Feasibility Study:
The Rehabilitation of the Szigetköz Reach of the Danube

Prepared by

the Hungarian Section of the Working Group for the Preparation of the Joint Hungarian-Slovak Strategic Environmental Assessment Established by the Governmental Delegations of the Gabčíkovo-Nagymaros Project

Governed by

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1. Introduction

The Governmental Delegations of the Republic of Hungary and the Slovak Republic in the course of the implementation of the Judgement of the International Court of Justice (ICJ) delivered on 25th September 1997 concerning the case of the Gabčíkovo-Nagymaros Project have agreed[1] on the realization of a joint Hungarian - Slovak Strategic Environmental Assessment (Joint-SEA). This is with the aim of evaluating technical solutions which have arisen relating to the implementation of the above Judgement of the ICJ when the Parties approved the proposals of the Hungarian-Slovak Joint Working Group for the preparation of the Joint SEA[2]. The Parties have also agreed on the procedural rules of the Joint SEA by establishing the Statute of the Steering Committee for the Joint SEA[3]. According to the Statute the preparations of background matters necessary for carrying out the assessment (background papers, proposals, *ex ante* evaluations and other documents) are elaborated separately by the two Parties involving international experts and exchanged in the English language. The main role of the joint Steering Committee is to harmonise the efforts of the two sides.

The Parties agreed that the Joint SEA extends over the Danube section between Bratislava and Budapest. Both Parties underlined that the Joint SEA has to be carried out according to European law, i.e. the Water Framework Directive (WFD), the Strategic Environmental Assessment Directive, the Habitat and Bird Protection Directives, and other relevant rules.

The Parties' original intention was to finalise the Joint SEA by December 2009, before the deadline of the River Basin Management Plan of the WFD. In the Statute of the Steering Committee the Parties have agreed that *"If no final and conclusive approval of the common Environmental Report is reached by the Steering Committee by 22 December 2009 this procedure of the joint Strategic Environmental Assessment shall be discontinued"*. However, on 15 December 2009 at the request of the Slovak Party the deadline was extended to 30 April 2010.

[1] Agreed Minutes of the negotiation of the Governmental Delegations of the Republic of Hungary and the Slovak Republic, held on 6 November 2007 in Bratislava.

[2] Agreed Minutes of the negotiations of the Working Group for the preparation of the joint Hungarian - Slovak Strategic Environmental Assessment, held on 2 July 2007 in Budapest

[3] Statute of the Steering Committee for Strategic Environmental Assessment approved by the Governmental Delegations of the Slovak Republic and the Republic of Hungary for negotiations on the implementation of the Judgement of the International Court of Justice in the case concerning the Gabčíkovo-Nagymaros Project. Annex No.2 to the Agreed Minutes of the negotiations held in Komárom on 12 August 2008 between the Governmental Delegations of the Republic of Hungary and the Slovak Republic on the implementation of the Judgment of the International Court of Justice at The Hague in the case concerning the Gabčíkovo-Nagymaros Project (Can be found at www.bosnagymaros.hu)

The Hungarian Party first defined its approach concerning the Joint SEA in a "Scoping Report" handed over to the Slovak Party on 5 February 2008[4]. Shortly following the Hungarian Party commenced the elaboration of, i) a Feasibility Study on the Rehabilitation measures of the Szigetköz Reach of the Danube and ii) a SEA Environmental Report proposal on the improvement of the navigation fairway and environmental conditions in the Danube section between Szap and the Ipel confluence. The other SEA Environmental Report proposal concerning the various rehabilitation measures of the Szigetköz area was planned to be carried out following the production of the Feasibility Study.

Following the "Scoping Report" the Hungarian Party handed over two more studies to the Slovak Party:

i) Preliminary Feasibility Study on the rehabilitation of the Szigetköz reach of the Danube[5] which was handed over to the Slovak Party on 5 March 2009 and
ii) Draft Environmental Report on the improvement of navigability and rehabilitation of side-arms along the joint Danube section between Sap and Szob on 22 December 2009[6].

The present study is a revised and extended version of the above mentioned Feasibility Study; fourth in sequence for further discussion with the Slovak Party.

The purpose of this study is to assist in the formation of the joint decision regarding the rehabilitation of the Szigetköz reach of the Danube and to provide a scientifically supported basis for the Environmental Report to be prepared under the Joint SEA for this section of the Danube in accordance with the applicable legislation.

The project area is part of the Szigetköz water body[7]. It includes mainly the Hungarian side of the floodplain area between the levees of the Danube from Čunovo to Sap.

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[4] "Scoping Report" of a planned Hungarian-Slovak joint Strategic Environmental Assessment concerning programmes of measures of the River Basin Management Plan on the Danube sections affected by the Judgement of the International Court of Justice in the Case of the Gabčíkovo-Nagymaros Project. Hungarian proposal. Prepared by the Hungarian Section of the Hungarian-Slovak Joint Working Group for the Preparation of the Strategic Environmental Assessment. 5 February 2008

[5] VITUKI (2009): Feasibility Study: The Rehabilitation of the Szigetköz Reach of the Danube. Commissioned by the Hungarian Section of the Working Group for the Preparation of the Joint Hungarian-Slovak Strategic Environmental Assessment Established by the Governmental Delegations of the Gabčíkovo-Nagymaros Project

[6] Background paper for the Strategic Environmental Assessment of the variants of the structural measures for the improvement of the navigability and the rehabilitation of the side-arms of the Danube section between Sap and Szob. Draft Environmental Report for discussion with the Slovak Party. Commissioned by the Hungarian Section of the Steering Committee of the Hungarian-Slovak Joint Working Group for the Preparation of the Strategic Environmental Assessment. Ministry of Environment and Water, December 2009

[7] Republic of Hungary (2005): Report according to Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy on analysis of the characteristics of the Hungarian part of the Danube River Basin District, and review of the environmental impact of human activities and economic analysis of water uses. Reporting deadline: 22 March 2005

The Hungarian Working Group, composed of Hungarian and international experts, has decided to perform a sound scientific analysis of extensive and complex technical-environmental interventions. Obviously, the assessment – based on scientific and technical approaches – must consider environmental as well as social and economic criteria and must provide a complex, systematic and transparent evaluation. Because of the limited time frame elements of the above mentioned issues such as social and economic aspects could not be taken into account. These segments of the assessment have to be considered during further planning steps.

The scientific analysis was based on well known principles and standards of the international scientific community dealing with large river restorations. The data base for the various analyses performed in this study comes mainly from both the national and the Hungarian-Slovak Joint Monitoring of the Szigetköz area. Because of the fact that the Project area is subject to the WFD implementation all of the requirements prescribed by European legislation on that topic were also strictly considered.

Riverine ecological integrity in the EU is governed by a number of legal instruments. The overall achievement of the requirements of the WFD and interfacing policies are of paramount importance, requiring attainment of “good ecological status” or in the case of Heavily Modified and Artificial Water Bodies “good ecological potential” as well as requiring no deterioration in the status of water. For the preservation/conservation of the ecological integrity of the Danube River, the basic needs are as follows[8]:

- the protection of natural or ecologically high-value riverine landscapes, river sections and aquatic populations,
- the restoration of modified/impacted river sections and their adjacent landscapes,
- a dynamic and type-specific channel and floodplain environment (regarding instream structures, shorelines, side-arms and floodplains) supporting a dynamic equilibrium and adequate connectivity conditions,
- undisturbed longitudinal and lateral migration of all fish species and other water related species to ensure their natural and self-sustaining development, and
- a balanced sediment budget ensuring long-term stability of bed levels.

These needs were considered throughout this study and a process oriented “Leitbild” approach [Kern (1992) - using a reference condition/visionary guideline approach including aquatic, semi-aquatic and terrestrial biological communities] was applied.

Plans and projects to be adopted at the end of the planning process must also be in conformity with the relevant international legal obligations as described in Chapter 6.

[8] After the “Joint Statement on Guiding Principles for the Development of Inland Navigation and Environmental Protection in the Danube River Basin”. ICPDR, IC 127, Dec. 2007

This study follows the scientific logic described in the “Scoping Report”[9] as ‘Planning steps for improvement of ecological status’.

The first step is to assess how the natural system works (see Chapter 2). In river restoration reference status refers to the functioning of an ecosystem without/before human intervention. The reference status does not necessarily refer to a specific historical period. A practical approach was preferred in this Chapter rather than an academic exercise. The reference status compares to the “good ecological status” of the WFD for natural water bodies.

The second step is to assess irreversible changes and to consider pressure and impact on the project reach according to findings of the WFD process (see Chapter 4). The stipulation of irreversible changes was applied with caution since there is a delicate border between irreversible human interventions and financial or political constraints. In order to obtain a more precise picture concerning what happened during river regulation work and changes in land use a retrospective review has been carried out in Chapter 3.

Chapter 5 describes the derogation from the reference status or from the ‘natural system’ as the third step. Here an emphasis was laid on changes in hydrological and geo-morphological processes resulting in deprived habitat conditions compared to the reference status.

Quite obviously the environmental objectives described in Chapter 7 result from the assessment of the reference status, the present (ecological) situation, the irreversible changes as well as the present and future human utilization. The environmental objectives have to meet the “good ecological status GES” or the “good ecological potential GEP” of the WFD, to be achieved by defined deadlines. It is worthwhile noting that the GEP may be very close to the GES, especially in the Szigetköz where urban pressure is low and the river flows in a wide semi-natural corridor. This Chapter also provides benchmarking for the evaluation of the variants of rehabilitation measures. The detailed methodology of ecological benchmarking is given in the Appendices.

Chapter 8 gives a description of rehabilitation measures (“variants”) selected for detailed analysis, a summary of the hydro-morphological modelling methods and simulation runs and presents results of hydro-morphological modelling and ecological predictions for each of the variants.

The evaluation of rehabilitation measures based on the criteria presented in Chapter 7 is found in Chapter 9 together with a final conclusion.

[9] Scoping Report” of a planned Hungarian-Slovak joint Strategic Environmental Assessment concerning programmes of measures of the River Basin Management Plan on the Danube sections affected by the Judgement of the International Court of Justice in the Case of the Gabčíkovo-Nagymaros Project. Hungarian proposal. Prepared by The Hungarian Section of the Hungarian-Slovak Joint Working Group for the Preparation of the Strategic Environmental Assessment. 5 February 2008

It is important to underline that this study has considered the comments of the Slovak Party on the Preliminary Feasibility study[10]. However, this study should be regarded as a discussion paper for further improvement. Variants should not be regarded as final ones but rather as starting points for future amelioration and as a sound data base for more detailed joint investigations in partnership with the Slovak Party.

[10] The standpoint of the Governmental Delegation of the Slovak Republic on the Hungarian document named "Preliminary Feasibility Study: The Rehabilitation of the Szigetköz Reach of the Danube" Bratislava, December 14, 2009. Annex 4 to the Agreed Minutes of the negotiation of the Governmental Delegations of the Republic of Hungary and the Slovak Republic, held on 15 December 2009 in Budapest.

2. Assessment of the natural system

The complex ecosystem of large floodplain rivers with their enormous variety of diverse habitats on a relatively small area contributes considerably to the natural biodiversity of an ecoregion. However, with river regulation and increasing use of floodplains a significant proportion of the natural functions have been lost. The degradation of the natural system not only endangers biodiversity but also future utilisation, e.g. water supply of good quality and high quantity from the aquifer, development of sustainable recreation and tourism etc. The rehabilitation of the ecological functioning of the Danube reach in the Szigetköz floodplain is of primary interest to both bordering states, Slovakia and Hungary.

A general difficulty in river restoration is that the reference conditions of the hydro-morphological processes, the resulting physical habitats and inherent biological elements of the near pristine condition are usually poorly documented. Some key elements can be deducted from historical maps, old records of hydrological data etc. The Water Framework Directive (WFD, 2000), defines the so-called good ecological status as a slight deviation from undisturbed conditions due to human activities. In the WFD the assessment of the ecological status as well as the definition of environmental objectives is based on so-called biological quality elements. The general procedure underlying this report is compatible with both, the scientific principle of river restoration, especially the rehabilition of large floodplain rivers and the legal obligations of the WFD.

Over the past two decades numerous concepts have been elaborated that explain the functioning of river ecosystems (see Thorp et al. 2006). These concepts represent a useful background when describing the natural river system of the Kisalföld (Little Danube Plain) Danube section.

2.1. Hydrological and hydro-morphological dynamics

In the Danube floodplain below the Devin gate water and sediments are the most important landscape-forming factors playing an essential role in the creation of surface formations and in the evolution of certain landscape ecology facies (Pécsi 1959, Göcsei 1979).

2.1.1. Hydrological regime

The driving forces of riverine ecosystems are the dynamics of the flow regime and the associated processes of erosion, transportation and deposition of sediments. The essential characteristics of the flow regime in the natural system are:

(1) the seasonal variations of flows and associated surface water levels at natural stages,
(2) corresponding variations of groundwater levels with associated processes of infiltration and exfiltration of river water,
(3) occurrence of flood flows filling branches to a varying extent and occasionally inundating the adjacent flood plain for days, weeks or even months.

The majority of the water discharge of the river and the water regime is determined by the precipitation and the snow and glacier melt water of the 131,000 km^2 water catchment area of the northern part of the Alps and the Alps' foothills. The Danube water regime is basically stochastic in nature; however, in the period extending from spring to the middle of summer, generally, several flood pulses arrive one after the other. The melting of snow cover and the glaciers in the Alps, and the simultaneous significant precipitation from the end of May and until June generally result in larger flood pulses. The low water period is usually formed by October, which is then followed by a weak increase in discharge. From December a new low water period begins, as the high mountain parts of the catchment area no longer provide water due to the freezing conditions. The fluctuation of discharge and the associated sediment transport are the governing forces in the evolution of the riverbed.

The seasonal variations as shown in Figure 2-1 of the flow at the Dunaremete gauge reflect the alpine flow regime with flood flows in spring and early summer preventing agricultural use in floodplain areas. This is the main reason for the absence of cultivated plants and the existence of large softwood and hardwood forest stands in the Szigetköz floodplain.

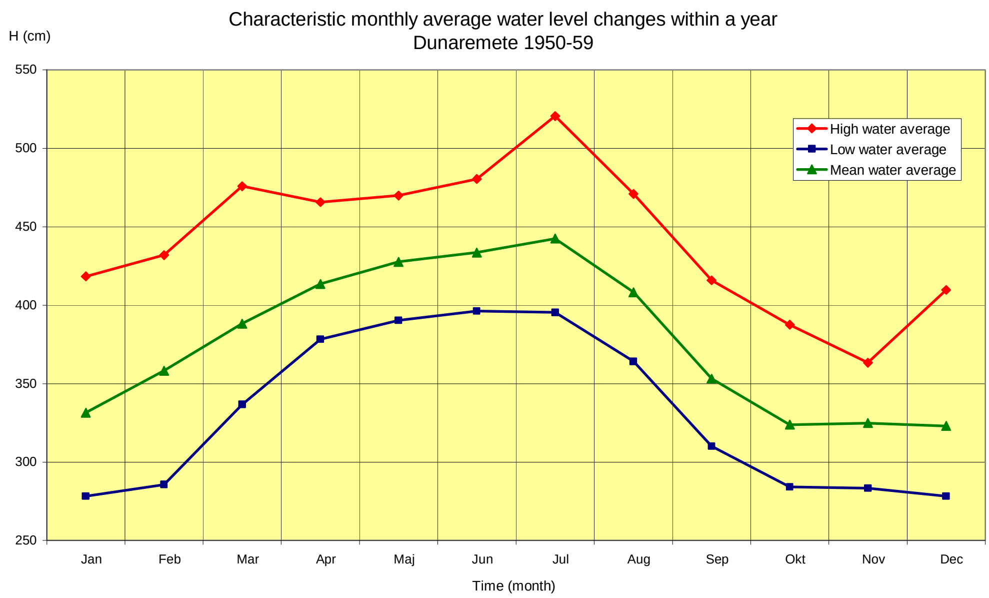
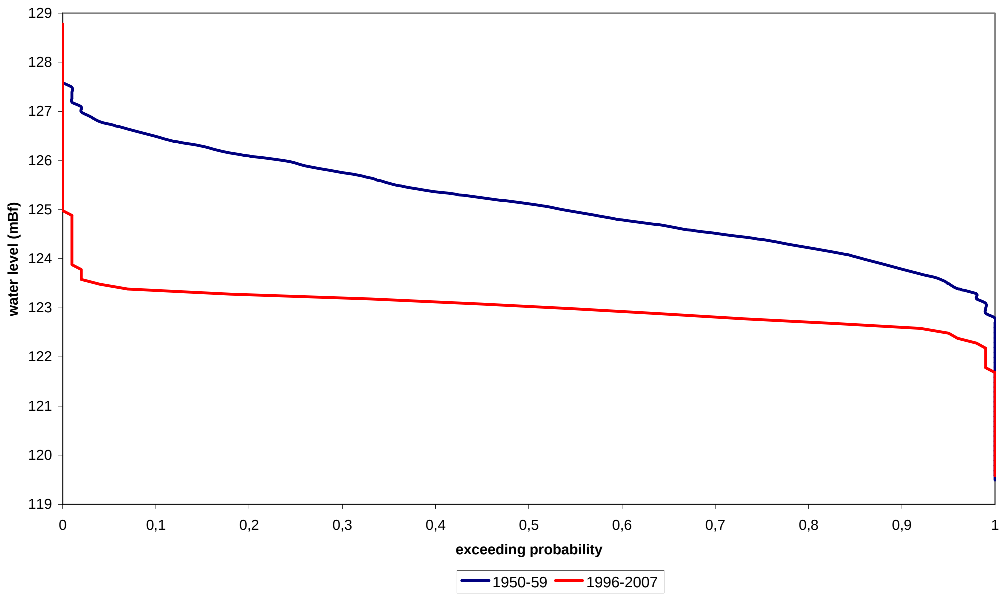


Figure 2-1 Seasonal variation of monthly flows at the Dunaremete gauge (1950-59)

According to Figure 2-2 the average annual fluctuations of water levels at Rajka and Dunaremete in the 1950s comprised a range of about 5 and 4 metres respectively when omitting extreme droughts and floods lasting only a few days. The entire amplitude of water levels encompassed 7 metres. For 80 % of the year the range of water level fluctuations varied by 2.7 metres at Rajka and 1.8 metres at Dunaremete. At Rajka the water level fluctuated around a median of 125.1 m+NN, at Dunaremete of 117.1 m+NN.

Duration curves of water levels at Rajka



Duration curves of water levels at Dunaremete

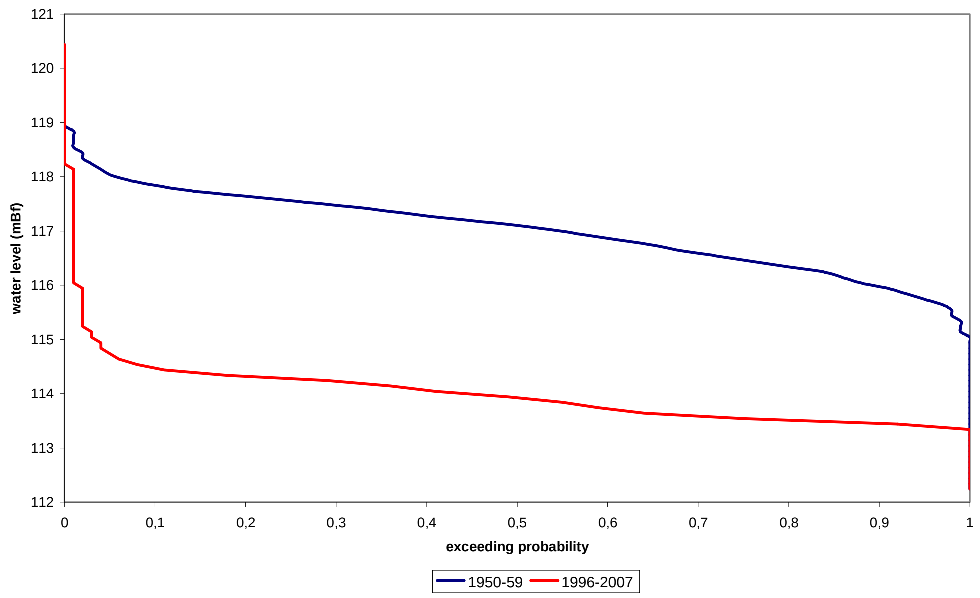


Figure 2-2 Duration curves of water levels at Rajka and Dunaremete in the 1950s and after implementation of the temporary side-arm water supply in 1995

In the natural system the main flow changed its course frequently during major flood events producing a channel network at various elevations with arbitrary distributions of flows at different stages. In order to improve conditions for navigation low water regulation included the closure of side-arms by overflow weirs. In the 1960's, the level of these overfall weirs were uniformly constructed to a water level corresponding to 2,500 m^3/s. They were designed to have a 30-50 m wide middle part in the crest, where the weir is lower by 50 cm. This means that the side-arms were already starting to receive water at a discharge rate of 2,000 m^3/s and showed significant flow volumes at 2,500 m^3/s. Due to the incision of the low-water riverbed, the construction level was changed from the 2,500 m^3/s corresponding to the uniform overfall level to 3,150 m^3/s by the end of the 1980's while the minimal discharge rate required for recharge initiation was changed from 2,000 m^3/s to 2,700 m^3/s.

