Possibilities of Water Storage in Drainage Channel System of the Upper Rye Island

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Abstract. Consequently, to the construction and operation at water power plant Gabčíkovo came to changes in water regime in adjacent area. The power canal of the Gabčíkovo power plant cut the upper parts of the drainage system in Danube Lowlands. Groundwater level changes have occurred in the vicinity of the Hrušov reservoir what caused changes in discharge and water level regime of the drainage channels. Presented contribution deals with theoretical and practical background of the water management in agriculturally exploited regions, especially with the possibility to create and store enough water for irrigation in the channels of one part of the Rye Island. It was therefore necessary to measure and calculate the capacity of given channels as well as the volume of water stored by means of improved operation on hydraulic structures or by construction of new structures. Rye Island belongs to an area where agriculture in the growing season, especially due to the irregular distribution of precipitation, very often suffers from drought. The probability of ensuring at least 10 mm of precipitation in one decade of the growing season is only 50% and the probability of 30 mm of precipitation is only 20%. It follows that without irrigation the moisture for vegetation cover is not ensured. But there can be years with heavy rainfall and then there is no need to irrigate. Rye Island is the warmest area of the Slovakia where the vegetation period is also the longest. Most of it belongs to the area of corn production type. The irrigation economy is therefore profitable. However, the technology of implementation and the effort to introduce large-scale irrigation as soon as possible led to the conclusion that this issue should be considered from several points of view.

1. Introduction

In the presented paper we deal with the possibilities of controlling the level regime of groundwater, resp. soil moisture regime using drainage channel systems used for draining the internal water of the Rye Island.

As a result of the construction and operation of the Gabčíkovo water power plant (GWPP), the network of drainage channels and their flow regime were interrupted. The upper sections of the secondary channels A, B, C of the S-VII system were partially liquidated by the derivation channel and the inlet structure at Gabčíkovo with a capacity of 10 m³·s⁻¹ to improve the flows of the Gabčíkovo - Topoľníky (S-VII) channel for irrigation was decommissioned (Figure 1). There was also a change in the groundwater level regime – an increase in the vicinity of the Hrušov reservoir on the upper Rye Island and a decrease mainly in the section of the downstream power canal, which is also reflected in the flow regime of the drainage channels of the adjacent area. As a replacement for the
cancelled water abstraction from the Danube near Gabčíkovo, increased seepage in the section of the reservoir and the diversion canal captured by the left seepage channel with possible filling through the abstraction structures into the Vojka-Kračany (A-VII), Šuľany-Jurová (B-VII) and Trstená-Baka (C-VII) drainage system of the main Gabčíkovo-Topoľníky channel and thus through connecting channels to other drainage systems, as well as water supply to the main channel Gabčíkovo-Topoľníky from the left seepage channel of GWPP and through the structure at km 16.0 on the power canal also from the power canal itself.

Last but not least, it is also possible to take irrigation water from the GWPP downstream power canal to Chotáryň channel, i.e. to the S-VI system and related systems [1], [2]. This ensures the possibility of increased use of drainage channels for direct abstraction for irrigation, but also for the possibility of creating increased infiltration from the channels into the adjacent soil profile and thus increase the groundwater level, which in certain localities can provide capillary rise from the groundwater level.

![Figure 1. Illustration of the area of interest with investigated drainage channels](image_url)

Rye Island belongs to an area where agriculture in the growing season, especially due to the irregular distribution of precipitation, very often suffers from drought. The probability of ensuring at least 10 mm of precipitation in one decade of the growing season is only 50% and the probability of 30 mm of precipitation is only 20%. It follows that without irrigation, moisture for vegetation is not ensured. But there can be years with heavy rainfall, so there is no need to irrigate. Rye Island is the warmest area of the Slovakia, where the vegetation period is also the longest. Most of it belongs to the area of corn production type [3], [4]. The irrigation economy is therefore profitable.
The source of irrigation water is the surrounding rivers, the water in the drainage channels and the groundwater of the first horizon of the gravel layers of the island. Much has been discussed about how to use these resources. It was reasonable to think that, first and foremost, the existing supplies should be used and, if these supplies would not be enough, to supply water from the rivers. However, the technology of implementation and the effort to introduce large-scale irrigation as soon as possible led to the conclusion that this issue should be considered from another point of view. Experience in our country and abroad has led to the fact that irrigation in our country is almost 100% carried out by sprinkling and as a source of water can be used directly water from rivers, to some extent water from drainage channels. On plots where there are no drainage channels, water must be brought with special channels. According to the current state, irrigation water from the rivers can be delivered gravitationally from the Little Danube through a special irrigation channel and from the Danube through the sluice at Gabčíkovo to the main drainage channel S-VII. Water from drainage channels, lakes, gravel pits and groundwater (using wells) is also often used to irrigate smaller areas. Monitoring of the groundwater regime has shown that it is not possible to irrigate only from one’s own groundwater sources, despite the multi-billion reserves in the Rye Island subsoil. We can use the groundwater supply if we do not want to change the natural conditions from the ground up, only the so-called dynamic part, i. e. the amount that will flow into the rivers directly or through drainage channels from the subsoil of the Rye Island in the average year. According to the data obtained by observation, if we do not take into account the current normal consumption, we can estimate a multiannual average at 7 to 8 m³ s⁻¹. That would be enough for regular irrigation of about 16,000 hectares of land.

