DANUBEPARKS (SEE/A/064/2.3/X) - Danube River Network of Protected Areas - Development and Implementation of Transnational Strategies for the Conservation of the Natural Heritage at the Danube River (South East Europe)

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Revitalisation of the Danube distributary in the Devín area

A STUDY

May, 2011, Bratislava

CONTENTS

1. INTRODUCTION

A study "Revitalisation of the Danube distributary in the Devín area" is a part of a project DANUBEPARKS (SEE/A/064/2.3/X) - Danube River Network of Protected Areas - Development and Implementation of Transnational Strategies for the Conservation of the Natural Heritage at the Danube River (South East Europe). Its aim is to verify possibilities of flow restoration of the Devín area distributary and to propose measures allowing improvement of the water regime, increase of the flow dynamics and by this means to achieve the overall ecological improvement. Regulations will be proposed in a way that they don't have negative impact on nautical conditions in the Danube's main channel as well as with regard to preservation, or improvement of the current state of anti-flood protection.

2. MORPHOLOGICAL EVOLUTION OF THE DANUBE IN THE DEVÍN AREA

Geological composition of river bed, geographical characteristics of the area, sediment transport and flow dynamics significantly influence forming of a river channel – the flow morphology. It is therefore necessary, when proposing effective and primarily sustainable revitalisation measures, to know how the course of the river has been developing in the period of its natural regime – free meander creation process, as well as in the period when its regime is significantly influenced by engineering improvements.

Historical analysis of the Danube's evolution (centuries), from the period when the natural regime dominated in the river and river processes weren't influenced by river improvement and human activity so much yet, forms a basic starting point in proposing suitable type of revitalisation measures which should be consistent with the morphological typology of the river and its natural regime. A short-term morphological course evolution which traces back to the beginning of systematic improvement implementation – especially establishing mean and low water, involves gradual affecting of the morphology of course channel and inundation by means of implemented improvements. Understanding of the effects of the channel improvement on changes in river processes enables to propose such regulations that will relieve their negative impact and will not only be effective on a short-term basis, but also sustainable on a long-term basis. In the following parts we therefore present a brief overview of morphological evolution of the Devín area distributary within a wider context of the Danube's evolution in its Austrian-Slovak section.

2.1 Overview of the basic channel improvements on the Danube

Free meander creation process of the Danube has been gradually restricted by the improvements of the Danube, the aim of which was primarily an anti-flood protection and securing of navigation. The improvements of the Danube can be divided into: improvement to high, mean and low water. These have been performed respectively and in different periods of time.

Improvement to high water, which consisted in building bilateral anti-flood dams, had been gradually performed since the 13th century until 1853, when the lines of the protection dams on the Danube were finished in their basic form which we know until now. Later, the dams went through major reconstructions – strengthening and heightening, which lasted up to 1903 and had been performed primarily in relation to the occurrence of dam failures during flood periods (1876 dam failure on the Rye Island, 1897 and 1899 failure near Lél and Čičov).

Improvement to mean and low water: Its aim was to achieve a balanced state for continuous motion of ices and bed load and to create a nautical channel. Dangerous icy floods in 1829 and 1831 and launching of steam navigation in 1838 made this improvement inevitable. Initially, only local improvements were performed, projects of systematic improvement were worked out only in 1880 - 1882 based on a German improvement method (typical transverse profile) with the aim to achieve 2 m of nautical depth and to secure the continuous motion of ices. For the sake of creation of nautical channel enclosures of distributaries were performed. The enclosures of distributaries, which fell within a so-called regulatory line, had a nature of longitudinal structures; otherwise they were dammed vertically to the course. **Improvement to low water** was basically only a necessary complement of the improvement to mean water. The aim of this improvement was to secure the nautical continuity during lower discharges, which was carried out by means of concentrating discharges in the channel – by the close-up of distributaries, building of guiding structures and groynes.

2.2 Historical evolution of the Danube in the Devín area – the period before channel improvement

The Danube, after crossing the Devín gate, changes its morphological nature and due to lessening of river bed gradient below Gabčíkovo it turns to a lowland course (from ~ 0.4‰ to 0.065‰) in our area. In the Devín area, in the section from the source, the biggest left-hand tributary river – the Morava - flows into the Danube. In the period of free meander creation process, the Danube was a very dynamic river, which created anastomotic areas in many sections, where the channel branched out to many distributaries, among which there were more or less stabilized islands. The increased morphodynamic activity of the Danube can be observed also in the area below and above Devín on the map from 1811 - 1821 (Fig.1), where a relatively dissected channel with several islands and benches is shown.

a) 1811

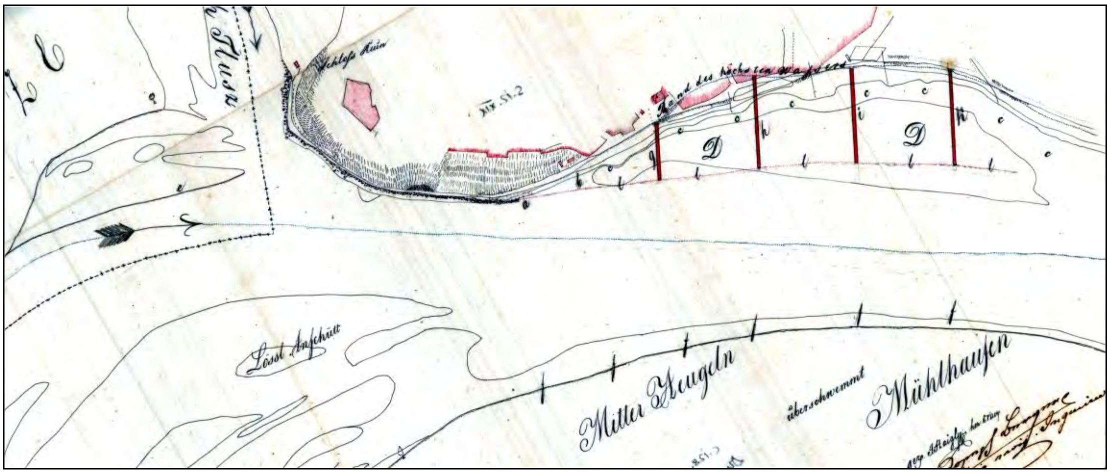
b) 1821

Fig.1 Historical maps of the Danube in the Devín area – the period before the improvement to mean water - free meandering (1811-1869)

The increased morphodynamic activity of the Danube can be observed also in the area below and above Devín on the map from 1811 - 1821 (Fig.1), where a relatively dissected channel with several islands and benches is shown. The area, in which the Devín area distributary is situated today; was back then a part of the Danube's main channel and despite the increased morphological activity above and below this section, the channel remained very stable in the long term owing to its rocky bed. An island formed in the top of a bend, which was initially changing its size depending on the actual flow conditions. Behind this island the current Devín area distributary began to form.

2.3 Historical evolution of the Danube in the Devín area – the period of local improvements

The period of free meander creation process of the river gradually finished with local channel improvements at first and later with initiating of systematic channel improvement to mean and low water. On the 1835 map there is a draft of a guiding structure, the aim of which was the improvement of dissected channel to a single width of 300 m and a cut-off of the Devín area distributary, which was, however, performed only later. The island which was forming in the top of the Danube's bend by the left bank increased in size since 1821, whereby extensive benches in the Morava's estuary area (the Danube's left bank) as well as in the convex part of the bend (the Danube's right bank) didn't change much.

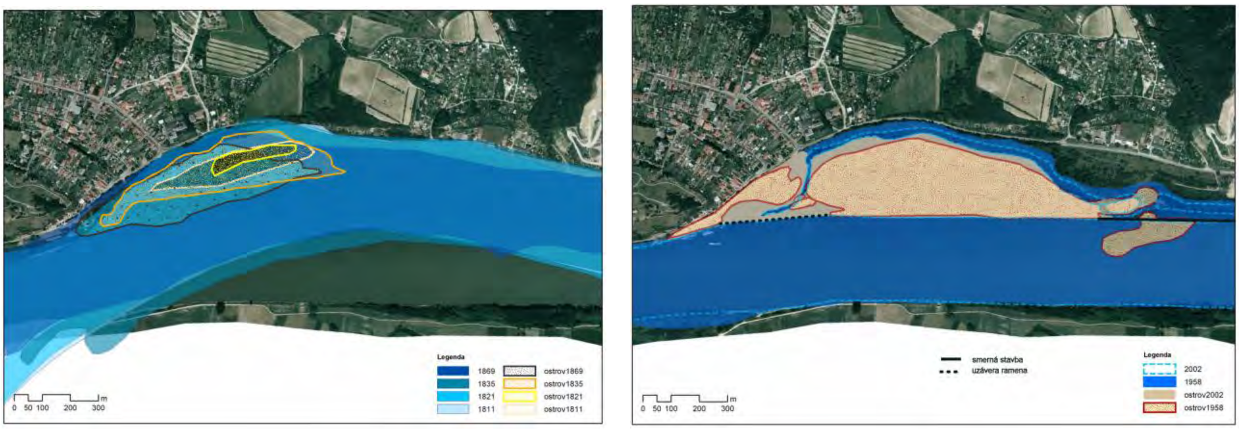


a) 1835

b) 1869

Fig.2 Maps of the Danube in the Devín area – the period of performing local improvements

The 1869 map shows already realized groyne system in the alluvial area by the Morava's estuary (Fig. 2b). The island area increased moderately and attached itself to the left bank, the Danube's channel, however, remained without significant improvements. In this period was thus the current Devín area distributary a part of the Danube's channel. A morphological evolution of changes of the island from the period before performing channel improvement to mean water is shown on the Fig. 3a.



a) Island and distributary evolution in 1811-1869 b) Island and distributary evolution in 1958 - 2002

2.4 The impact of the Danube channel improvement on the current status of the Devín area distributary

By means of performing the improvement to mean water the Danube’s channel in the Devín area narrowed to a single width of 300 m, which was achieved by a cut-off of the top of the original bend of the Danube’s channel through a guiding structure (Fig.4). This way the distributary was cut off and the island was isolated in the top of the bend at the same time. Alluviums in the lower part of the island, which were present in the channel area, have been gradually washed away. The extended guiding structure in the lower part of the island has formed a cove by the left bank - a part of the original Danube’s channel, which nowadays serves the purpose of a harbour used by a stone pit operation in Devín. In the late 1950’s, the improvement to low water in this section was yet to be performed.

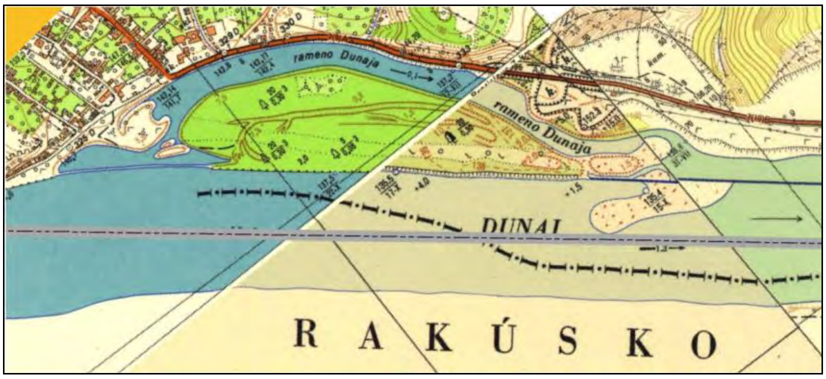


Fig. 4 The Danube’s channel by Devín – 1958, after the improvement

In the following period, alluviums formed in the area behind the guiding structure and the island area continued to grow because of the Danube’s sediment accumulating. One part of a solid area of the left-hand circumlittoral zone (in the upper and lower part of the island), where it originally overlapped with the Danube’s channel, was created artificially. Even though a relatively dissected distributary is branched in its upper part, the main distributary, separated from the Danube by the guiding structure in the inlet area and split into two by a small island in estuary area, is active.

Within the framework of improvement to low water 6 groynes were built in the Danube’s channel by the left bank, which concentrate low discharge in the channel in order to secure the nautical conditions. In the area behind groynes, sediments accumulate.

2.5 The current status of the Danube in the Devín area in relation to the waterworks operation

Fig.5 The Danube’s channel by Devín – 2006, the current status

Morphological evolution of the Danube’s channel after its dyking in Čunovo was a consequential period to a significantly degraded channel with modified flow conditions, sediment regime and, subsequently, the evolution tendencies of the channel. Flow dynamics has been modified in particular in the backwater area (retention dam Čunovo), which extends to the Lafranconi Bridge. Besides the operation of the Gabčíkovo waterworks (1992), the river processes in the Devín area are also influenced by performed channel improvements (primarily for securing of nautical conditions) and partially also by the operation of the Freudenau waterworks. The Danube’s channel is artificially supplied by bed load for the sake of securing of the river bed stability below the Freudenau waterworks. There hasn’t been any success in stabilizing the river bed of the Danube this way in the Austrian section so far and therefore a part of bed load is gradually transported down the river to the area below Devín.

The balance of morphological changes of the Danube’s channel in the Bratislava - Devín section from 1992 to 2009 (Fig.6) indicates gradual stabilization of river processes – the river bed finds itself in the conditions of “dynamic equilibrium”, that means that the volumes of alluviums equal approximately the volumes of erosion (sediment accumulating slightly prevails + 677 m^3). A detailed analysis of morphological changes has shown that in this section 4 areas formed, where processes of degradation and aggradation of the channel alternate. In the areas between km 1877.20 - km 1875.20 and km 1874.0 - km 1773.5 sediment accumulating slightly prevails and in the area from Devín to km 1877.20 there is still a relatively noticeable river bed degradation, which is related to the past evolution of this section (1970s). Degrading processes in this area were caused by extensive industrial dredging. That’s why there practically has been a noticeable river bed decrease in the Devín area until today. However, river bed degradation processes in this section are becoming gradually moderate.

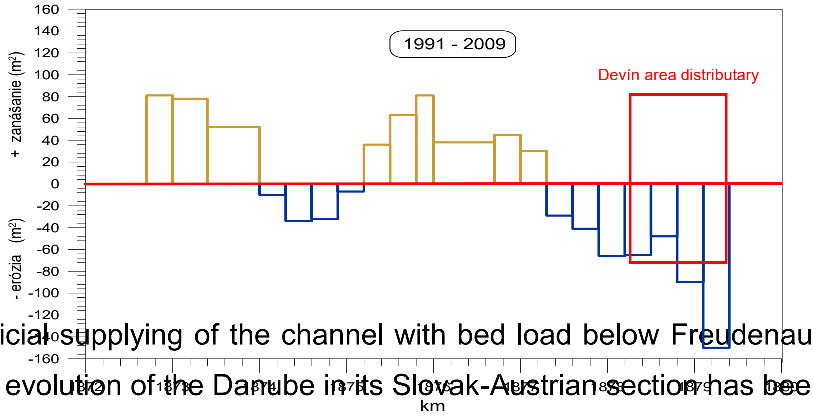


Fig.6 Volume changes of the Danube's river bed in the section Bratislava - Devín

Except of artificial supplying of the channel with bed load below Freudenau waterworks, the morphological evolution of the Danube in its Slovak-Austrian section has been influenced also by realization of some revitalisation measures (removal of bunding). The results of monitoring indicate a moderate increase of bed load and wash load feed in the Slovak-Austrian section, however, a longer lasting negative influence of these measures has not been corroborated so far. For the sake of flow restoration in the Devín area distributary it's crucial that the Danube's channel in the Devín distributary area isn't influenced by alluviation, which would increase the risk of increased sediment feed into distributary after its opening.