For the 1980s the connectivity of the side-arm system is quantified in Table 2-1.

Table 2-1 Side-arm connectivity and inundation in the 1980s (after EC Working Group Report, 1992)

Characteristic flow situation	**Discharge** (m^3/s) and **Average duration** (days per year)	**Frequency**
Flow largely confined to area within groynes in main channel	<1000 m^3/s, 13 days	Several times per year
Flow in main channel and permanent branches	1000-1800 m^3/s, 42 days	Several times per year
Flow in few river arms	1800-2500 m^3/s, 122 days	Several times per year
Flow in some river arms	2500-3500 m^3/s, 78 days	Several times per year
Flow in almost all river arms	3500-4500 m^3/s, 17 days	Several times per year
Complete inundation of flood plain	4500-6000 m^3/s, 4 days	Once per year
Deep inundation of flood plain	>6000 m^3/s, < 1 day	Once per 3-4 years

The frequency and duration of flood flows above a threshold of 530 cm at the Dunaremete gauge which corresponded to about 3,900 m^3/s are shown in Figure 2-3, Figure 2-4 and Figure 2-5. In general, the annual number of floods causing floodplain inundation is 1 to 3, however, as indicated by the statistical results, several years had no floodplain inundations at all. As a result of the repeated flood waves within a given year, the floodplain may be inundated for a longer period altogether, however, with the exception of a few years (1965, 1982, 1988, and 1989), on the basis of the available data it did not exceed 14 days and was generally less than 10 days. 1965 was an extreme year, when the duration of the longest floodplain inundation was more than 1 month. Another persistent inundation occurred in 1989. The duration of inundation was normally between 1 to 6 days.

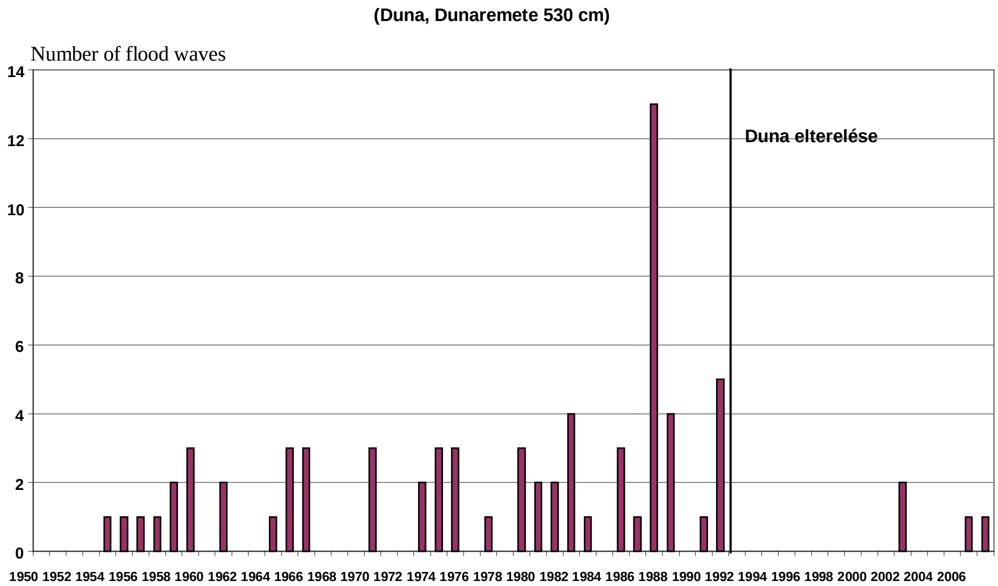


Figure 2-3 Number of flood waves causing complete inundation of the floodplain in the Szigetköz section of the Danube between 1950 and 2007 (Danube, Dunaremete 530 cm, ÉDUKÖVIZIG)

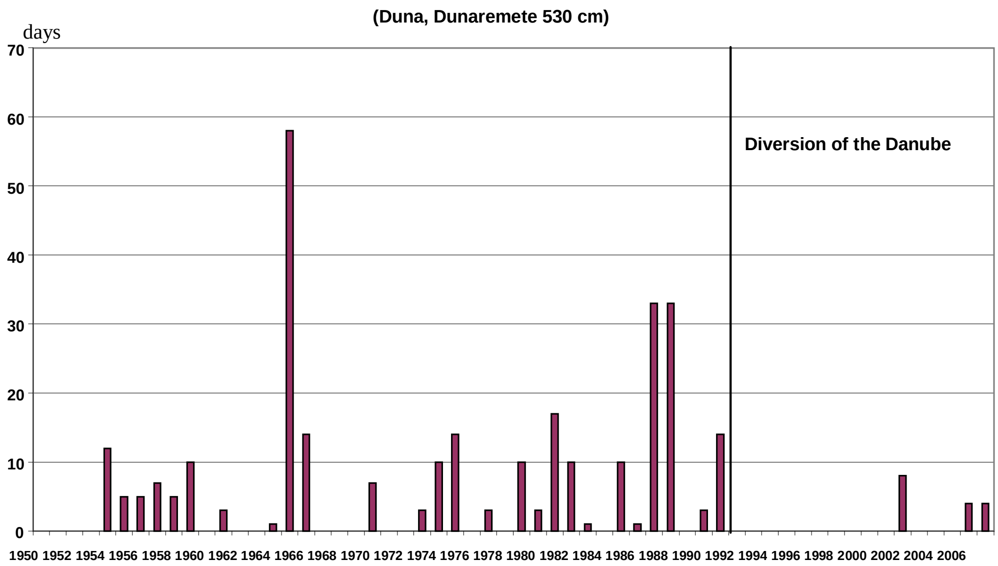


Figure 2-4 Total number of days with floodplain inundation in the Szigetköz section of the Danube between 1950 and 2007 (Danube, Dunaremete 530 cm, ÉDUKÖVIZIG)

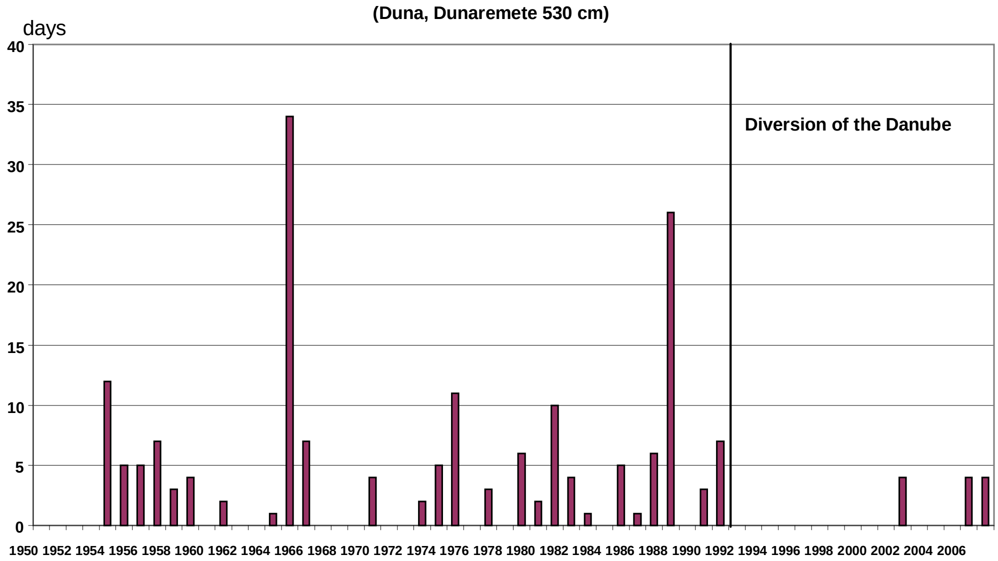


Figure 2-5 Duration of the longest flood waves causing floodplain inundation in the Szigetköz section of the Danube between 1950 and 2007 (Danube, Dunaremete 530 cm, ÉDUKÖVIZIG)

It is obvious that these data do not refer to undisturbed conditions. The regulated river bed had a larger discharge capacity than the main branches of the natural bed pattern. On top of this, river bed incision further increased the capacity of the channel. Confinement of the floodplain by dyke systems has increased the range of water level fluctuations (chapter 2.1). However, despite all interventions the essential hydrological character of the natural ecosystem can still be derived from the data given above (Table 2-2).

Table 2-2 Summary of the hydrological flow regime in the natural system

- The **seasonal flow regime** is largely influenced by the alpine catchment with summer floods and low discharges in winter.
- **Annual water level fluctuations** encompassed 5-7 m, the total range becoming smaller from Rajka to Dunaremete. When omitting the highest and lowest 10% levels of the duration curve the range of fluctuations was 2.7 m and 1.8 m around the mean annual position for Rajka and Dunaremete, respectively.
- There was no fixed **threshold for side-arm flow** in the natural system since main branches frequently altered their position. Only river regulation established a definite pattern of side-arms many of which received water at mean flow stages until the 1960s when intake weirs were reconstructed in order to improve navigability.
- **Inundations of the floodplain** may have been more frequent than indicated in Figure 2-3. However, due to the stochastic character of the flow regime there may be consecutive years without floodplain inundation. On the other hand wet years may

produce several overbank flows. Large scale inundations may last for several days, rarely two weeks and exceptionally one month.

2.1.2. Groundwater regime

The geological development of the Kisalföld has been significantly linked with the morphological development of the Danube, leading to the formation of an extensive Quaternary alluvial aquifer varying between 10 and 600 metres thickness. The Hungarian aquifer in the Szigetköz is estimated to have a volume of some 21.8 km^3 (Erdélyi, 1994) and is overlain by a spatially variable upper layer of fine soil, from 0-5 m in depth and underlain by a 1 km thick sandy-clayey complex, which holds thermal waters at depth. The pattern of groundwater flow and recharge is indicated by regional groundwater levels (Hajósy, A. - Liebe, P. and Szalai, J., 2008; Figure 2-6) and stable isotope tracer analysis (Deák et al, 1996; Stute et al, 1997; Deák et al, 2002). The Danube has been the dominant recharge source of the Szigetköz and Žitný Ostrov aquifers. Water originating from the Danube has been found at depths of several hundred metres in the Szigetköz, and beyond the Mosoni Danube. Tracer analysis based on radioactive fall-out confirmed that the groundwater flow is mainly horizontal and directed away from the Danube with horizontal flow velocities as high as 500 m/yr in the top layer of the aquifer. Before the diversion of the Danube 7 m^3/s of water was directly infiltrating into the groundwater from the Hungarian-Slovak sections of the Danube, and 0.8 m^3/s from the Mosoni-Danube and the Lajta. In contrast, the 0.05 m^3/s rainfall recharge is negligible (Simonffy, 1998) which can be indirectly demonstrated by the measurements indicating that the potential evapotranspiration exceeds rainfall by 30% (Petrasovits, 1988). However, beyond the Mosoni Danube, other recharge sources become progressively more important.

Hydraulic connection with the main Danube channel occurs throughout the Rajka-Gönyü reach and prior to construction of the Čunovo reservoir, Danube flows determined the groundwater levels throughout the Szigetköz and beyond. Figure 2-6, mentioned above, presents the average water-table elevations in 1991 (which are representative of the later 1980's surface water level response) from which approximate flow directions can be inferred. In fact the response is more complex; under high Danube flow conditions the predominant groundwater flow direction changes from south-east to south, reflecting the importance of high flow recharge to the Szigetköz. Groundwater levels in the Szigetköz follow closely the variation in Danube water levels, but with decreasing amplitude as distance from the Danube increases. Thus adjacent to the Danube, groundwater fluctuations in excess of 2.0 m can be observed. Close to the Mosoni Danube these have reduced to 1.0 m or less.

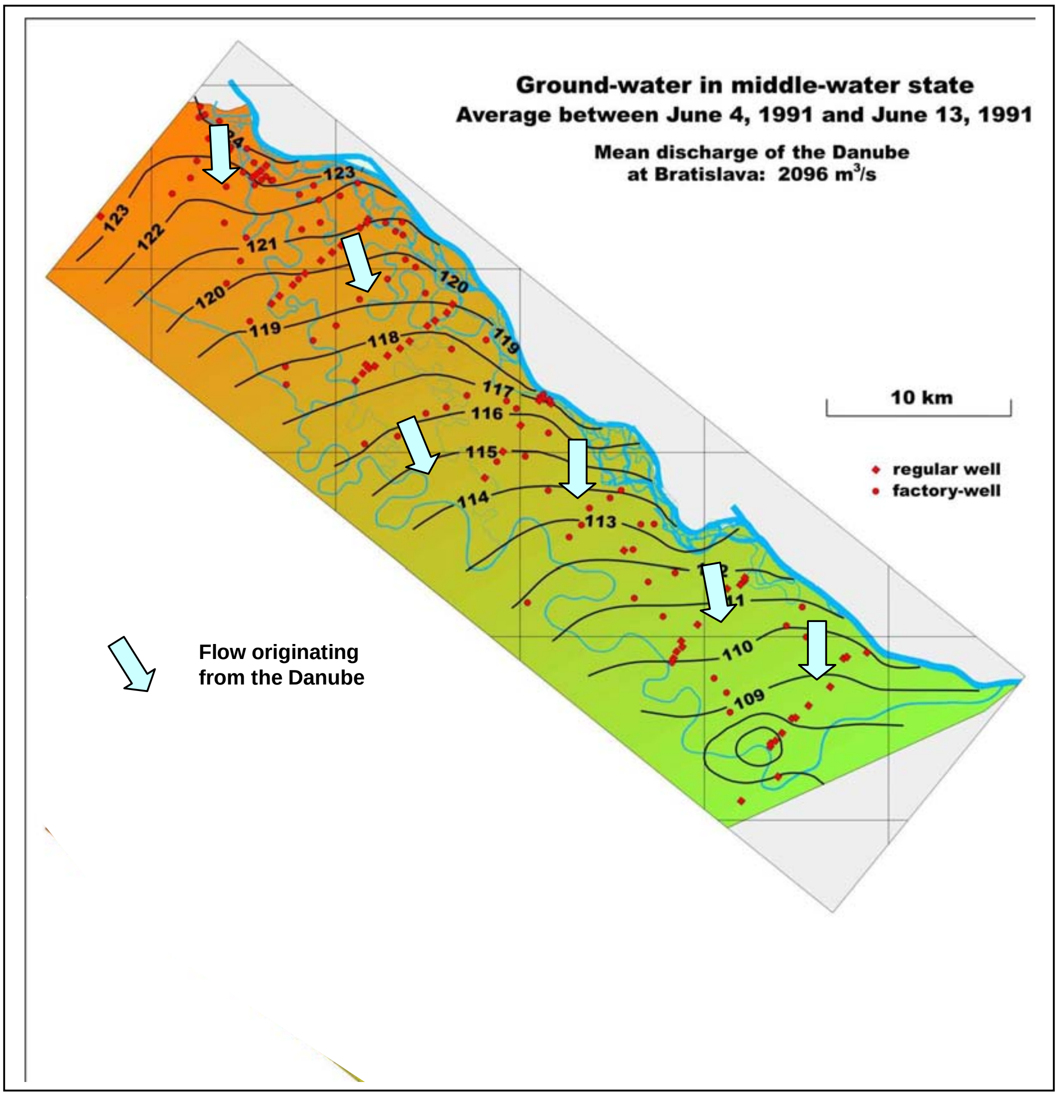


Figure 2-6 Groundwater level topography in 1991

The depth of the water-table below the surface is of major importance for capillary moisture supply. If the water-table rises into the fine soils overlying the coarse alluvium of the aquifer, the water can rise up the soil profile by capillary action and provide an important contribution to the water use of both natural vegetation and agriculture. The capillary supply becomes progressively more important moving from the Upper to the Lower Szigetköz and during flood flows in the Danube. Since floods characteristically occur in late spring/early summer and may be followed by late summer floods the highest groundwater levels coincide with the period of high water demand by plants and maximum climatic stress. This provides a natural sub-irrigation which has been an essential feature of the ecology and agriculture of this area. For demonstrating the situation of the 1980's Simonffy (1998) prepared a map showing the relationship between the groundwater level and the lower surface of the top soil layer (Figure 2-7).

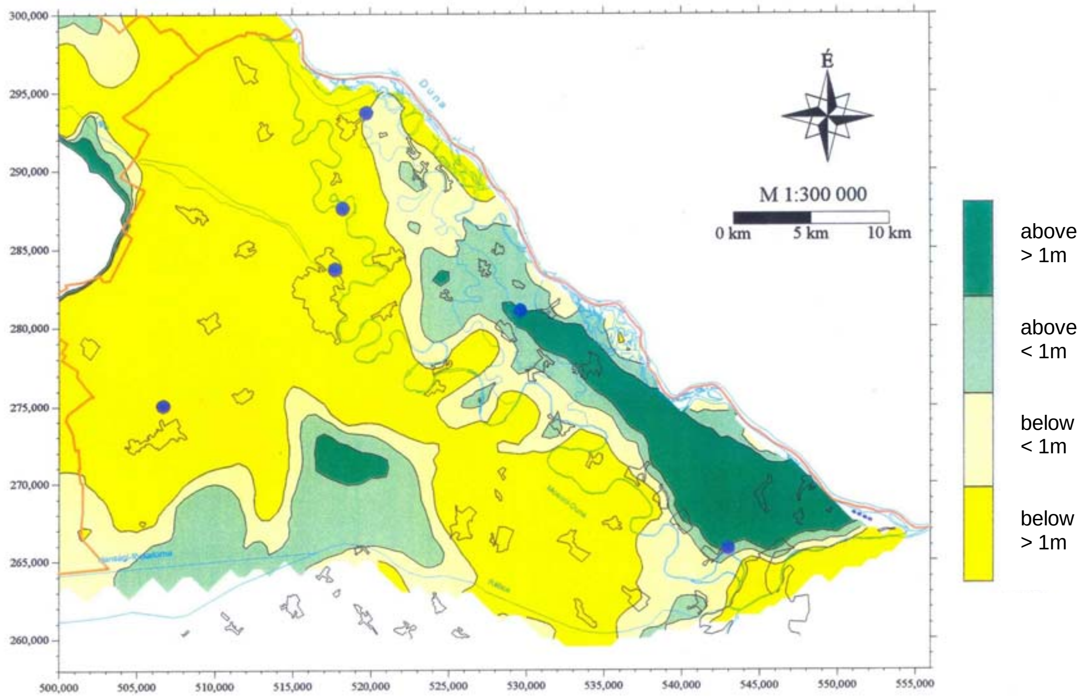


Figure 2-7 Groundwater levels in relation to the lower surface of top soil layer (situation in the 1980's) Editor: Z. Simonffy

The Szigetköz aquifer contains approximately 5.4 km^3 of groundwater. It is thus a unique resource of good quality water with national strategic significance, which at present is mostly not utilised. The larger waterworks in the area are Győr-Szőgye, Győr-Révfalu and Darnózseli. Together with Mosonmagyaróvár, production is estimated to be 75,500 m^3/day.

Table 2-3 Summary of the groundwater regime in the natural system

- The aquifer of the Kisalföld consists of deposits of sand and gravel of 10 to 600 m in depth representing the most important groundwater reserve in Hungary and Slovakia.
- Situated on the top of an alluvial cone the changing river bed pattern of the Danube represents the main source of recharge for the aquifer at all water stages. Only at falling flood stages groundwater infiltrates into the bed for a short period of time ensuring open contact between the bed and the aquifer for the time of groundwater recharge.
- The amount of recharge by the river system far exceeds the contribution of rainfall which would not even compensate for the loss due to evaporation. The recharge of

the aquifer in the Szigetköz by the Danube system was estimated to be 7-8 m^3/s before October 1992.

- Fluctuations of 1-2 m of the groundwater level provided humidity to the fine grain cover layer even in the northern part of the Szigetköz where its thickness was insufficient to provide permanent capillary rise through contact with the groundwater.

2.1.3. Hydro-morphological processes

The Danube appeared on the Kisalföld region about two million years ago. Entering the lowland area the slope and the velocity of the river drops and hence the bed load transport capacity falls significantly, which results in the deposition of sediment transported from the Alps. The Kisalföld lowland has been subsiding for several million years at a rate of 0.1 to 0.5 mm/year and it has been loaded with gravel alluvium. The Danube carries predominantly gravel-type bed loads along its German and Austrian sections, the share of which in the total sediment transport (about $5\text{-}7\times10^6$ m^3/year) varied from between 10 to 20 per cent before the erection of the barrages on the River Inn and Danube. The sedimentation process has been continuously filling up the Kisalföld lowland throughout geo-historical times resulting in wide floodplains and the river has been flowing in its own alluvium (Pécsi 1959, Göcsei 1979).

