IDENTIFICATION OF CHANGES IN THE HYDROLOGICAL REGIME DUE TO GABČÍKOVO WATER DAM OPERATION

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ABSTRACT

The Gabčíkovo Dam on Danube River was put into the operation in October 1992. The influence of the water reservoir has been observed mostly on the changes of water levels both on surface waters and groundwaters. The backwater influence on the Danube water levels has reached also the water-gauging station in Bratislava, which is the station with the longest data records among water-gauging stations in Slovakia. Due to the changes of flow velocities manifested into the changes of stage-discharge relations since then the discharge has started to be evaluated from the upper station in Bratislava-Devín.

A main topic of this article is the comparison of two 10-year periods: 1979-1988 (before damming) and actual last evaluated 10-year period 2006-2015, in selected monitoring objects of surface waters and groundwater. The changes in discharges are manifested mostly in the part of old Danube channel between the Čunovo weir and Sap, as part of the discharge is flowing through the inlet channel to the hydropower plant. The hydraulic regime of the Danube River under Gabčíkovo (the outlet of the waste channel) is affected just slightly. More significant are the changes in water levels in Danube River channel upstream of the dam, and the changes of velocities, especially in the periods of low flows.

Monitoring of the groundwater levels have confirmed that increased groundwater levels occurred in the surroundings of Bratislava and in the upper part of the Žitný ostrov downstream up to Šamorín and the Little Danube. Decreases of ground water level were recorded in between the entrance into the bypass canal and mouthing of the tailrace canal into the Danube. Besides this, a reduction of amplitudes of ground water level fluctuation occurred along the Danube, Čunovo reservoir and bypass canal; an increase of amplitudes appeared along the tailrace canal and the Danube downstream up to Čičov. The recent general decrease of the ground water level is important in the upper part of the Žitný Ostrov Island, where the largest increases of ground water levels occurred immediately after putting the Gabčíkovo hydraulic structures in operations.

Keywords: Gabčíkovo Water Dam, hydrological regime, Danube River

This article freely follows the poster presented in 2006 in Belehrad [1], where the changes in Bratislava profile on Danube River under the Nový most (New Bridge) were evaluated for the 20-year period 1986-2005.

The aim of this work was to use the results of surface water and groundwater quantity monitoring for the comparison and evaluation of possible changes in hydrological regime due to the construction of Gabčíkovo Dam in 1992 and its operation since then. For an assessment in this paper there were selected two 10-year periods: hydrological years (1979 - 1988 (from the period before the Gabčíkovo dam has been built) and 2006 - 2015 as last evaluated 10 –year period). The periods were selected in this way also to find the same comparable time sections covered in the area of interest by monitoring in stations from both monitoring networks – of surface water quantity as well as groundwater quantity.

Hydrological view of Danube River in Bratislava in selected time periods shows that first period (1997 - 1988) is in average slightly higher in mean discharge (104 %) than actually used mean long-term discharge for reference period 1961 - 2000 ($Q_{a,1961-2000}$) and second period (2006 - 2015) is slightly lower (97%). During the first period the mean annual discharges varied between 85% to 116% of $Q_{a,1961-2000,}$ while the minimum mean annual discharge was recorded in 1984 and maximum in 1980. The minimum mean annual discharge in second period was observed in years 2007 and 2015 (86% of $Q_{a,1961-2000}$) and maximum in 2013 (119% of $Q_{a,1961-2000}$).

The cross section of the river bed and its changes in this profile were assessed from the discharge measurements made those times by a rotating element current meter with a hundred kilogram weight, in the verticals with a 10 m step. During the second selected period in this paper most part of the discharge measurements on Danube were performed by an ADP instrument, and the measurements from New Bridge by the rotating current meter are made sporadically (usually once a year on Danube day in the frame of promo activities for public). In Fig. 1 we have compared the cross section measured in June 2016 with 2 previous ones – from the year 1991 (selected from the measurements made in the period before the Gabčíkovo Dam has been put into operation in October 1992), and one from 2002 (10 years after damming). We can see that between the status from 1991 and 2002 there is a significant increase of the river bed (in the middle part more than 1 m) as the consequence of the backwater influence of dam and in connection with that an increasing sedimentation of moving gravel on the river bed. The measurement in 2016 shows partial decrease of the middle part of river bed when compared with 2002, what can be the result of high flow velocities during the extreme flood from June 2013 (the mean value of flow velocity during the measurement of discharge close to the culmination on 6th June 2013 was 3,3 m/s).

