

Gabčíkovo locks operation safety, capacity and reliability improvement project

Pre-feasibility study

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1. Introduction

The Danube as a waterway of international importance E80 has to comply with mandatory navigational parameters required for year-round use of the waterway in accordance with the European Convention on Main Inland Waterways of International Importance (AGN) as well as with the Belgrade Convention and the recommendations of the Danube Commission. The Danube waterway as a waterway of international importance shall provide for a specific service efficiency under international classification of inland waterways, which is not possible under the current ratios due to insufficient provision of required parameters of the fairway throughout the navigable season.

The provision of the required parameters of the Bratislava Danube waterway is inter alia supported by multilateral and bilateral conventions, agreements and treaties as well as other relevant policy documents and policies.

The strategic objective of the project is to increase the efficiency, reliability and thus the competitiveness of the Danube waterway, which is part of the Trans-European Transport Network (TEN-T). Among other things, it aims to strengthen the sustainability of waterway transport between Slovakia and other countries of the Danube waterway and, in accordance with the policy of the European Union, to support this with an economical and environmental transport mode, which has enough spare capacity. At the same time, the focus of the study will assist in meeting the requirement of the Regulation of the European Parliament and of the Council (EU) 1315/2013 of 11 December 2013 on Union guidelines for the development of Trans-European Transport Networks, repealing the Decision No 661/2010/EU, to complete the construction of the core TEN-T network until 2030 and a comprehensive network later in 2050

Under the Treaty on the Construction and Operation of the Gabčíkovo – Nagymaros Dams (hereinafter the SVD G-N), the G-N Dams consists of Gabčíkovo Dam (VDG) and Nagymaros Dam (VDN), which forms an integral and unified operational system in terms of hydraulic, navigation and energy aspects.

Pursuant to Temporary Operational Procedure (DMP) for SVD G-N applicable for the entire territory of the Slovak Republic, which is the official document for managing the operation of the VDG, the purpose of the VDG is to use the given section of the Danube River and provide the conditions for:

- international transport by complying with the fairway parameters applicable for the Danube waterway set forth in the recommendations of the Danube Commission;
- water management, especially flood protection on the territories of both states - Slovakia and Hungary;
- the flow to the Danube (below Čunovo Dam) in accordance with the intergovernmental agreement between Slovakia and Hungary of April 1995;
- the necessary offtakes of water from the section Bratislava - Gabčíkovo Dam (Sap);
- production of electricity in Gabčíkovo Hydroelectric Power Plant (VEG), Small Hydro Plant (MVE), Dobrohošť, MVE on S-VII, MVE Mošon, VE Čunovo - until the construction of the Nagymaros Dam;
- safe drinking water in the adjacent area;
- environmental protection and economic development of neighbouring areas, including tourism.

Compliance with the conditions of International Danube Waterway is the priority of the VDG under this document.

1.1. VD Gabčíkovo today

VDG situation is summarized in figure 1, 2 showing the layout of the key groups of objects and placement of objects.

VDG is consisted of Čunovo Dam (StC) with its objects, Hrušov – Dunakiliti Reservoir (ZH-D), Diversion Channel (DeK) and Gabčíkovo Dam (StG). StG divides DeK to an supply channel (PK) and drain channel (OK). In parallel with DeK runs the old Danube riverbed (SDK) along the right side between StC and conflux with OK in rkm 1811 of the Danube at Sap.

Two locks (PLK) and a hydroelectric power plant (VEG) are part of the StG; 3 weirs, 2 VE and auxilliary lock (PoPLK) are part of the StC.

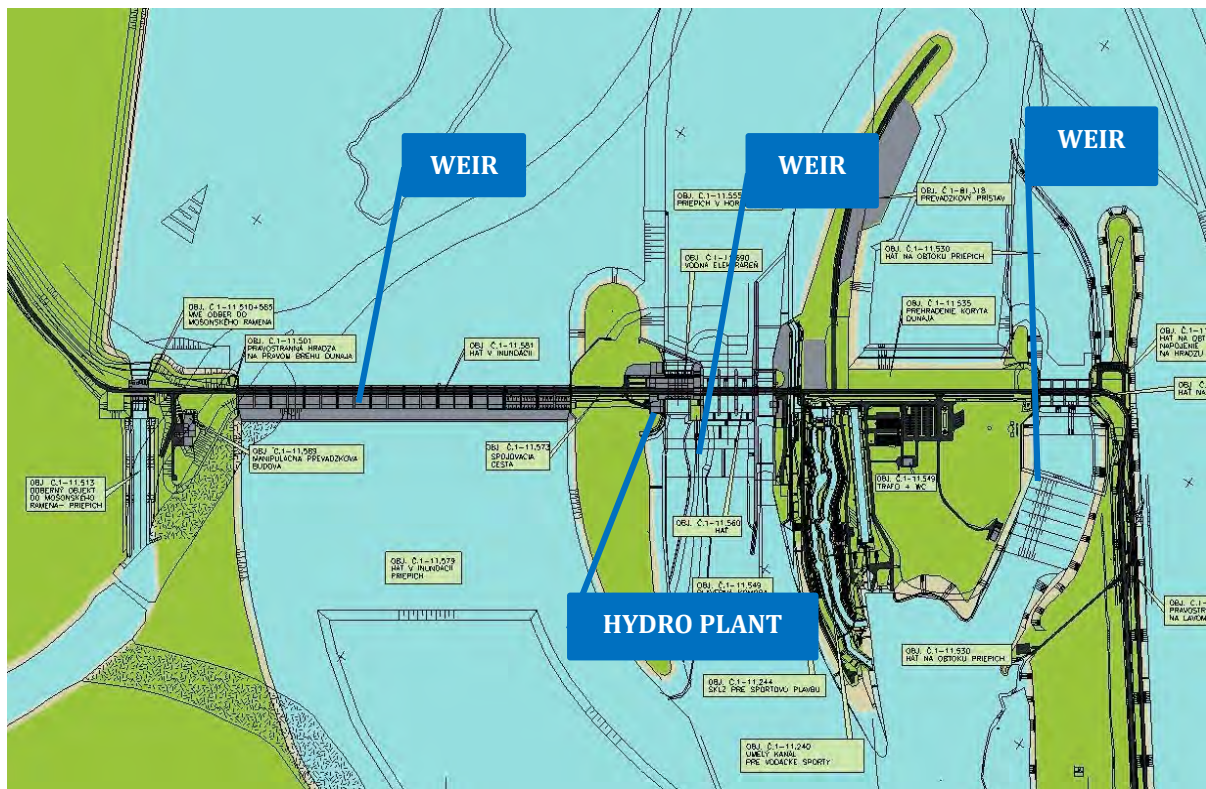


Fig. 1 VD Čunovo Situation

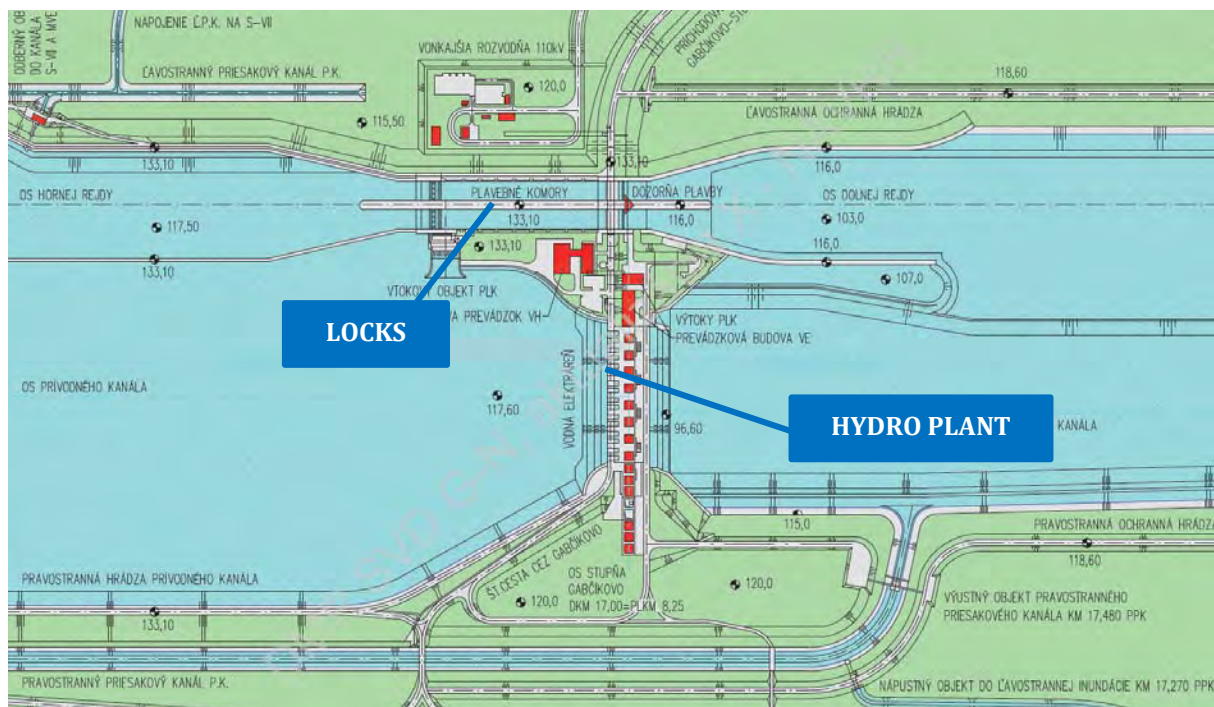


Fig. 2 Gabčíkovo Dam Situation

The current operation of the VDG is different than as it was originally planned in the Joint Contracting Protect (SZP) between Slovakia and Hungary due to the fact that VDN has yet to be carried out. The most important implications with regard to waterway aspects of the VDG operation are:

a) Without VDN that did not raise the level of the Danube in the section downstream below VDG, sufficient navigable depths in the section below VDG are not provided for and rkm section 1811-1708 (i.e. part of the

Slovakian Hungarian section of the Danube) is currently limiting in terms of navigation for the entire navigable Danube (i.e. containing shallow points with the lowest depths); See Chapter 9.

b) VEG does not operate with the so-called regulatory (peak) mode, which is characterized by the use of ZH-D volume to process larger than the natural flows inflowing into Slovakia at the Devin section. Regulatory operation of VEG would be causing significant volatility of flow rates in the section below StG. This is not possible without VDN, because significant decrease in flow rate could be significantly limiting navigable depths threatening the safety of navigation, especially in shallow points, for the part of the day outside peak energy production times. Regulatory operation is therefore limited to a period of higher flow rates and is subject to rigorous control systems, which control the passing of flows through VEG objects in order to not threaten the safety of navigation resulting from limitations of waterway parameters.

2. Responsibilities Scheme for VG Gabčíkovo

Ministry of Transport, Construction and Regional Development (hereinafter the "MDVRR") is the central government body for inland navigation, ports and maritime transport under the Act No 575/2001 Coll. MDVRR determines the strategy for the development of inland navigation, ports and waterways and in cooperation with the Ministry of Environment of the Slovak Republic, it provides for its implementation in accordance with the intentions of the state transport policy.

Vodohospodárska výstavba, štátny podnik (Water Construction Management, State Enterprise) (hereinafter the "VV"),

VV falls under the Ministry of Environment and inter alia is responsible for:

- functional navigation path following the Rhine - Main - Danube channel through Gabčíkovo locks;
- provision of works and supplies for safe operation of the GABČÍKOVO locks (reconstruction and modernization of GABČÍKOVO locks, dredging of the drain channel, and deepening of the supply channel and Hrušov reservoir);
- provision of recreational possibilities of GABČÍKOVO Dam - construction of canoe area;
- creation of the possibility to obtain support from EU funds.

Slovenský vodohospodársky podnik, štátny podnik (Slovak Water Management Company, State Enterprise) (hereinafter the "SVP").