The alluvial rivers can either be braiding or meandering depending on the ratio between erosion and sedimentation. The river is braiding if the sedimentation surpasses the erosion process. The braiding channel section splits into branches on the continuously aggrading alluvium and forms a delta-like network of river branches with overlapped islands. In the wide and shallow branches bars are formed from the deposition of the sediment. Bars develop into islands if their surface is bound by vegetation. With further sediment deposition the braided branches may split again later on. The erosion processes during high water periods may create new branches, when the river cuts a new bed in the floodplain after leaving its original bed. Upon major floods, the anastomosing main branch used to change course, forming a new main branch and abandoning its old channel. The terrain pattern of the braided river sections are mostly unstable, which prevents complete ecological succession, therefore the development of the ecosystem extends up to its middle stage.

The river starts meandering if the sedimentation is in balance with erosion. In a meandering channel erosion destroys the concave (external) banks, and after a short distance the eroded material is deposited building the convex banks. The concave banks are usually steep and the convex banks are moderately sloping sandy point bars. Over a long period the meanders migrate downstream along the river, their breadth increases until the thinning neck is cut off by a large flood and the meander loop becomes an oxbow lake or dead arm. The abandoned oxbow lakes gradually lose their connection with the river as sedimentation closes their upstream and downstream mouths, and are subject to aggradation due to biological sedimentation and to the deposition of suspended river sediment after floods. Over a few centuries, this morphological succession may lead to the complete disappearance of the oxbow lake leaving only a narrow depression on the floodplain surface (Amoros at al. 1987).

Figure 2-8 shows the river bed pattern resulting from hydro-morphological processes in the Szigetköz area before river regulation started in the late 19th century.

Figure 2-8 The Danube Section in the Szigetköz before the 19th century river regulation on the basis of the military cartographic surveys carried out between 1806 and 1869

The main cause for the depositing of the bed load and the formation of islands is the sudden break of gradient near Szap (1811 rkm) further reducing the bed load transportation energy of the river to half or a third. The location of the break in the slope is not quite constant: during high flows it moves upstream, while in the event of a significant drop of water levels due to, for example dredging of the river bed, it might shift downstream.

The formation of the Danube riverbed primarily takes place during the relatively short flood periods (Figure 2-9). In the rising flood wave the river performs mainly erosive work in the bed until the pulse culminates and only builds it to a smaller extent. At the same time the water spreading onto the floodplain is erosive only to a smaller extent, the sandy, sludge-like sediment deposited by the water is, however, of greater significance from the point of view of the formation of the surface. During the recession following the flood peak the deposition of sediment in the riverbed continues, as the flow velocity decreases. During mean and low water periods the Danube forms its riverbed to only a smaller extent as compared to the changes taking place during floods.

With decreasing gradient the morphology of the channel pattern changes in the Szigetköz reach, and four sections or sectors can be distinguished with significant ecological implications:

1) The central braiding channel sector between Rajka and Sap with a slope of 25-35 cm km^{-1}. It splits into smaller branches. The accumulation of sediment and the

fast reorganisations of terrain surface have regularly interrupted the ecological succession.

2) The lower braiding channel sector between Sap and Gönyű with a slope of 12-15 cm km^{-1}. It splits into some large branches and has a greater degree of stability. Its morphological changes have broken the succession of aquatic habitats more rarely.
3) Meandering side-arm sector on the surface of the alluvial cone (e.g. Zátonyi-Danube, Nováki-channel). The successions of the abandoned oxbow lakes are complete.
4) Meandering side-arm sector on the periphery of the alluvial cone with a greater water discharge (the Mosoni-Danube). The relatively wide and deep riverbed has been formed by the floods arriving from the Danube and the adjoining tributaries (Lajta, Rábca, Rába). The successions of the abandoned oxbow lakes are complete.

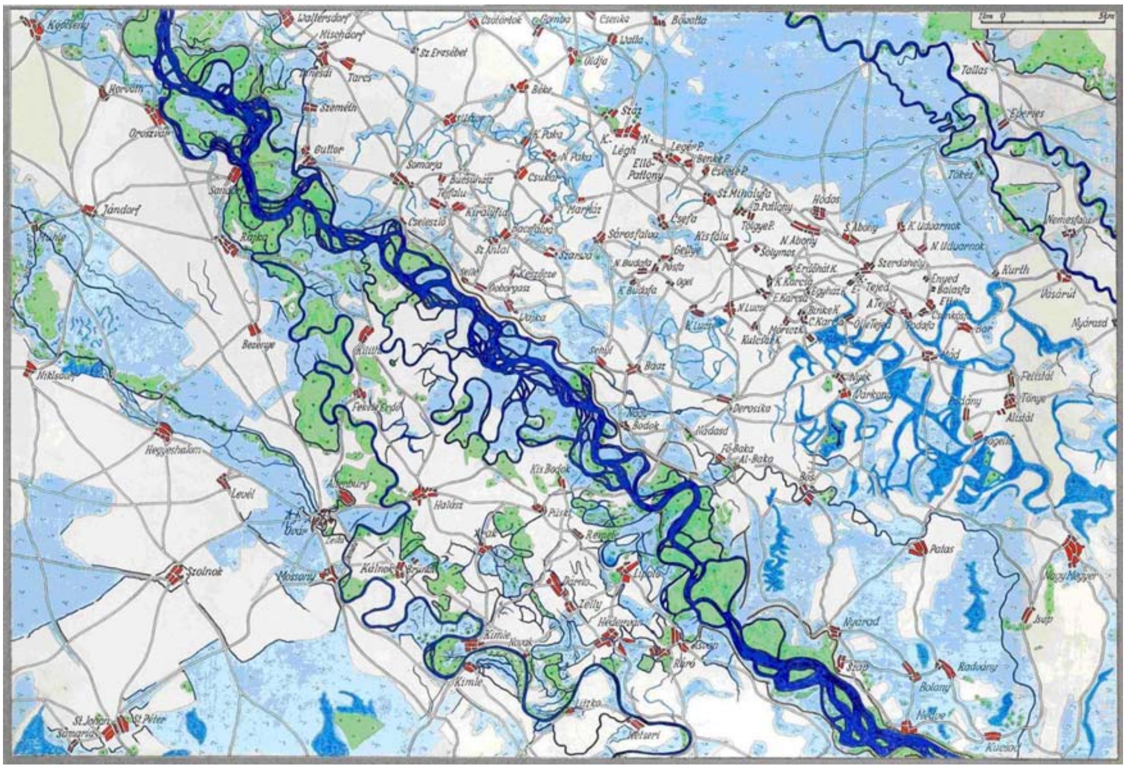


Figure 2-9 Regularly flooded area (light blue colour) along the Szigetköz section of the Danube before the extensive river regulations on the basis of the first military surveys carried out between 1763 and 1785 (from the collection of the Danube Museum)

Presently the terrain surface of the Szigetköz floodplain can be categorised into two vertical levels. The low floodplain lies 1-3 meters higher than the mean water level of the Danube and was inundated almost every year. The high floodplain is situated 1-2 meters above the low floodplain and it is only flooded during very high floods occurring every 3-4 years.

Morphodynamic processes related to habitat structures are given in chapters 2.2 and 2.3.

Table 2-4 Summary of the morphodynamic regime in the natural system

- The tectonic subsidence of the area was compensated by continuous deposition of alpine sediments. Due to a sharp break in slope a large **alluvial fan** developed between Bratislava and Gönyű.
- Under undisturbed conditions the Danube changed its course on a broad scale forming a **delta-like pattern of river arms** in the Szigetköz/Zitny Ostrov. In the recent river corridor a system of meandering and anabranching reaches developed with frequent changes of main branches, sub-branches receiving permanent flow and branches of lower order with higher bed levels and lower discharges or even isolation.
- The **governing processes** of the natural system were erosion, transport and deposition of silt, sand and gravel in large quantities. Rising flood flows eroded bed material and transported their load provide turbulent flows were strong enough. Enlarged geometries, e.g. by diverting channels, or receding flood flows lead to the instream deposition of sediments. Siltation of floodplains is a result of soil erosion dating back to the first settlements in the catchment area. The natural processes of erosion and deposition are closely linked to the total transport capacity of the flood wave (duration, rising and falling of the flood flows).
- The natural system was under **dynamic equilibrium conditions** with regard to bed levels, i.e. tendencies of incision or aggradation were negligible in terms of river management. Over hundreds and thousands of years the evolution of the alluvial cone eventually produced a gradient which was capable of maintaining a sustainable flow and transport rate.

2.2. Landscape structure resulting from the natural governing processes

2.2.1. Natural governing processes

The present concepts concerning the ecology of water flows prove that fluvial systems are complex four-dimensional ecosystems (Ward 1989, Ward & Stanford 1989). River systems are interactive in the direction of the three spatial dimensions: longitudinally (upstream–downstream or river–tributary linkages), laterally (river–floodplain interactions) and vertically (river–subsurface water interactions). The fourth dimension is time, which includes the long-term changes of the fluvial system and the short-term processes related to the annual hydrological cycle. The four-dimensional approach provides a general framework for examining the processes determining the ecological integrity of the habitat types of the water system in the Szigetköz region.

2.2.1.1.Longitudinal governing processes

The water discharge, sediment, vegetation nutrients, organic materials and drifting living organisms arriving from the upstream area of the Devin Gate basically determine the habitat pattern of the fluvial system of the Szigetköz as well as the composition and production of its biota. Water discharge has a direct effect on basic habitat characteristics such as water depth, flow rate, bottom type, etc. and on the erosion and deposition processes determining the morphology of the riverbed. The deposition of the sediment load of an annual amount of 400,000-500,000 m^3/year arriving from the Upper Danube (Károlyi 1962) is a factor of decisive significance in the development of the branch systems.

Hydromorphological processes were followed by changes of biota. During spontaneous succession several species lost ground at habitats becoming unfavourable for them, but they colonized the emergent new habitats. Spatial and temporal patterns of vegetation were dynamic mosaic like.

The composition of plant communities on the floodplain was supplied from local vegetation and vegetative propagula (seeds, fruits, viable pieces of shoots) drifted down from distant mountain areas. The propagula of mountain plants native in the upper catchment area of the Danube are regularly drifted into the Kisalföld section of the Danube, where they are spread on the floodplain by the floods. As a result the terrestrial flora of the region is characterized by a relatively high number of species. The main characteristic feature of the flora is not determined by the special rare species, but rather by the exceptional diversity of the composition of species as mountain and lowland species may occur in each other's direct vicinity (Hahn 2003).

The spreading or "migration" of fluvial macroinvertebrates by drifting is a process of primary significance in the organisation of benthic communities. The benthic habitats abraded by large floods are repopulated via colonisation coming from the upstream section.

The quantity and quality of detritus is influenced by the allochtonous inputs, autochtonous production, microbial and animal processing and retention characteristics of upstream areas.

2.2.1.2.Lateral governing processes

The successive alternating periods of flooding and low water (flood pulse) is the most important driving force of the river-floodplain ecosystem. It is described through the Flood Pulse Concept (Junk et al. 1989). According to this concept the floodplain is an essential part of the lowland fluvial system which is periodically connected to the river and then becomes disconnected from the river through the Aquatic-Terrestrial Transition Zone (ATTZ) moving laterally as the flood pulse passes. The ATTZ with outstanding biological activity is the riverine zone to a water-depth of 1-2 meters, the fluctuation range of which extends to the upper edge of the floodplain (Junk et al. 1989, Bayley 1995). Its extensive lateral movement has an effect on the flow of vegetation nutrients and organic materials and on the development and endurance of the fluvial-floodplain flora and fauna. The flora and fauna of lowland rivers has adapted to the utilisation of periodically inundated floodplains. When the flood pulse arrives a significant element of water invertebrates and fish migrate from the river channel to the recently inundated floodplain. Most of the fish start to reproduce when the floods begin during the spring and early summer. Fish and water invertebrates settling on the inundated floodplain use the organic materials in the ATTZ of mostly allochtonous origin until the flood pulse culminates. At the same time a significant proportion of terrestrial fauna elements find refuge by migrating to floodless habitats. When the flood pulse recedes biomass from the ATTZ flows from the floodplain into the permanent water bodies. The biomass produced in the ATTZ, such as the progeny of fish and invertebrates, contributes to the biological production of lowland rivers to a great extent (Figure 2-10). The amount of the autochtonous biomass depends on the extension of floods in space and time. The basic biological functions of the ATTZ are:

- important source of nutrients
- significant source of the allochtonous biomass
- location of a large proportion of autochtonous primary and secondary production
- key habitat in the ontogenesis of several aquatic and semi-aquatic organisms

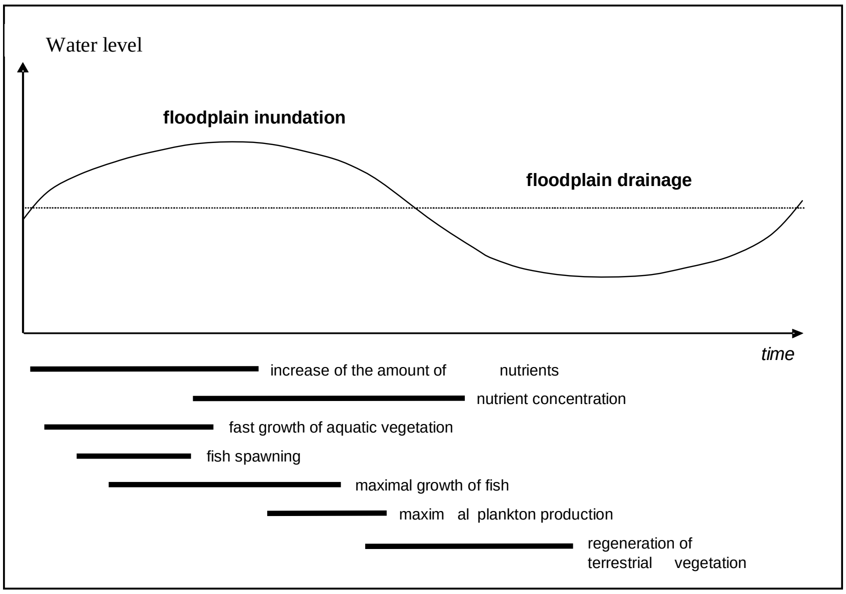


Figure 2-10 Biological processes related to the flood pulse passing in the river–floodplain system at the beginning of the vegetation period, shown in time

The high productivity of the river-floodplain ecosystem is due to the transformation of the aquatic and terrestrial status of the floodplain. If the floods discontinue, the productivity of the fluvial system significantly reduces changing the flow of nutrients and the organisation of ecosystems.

2.2.1.3.Vertical governing processes

The hyporheic zone in alluvial lowland rivers is well developed and therefore represents an essential component of the aquatic ecosystem (Stanford and Ward 1993). The hyporheic interstitial water body directly connected to the riverbed provides a specific habitat for numerous benthic invertebrate organisms. The hyporheic zone also bears key importance in the ontogenesis of several rheophilic fish species as a spawning and rearing substrate, or juvenile fish habitat and flood water refuge, particularly for rheophilic fish species (Jungwirth 1998).

The productivity of the benthic communities is significantly lower in filling up oxbow lakes, where the accumulating silty sediment rich in organic materials prevents direct interactions between the surface and interstitial water bodies.

2.2.1.4.Temporal dynamism

Temporal dynamism includes the long-term (>10 years) changes of the fluvial system and short-term events related to the annual hydrological cycle.

Long-term changes determine the geomorphologic development of the fluvial system and the succession of habitats. The rate of succession is influenced by allogenic (dropping of water-level, deposition of mineral sediment, etc.) and autogenic (vegetation dynamics, eutrophication, etc.) processes. An anabranch becoming isolated from the side-arm system can become filled up within a few decades as a result of allogenic processes. However, the autogenic filling up of an abandoned oxbow lake created as a result of the segregation of a meander and its transformation into a land ecosystem takes 200-300 years. A series of historical maps from one part of the Szigetköz demonstrates landscape changes in a two-century retrospective view in Figure 2-11.

Short-term changes influence the periods of interactions between the river and the floodplain in connection with water regime and weather, which controls the biological functions of the river-floodplain ecosystem (see the previous section).

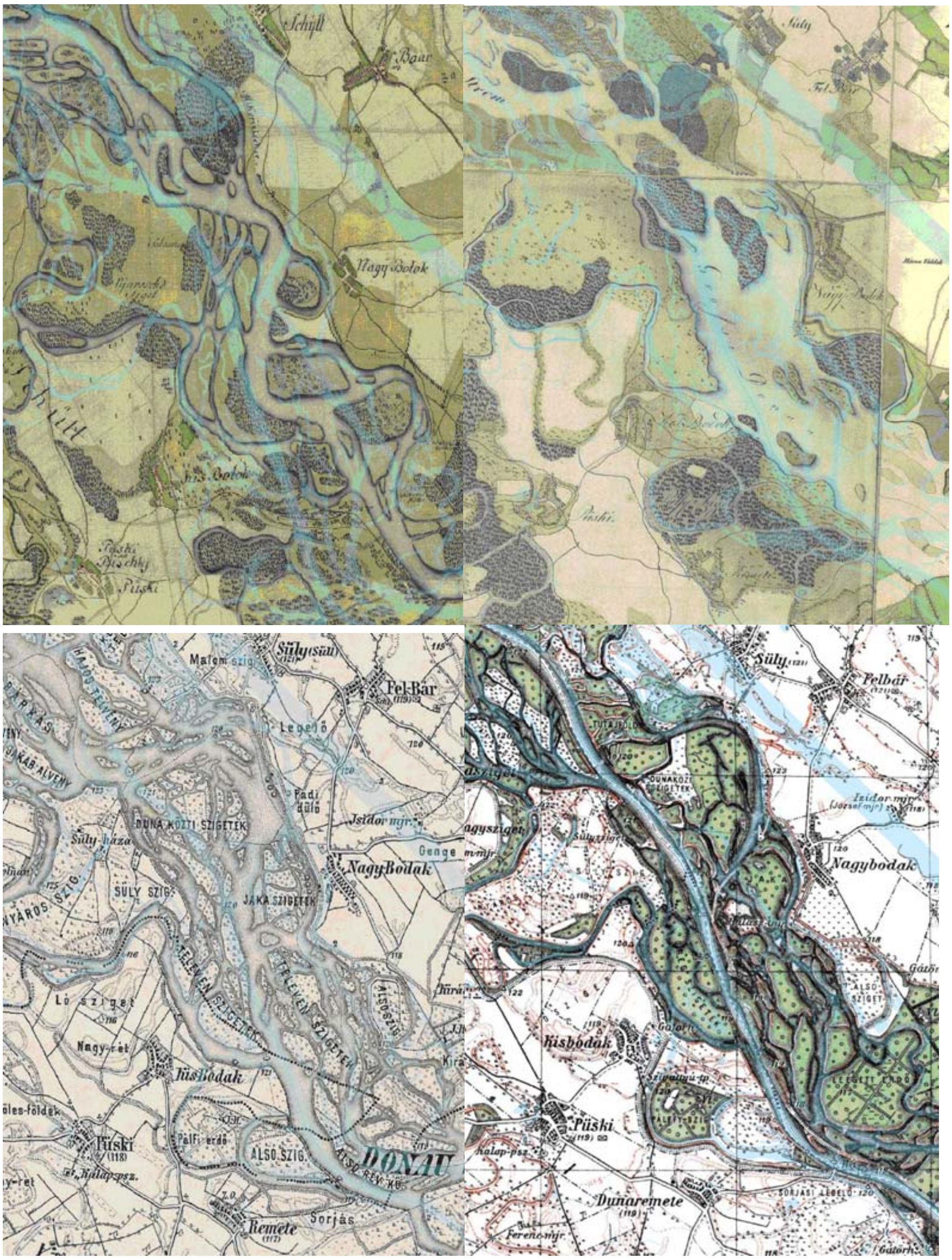


Figure 2-11 A sequence of four historical maps demonstrating landscape changes during a 140 year period in the Bodak area of the Szigetköz. Maps are from 1784 (top left), 1840s, (top right), 1872 (down left) and 1920 (down right) respectively. Blue contour layer shows existing channels.

2.2.1.5.Disturbances

Disturbances are unusual and irregularly occurring events resulting in abrupt structural changes in natural habitats, communities and populations. The assessment of disturbances may vary depending on scales in space and time. The passing of a medium flood pulse cannot be regarded as a disturbance. It contributes to the endurance of habitat patterns - for example its rinsing effect removes accumulated sludge-like organic and inorganic sediment from river branches and from the interstitial cavities of the hyporheic zone, it prevents the development of weed vegetation in the individual branches, etc. However, extraordinarily high floods are regarded as a disturbance. Intensified erosion processes spectacularly change the geomorphology of the floodplain, bars are created, branches appear or become filled up, meanders develop, etc. Disturbances interrupt the succession of habitats thus facilitating the appearance of less competitive pioneer species and communities. Following an extraordinary flood pulse the geomorphology of the river bed is characterized by a re-arrangement process lasting for years, interacting dynamically with the colonisation and organisation of ecological elements (individuals, populations, communities, ecosystems).