However, a new agricultural problem is emerging with irrigation management: how the irrigation regime, in particular the groundwater level, will develop. It is a fact that by delivery of foreign river water into the territory of the Rye Island, we will change the current water balance. There will be higher amount of water in the drainage channels not only in spring time (April, May), but also throughout the summer, what means that groundwater can receive replenishment from the channels instead of two months up to six months. When we irrigate, the soil will be wetter than before, the pores in the soil will fill faster with precipitation, so they will release more water into the groundwater during precipitation. Overdoses irrigation water can make this process even worse. These factors can cause the groundwater level to rise already in summer and winter rainfall to increase the spring level to harmful heights. In view of this danger for agricultural production, it is still necessary to monitor the overall balance in the irrigation fields and in their subsoil by setting up groundwater monitoring facilities. According to the data obtained, the operation of the entire irrigation and drainage system must then be guided. A comprehensive plan needs to be drawn up to determine the sources of irrigation for the whole area at once and to determine in advance from which source the individual areas will be irrigated [5].

2. Definition of the area of interest
Upper Rye Island area is bounded on the north by the road Bratislava-Komárno, on the southwest by the GWPP diversion power canal (Figure 1) and on the southeast by the main drainage channel Gabčíkovo-Topoľníky (S-VII). The total area of interest is approximately 11,000 ha. There are three main drainage channels in the area of interest:
- Vojka – Kračany channel (A-VII) with a length of 18,200 km,
- Šuľany-Jurová channel (BVII) with a length of 9,900 km and
- Trstená-Baka channel (CVII) with a length of about 3.0 km.
All three channels are left tributaries to the main drainage channel Gabčíkovo-Topoľníky (S-VII).

The Rye Island is a territorial unit bordered by the Danube River, the Little Danube and the Váh River. It belongs geologically to the Quaternary district. The area of the island is approx. 188,000 ha, with a length of 88 km and a width of max. 25 km. The highest point is below Bratislava 135 m a. s. l.
and the lowest at Komárno 108 m a. s. l. The average slope of the terrain is 0.03%. The formation of the regime and the creation of groundwater resources in the transverse area of the Danube are determined by several factors and conditions. Geological, tectonic, morphological and hydrological changes created a huge sedimentation reservoir in the central part of the Rye Island, in which gravel and sand accumulated during the Danube activities and at the same time created favorable conditions for the accumulation of groundwater that can be used for water management as well as for drinking purposes.

Geologically, the Rye Island is formed by a Neogene and a Quaternary. The Neogene is represented by Pannonian sediments, which were formed during the retreat of the sea from the Pannonian Basin. They are formed by clays and clayey sands. The Quaternary is composed mainly of gravel of various thicknesses. In the western part around Bratislava, the thickness of the Quaternary sediments is about 10 m, near Šamorin already about 100 m and along the Danube around Bodíky and Gabčíkovo over 250 m. Gradually north of the Danube, gravel sands, which have a typical fluvial character, pass into sandy sediments, which sink towards Kolárovo to a depth of 80-100 m [6]. The thickness of the surface cover layer ranges from 0.60 to 2.80 m, the average thickness is 2 m. The cover is represented by clays, loam and sands in the most varied proportions and combinations, and often with clayey admixtures. Loam with a predominance of organic matter of plant origin is often present. The imported material is usually gravel to sandy gravel. The evaluation of some boreholes on the composition of the cover layer in the area of interest is presented in [7].

According to Konček's classification [6] Rye Island belongs to the semi-desert type, which is characterized by the maximum precipitation in May followed by dry period and a secondary maximum precipitation in autumn. In long-term observation, the annual average precipitation in Šamorín is 573 mm, Dunajská Streda 568 mm, Veľký Meder 546 mm, but depending on the individual years, the amount varies between 330 – 830 mm. The time distribution of precipitation also shows large differences. For the proper development of vegetation, there is a lack of moisture in the root zone of the soil profile in the second half of the growing season, which is also reflected in the years with an average amount of precipitation. Average annual temperatures are around 9.7 °C. The average temperature in the growing season is 15 °C. However, the temperature fluctuation shows significant differences from -35 °C to 40 °C. The growing season on Žitný ostrov lasts an average of 245 days [8]. Northwest winds predominate. There are about 70 days without wind in the year, which is unfavorable in terms of vegetation, because the wind quickly dries the soil after the rain. Another important factor influencing irrigation is potential evapotranspiration. It is a kind of complex expression of the ability of the atmosphere in the ground layer to energetically allow evaporation (including from the leaf surface) of water and thermodynamic removal of released water vapor from the evaporating surface. The average annual value of potential evapotranspiration on Rye Island is 725 mm.