SVP is classified as a strategic state enterprise with a modified management mode, as it controls the property that is the exclusive property of the state pursuant to the Constitution of the SR, Art 4. It provides care for the rivers and tangible fixed assets built thereupon and takes care of the quantity and quality of surface and groundwater. Part of the Slovak Water Management Company has the nature of public services - especially flood protection and the creation of navigation conditions.

Transport Authority - a Division of Inland Navigation.

Act No 402/2013 Coll. on the Authority for the Regulation of Electronic Communications and Postal Services and Transport Authority, as amended, with effect from January 1, 2014 has established the Transport Authority as a state authority with a nation-wide competence in the field of railways, civil aviation and inland waterway. Transport Authority is a budgetary organization linked financially to the state budget through the budget of the Ministry of Transport, Construction and Regional Development of the Slovak Republic. Waterways and inland navigation fall under the Division of Inland Navigation.

In the field of navigation safety, the main activity of the Transport Authority is to provide for a permanent and intensive state professional supervision of navigation safety and compliance with existing legislation related thereto. Employees of the Transport Authority has devoted a special attention to the waterway of international importance - the Danube waterway - given the constant increase in the number of vessels and small boats moving in our territory.

3. Comparison of Possible Direct Remedies of VDG in Terms of Navigation

The following scenarios comes into consideration with regard to the remedies of the VDG situation:

a) repair of locks with VDG expert management systems - comprehensive solution of StG navigational issues;
b) repair of locks without VDG expert management systems - without the expert system the issues influencing navigable depths at the shallow points due to a poor operation remains and not much will be saved; c) the Old Riverbed will be used for international large vessels. Solution disadvantages:

- it significantly reduces the transport capacity, since PLK at VDC and VD Dunakiliti (VDDu) are substantially smaller than at StG,
- the navigation will be more demanding in terms of safety, since the PPD waterway parameters will worsen (smaller curvatures, small width, smaller hydraulic characteristics of the waterway) and the flow will hasten up,
- weirs are planned that will call for the implementation of PLK leading to a multiplication of losses in capacity and transport times,
- significantly more water will flow to the Old Riverbed (min. 1000 m³s⁻¹), which will significantly decrease revenues from electricity generation (EE) at VEG.

Table 1 provides a comparison of individual solutions with the factors influencing the success and sustainability of the project. Individual solutions are rated on a scale from 1 - least advantageous - to 10 - the most advantageous.

	Solution A	Solution B	Solution C
Navigation Conditions Improvement	10	6	3
Implementation Costs	8	10	5
Operational Costs	10	7	4
Feasibility	10	8	2

Table 1

Based on the foregoing analysis, the most efficient and also the most sustainable solution for upgrading PLK as well as GABČÍKOV locks parts is the solution B - Repairs of locks with expert management system, which addresses the navigation issues comprehensively.

4. VDG Navigational Aspects

According to the original plans, the VDG was to provide for sufficient water parameters in the backwater and OK section, i.e. in the rkm 1872 - 1811 (including Bratislava port pools) while observing the recommendations of the Danube Commission regarding the parameters of the waterway and navigational objects. Drop (level difference) caused by backwater, centred at StG, is crossed with 2 PLK with dimensions for class VII classification of waterways of international importance, which is part of AGN Agreement. PLK are equipped with a complex hydraulic filling and emptying system, which was designed so that the passing through the PLK was safe and fast and that no navigational safety and transport capacity conditions were restricted or omitted during the process.

Fairway leads in the Danube riverbed at the backwater section in PK at ZH-D, at approx rkm 1858. OK waterway leads under the StG a under rkm 1811 in the Danube riverbed.

The current status of some VDG objects, their operation, and adjacent sections of waterways show signs of limited reliability, operation and subsequently navigation safety. Areas requiring remedies are identified in the following section.

The current status of VDG - limited safety, capacity and reliability of navigational traffic of VDG:

1. One lock (PLK) is shut down due to a malfunction, the second PLK is functional only partially (not all channels of the hydraulic filling system). Defects lie in the hydraulic filling system (technological part - caps systems, construction part - degraded concrete and channel part - bad route shaping, poor management of the hydraulic system resulting from a poor control system of the PLK) and in the failures of large upper and lower gates directly at the lock chambers.
2. Poor VDG operation control system resulting in an unsafe manipulation with the water flows in terms of navigation limiting the navigation depths at the shallow points. It also includes unreliable flow and level measurements at important sites and profiles (consumption curves in managing profiles, capacity curves of weirs).
3. Poorly sealed subsoil and expansion joints in the construction of the PLK - flowing water in the subsoil is dangerous for the stability of the subsoil (scouring fine particles, formation of cavities) and subsequently the stability of the entire PLK is threatened - subsidence, shifts, deformations. Degraded areas in the PLK subsoil should be remedied (required identification of the degraded area, extent and subsequent filling by a sealant). It is required to seal the space between the filling object of the PLK and connecting wall between VE and PLK.
4. Hrušov reservoir fairway is clogged with debris, deposits are already in the supply channel.
5. Old Riverbenk, which is to serve as a replacement waterway, is unkempt, waterway parameters thereof are not provided for and the navigation through the Old Riverbenk is currently impossible.
6. Significant deterioration of parameters of some shallow points in the section below VDG (e.g. in rkm 1791).

Data presented in Table 2 represents the number of days of forced downtime due to defective GABČÍKOVŮ locks PLK.

Year	Left Lock Downtime (in Days)	Right Lock Downtime (in Days)	Both Locks Downtime (in Days)	Left Lock Downtime Lasting Less Than 12 Hours (in Days)	Right Lock Downtime Lasting Less Than 12 Hours (in Days)	Both Locks Downtime Lasting Less Than 12 Hours (in Days)
2010	235	69	3	12	50	5
2011	193	166	1	20	37	0
2012	21	366	16	0	35	0
2013	118	126	14	19	20	5
2014	365	29	3	0	166	0

Table 2. Statistical Analysis of the Downtime of StG PLK

4.1. Remedies Areas (Recovery) with Regard to Navigation

It is possible to identify 7 areas requiring substantial improvements in order to increase safety, capacity and reliability of navigational traffic of the GABČÍKOV locks:

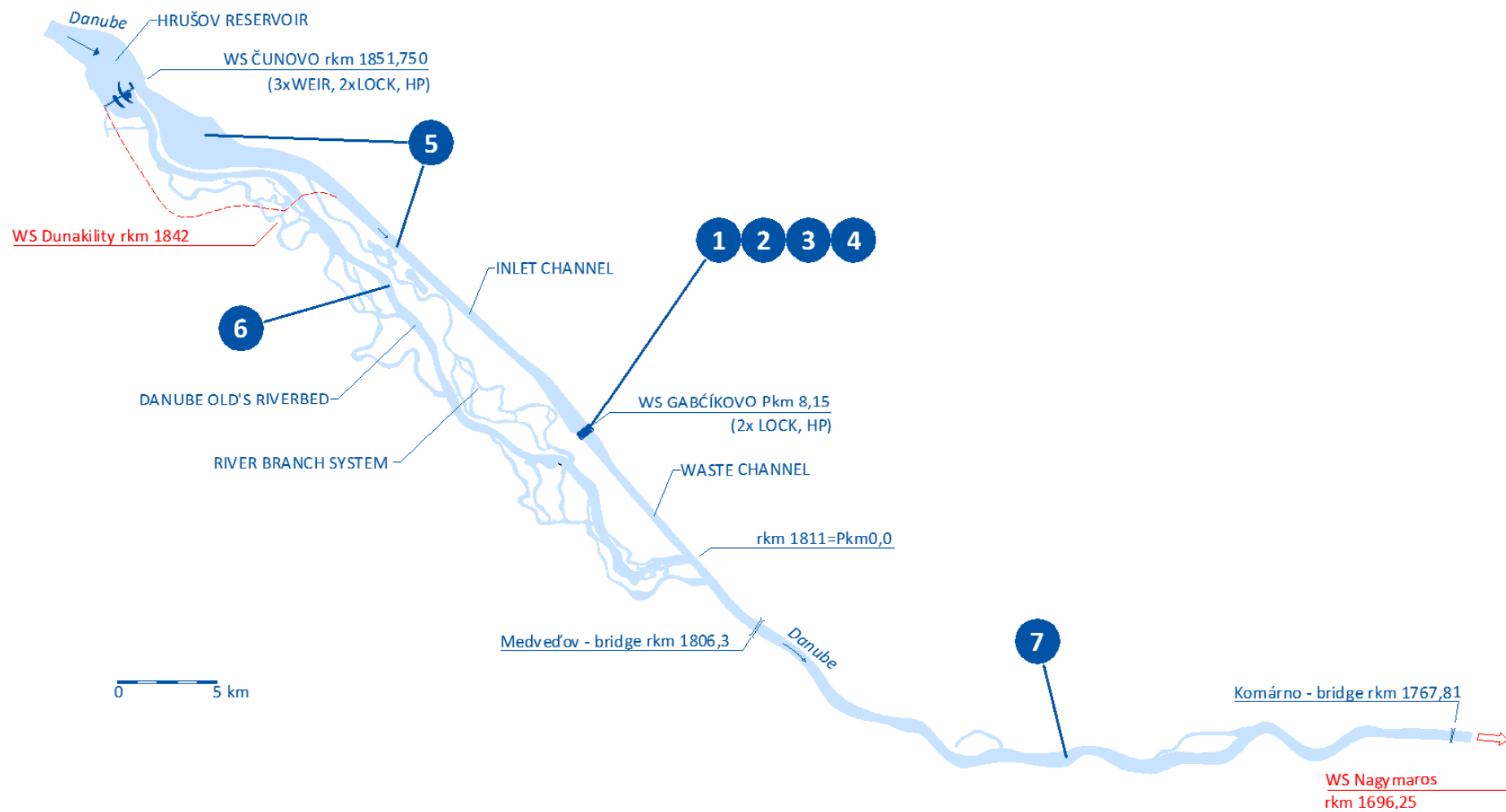
Direct

1. Hydraulic filling and emptying system of the locks (filling and emptying channel seals, channels, filling and emptying operation of the PLK)
2. Technological equipment of PLK weirs (upper gates, lower gates, upper spare flap gates, floating bollards)
3. The control system of the nautical-energy flow and level operation.

Indirect

4. Sealing of PLK subsoil and expansion joints.
5. Fairway in ZH-D and in supply channel.
6. Danube Old Riverbed in the section of rkm 1851-1811 of the Danube.
7. Fairway in the section of rkm 1811 - 1708 (below VDG)

The following figure shows the localization of areas.



GABČÍKOVO Dam Situation with the Remedy Layout

5. PLK StG Hydraulic Filling and Emptying System

5.1. Introduction and General Information

Special attention was already paid to the VDG PLK hydraulic filling and emptying system during the preparatory works of the research stage. It was imperative to ensure that the operation of the lock chambers (the "PLK") was reliable and safe and has sufficient transport capacity with regard to international Danube waterway.

It is required that the design of the hydraulic system addresses the optimization issues and the following conditions:

1. PLK to be filled and emptied as quickly as possible in order to maintain the highest transport capacity,
2. providing for a safety of transported vessels, i.e. mitigating the effects of water flowing to the PLK or from PLK on the vessels,
3. observing maximum limitations to the flow rate within the hydraulic system to prevent water from having destructive forces on the structural and technological components of the hydraulic system,
4. providing system reliability according to its class and importance of the waterway,
5. minimizing the cost of implementation and operation.

Due to the size of the PLK and to meet the demanding requirements of filling (emptying) parameters, a three-storey complex hydraulic system was designed consisted of filling and emptying longitudinal and transverse channels and bottom slots arranged under the entire area of both lock chambers (Fig 4-7). The system provides for a fast and evenly distributed, over the PLK area, inflow to and outflow from the PLK.

The flow in this complex system is complicated; the specification of parameters of its individual components in order to comply with all the necessary conditions was only possible on the basis of an extensive modelling research. This research was conducted in the 70s in hydro-technical labs of the Hydraulic Engineering Faculty of Civil Engineering in Bratislava.

