main river over a length of 40 km.
30. A **system of cascades in the inundation** on the Slovak side from Dobrohošť to Gabčíkovo, raises water level and enables the regulation of water levels in river branches of up to 2 m. Together with discharge control at Dobrohošť, it is possible to inundate the flood plain, to simulate a flood, to remove settled organic material from the main branches, and to control the ground water level fluctuation in the flood plain. Similar system has been developed in the Hungarian inundation.
31. **A system of hydrogeochemical experimental observation wells,** constructed during the PHARE project [3, 4] in 1993, is used to study ground water chemistry and ground water quality processes.
32. **The Gabčíkovo Hydroelectric Power Station** is producing environmentally clean energy (2-2.5 GWh annually) and regulating the water level in the reservoir. The Hydropower Station does not directly influence the level of air pollution; however, production of net energy associated with savings of fossil fuels is contributing to a decrease of Slovak emission of CO_2, SO_2, NO_X, and ash by some 5 - 7%.
33. **Dams** are wide and surfaced with asphalt, they are popular as cyclist, and tourist routs.

1.5. DISCHARGES AND WATER LEVELS IN THE DANUBE, MALÝ DANUBE AND MOSONI DANUBE

Discharge and water levels in the Danube, Malý Danube, Mosoni Danube, and river branches have been measured on a number of gauging stations. Fluctuation of discharge and water levels is one of the main characteristics of the Danube. The **fluctuation of discharges** observed in Bratislava and Komárno demonstrate that the long-term changes of discharge are, at least in Bratislava, negligible. The annual average discharge in Bratislava is 2.025 m^3/s, the minimum measured discharge is 570 m^3/s and the highest measured discharge is 10400 m^3/s. Predictable 100, 1000 and 10 000 year floods are 10 600, 13 000, 15 000 m^3/s, respectively.

The same data of the Danube discharge at Nagymaros are: 2421, 590, 8180 m^3/s for measured discharge, and 8700, 10 000, 11 100 m^3/s for predictable floods. It should nevertheless be 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 territories were flooded and the part of the discharges were thus dispersed in the region. The **retention function of the flood-plain area** between Bratislava and Komárno is clearly expressed in the lowering of the peak discharge at Nagymaros gauging station. For example, the highest measured discharge at Bratislava, 10 400 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 flood-plain area, which since the last century is restricted to the area between flood protection dikes. The Danube water levels measured at Bratislava, Rusovce, Gabčíkovo and Komárno show 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 in operation, using linear regression, are given on Table 1.2.

The discharge in the Malý Danube (one of two main branches of the Danube) is measured at a gauging station at Malé Pálenisko, Nová Dedinka and Trstice. The discharge in the Mosoni Danube (one of two main branches of the Danube) is measured at a gauging station at Mecsér and at Dunakiliti.

Table 1.2. Decrease of average discharge and average water levels in the Danube between the years 1962 and 1992

Locality	River km	discharge in m^3/s	Water level in m
Bratislava	1868.7	12.84	1.32
Rusovce	1855.9		1.10
Gabčíkovo	1819.6		0.20
Medveďov	1805.4		1.05
Kližská Nemá	1792.4		1.14
Zlatná na ostrove	17792		0.98
Komárno	1767.1	74.63	0.63

The long-term lowering of the water level in the Danube was one of the factors leading to the decrease of discharges in the Malý Danube and the Mosoni Danube, to lowering 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 exploitable ground water resources. In the upper part of Žitný ostrov there have also been some other factors influencing the ground water regime; for example, the constructing of the hydraulic blanket around the "Slovnaft" refinery, the development of Petržalka suburb on the right side of the Danube, including protective dikes and impermeable wall, and the construction of the waterworks supplying the capital and surrounding villages with drinking water.

1.6. GROUND WATER LEVEL REGIME

There is a basic network of more than 1000 observation wells in the Hungarian and Slovak area where the ground water levels are measured (On the Slovak territory mainly by the Slovak Hydro-meteorological Institute (SHMÚ). Several methods are used to present ground water level data. The most common is the well hydrograph, which visualises the ground water level fluctuation through time and which is the first step to characterising the ground water level changes.

The ground water level fluctuation is conditioned by mutual relationship and hydraulic interconnection between the Danube river water and other surface waters with ground water and the relationship between precipitation and evaporation. This ground water level fluctuation is further influenced by various other factors, such as drainage or irrigation of agricultural soils, regulation of water level in seepage canals, etc. In the region near the Danube the shape of ground water level fluctuation corresponds closely to the water level fluctuation in the Danube. At a larger distance the fluctuation is dependent upon the season and the relationship between precipitation, including snow melting, and evapotranspiration. The irrigation canal network, drainage facilities and melioration have a stabilising effect on ground water levels. The linear regression line is showing the drop of average ground water levels in a long-term pre-dam period. The long-term decrease on both sides of the Danube is evident over a part of the area. The average ground water level represented by the linear regression line for a chosen date is called a reference ground water level. The reference ground water levels were used for construction of ground water level contour maps, and these were used for drawing up the ground water level changes. From these figures a considerable decrease of ground water level, which occurred in the last 30 years (before putting the Gabčíkovo part of the Gabčíkovo-Nagymaros Project into operation) is evident in the upper part of the Danubian lowland. For more information and figures, see [3, 15], and www.gabcikovo.gov.sk/doc.

The impact of the damming of the Danube (putting of the Gabčíkovo part of the Project into operation by means of the dam at Čunovo, which has taken over the role originally destined for the works at Dunakiliti) can be evaluated on the background of the long-term development.

The changes in the ground water levels observed in the flood-plain area, and generally in the whole region, confirm the positive impact of the Project, in particular on the upper part of Žitný ostrov, and an important positive role of the water supply system for the left side Slovak flood-plain area since 1993, and the right side Hungarian flood-plain area since 1995.The observations support the expectation that, after completion of the water supply facilities for the remaining part of the flood-plain area in the vicinity of the tailrace canal and construction of some underwater weirs in the Danube 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 some 30 years ago on the greater part of the territory. Such ground water level situation is more natural.

1.7. GROUND WATER LEVEL AND SOIL MOISTURE REGIME

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 transferred via the aeration zone through capillary transport up to the soil.

The soil moisture is strongly conditioned by the availability of precipitation water (rain, snow melting 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, chemicals and pollutants, and also the long-term 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 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 the depth and course of ground water level fluctuation is, and mainly whether the ground water level in course of its fluctuation touches sediments with good capillary transport ability or not.

In the area of Szigetköz 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 growing season 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 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 ground water level is too shallow, mostly in the depth close to the surface as is usual in some zones in the flood plain. Usually it occurs if the ground water is at depth of 0 - 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. Shallow ground water level in the flood plain is welcome; it supports a typical flood plain biotope and it is naturally regulated by the river branches.

General changes

Important information is gained from the comparison of the position of the ground water levels in relation to the gravel and finer-structured sediments overlying the gravel as they existed in 1962, 1992 and at present. For this comparison, a map of thickness of finer sediments with good capillary transport ability, based on Irrigation Research Institute (VÚZH) data, was prepared. Shallow soils prevail in the upstream part of the area, while for the downstream part of the area deep soil horizons are typical. On the basis of surface topographic map and ground water level maps for 1962, 1992, 1993/94 the maps revealing the depth of ground water levels under the terrain were produced. The areas with the depth of ground water levels less than 0.5 m are the areas with soil water logging conditions. The other extreme is a depth of ground water table of more than 8 m. A comparison of the three maps shows that, except in the inundation area, there is no water logging, and an improvement occurred 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 Project into operation.

The ground water levels were generally raised after the damming of the Danube to nearly the level that existed in the 1960s. The situation has particularly improved in the area close to reservoir, downstream from Bratislava and its right bank through the Petržalka suburb. For more information and figures, see [3, 15], and www.gabcikovo.gov.sk/doc.