Figure 2 shows the ratio of total precipitation to potential evapotranspiration in the growing season in the years 1955 – 2005. It is clear that in the months from April to September (vegetation period) this ratio does not reach the value µ = 0.7 (it is not necessary to irrigate). It follows that irrigation of land in the district of Dunajská Streda is justified and irrigation structures will be used in virtually every growing season.

Groundwater on Žitný ostrov is located in heavily permeable sediments, which are gravels, sands and sandy gravels. It is supplied from three basic sources:

- by bank filtration of the Danube, the Little Danube, the Váh and the surrounding rivers,
- infiltration of atmospheric precipitation and
- groundwater flow from the higher areas (Little Carpathians).
Each of the sources represents a certain groundwater regime. Bank filtration from the Danube creates a complex groundwater regime. From a hydraulic point of view, this can be characterized as a constant uneven flow of groundwater with a free surface over an impermeable subsoil. The impermeable subsoil here is formed by Neogene sediments.

In general, in the Danube Lowland we can observe three main streams of groundwater. The first, almost parallel to the Danube, proceeds from the Hrušov reservoir, the second almost parallel to the Little Danube on its northern side and the third from the North to South through the Váh River valley. These streams of groundwater converge on the lower part of Žitný ostrov and are drained by them during periods of low river levels. At high river levels, even in these areas, groundwater is replenished by bank infiltration, so that large amounts of groundwater accumulate here, but without the possibility of groundwater runoff and therefore rise to the surface and drained, unless they evaporate, only a system of channel stations at the mouth of the rivers (Little Danube, Danube and Váh).

![Figure 2. Ratio of mean precipitation and evapotranspiration for years 1955 – 2004](image)

### 3. Results and discussion

One of the main factors of soil fertility is the optimal state of moisture in the root zone of the soil profile, which can also be influenced by technical measures in connection with the control and regulation of the amount of water. Especially in the territory of Rye Island which is intersected by a network of drainage channels, there are possibilities of suitable water control given by rapid replenishment from the Danube River and currently especially from Hrušov reservoir, as well as conditions for water distribution for irrigation using main drainage channels. First and foremost, it is the effect on the groundwater level in the adjacent area.

The control system of the channel network is multi-purpose. Its elements are channels, sluices and pumping stations. Any individual unit can serve a single goal in a bounded area or multiple goals in area cooperation. However, the structure of all units has to contribute to optimization of overall environmental and economic needs of the territory. The concept of drainage is adequately followed by the concept of irrigation, which is directly imposed by the profitability of irrigation management in the warmest area of the republic with the longest growing vegetation period and the richest natural groundwater resources. The direct cause of soil drying in the area of interest is due to lack of water caused by lack of precipitation and irrigation during the growing season, water consumption for evapotranspiration and low groundwater level. The roots of the causes must be sought not only
in natural conditions, but also in technical interventions in the natural environment, especially in the conceptual solution of irrigation. The concept of irrigation should focus primarily on selecting the most cost-effective sources of irrigation for defined areas. Suitable sources of irrigation water are the surface waters of the surrounding rivers, drainage and irrigation channels and groundwater from gravel pits, lakes and wells in accordance with applicable water quality standards for the protected water management area [9].

Drainage channels and their capacity – as shown by the findings of recent years – is able to ensure their good functioning (especially good maintenance) and efficient operation (handling of control devices – sluices) to drain the internal water caused by precipitation and high groundwater levels. The change in surface water level after closing the sluice is well illustrated in Figure 3. It illustrates the longitudinal slope of the bottom of the A VII channel with changed surface water level caused by closing the sluices on it. It has consequent impact on groundwater level increase which was measured in boreholes near the channel.

Irrigation of land close to the channel in the area of interest is carried out by irrigation machines. These are mostly crawler sprinklers. They consist of a winding spool and a trailing hose, at the end of which there is a sprinkler on a special base. The length of the hose is approximately 285 m and the sprinkling of one sprayer is about 35 – 40 m. For an irrigation dose of 40 mm (corn) on the entire surface, a time of complete winding of 24 hours is required at a hose winding speed of 20 cm·min⁻¹. At this winding speed and flow rate of 8 l·s⁻¹, the size of the effectively irrigated area is 1.8 ha. Water is supplied to irrigation machines by pumping from irrigation channels. To pump water from channels for irrigation machines, so-called submersible pumps are used. The depth of water in the channels must be at least 0.6 – 0.8 m. When the sluices in the AVII channel are completely closed, the levels do not reach the required depth everywhere. The levels above the gates No. 5 (km 10.981), No. 6 (km 10.981) and No. 7 (km 14.772) are insufficient (Figure 3).