This extensive research resulted in a draft specification determining the form, size and operating characteristics of individual system components (supply object, channels, galleries, outlet slits, joints of lock chambers, channel valves, outlet channels). Fig 5 shows the PLK model, Fig 9 shows the final draft outflow section form, Fig 10 shows the filling gallery section with a dividing construction and Fig 11 shows the supply channels. Fig. 8-11 are taken from the archives of the Hydraulic Engineering Faculty.

The system was designed so that the PLKs were filled / emptied at a time, which expressed in minutes is equal to the approximately half of the drop expressed in meters. At the designed drop over 23m, one PLK could be filled up in approx. 12-15 min. (if a comprehensive PLK interconnection system was not used), while the flow rate of the feeding system does not exceed 10 ms^{-1} set forth by the designer of the construction part - PLK Hydroconsult Bratislava. The hydraulic system was fully proven in terms of vessel safety, the water flows into/from the PLK evenly over the entire area of the PLK, which prevents excessive horizontal flow of water along and across the PLK and subsequent forcible action of the water on vessels.

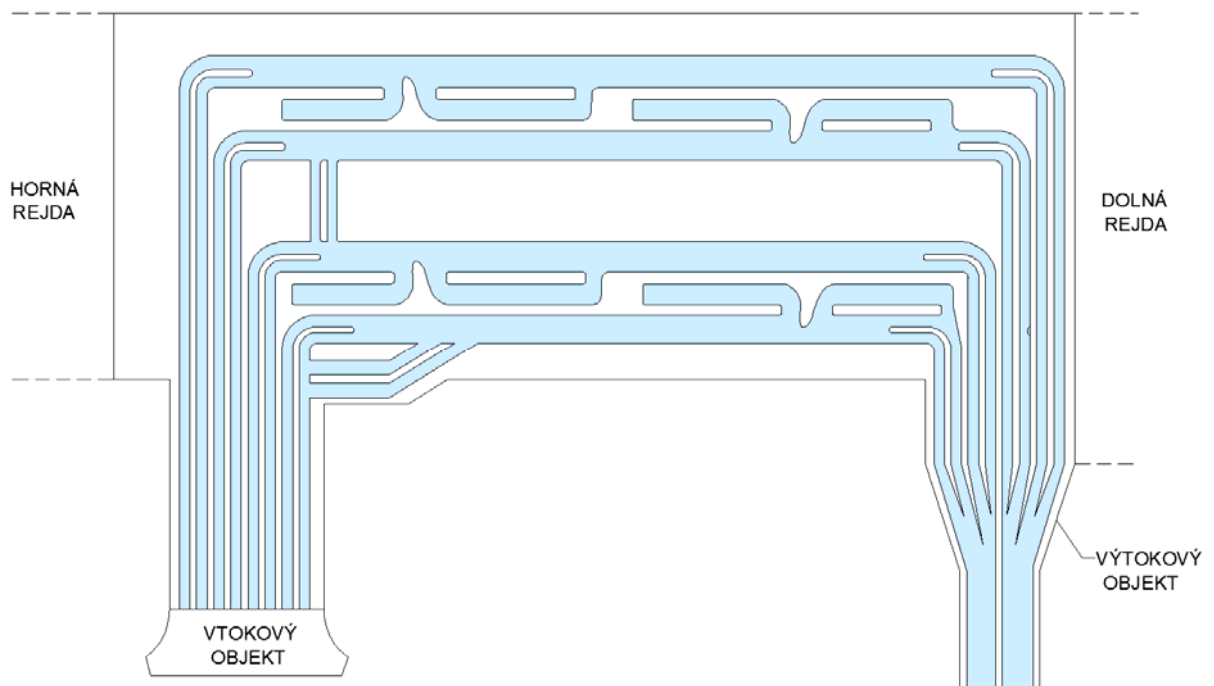


Figure 4 Subsoil Layout of the PLK GABČÍKOV Dam Filling and Emptying Hydraulic System - Channels and Galleries of the Lowest Geo-Level of the System

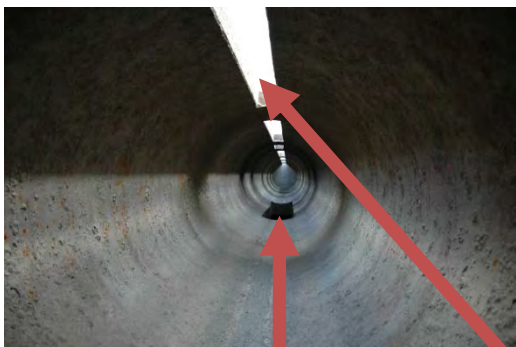


Figure 5: Transverse Channels with Filling Slits



Figure 6: View into the Filling Gallery with Waste Slits into Transverse Channels in the Ceiling

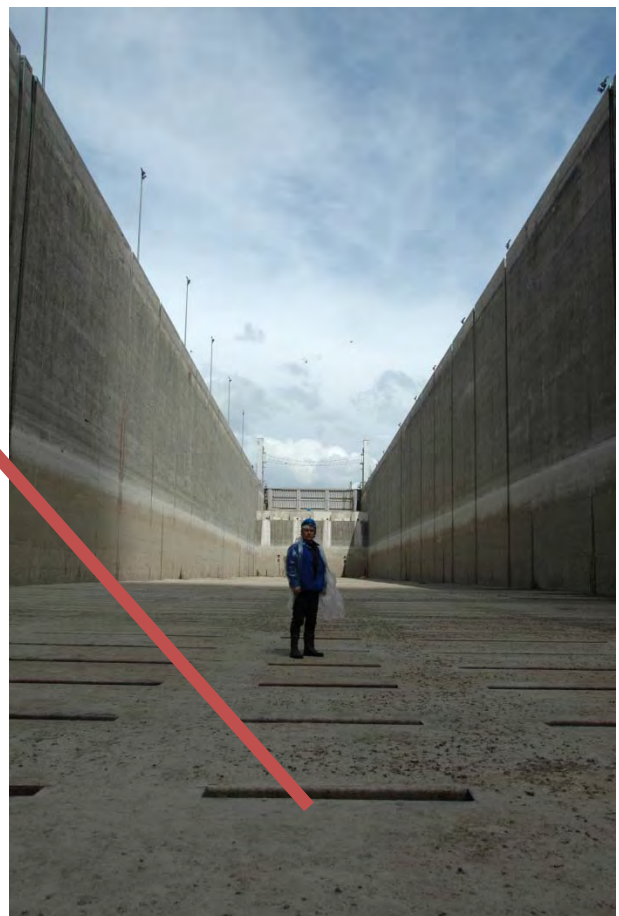


Figure 7: View into the Upstream Right PLK

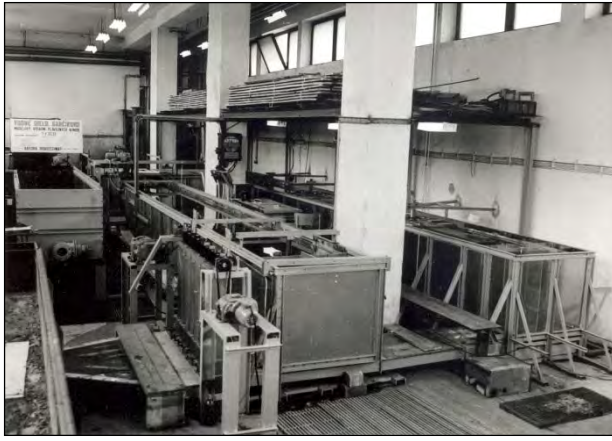


Figure 8: PLK GABČÍKOVŮ Dam Model

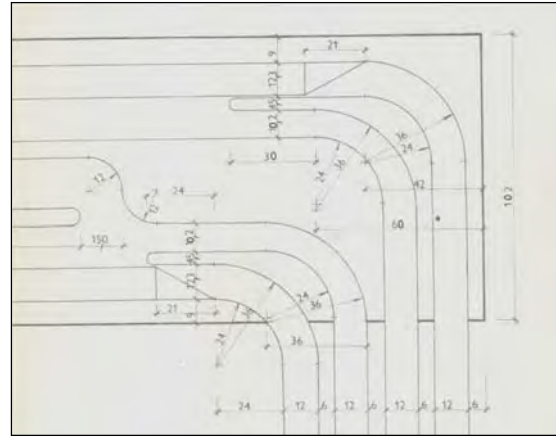


Figure 9 :Draft System Waste Part



Figures 10 and 11 View into the Hydraulic System Model Part

5.2. Difference Between Research and Reality

Inspection of the filling and emptying system showed that the emptying channels of the right PLK, Fig. 8-11, are executed not in accordance with the recommendations of the hydraulic research and that the differences between the research recommendations and actual situation lies in the execution of the multiple sharp breaks in the vertical channel route and size of the channels cross sections (see in Fig. 12,13 and especially 14).



Figures 12 and 13 Examples of Channel Route Breaks (photo by Možíšek)

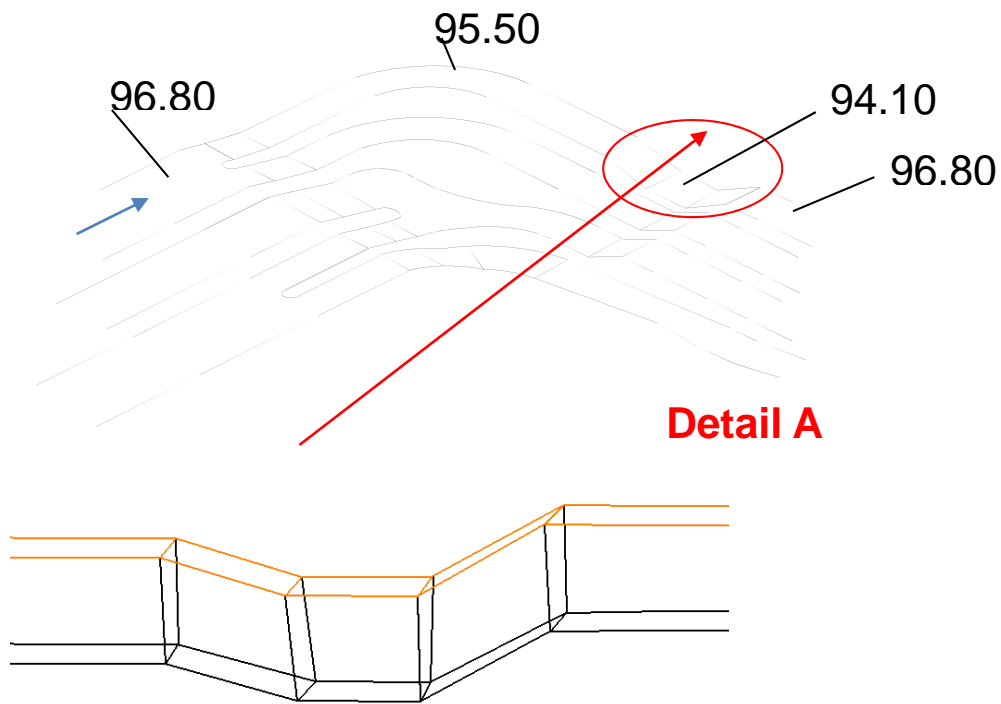


Figure 14: Detail of the Channel Break



Figure 15: View into the Channel Break Before Outlet Valve



Figure 16: Channel and Valve Defects

The sharp breaks in channels must cause significant changes in the nature of flow (creation of strong turbulence and local hydraulic losses) compared to the stimulated flow on physical model.

Most likely, such changes in flow force causes dynamic force effects on the entire PLK structure, which is directly or indirectly in contact with the channels.

This turbulence not only acts directly on the wall of the channel sections but also on the valve structure of the emptying channels. Changed field from channel breaks acts on the valves with a force, which is distributed in space differently than it was planned in the modelling research. Therefore, in addition to the direct effect of the flow to channels, the lower weir turbulence may be also caused indirectly through valves pulsating as a result of the flow.

The events of turbulence and subsequent tremor intensity resulting from a force effect of the water are a function of water velocity and size of hydraulic losses caused by local changes in shape and flow of the channels.

