# The Impact of Operation of Gabčíkovo Waterworks Parts on Surface and Groundwater Level Regime in the Area of Bratislava Floodplain Forests and Moson-Danube

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Delimitation of floodplain forest area from a geological and hydrogeological perspective

The floodplain forest area is a part of the Great Rye Island and it's directly affected by Gabčíkovo Waterworks. Historically, this area was affected by the Danube River.
The Great Rye Island is a natural shape formed by a trunk stream of Danube and its distributary – Small Danube. It is shown schematically in Figure 1. Length: app. 100 km, width: app. 20 km. Its area comprises approximately of 2000 km$^2$.

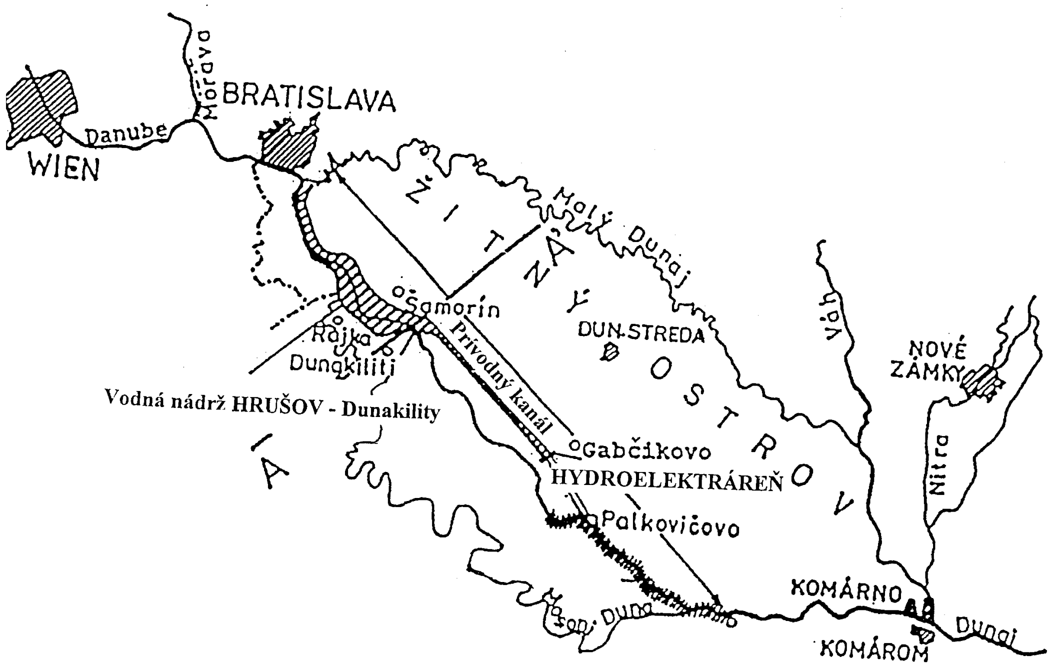


*Figure 1: Schematic delimitation of the Great Rye Island.*

Natural environment of the Great Rye Island creates an individual natural characteristic whole, which is characteristic by a number of peculiarities of geological, hydrogeological, geochemical and pedological nature. A unique and protected area is concerned here and that's the way it should stay in the future. Floodplain forest area is a part of this whole.

## Geological structure

Geologically, this area is built by quaternary alluvial sediments of Pleistocene and Holocene age. There are sandy sediments in a core of the island, which reach thickness of around 300 m in the middle, tectonically subsiding part of the island.

Young Holocene sediments create main zones around Danube and Small Danube and notable part of middle and lower part of the Great Rye Island.

**Gravel bed is situated in the depth of from 50, eventually 70 cm under terrene (in the middle and notably in the upper part of the island) up to 6, eventually 8 m (mostly in the lower part of the island). The depth of this interface is characterized by a huge variability in the Great Rye Island area.** Gravels or gravel sands are covered with younger alluvial clayey and loam sediments, less sandy loams and clayey sediments. They are considered of Pleistocene age. These form a so-called cover layer. Interface gravel bed – cover layer **plays an important role in hydrological cycle in the environment of the Great Rye Island, more precisely in hydrology of groundwater of this region.** The reasons for the fact are following.