A comparison of the 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 into operation, there is an improvement of the water supply to soils via capillary transport in the upper part of the area in comparison with the pre-dam conditions. The improvement for deep rooting plants and trees also has occurred at places where the rising ground water level has not reached the overlying finer sediments, as occurs just downstream from Bratislava.

Soil moisture monitoring sites

To improve the clarity of time and depth dependencies of the soil moisture, the colour pictures were drawn with the depth values on vertical and the time axis on horizontal axis. The moisture levels are distinguished by colour. The shades of brown stand for deficit of moisture and its low accessibility for plants, green and blue represent sufficient moisture, and shades of violet represent high soil moisture and soil fully soaked with water (water logging). Exact times of measurements are marked on the top of the picture by ticks. Moreover, ground water level fluctuation is drawn at the same depth scale. Where data from the local well was missing, the plot of ground water level was estimated from the nearest SHMÚ (Slovak Hydro-meteorological Institute) well. From these pictures, the impact of ground water level fluctuation on the moisture conditions is evident. Besides, it is possible to compare the impact of precipitation or irrigation, seasons with high evaporation, and to deduce general conclusions about soil moisture changes. It is also evident how the soil moisture reflects the image of the geological profile, granulometric structure of sediments and impact of so-called capillary barrier. "Moisture" measured under the ground water level clearly reflects the structure of gravel formation while individual layer are distinguished by porosity and by the percentage of the fine-grain material. The dates of the damming the Danube, filling up the Slovak left side arm system with water, and start of water supply of Hungarian river branches are also given. For more information and figures, see [3, 15], and www.gabcikovo.gov.sk/doc.

Brief description of monitoring sites

Monitoring site Dunajská Lužná is located 450 m from the reservoir, in an agricultural area. Gravel is at a depth off 2 m. Locality is typical for the area downstream from Bratislava, where during the last 30 years of pre-dam conditions ground water level decreased by 2 – 3 m, to the depth off about 6 m. After the Danube damming, the ground water level risen nearly to level 2 m under the surface. In the depth zone, down to 1 m, moisture was only slightly risen (ground water is still in gravel). In the depth of 1 – 2 m the soil moisture risen by 5 – 15 %. This impacts mainly the plants with roots at depth of 1 m and more and the plants which roots are reaching deeper into gravel. Seepage canals along reservoir permit regulation of the ground water level, so it can be increased further by approximately 0.5 m and decreased by some 1.5 m.

Monitoring site Bodíky (Bodícka brána) is situated in the inundation area near its native riverbed. During the last 30 years of pre-dam conditions the ground water level decreased by some 1 m, and after damming the high and middle water levels additionally decreased. Soil moisture to the depth of about 0.7 - 0.8 m reveals that this locality had already been successively drying before and after the Danube damming, this process is more notable. The impact of climate is visible to the depth of about 0.8 m and is most expressive at gravel position in the depth from 0.4 to 0.8 m and from 1.3 to 1.5 m, which did not allow capillary transport of water to higher layers at a low water state. Soil moisture conditions can be turned back to the pre-dam state by raising the water level in the Danube by 1 – 2 m, e.g. by shallow under water weir (submerged river bottom weir, see chapter 7). Artificial flood is an important regulation tool of the soil moisture.

Monitoring site Gabčíkovo (Istragov) is situated narrowly at the Danube in the inundation area. In the past, the minimal ground water levels decreased by 0.6 m and after damming by some 1 m more. The impact of climate is visible down to a depth of about 0.6 m. This horizon is supplied by ground water during increased discharges in the Danube. In the depth 0.6 – 1.0 m, the impact of the ground water level fluctuation is larger. Since this layer consists of coarse-grain sediments, soil moisture is very sensitive to the ground water level position. A similar situation occurs also in the depth under 2.2 m, where a continuous layer of gravel and gravel-sand begins. It would be suitable to raise the low ground water levels by approximately 1 m by increasing the low water level in the Danube by means of under water weir. For more information and figures, see [3, 15], and www.gabcikovo.gov.sk/doc.

2. DANUBE AT BRATISLAVA

For over 300 years, the Danube has served as an avenue for commerce and as the basis of the economic development of its riparian States. Its waters have been managed and extensively utilised by these States. The region of the Danube downstream Bratislava, along the Slovak-Hungarian boundary has also become an increasingly developed area. It is high urbanised, intensively farmed, and the forests between Bratislava and Budapest have long been managed so as to produce industrially useful wood, leading to the gradual replacement of the original species. This, along with the extensive navigation and flood protection works, both in the region downstream Bratislava and also in upstream States, has created specific environmental effects.

The Danube water flow velocity just over the granite threshold between Alps and Carpathians is very high, it reaches 2 – 5 m/s. Downstream from this threshold, as a result of construction of dams and dredging of the Danube upstream Bratislava, erosion of the river bed prevailed during pre-dam conditions. At present the slope of the water level and flow velocities are lowered by the Gabčíkovo structure's impoundment and equilibrium is reached between erosion and sedimentation in the Bratislava stretch of the Danube, or sedimentation prevailed on some stretches.

2.1. SOME CHARACTERISTICS OF THE DANUBE

The Danube is 2850 km long and it passes through the central part of the Europe.

The Danube's spring source is to be found in the lower foothills of Baden-Württemburg, in the middle of the Black Forest (Schwartzwald), at an altitude of 1078 m.

On the long way down, the Danube passes through several countries, important regions and towns, and connects some 70 million people.

The Danube also creates a natural border between states along several parts of its flow, including the Slovak-Hungarian border, between Čunovo-Rajka and Štúrovo-Estergom.

The average flow volume is 6500 m^3/s at the estuary of the Danube, 2340 m^3/s at Budapest, 2025 m^3/s at Bratislava and 1920 at Vienna. For comparison, the flow in the Rhine river, downstream of Basel, is 1000 m^3/s. The minimum flow volume measured at Bratislava is 570 m^3/s and maximum 10 700 m^3/s.

The largest estimated Danube discharge in Vienna was some 14 000 m^3/s at the time of the flood of 1501 when the water level was some 1.8 m above the water level at the time of the 1954 flood.

In 1954 the river flooded some 33000 hectares in the Szigetköz area and in 1965 it flooded some 114 000 hectares (peak discharge of 9170 m^3/s) in Slovakia.

The first big dikes, designed to protect agricultural land and settlements from floods, were constructed under the rule of Béla IV. in 1235-1270, downstream from Bratislava, at Gönyü.

The Iron Gate hydropower project is a joint Romanian and Yugoslav project, and it is also the largest hydroelectric power station in Europe with an installed capacity of 2050 MW.

Systematic observation of water stages and discharges started in Bratislava in 1823, and records are available dating from 1876.

2.2. DANUBE AND DRINKING WATER SUPPLIES

The central depression of the Danube Lowland is made of water bearing sediments, gravel and sands. These sediments constitute one of the most important aquifer complexes in Central Europe. In terms of recharge of this aquifer, the dominant factor is the Danube. It influences the intensity of aquifer recharge (by infiltration, speed and direction of ground water flow and also the chemical composition of the water in the aquifer. Thus, in terms of ground water quantity and quality in the aquifer, water level and water quality in the Danube are the major factors.

Typical natural Danube riverbank exists, for example, in front of the waterworks well fields of Pečniansky les, supplying Bratislava by some 600 l/s of drinking water. Wells are situated, on average, 120 m from the Danube.