The emptying process was managed differently than what was determined by the results of the modelling research. In particular, in real situation the opening time of waste channels was minimized (probably with the intention to minimize the time of exposure of valves to the flowing water) and only 2 channels were used for the emptying (probably due to an increased failure rate of valves). Another factor influencing the dynamic effects around the valves is the method of handling the pipeline deaerating valve shafts - the research recommended to close the pipeline for some handling procedures in order to avoid sucking water during the extrusion of the air from the shaft.

In addition to the sharp channel breaks, other emptying procedures, which were not in line with the research recommendations, had adverse effects on the flow characteristics

Impacts of the operation procedure on the drainage process and flow rate are described in the following section.

5.3. Measurements, Calculations

In February 2010, measurements of the emptying procedure of the right PLK (conducted by VV, SVP, Faculty of Mechanical Engineering) were to demonstrate the impact of different emptying procedures on the intensity of dynamic effects in the hydraulic system. Emptying procedure was measured by using 1, 2 and 4 channels. The following was measured and recorded:

- opening times of valves,
- water level decrease times in PLK,

- tremors of selected parts of the lower weir structure.

Based on the water level decrease times in PLK and known area of horizontal cut through the PLK, it is possible to indirectly determine the drainage process from PLK in m^3s^{-1} .

The authors of this report used the results of the measurements to calibrate the calculations of the emptying procedure and to compare the results of the measurements with the results of the calculations. The intention was to design an appropriate means of manipulation during the emptying procedure on the basis of the calculation. Calculation methods for such a complex flow that occurs in the hydraulic system of the PLK limited and it is not possible to give a direct answer to some questions - especially the three-dimensional distribution of the flow velocity vectors can only be simulated by relevant simulation models for 3D flow. Laboratory hydraulic physical models are the most appropriate method to accurately simulate the flow in these systems; for support simulations it is already possible to use simulations and mathematical models of flow. Some test simulations are shown in Chapter 5.4 "3D Mathematical Model Simulations"

The following figures 16 and 17 show the measured and calculated times of PLK drainages and calculated flow velocities in the channel during the emptying of the channel 1.

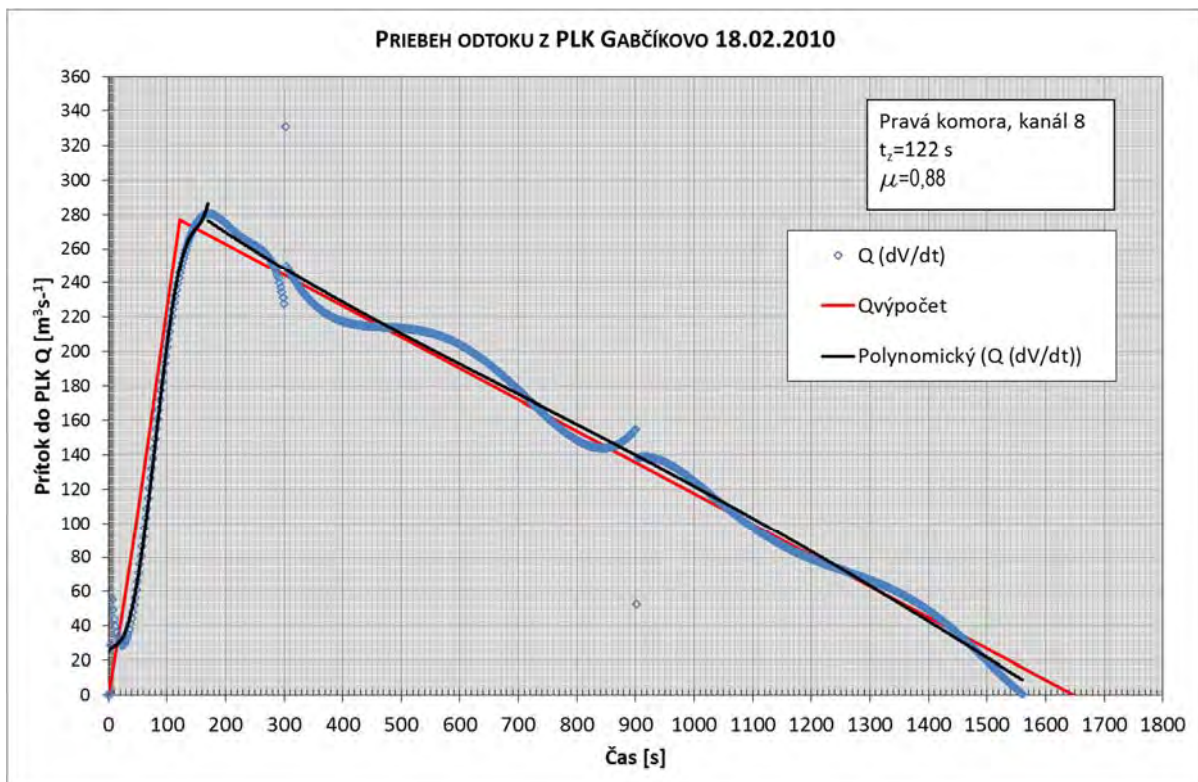


Figure16: Drainage Process when Emptying the Right PLK by a Single Channel - Measurement and Calculation

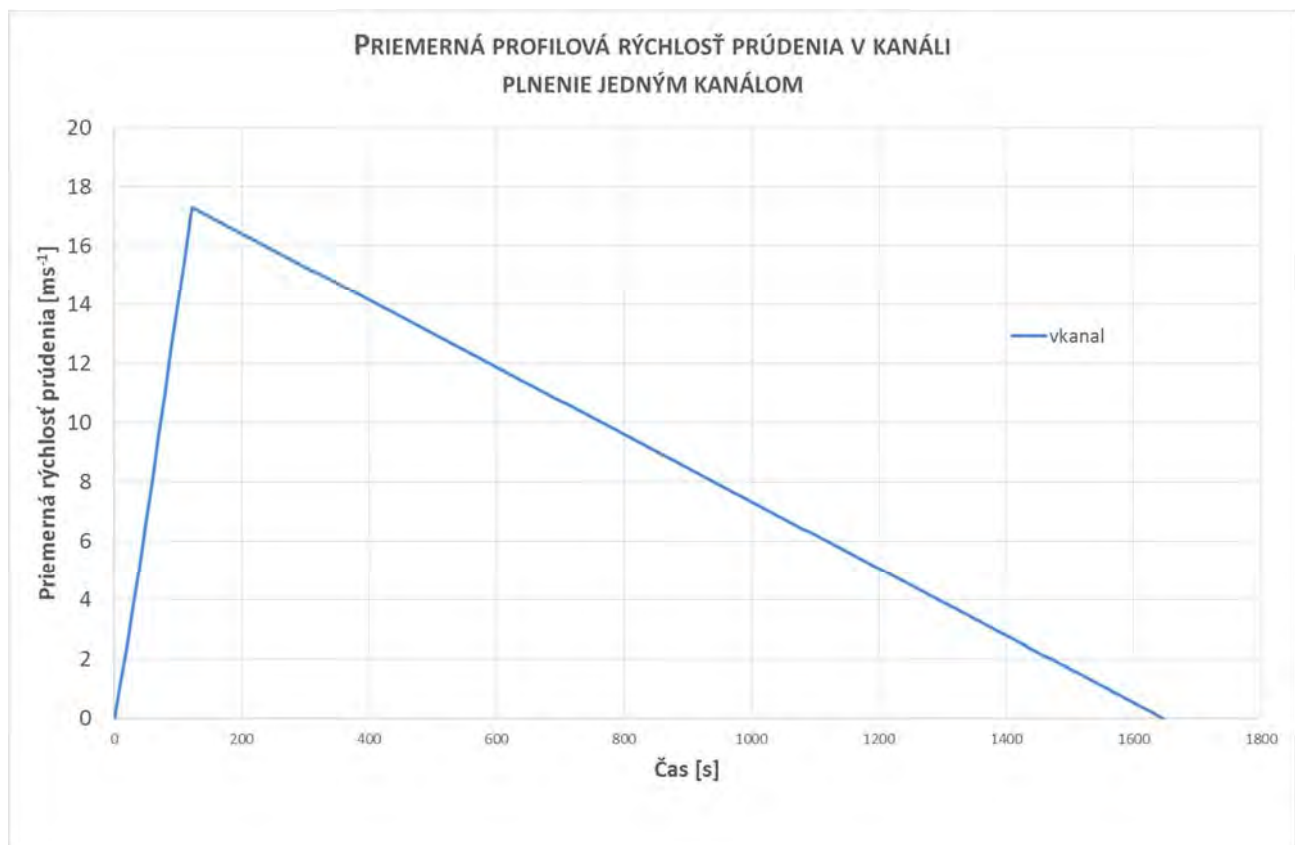


Figure 17: Average Velocity Profile Process in the Channel when Emptying the Right PLK by a Single Channel - Calculation

Calculation results after calibration of the emptying coefficient show a substantial compliance with the emptying characteristics of the measured values; calculation results can be considered sufficiently representative.

Number of Channels	Valve Opening Times	Emptying Times		Maximum PLK Drainage		Maximum Average Flow Velocity
		Measurement	Calculation	Measurement	Calculation	Calculation
	[s]	[min]		[m³s⁻¹]		[ms⁻¹]
1	122	25.30	27.45	280	277	17.3
2	244	14.00	15.37	510	492	15.4
4	242	9.20	10.43	730	712	11.1

Table 3: Measurement and Calculation Results

Notes to table results:

- In all cases the allowable flow velocity was significantly exceeded when emptying by a single or two channels (by 73 or 54%).
- Hydraulic system capacity is extraordinary; the flow values in the system reach extraordinary parameters.

5.4. 3D PLK Filling and Emptying Mathematical Model Simulations

Due to lack of data (no documentation on the geometry of the cross channels and slits was available) and lack of time (the calculations of short sections took several days), only channel sections no. 5 and 6 on the right PLK, when the waste valve on channel 6 was closed, were modelled by simulation flow model Flow3d (Flowsience,

l.n.c.), Emptying was executed only through the channel no. 5. Only this configuration allowed to determine the boundary conditions at the inlet and outlet of the model, since the entire PLK model with hydraulic system is not available. The simulation was conducted in a steady mode, while the flow rate was set by the calculation referred to in the previous Chapter, i.e. $280 \text{ m}^3\text{s}^{-1}$ (max flow during emptying by 1 channel). Simulation results are shown in Figure 18.

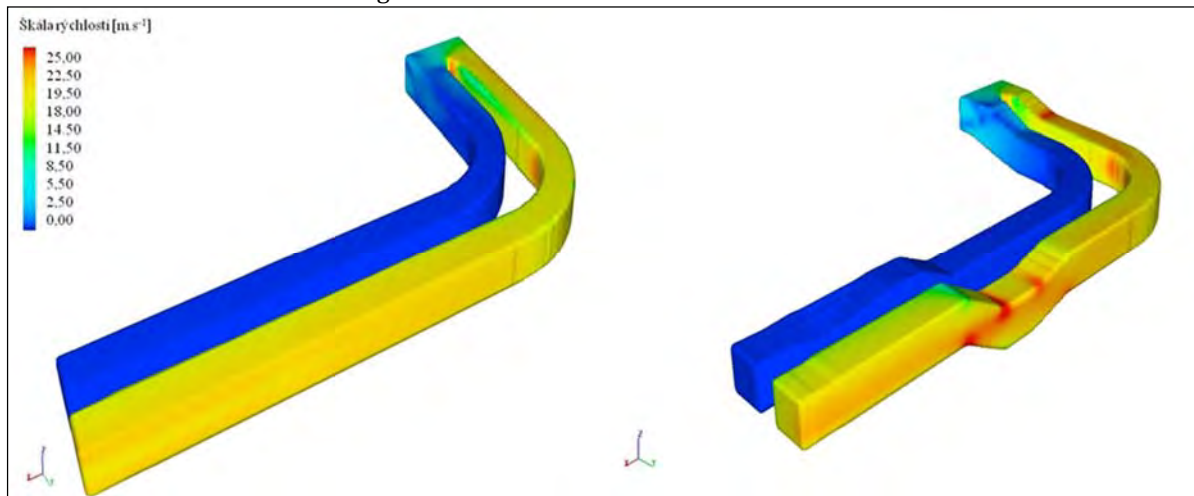


Figure 18: Flow Velocity in Channel 6 for an Optimized Research Shape and Current Shape

The simulation shows that the velocity extremes exceed by up to 50% the average velocity profile shown in Tab. 1 (25 versus 17 ms^{-1}). This would mean that when operating two channels, which were used most of the operation of the VDG, the velocity values reached in some sections (e.g. at channel breaks) up to 23 ms^{-1} , i.e. exceeding the allowable velocities by 130% !!!.