The environmental area above the area of interface gravel bed – cover layer differs significantly in retention and water dynamics in the area above this interface, i.e. in the cover layer in comparison to these characteristics below this area, i.e. in the gravel bed.

In hydromelioration practice the water outflow from the area above the sinking level of water in soil is characterized by drainage porosity, which reaches the levels of almost 0 (in very heavy soils) up to 0.2 – 0.25 volume %. Therefore, a drainage porosity coefficient is considered an important hydro-physical characteristic of soil.

As far as retention is concerned, after a decrease of groundwater level through the cover layer, 20 – 60% of water of total saturation volume remains in the layer depending on grain composition of the environment.

Under the interface cover layer – gravel bed, a retention volume of water above sinking groundwater level is negligible. This corresponds with a situation, when in time of water level decrease nearly full volume of water from environmental pores flows out with the water (Mucha et al., 1992, 1993; Mucha, 1995; Kosorin, 1997, 1998; Burger, 1979, 1999; Burger-Čelková, 1992; Pospíšil et al., 1979, 2000).

## Soil water regime

Groundwater of the Great Rye Island is permanently supplied from Danube in the infiltration area. According to geological data (Porubský et al. 1971), this area is between Bratislava and Palkovičovo. Infiltrated water flows through highly permeable gravel sands in southeast direction, approximately parallel to Danube. The groundwater level during the year before the Gabčíkovo Waterworks was put into operation was showing a relatively high fluctuation. In a long-term average it varied between 4 – 7 m in the upper part, 2 – 4 m in the middle part (to Dunajská Streda) and 0 - 2 m in the lower part of the island and its surface depressions (Porubský et al. 1971, Kalnová 1976). After Gabčíkovo Waterworks was put into operation, the situation changed. Using figures of groundwater levels obtained during monitoring of water content in the soil aeration zone, data in Table 1 presents their middle, minimal and maximal levels and amplitude of their oscillation in 1996. On the stand Kalinkovská horáreň of Bratislava floodplain forests there is a 230 cm deep gravel bed. The groundwater level varied from 186 to 220 cm under terrene with the middle level of 198 cm. This means that water regime of the soil surface level on this stand had been affected by the groundwater level.