![Figure 3. The longitudinal slope of the A VII channel with illustration of 1.6 m high sluices](image)

Our first suggestion was to fulfil drainage channels in this region as soon as possible after the winter period so that they can be pre-filled for irrigation purposes (not earlier than in May). In a very detailed “in situ” investigation we have tried to measure at different discharges and water levels in the
drainage channel the extent of its influence on groundwater regime [10]. Unfortunately, the effect of operation on controlling gates (increase or decrease of water level) have shown not more than 50 m distance from the channel which is directly affected. But measuring discharges downstream the channel it was shown that the drainage effect can be decreased by means of good operation up to 45%. It means in digits, that in beginning of the drainage channel there are usually about 25 l·s⁻¹ flowing from seepage channel and without any operation on gates (Figure 3) and the discharge flowing out from the drainage channel is about 250 l·s⁻¹ leaving the channel. After handling the gates before and during the vegetation period (March – October) the amount at the end of the channel decreased to 150 l·s⁻¹. The solution of this problem would be the realisation of three new sluices on the AVII channel. This solution is illustrated in Figure 4 where those mentioned gates are included. They would ensure sufficient depth for the pumping of water for irrigation machines along the whole drainage (irrigation) channel.

**Figure 4.** The longitudinal slope of the A VII channel (proposal) with three additional sluices

4. Conclusion

Gabčíkovo power plant is one of the largest water management projects in Europe. Its construction and operation has changed the groundwater regime in the adjacent area, as well. Presented paper has tried to show very briefly the water management in the agriculturally exploited region of the Danube Lowlands – Rye Island, especially the upper part of it. In last fifty years a dense system of drainage channels has been constructed in this region. Nowadays, in period of climate changes, the second – irrigation function of these channels is appearing more and more. It gives a possibility of subsurface groundwater supply as well as the opportunity for a surface irrigation directly from the channel. The permanent water supply from left seepage channel of the GWPP enables such water management and irrigation realisation in this agriculturally exploited region.

Other possibilities of influencing the groundwater regime have been investigated in the past, as well. All of them are very important, maybe more important that an artificial supply of drainage channels, but they are much more expensive and their realisation takes a lot of time and expenses.
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References
[1] Y. Velísková, R. Dulovičová, R. Schügerl, “Impact of vegetation on flow in a lowland stream during growing season,” *Biologia*, vol. 72, No. 8, pp. 840–846, 2017.
[2] A. Šoltész, D. Baroková, Z. D. Shenga, and M Červeňanská, “Hydraulic assessment of the impacts of gate realization on groundwater regime,” *Pollack Periodica*. vol. 15, no. 3, pp. 162–171, 2020.
[3] B. Kandra, M. Gomboš, “The importance of volume changes in the determination of soil water retention curves on the East Slovakian Lowland,” *Journal of Water and Land Development*, vol. 45, pp. 54–60, 2020.
[4] L. Jurík, K. Halášová, J. Pokrývková, Š. Rehák, “Irrigation of arable land in Slovakia: History and perspective,” *Handbook of Environmental Chemistry*, vol. 69, pp. 81–96, 2019.
[5] A. Šoltész, “Water Management in the Shared Danube River Section with Respect to Hydro Power Plant Construction,” *Proc. Of Conference on Shared Rivers*, USCID Park City, pp. 281–292, 1998.
[6] J. Šútor, and V. Štekauerová, “Hydrophysical parameters of Žitný ostrov, *Institute of Hydrology of the Slovak Academy of Sciences* – ASCO, Bratislava, 168 p., 2000.
[7] R. Dulovičová, Y. Velísková, “Aggradation of irrigation canal network in Žitný Ostrov, Southern Slovakia, *Journal of Irrigation and Drainage Engineering*, vol. 136, Issue 6, pp. 202–209, 2010.
[8] M. Gyalokay, “Protection of the Žitný ostrov from waters,” *Theses and studies*, vol. 62, WRI Bratislava, 102 p., 1972.
[9] F. Gažovič, “Optimization of the operation of the Žitný ostrov canal network system,” *Research report No. R-99-531-044-05*, WRI Bratislava, 145 p., 1983.
[10] R. Slota, L. Tóth, “Determination of the consumption curve of channel A VII on the basis of calibration measurements on the sampling structure from the left seepage channel,” *Final Research Report*, WRI Bratislava, 35 p., 1995.