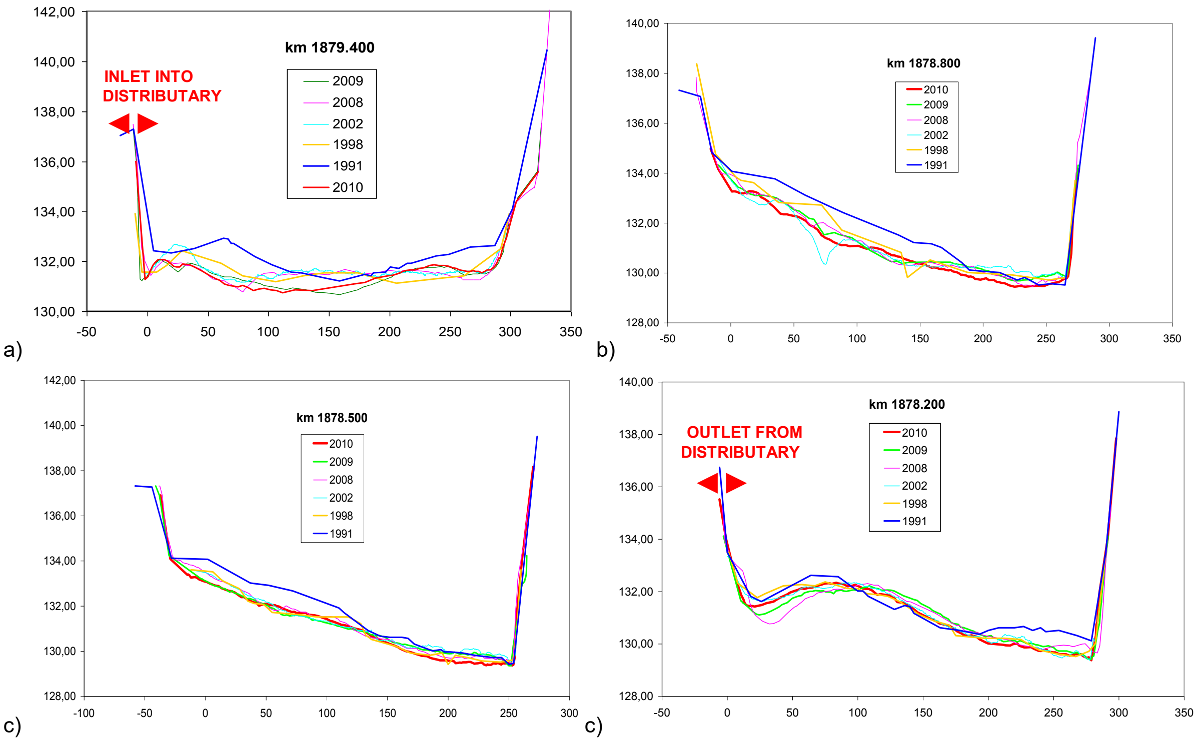


Fig.7 Morphological changes of the Danube's channel in the Devín area distributary

The Danube's channel in the section of Devín area distributary is relatively stable (Fig.7), however, the flow conditions are locally influenced by a groyne system, which was built along the island (Fig.11). The Danube's streamline is located in the middle of the stream in the inflow area (Fig.7a), which is favourable not only for the flow conditions in the area of the proposed inlet, but also regarding potential sediment feed, as the transport of bed load is concentrated in the middle of the stream. The lower section of the distributary is located in the area where the channel is a bit asymmetric and the streamline is due to groyne influence attached to the right bank, which becomes evident in the increase of the Danube's river bed by the left bank (Fig.7d). Moreover, the outflow out of the distributary is located behind the groyne system, where usually larger amount of sediments accumulates. That's why it is also important to achieve not only the improvement of the water regime of the distributary by its flow restoration, but also restoration of flow dynamics.

2.6 Composition of river bed sediments in the Danube

Morphological conditions of the Danube as well as flow conditions (described above) in the given area are favourable and constitute premises for the effective flow restoration. Physical features of river bed sediments in the Danube are important in terms of their potential transport into the distributary in the bifurcation area (merging of a stream with a distributary). River bed sediments of the Danube in this area are composed of fine-grained and course-grained gravel (Fig.8). In the convex area (the inner part of the bend) a fine-grained material accumulates, whereas in the middle of a stream and by the left bank the material is more assorted and thus course-grained (Fig.9 – vz.3, vz.4). Based on the flow conditions and features of the river bed material in the Danube one can assume that under current conditions only restricted amount of bed load gets into the distributary and only under specific circumstances (longer lasting medium-high discharges within 3 500 m^3s^{-1} - 4 000 m^3s^{-1}).

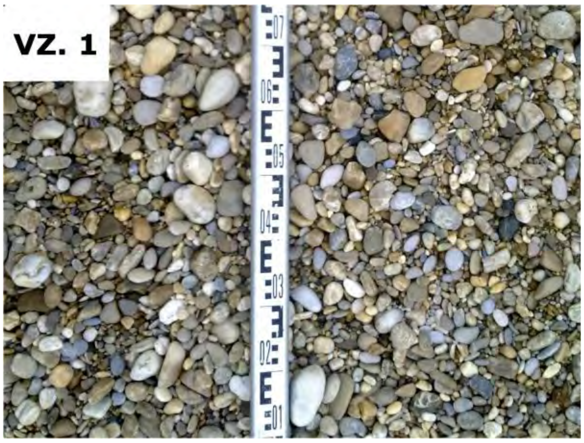


Fig.8 Sediments from the gravel bench km 1880

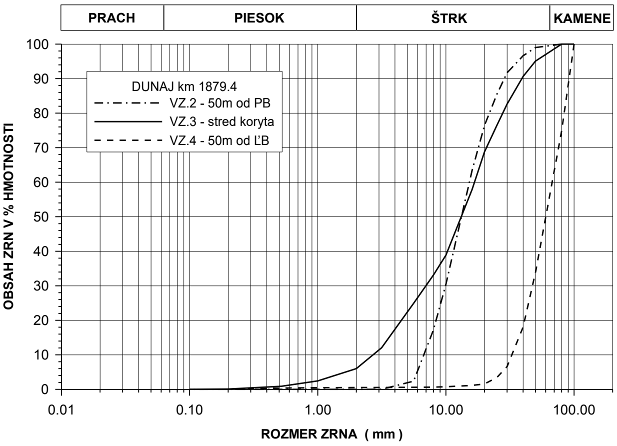


Fig.9 Grain-size curve of the river bed material in the Danube (dust, sand, gravel, stones)

In connection with the increased wash load feed into the opened distributary a moderate risk is presented by the Morava distributary, which feeds the Danube with relatively large amount of fine-grained sediments (wash load) in the period of higher discharges. Moreover, the density currents of wash load are concentrated by the left bank of the Danube where both inflow and outflow area of the distributary are located. However, if the flow dynamics in the opened distributary is restored successfully, not even this increased concentration of wash load in the Danube presents the risk of its alluviation.

2.7 Hydrological circumstances – discharge and water level regime of the Danube

There are so-called standard levels for the Slovak-Austrian section of the Danube. The progress of these levels for the Devín - Devín-Lom section is presented in numbers in Table 1. For the flow restoration in the Devín area distributary, the low water level Danube Commission (LDC=HNR PV), which is the minimum level allowing navigation on the Danube, is the most important. It is possible to open the distributary within the range of levels higher than HNR PV + 0.5 m. In Table 1, levels of HNR PV corresponding to the inflow and outflow of the distributary are already included. With regard to the flow conditions below the confluence of the Danube and the Morava and to the nautical requirements, the level of the minimum discharge in the Danube for the opening of the distributary should be higher than 134.03 m.a.s.l. + 0.50 m; i.e. **134.53** m.a.s.l.

Tab.1 Standard levels for the Slovak-Austrian section of the Danube

Fluviometric profile	**km**	**HNR PV 1042 (m^3s^{-1}) RNW**	**Q_{middle} 2030 (m^3s^{-1}) MW**	**HVP 4940 (m^3s^{-1}) HSW**	**Q_{30} 9570 (m^3s^{-1}) HW30**	**Q_{100} 11000 (m^3s^{-1}) HW100**
		m.a.s.l. Balt	m.a.s.l. Balt	m.a.s.l. Balt	m.a.s.l. Balt	m.a.s.l. Balt
	1880,00	134,18	135,56	138,57	141,87	142,74
Devin	1879,80	134,14	135,54	138,56	141,82	142,72
Inflow into distributary	**1879,40**	**134,04**	**135,46**	**138,49**	**141,58**	**142,60**
Thebnerstraßl	1879,25	134,00	135,43	138,47	141,52	142,54
	1879,00	133,92	135,31	138,28	141,42	142,46
Outflow out of the distributary	**1878,15**	**133,61**	**135,06**	**138,03**	**1421,25**	**142,13**
	1878,00	133,56	135,02	137,99	141,22	142,07
	1877,00	133,16	134,64	137,61	140,83	141,82
Devin-Lom	1876,85	133,12	134,61	137,57	140,77	141,77

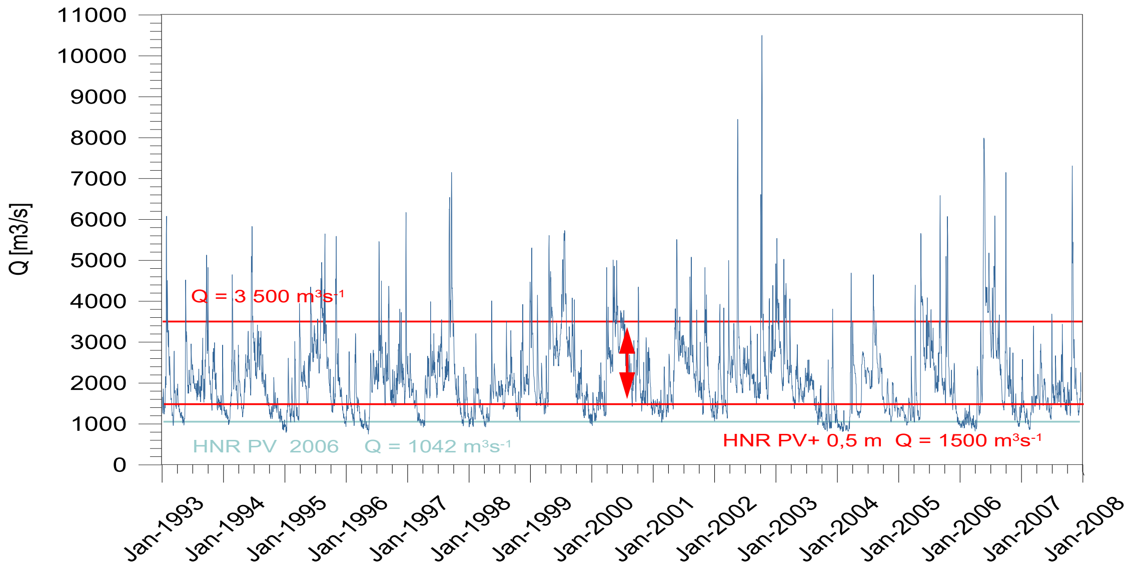


Fig.10 The occurence of the average daily discharge of the Danube in the hydrometric profile Devín

Discharge levels for the sake of flow restoration can thus range from the discharge level congruent with the water level of 134.53 m.a.s.l., which is approximately ~ 1 500 m^3s^{-1} to 3 500 m^3s^{-1}. In case of discharge levels higher than 3 500 m^3s^{-1}, waters gradually start to overflow their banks and flood both the island and the distributary. Discharge suitable for the opening of the distributary depends on its capacity and morphological state.

3. THE CURRENT STATUS OF THE DEVÍN AREA DISTRIBUTARY IN RELATION TO POSSIBLE IMPROVEMENTS

3.1 Field measurements

Two detailed field surveys (October 2010, January 2011) were performed for the purposes of examination of the current status of the Devín area distributary and channel improvement measures projects for the securing of the functional flow restoration. Within the field survey, geodetic measurements of inflow/outflow area of the distributary (Fig.12, Fig.18), the area of dyking of the distributary in the locality of the road communication (Fig.14, Fig.15) and a detailed measurement of a network of transverse profiles of the distributary (19 profiles, Appendix 1) were performed for the purpose of designing a 1D hydrodynamic analysis model of the flow conditions and morphological characteristics of the distributary channel.

3.2 Current hydro-morphological status of the distributary

The analysis of historical evolution of the Devín area distributary has shown its long-term morphological stability which is influenced particularly by the overall nature of morphological evolution in the Devín Gate area. In the past, the state of the distributary, as well as the island, remained without considerable changes on a long-term basis. After performing the improvement to mean water and cutting off the distributary from Danube, the distributary kept narrowing down, mainly in the inflow area. Despite the restricted interaction between waters and the Danube, the distributary still keeps a sufficient volume and is not considerably influenced by the alluviation at the present time.

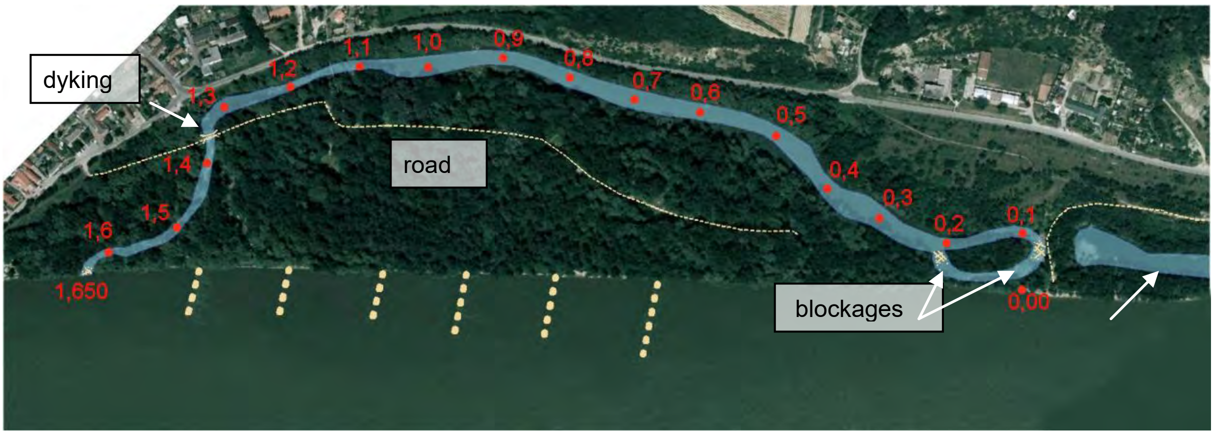


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Fig.11 Scheme of the current status of the Devín area ditributary - ortophotomap groynes

cove

The distributary is cut off from the Danube by a stone levee in the upper part; in the lower part, a high earth fill dam (vertically to the Danube's course. km 1878.15) separates it from a cove which was created by the lengthening of a guiding structure by the Danube's left bank – nowadays it serves the purpose of a harbour for a stone pit in Devín. In the estuary area, a small island dividing the distributary into two branches formed after performing the channel improvement to low water. The island is stabilized by vegetation – by trees and bushes. The overall distributary length is 1765 m including both distributary branches separated by the island. In the km 1,335 the distributary is dammed by a roadway and the interaction of waters between the separated parts of the distributary is secured by a single pipe culvert (Fig.16). Altitude conditions along the distributary are graphically elaborated into a longitudinal profile of the distributary showing the deepest spot of transversal profiles (Fig. 11a). The longitudinal profile shows two more extensive areas which were influenced by alluviation in the past. These are located in the inflow and outflow area of the distributary.