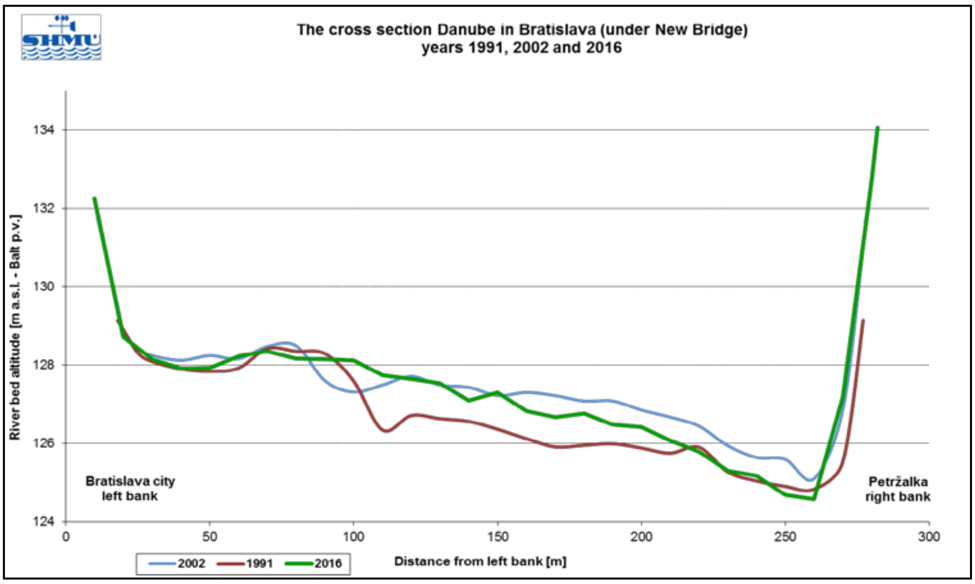

Fig. 1: Cross section Danube – Bratislava (under New Bridge)

The backwater influence together with consequently raised river bed level have caused the change of stage-water relation in the profile of Bratislava water-gauging station. The comparison between the discharge measurements and corresponding water stages in selected periods (1979 - 1988 and 2006 - 2015) on Fig. 2 shows, that in the area of low flows (Q_{364d} = 800 m^3/s) the difference in water levels is about 1,75 m (in previous article comparing also the period shortly before damming the difference was even higher, close to 2 m) and in the area of long-term mean discharge the water level difference makes slightly more than 1 meter. Up to the high discharges (more than 8000 m^3/s) the difference is disappearing.

Similarly, the velocities in this profile have been changed, in the area of low flows (< 800 m^3/s) the values of mean flow velocities have decreased for about 0,5 m/s and for mean long-term discharge (2061 m^3/s) the difference makes about 0,34 m/s.

The mean flow velocities in the profile during the discharge measurements in the period 1979-1988 varied from 1,6 m/s to 3,06 m/s (maximum in August 1985, at discharge ca. 7600 m^3/s), in the period 2006-2015 the mean profile velocities varied from 1,0 m (low flow period in 2011) to 3,3 m/s (during the exceptional flood in June 2013, measured discharge 10 540 m^3/s).

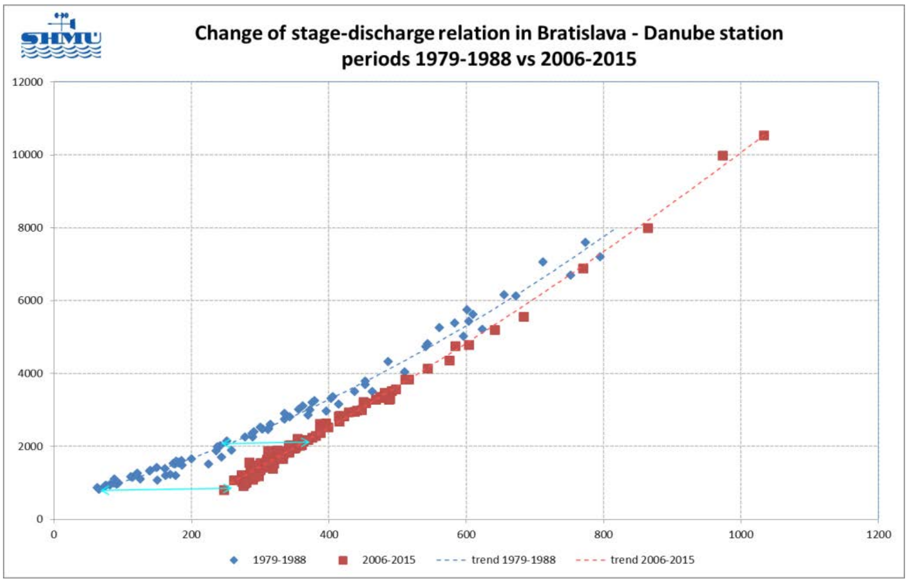

Fig. 2: Change of stage-discharge relation in Bratislava – Danube water gauging station (periods 1979-1988 vs 2006-2015)