2.3. PETRŽALKA SUBURB

The technological skills related to dam construction, and the deeper knowledge of the hydrology conditions, have been combined with the experiences from many flood disasters. In the course of the 20th century, there were large floods in 1929, 1947, 1954, 1959 1965, 1975, and 1991 which all provided opportunities to study the changes of the hydrological conditions in the upper part of the central Danube. During floods, but also during normal high water levels in the Danube, the water masses quite often penetrated through the dikes on the right side Danube area at Bratislava, mainly the area of the village and later a suburb of Bratislava, Petržalka. The previously small village has grown into the suburb of Petržalka having some 150000 inhabit. In connection with the development of the Petržalka, the objectives to river training were significantly changing. **The first priority is given to the flood protection.**

Because the riverbed between Bratislava and Petržalka is narrow, only a few measures were available. On the Bratislava Danube's left bank quay under the castle have been increased in height by 1 to 2 metres and riverbanks have been additionally strengthened. On the right Danube side, in Petržalka, the protective dikes have been sealed and reconstructed to the same level. But this was not sufficient. The only possibility was to **increase the Danube water flow cross-section** by means of deepening the riverbed. This has decreased the Danube water levels, decreased passage possibilities for ships into the harbour, decreased discharges into the Malý Danube and increased the possibility of erosion of the Tertiary sands situated beneath the quaternary gravel. The situation was partly solved using the technical possibilities given by the construction of the Gabčíkovo part of the Project.

The present flood protection of Bratislava and Petržalka, consisting of increasing and reconstruction of left and right side quays and enlarged the Danube water flow cross-section. By means of water impoundment by the Čunovo structures, the Danube water level corresponding to low Danube discharges have been increased to stages 1 to 2 metres higher than in pre-dam conditions, thus passage for ships into harbour is assured. Water levels up to 6000m^3/s are in Bratislava similar to natural water levels. During larger discharges of the Danube, characterising the flood situation, gates on Čunovo inundation weir are open and thus water levels in Bratislava are reduced in comparison with the long-term pre-dam conditions (because the water flow cross-section in the river bed is enlarged).

In the Petržalka suburb the inundation by inland water during and after the flood event (seepage water by ground water level increase), is of special importance. The Petržalka is protected by new dike with impermeable wall, downstream the Old Bridge. The function of the Chorvátske rameno river arm was to take away surplus seepage water, during and after the flood. After decrease of ground water level in the pre-dam conditions the Chorvátske river arm was mostly dry or partially filled with stagnant stinking water. After putting the Gabčíkovo system into operation ground water level increases and water flow in Chorvátske rameno river arm was re-established. Because the area around the river arm was developed, works are prepared to increase the minimum flow and to re-naturalise further the area along this river arm.

2.4. BRATISLAVA HARBOUR

The scope of problem of navigation may be seen in the fact that in the Bratislava section of the river, the minimum navigation depth of 2.5 m was guaranteed in terms of navigable days for just 51 % of 1984 and just 40% of 1991. The percentage availability for each year from 1980 to 1991 is shown in the following table

Tab. 2.1. Percentage of days with full navigation possibility at Bratislava

Year	Navigation possibility %
1980	64
1981	88
1982	73
1983	61
1984	51
1985	65

Year	Navigation possibility %
1986	54
1987	66
1988	62
1989	50
1990	46
1991	40

The technical experts of the Danube Commission, on the meeting held 7 – 15 December 1992 stated: "During period of low water levels in a series of ford sections (including in the Bratislava – Nagymaros sector), the minimum depths were down to 1.3 – 1.4 m.

The most significant positive impact of the impoundment of the Danube water level is the navigability of the Danube in any discharge conditions and the avoidance of a gradual failure of the harbour due to erosion of the riverbed, which would lead to a significant investment to remedy. By raising the water level in the Čunovo section to 131.1 m a. s. l. elevation, the effectiveness of the harbour will be ensured during the whole year.

3. ČUNOVO RESERVOIR AND SURROUNDING

3.1. ČUNOVO RESERVOIR

The Čunovo reservoir (approximately 4000 hectares in extent) which was created between Bratislava and Dobrohošť (as far as bypass canal) **is a new biotope.** Although the reservoir represents the creation of a new biotope, **it harbours conditions that are typical for river and flood-plain ecotopes,** such as a moderately- to fast-flowing main channel, permanent moderately flowing deep and shallow river branches, and flood-plain through-flowing lakes with variable flow velocity.

The reservoir consists of an upstream part from Bratislava down to the Čunovo weir, and downstream part from the Čunovo weir down to the by-pass canal. **The retention time of water flowing through the reservoir is short, from 1 to 6 days.**

The upstream part of the reservoir begins at Bratislava, where it is still the original rapidly flowing Danube (at average discharges of 2000 m3/s – 1.2 m/s), with water levels during a low discharge period higher than before, and similar water levels during higher discharges. This character of the river continues down to Čunovo weir, where the flow velocity has an average discharge of 0.3 m/s. In this stretch sedimentation of bed-load and riverbed substrate is gradually changed from the original gravel one at Bratislava to one of more sandy gravel and coarse sand. This part of the reservoir is an optimal and sub-optimal biotope for rheophile species. Because of the reduced flow velocities and water level fluctuation, littoral communities are better developed than under pre-dam conditions. The littoral and the bank zones are natural and more than 3-times longer than under pre-dam conditions.

The upstream part of reservoir is connected to the old river branch at Rusovce, through excavated pits, and by a 2 km long bay having several islands upstream from Kalinkovo village. It has a variable water depth and high biomass productivity. The area is also suitable for many limnic and some eurytopic rheofhile species. Rheophile species find appropriate living conditions along the path of the former river cannel. In addition, species typical for river branches may be expected in adjacent, shallower areas having moderate to slow flow conditions. No temperature and oxygen stratification occurs. A good food base and sprawling places exist. The area is suitable for nesting waterfowl (significantly reduced water level fluctuation compared to pre-dam conditions, especially during the nesting period, suitable gravel banks).

In general, the water quality is good, with better visibility, which improves the living conditions for many species that hunt on sight. The settlement of aquatic vegetation creates friendly living conditions for a wide range of species that are confined to shallow river water. All this together, especially the aquatic flora, contributes a great deal to self-purification processes in the reservoir, which did not exist in this part of the previous heavy fortified Danube.

In the lower part of the reservoir, downstream from the Čunovo weir, the reservoir is divided into a main navigation canal with large flow velocities and a large area of variable depth and of comparatively small flow velocities. This part of the reservoir is more suitable for limnic species. The diversity of water flow velocity, and thus also the sedimentation-erosion processes, is ensured by the hydraulic structures in the reservoir. Here the reservoir is hydraulically divided into a main navigation canal, with larger flow velocities, and a large area with variable depth and comparatively smaller, but still turbulent, flow velocities. Hydraulic structures are active mainly when the reservoir water flow is significant.

A combination of fast flowing and slowly flowing reservoir parts, various water depths, large shallow areas and areas with aquatic plants, increases the variability of aquatic living conditions. The reservoir combines substantially conditions previously present in the river branches and in the main river cannel.

3.2. KALINKOVO WATERWORKS

The waterworks at the village of Kalinkovo were set in operation in 1972. Ten wells are situated near the old Kalinkovo river arm. The first well, with a screen (filter) for the interval of 21 - 55 m beneath the surface was excluded from the water supply because its waters carried high levels of iron and manganese. Therefore, all the other wells were equipped with well screens at depths of 40 - 80 m, and some of them are still in use. The capacity of the system of wells is 850 l/s. At present less than 200 l/s is used. Ground water is exploited mainly experimentally with the goal to study chemical processes in ground water and the impact of the reservoir on the ground water quality. Wells were originally covered and protected by an earthwork from flooding. Under pre-dam conditions, floods sometimes covered the waterworks area and polluted the ground water and wells from the surface for some time. It had been proposed to move these wells to other places, more distant from the reservoir. At present, wells are protected from flooding by reservoir dikes.