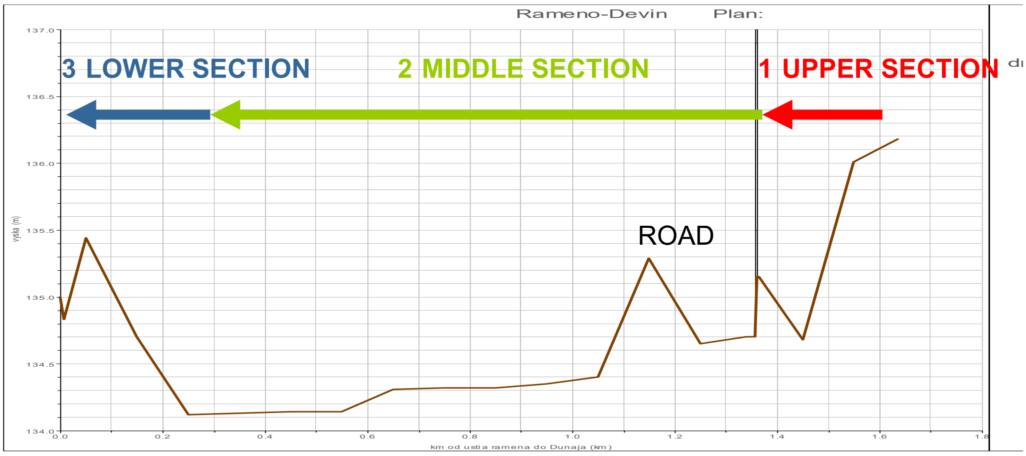
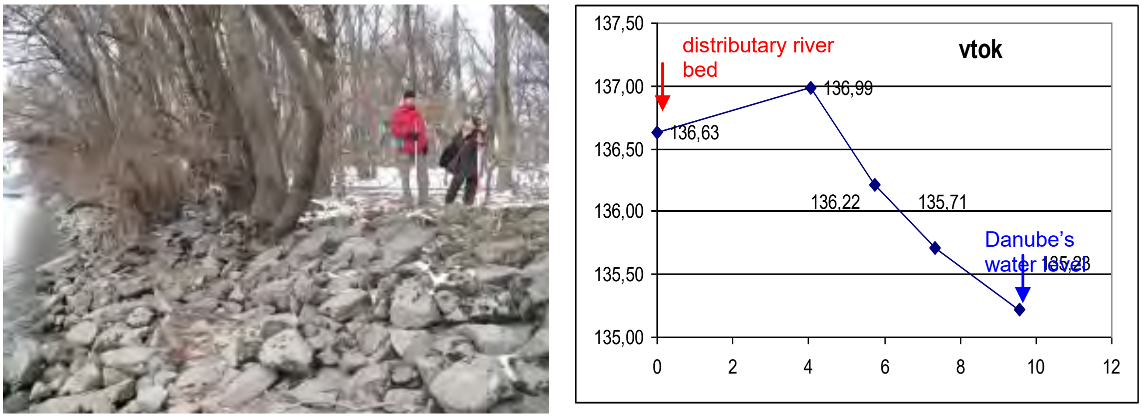


Fig. 11a Longitudinal profile of the Devín area distributary (the deepest bottom)

The inlet (Fig.12) into the distributary is located in the km 1879.40 (the Danube) in the altitude of app. 137 m.a.s.l. and the outlet in the km 1878.15 in the altitude of app. 136.0 m.a.s.l. At the present time it comes to flowing of the Danube's waters into the upper part of the distributary only when the discharge is higher than 3 300 m^3s^{-1}. In the lower part the interaction of waters occurs when the discharge is higher than 2 800 m^3s^{-1}. In the periods of mean discharge, backwater remains in the lower and middle part of the distributary, whilst the upper part remains often without water. During low discharges and drought periods the water level in the distributary decreases and also the water area reduces. Merging of the Danube's waters with the distributary (both in the inflow and outflow area), which occurs during 50 days on the average, actually represents only flowing of water from the upper or lower part of the distributary. Even in this period flow dynamics doesn't fully restore, as the road communication in the place where the distributary is dammed creates practically an impermeable barrier. The water in the distributary flows only if the upper part of the distributary fills to a higher level than the road level, then the water in the distributary flows over the roadway. Such conditions occur in the distributary only during higher mean discharges which generally get higher and gradually overflow and flood the inundation (both the island and the distributary).



a) b)

Fig.12 inlet into distributary, (a) levee by the inlet, (b) levee height in the inlet into distributary

Restoration of flow dynamics, which is important for the effective flow restoration in the distributary, depends above all on the restoration and increasing of flow capacity of the distributary in the road communication area. Increasing of the flow capacity of the distributary in this profile will secure not only an unobstructed water discharge, but also a fluent sediment transport along the distributary into the outflow area and into the Danube at last.

<u>1 – Upper section – from the inlet to the road communication:</u> The inlet is separated from the Danube by a high levee of fractured stone (Fig.12a, Fig.13a). Behind it, there is a narrowed part of the distributary of the width B~10 m, which gradually widens up to ~30 m in the length of 80 m.

The distributary river bed level is greatly unequal in this section (Fig.11a). Obviously, this part will require terrain improvements the extent of which will depend on the height of the inlet top. The distributary length after dyking is 290 m, whereby more than its half is frequently without water (13d). This section remains mostly dry and without water during the year.

2 – Middle section - from the road communication to the island: The distributary is dammed through a road communication which is basically the only access route to the island creating the distributary. The road communication consists of stone levee which is reinforced by concrete blocks on the surface (Fig.14).


a) b)

Fig.14 Interconnection of the distributary through a pipe culvert – upper part (a) roadway (b)

The height of the road top varies and in the distributary area it gradually rises in the left to right direction from 135.66 m.a.s.l. to 136.66 m.a.s.l. (Fig.15). The length of dyking across the distributary is ~ 35 m and the road is ~ 3 m wide.

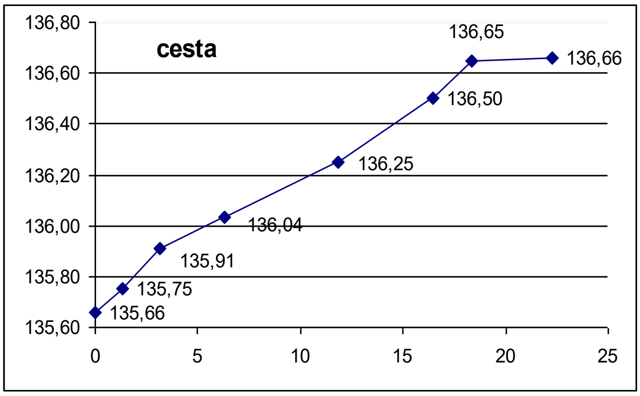


Fig.15 Height measurement of the road across the distributary

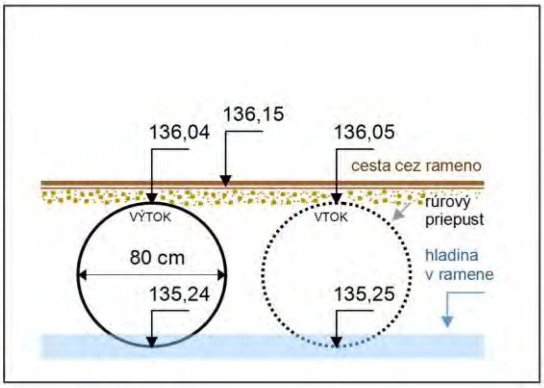


Fig.16 Pipe culvert scheme

The interconnection of the distributary is provided by a single 80 cm diameter pipe culvert (Fig.16) which is in terms of flow capacity totally insufficient considering the 35 m width of the distributary. If the Danube's water level in the inflow area goes over the height ~ 137.00 m.a.s.l., the water flows into the upper part, but the distributary only fills with water, as there is only minimum discharge through the pipe culvert. The road communication creates a practically impermeable barrier on the distributary; full flow capacity doesn't occur until the water level goes over the top of the road (over ~ 136.0 m.a.s.l.). Accordingly, this profile is critical in terms of functional flow restoration in the distributary; therefore it is necessary to propose suitable measures in this section with the aim to increase its flow capacity.


a) b)

Fig.17 Interconnection of the distributary through a pipe culvert (b), the distributary in the area below the road (a)

The most optimal way for a complete restoration of natural flow dynamics in the distributary would be the complete removal of the road communication and thus the restoration of the original distributary capacity in this profile. As the road through the distributary is the only connecting communication for the entire island, it is necessary to propose a solution which considerably increases the flow capacity of the profile and, at the same time, makes the preservation of the road possible.

Below the dyking the distributary gradually widens (Fig.17) to the width from B ~ 40 to 50 m with the maximum width of 65 metres in the profile 9 in the km 0.75. The river bed gradient in the area from dyking to estuary is more favourable for the flow capacity – the deepest river bed gradually sinks from 134.80 m.a.s.l. to 134.00 m.a.s.l. However, in the longitudinal profile

(Fig.11a) there are two areas where the river bed is higher. For the securing of better flow capacity and increasing of optimal flow dynamics it will be therefore necessary to improve the river bed in these areas. The first area is in the km 1.15 where the current river bed reaches up to 135.20 m.a.s.l. and the second is the outflow area of the distributary.

<u>3 – Lower section – from the island to the outlet</u>: The island in the outflow area divides the distributary into two branches. Both branches are clogged with deposits of tree branches, trunks and sediments (Fig. 11 and Fig.20b). These deposits need to be removed and the river bed height needs to be adjusted. Degradation of the river bed to 134.00 in the outflow area will secure the watering of the distributary from the lower side by the level of HNR PV (LDC) + 40 cm, which equals the discharge of ~ 1 250 m^3s^{-1}. The average height of the bunding in the outflow area is 136.00 m.a.s.l. (Fig. 19a). The estimated outlet width is 25 metres.

Tab.2 Levels of standard discharges of the Danube in the Devín area and inflow/ouflow area of the distributary

LOCALITY	km	HNR PV 1040 m^3s^{-1}	Q_{middle} 2030 m^3s^{-1}	HVP 4940 m^3s^{-1}	Q_{30} 9570 m^3s^{-1}	Proposed opening height
		Balt	Balt	Balt	Balt	Balt
Dunaj -Devin	1879,80	134,14	135,54	138,56	141,82	
Distributary - INFLOW	1879,40	134,04	135,46	138,49	141,58	135,00
Distributary – OUTFLOW	1878,15	133,61	135,06	138,03	142,25	134,00 – 134,50

a) bunding in the outflow area b) bank line – between the Danube and the distributary

Fig.18 The outflow area out of the Devín area distributary

Along the lower branch of the distributary adjoining with the Danube the bunding is relatively low. The water from the Danube flows into the lower part of the distributary through several terrain cavities (Fig.18b, Fig.19b). The energy from the Danube's flow had decomposed the bunding in several parts and created its natural ways of interconnecting with the distributary. These "naturally created" interconnections can be left without improvement as complementary to the distributary opening in the outflow area (if the water level goes over app. 135.5 m.a.s.l. ~ i.e. for discharges higher than 2400 m^3s^{-1}) to the main interconnection to the inlet.

upper ridge of bunding

Danube's water level

water level in the distributary

zápcha

a) the distributary parallel with the Danube's bank

b) branch of the divided distibutary clogged with deposits

Fig.20 Distributary in the outflow area – divided into two branches by a small island

Conclusion: Based on the field survey and the analysis of the current state of the distributary and morphological, hydrological and water level regime of the Danube in the Devín area, basic improvements that need to be performed for the sake of flow restoration in the distributary can be defined:

- Opening of the distributary in the inflow area – removal of bunding and improvement of the height of the inlet top to the altitude 135.00 m.a.s.l., building of an intake structure
- Improvement of the profile in the area of the road communication connected with the reconstruction of the roadway – increasing of the flow capacity of the profile

- Opening of the distributary in the outflow area - of bunding and improvement of the height of the inlet top to the altitude 134.00 m.a.s.l., eventually 134.5; outlet improvement
- River bed improvement (degradation of the river bed) in the inflow and outflow section in the selected locations where the river bed presents an obstruction for flow restoration; removal of deposits of alluvial wood and tree branches in the lower part of the distributary (near the outflow area - in the bifurcated branches of the distributary around the small island).

4. FLOW RESTORATION IN THE DEVÍN AREA DISTRIBUTARY – IMPROVEMENT PROJECT

Parameters of flow restoration as well as other improvement measures have been proposed based on the analysis of the current status, results of the field survey and utilization of results of distributary water regime modelling in the hydrodynamic model. Numerical model enabled the verification of the effectiveness of a proposed improvement in relation to water level regime and flow dynamics and also optimization of improvement parameters. The proposed improvement focus on four areas: inflow area, outflow area, dyking of the distributary (road), distributary river bed improvement.

4.1 Hydrodynamic flow model

In order to design a one-dimensional hydrodynamic model of the water regime of the Danube in the section from km 1877 to km 1880, commercial software HEC - Ras (US – Army, Corps of Engineers) was used. In the designed numerical model water level regime was discussed for the main channel of the Danube with bifurcation in the distributary area. Inlet into distributary was counted as side overflow with a wide top. Marginal conditions were represented by – water level and discharge in the Danube in the gauging station Bratislava – Devín.

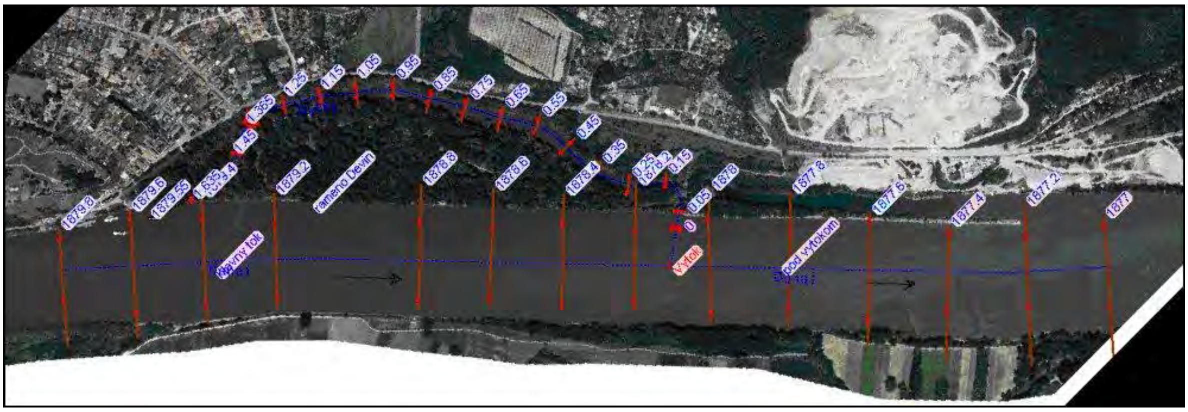


Fig. 21 Schematization of transverse profiles in the mathematical model

Topographic model was designed for channel discharges (up to 4 000 m^3s^{-1}) utilizing transverse profile of the Danube's channel (overall 14 PF) and measured profiles of the Devín area distributary (overall 21 PF). Distribution of computing profiles in the numerical model can be seen in Fig.21.

Results of water level regime modelling (division of discharges, water levels and velocities in the distributary) were used for proposing parameters for structures in the inflow, outflow and dyking area of the distributary. Calculations were performed with discharges ranging from HNR PV (2006) – 1 040 m^3s^{-1} to 4 000 m^3s^{-1}, which represent discharges during which water partially floods the inundation and starts to flow through the high water channel. Division of discharges and progress of water levels in the distributary and corresponding water levels in the Danube including progress of velocities in the given discharge set for the purpose of final combination of revitalisation measures are listed in 4.5.

4.2 Inlet and river bed improvement of the distributary – longitudinal profile

For the sake of the effective flow restoration in the distributary it is necessary that inlet into and outlet out of the distributary have sufficient capacity and that the river bed allows fluent outflow of waters which is important mainly for the restoration of flow dynamics. Inlet and outlet improvements consist in removal of a part of bunding. (Fig. 22a).