After building the Gabčíkovo Dam, the discharge of Danube in the area of water work has been divided into two channels: old Danube river channel and inlet/outlet dam channel. The discharge in the old Danube channel is evaluated in water-gauging station Dobrohošť since November 1995. During the first evaluated period (before Gabčíkovo Dam) the station was not in operation, however, those times the discharge flowing in the old channel was similar to that in Bratislava. In the second evaluated period (hydrological years 1979 - 1988) the mean daily discharges in Dobrohošť varied from 157,3 m^3/s (22nd May 2013) to 5 834 m^3/s (7th June 2013). The mean annual discharges in this profile during evaluated period varied from 335,7 m^3/s (2012) to 428,3 m^3/s (2013), what represents relative parts from 16,6% to 20,1% of the mean annual discharges in water-gauging station Bratislava – Danube, the rest was flowing through the water work.

The nearest water-gauging station on Danube River downstream of the water dam Gabčíkovo is in Medveďov (river log 1806,3 km, what means 62,45 km downstream from Bratislava station). The situation of water-gauging stations Bratislava (5140), Medveďov (5145) and Dobrohošť (5153) is shown at Fig. 4. When comparing the mean long-term discharges in Bratislava and Medveďov maybe it looks unusual, that in downstream station (Medveďov) the discharge is lower than in the upper station. The reason is that between these stations the river is feeding the groundwater, especially at Žitný ostrov, which is a very important groundwater source of drinking water.

The ratio between mean annual discharges in Medveďov and Bratislava in selected periods varied from 92,6% to 98,2% in first period (1979 - 1988) and from 95,1% to 98,1% in second one (2006 - 2015) – see Figure 3. The mean value of the ratio Qr_Medveďov / Qr_Bratislava in first period is 95,5%, while in second period the mean value is higher, 96,4%. The difference 0,9% represents the difference in discharge in average about 18 m^3/s.

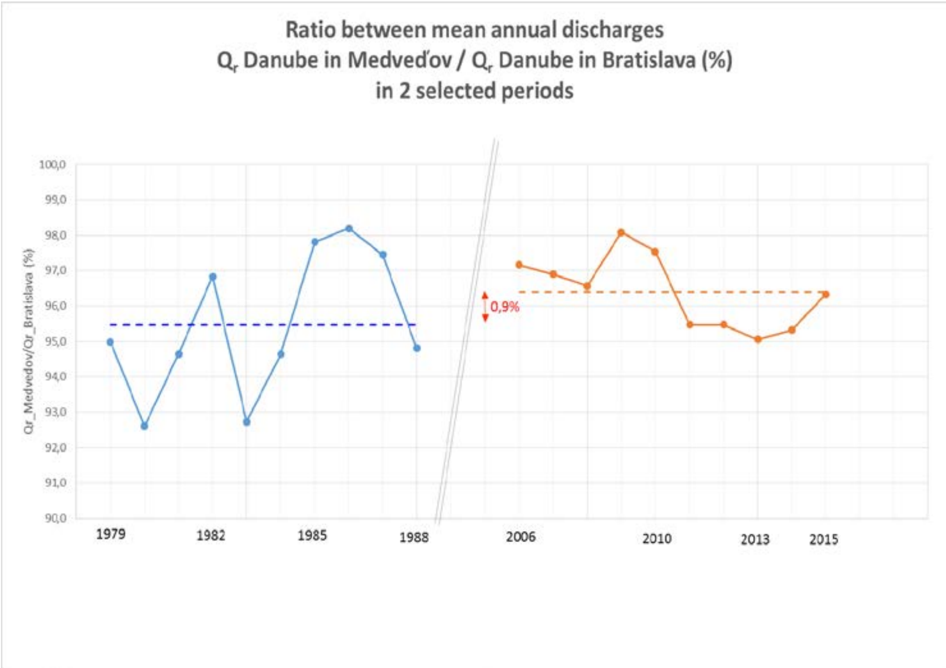

Fig. 3: Ratio of mean annual discharges in stations Bratislava and Medveďov in two selected periods (1979 - 1988; 2006 - 2015)

Groundwater

Monitoring network

During the first evaluated period (1979 - 1988) the groundwater quantity was monitored in more than 300 objects in the broad area of the Gabčíkovo hydraulic structures, and during second period (2006 - 2015) it was in 234 objects. From these monitored objects we have selected 203 objects for evaluation of ground water level regime (**Fig. 4**). The characteristics used for evaluation of ground water level were: maximum, minimum and average states of ground water level, and their fluctuations.