**Table 1** **Characteristics of groundwater level regime on the selected stands of the Great Ray Island in 1996.**

| N | Lokalita | kód | str.hodnota | minimum | maximum | rozdiel | hĺbka štrk. |
|---|---|---|---|---|---|---|---|
| | | stanovišťa | | | | | podložia |
| | | | cm | cm | cm | cm | m |
| 1 | BA Ružinov | R1 | 601 | 528 | 665 | 136 | 3 až 4 |
| 2 | Vrakúň | V1 | 101 | 80 | 114 | 34 | pod 3 |
| 3 | | V2 | 241 | 228 | 257 | 29 | 4 až 5 |
| 4 | | V3 | 159 | 126 | 176 | 50 | pod 3 |
| 5 | | V4 | 126 | 100 | 144 | 44 | 4 až 5 |
| 6 | P.Biskupice | B1 | 488 | 444 | 550 | 105 | 3 až 4 |
| 7 | | B2 | 347 | 263 | 563 | 299 | po 3 |
| 8 | | B3 | 319 | 205 | 403 | 205 | 3 |
| 9 | | B4 | 377 | 292 | 537 | 245 | 3 až 3.5 |
| 10 | Dunajská | D1 | 607 | 595 | 639 | 44 | pod 3 |
| 11 | Lužná | D2 | 500 | 490 | 530 | 40 | 2,8 |
| 12 | K.Horáreň | NZ14 | 198 | 186 | 220 | 34 | 2,3 |
| 13 | Mierovo | M1 | 305 | 282 | 330 | 48 | 1 až 2 |
| 14 | | M2 | 332 | 307 | 355 | 48 | 2 |
| 15 | Bellová | B1 | 206 | 156 | 230 | 74 | pod 3 |
| 16 | Ves | B2 | 209 | 157 | 233 | 76 | pod 3 |
| 17 | Lehnice | N1 | 120 | 77 | 142 | 65 | pod 1 |
| 18 | | N4 | 171 | 123 | 197 | 74 | 1 |
| 19 | | N8 | 232 | 180 | 263 | 83 | pod 1 |
| 20 | | N9 | 123 | 75 | 147 | 72 | 1 |
| 21 | Mliečno | NZ13 | 334 | 295 | 413 | 118 | 2 |
| 22 | Báč | NZ12 | 487 | 449 | 550 | 101 | 1 až 2 |
| 23 | Rohovce | R1 | 182 | 151 | 218 | 67 | 2 až 3 |
| 24 | | R2 | 204 | 183 | 240 | 57 | 2,50 |
| 25 | Dobrohošť | NZ17 | 235 | 185 | 298 | 113 | 2 |
| 26 | Bodíky | Bo1 | 215 | 190 | 262 | 72 | 2 |
| 27 | | Bo2 | 228 | 197 | 282 | 85 | 3 |
| 28 | Bodíky | NZ18 | 250 | 207 | 298 | 91 | pod 3 |
| 29 | Trstená | NZ9 | 188 | 155 | 275 | 120 | pod 3 |
| 30 | Kr.Lúka | NZ19 | 191 | 150 | 241 | 91 | 2,50 |
| 31 | Dekan | NZ20 | 247 | 116 | 201 | 116 | 2 |
| 32 | Dol.Štál | DS12 | 221 | 204 | 239 | 35 | pod 1 |
| 33 | Gabčíkovo | G1 | 192 | 85 | 329 | 244 | po 3 |
| 34 | Sap | S1 | 258 | 197 | 338 | 140 | 1 až 2 |
| 35 | H.Zlatná | HZ1 | 205 | 165 | 236 | 71 | 3 až 4 |
| 36 | | HZ2 | 355 | 304 | 391 | 87 | pod 4 |
| 37 | Čalovec | Č1 | 129 | 75 | 175 | 100 | 3 až 4 |
| 38 | | Č2 | 132 | 81 | 172 | 91 | pod 4 |

** Locality – Stand Code – middle level – minimum – maximum – difference – gravel bed depth*

Apart from the agricultural land also other ecosystems can be found on the Great Rye Island of which floodplain forests in the area between the Danube's old river-basin and head-water channel are interesting.

**The hydrologists' and ecologists' effort is to secure the stability of this area with regard to optimal water supply in the region.**

It is important to have an idea about soil water regime in the floodplain forest area. Institute of Hydrology SAS within its research activities is monitoring depth levels of groundwater levels and soil moisture from the water surface to the groundwater level in two floodplain forest localities - Bodíky and Kráľovská Lúka. Monitoring has been in progress since 1999 with the frequency of every other week during vegetation period and app. once a month in winter.

As seen in Table 1, in 1996, that is 4 years after Gabčíkovo Waterworks was put into operation, on two stands (Dobrohošť and Bodíky) in the floodplain forest area the surface layer above the interface of gravel bed was only slightly affected by the groundwater level. Gravel bed in Dobrohošť begins in 200 cm depth and the groundwater level in 1996 varied from 185 cm to 298 cm in depth under terrene with the average of 235 cm.

The situation is similar in Bodíky. Gravel bed in Bodíky (Bo1) begins in 200 cm depth a and the groundwater level in 1996 varied from 190 cm to 262 cm under terrene with the average of 215 cm.

Groundwater level in both of these localities was changing rather in gravel bed and thus didn't affect the surface layer soil water regime in these localities. However, on two other stands in the Bodíky locality, gravel bed begins in 300 cm depth and surface layer soil water regime on these stands had been affected by the groundwater level. This also implies that the depth of interface gravel bed – cover layer shows even on a relatively small area of land rather huge non-homogeneity.

Similarly, in Kráľovská Lúka (NZ19) surface layer soil water regime was affected by the groundwater level. Gravel bed begins here in app. 250 cm depth and the groundwater level in 1996 varied from 150 cm to 241 cm in depth under terrene with the average of 191 cm.