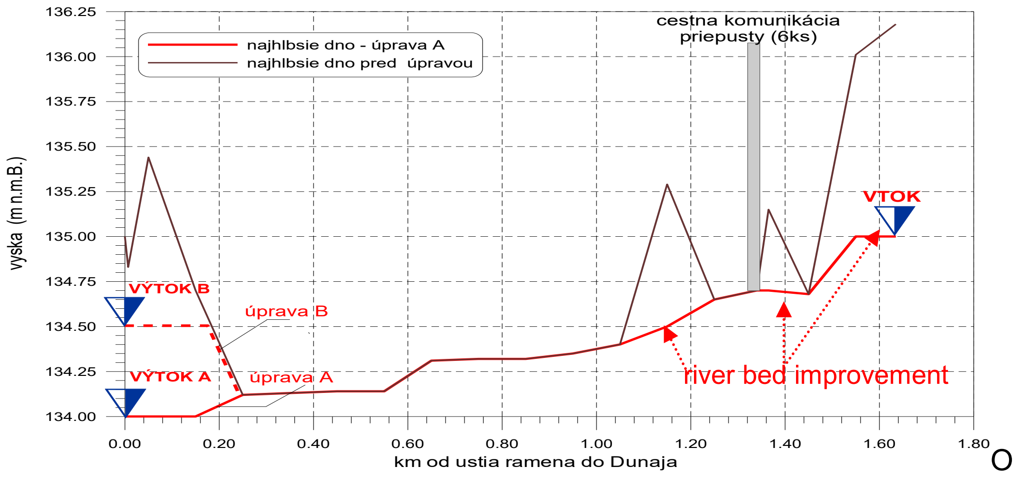


Fig. 22 Longitudinal profile of the Devín area distributary (the deepest river bed)

Tab.3 Number of days with / without interconnection between the distributary and the Danube (1995-2007)

YEAR	DISTRIBUTARY		>4000 m^3s^{-1} Number of
	INFLOW Number of days with flow restoration	OUTFLOW Number of days without flow restoration	

	1 650 – 2 030 (m^3s^{-1})	for 2031 - 3500 (m^3s^{-1})	<1 250 m^3s^{-1} **A variant**	<1 600 m^3s^{-1} **B variant**	days with flooded area
1995	51	154	51	116	18
1996	63	137	68	136	8
1997	81	140	64	108	17
1998	129	75	70	147	1
1999	59	150	18	67	40
2000	55	166	25	90	16
2001	49	155	17	120	13
2002	76	193	12	50	20
2003	76	122	64	127	16
2004	46	121	99	184	4
2005	62	110	65	143	24
2006	29	86	122	182	43
2007	93	65	47	173	8
∑	869	1674	722	1643	228
average	**67**	**129**	**56**	**126**	18

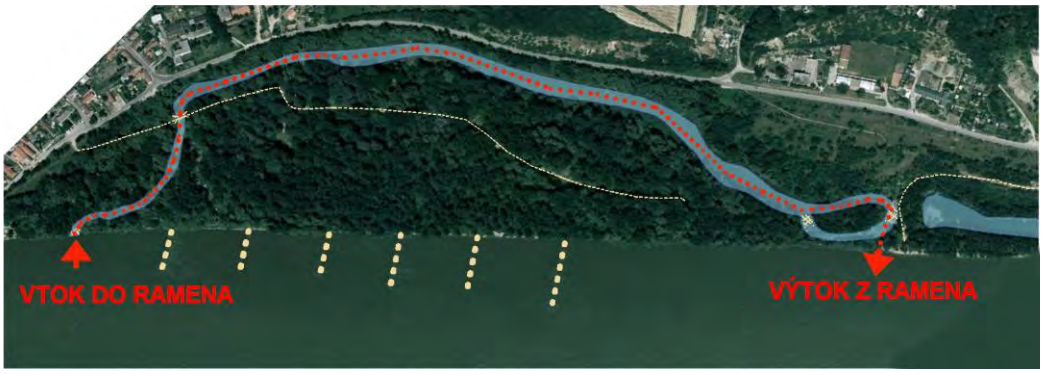
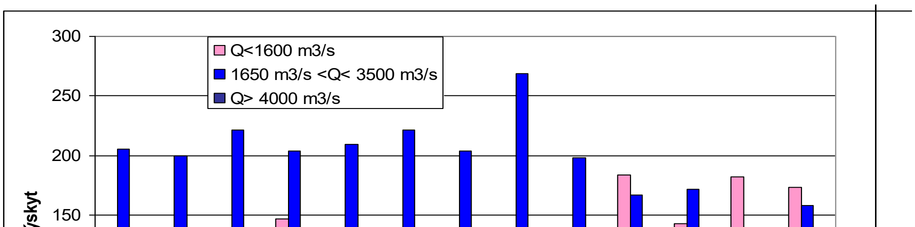


Fig.22a Locations of distributary opening in the inflow and outflow area

In the inflow area it involves the removal of enrockment which at present reaches to app. 137.0 m.a.s.l. River bed of the distributary in the inflow area is in app. 136.0 m.a.s.l. and gradually decreases to 135.0 m.a.s.l. in the direction of dyking. If the inlet was open to the extent of present river bed of the distributary in its upper part (136.0 m.a.s.l.), it would come to its filling only during discharges higher than 2 000 m^3s^{-1}, which would represent a restriction in a number of days to 129 days (Tab.3) on the average and particularly a restriction of water inflow into distributary in the period of lower discharges. Therefore we propose opening of the inlet of the distributary to the altitude of 135.00 m.a.s.l. (Fig.22), which will enable to increase the number of days with flow restoration by 67 on the average, thus to total 196 days of the year. The number of days of occurrence is only informative and it's derived from the elaboration of hydrological series of observations of the average daily discharge in the Devín profile in the period from 1995 to 2007 (Tab.3). This period, however, includes both dry and wet years and therefore it is sufficiently representative for the informative estimation of the occurrence of days of distributary flow restoration. It results from the nature of the hydrologic regime that the actual occurrence of flow restoration will be higher than the cited average in wetter years and lower in drier years.



The number of days in which it doesn't come to the flow restoration of the distributary, and thus to inflow of water through the inlet, equals 126 days on the average. The distributary area will be flooded during 18 days of the year on the average. The occurrence of days with flow restoration, without flow restoration and the flooding period of the distributary for the hydrological series between 1995 and 2007 are illustrated in Fig.23.

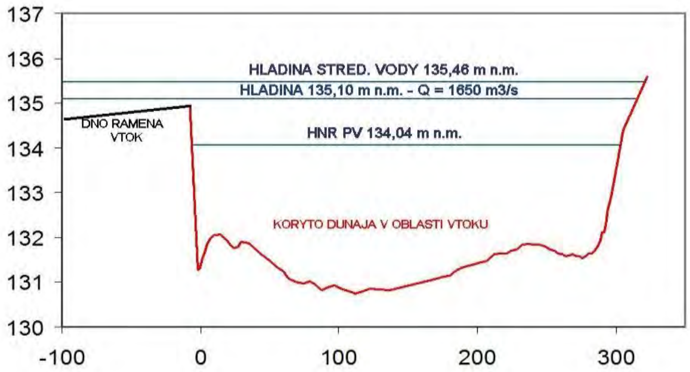


Fig.24 The Danube's water levels in the inflow area of the restored distributary

Discharges in the Danube during which water will start to flow into the distributary will decrease from 2 000 m^3s^{-1} to 1 650m^3s^{-1}, which represents, taking LDC in the inflow area into consideration (LDC; HNR PV 2006 = 134.04 m.a.s.l.), HNR PV + 96 cm (Fig.24). The inlet level lower than 135.00 m.a.s.l. is not advisable, although it would be possible with regard to the condition of observance of minimum inlet level (LDC; HNR PV + 50 cm). The reason for this is a relatively extensive river bed improvement that would become necessary, not only in the upper part of the distributary, but also in the dyking area (Fig.22).

Degradation of the inlet level by 1 meter will also require the improvement of the distributary river bed 136.00 m.a.s.l. to 135.00 m.a.s.l. in the length of app. 200 metres (Fig.22). The improvement of the river bed is indicated in the transverse profiles (Appendix 1) as well as in the longitudinal profile. Except of the inflow and outflow area of the distributary, we also recommend the improvement of two areas with higher river bed located near the dyking of the distributary (Fig.22), primarily in order to secure the flow dynamics. The first is located in the km 1.15 to km 1.25 where the river bed is increased by app. 80 cm. The second area is located just above the dyking. Here, the river bed is increased only moderately (~ 40 cm) and its improvement could be combined with rebuilding of the road communication.

The inlet length has been proposed to 20 metres in the bottom (with total length of 28 metres, Fig.25). As the distributary is relatively low in the inflow area (12 -14 m), it is also necessary to adjust the distributary width to ~ 25 metres in a short section of app. 90 metres (see Appendix 1). The top of the dike is connected to the existing bunding through slopes in gradient 1:2.

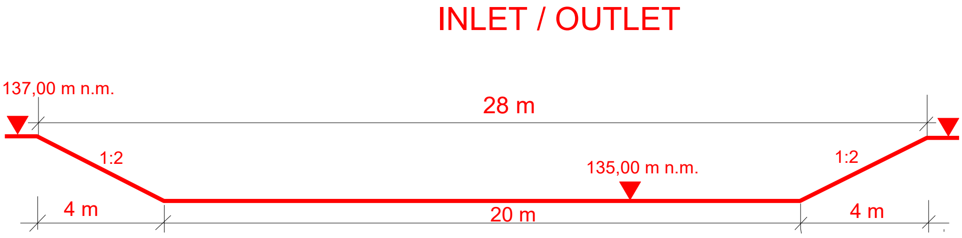


Fig.25 Transverse profile of the improvement – stone dike in the intflow area of the distributary

We propose to adjust the inlet as a simple spillway with a wide top in a trapezoidal shape. The inlet dike should be made of quarry stone. Quarry stones from the bunding can be used constructing it. The top of the dike doesn't require any special treatment, as in this part there are no requirements as to the passability of the object. The dike width should be 5 m.

4.3 Improvement in the road communication area

The improvement in the road communication area focuses on increasing of flow capacity of the profile. In terms of complete flow restoration in the distributary, the most optimal solution would be the complete removal of the dyking of the distributary, which would allow the maximum possible restoration of the flow dynamics under the proposed conditions of the flow restoration. This, however, isn't possible, as the roadway on the top of the dyking is at the present time the only access route to the island. The improvement project has therefore been restricted to increasing of flow capacity. The bridge structure, which could secure the complete flow capacity of the distributary too, would be a suitable solution; however, as it is both technically and financially demanding project, its feasibility is difficult and unlikely.

As a compromise solution we therefore propose the usage of suitable culverts which should however have considerably bigger capacity than the present pipe culvert. For the securing of increased flow capacity of the distributary in the dyking area we propose to use prefabricated units – frame culverts IZM 2400 x 1400 – 12.0 (Fig.26) manufactured by Inžinierske stavby, PREFA KYSAK (Fig.26). Considering the proposed flow capacity circumstances after the flow restoration in the distributary, it will be enough to use 6 such culverts for the purpose.

In the middle part, the road communication will be dismantled (it's formed by a levee reinforced by concrete blocks on the surface) in the length of app. 15 m. The river bed needs to be deepened to 134.60 m.a.s.l. and culverts embedded one next to another. Considering that the road communication has to be at least 3 m wide, prefabricated units should be embedded in three successive rows. That's why the total number of them is 18. The scheme of culvert embedding in a way they are included in the numerical model can be seen in Fig. 27.

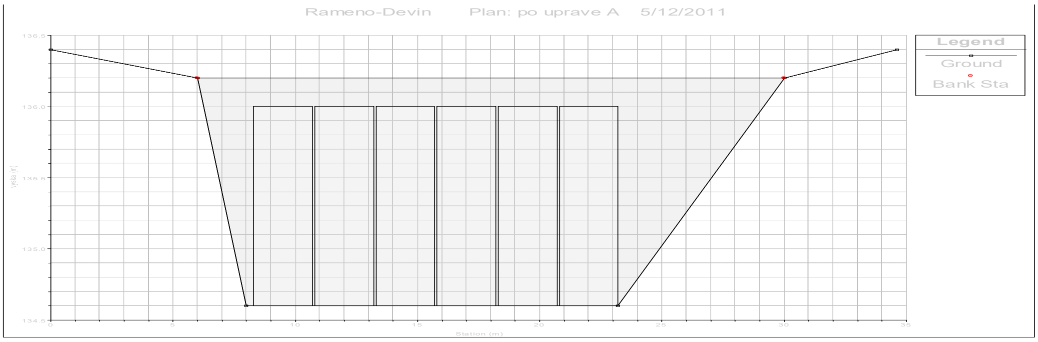


Fig.27 Scheme of culvert embedding in the profile of dyking (model HEC-RAS)

The water will flow through the culverts until the water level goes over 136.20 m.a.s.l. (the top of the road). The culverts will secure interconnection of the distributary and flow dynamics for discharges lower than 2500 m^3s^{-1}, i.e. ranging from 1650 m^3s^{-1} to 2500 m^3s^{-1}. If the discharge is higher than 2500 m^{3}s^{-1}, water level will go over 136.20 m.a.s.l. and water will begin to flow over the bypassing as well.

The size of the culvert's opening will secure a fluent runoff of sediments and smaller bed load of wood and tree branches along the distributary into the Danube. The object will require certain maintenance, particularly after high waters when bigger tree trunks and branches get into the distributary that could clog the culverts. With regard to higher flow capacity of the culverts one can expect that they will require less maintenance than they would in the present situation.

4.4 Improvement in the outflow area

The opening of the distributary in the outflow area is proposed in two variants – A and B, which differ only in the outlet height of the distributary.

<u>Variant - A</u> implies the opening of the distributary and the improvement of the river bed in the lower part of the distributary to the altitude of 134.00 m.a.s.l. (Fig. 28). With such interconnection, a fluent runoff of waters will be secured, however, with water levels lower than 134.00 m.a.s.l., the distributary will empty. The river bed in the outflow area needs to be decreased by 1.50 m in the length of 200 m. Using this variant would under certain circumstances result in emptying of the distributary into the Danube (Fig.22). Such situation would occur every time the discharge went lower than 1250 m^{3}s^{-1}, i.e. in the drier periods, which are generally associated with lack of moisture and in the period when the unrestored flow in the distributary. Based on hydrological series of the observed discharges in the period from 1995 to 2007, such situation could occur on 56 days of the year on the average (Tab.3). This fact should be considered in regard to fish and other aquatic organisms in particular.

<u>Variant – B</u> implies the improvement of the river bed in the lower part of the distributary to the altitude of 134.50 m.a.s.l. (Fig.28). It is a compromise solution which will still secure the restoration of flow dynamics and prevent the distributary from emptying at the same time. In the period of lower discharges (lower than 1250 m^{3}s^{-1}), with water not flowing into the distributary yet, minimum water depth of app. 0.5 m would still hold in the lower part of the distributary. The river bed would thus decrease by app. 1 m in the length of 200 m in this case.

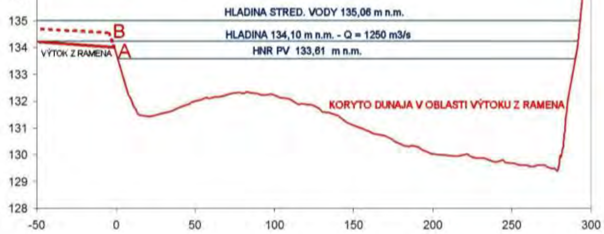


Fig.28 Danube's water levels in the outflow area of the opened distributary

In both variants the outlet will be adjusted the same way as the inlet (Fig.25). Bunding will be removed in the length of 20 m. Quarry stone from the bunding can be used to reinforce the outlet’s surface. Slopes in the gradient 1:2 will be connected to the existing bunding.

4.5 Water level regime and flow dynamics in the improvsed distributary

Discharge and water level regime: During discharges in the Danube ranging from 1700 m^3s^{-1} to 3500 m^3s^{-1} (gauging station Bratislava Devín), discharges after opening of the distributary will range from 0.35 m^3s^{-1} to 27.3 m^3s^{-1}. They will most frequently occur during mean discharges in the Danube ranging from ~ 2000 m^3s^{-1} to 3500 m^3s^{-1}, thus the discharges in the distributary will be ranging from 4.4 m^3s^{-1} to 27.3 m^3s^{-1}. The flow in the distributary will be restored in 196 days of the year on the average. (Tab.2, Tab.3).

During discharges higher than 4000 m^3s^{-1} the water will flow through the inundation. Flow restoration in the Devín area distributary with the Danube’s channel will create favourable conditions for the increasing of flow dynamics in the distributary and thus the overall biotic revitalisation. Even though the Devín area distributary won’t be restored during periods when the water levels in the Danube by the inlet will be lower than 135.00 m.a.s.l. (Q~1650 m^3s^{-1}), the waters will get into the distributary from the lower part – the outlet. Interaction of the waters from the lower part will be secured up to the level of 134.00 m.a.s.l. (Q~1 250 m^3s^{-1}) – for the A variant. During lower discharges it will come to emptying of the distributary into the Danube in this case. For the B variant, the interaction with the Danube is secured up to the level of 134.50 m.a.s.l. (Q~1 600 m^3s^{-1}). Even though during lower discharges the distributary won’t be directly connected with the Danube, minimum levels will keep in the lower and middle part of the distributary. The upper part of the distributary will be without water during this period. On a short-term basis, water may stay in the deeper parts of the distributary.