According to the intermediate-disturbance hypothesis (Ward & Stanford 1989), disturbances of intermediate frequency and intensity enable the endurance of various groups of species by continuously maintaining non-balance conditions which results in greater bio-diversity of river ecosystems. In the development of river ecosystems the repeated occurrence of disturbances restricts the biotic interactions unlike in the case of the development of lake ecosystems. Predictability is an important aspect in the course of the assessment of disturbances. The habitats of lowland rivers are adapted to the seasonal fluctuation of the water regime, temperatures, etc. Therefore only unpredictable events can be regarded as typical disturbances. In a statistical sense an event can be regarded as unpredictable if the probability of its occurrence is < 5% (Resh et al. 1988).

Table 2-5 Summary of the dimensions of the governing processes

- Floodplain-river ecosystems are interactive along three spatial dimensions. Longitudinal patterns and processes along river courses have long been recognized as a fundamental feature of the river systems. There are interactive pathways between the river channel and the riparian zone. The kinetic energy of flooding (fluvial dynamics) maintains connectivity. Vertical interactions occur between the surface and groundwater.
- Floodplain-river ecosystems are characterized by disturbance. Especially rare flood events with competent flows reshaping channel patterns interrupt the succession of habitats producing new starting points (rejuvenation of floodplain habitats). However regular floodings (occurance interval < 10 years) are crucial for the development of the typical floodplain vegetation along flooding gradients.

2.2.2. Habitat pattern

The Szigetköz floodplain of the Danube appears as networks of more or less interconnected water bodies (Figure 2-8). Within the floodplain, several types of habitats can be distinguished, which result from hydrological and geomorphologic processes. The habitat difference between the floodplain water bodies at a small spatio-temporal scale is based on the water movement during seasonal inundation. The pattern of the habitats in the functional sectors of the fluvial system changes according to the water level. During low water periods the water discharge is restricted to the larger and deeper channels. Depending on the degree of connectivity, the side-arms and oxbow lakes differ from those habitats where the water is flowing. As a consequence of evaporation and seepage their water loss may be significant, the quality of their water may change and they may even dry out. The habitat difference at a moderate spatial scale refers to attributes such as connectivity and the stage of ecological succession. Four main types of aquatic habitats characterising the water system can be distinguished (Roux et al. 1982 and Amoros et al. 1987). There is a transitional continuum in the ecological succession process between the four types (Figure 2-12 and Figure 2-13):

- *Eupotamon*: River branch with permanent flow (main channel, side-arms). The bottom is course-grained, often gravelled. The suspended load content is high; it is especially significant during floods. The vertical stratification of the temperature and of the oxygen are not characteristic, water conductivity is low. Its phytoplankton content is poor, primarily it is formed by drifting diatoms, and its macro-vegetation content is insignificant. The dominant elements of the zooplankton are protozoa and rotifers, which represent small biomass. The zoobenthos and the fish, which is relatively rich in species, is characterized primarily by rheophilic species, which represent small biomass.

- *Parapotamon*: Periodically flowing side-arm permanently connected to the main arm of the river at the confluence. Its flow can be fed both by surface and ground water, the rate and direction of the flow may vary depending on the water level fluctuation of the river. The suspended load content is low in low-water periods. The bottom contains less coarse-grained gravel often mixed with sand and silt. There is a periodical occurrence of vertical stratification of the temperature and oxygen content depending on water depth. The water conductivity is on an intermediate level. Its phytoplankton is species rich, the biomass of diatoms and green algae is significant, and however, the macro-vegetation is poor. The zooplankton represents a large biomass; its dominant elements are protozoa and rotifers. The biomass of zoobenthos is significant. The fish fauna is less demanding with respect to habitat characteristics. Eurytopic and to a small extent rheophilic species prevail and represent a medium biomass.

- *Plesiopotamon*: Periodically isolated still-water oxbow lake or abandoned loop; the extension and water mass varies depending on the water level of the river. Its bottom is composed of silt and sand. The suspended load content is generally low. It is characterized by vertical stratification of temperature and oxygen. Water conductivity is high. It has a great mass of phytoplankton, and plankton bloom is a frequent phenomenon, macro vegetation is abundant. The dominant elements of the zooplankton are rotifers and crustaceans, which represent an especially large biomass. The biomass of zoobenthos is significant. The fish fauna is characterized by eurytopic and limnophilic species. As a result of periodically extreme environmental conditions the fish population is often mono- or bispecific. The biomass of the fish fauna varies between extreme limits; it may even be especially large.

- *Paleopotamon*: Permanently isolated still-water oxbow lake or abandoned loop. Direct surface connection with flowing-water branches occurs only in the case of the highest water levels. Its water supply is mostly ensured by infiltration of groundwater through the alluvium and by precipitation. Its bottom is composed of silt and clay, the organic material content of the surface of the sediment is very high. The suspended load content is low. The daily vertical stratification of temperature and oxygen is significant, water conductivity is very high. Its phytoplankton contains a low number of species and its biomass is not significant. Its macro-vegetation is especially abundant. The dominant organisms of the zooplankton are crustaceans representing a low amount of biomass. The biomass of zoobenthos is not significant. The fish fauna is composed of a relatively low number of limnophilic species representing a significant biomass.

Figure 2-12 Illustrates the position of aquatic habitats (Amoros-Roux types) within the riparian landscape in a near-natural river system (example from Eurasia, source Google2009)

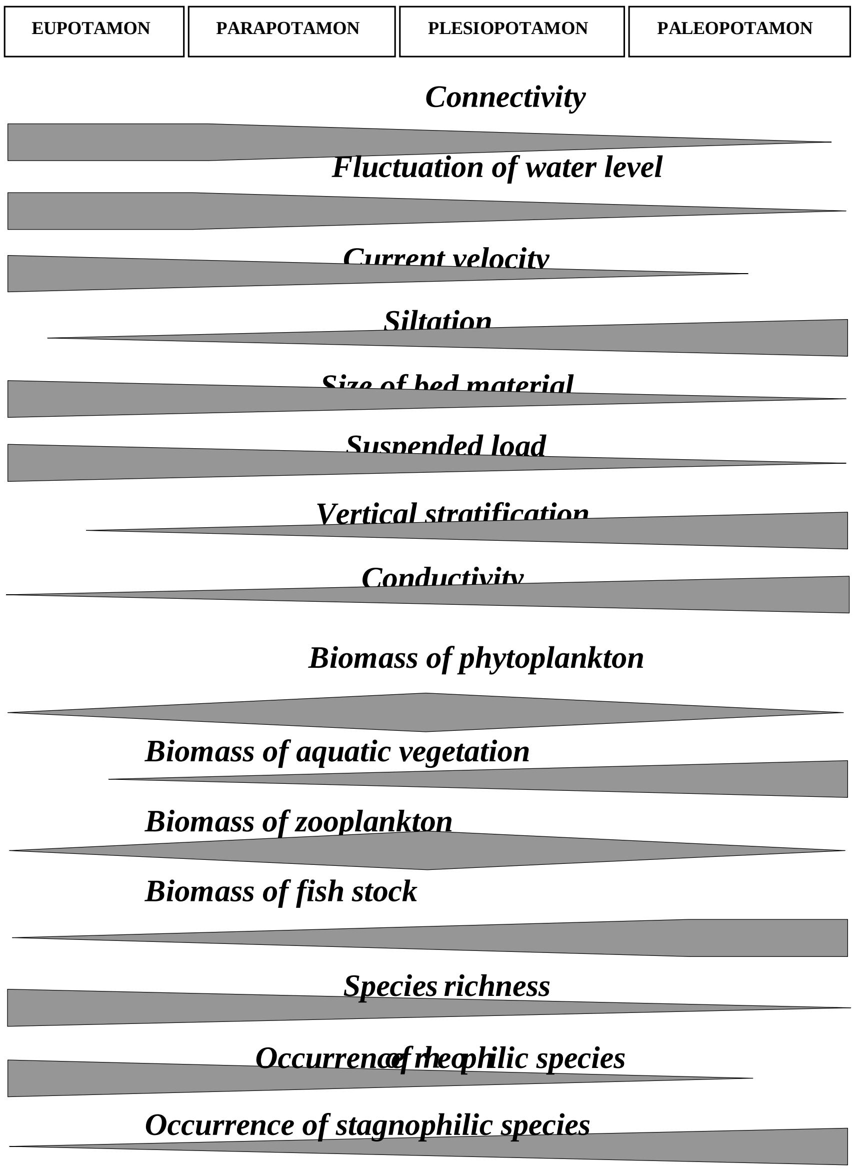


Figure 2-13 Comparison of some physical and biological characteristics of main types of aquatic habitats

Historical habitat analysis can help to determine the hydromorphological conditions in the pristine situation (Hohensinner et al. 2005). For these purpose numerous historical maps, reports as well as longitudinal profiles and river engineering plans were collected and evaluated. The following maps were used and assessed in detail (from 1782):

- Maps from 1100-1600: Those maps indicate the general large scale development of the whole inland delta (first bi- than tri-furcation) of the Danube

- 1699: Marsigli maps providing the first detailed reference including side channels and islands
- 1782-84: First Austrian military survey (topographical map 1: 28,800)
- 1834: Detail map (with written and coloured landuse information)
- ~1840: Second Austrian military survey (topographical map 1: 28,800)
- 1859: “Stromkarte” (River map) from Passau to Orsova including a lot of information regarding channel depths and velocities for navigation and initial regulation works (1: 28,000)
- 1882-87: Third Austrian military survey (topographical map) (1:25,000)
- 1901: Regulation map (1:100,000)
- 1910: Regulation map (1:25,000)
- 1925: Topographical map (1:25,000)
- 1970: Danube river map and topographical map (1:10,000)
- 2008: Colour Infrared aerial images from 2008

Harmonised thematic content was extracted from all maps (aquatic, semi-aquatic and terrestrial habitats of the riparian landscape as well as hydraulic structures), compare legend and map examples on the next pages.

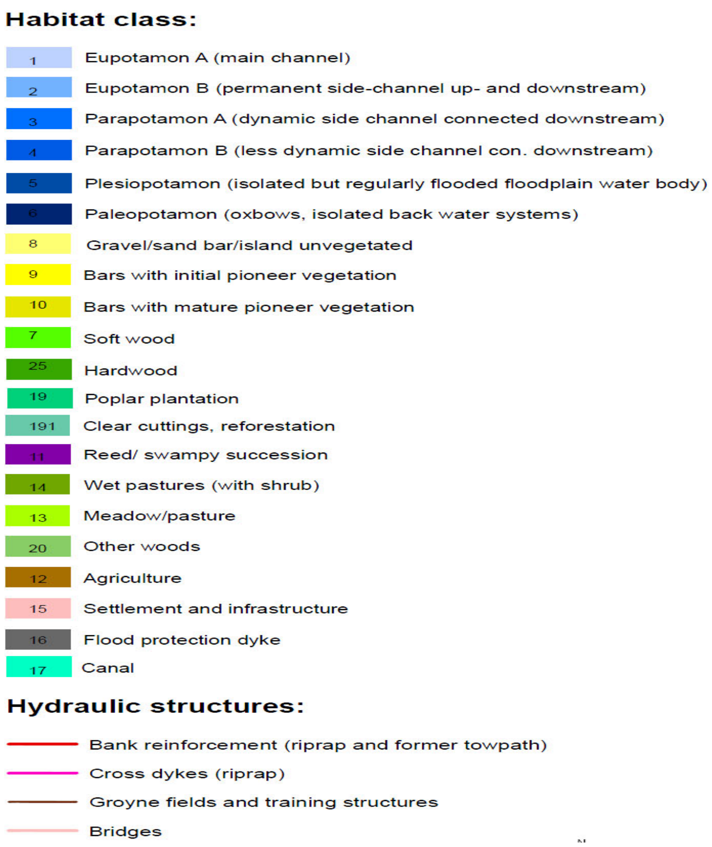
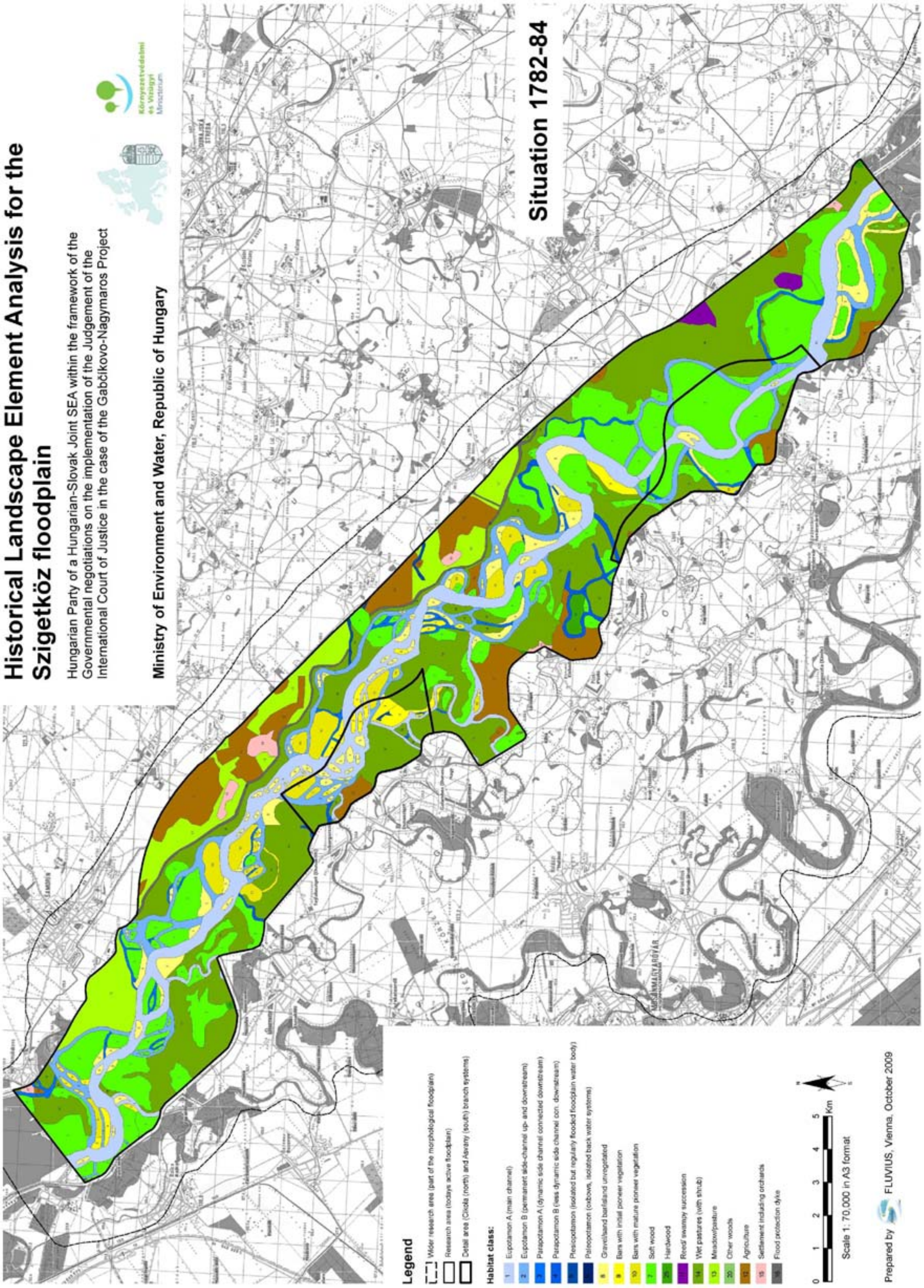
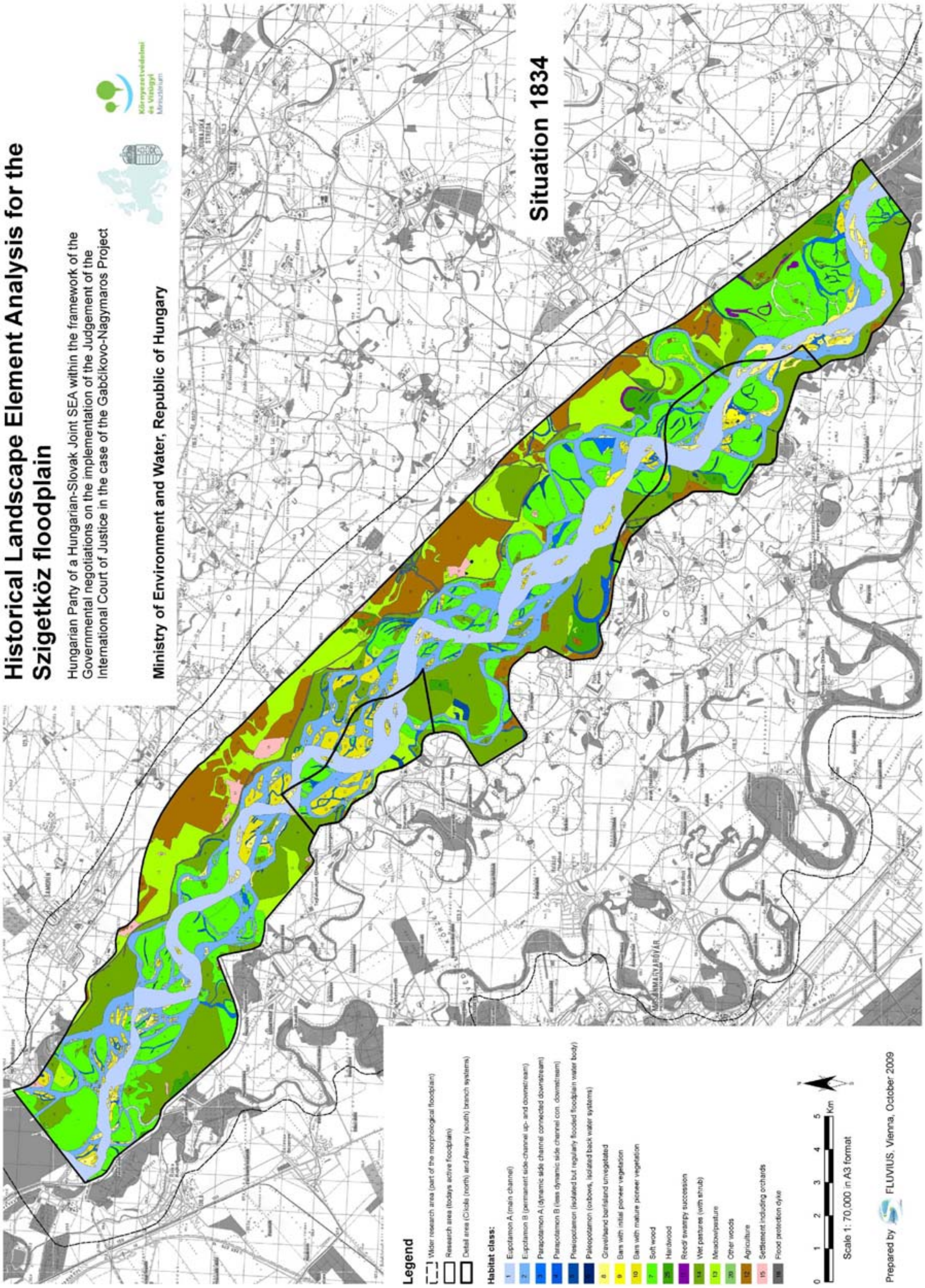


Figure 2-14 Overall habitat classes (not all habitats/hydraulic structures are relevant for the first time steps such as “Poplar plantation” or “Filled gravel pit”)

The following map sequence (Maps 1 - 7) indicates the most significant changes since 1782. The black polygon indicates the whole 30 km long Szigetköz stretch in between the existing dikes (active floodplain). Two bold polygons show areas chosen for detailed studies and the thin dotted line delineates the wider project area including the Mosoni Danube on Hungarian territory.