Experimental ground water quality monitoring is stressed mainly because of the fact that water wells were situated near to the previously existed river arm, and experience showed, that this river arm had negatively influenced the first shallow well. At present, these water wells are situated close to the reservoir, just behind the seepage canals. The course of changes in the water quality from well S-4, which was selected because it is situated in the middle of the well system and is now closest to the reservoir, is not significant, which means that the measured changes do not exceed previously measured values. The filling of the reservoir with water did not have a significant negative influence on water quality, and this in spite of the vicinity of the reservoir. The vicinity of the wells to the reservoir, negative experience with the shallow well, and generally negative experience at the observation wells situated close to the river branches were the reason of the construction of special ground water monitoring system of wells in the framework of the PHARE project [4]. This is described, for example, in the publication of the Faculty of Natural sciences in 1995 [3]. The goal of the ongoing research is to study water quality processes and to propose new well field for waterworks at Kalinkovo, situated a larger distance from the reservoir. Such a solution was proposed despite the fact that the presence of chemicals indicating water pollution was not detected. According to the microbiological and biological criteria of the Slovak Technical Standards, ground water from the wells is permanently suitable for drinking water purposes without treatment. The only signs of the changes were seasonal fluctuations and a decrease in the content of nitrates. A decrease of nitrates can lead firstly to an increase of the content of manganese and later also to an increase in the content of iron, which is usually treated by aeration of water in the waterworks or by in situ treatment directly in the aquifer.

A typical component of ground water in European countries, including Slovakia, is iron and manganese. Iron and manganese are not pollutants but are part of the geological composition of an aquifer. Whether iron and manganese occurs dissolved in the ground water depends on the oxygen condition in the water and the content of organic carbon in the water and in an aquifer. The common occurrence of iron and manganese dissolved in the ground water is well known from Hungary, in eastern Slovakia, the eastern part of the Žitný ostrov area - east of the city of Gabčíkovo, and in some places also downstream from Bratislava, mostly in places where the water wells are situated close to the river branches. A typical example is the area of the large well field at Rusovce, where in situ ground water treatment facilities for iron and manganese were installed. A similar situation is found, for example, at Vac in Hungary. Another typical examples are the Kalinkovo shallow well and observation wells at Dobrohošť etc. In Europe, the best-known and simplest treatment of ground water containing iron and manganese that is used for municipal water supply is water aeration and sedimentation of iron and manganese oxides.

3.3. ŠAMORÍN WATERWORKS AND HYDRAULIC STRUCTURES IN THE RESERVOIR

The waterworks at Šamorín is situated opposite the down stream part of the reservoir. The waterworks well system was set into operation in 1975, with six wells being equipped with screens (filters) at depths of 45 - 90 m, with the combined discharge of as much as 900 l/s. Three additional wells (as eventual compensation for the closing of the waterworks at Kalinkovo) were added just before filling the reservoir with water, which increased the discharged capacity of the whole waterworks to 1200 l/s. At present approximately half of this capacity is used.

The ground water quality, according to systematic observations since 1975, corresponds to the requirements of drinking water in all parameters, in accordance with the Slovak Technical Standards. The ground water quality is constant, without any significant changes.

Measures to protect the quantitative and qualitative recharge of ground water with water from reservoir included the construction of hydraulic guide structures in the downstream part of reservoir. Diversity of water velocity, and thus also of sedimentation-erosion processes is ensured by hydraulic structures. They are quite well active if the reservoir water flow is significant.

3.4. KOPÁČ ISLAND AND BISKUPICKÉ RAMENO RIVER ARM

The nature reserve of Kopáč Island, on the left side of the Danube, surrounded by the Biskupické rameno arm, is an area covered by a flood-plain forest (Ulmeto-Fraxineto carpineum) which at some places turns into a forest steppe biotopes with xerotermofilous zoocoenoses. The area was not flooded before the Danube damming. The ground water level was dropped severely before the filling of the Čunovo reservoir. Before 1993, the drying process was visible especially in the tree stratum. After 1992, after filling the Čunovo reservoir; the ground water level raised and the Biskupické rameno arm and terrain depressions were filled with water, leading to the regeneration of the most humid willow-poplar forest. Numerous natural reseeding of poplar, up to this time rare in this area, have been observed. Lowering of leaf losses and an increase in thickness increments in poplars in comparison to previous conditions were measured. A comparison of the qualitative structures of terrestrial fauna, for example the Centipede taxocoenoses, before and after filling of the reservoir shoved a moderate shift from the xerothermophilous species to the mesohygrophilous ones. In general it means humidity increase. After the rising of the ground water level, the water stayed also in the gravel pits and other terrain depressions, which became a hatching site for frogs. The recorded species reproduced there, finished their development up to metamorphosis and migrated into the surrounding vegetation. The amphibian taxocoenosis is stabilised. All monitoring data indicate that the continuing retardation of aridization of this area and improvement of conditions for hygrophilous and mesophilous species. This means that the hydrological and soil moisture conditions prevailing downstream from Bratislava some 30 years ago are being re-established.

3.5. WATER INTAKE STRUCTURES OF IRRIGATION WATER SUPPLY SYSTEM

Seepage canals on both sides of the reservoir and on each side of the by-pass canal were designed to channel excess seepage water from the reservoir, to regulate by the reservoir evoked rise of ground water level, and to ensure ground water level fluctuation. The water level can be regulated by up to 2 m in amplitude.

Water from seepage canals is also used to supply water to the irrigation canals in all of Žitný ostrov. The system of irrigation canals and irrigation facilities were been constructed as a response to the long term pre-dam ground water lowering and long-term climatic changes, mainly decrees of precipitation and increase of temperatures. There are several intake structures for water supply of irrigation canals.

3.6. AREA RIGHT SIDE OF THE DANUBE

A lowering of ground water level occurred on the right side of the Danube, during the long-lasting pre-dam lowering of the riverbed of the Danube. The ground water flow from the inland agglomeration of Petržalka and the Austrian territory supported the transport of contaminants towards the wells of waterworks at Rusovce-Ostrovné lúčky-Mokraď and other local municipal wells. The rise of the water level in the Čunovo Reservoir constituted a radical change in the ground water level and flow. The ground water level in the area of water works and also the right side of the Danube River branches rose approximately 2 – 4 m. The rise of the ground water level has had a positive impact on the discharge of the waterworks wells, on the inundation area of Rusovecké ostrovy and also on agriculture. At present, the prevailing direction of ground water flow is from the Danube towards the water supply well field at Rusovce, and further inland. Since the total dissolved solids in the ground water were originally very high (as much as 1000 mg/l in some localities), a decrease in these solids is regarded as the dominant positive change in the area. The content of chlorides and sulphates, and the total dissolved solids, rapidly decrease at the wells, which were directly affected by the water from urbanised territory in pre-dam conditions. Concerning microbiological parameters, the water level raised in the Danube has not caused any extraordinary changes in the wells. Concentration of all metal microelements is far under the standard limits for drinking water. Therefore, a very positive change with respect to ground water quality, linked with the increase of the proportion of the water infiltrated from the Danube, has been observed. New conditions constitute, from both quantitative and qualitative points of view, an unambiguous profit.

The Rusovce-Ostrovné lúčky-Mokraď waterworks, located between villages of Rusovce and Čunovo parallel to the Čunovo reservoir, utilise ground water recharge from the reservoir on places of the previous Danube riverbed. The system consists of 23 wells located about 120 m from the seepage canal, and 500 – 600 m from the reservoir.

The distance between the individual wells is 100 m. The capacity of the whole waterworks, after setting the hydroelectric power structures of Gabčíkovo step into operation, equals 2480 l/s. For more information and figures, see [3, 15], and www.gabcikovo.gov.sk/doc.