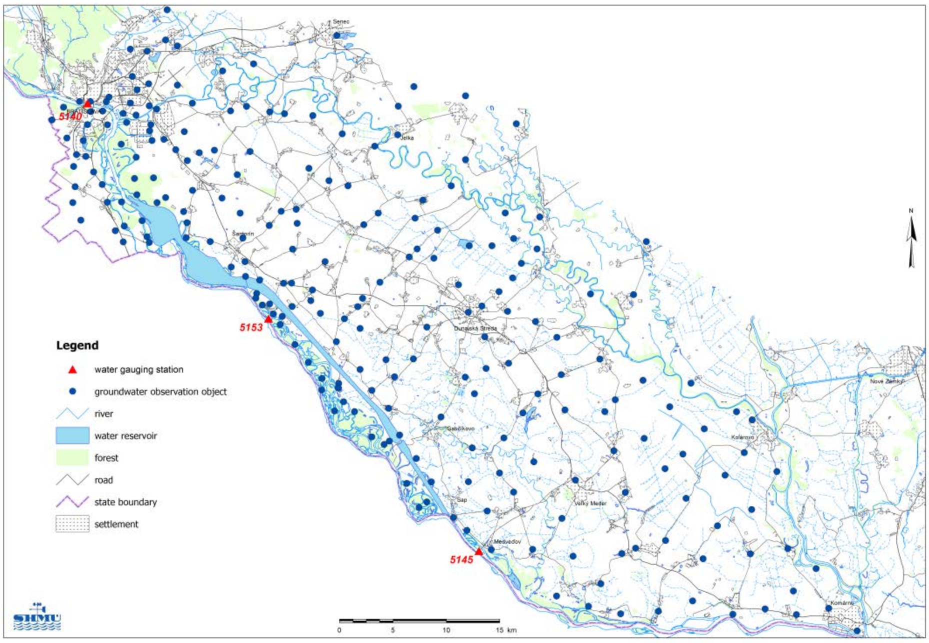

Fig. 4 Ground water level observation network and selected water-gauging stations at Danube River

Maximum states

The maximum level of ground water in the major part of the territory in the period 1979-1988 were higher than those recorded during the period in 2006 - 2015 (**Fig. 5**). Exception is the area between Dunajská Lužná, Trstená na Ostrove, Senec and Jelka where the maximum states decreased (-30-140 cm). In other parts of the territory we recorded increase of maximum states. On the Danube right side, increase up to 100 cm prevailed. The largest declines of maximum states can be observed near Čunovo reservoir, bypass canal and arm system, where the declines reached as much as 140 cm. In other parts of the territory the decline did not exceed 50 cm.

Depth of ground water and its maximum state ranges between 1-3 m in the middle and lower part of the Žitný ostrov Island, with the exception of the area of Nová Stráž – Komárno, where the depth of ground water reaches 4 – 4.5 m, and of the area of the arm system, which is flooded at high water levels in the Danube. In the upper part of the Žitný ostrov Island, the ground water level declines below 3.5 m under the ground surface in the area defined by the line Ivanka pri Dunaji – Zlaté Klasy – Šamorín – Kalinkovo – Biskupické rameno in direction toward Podunajské Biskupice, where the largest water level depth was recorded – almost 9.0 m.