Historical Landscape Element Analysis for the Szigetköz floodplain
Hungarian Party of a Hungarian-Slovak Joint SEA within the framework of the Governmental negotiations on the implementation of the Judgement of the International Court of Justice in the case of the Gabčíkovo-Nagymaros Project
Ministry of Environment and Water, Republic of Hungary
Situation 1782-84
Legend
Habitat class:
Scale 1: 70,000 in A3 format
Prepared by FLUVIUS, Vienna, October 2009

Map 1: 1782-84


Historical Landscape Element Analysis for the Szigetköz floodplain
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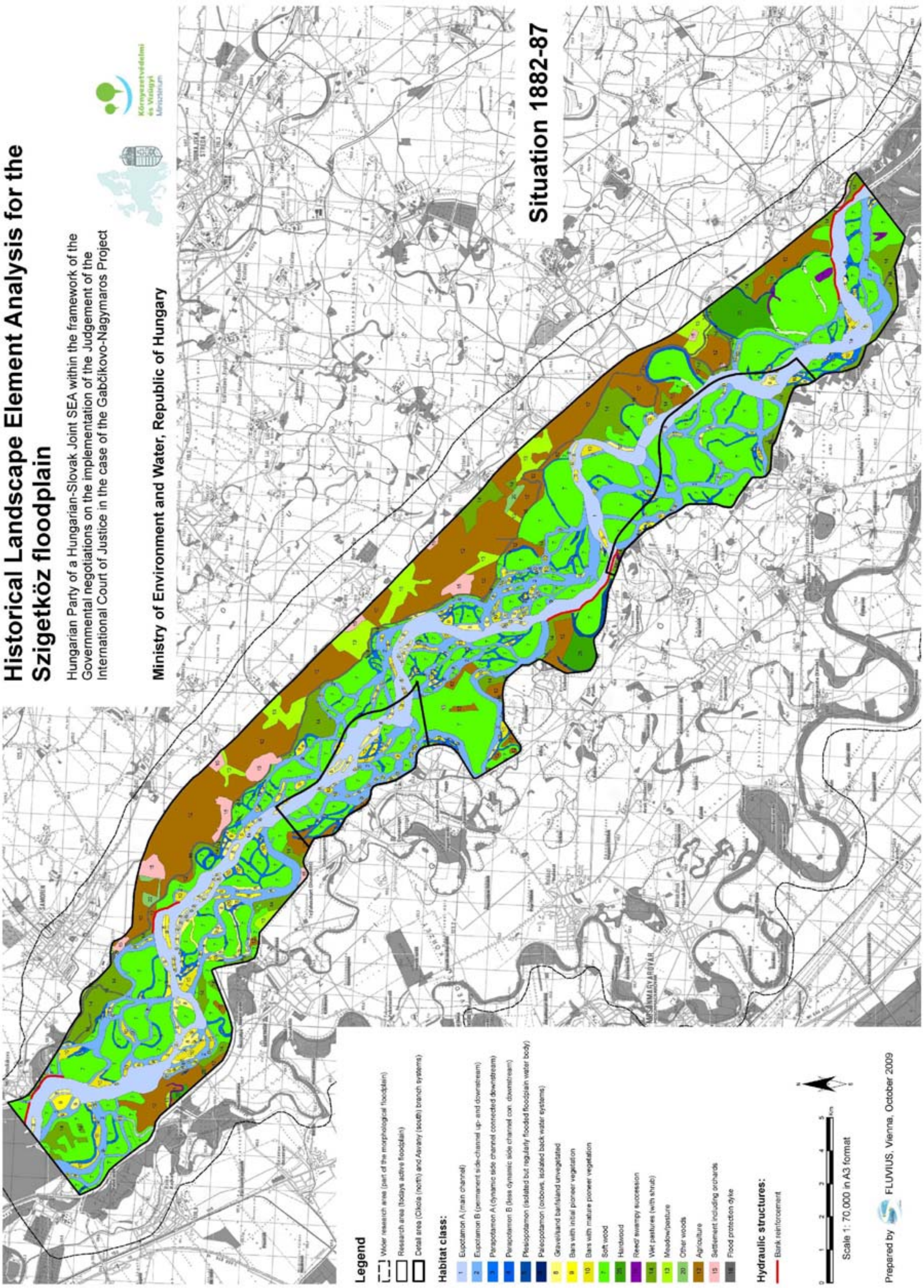
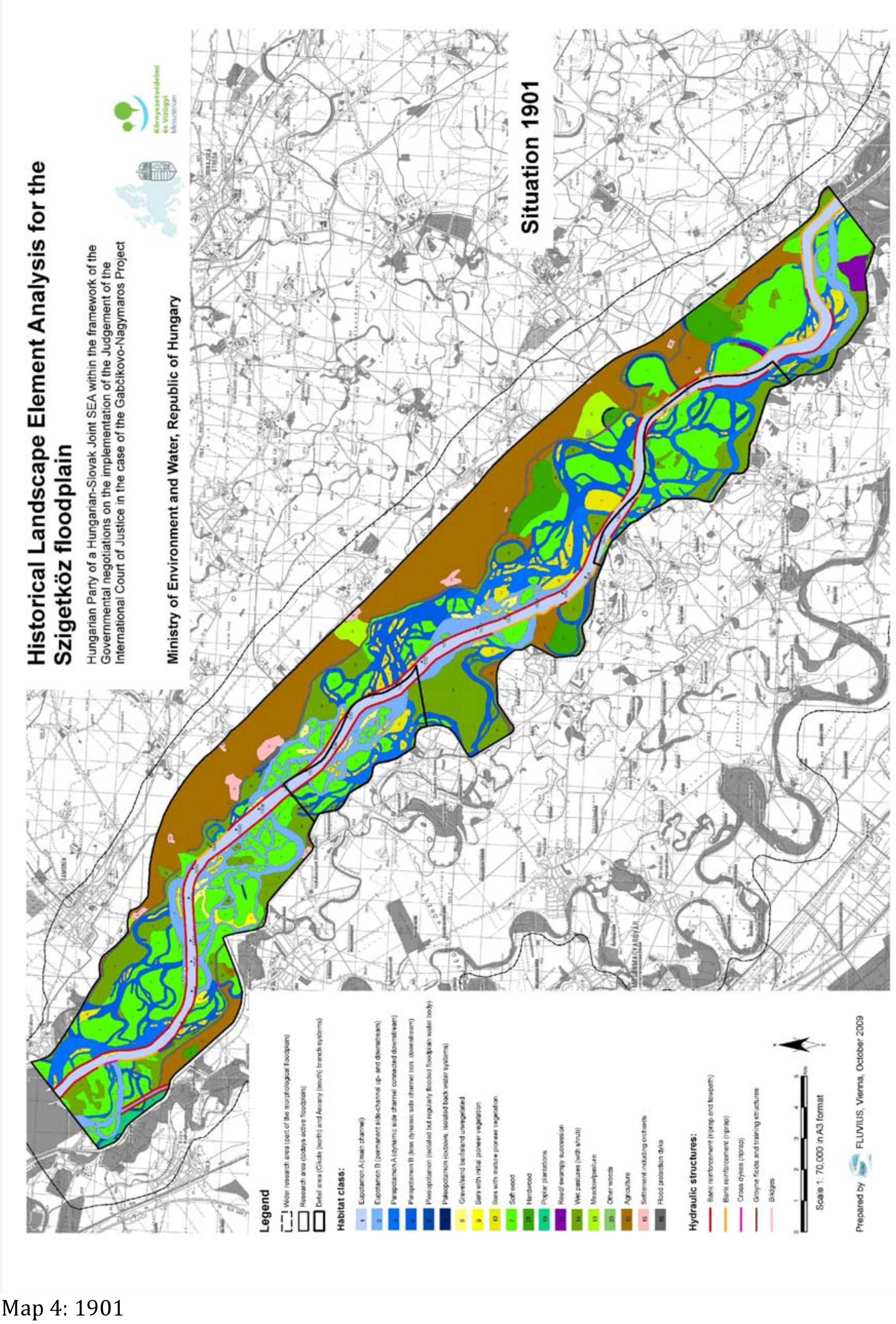
Ministry of Environment and Water, Republic of Hungary
Situation 1834
Legend
Habitat class:
Scale 1: 70,000 in A3 format
Prepared by FLUVIUS, Vienna, October 2009

Map 2: 1834

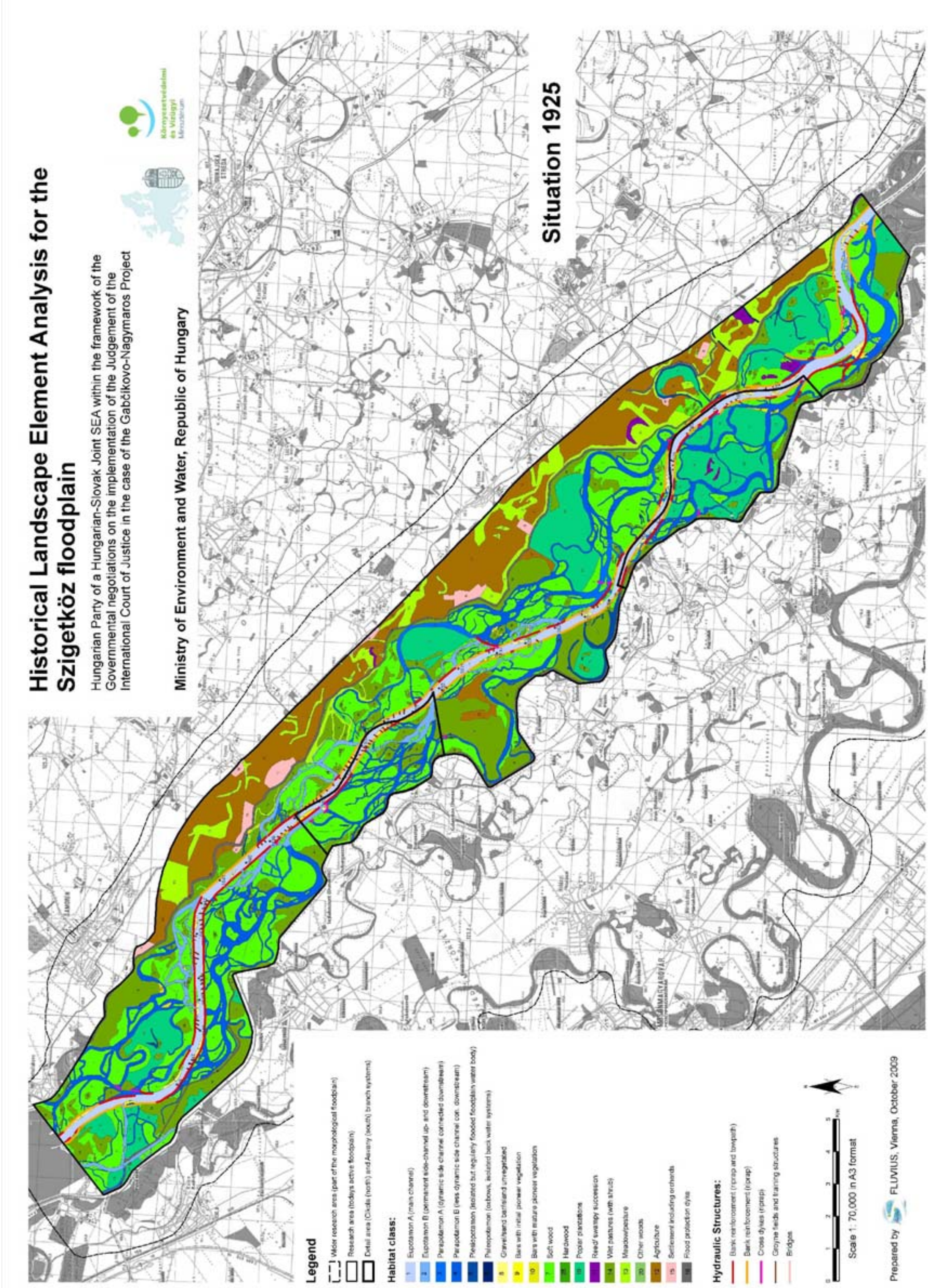


Historical Landscape Element Analysis for the Szigetköz floodplain
Hungarian Party of a Hungarian-Slovak Joint SEA within the framework of the Governmental negotiations on the implementation of the Judgement of the International Court of Justice in the case of the Gabčíkovo-Nagymaros Project
Ministry of Environment and Water, Republic of Hungary
Situation 1882-87
Legend
Wider research area (part of the morphological floodplain)
Research area (todays active floodplain)
Detail area (Cikola (north) and Ásvány (south) branch systems)
Habitat class:
Eupotamon A (main channel)
Eupotamon B (permanent side-channel up- and downstream)
Parapotamon A (dynamic side channel connected downstream)
Parapotamon B (less dynamic side channel con. downstream)
Plesiopotamon (isolated but regularly flooded floodplain water body)
Paleopotamon (oxbows, isolated back water systems)
Gravel/sand bar/island unvegetated
Bars with initial pioneer vegetation
Bars with mature pioneer vegetation
Soft wood
Hardwood
Reed/ swampy succession
Wet pastures (with shrub)
Meadow/pasture
Other woods
Agriculture
Settlement including orchards
Flood protection dyke
Hydraulic structures:
Bank reinforcement
Scale 1: 70,000 in A3 format
Prepared by FLUVIUS, Vienna, October 2009

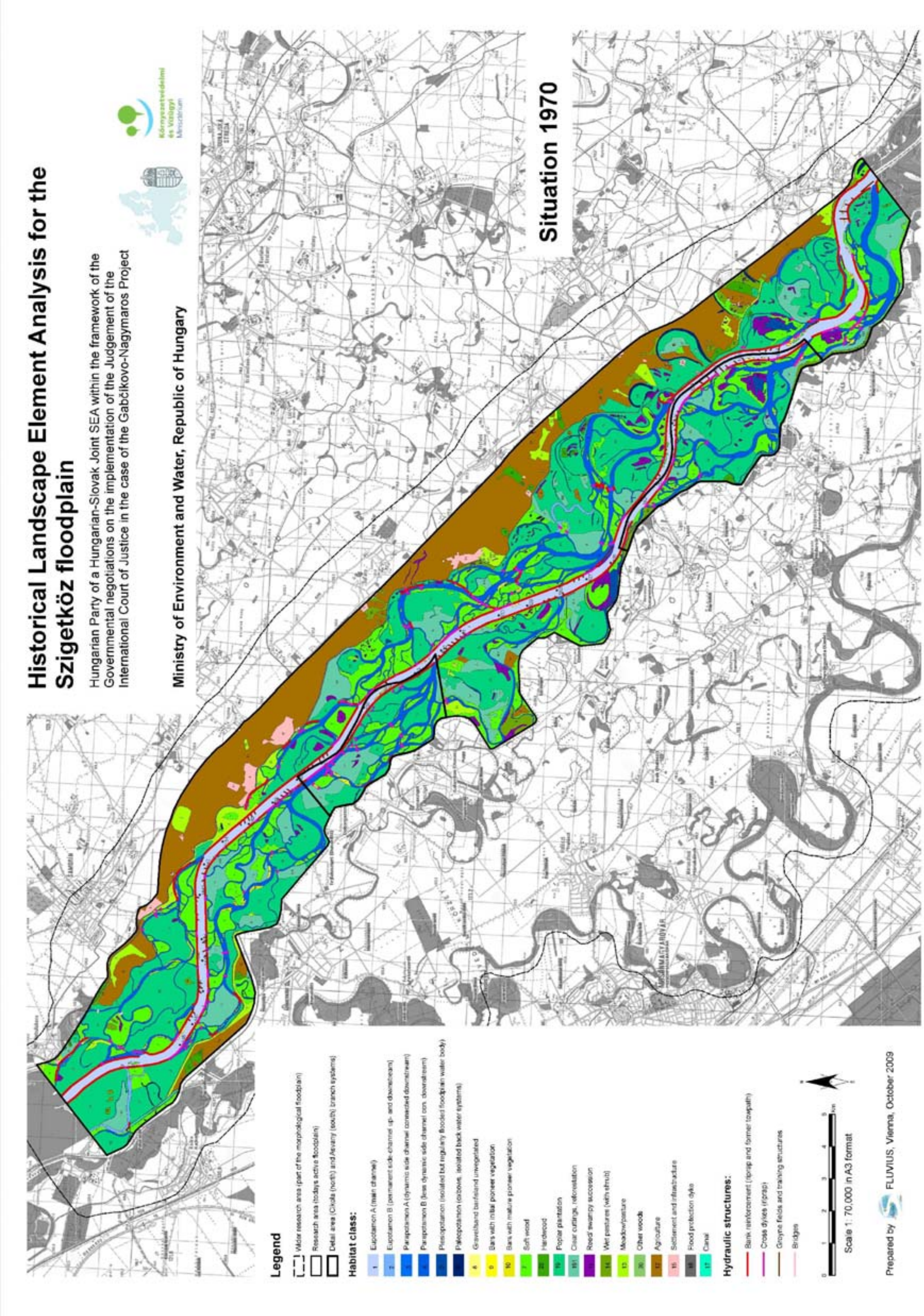
Map 3: 1882-87


Historical Landscape Element Analysis for the Szigetköz floodplain
Hungarian Party of a Hungarian-Slovak Joint SEA within the framework of the Governmental negotiations on the implementation of the Judgement of the International Court of Justice in the case of the Gabčíkovo-Nagymaros Project
Ministry of Environment and Water, Republic of Hungary
Situation 1901
Legend
Habitat class:
Hydraulic structures:
Scale 1: 70,000 in A3 format
Prepared by FLUVIUS, Vienna, October 2009

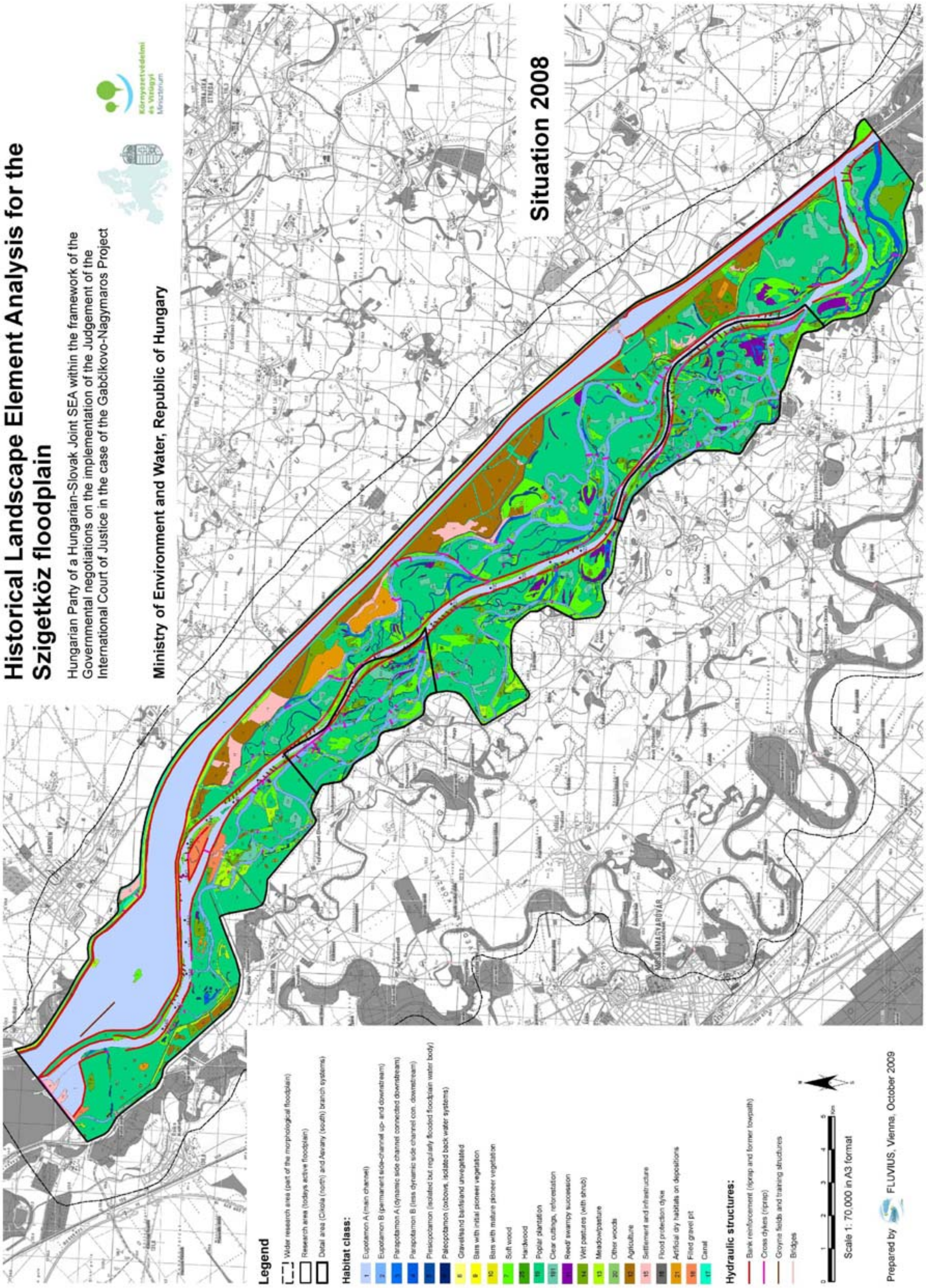
Map 4: 1901


Historical Landscape Element Analysis for the Szigetköz floodplain
Hungarian Party of a Hungarian-Slovak Joint SEA within the framework of the Governmental negotiations on the implementation of the Judgement of the International Court of Justice in the case of the Gabčikovo-Nagymaros Project
Ministry of Environment and Water, Republic of Hungary
Situation 1925
Legend
Habitat class:
Hydraulic Structures:
Scale 1: 70,000 in A3 format
Prepared by FLUVIUS, Vienna, October 2009

Map 5: 1925


Historical Landscape Element Analysis for the Szigetköz floodplain
Hungarian Party of a Hungarian-Slovak Joint SEA within the framework of the Governmental negotiations on the implementation of the Judgement of the International Court of Justice in the case of the Gabčikovo-Nagymaros Project
Ministry of Environment and Water, Republic of Hungary
Situation 1970
Legend
Habitat class:
Hydraulic structures:
Scale 1: 70,000 in A3 format
Prepared by FLUVIUS, Vienna, October 2009

Map 6: 1970


Historical Landscape Element Analysis for the Szigetköz floodplain
Hungarian Party of a Hungarian-Slovak Joint SEA within the framework of the Governmental negotiations on the implementation of the Judgement of the International Court of Justice in the case of the Gabčikovo-Nagymaros Project
Ministry of Environment and Water, Republic of Hungary
Situation 2008
Legend
Habitat class:
Hydraulic structures:
Scale 1: 70,000 in A3 format
Prepared by FLUVIUS, Vienna, October 2009

Map 7: 2008

2.3. Biota, biodiversity, ecological processes referring to water quality

With regard to the natural conditions of the Szigetköz floodplains prior to major regulation schemes we can conclude that due to the high habitat diversity resulting from the fluvial dynamics, the frequent flood-controlled resetting towards early successional stages and the large lateral extension of the floodplains, the biodiversity of characteristic river-floodplain associations was high and self-purification processes were in a balanced state. In comparison to the landscape development induced by the regulation scheme in the 19th century habitat diversity was higher and dominated by aquatic and semiaquatic areas. They exhibited a broad range of habitat conditions - hydrological connectivity to the main river stem, flow, retention characteristics, sediment type and wet/dry-falling phases. The analyses of historical maps clearly indicate this predominance of habitats in the early successional stages– bare gravel bars and areas with finer sediment depositions. Shallow islands were constantly formed and eroded. Habitat turnover rate was high and the extent of terrestrialisation processes was reduced. We thus can conclude from historical records and the available knowledge of autecological requirements of characteristic species that the biodiversity of rheophilic species, early pioneer and mid-term successional species of plants which require raw riverine sediments for early growth and are tolerant to frequent flooding were enhanced together with semi-aquatic associations of terrestrial invertebrates (e.g. carabid beetles, spider and ant communities) respectively characteristic bird species requiring open gravel bars for breeding.