4. RIVER BRANCHES AREA

Independent experts of the Commission of the European Communities in their working group report stated [1]: "**In the past, the measures taken for navigation constrained the possibilities for the development of the Danube and the flood-plain area. Assuming that navigation will no longer use the main river over a length of 40 km, a unique situation has arisen. Supported by technical measures, the river and flood-plain can develop more naturally.**"

The Danube River branch system, with its typical alluvial inundation, is an area between flood-protecting dikes and the main river. This area was not touched by the construction of the bypass canal, hydropower station or other engineering structures. On the Danube this is a really unique situation. In general, two basic ideas have been implemented. The first idea, to **supply water to the inundation river branch area,** has been realised on both sides of the river. On the Slovak side the intake structure is in the upper part of the inundation area at Dobrohošť; on the Hungarian side the intake structure is constructed directly inside the Dunakiliti weir, in the upper part of Szigetköz. The second idea was to **recover the lowered water level in the Danube**, which had declined in the past, and then further, after putting the Gabčíkovo Project structures into operation. Various solutions have been proposed, all of them based on some **structures in the original Danube.** Example of accepted versions are shallow underwater weirs together with existing navigation spur-dikes between them. Some other, similar measures are the stabilisation of natural fords, low weirs (for example, inflatable), etc.

An intake structure to supply water to the Danube side arms on Slovak territory takes water from the bypass canal at Dobrohošť. Its discharge capacity is up to 240 m^3/s. The Dobrohošť intake structure supplies the inundation area and river branch system with water and simulates water level fluctuation and floods for forestry and ecological purposes, e.g. the period needed for laying fish eggs, simulating floods, cleaning the river branches bed, etc. Water flow and water levels inside of the inundation area are regulated according to the needs of forest management by cascades with culverts and water passes. The first artificial flooding was realised in the period from July 19 to August 18, 1995. Hydrological analysis showed that the extent and duration of the flooding corresponded to the discharges in the Danube in pre-dam conditions of 3000 to 4500 m^3/s.

A **continuous water flow** (or arbitrarily regulated water flow) **into the river branches is guaranteed, areas covered by water and river branch banks are enlarged, the water level is higher, and water quality is dramatically improved.** Conditions in the river branches resemble conditions in the 60's, before heavy stabilisation of the Danube River banks (done to improve conditions of navigation). This stabilisation of riverbanks had already changed the natural relationship between the river and the flood plain. At present, there is a **large variability of flow velocity and depth in the river branch system,** with velocities at some places from as high as 1 m/s, to nearly stagnant water in side branches and stagnant water in old dead branches supplied by ground water. The settling of aquatic vegetation in shallow river arms creates suitable living conditions for a wide range of species. Thus, a large variety of living conditions was recovered. Water vegetation typical for areas having periodic desiccation has, with former high water branches, moved to places covered by simulated floods. An overall increase in primary and secondary aquatic production has occurred. The water is of good quality. **The danger of anaerobic conditions** (known from pre-dam conditions) **and the drying up of branches accompanied by the extinction of fish, does not exist any more. Eutrophication, as far as it may occur in dead-end branches, will be within the range of original natural variation.**

According to the international agreement on **wetlands, the** "**Ramsar agreement**", wetlands are especially important for waterfowl, and they are especially valuable areas because of their biodiversity. The term **wetland includes bogs, marshes, swamps, morasses, moors, peat, natural and artificial water bodies, permanent and temporary waters, flowing and stagnant waters, fresh, brackish and salty waters, including the areas of sea water with a depth during an ebb (ebb end tide) not larger than 6 meters.**

According to the Ramsar agreement (Article 4), concerning all water bodies enlarged and created by the Gabčíkovo structures, and the increase of soil moisture as a result of surface and ground water level increases, whether they are included or not on the list of intenationally important wetlands, the country should support the existence of wetlands. **Construction of the Gabčíkovo hydropower structures and hydraulic measures have increased the area of all types of water bodies, including all types of river branches, and have increased soil moisture of the inundation and river branch areas. The whole inundation area and flood plain forests at Gabčíkovo have been accepted as additions to the list of international important wetlands.**

Due to the low water levels in the Danube, a water supply for the river branch system was created. This, together with a system of cascade hydraulic structures, hydraulic lines (named alphabetically from A to J), constructed nearly perpendicular to the main flow in the branches, help to keep the inundation area wet and can even be used for simulating floods.

The cascade hydraulic structures are constructed with culverts including water level regulating enclosure sets and water passes. The closure of culverts for a particular time period can increase the water level in the compartment behind the cascade hydraulic line, and thus simulate a flood wave or water level fluctuation. Such water discharges and the managing of the water level regime, and thus the optimisation of the whole environmental impact, is based on careful monitoring and its proper interpretation.

5. FLOOD PROTECTION

The first basic stage of the Danube regulation and flood control development was realised between 1759 and 1914. The main channel, which has been in use ever since, was created by regulation, started in 1831 and completed in the last years of the past century. Floods through breaches in the protected and reinforced levees have devastated large parts of the Hungarian Szigetköz area in 1954, and of Slovakia at Žitný ostrov in 1965. To appreciate the proportions of the disaster, it should be noted that in 1954 one-half of the Szigetköz area was flooded and the water rose to the second floor windows in the Bács district of Győr. The area flooded in 1965 was much larger in the Slovak Žitný ostrov territory.

5.1. AREA BETWEEN BRATISLAVA AND GABČÍKOVO, PROTECTION OF SZIGETKÖZ AREA

The protection of the area downstream from Bratislava was incorporated into the Gabčíkovo/Nagymaros project which, based on a great deal of study and interpretation of previous flood events, provided further for the dissipation of flood waters through a precise water regulation system and the construction of dikes with underwater sealing screens to prevent the seepage.

In the section from Bratislava downstream to Gabčíkovo **the floodwater will be divided between the bypass canal, the Danube riverbed and the side arm system, thus allowing some dissipation of floodwaters.** In addition, appropriate safety margins were incorporated into the design, of Gabčíkovo and Čunovo structures so that water levels could always remain comfortably below retaining levels of the various structures. The **Gabčíkovo structures protect mainly the Szigetköz area,** flooded for example, in 1954.

5.2. AREA DOWNSTREAM GABČÍKOVO, PROTECTION OF ŽITNÝ OSTROV AREA

In the reach downstream from the Gabčíkovo power station (reach of the Nagymaros part of the Project) the risk of flooding is greatest, Slovakia is particularly vulnerable. Therefore **the protective lines on the Slovak territory were reconstructed so as to meet the conditions issuing from the operation of the planned project at Nagymaros.** In the reach **between Gabčíkovo and Kližská Nemá the projected Danube riverbed deepening was not realised. This was one of the pre-conditions for the increase of flood control of the adjacent territory.** Thus, the protective sealing walls were constructed additionally at Sap, but it is still necessary to strengthen the protective measures on the Slovak side in this reach of the Danube. The best way to protect this region, flooded extensively in 1965, would be the construction of a downstream dam (for example Nagymaros). This would allow the realisation of the projected **deepening of the riverbed and thus an enlargement the Danube flow cross-section.** The adjacent section on the Hungarian territory downstream of Győr is formed by the higher ground of the nearby foothills and there is therefore no need for dikes since floodwaters are contained by the natural terrain. The higher ground and the hills bordering the Hungarian side of the Danube provide considerable protection against flooding, whereas the low-lying flood plain on the Slovak side, by contrast, forms a natural outlet into which the ground water seepage and surface flood water can escape.

Downstream of Gabčíkovo and Sap, where the deepening of the riverbed was not realised, protective measures against the seepage during the flood were implemented. The most dangerous situation occurs where the ground water flow direction is from the depth towards surface. Such situation usually occurs during the high water level in the Danube at places behind the protective dikes. Suffusion of fine sand particles upwards can result in the inner erosion and undermining and falling down the protective dikes.

The main measure is to decrease the vertical ground water flow velocity to the state that sand particles are not washed out. This is usually done by deep wells, which decrease the hydraulic pressure in the deeper part of the aquifer behind the protective dikes, or by construction of deep impermeable concrete or clay-cement wall and waterproof insulation between the wall and the top of the protective dike. Downstream from Sap both systems are used.