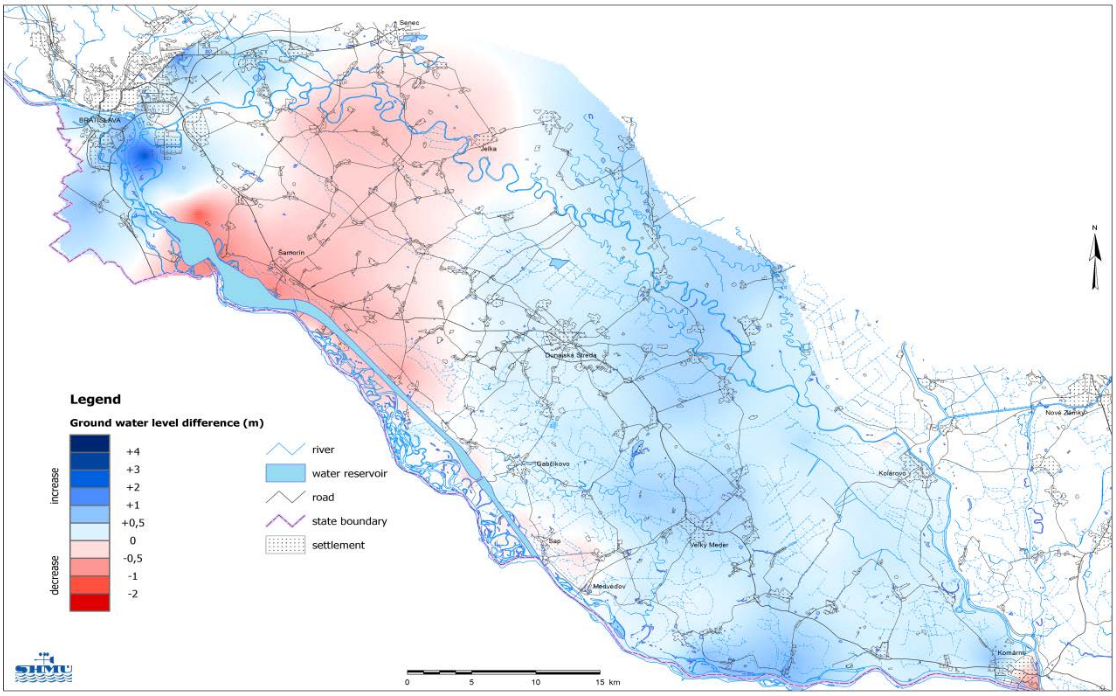

Fig. 5 Ground water maximum level differences between periods (2006-2015) and (1979-1988)

Minimum states

On the Danube right side and in area of the upper part of Žitný ostrov Island, the minimal states in the period 2006 - 2015 were higher than those recorded during the period 1979 - 1988 (by 200 - 400 cm, sporadically even more) (**Fig. 6**). The increase of the minimum states reached 10-30 cm on the remaining part of the Žitný Ostrov Island. In comparison with the earlier states, the difference decreases with increasing distance from the Gabčíkovo hydraulic structures. In the area of the lower Žitný Ostrov at the Danube a decline reaching 30 cm predominated. More significant declines also occur in the stretch Gabčíkovo – Medveďov, even to 100-200 cm.

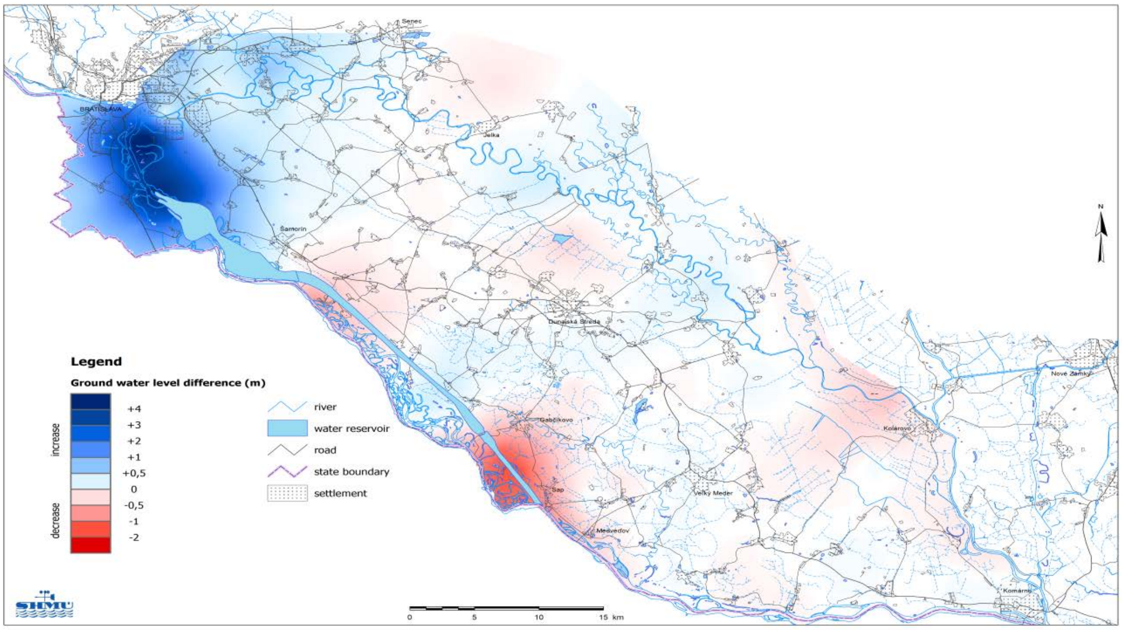

Fig. 6 Ground water minimum level differences between period (2006-2015) and (1979-1988)

Average states

The long-term average states are expressed as their differences between the first (pre-dam) period (1979 - 1988) and the second period (2006 - 2015). As to the average monthly states of the ground water levels, increasing of their values are obvious in the upper part of the territory in 2006 - 2015.

Fig. 7 also shows the reach of changes in ground water levels. An increase was recorded downstream from Bratislava – inclusively of the whole right-side of the Danube – up to Šamorín and towards the Žitný ostrov Island interior up to the villages Most na Ostrove – Tomášov – Kvetoslavov (the highest increase 340 cm), but also insignificant in the central part of Žitný ostrov (up to 30 cm). On the contrary, decreases occurred downstream from Šamorín, in a narrow zone at the left side of the bypass and tailrace canal, as well as along the Danube downstream up to Čičov (the largest decline was at Dobrohošť – 215 cm) and from the Dobrohošť towards the Žitný ostrov interior. The largest increases occur in the surroundings of Rusovce (the Čunovo reservoir right side) and Podunajské Biskupice – Kalinkovo and Hamuliakovo of the Danube left side.