As an example on Figures 2 and 3, development of moisture profiles during 2000 on the stands Bodíky (Bo1) and Kráľovská Lúka (NZ19) is shown. It can be seen that in Bodíky (Figure 2) gravel bed begins in around two meters depth. The moisture of soil profile in this depth decreased markedly. Groundwater level varied exclusively in the gravel bed, except of the time when artificial inundation was carried out. Water regime of cover layer depended on rainfall, eventually on seepages from the channel system in this area of the Great Rye Island. On the contrary, in Kráľovská Lúka (Figure.3) groundwater level varied above the gravel bed and supplied the cover layer.

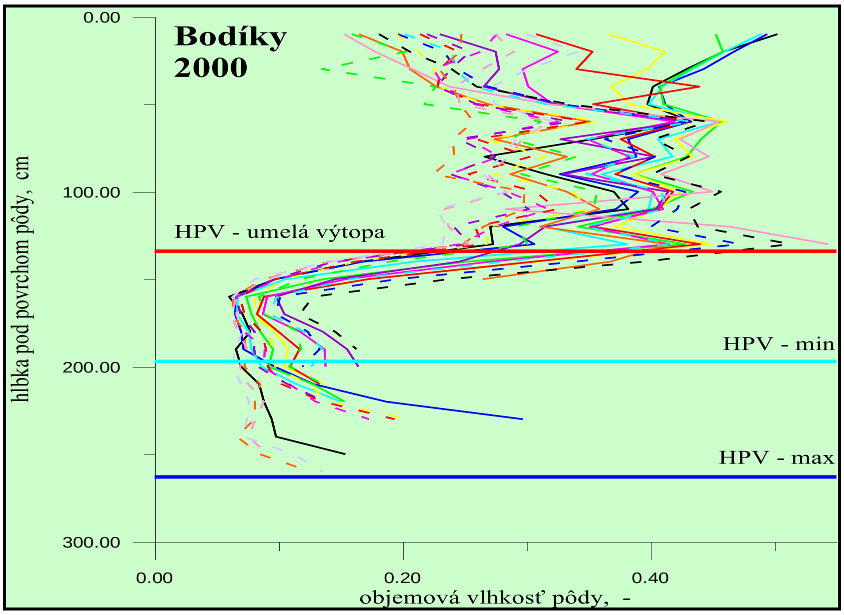


*Figure 2: Development of moisture profiles in Bodíky in 2000. Borderline values of groundwater levels measured in the year are shown.*

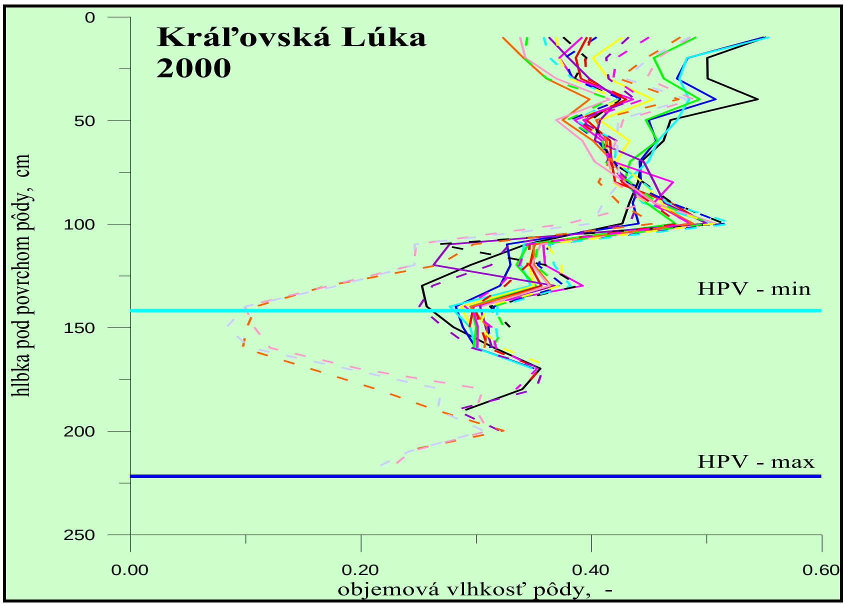


*Figure 3: Development of moisture profiles in Kráľovská Lúka in 2000. Borderline values of groundwater levels measured in the year are shown.*

Rainfall recorded by rain gauge station in Gabčíkovo during 1999 - 2009 is shown in the Figure 4. Development of groundwater levels during the same period on the stands Bodíky (Bo1) and Kraľovská Lúka (NZ19) is shown in Figures 5 and 6 respectively.