If the presumption is valid, the channel breaks, usage of less than all 4 channels and incorrect opening of valves during emptying causes tremors of the lower weir of the PLK, and the most vulnerable expansion joints are located on the lower weir. This presumption is confirmed by the results of the simulation conducted within the review of [] Mucha and Hulla from 2008.

Stressed expansion joints are shown in the following Figure.

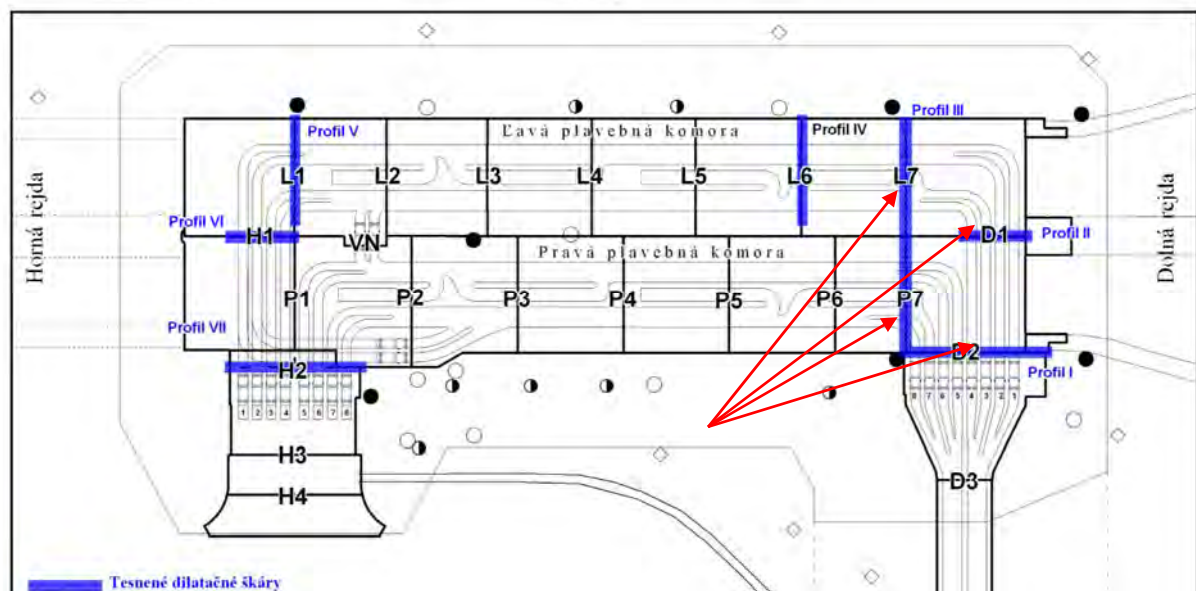


Figure 19 Expansion Joints at Risk Due to Tremors

5.5. Conclusions

Based on the results of the measurements, calculations and simulations it is possible to formulate the following conclusions:

1. Sharp channel breaks contradicts the recommendations of the modelling research results. It is highly probably that this fact is one of the primary causes of turbulent phenomena in the hydraulic system with following force effects of flowing water to the structural parts of the PLK and adverse effects manifested by tremors in the PLK structure. The question arises whether and how the tremors of the lower weir affect the tightness of expansion joints.
2. The turbulence in the channel break profiles and subsequent force effects are a function of the flow rate in the system.
3. The method used during emptying (only 2 channels and rapid opening of channel valves) causes extreme speeds in the channels (speed is a function of the break and areas of filling holes). Approximate calculations have shown that by using 2 channels, the extended opening times of valves from 240s to 800s lengthen the emptying by 5 minutes on one hand but on the other it reduces the average flow velocity in the channels from 15 ms^{-1} to 10 ms^{-1} .
4. Turbulence at the channel break profiles and subsequent flow force effects are a function of "Severity" of the route breaks of the channel and subsequent hydraulic losses.
5. Tremors of the valves and turbulence phenomena in valve shafts are a function of flow velocity and distribution of velocity flow fields affected by channel breaks but also relate to the handling of the vent pipeline.
6. It is highly likely that the dynamic load of valves is diametrically different to what was planned during their design.
7. The mathematical model allows us to identify critical flow areas, verify the effect of the manipulation procedure time and channel shape on the flow as well as identify the load on channel valves.

5.6. Recommendations

1. Perform optimization calculations during the emptying procedure. Find the optimal valve opening process (not linear), e.g by the use of heuristic methods to find such an emptying procedure that will minimize flow velocities and PLK emptying times. It is likely that a specific process of this function will vary according to the break.
2. Design filling and emptying procedure that will provide for a fast and safe crossings of vessels and minimize stress on the structural and technological parts of the filling system based on a research in simulation, hydraulic and mathematical water flow models.
3. Calculate dynamic load progress on bypass valves and channels based on a research in simulation, hydraulic and mathematical water flow models.
4. Design correction of emptying channel routes to minimize turbulence phenomena and subsequent tremors of the lower PLK weirs based on a research in simulation, hydraulic and mathematical water flow models.
5. Replace all bypass valves by new ones that are long-term able to transmit load; opening procedure will allow a non-linear velocity for optimization during filling and emptying.
6. Replace related technology (temporary closures).
7. Reinforce the channel parts identified by research as extremely stressed by water and underpressure.
8. Valve control systems shall be in line with the recommendation #1 and they shall be operable in such way that will allow to change the velocity during a defined course of the function "position - time".
9. If the above recommendations will not be enough, because they unproportionally prolong the emptying time, it will be necessary to carry out an adjustment of the hydraulic system and eliminate sharp breaks of the routes to have a smoother transition between different height levels of the channel.
10. Fulfil the recommendation #3 can be done on the basis of a laboratory modelling research of the PLK hydraulic system with a support of the 3D mathematical turbulence flow patterns. Subsequently implement the measures according to the results of this research. Also perform valve research.
11. Use 3D flow model simulations to define channel valve loads.

6. Locks Weir Technological Equipment

6.1. Current Status

Upper and lower weirs to both PLKs are at the end of their life due to their natural wear and tear as well as several non-standard situations (gates failures, ship collisions). They need to be replaced as soon as possible.



Figure 20: Example of the Damage to the Upper Gate Caused by a Ship Collision



Figure 21: Example of the Damage to the Lower Gate (Inappropriate Material Wear) from the Late 90s.

6.2. Draft Measures:

1. Calculate the load on the upper and lower gates and replacement flap gate by a dynamic water load for all actual operating conditions and for the replacement upper flap gate based on a research in simulation, hydraulic and mathematical water flow models.
2. Replace upper gate, lower gate, upper replacement gate, temporary barrier structures used during repairs of the main gate.
3. Replace technological equipment of the PLK (floating bollards, dynamic protections). Add heating niches of floating bollards for the safety of winter traffic.

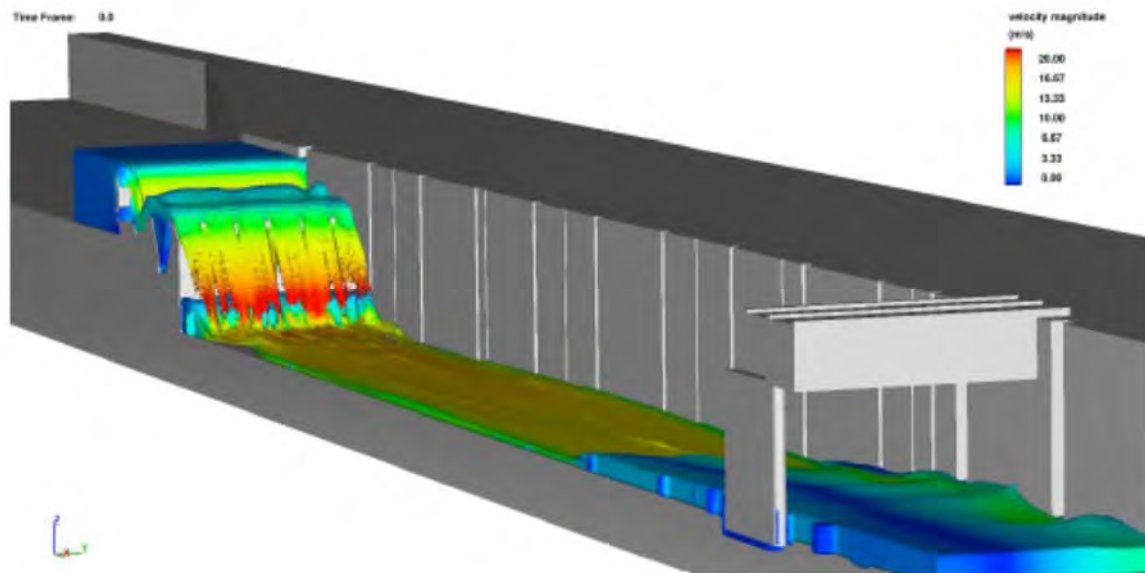


Figure 22

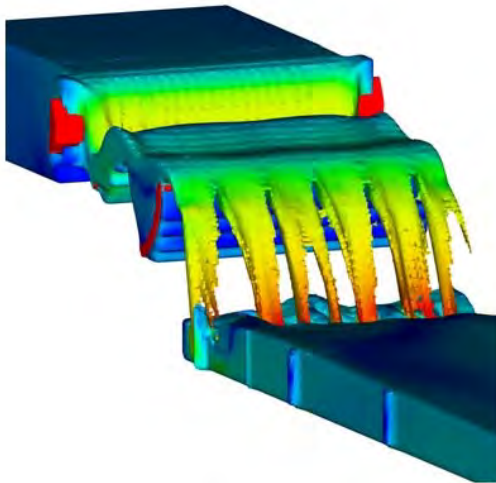


Figure 23

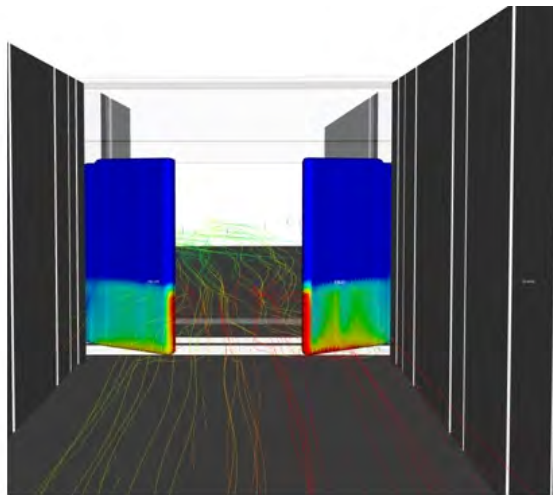


Figure 24

Figures 22, 23, 24 Examples of Water Flow Simulations through PLK at weir operation of PLK in 3D Mathematical Model Environment

7. Nautical-Energy Flow and surface operation Control Systems - VDG Expert Control System

7.1. Current Status

VDG as a stand-alone dam cannot itself affect the flow levels to decrease the parameters of the fairway (especially depth). If any sections within the reach of the VDG are reported to have a limited depth (shallow points) the VDG operation shall not cause a drop of traffic depths under the reported values. If no shallow points are reported the VDG operation shall not limit fairway depths below 27 dm.