The high biodiversity was expressed by the broad representation of plant associations.
Raw alluvial soils formed on the gravel beds which were deficient in humus but rich in nutrients. Soils were saturated with water during floods and respectively water reached the roots of plants from the ground water through capillary rise. Along the shoreline of shallow islands and side-arms normally low willow scrubs were formed with the species composition depending on the quality of the soil. On the gravel shallows purple willow scrubs (*Rumici crispi-Salicetum purpureae*) were established. In sections with a lower flow where fine sand and silt formed islands, almond-leaved willow scrubs (*Polygono hydropiperi-Salicetum triandrae*) were developed. In closed-drainage areas with a good water supply, swamp willow and alder woods (*Calamagrostio-Salicetum cinereae, Carici elongatae-Alnetum*) were formed. On higher terrain where the regular floods lasted for 1 to 2 months, larger willows and poplars create softwood forests. The forested habitats of willow groves (*Leucojo aestivi-Salicetum albae*) occurred in regularly flooded areas. The black poplar groves (*Carduo crispi-Populetum nigrae*) were developed in forest habitats also regularly flooded with water but where their soil formed on sand-gravel underlay dries off more rapidly in flood-free periods. Among the species of hardwood groves the European white elm (*Ulmus laevis*) often appears in this association.

At higher levels of the floodplain terrain, which are flooded only in the case of larger floods, white poplar groves (*Senecioni sarracenici-Populetum albae*) were developed. Further up in the rarely flooded areas various hardwood associations are predominant: Alder groves (*Paridi quadrifoliae-Alnetum*), oak ash elm groves (*Pimpinello majoris-Ulmetum*), hornbeam oak forests (*Majanthemo-Carpinetum*), and closed and open dry oak forests (*Piptathero virescentis-Quercetum roboris, Peucedano alsatico-Quercetum roboris*) formed a vegetation mosaic.

Typical associations of the aquatic vegetation include a variety of pleustonic plant communities (*Lemnetea: Salvinio-Spirodeletum, Lemno-Utricularietum vulgar I, Hydrocharitetum morsus ranae, Ceratophylletum demers)* and submerged aquatic communities (*Potametea:* (*Nymphoidetum peltatae, Nymphaeetum albo-lutea, Hottonierum palustris, Ranunculetum fluitantis*)
Semi-aquatic vegetation and reeds showed also a high diversity *(Phragmitetum communi, Sparganietum erecti, Glycerietum maximae, Typhetum angustifoliae and Typhetum latifoliae, Butomo-Alismatetum plantaginis-aquaticae* and *Hippuridaetum vulgaris*).
In ox-bows not affected by the floods – primarily in the Upper-Szigetköz – moors of grey willow shrubs (*Calamagrastio- Salicetum cinereae*) and black alder marshy woods (*Thelypteridi – Alnetum*) were formed.
In addition swamp- and fen-meadows (*Carici flavae-Eriophoretum*) and the fen-meadow of calciferous ground (*Succiso-Molinietum hungaricae*) were prominent.

Among the aquatic fauna rheophilic guilds dominated both among invertebrates (e.g. molluscs, trichopterans, odonates as well as fish. However, the large lateral extension of the floodplain good habitat conditions were created for associations characteristic for lower connectivity and latter stages of terrestrialisation successions in the more distant locations of the floodplains. We have evidence that prior to river regulation both the rheophilic as well as the characteristic limnophilic guilds (due to the larger lateral extent of the floodplains) found better habitat conditions compared to the present day situation.
Table 2-6 illustrates the present distribution of fish guilds in the Szigetköz area.

We can derive from modern studies on functional processes in floodplains (e.g. Schiemer et al. 2008) that the broader gradients of water currents, flow and retention which existed prior to regulation stimulated functional processes of nutrient recycling, deposition and decomposition processes. Bacterial activity was enhanced by the production of dissolved organic carbon (DOC) by the local primary production by phytoplankton, phytobenthos and macrophytes.We also can conclude from our present understanding of floodplain ecology that wide windows existed between surface water, hyporheic zones and groundwater, stimulating the self purification processes.

Table 2-6 Reference fish fauna of the main habitat types in the Szigetköz section of the Danube. +++ abundant (estimated relative abundance >5%), ++ common (estimated relative abundance >1%), + rare (estimated relative abundance <1%).

	habitat type			
fish species	**eupot.**	**parapot.**	**plesiopot.**	**paleopot.**
Abramis bjoerkna	++	+++	+	
Abramis brama	++	+++	+	
Acipenser gueldenstaedtii	++	+		
Acipenser nudiventris	+	+		
Acipenser ruthenus	++	+		
Acipenser stellatus	+	+		
Alburnoides bipunctatus	+			
Alburnus alburnus	+++	+++	++	+
Anguilla anguilla	+	+		
Aspius aspius	++	++	+	
Ballerus ballerus	++	+		
Ballerus sapa	++	+		
Barbatula barbatula	++	+		
Barbus barbus	+++	++		
Carassius carassius			+	++
Chondrostoma nasus	+++	++		
Cobitis elongata		+	++	+
Cottus gobio	+	+		
Cyprinus carpio	++	++	+	+
Esox lucius	+	++	++	++
Eudontomyzon mariae	+	+		
Gobio gobio	+	++		
Gymnocephalus baloni	++	++		
Gymnocephalus cernuus	++	++	+	
Gymnocephalus schraetser	++	+		
Hucho hucho	+			
Huso huso	++	+		
Leucaspius delineatus			+	++
Leuciscus cephalus	++	++	+	
Leuciscus idus	+++	++	+	
Leuciscus leuciscus	++	+		
Lota lota	++	++		
Misgurnus fossilis		+	++	++
Pelecus cultratus	+			
Perca fluviatilis	++	++	++	+
Rhodeus amarus	+	++	+++	++
Romanogobio kesslerii	+	+		
Romanogobio vladykovi	+++	++		
Rutilus rutilus	++	+++	+++	++
Rutilus virgo	++	+		
Sabanejewia balcanica	+	++		
Salmo trutta fario	++	+		
Sander lucioperca	++	++	+	
Sander volgensis	+	+		
Scardinius erythrophthalmus	+	+	++	++
Silurus glanis	+++	++	+	
Tinca tinca		+	++	++
Umbra krameri				++
Vimba vimba	++	+		
Zingel streber	++	+		
Zingel zingel	++	+		

3. History of river regulation and land use of the area

The early anthropogenic activities such as the cutting of the forests of the Upper Danube catchment area and, due to this, the change in the proportion of the precipitation runoff of the mountainous areas, and the acceleration of the soil erosion processes have all possibly created visible changes to the Szigetköz section of the Danube which occurred centuries ago. Activities that directly affected the water system were usually related to river regulation work. As indirect anthropogenic effects agricultural activities and forestry work in the catchment area have a significant effect on the Szigetköz water system.

3.1. History of river regulation works

The first written record concerning the regulation of the upper section of the Danube in Hungary dated back to 1247. King Sigmund appointed a commissioner to control the construction works of the flood prevention dykes of the Danube in the Csallóköz (Zitny Ostrov), and even remains of a Roman age dam have been found. In the 17th century many settlements were protected by a surrounding dyke (Károlyi 1973). Besides protecting against floods an inland water drainage network was constructed, the total length of which was 92 km in 1850. Significant changes have occurred in the river system of the Szigetköz region during the past 150 years.

As the first modern time attempt to regulate the river between Gutor and Vének starting in 1837 using exclusively *cross-dykes* remained unsuccessful, shorter, but long-lasting *embankments* were constructed between Remete and Lipót as well as at Szap. Encouraged by the positive experiences, mean-flow river bed regulation of the Upper Danube was accomplished between 1886 and 1896 through the use of *guiding walls*. By these training projects, the main river channel was successfully stabilised, but, at the same time adverse effects were already beeng experienced at the turn of the century (*Tőry* 1952).

Regulation of the mean-flow river bed has stopped the natural meandering process of the Danube at several sections and created long straight or almost straight reaches in which the drift line of the flow has no definite guidance.

The first interdependent system of *embankments for flood protection* was constructed on the right banks of the Danube by the “Szigetköz Flood Prevention Co” between 1892 and 1896. River regulation operations stopped the wandering of the riverbed, while with the construction of the embankments the spreading of the floods was prevented. A unified, homogenous main riverbed was formed in order to ensure the navigation route (Figure 3-1).

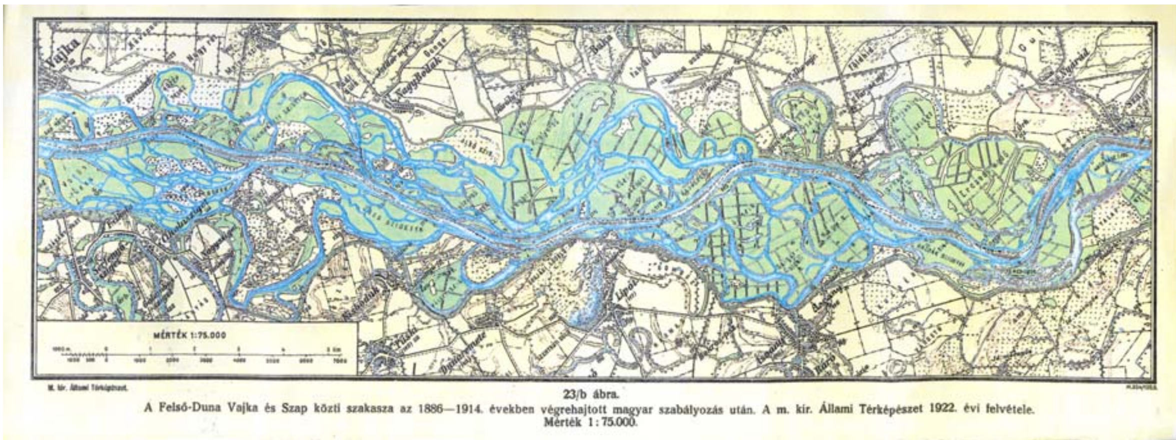


Figure 3-1 The Danube Section in the Szigetköz after the river regulation, 1922

It had already been observed in the first decades of the 20th century that the Danube bed was significantly degrading downstream of Bratislava, while it became aggraded in the oversized and straightened channels at many places in the Szigetköz and downstream of the slope gradient at Szap. The deposited sediment then continues to move further in the form of moving bars. Due to economic reasons the relocation of all the guiding dykes and embankments and the re-establishment of the meanders was practically impossible and, therefore *low-flow training projects* were started. On the one hand, this method narrowed the too wide main riverbed with a series of groynes (spur dykes), and, on the other it forced the flow of the stream and the drift line to small amplitude meanders within the banks of the straight sections.

Construction of the low-flow river training works were suspended during World War I and the maintenance of the existing structures was also neglected, resulting in the development of several new fords along the section. By the end of the war the main channel of the Danube had become a state border, thus, regulation and improvement projects on the river had to be carried out by Hungarian and Czechoslovak water management bodies jointly. In spite of improvements on the fords the rise of the riverbed level could not be eliminated, therefore, from the fifties both countries tried to establish and maintain the required depth of the navigation route by *dredging*. Although the rise of the main riverbed could be successfully overcome in this way the settling of the suspended sediment on the flood plain in flood periods could not be prevented, thus the peak flood levels kept on rising.

The volume of gravel dredged from the ford sections was quite small compared to the annual volume of bed load of the Danube at that time: 650,000 m^3/year estimated on the basis of measurements as entering to Hungary and the still remaining more than 100,000 m^3/year at Dunaremete (Bogárdi 1955). The ford material was primarily used for river training purposes, such as elevation of the embankments and backfill. As an impact of the interventions and the bed-load retention caused by the river barrages on the Austrian Danube, the bed load transport of the Hungarian Upper Danube section approached a dynamic equilibrium, and resulted in gradual filling of the main bed only at the locations where major slope breaks occurred.

Construction of a system of dams was considered as early as the 1940's. Between 1952 and 1955, 13 alternatives were discussed by the Czechoslovak experts and a further 12 by the Hungarian ones. Finally, the competent government agencies decided on a joint dam system in 1963. The relevant bilateral agreement on the implementation and operation of the Gabčíkovo-Nagymaros Dam System was concluded in 1977. In 1989, due to the increasing awareness of the environmental and ecological aspects and the intensifying protest against the dam system, the Hungarian Government suspended the project and launched an initiative to amend the bilateral agreement.

Such an amendment could not be achieved by negotiations. Therefore, the Hungarian Government proposed that the agreement be terminated, while the Federal Government of Czechoslovakia adopted a decision on the unilateral completion of the structures at Gabčíkovo, the implementation of which was started in January 1992. On the 9th of June 1992, the Hungarian Parliament repealed the bilateral agreement, while on the 24th and 25th of October 1992, the Czechoslovak party dammed the Danube at river-km 1851.75 and diverted it into the head race canal of the Gabčíkovo Hydropower Station. Thereafter, Hungary had no influence on the regulation of the discharge into the main channel. The dispute between Hungary and Czechoslovakia was submitted to the International Court of Justice at The Hague. In its decision of September 1997, the Court deemed both, the unilateral termination of the agreement by Hungary and the operation of the unilateraly diverted river by Czechoslovakia as illicit.

The various direct anthropogenic interventions as an overall view are shown along a time scale in Figure 3-2 and the chronology of river training works is summarised inTable 3-1.

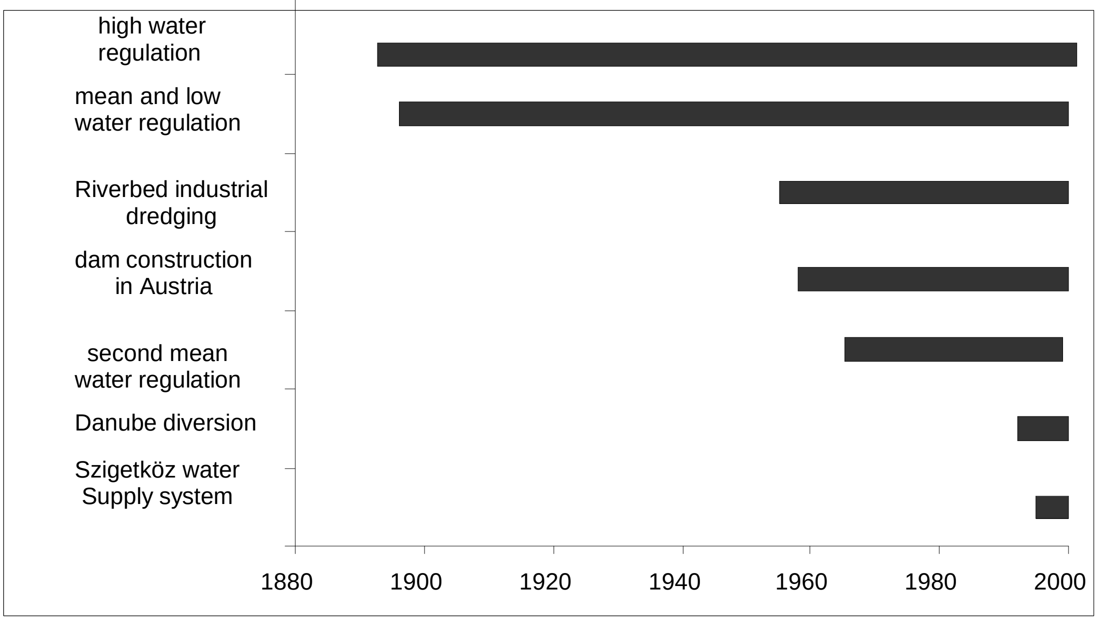


Figure 3-2 The chronological illustration of the most significant water management interventions directly forming the Szigetköz water system.

Table 3-1 Chronology of river training works

Between 1886 and 1896 the overall flow regulation of the Szigetköz Danube section was carried out with the aim of improving navigation possibilities and improving the passage of ice-floods. At this time the main channel was created with a width of 300-380 m. The banks of the main riverbed were stabilised with stone protection extending up to the mean-flow level, the footings of which were protected against under-washing by rock fill. More than 3 million m^3 of stone was used, in many places changing the composition of the bottom material (Károlyi 1973, Várday 1987).
Between 1892 and 1895 comprehensive flood protection work was carried out in the Szigetköz Danube section. The flood protection dykes protected 80% of the right-hand 375 km^2 floodplain from flooding. In the high water cross-section bounded by embankments the passage of the flood pulses accelerated, therefore the duration of flooding dropped.
Between 1886 and 1900 the majority of the drainage channels were built on the protected side. The drainage of rising water became a demand with the construction of the flood protection dykes. To facilitate this the streams and the earlier anabranches were connected together with channels, the total length of which was 157 km (with the later extensions this is now nearly 400 km). Weirs were constructed where the embankments were crossed and here, later on, pumping stations were constructed.
1888: Inflow to the Mosoni Danube was regulated by training works and later by the sluice of Rajka (1908). The sluice controlled the surface water supply from the Danube during the floods.
Between 1899 and 1940 low-flow regulation was accomplished by constructing cross-dykes, the further closing of side-arms and the extensive dredging of fords. These regulation works deepened the section of the main channel between Devin and Rajka and the scoured sediment deposited in the downstream sections. By the 1920s, the centre of deposition processes shifted to the section between Dunaremete and Ásványráró, and by the 1950s, to the section between Szap and Medve (Molnár 2004). Due to the continued rising of the riverbed, the guide banks and bank protection works became too short and the structures ensuring low-flow regulation were filled up. As a consequence of the weir construction in the branch systems the flow of water in the side-arms slowed down and the deposition of suspended sediment increased.
Between 1963 and 1983 a new comprehensive mean-flow regulation project was undertaken in the section between Rajka and Sap. The intervention became necessary owing to the rising of the riverbed due to sediment deposition. During the regulation work the upper intake weirs of side-arms were constructed for a water discharge rate of 2500 m3s-1, therefore the flushing of the branch systems was significantly restricted by the 1980s (by an annual average of 20%). With the reduction of the frequency of flow-through there was an increase in suspended sediment deposition at the upsteam end of the anabranches (Károlyi 1973, Várday 1987).
In the second half of the 20th century dredging was carried out in the Szigetköz section of the Danube in order to achieve gravel for industrial mass-production of concrete both in Hungary and Slovakia. The mass of gravel excavated annually exceeded the amount of bed-load transport of the Danube many times, causing a significant incision of the riverbed. For flood protection purposes, intensive dredging occurred in Bratislava. Dredging also occurred in the Austrian reach downstream of Vienna, to improve navigation conditions.
From the 1980s the sediment retention effect due to upstream dredging and the barrages constructed in the Austrian section of the Danube contributed to the riverbed incision process. Approximately 30-40% of the suspended sediment is deposited by the Austrian dams, and they retain the entire bed-load (Rákóczi 1993). From the middle of the 1970s the riverbed in the Szigetköz section of the Danube deepened on

average by 3 cm/year as compared to the previous riverbed rising rate of 1.5-8 cm year-1. In recent decades as a result of the local dropping of low-flow water levels in excess of 1.5 metres the surface connections between the active floodplain branch systems and the main riverbed of the Danube have become restricted.
In 1992 when the Gabčíkovo barrage was put into operation some 80% of the discharge of the Danube was diverted into the 29 km long bypass canal. As a consequence of this, the water level in the river reach between Čunovo and Sap dropped by 2-3 m within days and a significant proportion of the side-arms dried out. In the following two years the flow of water practically stopped in the active floodplain branches which were closed off from the main riverbed.
In 1995, an underwater weir was constructed in the main riverbed of the Danube at Dunakiliti with the aim of providing water for the floodplain side-arm system via gravitation. The amount of diverted water using the weir gates at Dunakiliti can be varied between 40-130 m^3/s. The majority of the water discharge arriving through the Čunovo reservoir seepage canal provides the water for the Mosoni-Danube. It is partially from this system that the water for the side-arms and canals of the protected side comes. In order to make the active floodplain water recharge more flexible a drainage facility was established at the lower confluence of the Cikola-branch system in 1998. The facility also includes a fish ladder, which creates a direct passage between the main riverbed of the Danube and the floodplain side-arms.