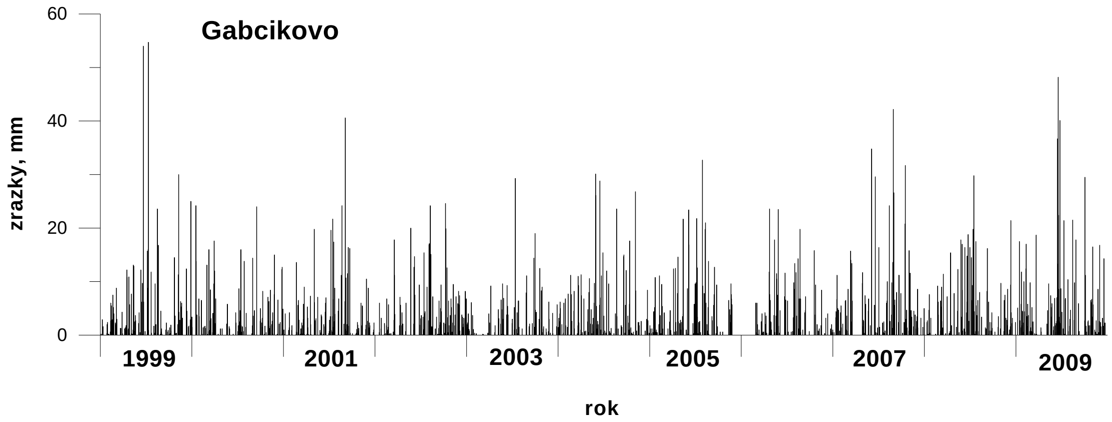


*Figure 4: Daytime rainfall measured by the rain gauge station in Gabčíkovo during 1999 - 2009.*

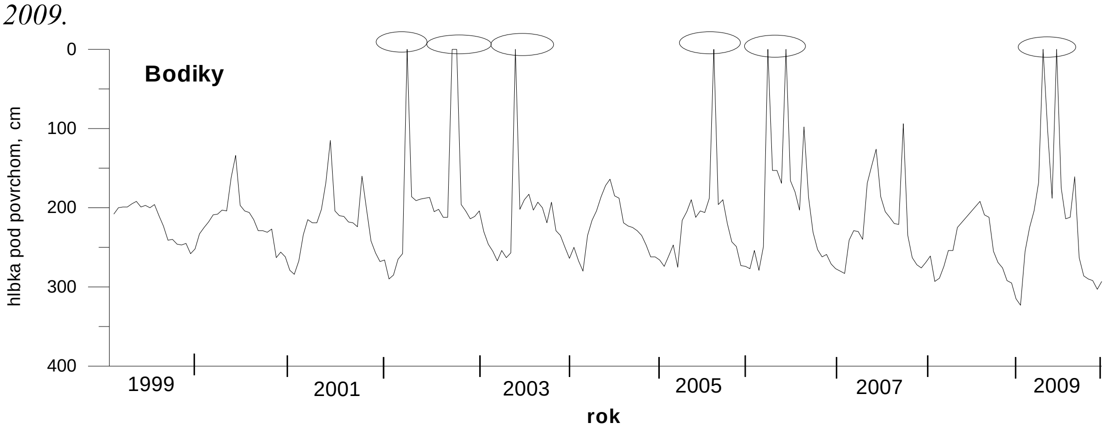


*Figure 5: Development of groundwater levels measured in Bodíky during 1999 - 2009. Inundations, eventually floods and overflowing that occurred in this area are marked by ellipses.*