The largest difference between both periods occurred in the months showing the lowest states of ground water level (October – December) in pre-dam conditions, while the lowest difference occurred in the months originally showing the highest states (May – June). In the surroundings of Šamorín, the levels increased after putting the project into operation, but the differences are already not so strong; similarly in the upper parts of Žitný ostrov, which are more distant from the Čunovo reservoir (Tomášov). Downstream of Horný Bar up to Medveďov, the states of water levels were higher in the initial stage; the highest differences occur in the surroundings of Dobrohošť and Gabčíkovo.

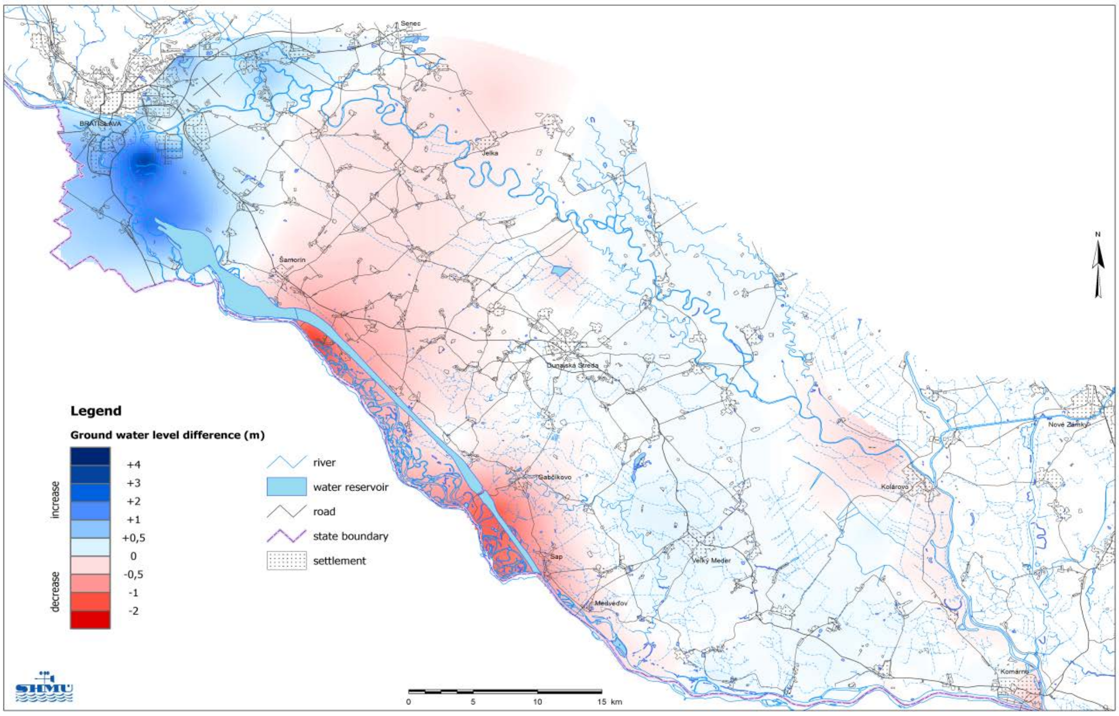

Fig. 7 Ground water minimum level differences between periods (2006-2015) and (1979-1988)

Evaluation of trends

Development trends of ground water levels are estimated on the basis of data from one cross-section in upper part of Žitný Ostrov Island (**Fig. 8**) separately for the period 1979 - 1988, and for a 10-year period of operation of the project (2006 - 2015). In the pre-dam period, the decreasing trends prevailed at all measuring objects: most strongly in the upper part of the territory of the Danube - Petržalka, Podunajské Biskupice, Kalinkovo; in the downstream direction the decline was weaker; in the surroundings of Sap and Medveďov the declines were already moderate. After putting the project into operation, the character of the trends turned into increasing trends. In the first five years this increase was strongest just in the upper part of the territory, upstream of the Čunovo reservoir and along it. Only in the surroundings of the tailrace canal did the decrease continue. In the course of time, the character of the trends started to change. Upstream from the Čunovo reservoir, in vicinity of the stream, the increasing trend persists, but already in the surroundings of the reservoir a decreasing trend occurs. In the upper part of the Žitný Ostrov Island the increasing trend has turned into a balanced state. At Šamorín, the ground water level, after a strong initial increase, is gradually decreasing almost to the pre-dam level with a tendency to further decreasing. The decreasing trend also continues along the tailrace canal. In the area of confluence of the tailrace canal with the Danube old riverbed, the earlier balanced trend turned into a decreasing trend.