The current operator of the VDG (i.e. Vodohospodárska výstavba Bratislava, š.p.) uses a software tool (i.e. **VEGA Hydromodel**) for preparatory and operational control of the VDG, taken by the previous operator (i.e. Slovenské elektrárne, a.s.). This software solution is not suitable for the current needs of the traffic management of the HPP GABČÍKOVO, since it operates in the so-called hydro-thermal coordination mode -- evaluates the cooperation of thermal and hydroelectric power plants. The current operator must control the operation of the HPP GABČÍKOVO on the basis of other criteria, since in addition to Žilina Dam it has no other comparable high-capacity power plants.

The previous operator of the HPP GABČÍKOVO had sufficient comparable energy resources creating adequate conditions for the possibility of operating the HPP GABČÍKOVO in the so-called flow mode and thus de facto provided for safe and reliable navigation traffic on the given section of the Danube river.

Insufficient portfolio of energy sources of the current VDG operator calls for a greater use of regulatory options of the HPP GABČÍKOVO and thus it poses a significant increase in risk to the safety of international navigation.

In addition, currently used software Hydromodel VEGA is outdated, since it works with data from the Danube riverbed from 2008 and monitors the flows and levels only up to Medved'ov, as in that time the limiting shallow point for the international waterway was located nearby.

The only possibility of the current VDG operator is to assess the safety of the VDG navigation operation either during the preparation process of the operation or during the operation management, particularly with a regard to the development and use of the software tool. The main task of this simulation tool will consist of simulations of the water-level mode in the section Devín – Komárno (including simulations of the water-level of the Old Riverbed). The simulation instrument will recalculate the water levels for the given period of time by entering the values of inflows (or outflows) in each singular point.

Given the above analysis of the current situation it is possible to state that the current VDG operator does not have an adequate software tool (or any other tool) to control the nautical-energy flow and water operation of the dam. This results in frequent reductions of navigational depths and subsequent collisions of ships with the bottom (Figure 25).

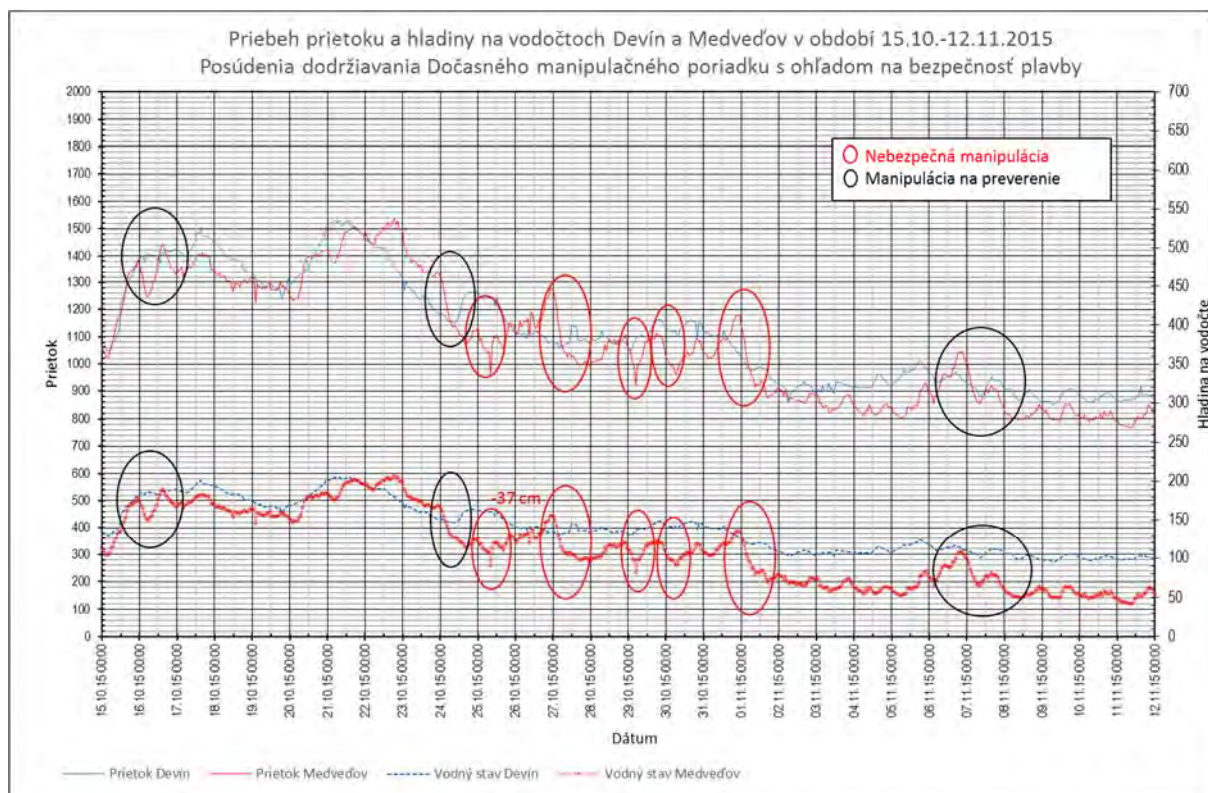


Figure 25: Examples of Unsafe Practices and the VDG in the period of 15.10.2015 - 12.11.2015

7.2. Draft Measures

Develop and implement a nautical-energy and surface operation control system of the VDG, which would provide for a safe passage of vessels on the section of the Danube affected by the VDG operation.

The standard solution includes the development of a **VDG Expert Control System**, which will provide for the following functions:

- processing of hydrological inlets and modelling of hydraulic conditions and hydraulic links with the HPP GABČÍKOVO or to the entire section of the Danube between Devín and Komárno, including the Old Riverbed,
- draft redistribution of Danube natural flows to the VDG objects in order to comply with all boundary water management, energy and especially **navigation** conditions in the relevant section of the Danube,
- providing a comprehensive picture of the water-level and inflow mode of the Danube for the section Devín - Komárno with the possibility to directly integrate the inputs to the existing VDGA complex information - control system of trading and production of electricity,
- assessment (verification) of the draft operation of the VDG in terms of impacts on the flow and water-level mode of the VDG,
- **assessment (verification) of the draft operation of the VDG with regard to the provision of navigation conditions below or above the GABČÍKOVO level in line with the recommendations of the Danube Commission.**

VDG expert control system shall operate with a high degree of accuracy simulations (especially Danube water-level), since the safety margin of vessels at shallow points is only 20cm.

Given the high degree of complexity and interactibility of the VDG hydraulic system it is possible to solve the flow and water-level mode in the given section of the Danube (Devín - Komárno, including the Old Riverbed) exclusively by a mathematical apparatus describing unstable water flow in open channels (Saint-Venant equations supplemented with appropriate boundary conditions). Any approximations of unsteady flows by simplified flow models would most likely result in a gross simplification of modelling results of water-levels of

the Danube and thus in an increased risk of non-compliance with the fairway parameters, particularly at the shallow points.

Compatibility of the preparation and operation control system of the VDG can be effectively achieved by direct integration of the mathematical model of unsteady flow in an existing complex information - control system of trading and production of electricity of the VDG.

The expert control system of the VDG should operate with the current status of the Danube and current location of shallow points and their parameters. For the reliability of the expert management system of the VDG it is important to continuously update the section related to the morphology of the riverbed, as this changes over time as a result of erosion and sediment. It leads to a changing shape of the shallow points and their parameters. This update should be conducted annually after the assessment of a riverbed, which is carried out by Slovenský vodohospodársky podnik, š.p. and after any event of a flood or so-called riverbed-shaping flow.

7.3. Conclusions

Based on the analysis of the current state of VDG nautical-energy and surface operation control system it is possible to state the following conclusions:

1. Insufficient portfolio of energy sources of the current VDG operator calls for a greater use of regulatory options of the HPP GABČÍKOVO and thus it poses a significant increase in risk to the safety of international navigation at the section of the Danube affected by the VDG operation.
2. VDG operator has currently no adequate software tool (or any other tool) for managing nautical-energy flows and surface operations of the locks, which means it has virtually no control over the safety of the shipping traffic on the Danube River affected by the operation of the VDG.

7.4. Recommendations

Based on the draft measures intended to remedy the current situation with regard to the control systems of nautical-energy and surface operations of locks, it is possible to state the following recommendations:

1. Prepare and implement **VDG Expert Control System** into the existing VDGA comprehensive information - control system of trading and production of electricity, providing the possibility to verify the draft operation of the VDG in terms of compliance with the navigation conditions at the section of the Danube affected by the operation of the VDG.
2. Due to the high demands on the accuracy of the simulation results of the Danube water-level, the VDG expert control system should be based on a mathematical simulation model of unsteady water flow at the Danube Section (Devín – Komárno) and should use Saint-Venant equations supplemented with relevant boundary conditions.
3. The reliability of the VDG expert control system should be provided for by regular updates of the system related to the morphology of the riverbed at least once per year or after any event of a flood or so-called riverbed-shaping flow.

8. PLK Subsoil and Expansion Joints Sealing

8.1. Current Status

The current technical condition of the locks in terms of their subsoil stability is serious. Past development since the commencement of the operation is heading to a disruption of the subsoil stability. This is caused by leaking dilatation chambers and subsequent flowing of water into the groundwater between the chambers and sealing construction foundation. This process continues. Its ultimate result leads to a deterioration of the subsoil and subsequent uneven construction base.

The basic issue concerning the functionality of the locks is their stability (to avoid unacceptable deformations). The instability of locks means sudden or gradual and uneven, or other destructive, damage affecting the construction and its operation and creating unacceptable deformations, vibrations and similar, which leads to a reduced capacity utilization and durability of locks, including the functionality of the connected technical equipment, as a result of inclination or deformation of the locks and their parts.

Leakage of expansion joints is the initial cause of the issues related to groundwater between the locks and sealing construction foundation of the locks. Leakage of expansion joints and thus caused problems with leakage and groundwater flow problems and their sealing are described in the report "Assessment of the Locks of the GABČÍKOVŮ Dam Upon Special Operation in 2008" prepared by Prof. Mucha, DrSc. and Prof. Hullu, DrSc., from 2008.

The operation of locks showed evidence of problems and insufficient tightness of expansion joints of individual blocks of locks, which was subsequently reflected in the state of the locks subsoil.

For the PLK construction stability and functionality it is important to eliminate the movement of groundwater in the area under the PLK, because it can cause scouring of fine particles, formation of caverns and subsequent degradation of subsoil stability and PLK.

In the area of the inlet object, leaks unrelated to the filling and emptying of locks were detected at the beginning of the operation. These leaks however were not significant at the beginning. Continuous comparison of special operations while the both locks are empty is significant. The flow of water from the inlet VD channel (elevation level 131.10m above sea) in groundwater (between the locks and sealing wall of the sealing tub). The flow has a high hydraulic gradients and thus considered very dangerous.

The space of the lower circle is hydraulically connected with the foundation of locks. The role of this link is to balance water pressure in the foundations of the locks depending on the fluctuations of the water level of the Danube and divert leaking water from the locks foundation space. The area of the lower circle and lower weir contains extreme hydraulic gradient and suffodion in the area of groundwater and in the lower circle subsoil. Suffodion deposits of silt were also detected in the lower circle (floor and suffodion in the vertical direction).

8.2. Draft Measures

Degraded areas in the PLK subsoil should be remedied (required identification of the degraded area, extent and subsequent filling by a sealant). It is required to seal the space between the supply object of the locks and connecting wall between VE and PLK.

The subsoil degradation in case of locks means the disruption of structure and composition of foundation soils caused by water flow. This disruption can be in the form of suffodion of certain parts of the grain composition (formation of more passable routes, i.e. privileged routes), internal erosion (wash out tunnels, funnels, empty spaces in the subsoil), surface breaking and breaking of contact border sediments (e.g. border gravels with lens fine sand) and subsequent compression of the subsoil and placement of structures (elastic and inelastic deformations). This process is irreversible with regard to lock chambers. The basic countermeasure is to replace the degraded subsoil, called degraded material compensation - compensation grouting. Currently, this area is subject to degradation at the inlet object in the place of the bore PR-4 and at the space between the locks at the inner bypasses.