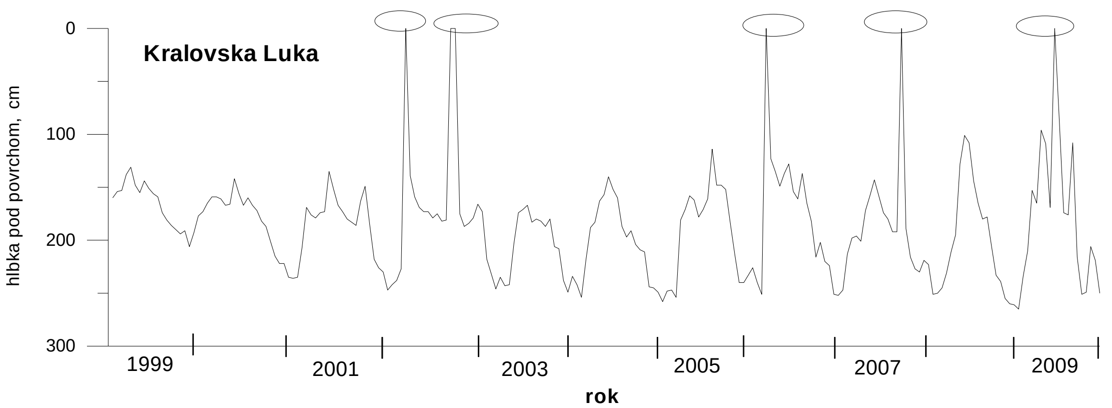

*Figure 6: Development of groundwater levels measured in Kráľovská Lúka during 1999 - 2009. Inundations, eventually floods and overflowing that occurred in this area are marked by ellipses.*

In Table 2 regression coefficients are stated, which express the closeness of the relationship between water supplies in particular 10 cm thick layers of soil profile and groundwater level depth in Bodíky and Kráľovská Lúka during 1999 - 2007. As seen in Table 2 and as easily expected during this period, the water supplies in Bodíky were in a significant relationship with the groundwater level only in the layer around 40 cm above the soil horizon of 190 cm. Soil horizon of 190 cm in depth was chosen, because the groundwater level in the observation period was changing largely blow this point, with the exception of extreme occurrences, which however didn't last long as well as their subsequent impact on soil water regime. Works published as early as 2001 are an evidence for this (e.g. Štekauerová,V., Nagy, V., 2001). Saturated hydraulic conductivity reaches higher levels here (Mikulec, V., 2007).
Similar applies to Kráľovská Lúka, even though the cover layer is affected by the groundwater level a bit more, considering that during the observation period the groundwater level was changing above the gravel bed. Interestingly, the distance between Bodíky and Kráľovská Lúka is only a couple of kilometers.

**Table 2: Regression coefficients**

| Horizon | Bodíky | Kráľovská Lúka |
|---|---|---|
| [cm] | *Regression coefficient* | |
| 10 | 0.2254 | 0.1857 |
| 20 | 0.1789 | 0.2193 |
| 30 | 0.1520 | 0.3058 |
| 40 | 0.0812 | 0.3071 |
| 50 | 0.0447 | 0.5848 |
| 60 | 0.2071 | 0.1068 |
| 70 | 0.2098 | 0.0849 |
| 80 | 0.2898 | 0.4777 |
| 90 | 0.3084 | **0.7938** |
| 100 | 0.3493 | **0.8463** |
| 110 | 0.3614 | **0.8192** |
| 120 | 0.3822 | **0.8598** |
| 130 | 0.4589 | **0.8888** |
| 140 | 0.4992 | - |
| 150 | 0.4866 | - |
| 160 | **0.6405** | - |
| 170 | **0.7616** | - |
| 180 | **0.8305** | - |
| 190 | **0.8587** | - |

From the presented we can state that

- floodplain forest area has a gravel bed whose depth of interface gravel – cover layer is considerably variable,
- groundwater level in many localities varies exclusively in this gravel bed and by that its contact with cover layer is disrupted,
- such localities then depend on rainfall, eventually lateral tributary streams or seepages from channel systems.

In order to be able to secure ecological stability in this area, it should be supplied with water optimally, that means that soil water regime should be affected by groundwater level to a greatest possible extent in order for this area to prosper even in times of rainfall shortage.