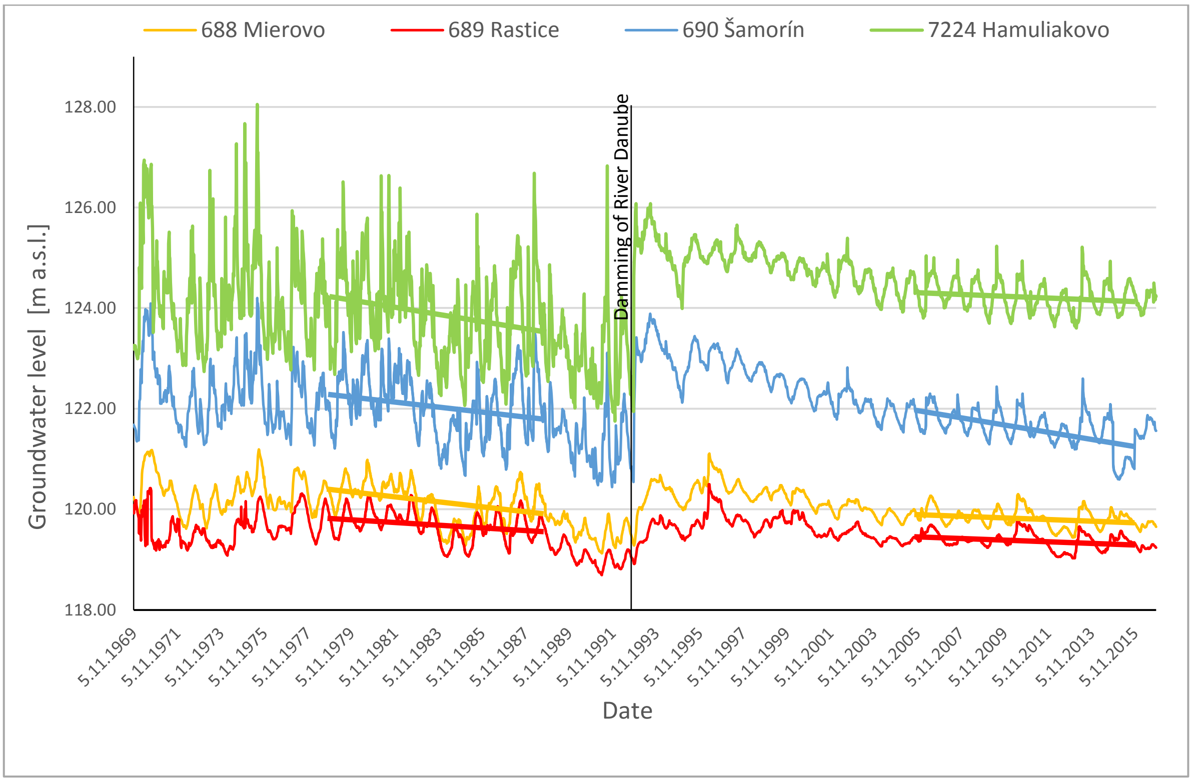

Fig. 8 Trends of groundwater level

Fluctuations of ground water level

Fluctuation of ground water level is evaluated first of all on the basis of annual sums of weekly amplitudes. The weekly amplitude means the difference in two subsequent measurements. The annual sum of weekly amplitudes is the sum of the absolute values of weekly amplitudes. For comparison of both periods we elaborated differences of average annual sum amplitudes, which show areas of increased or reduced movement of ground water levels. A reduction of amplitude of ground water levels occurred along the Danube, actually downstream from Bratislava up to Trstená na Ostrove and toward the interior of the Žitný ostrov Island downstream from Podunajské Biskupice, through Rovinka up to Šuľany [2]. On other hand, the fluctuations increased along the tailrace canal and downstream along the Danube up to Čičov, but the area showing a reduction of fluctuations is larger than that with increased amplitude of ground water levels. In remaining part of the territory, the enlargement of decreases of average annual sum of amplitudes are insignificant and they cannot be explained by influences of the Gabčíkovo hydraulic structures.

Groundwater level contour map

To visualize the ground water level in the area, contour map are used. The high ground water levels were used to construct high ground water level contour maps on 2.6.2010 **(Fig. 9).** This contour map shows the general changes in ground water level position and flow direction.