Tab.3 Division of discharge between the Danube and the distributary and corresponding water levels and velocities

LOCALITY	DISCHARGES (m^3s^{-1})				
The Danube	1700	2030	2500	3000	3500
distributary	0,35	4,4	11,0	19,0	27,3
	WATER LEVELS (m a.s.l.)				
distributary - INFLOW	135,12	135,63	136,20	136,71	137,22

distributary - OUTFLOW	134,88	135,38	135,97	136,54	137,07
	VELOCITIES (m.s^{-1})				
distributary - INFLOW	0,13	0,33	0,41	0,47	0,51
distributary - OUTFLOW	0,02	0,16	0,29	0,38	0,45
DAYS OF OCCURRENCE OF FLOW RESTORATION	196				

The progress of water levels of the selected discharge (Tab.3) in Fig.29 is defined for the final improvement project, i.e. with the inlet on the level of 135.00 m.a.s.l., the outlet on the level of 134.00 m.a.s.l., the longitudinal profile of the river bed improved (in 4 locations) and the bypassing of the distributary secured by 6 culverts (Fig. 27) and discharge in the Danube (2030 m^{3}s^{-1} - 3500 m^{3}s^{-1}) during which the minimum discharge already flows into the distributary (4,4 m^{3}s^{-1}). There are no noticeable differences in the water level regime. A moderate water swell of water levels occurs in the area above the dyking which is a result of the dyking of the distributary by a road communication. Even though the proposed culverts will increase the flow capacity of the profile significantly, around a half of flow capacity will still be blocked by a roadway. This will become evident in the swell of water levels of discharges lower than 12 m^{3}s^{-1}. During higher discharges water will flood the road communication and begin to flow over the road as well.

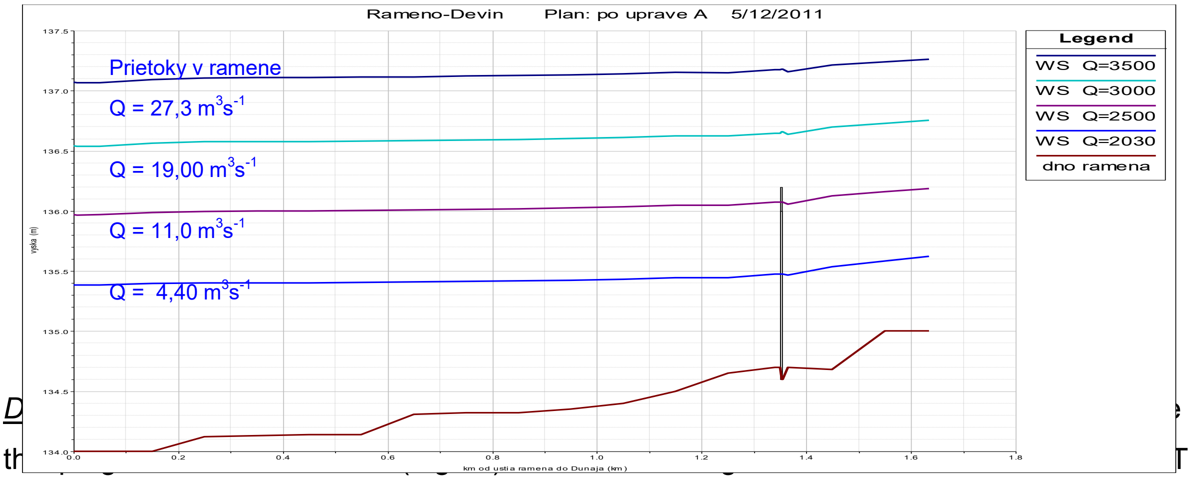


Fig.29 Progress of water levels in the distributary for the selected discharges in the Danube and in the distributary – after the improvement

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highest velocities are concentrated in the outflow area and in culverts in the dyking of the distributary. In both cases flow is influenced by narrowing of flow profile where the decrease of velocity (above the narrowed profile) on one hand, and the increase of velocity (in the narrowed profile) on the other hand, occur. The decrease of velocity (v < 0,3 m.s^{-1}) will occur in the middle part of the distributary which is caused by larger flow capacity of this section (larger widths of the distributary channel). However, this decrease of velocity doesn’t present more severe problem in terms of potential clogging. During higher discharges in the Danube (Q> 4000 m^{3}s^{-1}) the velocities will be higher also in these parts and therefore we assume that sediments that will get into the distributary and could accumulate in this short section will be washed off into the Danube by increased discharge.

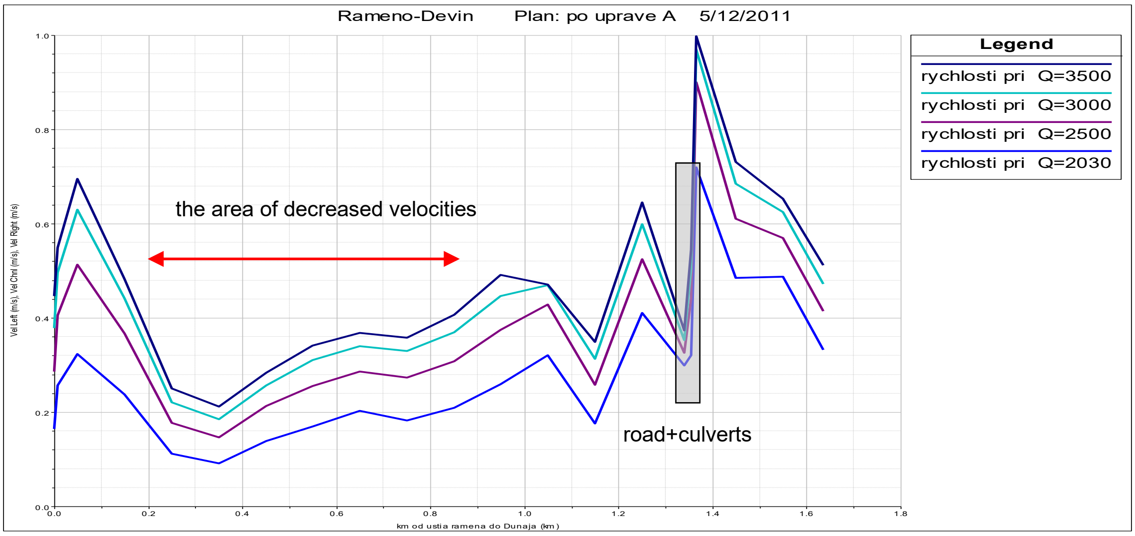

Fig.30 Division of velocities in the distributary for the given discharge

5. CONCLUSIONS

- The study reviews the evolution of the Devín area distributary and the Danube in the Devín area in the wider context of morphological evolution of the Danube's channel in the period before and after the channel improvement to mean and low water. The current status was assessed in relation to the ongoing river processes of the Danube which are influenced by building of waterworks and other human activities. The current river processes significantly influence sustainability of the proposed revitalisation measures,
- Based on the field survey, numerical modelling of flow dynamics in the Danube's channel and in the distributary, the effective flow restoration has been proposed which will secure the necessary flow capacity of the distributary and fluent transport of sediments along the distributary,
- The improvement project measures include: opening of the distributary in the inflow area to the height of 135.00 m.a.s.l. and overall width of 28 m; opening of the distributary in the outflow area using two variants: A – to the altitude of 134.00 m.a.s.l. or B- to 134.5 m.a.s.l. in both cases to the overall width of 28 m; reconstruction of the road communication and embedding of 6 culverts (dimensions: 2,4mx1,4mx1,05m), minor improvement of the river bed in 4 locations (inflow area, outflow area and sections near the dyking of the distributary).
- Intake structure (dike) is proposed as a side spillway with wide top made of quarry stone (material from the bunding can be used). The proposed parameters of the dike (the top of the spillway in the height of 135.00 m.a.s.l. and the overall length 28 m, slopes in the

gradient 1:2, spillway width 5 m) need to be specified in more detail by the project engineer.

- The study provides information on division of discharges, velocities and water levels which is important for the preparation of the project of dike in the inflow area as well as other channel improvement projects in the distributary,
- The results of modelling of the water level regime of the Danube including the Devín area distributary have shown that the proposed flow restoration (division of discharges) won’t have a negative impact on the securing of navigation on the Danube (the height of the structure’s overflow edge is proposed in a way that it doesn’t influence the water level of the low navigable water) nor the progress of flood water levels,
- For the realization of the improvements we propose the following time progression of the works: 1) reconstruction of the roadway and embedding of culverts, 2) improvement of the river bed in 4 proposed locations, 3) opening of the distributary in the outflow area, 4) opening of the distributary in the inflow area,
- Realization of the proposed measures will secure increasing of the flow dynamics, improvement of the water regime and overall revitalization of the Devín area distributary
- The proposed measures are consistent with the requirements of the European Directive on the improvement of the status of the improved water bodies (Water Framework Directive 2000/60/EC) and the Directive on the conservation of wild birds 79/409/EEC **(**EU Birds Directive).

11.05.2011, Bratislava

Ing. Katarína Holubová, PhD.
RNDr. Zuzana Capeková

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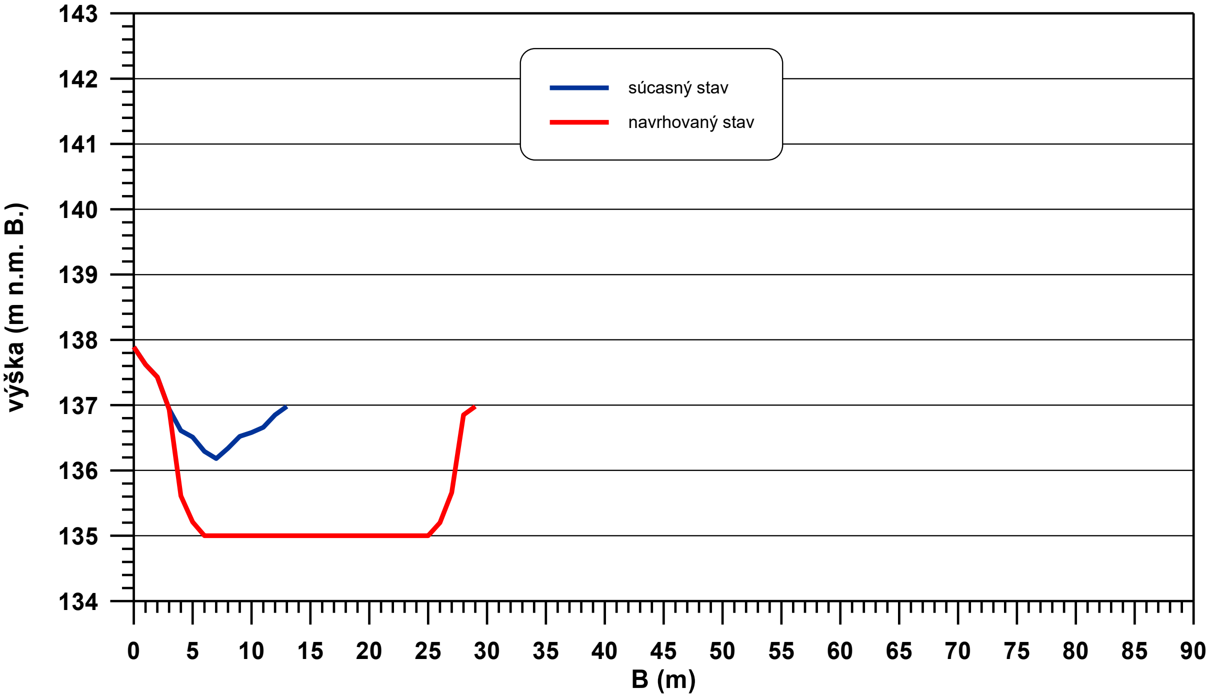
SUPPLEMENT Nr. 1