6. RELATIONSHIP BETWEEN SURFACE WATER AND GROUND WATER

Between falling as precipitation and passing out of an area as stream-flow, water moves over (surface water) or through the ground (ground water). This is the typical relation between precipitation and river flow. **The peculiarity of the Danube section of Danubian Lowland in the Gabčíkovo project section between Bratislava and Sap is that the Danube flows above the local terrain, on top of its own alluvial fan. This fan is made up of layered gravel and sand typical of piedmont situation, where a mountain stream enters the plain. The Devín gate at Bratislava, through its bedrock river bottom, acts as the mountain front. Immediately downstream the river gradient is relatively steep while downstream near Sap it is gentler and thereby thick layers of gravel and sand are deposited on the Neogene bedrock. This provides a highly permeable aquifer as much as 450 m thick near Gabčíkovo. As the river splits over its banks and shifts its position a low-angle alluvial cone is built on whose upper surface the Danube flows** (as far as the Malý Danube to the north and the Mosoni Danube to the south).

At **all water stages** the **elevated river bed supplies the ground water,** which flows partly towards the Malý Danube and Mosoni Danube and partly towards the system of drainage canals. The significance of this arrangement is also vital during the flood events. **The effect of the bursting of the Danube banks and protective dikes is extreme inasmuch as there is no natural raised terrain or higher terraces to contain the escaping water flow, as it is the case in normal alluvial conditions.** Because of the thick and highly permeable aquifer, there is also a secondary form of flooding. During high water levels in the Danube the ground water recharge is high and the ground water level is pushed upward to the ground surface. This leads to a flooding of the lower lying areas even at some distance from the river, a situation called inland water flooding.

6.1. INFILTRATION - RECHARGE OF GROUND WATER

Infiltration or exfiltration of the river water into the aquifer or from the aquifer into the river is conditioned by the hydraulic gradient between the river water and ground water. **When the water level in the river is higher than the ground water level, water from river infiltrates into the aquifer. When the water level in the river is lower than the ground water level, water flows from aquifer (exfiltrate) into the river.** If the water level in the river and ground water level equals, there is no water flow via the riverbed. The relationship between the river water level and the ground water level is decisive for the water flow direction from the river or into the river.

The amount of water flow from or into a river (measured in m^3/s per selected area or per unit area of river bed) depends on the following physical phenomenon:

- distribution of difference between river water level and ground water level,
- distribution of permeability of the river bed and thickness of the river bed sediments,
- permeability of aquifer,
- geometric characteristics of aquifer,
- geometric characteristics of the river bed.

The distribution of permeability of the riverbed sediments and the thickness of the riverbed sediments having this permeability is called clogging or colmatation of the riverbed. If the riverbed is not permeable, there is no water flow across the riverbed. Colmatation means reduction of infiltration to some degree.

6.2. GRAVEL PITS AT VOJKA

Gravel pits at Vojka illustrate typical examples of ground water relationship to the surface water in the river branches. Water in the gravel pits - lakes - originates from ground water. At the upper part of the lakes ground water flows into the lake, then from the lake flows downstream, and at the lowest part of the lake it flows out and infiltrates again into the gravel aquifer. Ground water, and thus water in the lakes, originates from the water of river branches, reservoir and in some places also from the seepage canals. Water in the lakes is therefore of ground water quality, and is continuously exchanged by fresh ground water. This water and area are suitable for recreational purposes.

6.3. COLMATATION - CLOGGING OF THE RIVERBED OR RESERVOIR BOTTOM

Colmatation is an important phenomenon, which creates a more or less impermeable barrier between the river water and the water in an aquifer. The aquifer downstream from the granite threshold at Bratislava is recharged mainly by water from the Danube. If the Danube riverbed, river branch bed, or the bed of the reservoir or lake were to become clogged with fine sediments, for example, recharge would be impeded to some degree.

Colmatation is a process. The most usually measured characteristics of colmatation are permeability and thickness of the riverbed (river bottom) sediments. The permeability of the riverbed varies from the permeability values of the underlying aquifer, down to some low values depending on the permeability of the sediment just on the river bottom. The finer are the river bottom sediments, the smaller is the permeability. **In the Danubian Lowland conditions no absolute colmatation exists, neither in the old dead river branches.** The permeability of river bottoms vary in time, and is influenced mainly by the sedimentation - erosion processes and the morphological changes in the riverbed. The protection of a sufficiently high permeability means keeping the riverbed free of finer particles, such as mud. The sedimentation of fine particles - mud - is a function of water flow velocity. **If flow velocity is at least higher than some 0.2 m/s for part of the year, the river bottom is usually free of mud and the permeability of the riverbed is usually by far higher.**

An example of such a situation is mentioned in the EC Working Group report [1]: **"However, after discharging water into the side channels in the Slovakian flood plain from May 1993 onwards, the ground water levels have increased above those corresponding to pre-dam conditions.** This demonstrates that a considerable recharge now takes place from the side channels. **This has become possible because the running water has removed the fine material, previously clogging the bed of these river arms**". And the report goes on to say: "…it is evident that a good hydraulic connection between the side river channels and the ground water system has been established. Thus, a substantial ground water recharge takes place from the river side channels resulting in up to 1.5 m increased ground water levels".

Colmatation is manifested by the difference between water levels in the reservoir and aquifer just under the reservoir bottom, or between water levels in river or river branches and aquifer. The difference between water levels in reservoir or, for example, the river arm and piezometers (observation well with short filter - screen) consists of one part characterising the flow line between the top and bottom of the colmatation zone, and of another part between the bottom of the colmatation zone and the entrance into the observation well. Thus, by recharging an aquifer from river or reservoir there exists always a water level difference (if there is no water level difference, there is no flow, no recharge). During aquifer recharge the water level in an observation well is below the water level in the river, river arm, or reservoir. Therefore, **the main criterion of colmatation is not the water level difference, but the water recharge of the aquifer or the water infiltration rate via the river bottom.** If the ground water level increases too much, because of high infiltration rate (low colmatation), the drainage canals carrying away the surplus infiltrated water should be constructed. Typical examples are the seepage canals bordering the reservoir and bypass canal. A flow of water in the seepage canal is a sign of small or no colmatation.

In the case that the reservoir or river is draining an aquifer, clogging of the reservoir or river bottom does not really exist, because the small particles are, at least at some places, lifted upwards as point sources lifting or rising of sand.

7. MONITORING

A typical example of monitoring is the publication "GABČÍKOVO PART OF THE HYDROELECTRIC POWER PROJECT - ENVIRONMENTAL IMPACT REVIEW (Evaluation Based on two Year Monitoring) [3, 15], published by the Faculty of Natural sciences, Comenius University in Bratislava, in 1995" or reports [7, 11, 12, 13] "Joint Annual Report of the environment monitoring in 1995, 1996, 1997, 1998" elaborated regularly according to the "**Agreement between the Government of the Slovak Republic and the Government of Hungary About Certain Temporary Measures and Discharges to the Danube and Mosoni Danube,** Signed April 19, 1995.

The monitoring of the environment should provide information about the impact of various activities and realised measures on the natural conditions, and to compare prognosis with the reality. The **impact of the hydropower structures and realised measures is expressed via changes in the hydrological regime of surface and ground water, further through the changes in the zone of aeration (zone between surface and the ground water level), which include the soil horizon with plant roots, and further on through the changes in flora and fauna.** The goal of the monitoring is not only to estimate the changes after putting the hydropower structures and measures into operation, but mainly to observe, evaluate, and to manage the water regime in such a way that the processes lead to improving the impact of the hydropower constructions on the various parts of environment. Hydropower structures usually have many technical means for managing the surface and ground water regime and thus also have large possibilities to positively influence environment.