The effect of the various river regulation interventions can also be observed in the water regime. The gauges of Dunaremete and Gönyű have the longest standing set of data in the region, stretching back more than 100 years. At the end of the 19th century the impact of flood protection measures and, the construction of flood protection dykes can be demonstrated on the hydrological behaviour of the river. The incoming sediment, which was spread out earlier over the entire region of the Szigetköz and Zitny Ostrov, was subsequently seen as filling up the unprotected land between the dykes rapidly, resulting in the growth of low, mean and high flow levels alike.

3.2. History of land use

3.2.1. Agriculture

In the Middle Ages the Szigetköz floodplain mainly covered with forest and meadow was most suitable for extensive animal stock keeping. The frequent floods did not allow extensive arable farming. The earliest written records of the local extensive stock keeping originate from the 13th century. The villages were established on the higher areas, in forest clearings and meadow breaks. The houses in the settlements stood on island rises or on the highest points of the floodplain. The villages were surrounded with zones of garden, orchard, arable land, meadow and forest.

The comprehensive river regulation carried out at the end of the 19th century fundamentally changed the farming in the Szigetköz. Stock keeping became more intensive, and the practice of keeping the animals in stables gradually spread. Fallow land and rotation farming disappeared being replaced by crop rotation. Arable farming became possible and increasing areas were involved in cereal farming. The favourable water conditions of the soils made a relatively high level of production security possible. In the 1980s 91% of the arable land received herbicide through land-based mechanical spraying. Nearly 30% of the arable land was affected by plant protection spraying carried out during the production period. The artificial fertiliser active agent amount used annually was on average 120 kg/ha N, 90 kg/ha P, and 157 kg/ha K (MKK, 2003).

At the end of the 20th century with the rearrangement of the ownership relations the farming structure also changed. Free market aspects coming to the foreground influenced the planting structure and the use of artificial fertiliser, etc. Stock keeping lost a great deal of significance since animal production using intensive methods is not competitive on the European markets. At present there are 42 business associations, 105 sole traders, 1130 primary producers and 15 cooperatives dealing with agriculture in the Hungarian part of the Szigetköz.

3.2.2. Forestry

Forest management was not carried out in the Szigetköz for a long period. The human population of the region gained their wood requirement from the floodplain forests. The remaining trees reproduced themselves in a natural way.

Intensive forest management started in the 1920s on the then large estates of the Hungarian side. New forests were established using improved propagation material giving a greater yield in the place of the natural forests. In the 1950s, the willow was the dominant tree in terms of the area covered, and hardwood deciduous stands and domestic stands of poplar covered significant areas. At this time improved varieties of poplar started to be planted to a greater extent. The popularity of the improved poplar varieties remained until the 1980s, at which time they covered 68% of the forest areas in the Hungarian part of the Szigetköz (Limp 2007). The natural forest communities had been significantly suppressed. The willow-poplar-alder (*Saliceto-Populeto-Alnetum*) groves, which demand a significant variation in water level and lower floodplain locations, can now almost no longer be found in their original form. Due to the changed habitat conditions the alder marsh forests (*Alnetum glutinosa*) have completely disappeared, and the elm-poplar grove forest (*Ulmeto-populetum*) hardly occurs at all. Today the elm-ash-oak grove forests (*Ulmeto-Fraxineto-Roburetum*) can only be found in small areas and in artificial form.

In the 1990s, as a result of a conceptual change in forestry, there have been endeavours to set up near-natural forests. This has not changed the earlier conditions spectacularly, but renewals have taken place using naturally native tree species in a one hundred hectare range. The hybrid poplar woods covered 61% of the forest areas of the active floodplain in Hungary in 2006 (Limp 2007, Table 3-2).

Table 3-2 Forest types and age distribution by area (ha) in the active floodplain of the Szigetköz section of the Danube in 2006 (Limp 2007).

forest / age	1-10	11-20	21-30	31-40	41-50	51-60	61-	Sum.	%
oak	36	5	--	--	3	--	1	45	1,5
ash	13	15	1	--	4	1	13	47	1,5
false acacia	59	13	4	4	4	2	--	86	2,8
hardwood	2	4	--	--	--	--	--	6	0,2
hybrid poplar	570	558	454	182	66	14	3	1847	60,0
native poplar	82	99	78	42	23	12	1	337	10,9
willow	11	179	238	93	13	2	3	539	17,5
softwood	2	--	2	--	--	--	--	4	0,1
pine	--	--	--	--	4	--	--	4	0,1
no wood	--	--	--	--	--	--	--	165	5,4
%	26	30	27	11	4	1	1	100	--
Total:								3 080 ha	100

4. Assessment of irreversible changes and constraints, pressure and impact analysis

Determination of irreversible changes is an important practical question from the point of view of the delineation of achievable ecological objectives. Those changes of the ecological system are deemed irreversible that cannot be restored even after human intervention has been terminated (e.g. the extinction of certain species). Constraints, on the other side, are those anthropogenic pressures which cannot be terminated due to socio-economic circumstances (e.g. flood protection).

4.1. Hydrological and hydro-morphological dynamics

4.1.1. Impacts of forestry

Deforestation of large areas in the Danube basin for farming in early human history led to modifications in discharge regimes and increased soil loading of the river. The increased transport and deposition of silt caused changes in channel and floodplain morphology and river habitat destruction (Petts et al. 1989, Kern 1994).

4.1.2. Climatic change

The climate of the Earth has never been stable and the prehistoric changes in climate were clearly natural in origin. However the causes and rate of present-day and future changes in climate are notably different. The causes are now dominated by the human disturbance of the atmosphere and the rate of warming already exceeds anything experienced in the last 10,000 years. Due to increasingly intensive global warming induced by the change of the carbon cycle of the atmosphere and the greenhouse effect, the frequency of extreme weather conditions has been increasing (drought, flash-flood rainfall, windstorms) from the beginning of the 20th century.

Estimation of climate change impacts on European rivers is difficult and inherently uncertain, in particular when analyzing extreme events. It is difficult to distinguish between the changes in flood frequency that are climatically induced and those that are due to human activity. Possible increases in the variability of daily precipitation may lead to a significant rise in flood frequencies (Lehner at al. 2006).

4.1.3. Impacts of river engineering

The dykes bordering the floodplain permit significantly less space for the flood pulses and the sediment carried by the river to be spread out. Evidence is given by the continuous increase of the high water levels in the 20th century. With the increase of the height of the waters covering the dry land areas the extent of shallow habitats along the banks that warm up quickly has been reduced. The allogenic processes have come more to the foreground in the succession of the aquatic habitats. The passing of floods has accelerated, and the peak levels of the flood waves have increased the frequency of disturbances in general.

The Danube was declared an international navigable route. In 1948 by signing the Treaty of Belgrade Hungary undertook the obligation to *ensure the conditions of navigability* determined in the recommendations of the Danube Comission. Today on the section above Szap navigability is ensured by the power canal of the Gabčíkovo dam, but between Szap and Gönyű the navigable route fulfilling international regulations can only be sustained by low-flow and mean-flow regulations. Generally interventions to improve navigability contribute to the bed deepening process that can be observed in the river section below Szap.

4.1.4. Impacts of the sequence of upstream dams

The *sediment retaining effect of the series of dams* built on the Austrian section of the Danube after 1955 resulted in significant morphological effects in the Szigetköz reach of the Danube. The amount of suspended sediment carried annually varies between wide limits (1-10 million tons year^{-1}) depending on the annual flow regime. Since the beginning of the 1950's, on the basis of a series of data relating to three decades, it can be clearly indicated that from the 1970's the amount of suspended sediment carried annually reduced significantly (Láng et al. 1993), which has been accompanied by the increasing of the transparency and light transmissibility of the waters. This may improve the ability of the plants to photosynthesize, increase the level of aquatic primary production and autogenic succession of the aquatic habitats.

According to the estimates the annual volume of sediment load arriving from the Upper Danube to the river section below the Devin Gate was 400,000-500,000 m^3 (Károlyi 1962), 150,000 m^3 of which was deposited on the main arm between Rajka and Szap, while 50,000-60,000 m^3 was deposited on the section between Szap and Medve. The remaining part accumulated in the branches or got worn away. In the last decades before the diversion of the water, due to the dams built on the Austrian river section and the industrial bed dredging performed in the region Bratislava Pozsony no significant sediment load arrived any longer to the Rajka section (Láng et al. 1993). Large-scale industrial dredging was also performed on the common Hungarian-Slovakian section (see Table 3-1). Since the 1960's the reducing mean and low flow levels indicate the termination of the sediment load supply, the increase of sediment moving ability of flow and the embedding of the riverbed. The sinking of the main bed was not observed in the branches on the active floodplain, therefore branches that used to be mostly through-flowing received only seepage water during most of the year. Due to the significant reduction of the amount of sediment load, bar and island formation became suppressed, which also influences the succession process of aquatic habitats.

4.1.5. Impacts of dredging

Due to certain economic political decisions at the end of the sixties, Czechoslovakia and Hungary began the mass-housing development (panel construction) programme simultaneously whilst at the same time the mass-production of concrete slabs for other purposes was commenced. All this generated a pressing need for mining extremely large quantities of gravel. According to a statement made in 1994 (Delft Hydraulics, F.R.Harris and VITUKI, 1994) in the section of the Danube between 1811 and 1702 rkm a total of 64 million m^3 gravel was extracted from the Danube bed by dredging by the two neighbouring countries in the period 1968 - 1991. The re-supply of this gravel volume would have required a bed-load transport of an average annual volume of 2.8 million m^3 arriving from upstream over something like a 23 years period. According to the Slovak bed-load data from 2002 less than a tenth of this amount is actually transported to the Danube section at 1795 rkm. The part extracted by the Hungarian party can be estimated as 29 million m^3 and approximately 25 million m^3 of this accounts for industrial dredging. Over-dredging of this extent was permitted by the local water management authorities in both neighbouring countries.

In terms of the gravel resources of the Danube bed, the extraction of the 64 million m^3 bed material can be judged as over-exploitation especially when the volume of stream bed material dredged from the section upstream of Bratislava is added. In fact, on this section which is under Slovak sovereignty in its entirety, between 1860 and 1870 rkm, a total of approximately 7.5 million m^3 gravel was dredged from the Danube bed in a 16 years period and two thirds of this amount, 4.8 million m^3 from a stretch of merely 2 kilometres long (Topolská and Klúcovská 1995). The total dredged gravel volume can only be recharged by the stream over a period exceeding 50 years. However, the transport of gravel bed load has dropped to near 200,000 m^3/year since the Austrian section of the Danube has been canalized by a series of river barrages. The amount of bed load arriving from upstream has somewhat increased since the Austrian water management bodies drop approximately some 170,000 m^3 gravel into the Danube channel downstream of Vienna following the completion of the barrage at Freudenau (1993). It is to be noted that the dredging section upstream of Bratislava is at the limit of impoundment of the Čunovo Barrage System built since then. In other words it could be reckoned that the majority of the gravel bed load still arriving from the Austrian section of the Danube will be accumulating there.

4.2. Landscape structure

4.2.1. Impacts of river engineering

The flood protection dykes constructed during the high water regulation carried out at the end of the 19th century divided the 375 km^2 Szigetköz floodplain into an active floodplain and a protected area. The extent of the inundated areas decreased by nearly 80%, which resulted in the fragmentation and destruction of numerous characteristic habitats of the river-floodplain system in the Szigetköz. The direct connection between the active floodplain and the protected side of the floodplain was terminated and their development continued in different directions.

The former river branches and abandoned oxbows on the protected side have on the one hand lost their direct connections with the Danube, and on the other hand many of them were buried. The water supply of the abandoned branches was ensured basically by infiltrating groundwater and precipitation. The paleopotamon habitat features proceeded in the old branches in the 20th century (until the 1990's). Groundwater infiltration varied according to the regime of the Danube. The majority of the old branches was connected to the internal water drainage system and used for drainage. The water system became fragmented, sluices and closing dykes restricting longitudinal connectivity. The interactions between the aquatic and the terrestrial habitats became limited as a result of the narrow range of the water level fluctuation.

4.2.2. Impacts of land use

A considerable part of the floodplain forests was cut over and altered to grass-land in the Middle Ages. The proportion of the forested areas has increased since the 19th century but most of the recent forests are artificial plantations. Nutrients getting into the ground water from neighboring agricultural areas contributed to the eutrophication of water bodies. On the areas on the protected side the extensive agricultural areas are characterized by arable land cultivation including regular chemical weed control, the spraying of pesticides and the use of artificial fertilizers. The major impact of agriculture comes from the diffuse discharge of dissolved materials in run off or seepage drainage waters (non-point source pollution). Such discharge increased where the land is cultivated. This input is intermittent in its intensity and depends upon the rainfall patterns and the seasonal cycle of agricultural activity.

4.2.3. Impacts of pollutants and plant nutrients on water quality

Environmental pollution is a form of the deterioration of habitats that cannot be directly perceived. Human alterations of the nitrogen cycle have greatly increased the transfer of nitrogen through rivers to estuaries (Vitousek et al 1997b). The quality of the Danube's water, as it enters Hungary, has consistently deteriorated in terms of nitrate and total dissolved solids (Hock and Somlyódi 1990).

4.3. Flora and fauna, biodiversity

4.3.1. Climatic change

Rising temperature and the changing flood regime and other aspects of climatic change are starting to have an impact on biodiversity in the Middle Danube basin. Due to global warming the average temperature of large rivers is also increasing which affects the areas populated by aquatic flora and fauna, including certain fish species. Along the Danube as an ecological corridor the obvious signs of flora and fauna changes related to global climate change can be observed. The suppression of the natural northern biota elements towards the arctic region can be expected, as well as the further successful settlement of invasive species of Ponto-caspian origin. Today no consensus has been achieved among researchers in respect of the assessment of the rate and biological effects of global climate change.

Climate change may be an important factor in the spreading of non-native biological invaders. The Danube is an important ecological corridor of native biota, and on the other hand an important spreading route for alien organisms. The rapidly changing climate might favour species that can extend their ranges quickly or that can tolerate a wide range of climatic conditions. Invasive species tend to be generalist, which may increase their success and threaten some native species. Biological invasion is one of the most important drivers of global biodiversity loss (Vitousek et al. 1997a).

Since the beginning of the 20th century, occurrences of 19 non-native fish species have been observed and 13 of these have a permanent population in the Szigetköz region of the Danube. Since the beginning of the 1990's four Ponto-Caspian gobiid species, the bighead goby (*Neogobius kessleri*), the round goby (*N. melanostomus*), the monkey goby (*N. fluviatilis*) and the racer goby (*N. gymnotrachelus*) have appeared and multiplied. The effects of invasive alien species on native fish populations and changes of biotic interactions (competition, predation) have not been investigated along the Hungarian section of the Danube.

According to the results of the fish monitoring of the Hungarian Danube Research Station, the native population of bullhead (*Cottus gobio*) disappeared in the Szigetköz section of the Danube after the coming in of the *Neogobius* species. The relative density of bullhead exceeded 1,000 ind./km along the rip-raps of the main channel of the Danube at a sampling site at Dunasziget in 1993. The density of the species declined in the 1990's and it was not observed in the area from 2003. Bullhead is known for its sensitivity to temperature, however most probably it was affected by biotic interactions with the *Neogobius* species.

Invasion of several alien plant species has been established in terrestrial habitats of the Szigetköz region. Common non-native herbs are *Aster lanceolatus, Impatiens* *glandulifera, Impatiens parviflora, Solidago gigantean*. Alien trees are for example *Acer negundo* and *Ailanthus altissima.*

4.3.2. Impact of hydrological changes

The damping of seasonal and interannual variability of the flood regime by the upstream dams has altered the natural dynamics in ecologically important flows. Alteration of the flow regime can be characterized by the frequency of events when the daily change of the water level exceeds 50 cm (Figure 4-1).

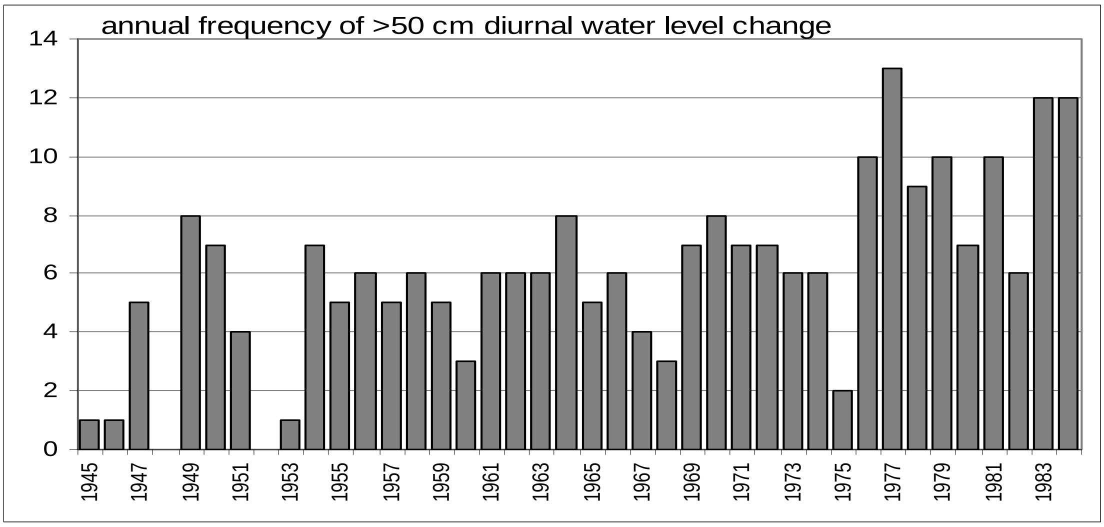


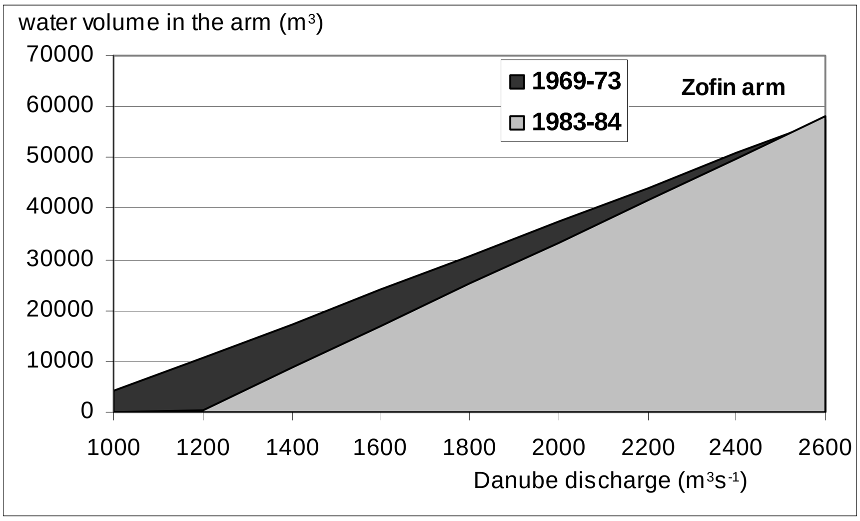
Figure 4-1 Annual frequency of events at Dunaremete when the diurnal changes of water level exceeded 50 cm.