**Impact of Gabčíkovo Waterworks on regimes of groundwater levels**

A book „Gabčíkovo-Nagymaros, Old and New SINS „ by Egil LEJON, published by publisher H&H, Bratislava 1994 (ISBN 80-88700-27-2, 271 p.), is dedicated to a not-so-distant history of the area mentioned in its title until the year in which already first implications of Gabčíkovo Waterworks regarding the regime of groundwater levels had been monitored.
Following figures and results originate from this book.
In close surroundings of Bratislava, a decrease of groundwater levels of 2 meters, in floodplain forest areas around 1 meter, was recorded during a 30-years period (from 1960 to 1990) z, Figure 7.

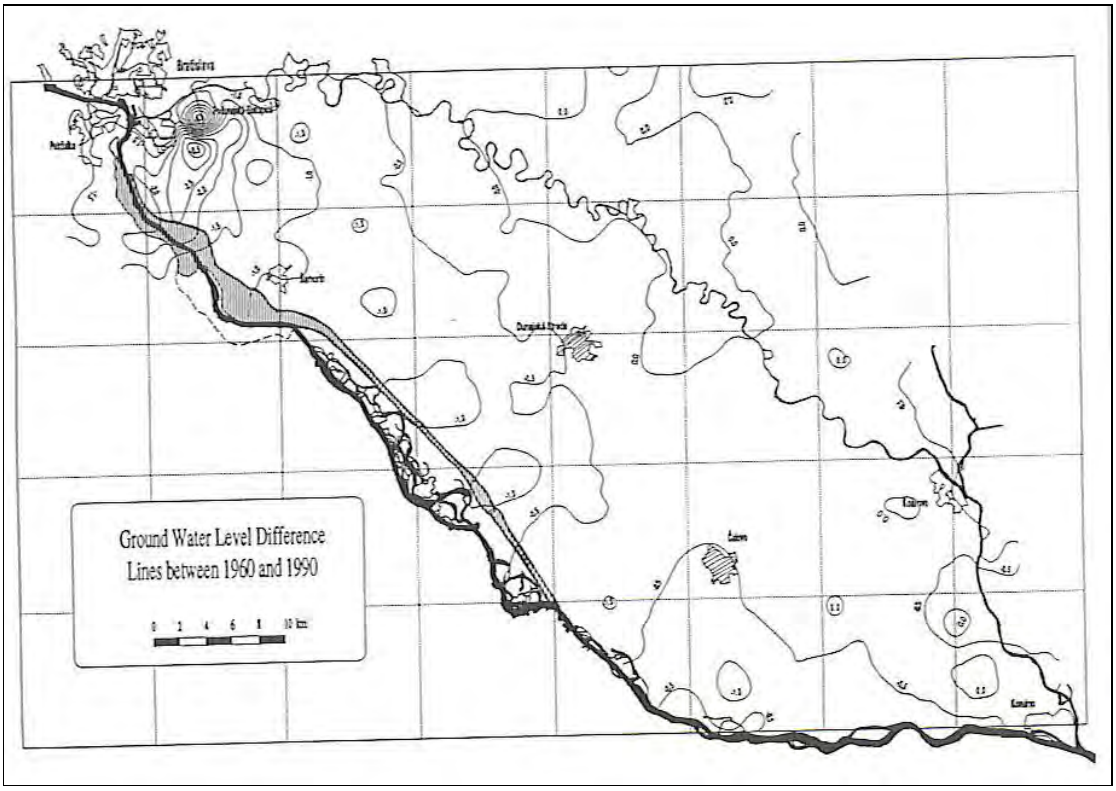


*Figure 7: Difference in depth of groundwater levels between 1960 and 1990 in the Great Rye Island Region.*

Eight months after Gabčíkovo Waterworks was put into operation, an increase of groundwater levels in the close surroundings of Bratislava of 2 meters was recorded, so the groundwater level status reached the 1960’s level. However, practically no increase in groundwater levels occurred, Figure 8.
In the floodplain forest area there is a channel system, which supplies this area with water from the head-water channel. Dobrohošť intake controls the water inflow, Figure 9.