The final aim of monitoring is not to define a **"status quo"**, nor so called **conservation or restriction measures**, but to provide measures for **ensuring development** from any point of view, and also with the aim of improving conditions for natural biodiversity and ensuring **sustainable development in the broadest meaning of term**. Continuous development, which is called **"sustainable development"**, can continue only through **improvements in knowledge, development of science, study of natural processes and continuous development of the educational level of inhabitants, including technical disciplines. Monitoring of the impacts of the hydropower structures and man's other activities is a key basis for such processes.**

Monitoring is based on sampling and measuring data. There are two general types of sampling, **probability sampling and non-probability sampling.** Probability sampling means that each item in the population has a chance of being chosen. In non-probability sampling methods not all items have a chance of being included in the evaluation process. This means that the monitoring results may not be representative of the population. The **Method of stationary plots** might not represent the monitoring area, if monitoring plots are not correctly chosen statistically. Monitoring of such an area as is the area influenced by the hydropower project, should include correctly distributed monitoring plots that characterise all the principal types of impact, and, in addition, also **movable monitoring plots which follow the spatial shifting of biotope conditions.** The recommendation is to measure in profiles and to map the area of individual components of monitoring. **Sampling should, therefore, be of purpose, based on typical structures of communities - taxocoenoses.** In the case of flora, it is better to monitor growing parameters of typical representatives of flora. Estimates of biodiversity should refer to the whole area of inundation, or at least to its characteristic units.

The interpretation of monitoring should be transformed into an examination of the whole area, using causal relations between the surface and ground water level and the changes of bio-indicative characteristics. The interpretation of changes in surface and ground water levels should, therefore, be included in the interpretation of the hydropower project impact on biota. A typical example of such monitoring is monitoring of forest.

The impact of the Gabčíkovo structures on biota occurs through changes in the ground water level in the zone of aeration. These changes are manifested through changes in the soil moisture conditions of the zone of aeration, as compared to the soil moisture conditions without the impact of the structures under similar other conditions. **If there is an rise in the ground water level** due to the construction of hydropower structures, **than there is also an increase of moisture in the zone of aeration, or occasionally the moisture may remain unchanged at some depths, but there is in no case a decrease in the moisture** caused by the engineering works. Reciprocally, **if there is a decrease in the ground water level** due to the construction of the engineering structures, **then there is also a decrease in the soil moisture, or occasionally the moisture may remain unchanged at some depths, but there is in no case an increase in the moisture** caused by the engineering works. Therefore, neither an increase of the moisture in the zone of aeration due to a lowering of ground water level, nor a decrease of the moisture in the zone of aeration due to a rise of ground water level, can happen.

The interpretation of ground water level changes, is therefore, the basis for interpreting biota monitoring data.

In an interpretation of the impact on the environment, a **lowering of the ground water level means changes into more hygrophobe (dry) biocoenoses, a rise of the ground water level means changes into the more hygrophilous (wet) biocoenoses.** If the criterion is accepted that **hygrophilous biocoenoses are more valuable, more original or native in the flood-plain area, that they have higher biodiversity and higher genetic diversity**, then it is very easy to **define areas with negative and positive changes, and this according to the changes in ground water levels.**

8. SLOVAK - HUNGARIAN AGREEMENT AND THE UNDERWATER WEIR

On April 19, 1995, the Governments of the Slovak Republic and the Republic of Hungary signed an **"Agreement between the Government of the Slovak Republic and the Government of Hungary about Certain Temporary Measures and Discharges to the Danube and Mosoni Danube"** [6].

The specifications of water management measures according to the "Agreement" are as follows:

- **Increase the water discharge into the Mosoni Danube** from 20 to 43 m^3/s via the Čunovo intake structure, under certain assumptions of hydrological and technical conditions specified in the "Agreement".
- **Distribute this water on the Hungarian territory** into the river branches on the right side of the Danube, into the protected area, and into the Mosoni Danube.
- **Increase and regulate the discharge into the main Danube** downstream from the Čunovo weir, to values between 250 and 600 m^3/s - 400 m^3/s on average - according to rules specified in the appendices to the "Agreement".
- **Construct an underwater weir in the main Danube** at Dunakiliti (Hungary), (river kilometre rkm 1843) to increase the water level in the Danube upstream from the weir, **connect the Danube with the Hungarian river arms by openings in the river banks** and **regulate the supply of the Hungarian river branches** with water up to 130 m^3/s or even more.
- **Collect and exchange the environmental monitoring data** which are necessary for an analysis of the impact of the mentioned measures
- **Prepare National annual reports.**
- **Prepare Joint annual reports.**

The results of the "Agreement" ensured the following surface water regime:

- The **discharge into the Mosoni Danube** increased, is regulated, and is permanently ensured throughout all the year round. Water is distributed into the Mosoni Danube arm, the Zatonyi Danube arm and other Hungarian branches.
- **The Hungarian river branch system in the flood plain is supplied permanently and sufficiently with water.** Water levels and discharges are **regulated by the Dunakiliti weir and inside the Hungarian river branch system,** similar to the Slovak cascades with culverts.
- **The water level raised in the Danube riverbed, upstream from the underwater weir at Dunakiliti,** and as far as the Čunovo weir.
- These measures have **also raised the ground water level.**

After putting the Gabčíkovo part of the project into operation, a 20 m^3/s discharge was released by the Slovak Water Authorities at the Mosoni Danube intake into the seepage canal. From October 1994, in accordance with the agreement between the Slovak and Hungarian parties, this amount was **increased to 40 m^3/s**. [10, 7]

The underwater weir, constructed in the framework of the joint Slovak - Hungarian Agreement, is situated opposite the already constructed Dunakiliti weir on the Hungarian side. **The Dunakiliti weir is the point where the Čunovo structures join the structures and dikes of the original Gabčíkovo-Nagymaros Project.** The structures are situated in Slovakia and inside of the original project area. The goal of the Čunovo complex is the same as had been the goal of the Dunakiliti weir, **to impound the water, to put the Gabčíkovo hydropower station into operation, and to open a new international navigation corridor via the diversion canal and ship-locks at the Gabčíkovo hydropower station.**

From the 23rd of June, 1995, **the increased water level caused by the underwater weir and the Dunakiliti weir allowed, in general, a 40 - 130 m^3/s discharge of water into the branch system of the Hungarian flood-plain, directly from the Danube.** The water level of the main channel of the flood plain was raised by 1 m on average. Thus, some side branches, formerly totally dry (as a result of long term development and not construction of projected measures), could to some extent be supplied with water again [10,7]. These main channel and side branches are now directly connected with the Danube by openings in the riverbank. The water level upstream of the underwater weir is on a level of about 123 m a.s.l. (above see level) and is regulated by the Dunakiliti weir.

Regular measurement of surface water quality was carried out for many years before damming the Danube [9, 10, 7]. Long term monitoring of the Danube water shows improvement of the Danube water quality, especially in the amount of organic matter, plant nutrients, nitrogen and phosphorus [7].

The water quality alongside the Mosoni-Danube depends on a number of conditions. The most important factor is the water quality of the tributaries Lajta, Rábca and Rába [10], according to the Hungarian report.. The quality of the Mosoni Danube water, mainly in the upper part, was substantially improved and resembles the Danube water quality. In the past, before building the intake structure into the Mosoni Danube, water stagnated in the upper part of the Mosoni Danube, and side river branches were without water or only with stagnant water. For most of the year the Mosoni Danube was disconnected from the flow in the Danube.

It is obvious that when interpreting the impact of water management measures according to the "Agreement", **ground water has an identification role for estimating impacts upon the natural environment.** If the ground water level rises, more water is at nature's disposal; if the ground water level lowers, less water is at nature's disposal. **A decrease of soil moisture in the inundation area, or flood-plain, is generally considered as a negative impact, an increase as a positive one,** especially if the previous pre-dam long-term development demonstrated a long term continuous trend of lowering of ground water level.