Transverse sections of the Devín side arm

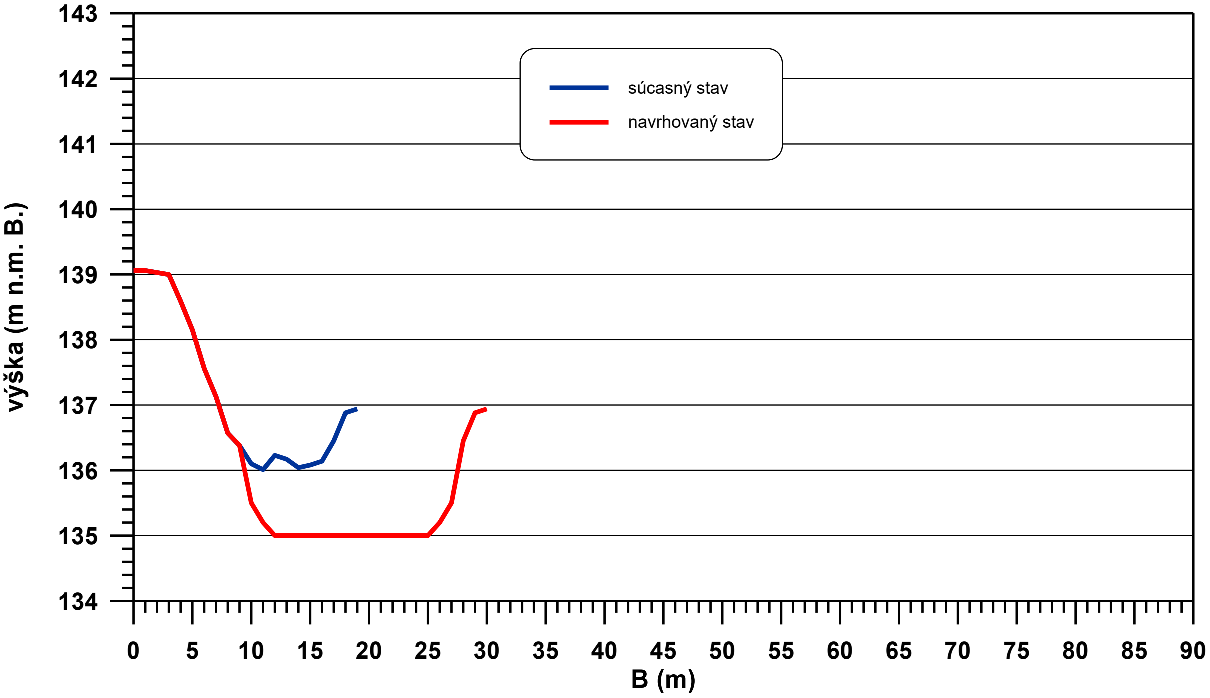
km 1.635 - INLET

PF 0



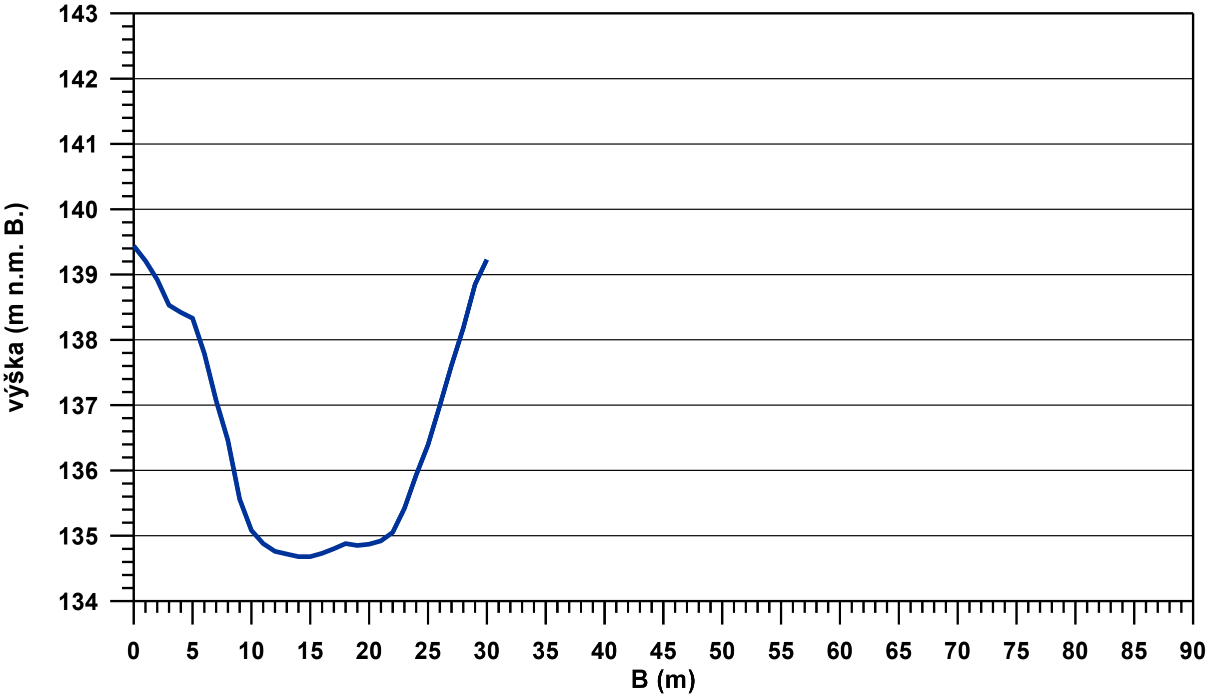
km 1.550

PF 1



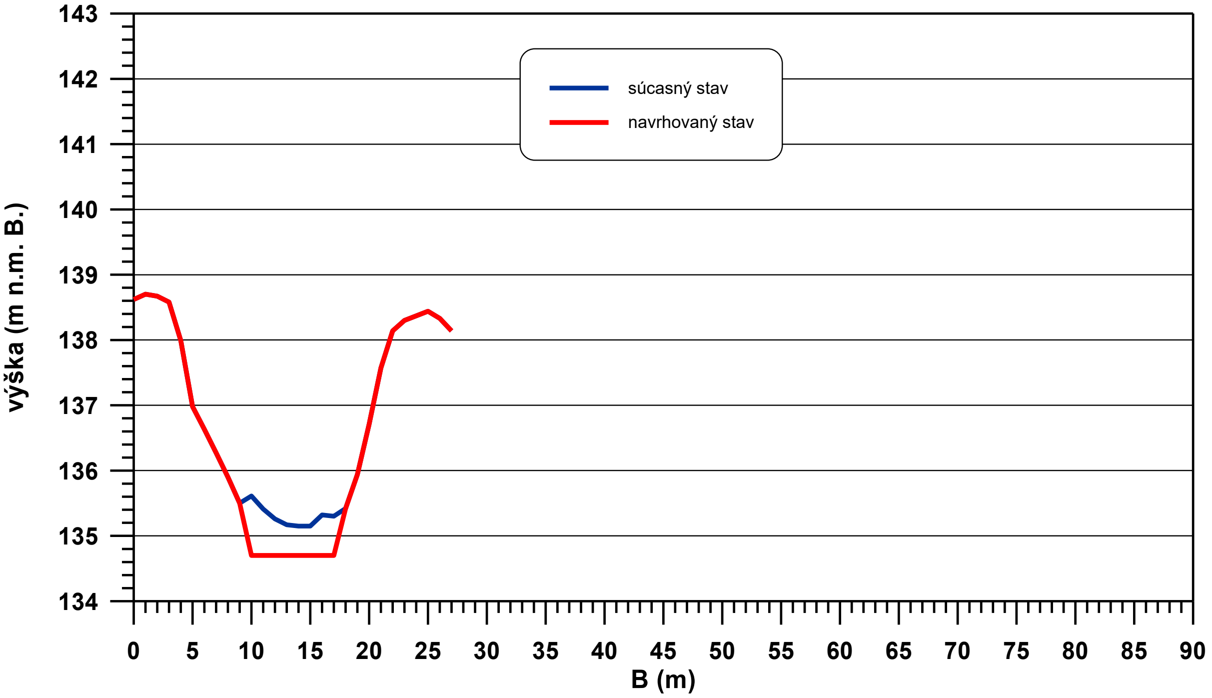
km 1.450

PF 2



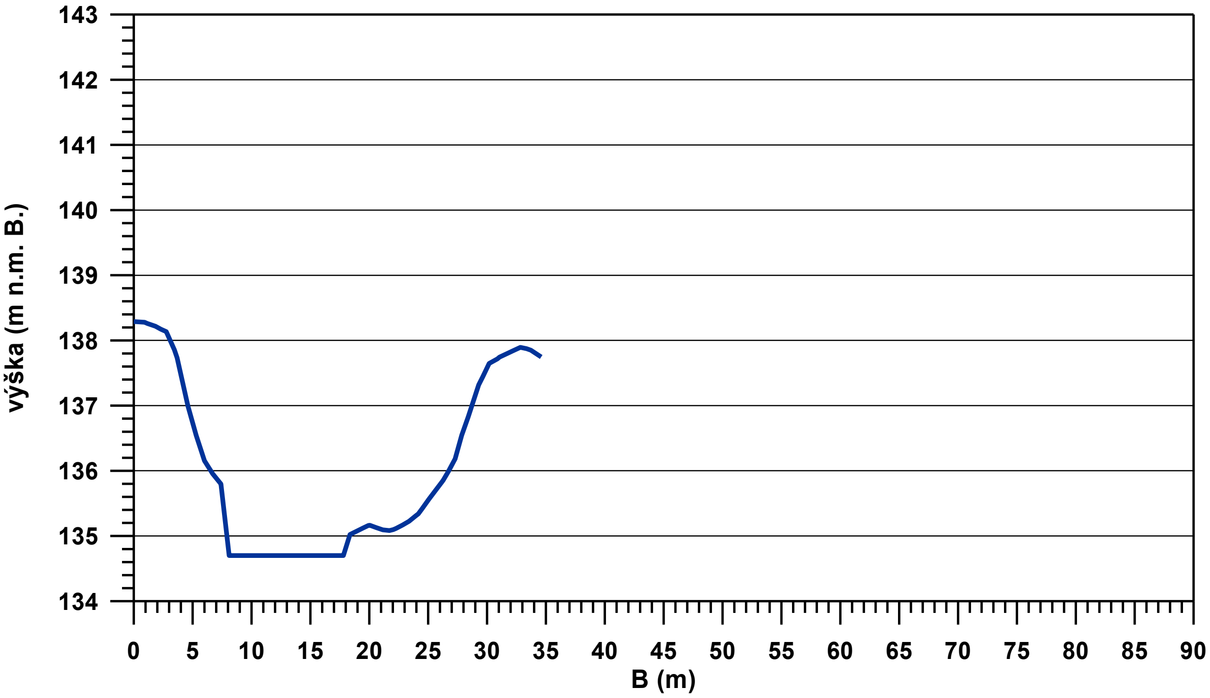
km 1.365

PF 3



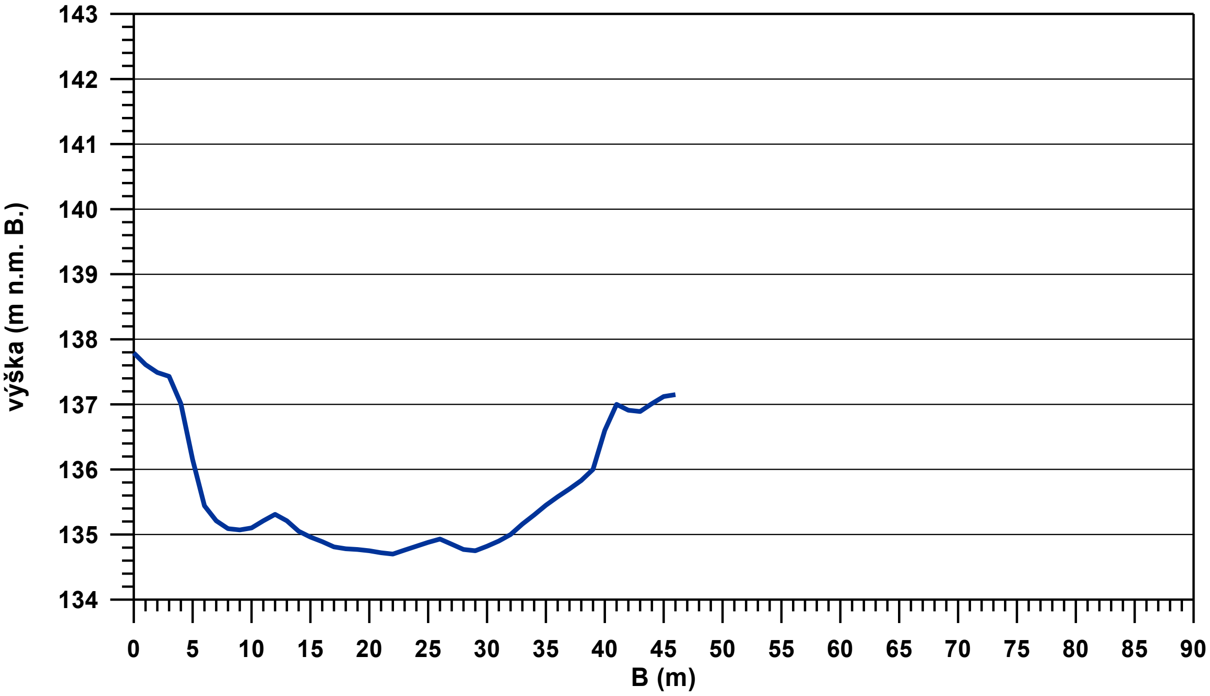
km 1.355

PF nad cestou



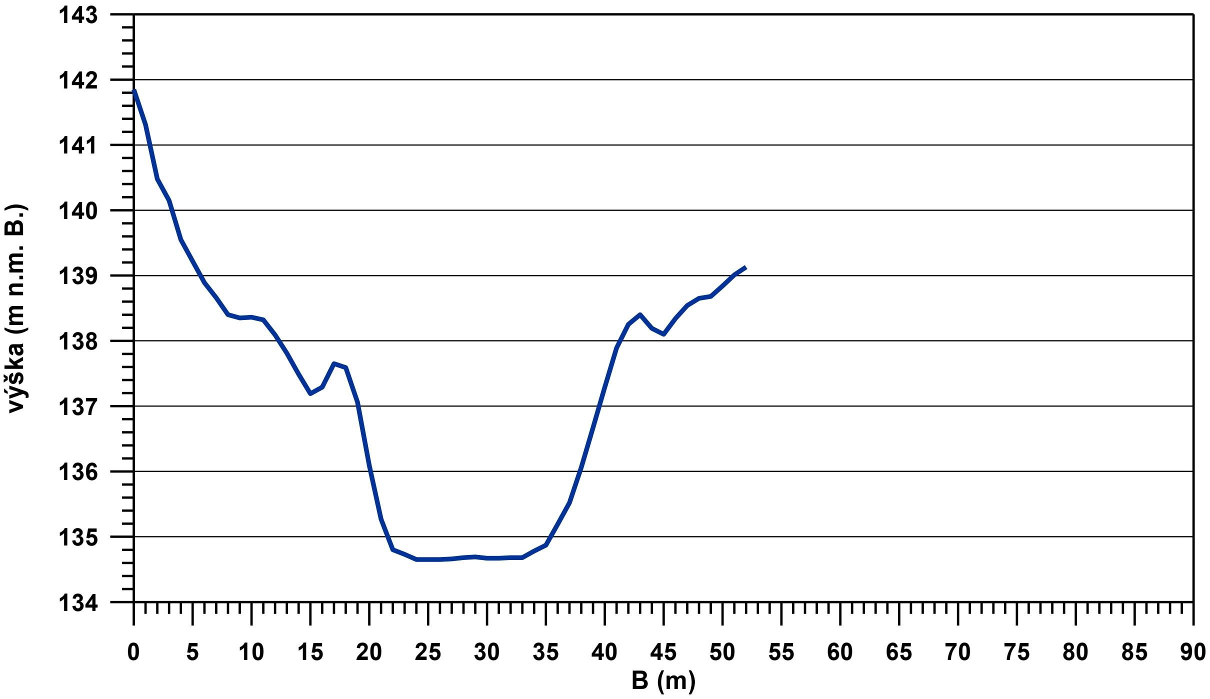
km 1.340