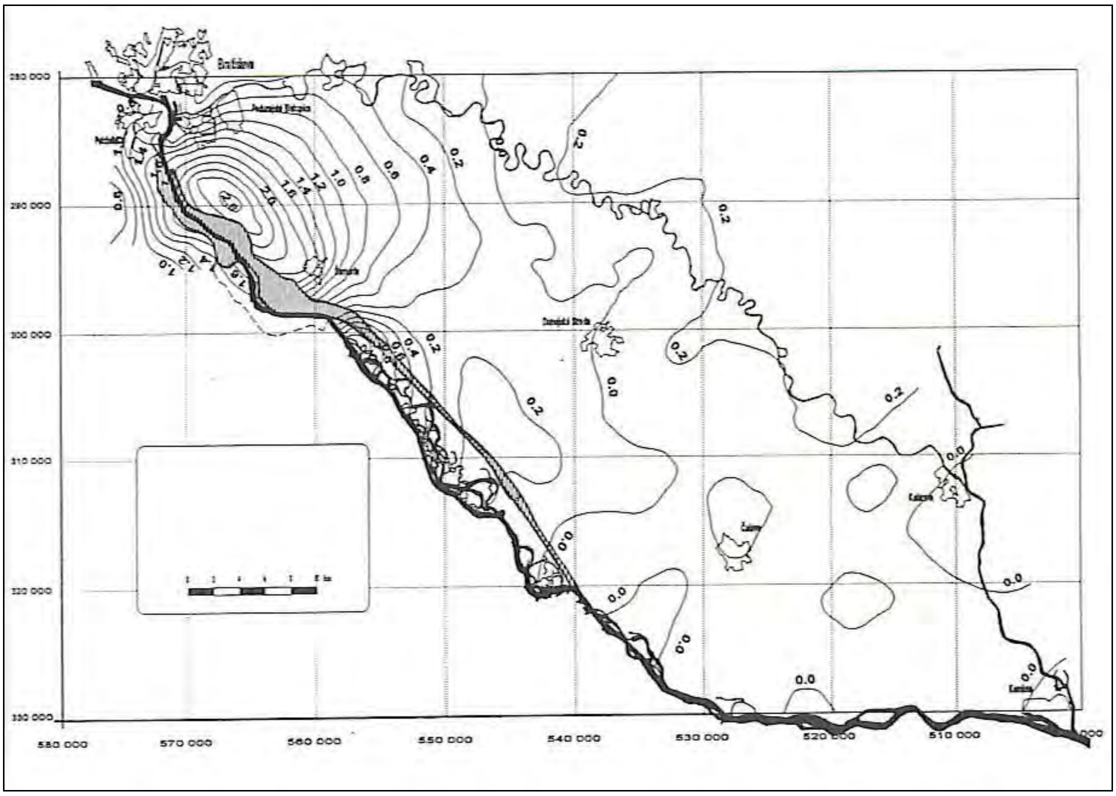

*Figure 8: Difference in depth of groundwater levels between 1990 and 1993 (i.e. 8 months after Gabčíkovo Waterworks was put into operation) in the Great Rye Island Region.*

*Figure 9: Dobrohošť intake.*

In order to preserve the stability of this part of the Great Rye Island it is necessary to find out how the water regime of this area develops and how can it be influenced.
This area is naturally supplied with water by rainfall. Artificial supply is influenced by the Dobrohošť intake, more precisely by filling the old river-basin of Danube with water.

In order to be able to optimally evaluate the impact of Gabčíkovo Waterworks on floodplain forest area since its operation started it is necessary:

- to obtain development data of groundwater levels in floodplain forest areas,
- to evaluate development data of groundwater levels in relation to the water volume filled into channel system by the Dobrohošť intake (to obtain handling instructions of Dobrohošť intake) and overflows in the old river-basin of Danube, which are regulated from Čunovo,
- to have knowledge of overflows in Danube, more precisely the water level of Danube near Bratislava floodplain forests,
- to obtain development data of water supplies in soil and to evaluate them in order to secure the optimal supply of growth by water.