9. Fairway in the Hrušov - Dunakiliti Reservoir in the Inlet Channel

Fairway in the ZH-D and Danube riverbed in Bratislava is being vigorously clogged.



Figure 26: Clogged ZH-D above VDC

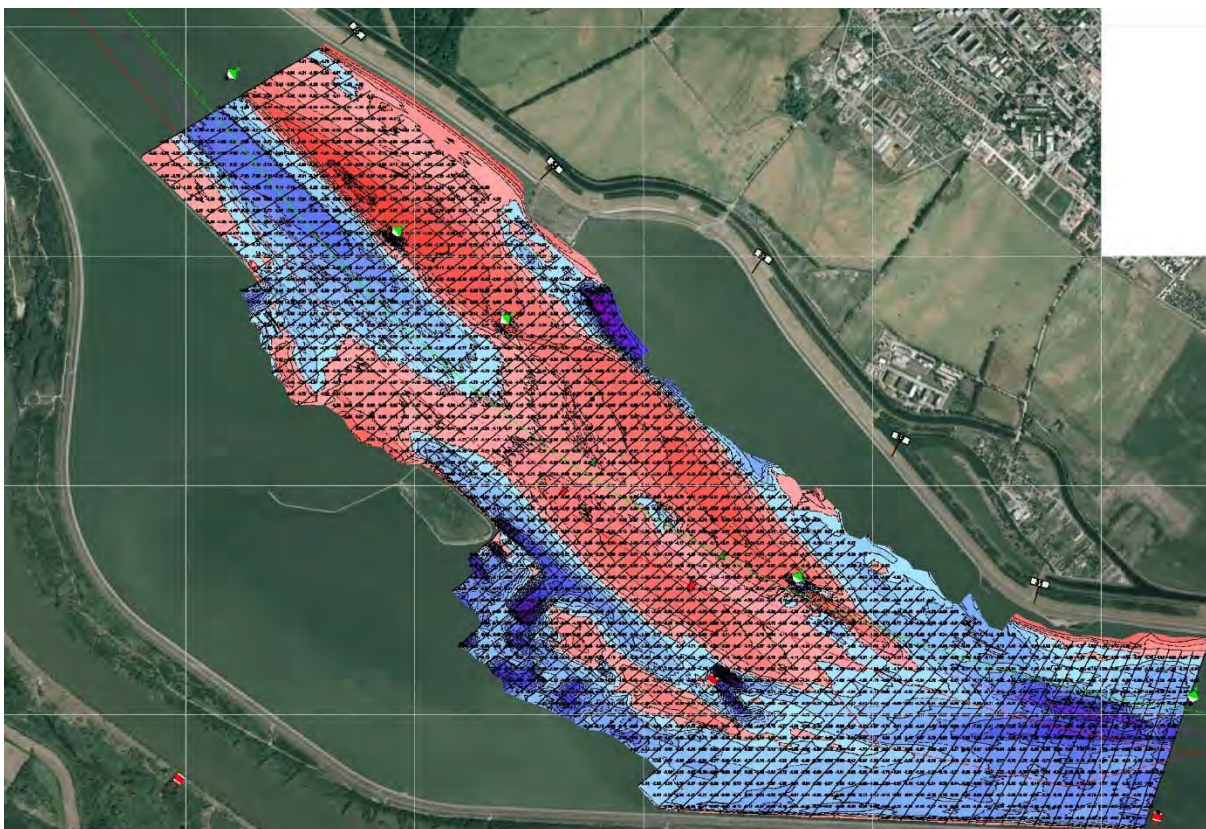


Figure 27: Navigational Depths in the ZH-D in May 2015 (Red Colour Shows the Area with Limited River Navigational Depths)

Shallow points around Bratislava as of 14.12.2005 (in Devín flow $970 \text{ m}^3\text{s}^{-1}$), water-level in ZH-D 130,83 mn.m Bpv (at min level in ZH-D 130,10 mn.m the depth will be approx. 4-5 dm lower)

Rkm	hlbka [dm]	šírka [m]	dĺžka [m]
1863,700	22	200	200
1871,000	25	110	200

Draft Measures:

Remove deposits from the fairway.

10. The Danube Old Riverbed in the area of rkm 1851 - 1811 of the Danube.

The Old Riverbed is abandoned for 23 years with regard to navigation as the waterway was moved to Dunakiliti dam (Figure 28).

The following figures shows critical sections in terms of navigation and provision of PPD (from the interim report of the research „Mišík, M & all: The necessary technical measures to provide for a compliance with navigation requirements in the Old Riverbed of the Dunabe at the section Čunovo - Sap VD for cases of shutdowns of lock chambers in HPP GABČÍKOVO - research. DHI 2012“)

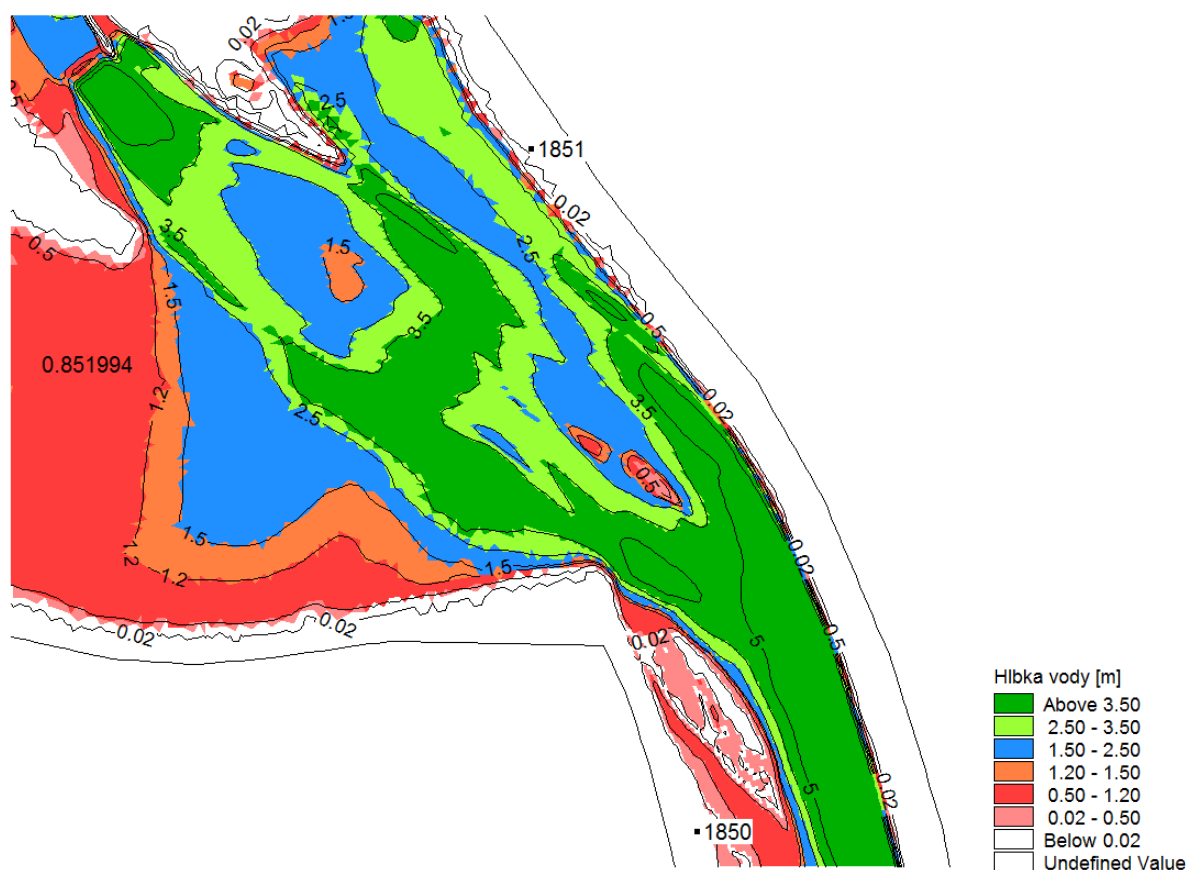
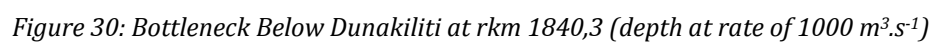
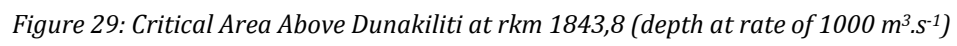


Figure 28: Critical Area Just Above Čunovo Dam, rkm 1850,4 - 1851,3 (depth at rate of $1000 \text{ m}^3 \cdot \text{s}^{-1}$)



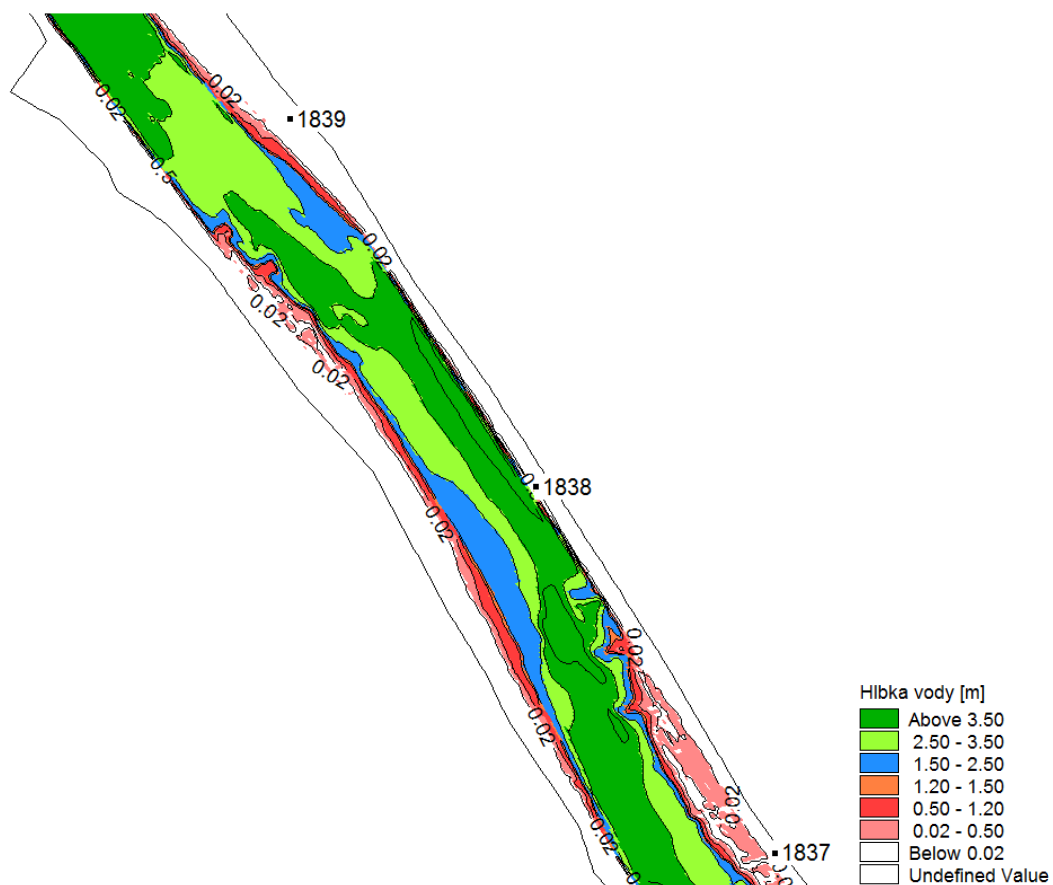


Figure 31: Bottleneck Between Dobrohošť and Vojko at rkm 837,8 and 1838,75 (depth at rate of $1000 \text{ m}^3 \cdot \text{s}^{-1}$)