PF pod cestou



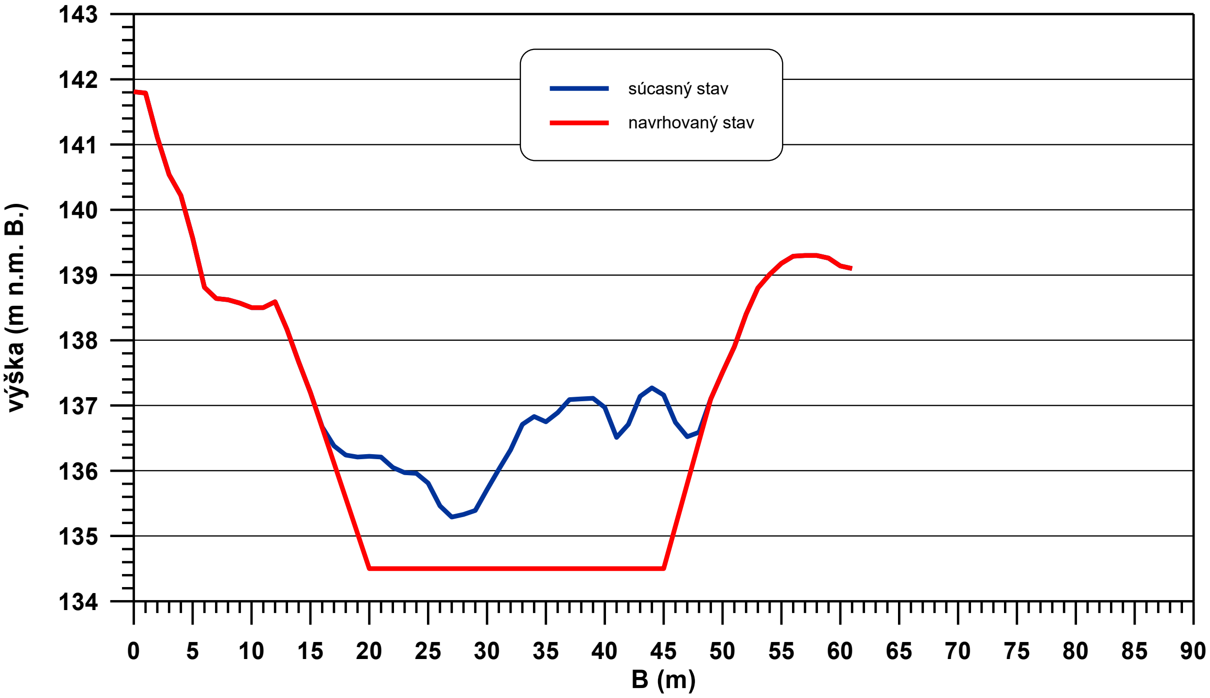
km 1.250

PF 4



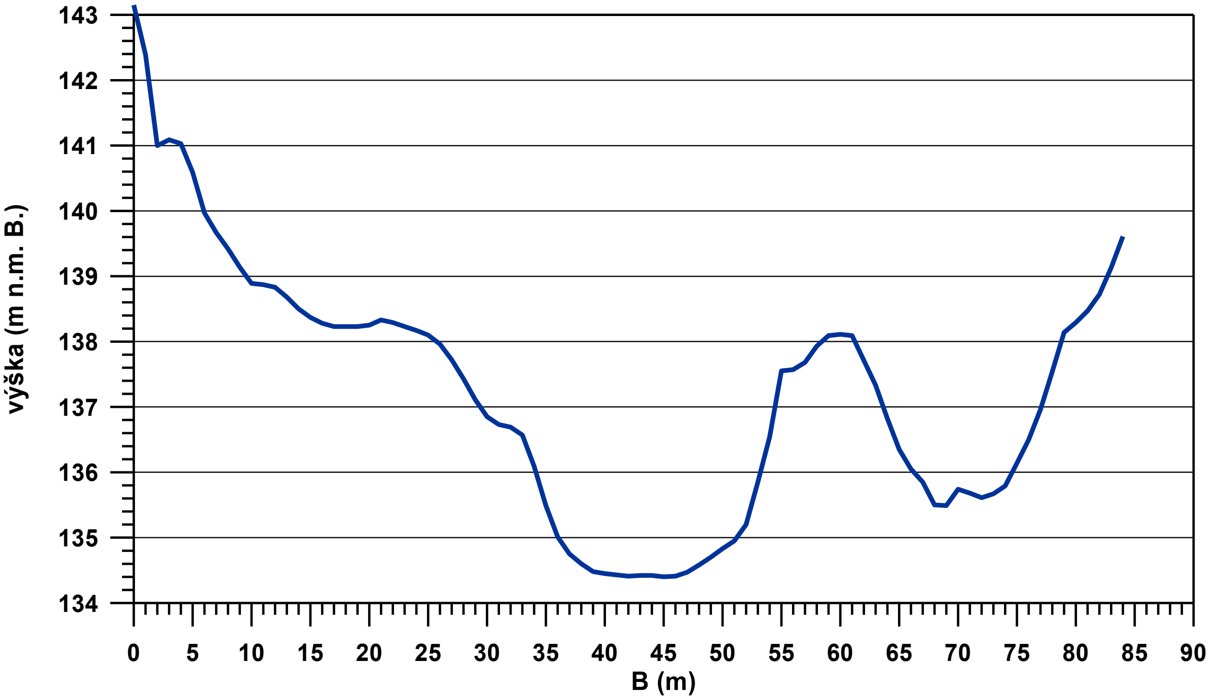
km 1.150

PF 5



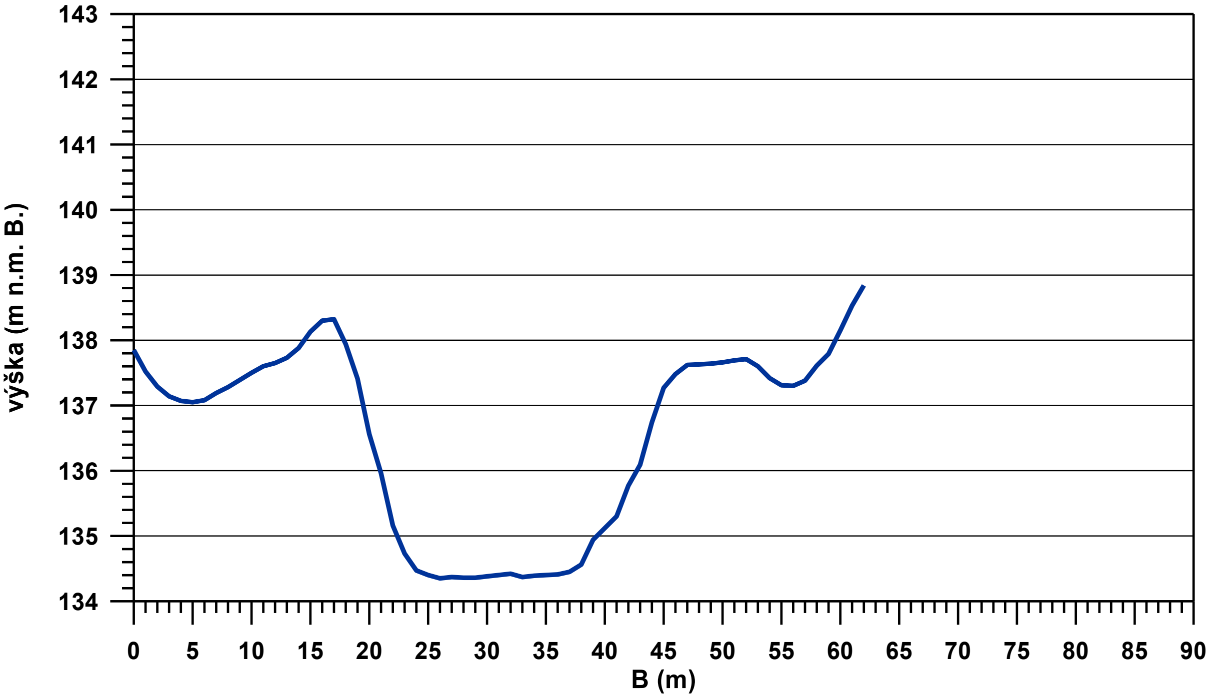
km 1.050

PF 6



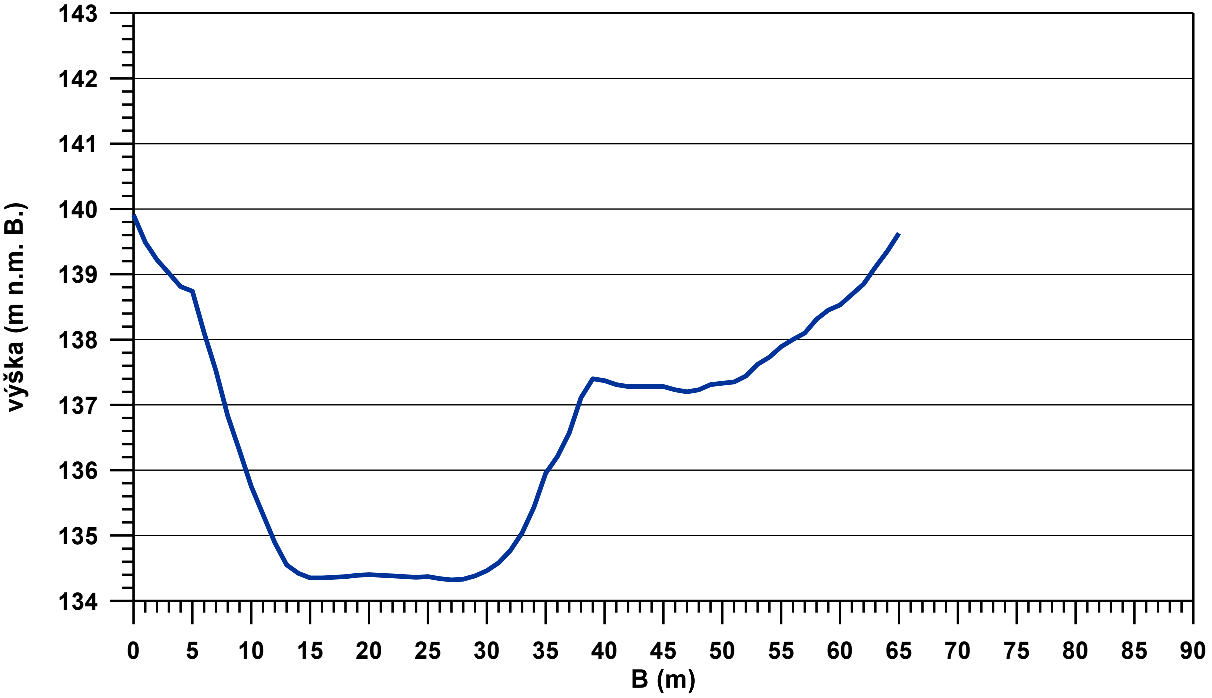
km 0.950

PF 7



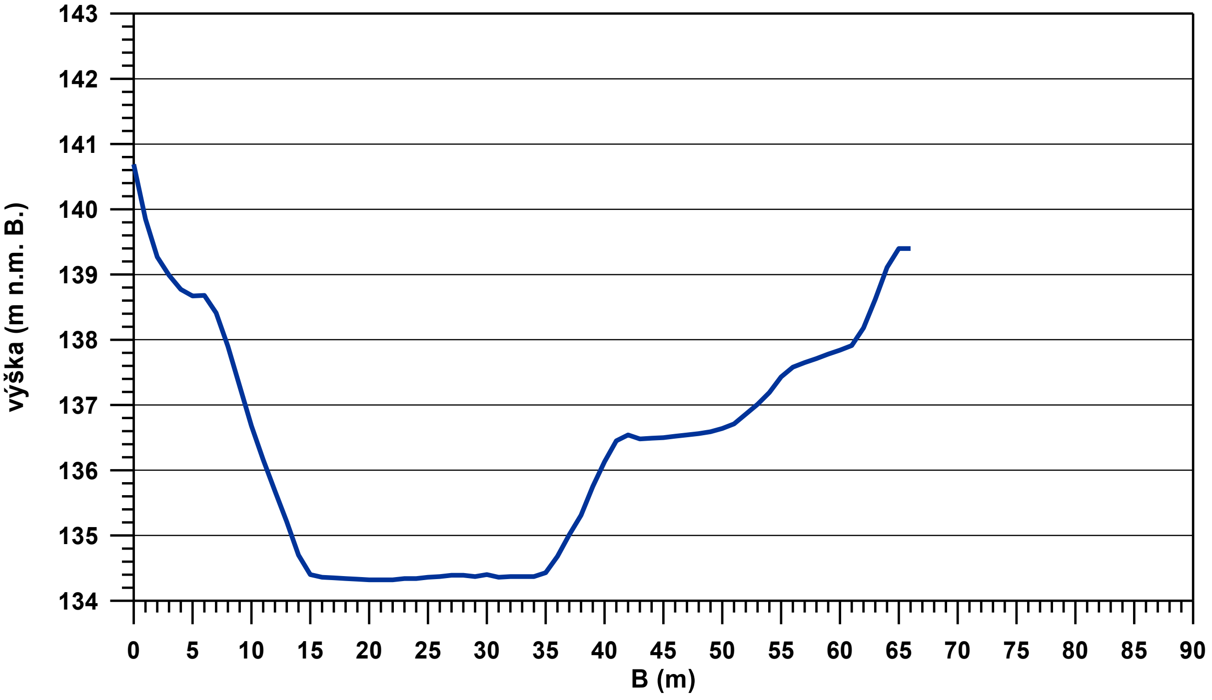
km 0.850

PF 8

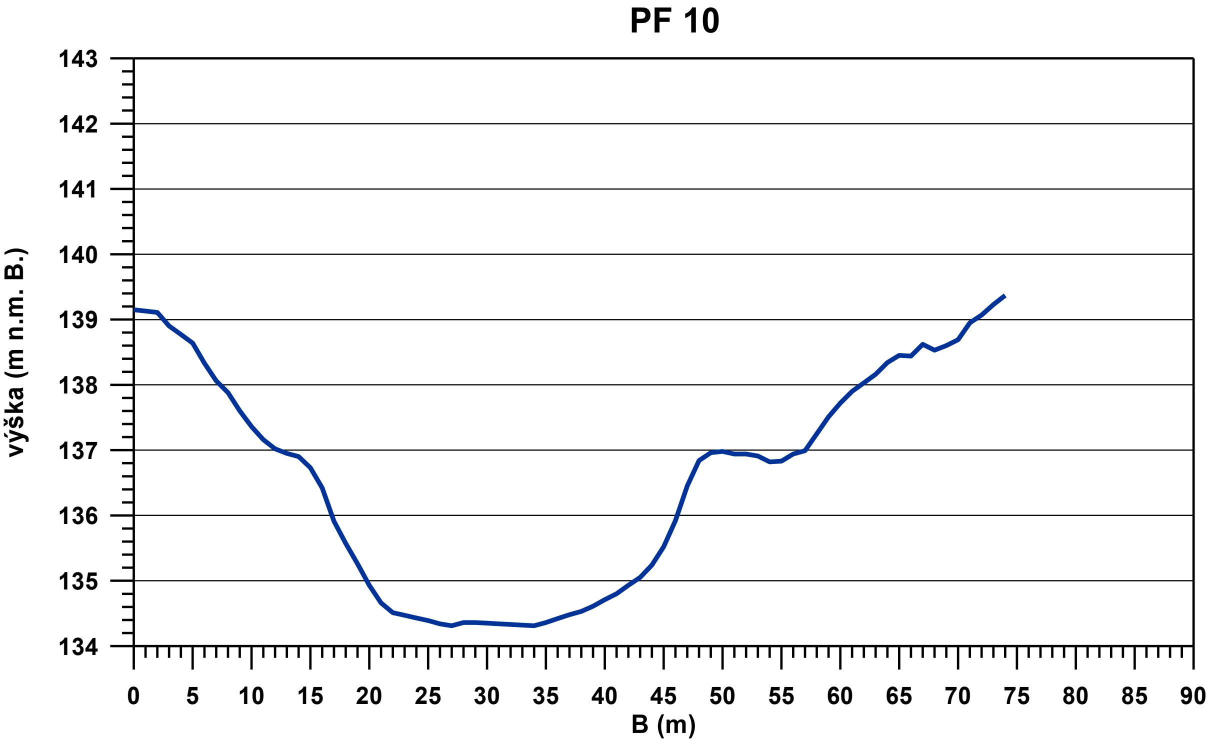


km 0.750

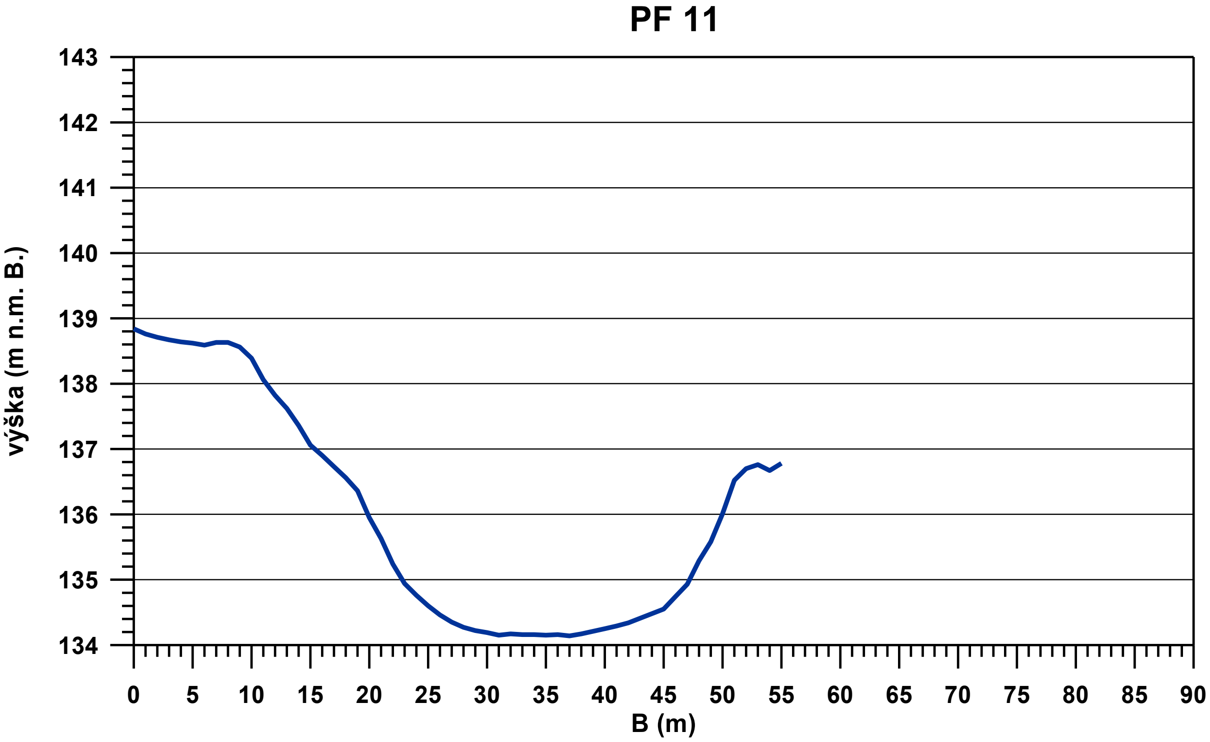