The underwater weir at Dunakiliti increased the water level in the Danube riverbed, upstream to the Čunovo structures. Discharges into the Hungarian flood-plain branches via openings in the Danube riverbank were usually around 100 m^3/s, with the regulation at the Dunakiliti weir (regulation of water levels) from 30 m^3/s or less to 130 m^3/s and more. This **substantially increased water levels in the whole Hungarian branch system and also supplied previously dry arms.** The discharge into the Mosoni Danube of approximately 40 m^3/s increased water levels and discharges in comparison with the pre-dam conditions (1992)

The area where there is a visible impact of measures is according to the "Agreement", defined as at least from the river branches lying closest to the Danube up to at least the Mosoni Danube river arm, and from Čunovo downstream to the Mosoni Danube inlet into the Danube at Győr. In reality, impacts exist from the Danube to the area behind the Mosoni Danube. On the Slovak side, the impact of these measures is minimal, usually not measurable, and occurs only on the right side downward from Čunovo village and between the Danube and the reservoir from Čunovo to Dunakiliti. **In general, the impact of measures realised according to the "Agreement" is visible in the whole Hungarian flood-plain and on the whole area of Szigetköz.**

In the following, we explain changes in the ground water levels in the Hungarian Szigetköz area using jointly exchanged data from the Szigetköz area and using the Hungarian report [14], including the Hungarian inundation river branch area.

The Hungarian data is shown on Tab. 8.1. The exchanged data of the ground water level were chosen for comparable discharges in the Danube [7]. Differences between ground water levels for various years can be seen from Table 8.1. Differences characterise the following changes:

1995 - 1994 changes after the realisation of measures according to the "Agreement",
1994 - 1992 changes after putting the hydropower station into operation,
1995 - 1992 comparison between the states after realisation of the measures with the pre-dam conditions,
1995 - 1991 comparison between the states after realising the measures with the low Danube discharge state in pre-dam conditions,
1994 - 1991 comparison between the state without the measures after damming the Danube and the low Danube discharge state in pre-dam conditions.

From Table 8.1. it can be seen that, based on the Hungarian data, **of the Szigetköz, from the river branch system to the Mosoni Danube, ground water levels rose after realisation of measures according to the "Agreement" (1995 - 1994).** Ground water levels, after implementation of measures of the "Agreement", are higher than the low ground water levels in 1991 (1995 - 1991), and mostly higher than the corresponding states in pre-dam conditions (1995 - 1992). **This means that the ground water levels in the Szigetköz area are mostly higher than in the pre-dam conditions for the average discharges in the Danube.** This is also expressed in profiles on Hungarian territory. **There is no tendency of ground water level drop towards the river branches**, which means that **the river branches are recharging the ground water** after implementation of the water management measures. This also means that, **if the underwater weirs would be constructed and the Hungarian river branches would be supplied with water from the Dunakiliti weir, according to the original project, ground water levels would not be lowered after putting the Gabčíkovo part of the project into the operation.** Comparing the ground water levels after damming the Danube without the "Agreement" measures, to the low Danube discharge state (1994 - 1991), it can be seen that the average ground water levels after damming the Danube have not dropped below the low ground water levels known in pre-dam conditions (see Tab. 8.1.).

Using the data in Tab. 8.1. [7] and data from report [14], contour lines of ground water levels were constructed. Using the ground water level contour lines maps, coloured **maps showing the ground water level changes** were constructed. **A brown colour means a decrease of the ground water level, a blue colour means an increase of the ground water level.** For more information and figures, see [3, 15], and www.gabcikovo.gov.sk/doc.

Tab. 8.1. Ground water levels - Hungarian territory (m a.s.l.)

year Well number	1991	1992	1994	1995
9310	122.42	123.48	123.22	124.16
9312	122.16	123.38		124.01
9327	121.27	122.56		122.99
9330	121.70	122.89	122.31	123.25
9368	122.07	123.11	122.88	123.68
9379	121.89	122.75	122.58	123.33
9383	120.25	121.04	121.00	121.83
9384	119.80	120.56	120.46	121.12
9385	119.46	120.14	120.05	120.57
9412	118.54	119.87		119.76
9413	118.36	119.47	118.82	119.61
9415	118.24	119.17	118.72	119.38
9416	118.02	118.75	118.55	119.11
9417	117.78	118.40	118.44	118.90
9418	117.34	117.95	117.89	118.21
9425	115.68	116.17	116.19	116.35
9430	115.90		115.87	116.76
9434	115.57	116.36	115.88	116.26
9435	115.55	116.27		116.30
9457	112.40	113.35	112.34	112.94
9458	112.43	113.18	112.52	112.87
9459	112.21	112.82		112.72
9460	112.01	112.55		112.57
9475	109.35	110.19	110.34	110.55
9480	109.58	109.91	109.98	110.17
9484	109.25	109.74	109.79	109.98
9536	115.63	116.42	115.86	116.33
9555	111.51	111.93	111.84	12.18
9564	109.44	109.66		110.16

It is clear that ground water levels corresponding to the approximately average conditions after the implemented measures, in comparison to the low ground water levels in pre-dam conditions (1991), decreased only near the Danube.

In comparison to the average conditions, the ground water levels of the lower part of the Szigetköz decreased in zones next to the Danube River, which is not influenced by the underwater weir in the Danube at Dunakiliti. The underwater weir at Dunakiliti increased the water level in the Danube and the neighbouring ground water level, between Dunakiliti and Čunovo. The results are shown on a series of maps. **Jointly elaborated, in the frame of the Joint monitoring, ground water contour lines and maps show the ground water level changes in comparison with the pre-dam conditions** [13].

It is evident that, after the realisation of water management measures according to the "Agreement" [6]**, ground water levels have significantly increased on the whole Hungarian flood-plain and Szigetköz area. The aims of the measures, according to the "Agreement", have been evidently fulfilled.**

8.1. IMPACT ON THE NATURAL ENVIRONMENT

The impact of the measures realised according to the "Agreement" is transferred to the natural environment via changes in the ground water levels. In the long-term pre-dam development, a lowering of the ground water levels had prevailed. **Because ground water level rose after the implemented measures and rose in comparison with the pre-dam conditions, this should be recognised as a positive result of the measures. An rising of the ground water level and an increase of soil moisture in all of the Hungarian inundation area and Szigetköz, in comparison with previous stages, and the increase of water areas and lengthening of the river arm banks, is returning the conditions for flora and fauna back to those supporting more hygrophylous species, which are more valuable, more original and more native especially in the inundation area. For the agricultural Szigetköz, an rise of ground water improves agricultural conditions** mainly for deeper rooting plants. The construction of some other underwater weirs in the Danube will further improve these changes. Based on monitoring of the impact of these measures, the changes could be optimised.

8.2. EVALUATION

The measures implemented according to the "Agreement" fulfilled the assumptions and have improved the regime of surface and ground waters on the Hungarian side and in the agricultural area of Szigetköz have returned the ground water regime to one similar or better to that existing in the pre-dam conditions, and the conditions of future development as they would be without operating the Gabčíkovo structures. The continuous discharge in the Mosoni Danube and in the river branch system in the Hungarian inundation corresponds to the condition when a relatively large part of the Danube water flowed through the Danube branches. The regime of surface and ground water in the Hungarian inundation and Szigetköz can be regulated by the Dunakiliti weir and optimised by some other measures, for example, by **shallow underwater weirs and stabilised natural river fords.**

Important information from the monitoring is that the self-purifying processes in the reservoir have had a positive impact on the Danube water quality. This impact is also evident on the Danube stretch downstream from Gabčíkovo on Hungarian territory. The reservoir has this positive impact on water quality because it is no more a single water body between strengthened riverbanks. Variability of water body and aquatic vegetation in shallow water and the banks contributes to the self-purification.

For more information and figures, see [3, 15], and www.gabcikovo.gov.sk/doc.

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