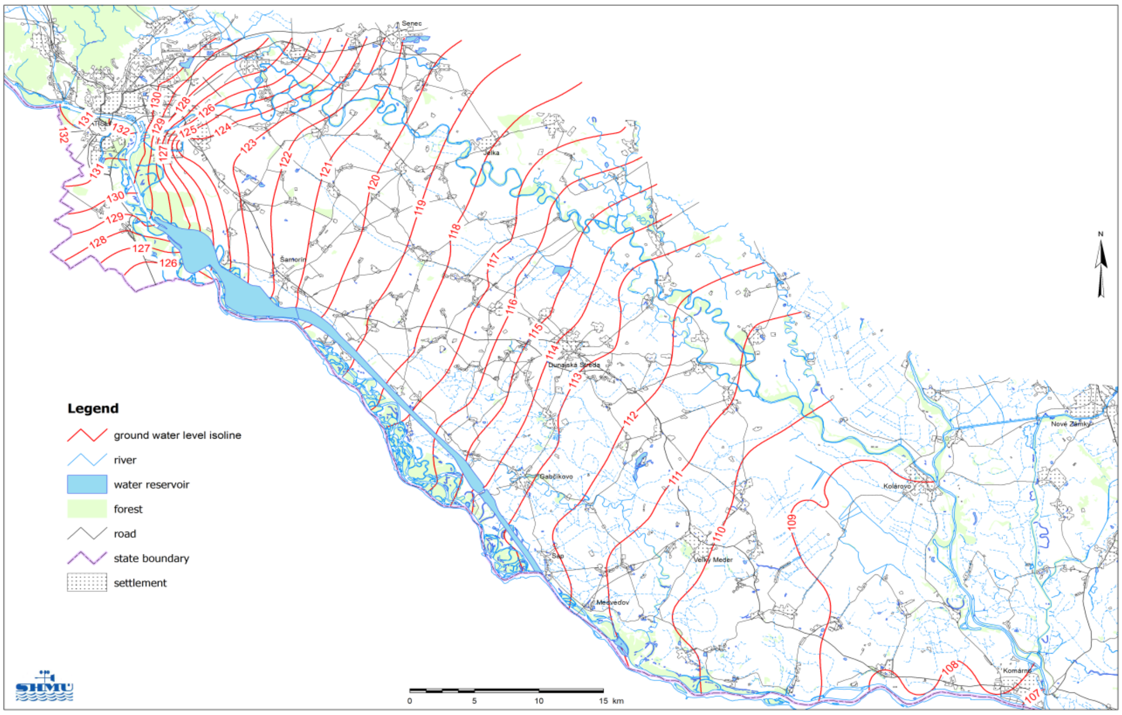

Fig. 9 High ground water level contour map on 2.6.2010

Summary

The Gabčíkovo Dam has significant backwater effect in Bratislava water gauging station, where the water level has increased in the area of minimum discharges for about 1,75 m and the velocities have decreased for about 0,5 m/s. This influence is also manifested in changes of the cross-section, where the river bed in middle and deeper part of the cross-section in this profile was raised by accumulation of the transported material (gravel), even in last years it has been partly lowered, probably by high flow velocities during the flood in 2013. The changes in discharge regime in Danube River between Bratislava and Medveďov (water-gauging station under the water work) are not significant; however, we can see the change in the ratio between mean annual discharges in Medveďov and Bratislava in selected periods, the slight increase of this ratio in second period can indicate a decrease in feeding of the groundwater in this area; the difference in average about 18 m^3/s represents the amount about 568 millions m^3 per year possibly not getting into the groundwater in the section between Bratislava and Medveďov (upper part of Žitný ostrov) in comparison with the first period.

During the whole period of operating of the Gabčíkovo project it has been confirmed that increased groundwater levels occurred in the surroundings of Bratislava and in the upper part of the Žitný ostrov Island downstream up to Šamorín and the Little Danube. Decreases of ground water level were recorded in the stretch between the entrance into the bypass canal and mouthing of the tailrace canal into the Danube (with two localities of the largest decrease – Dobrohošť and Gabčíkovo). Besides this, a reduction of amplitudes of ground water level fluctuation occurred along the Danube, Čunovo reservoir and bypass canal; an increase of amplitudes appeared along the tailrace canal and the Danube downstream up to Čičov. The recent general decrease of the ground water level is especially important in the upper part of the Žitný Ostrov Island (surrounding of Šamorín), where the largest increases of ground water levels occurred immediately after putting the Gabčíkovo hydraulic structures in operations. These findings are consistent with the evaluation of changed ratio between the Danube dicharges in Bratislava and Medveďov mentioned in previous paragraph.

References

[1] Blaškovičová, L. – Martinka, M. – Poórová, J.: „Changes of river cross-sections on Slovak part of Danube in the period 1986-2005“, poster, XXIII Conference of the Danubian countries on the hydrological forecasting and hydrological bases of water management, Belehrad, Srbsko, 2006.

[2] Chalupka, J. – Paľušová, Z.: Monitorovanie hydrologického režimu podzemných vôd v oblasti Vodného diela Gabčíkovo, Ročná správa za rok 2002, SHMÚ Bratislava, 2003.