PF 9



km 0.650

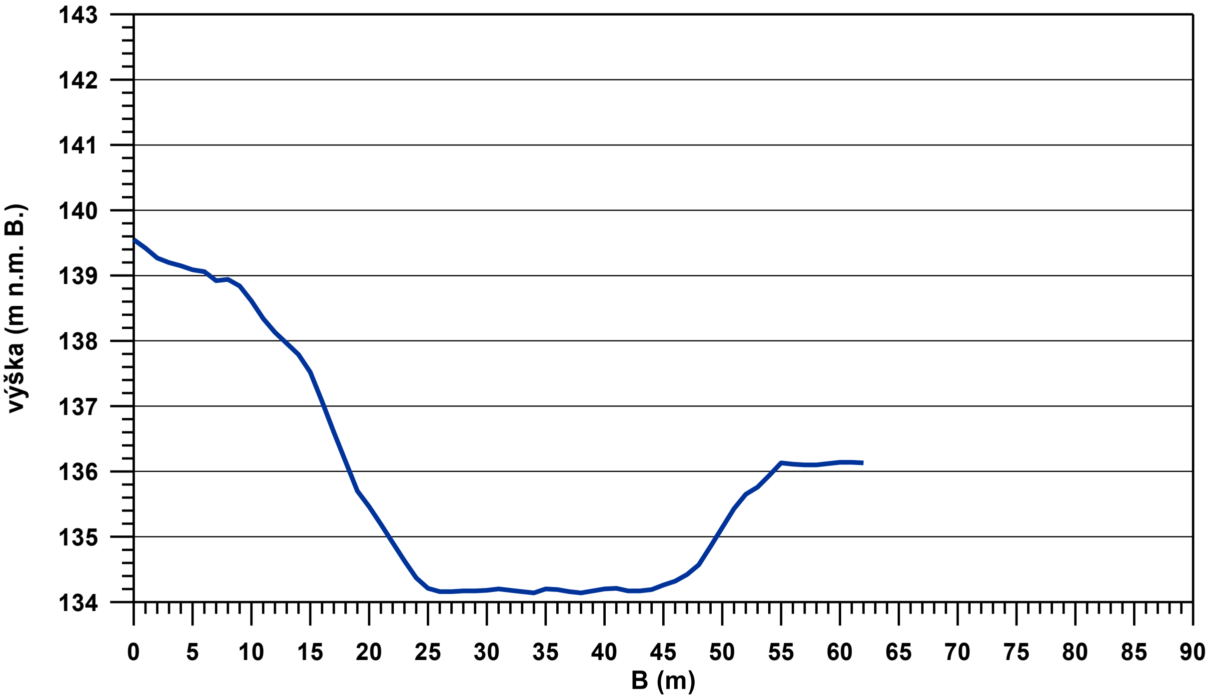


km 0.550



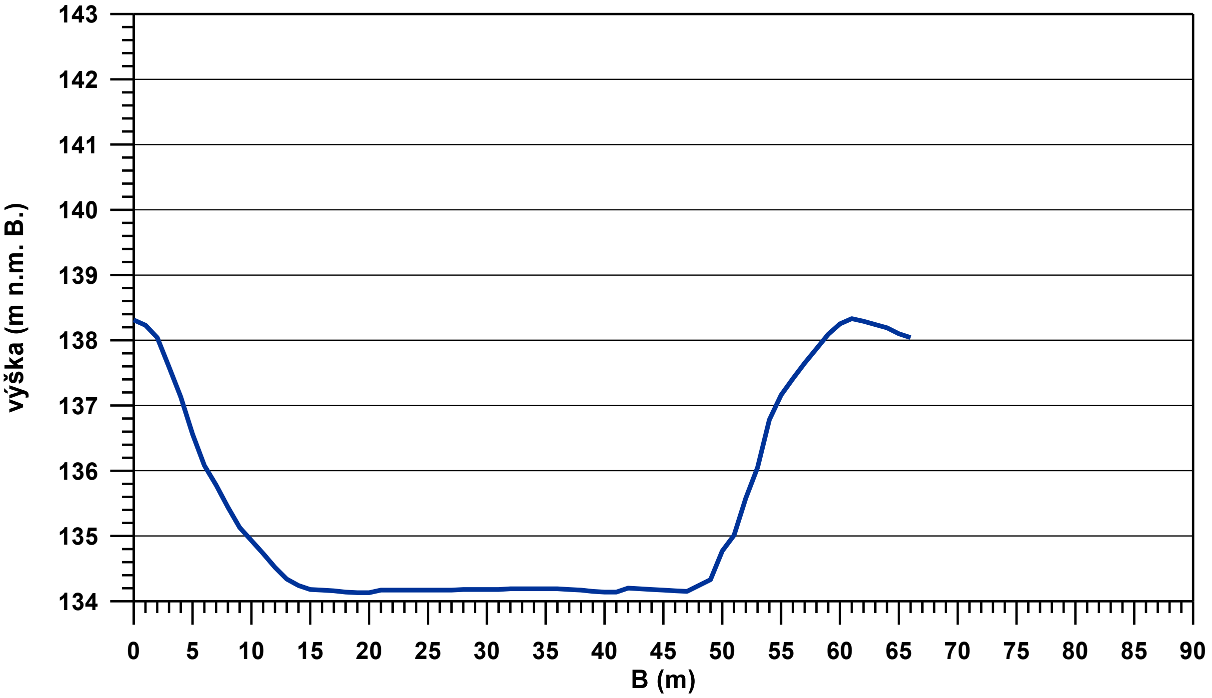
km 0.450

PF 12

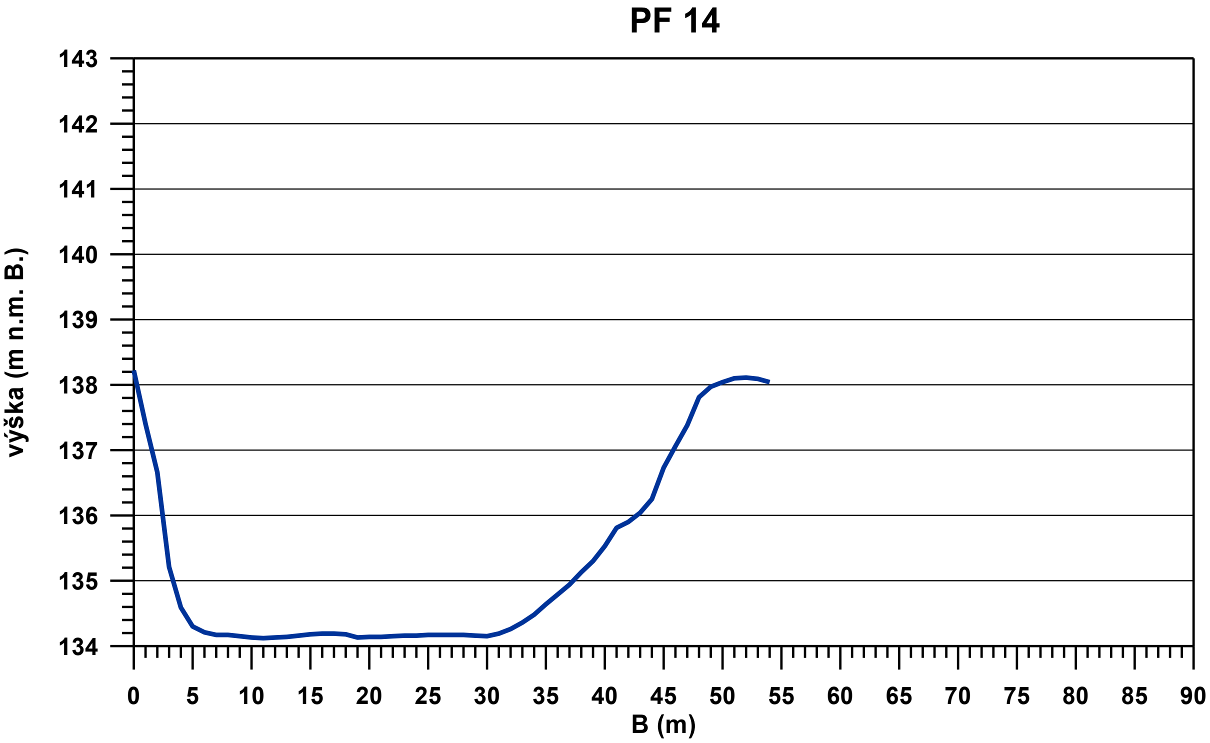


km 0.350

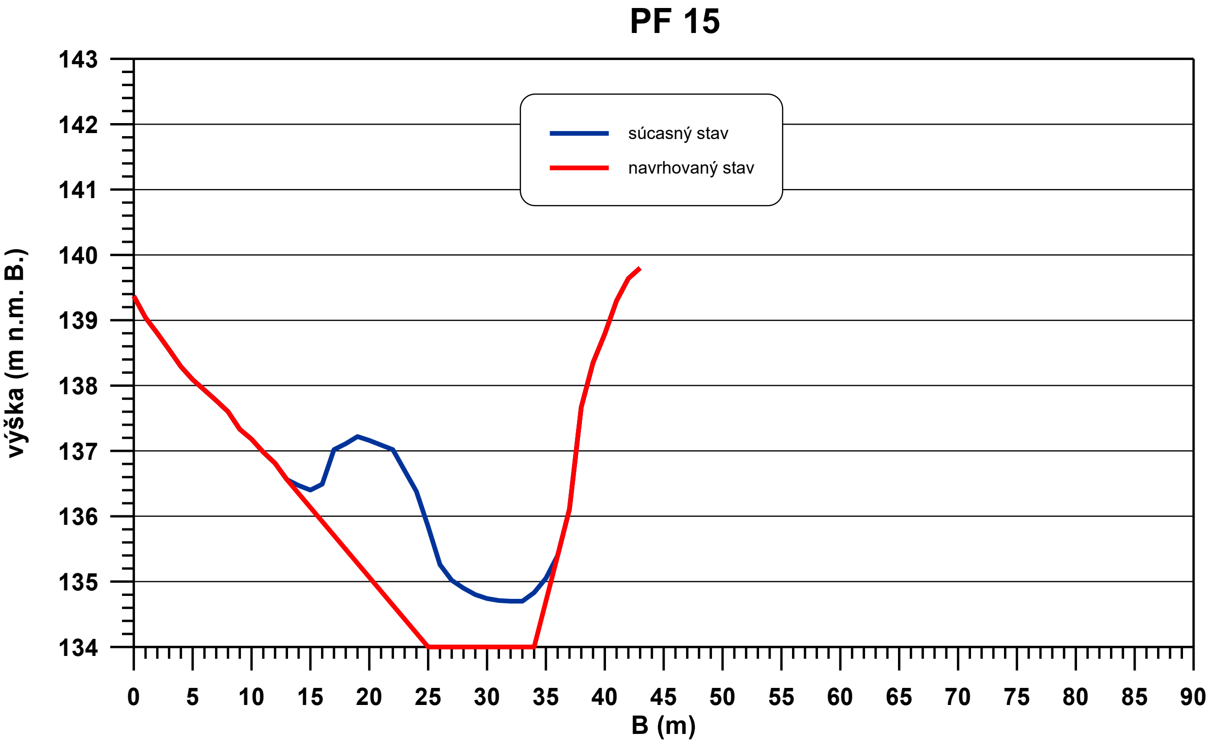
PF 13



km 0.250

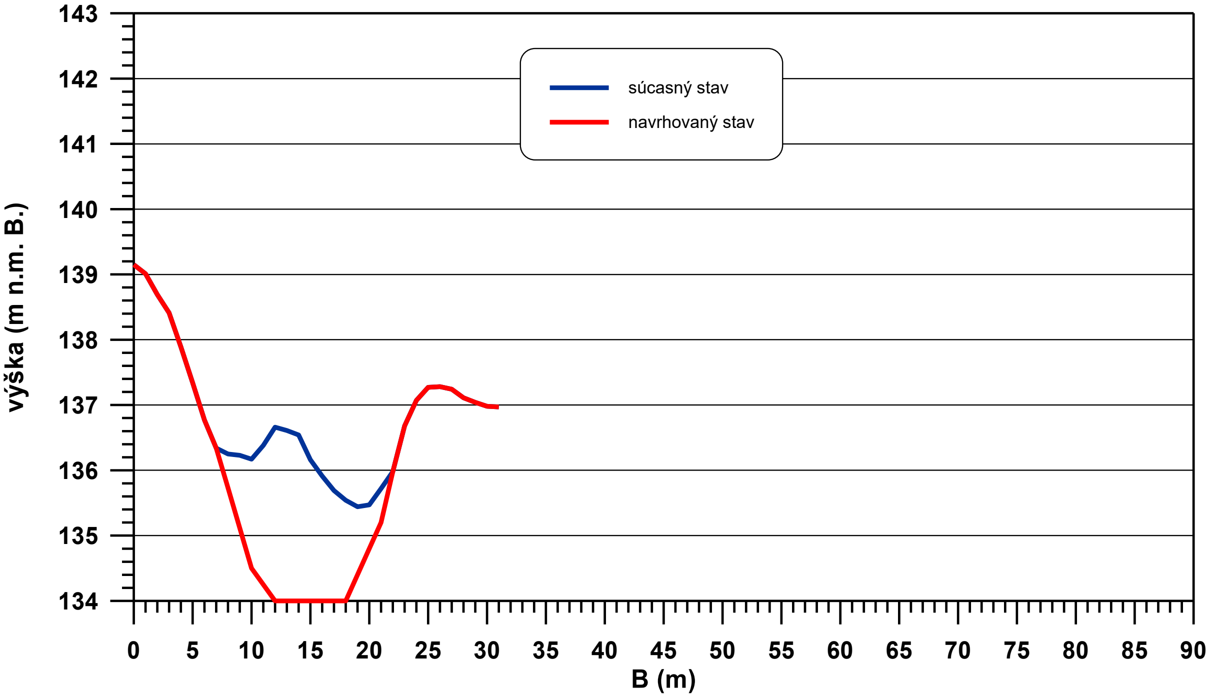


km 0.150



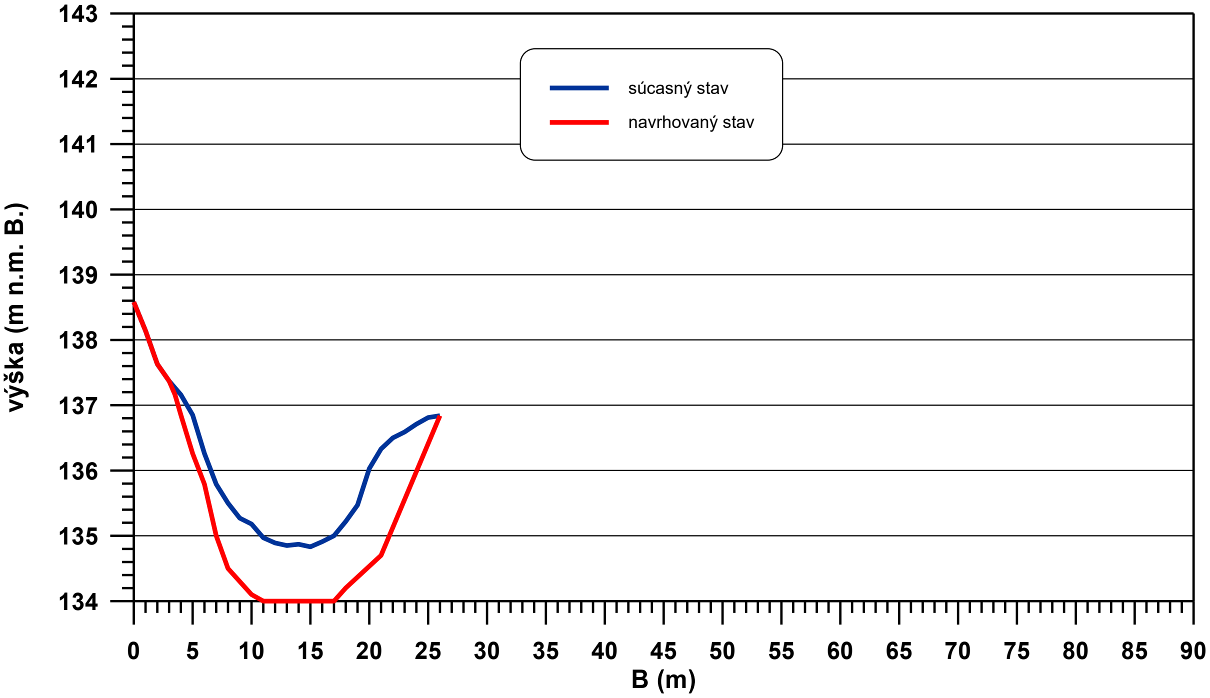
km 0.050

PF 16



km 0.007

PF 17



VÝTOK

km 0.000 - OUTLET