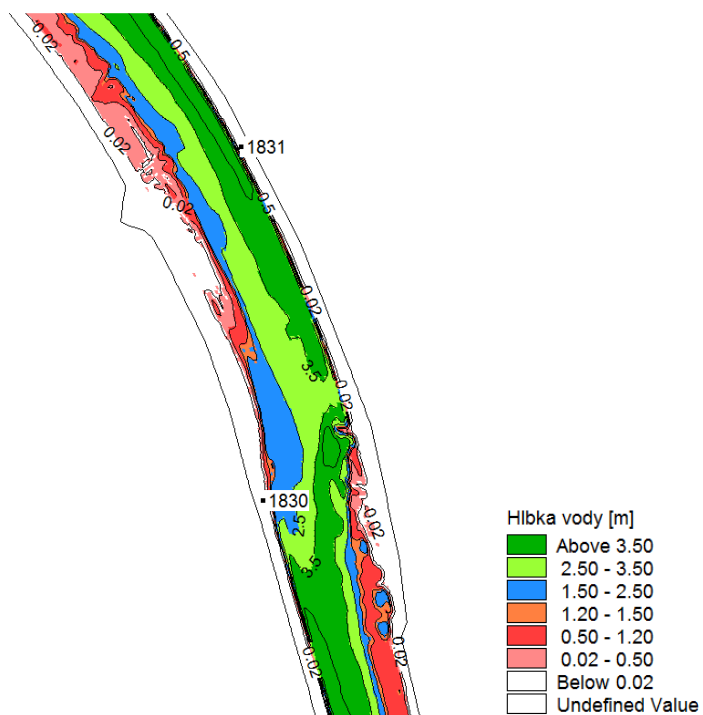


Figure 32: Critical Area Near Bodíky at rkm 1830,2 (depth at rate of $1000 \text{ m}^3 \cdot \text{s}^{-1}$)

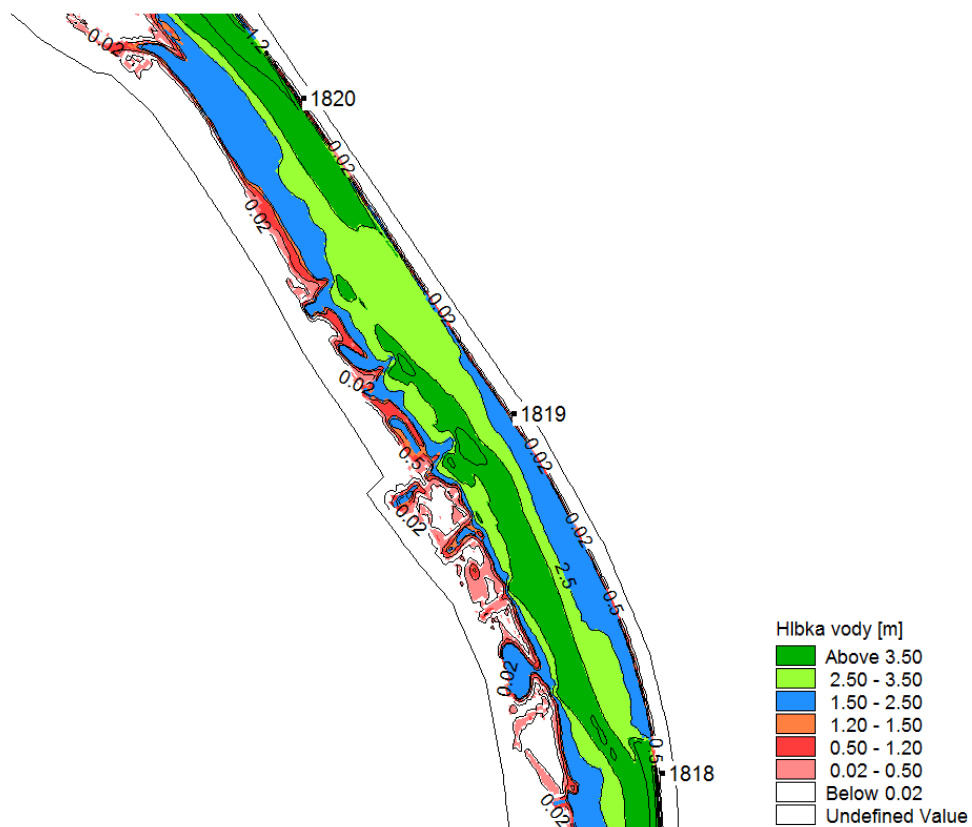


Figure 33: Bottlenecks at GABČÍKOV between rkm 1818, 1819 and 1820 (depth at rate of $1000 \text{ m}^3 \cdot \text{s}^{-1}$)

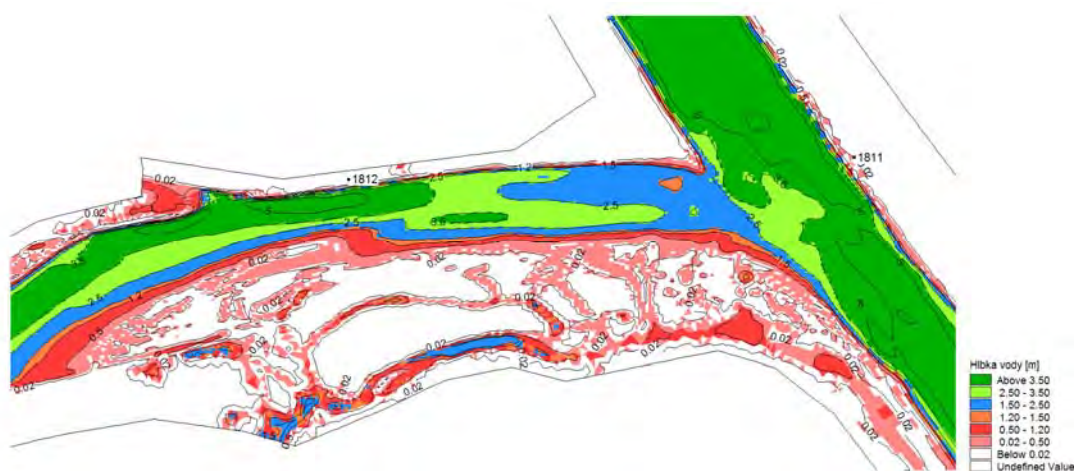


Figure 34: Critical Point Just Above the Conflux with the Waste Channel at rkm 1811,3 (depth at rate of $1000 \text{ m}^3 \cdot \text{s}^{-1}$)

Draft Measures

Adapted to the needs of recreational boating and the use if needed as a temporary waterway.

11. Fairway in the section of rkm 1811 - 1708 (below VDG)

Several shallow points are located below rkm 1811. They are limited at rkm 1791,6 and 1735,5. The following figure shows the location and parameters of the shallow points as of 16.12.2015

Brody a úžiny 2015-12-16									
Horná hranica (rkm)	Dolná hranica (rkm)	Hĺbka (dm)	Šírka (m)	Dĺžka (m)	Miesto	Hĺbka (dm)	Šírka (m)	Dĺžka (m)	Poznámky
1711.3	1710.7	20	100	600	pri červenom plaváku	22	60	600	
1714.3	1713.9	23	120	400					
1726.0	1724.7	23	130	1300					
1732.4	1731.9	25	150	500					
1735.5	1733.7	19	100	1800	pri červenom plaváku	21	60	1800	
1740.2	1739.8	27	150	400					
1757.1	1756.7	27	150	400					
1764.3	1764.0	27	150	300					
1789.4	1788.9	26	120	500	pri červenom plaváku	30	60	500	
1791.6	1791.0	18	90	600	pri červenom plaváku	22	40	600	
1792.1	1791.6	21	80	500	pri zelenom plaváku	25	40	500	
1793.0	1792.1	23	110	900	pri zelenom plaváku	28	60	900	
1794.0	1793.5	24	100	500	pri červenom plaváku	28	60	500	
1795.9	1795.3		80	600					úžina
1796.3	1795.9	23	80	400	pri ľavom brehu	27	60	400	
1797.4	1796.6	23	90	800	pri červenom plaváku	28	60	800	
1799.0	1798.3		100	700					úžina
1808.1	1807.6	24	120	500	pri červenom plaváku	26	60	500	

Figure 35: Shallow Points at SVK-HUN Section of the Dabune (1811 - 1708) as of 16.12.2015 at $920 \text{ m}^3\text{s}^{-1}$ (at 6:00am) min nav. depth is $1010 \text{ m}^3\text{s}^{-1}$

Draft Measures

- 1 Implement the expert control system as soon as possible (see Chapter 4)
- 2 Looking ahead - construct VDN

12. Conclusions, Comparison of Possible Scenarios

12.1. Conclusions

- A. In terms of safety, capacity and reliability of the navigational traffic of the VDG it is possible to identify 7 areas related to the VDG and adjacent waterway sections requiring corrections (referred to in Chapter 4).
- B. **Necessary direct remedies**
 - 1. Restore PLK hydraulic filling and emptying system, including technologies (valves) in order to achieve the fastest possible filling and emptying of the PLK while minimizing loads on parts of the filling system. Details in Chapter 5.
 - 2. Replace upper and lower gates on the PLK, replacement upper flap gates, dynamic protection of the gates, floating bollards with heating niches for winter operation. Details in Chapter 6.
 - 3. Design and implement VDG expert control system, which will avoid any risk to ships resulting from a limited PPD or incorrect manipulation with flow rates and levels. A secondary benefit may be to maximize the benefits from the production of EE. Details in Chapter 7.
- C. Necessary indirect remedies
 - 1. Seal the subsoil and expansion joints of the PLK in order to increase the reliability and structural safety of the PLK. Details in Chapter 8.
 - 2. Remove sediments from ZH-D, especially from the waterway in ZH-D and inlet channel and achieve required PPD. Details in Chapter 9.
 - 3. Adjust the Old Danube Riverbed in the section of rkm 1851 - 1811 of the Danube for the needs of a temporary waterway and recreational boating. Details in Chapter 10.
 - 4. Remove sections with unsecured navigational parameters (shallow points and straits) in the waterway at rkm 1811 - 1708 (below VDG). Details in Chapter 11.

12.2. Financial Assessment

One-off costs for the operation of the Old Riverbed would indeed be lower than the restoration of the PLK, but in the medium and long term it will be significantly more beneficial to restore the PLK, because it will maintain the high production of EE (annual profit of 30-60 million € according to the Danube water content in a given year).

Ideally - repair PLK, including the filling hydraulic system, implement VDG expert control system.

Restore the Old Riverbed for the so-called backup waterway (if it will not be possible to sail through DeK and PLK) and otherwise the Old Riverbed for recreational boating.

In the case of construction of a system of dams it is necessary to equip these facilities with PLK.

12.3. Financing Options

The private sector - in terms of the Belgrade Convention, the Danube waterway is a waterway of an international importance and Danube States must therefore provide for passage through artificial barriers in the waterway.

Public finances - since the implementation of the goals set forth in the White Paper cannot be sufficiently achieved by the Member States themselves, the relevant coordination with the Commission is therefore required in this respect. Regulation of the European Parliament and of the Council (EU) No 1315/2013 on Union Guidelines for the Development of Trans-European Transport Networks and repealing Decision No 661/2010/EU identifies the infrastructure of TEN-T, specifies requirements and sets forth measures for the implementation thereof. Provision of financial funds for the development of TEN-T in order to achieve the best

possible compliance with the guidelines and schedule within relevant financial instruments available at the EU level should be in line with this regulation and should be based on the Regulation of the European Parliament and of the Council (EU) No 1316/2013 from 11 December 2013, establishing the **Connecting Europe Facility** and amending Regulation (EC) No 680/2007 and (EC) No 67/2010 (hereinafter the "NPE"). This NPE currently seems to be the most sustainable solution.

13. Evaluation

In order to eliminate the bottleneck in the Slovak section of the Danube, which was identified in the corridor study of TEN-T Corridor Rhine - Danube Waterway, Danube Waterway Development Agency has developed preliminary feasibility study aimed to improve reliability, safety and continuity of navigation through GABČÍKOV.

Three possible options were compared to achieve the defined objectives. The most appropriate way of achieving safety, reliability and continuity of navigation seems to be the option A, which at given costs meets all aspects of the sustainable solution.

Achieved knowledge can be used as a suitable basis for a feasibility study and development of a demand-supply analysis.