The occurrence of high diurnal variations shows a rising trend in the second half of the 20th century. The increasing frequency of this hydrological disturbance may result in a loss of biodiversity in the Aquatic Terrestrial Transition Zone.

4.3.3. Impacts of habitat alterations

From the end of the 19th century, after the complex regulation of the Szigetköz section of the Danube, bed aggradation became more intensive in the floodplain side-arms, than in the main arm. The upstream blocking of floodplain side-arms affected their hydrological regime and sediment transport. According to this habitat alteration, occurrences of several rheophilic species were restricted only to the main arm. Deposition of fine sediment in the branch system eliminated a number of spawning sites of the lithophilic fish species.

For example, morphological characteristics and the fish community of the Zofin arm in the Zitny Ostrov floodplain were investigated in two periods: from 1969 to 1973 and from 1983 to 1984. Figure 4-2 demonstrates the calculated volume of water in the side-arm as a function of the Danube discharge. In the second period the mouth of the side-arm was blocked by an alluvial plug and its volume decreased significantly by the low discharge of the river. The change in composition of the fish community was considerable. The number of fish species decreased from 22 to 16, the lithophilic spawners disappeared. The fish biomass decreased from 292 kg ha^{-1} to 189 kg ha^{-1} (Holčik 1990)



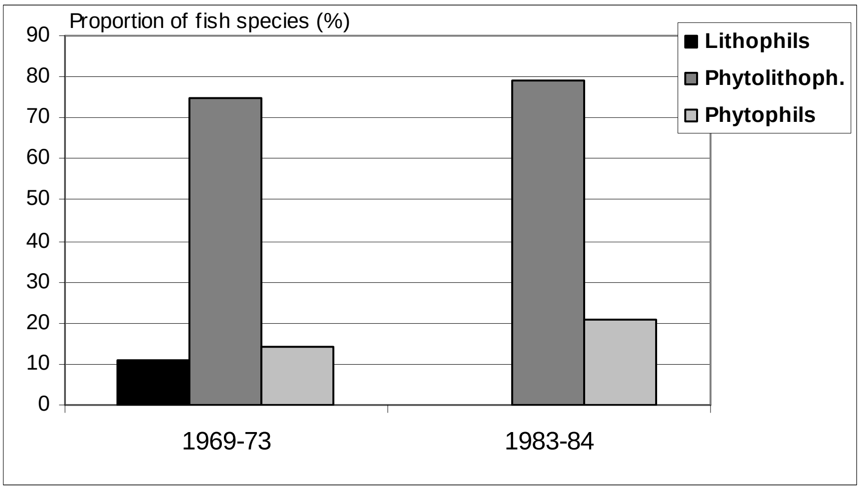


Figure 4-2 Calculated volume of the water in the Zofin arm as a function of the discharge in the Danube in 1969-1973 and 1983-1984 (upper) and changes in composition of the fish community (data from Holčik 1990)

The slow flowing and temporary stagnant side-arms provided favourable conditions for the high production of phyto- and zooplankton. Branches were important feeding and refuge area for juvenile fish assemblages, and fish production of the floodplain side-arm system was one of the best along the Hungarian section of the Danube.

In the water bodies of the flood-protected area mostly the features of the paleopotamon type aquatic habitat became characteristic in the second half of the 20th century (until the 1990's). Due to the general changing of habitat conditions and the reduction of the frequency of natural disturbances the pristine composition of communities has changed, most rheophilic species have disappeared and the occurrence of limnophilic flora and fauna elements has increased. Abundance of some threatened limnophilic fish species (*Umbra krameri, Misgurnus fossilis, Carassius carassius, Tinca tinca*) was high before the 1990's. As a result of ground water seepage rich benthic communities were able to develop in numerous bed sections in the hyporheic zone.

4.3.4. Impacts of navigation

In rivers used for navigation the wave actions and turbulence caused by the passage of ships damage the banks and fringe vegetation. The erosion of the banks re-suspends sediment leading to blanketing of the substrate and loss of the productive ecosystems. Increased loads of suspended soil reduce transparency and light penetration and overall primary productivity. In addition, the physical disturbance by the passage of ships and the noise created may disturb feeding and breeding behaviour. This may be significant where the passage of vessels perturbs permanently the spawning and nursery habitats which are important in the maintenance of fish populations.

The improving of shipping possibilities and navigation promotes the spreading of invasive organisms. Passive dispersal of non-native gobiid fishes by ships is known (Moyle 1991, Ahnelt et al. 1998).

4.3.5. Impacts of pollution and eutrophication

In stagnant water conditions, the increased concentration of nutrients leads to increased levels of production and shifts in species composition follow sustained eutrophication. The enhanced plant growth may be of relatively small numbers of submerged or emergent macrophytes (*Elodea nuttallii, Potamogeton crispus, Nuphar lutea*), floating-leaved plants (*Spirodella polyrhizza*) or diatoma, *Cyanobacteria, Dinoflagella and Eugleonid species*. The particular species that predominate will depend on the original diversity present, but essentially the effect is one of species impoverishment with a large biomass of a very few species. Habitat provision afforded by plant communities is a major influence on the diversity of macroinvertebrates. The eutrophic water bodies become impoverished in their macroinvertebrate fauna and the changes control the composition of the fish community. The eutrophication can lead to local loss of aquatic organisms throughout periods of lethally low dissolved oxygen.

Pesticides can be washed out from soils and thus pass into the drainage waters and severely reduce or kill aquatic plants and animals. Impacts of agriculture on aquatic biota have not been investigated in the Szigetköz region.

4.3.6. Impacts of fishery and recreation

Over-fishing probably played a primary role in the decay of certain sturgeon species in the Middle Danube. Sturgeon catches began to decline from the 16th century and in the 19th century sturgeon were only rarely caught in the region (Kriesch 1876, Károli 1877, Herman 1887, Khin 1957, Hensel és Holčik 1997, Guti 2008). Excessive fishing reduced the number of anadromous sturgeon not only on their spawning area in the region of the Kisalföld, but also on their 2,000 km-long migratory journey from the Black Sea. Presumably some species of anadromous sturgeon used to populate the Danube forming a meta-population, which means individuals of different genotypes of a species formed several sub-populations. Spawning grounds of the sub-populations were separated from each other. The individuals of the different genotypes mostly migrated back to their place of birth to spawn. The fishing mortality rate of the genotypes migrating the long distance from the Black Sea to the upper sections of the Danube could be almost one order of magnitude higher than that of the sub-populations reproducing in the Lower Danube. In the 19th century, when the annual sturgeon catch was near 1,000 tons along the Lower Danube, the great sturgeon were rarely caught in the region of the Szigetköz. The dams built at the Iron Gate (1970, 1984) resulted in an additional decay of the remaining populations of anadromous sturgeon species along the Middle Danube. Great sturgeon (*Huso huso*) and stellate sturgeon (*Acipenser stellatus*) can now be regarded as extinct fauna elements in the Szigetköz section of the Danube, their last representatives were observed in the region more than fifty years ago.

Sport fish populations appear to be more threatened by habitat loss and degradation than by overfishing. Releasing hatchery-raised fish is an approach used to maintain sport fish stocks in several waters of the Szigetköz area without any consideration of its effect on native fish populations. The most common populated fish species is the carp (*Cyprinus carpio*) (Guti 1993).

Table 4-1 Summary of the most important irreversible changes in the Szigetköz region

- Alteration of hydro-morphological dynamics of the Danube:
  – Reduction of bed load transport by upstream dams;
  – Accumulation of fine sediment in floodplains;
- Changes of allogenic and autogenic processes, habitat succession and diversity;
- Human alterations of the nitrogen cycle and increasing level of plant nutrients have caused changes in the composition and functioning of floodplain ecosystems;

• Changes of biodiversity:
– Extinction of two native species (*Huso huso, Acipenser stellatus*);
– A number of native species became threatened;
– Spreading of several non-native invasive species.

Table 4-2 Summary of the most important constraints in the Szigetköz region

• Flood-protection
• Diversion of the Danube due to the operation of the Gabčíkovo Hydroelectric Power Station;
• Maintenance of conditions of navigability (bypass canal and downstream of Sap);
• Land use:
– Forestry;
– Agricultural activity in the protected side of the floodplain.

4.4. Pressure and Impact Analysis

According to the Water Framework Directive a pressure and impact analysis has to be conducted for all water bodies. In the Hungarian Danube Section four water bodies have been designated for the River Basin Management planning. As far as the present study is concerned one section of these should be considered: the Szigetköz area (water body No.249, rkm 1790-1852).

The significant pressures and impacts in the Szigetköz area according to the Report on the Significant Issues[11] are summarised as follows:

4.4.1. Water regime disadvantage due to the unilateral diversion

Since the operation of the Gabčíkovo Hydropower Plant started 80 % of the average water discharge of the Danube goes into the bypass canal causing major changes in the

[11] Republic of Hungary (2005): Report according to the Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy on analysis of the characteristics of the Hungarian part of the Danube River Basin District, and review of the environmental impact of human activities and economic analysis of water uses. Reporting deadline: 22 March 2005

water regime of the main Danube channel and in the Szigetköz side-arms. The temporary water supply system can only provide a limited quantity of water for a restricted part of the Szigetköz and the previous dynamic character of the water regime is still missing. The periodic flooding of the area can be provided only partly through artificial methods.

The lack of water quantity is causing the following unsolved problems:

- the rehabilitation of the main riverbed of the Danube has not been resolved;
- the temporary water supply system is effective only as far as Ásványráró;
- regular flooding of the floodplain is only partly ensured;
- the water supply system of the protected area is not solved;
- the hydrobiological character of the former wetland system has been completely transformed in order to avoid desiccation;
- the hydrobiological character of the river has been completely transformed;
- loss of important spawning places occurs;
- water abstraction possibilities for mainly irrigation purposes have decreased.

4.4.2. Lack of longitudinal continuity, changes in sediment transport

The Čunovo barrage is the basic obstacle of the longitudinal continuity of the upper Danube section. The barrage was built without any adequate facilities to provide access for the migrating fish species.

The diversion caused a significant lowering of the water level in the Danube River and as a result most of the side-arm systems have dried out. For the sake of the temporary water supply an underwater weir was constructed within the framework of an Agreement between the Republic of Hungary and the Slovak Republic on the temporary mitigation measures which can provide a water supply for the Upper and Middle Szigetköz area, however, at the same time the lower ends of the side-arms had to be closed. The additional structures at the closures which would have provided passages for aquatic animals have not yet been completed in all places.

One of the main pressures is to provide a passage for aquatic species all over the branch system and in the main Danube riverbed to provide access to spawning and breeding grounds.

The Čunovo reservoir has caused a significant impact on the sediment transport of the Danube as a considerable part of the remaining bed load is retained there. At the same time the changes in the water velocity have caused extended sedimentation in the river branches.

4.4.3. Lack of lateral continuity

The extensive flood protection measures and the changes in land use have also significant effects on the lateral continuity of the river system. The floodplain has been transformed into agricultural land behind protecting dykes and so cannot fulfil its original role as a functioning floodplain. Parts of the old floodplains were cut off from the periodic water supply and/or obstacles were created in the natural runoff of waters causing excess water problems.

The land use change, widening of the flood area, dyke replacing or breaching, reconnection of wetlands, former side-arms and oxbows have to be investigated taking into account the protected areas as well.

4.4.4. Groundwater resources at risk

There are five operating and six potential sites for groundwater abstraction in the Szigetköz area. Due to their hydrogeological relations the groundwater sources are vulnerable. According to the expert evaluation groundwater sources are at risk of nitrate pollution and of decreasing quantity.

In some parts of the Szigetköz area significant changes can be monitored concerning the subsurface water level decrease. Partly it can be improved by the temporary artificial water supply system but the effect of the water supply is restricted. The investigation of the relationship between the decrease of the groundwater level and the groundwater dependent ecosystems is also important.

4.4.5. Pollution

Significant point pollution sources will be eliminated by the implementation of the provisions of the Urban Waste Water Directive. The effects of the existing and planned WWTP's should be taken into account. To prevent increased nutrient pollution the tertiary treatment possibilities have to be investigated as well. Existing discharge limits for the operating WWTP's should be revised according to the vulnerability and the pollution load of the receiving water body.

Pollution from diffuse sources markedly influences the water quality of the Danube. It is important to note that not only are the general conditions of the river and the biota in danger because of the water quality but also the drinking water supply along this section of the river. The implementation of the Nitrate Directive and best environmental agricultural practice will also decrease nutrient pollution from agricultural lands.

4.4.6. Ecological end biodiversity issues

The significant changes in the flow and sediment regime accompanied by the decreasing water level in the main channel and side-arm closures have resulted in severe changes to the natural wetland system. Rehabilitation measures need to restore hydromorphological processes that are essential for the evolution of typical wetland habitats with associated biota which had been characteristic for the Szigetköz area. The functioning of the wetland ecosystem largely depends on the flow and sediment dynamics. The unique diverse pattern of habitat types is a prerequisite to the natural biodiversity of the region. The original flora and fauna has been changed from aquatic or aquatic-related species to more terrestrial forms decreasing the biodiversity with the increase of invasive species. The unfavourable changes have to be evaluated to see whether they are irreversible changes or if the original can be restored. The ecological function of the main channel of the Danube has to be restored.

4.4.7. Climate change

The long term impact of climate change also has to be taken into account. It can strongly influence the available water quantity for water abstraction and the flood regime.

4.4.8. Increasing flood level

Both the floodplain siltation and the water conducting capacity deterioration of the Danube river bed resulted in increasing flood levels according to the results of discharge measurements and water level recording in the course of the last floods. The newly developed situation fails to ensure the expectable level of safety. The structure of the flood protection system has to be modified: more space has to be provided to the natural floods by the widening of the floodplain areas. The discharge capacity of the original Danube river bed should be maintained in order to provide a possibility for the discharge of the excess water exceeding the total discharge capacity of the bypass canal.

4.4.9. Navigation, tourism, recreation

As the navigational transport route has been shifted into the bypass canal of the Gabčíkovo Hydropower Plant there is no need for commercial navigation in the original river bed. The Governmental Delegations of the Slovak Republic and the Republic of Hungary on the implementation of the Judgment of the International Court of Justice at the Hague in the case concerning the Gabčíkovo - Nagymaros Project have agreed that the traffic of big ships must be handled on the power canal in the section of Bratislava-Szap by approving the report of the Expert Working Group on River Management, Environmental Protection, Energy and Navigation (2006)[12]. According to this Report *"the traffic of small ships (rowing boats, kayaks, canoes, and small engine-powered yachts) may be allowed in the original Danube riverbed and in the side-arm system. The issue of which side-arm will be open or closed for such traffic must be decided on the basis of the aspects of tourism and, in particular, nature conservation. For example, engine-powered ships may be denied access to certain by-channels of nature conservation importance."* The Danube riverbed and the branch system are also used for recreational shipping. It is important to establish a concept for the future recreation in the area since the Szigetköz is still one of the major tourist destinations of the region. In this concept environmental objectives of nature protection and targets of tourism and recreation have to be reconciled. Taking into account the sustainable utilisation of the natural values, the various recreational possibilities should be preserved or improved during the implementation of the Programme of Measures of the River Basin Management Plan.

4.4.10. Land use

The change in the land use patterns in the region heavily modified the retention and storage capacity/potential of the floodplain and the sediment regime. Agricultural utilization has to be restricted in the floodplain area to improve ground water recharge and the storage of floodwater in the alluvial aquifer. The drop of the groundwater level is also influencing the moisture content of the arable soil which resulted in the decline of the farming production rate in a significant part of the region. The compensation for the lack of water has to be taken into account. Investigation should focus also on the impact to forestry due to the water quantity and groundwater level decreases.

4.4.11. Effects of future infrastructural projects

Future infrastructural projects should be conducted in a transparent way using best environmental practices and best available techniques. Impacts on, or deterioration of, the good status and negative transboundary effects to be fully prevented, mitigated or compensated.

[12] Agreed Minutes of the negotiation of the Governmental Delegations of the Republic of Hungary and the Slovak Republic, held on 5 October 2006 in Bratislava

5. Assessment of deficiencies of the present situation

5.1. Hydrological and hydro-morphological dynamics

5.1.1. Sediment regime

The opening of the Gabčíkovo by-pass canal in 1992, the construction of the Čunovo Barrage and the Gabčíkovo Hydropower Plant and its gradual putting into operation, respectively, altered water flows and bed load transport of the river dramatically and radically in the section between Szap and Szob. Detailed (distance of cross-sections of 100 m) bed surveys were carried out on the Upper Danube between Rajka and Vének since the diversion of the river through to the present day, accompanied by repeated sampling of the bed material in the VO sections (Rákóczi and Sass 1996). The results show that the so-called “maintenance flow” discharged into the Old Danube, i.e. in the original main bed, of an amount of 200-600 m^3/s is unable to break up the armoured gravel bed established at the time of diversion, it rather locally rearranges the overlying sand material. Namely, a significant part of the sandy gravel material in the bed and the flood plain loosened in the course of the construction of the Čunovo Barrage system was drifted into the Old Danube by a significant flood wave passing by following the diversion (in November, 1992). The bed load movement between Rajka and Szap in the main bed (Old Danube) consisted in the past decades of transporting fine gravel and sand material on the surface of the *immobile bed cover* by the part of the flood waves exceeding 4,000 m^3/s and discharged here by the Čunovo Barrage. This bed load movement, very weak compared to the pre-construction situation, is also limited in space, due to the very short period of competent flow levels (usually a couple of days only).

In addition the greater part of the main bed between Rajka and Szap, which is fed artificially by the “maintaining” discharge, is further narrowed and the near-shore strips became covered by a thick, dense and perennial vegetation. In addition, the water flow returning to the Danube bed from the tailrace canal of the Gabčíkovo plant impounds the ‘maintenance flows’ up to approximately Dunaremete (1826 rkm) in the Old Danube.

The main side-arms of the Szigetköz branch system have shown remarkable siltation since the diversion of the Danube (see Figure 5-1). The Bagomér branch within the area impounded by the Gabčíkovo tailrace canal was filled by 346,000 m^3 silt up to 2005. The average sediment thickness in that branch is 60 cm, the upper third of which consists of fine mud fractions. The branches were once silting up at a moderate rate only, because the natural flood waves of the Danube flushed the arm system and the islands between them several times annually. The flow velocities since 1992 depend on the operating schedule of the Čunovo Barrage. The artificial flow regimes are characterized by the sudden opening of the weirs at the beginning of the flood waves, therefore the inundation of the Szigetköz usually occurs with dramatic rapidity. After the end of the flood waves, the weir gates are also closed down suddenly in order to reduce water loss from the reservoir. This operation implies water flowing quickly and at a high speed from the branches, occasionally damaging the structures of the Szigetköz water distribution system.

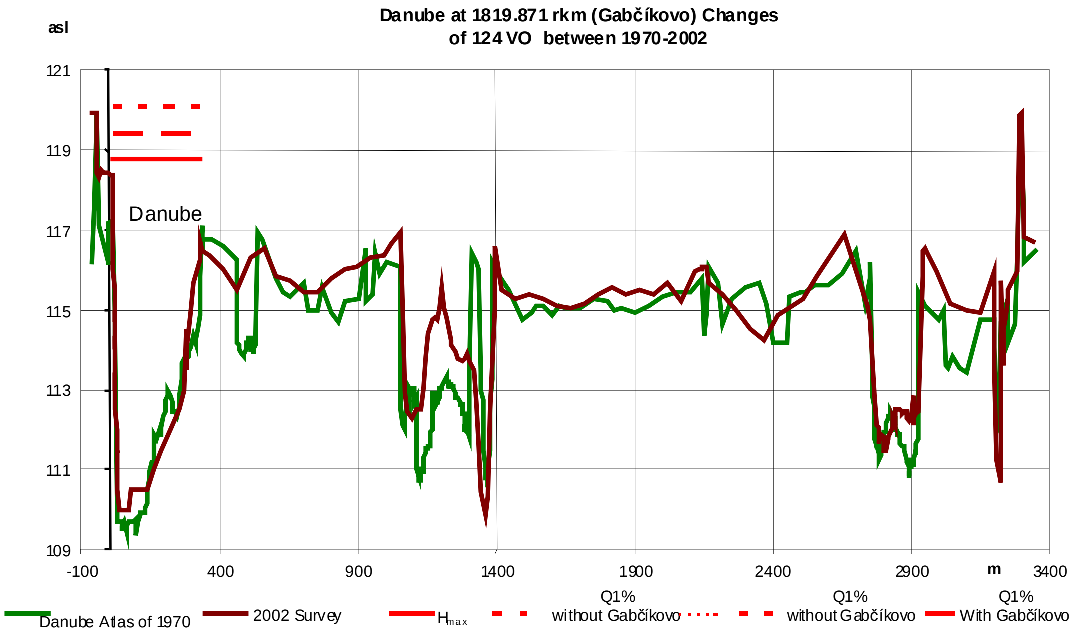
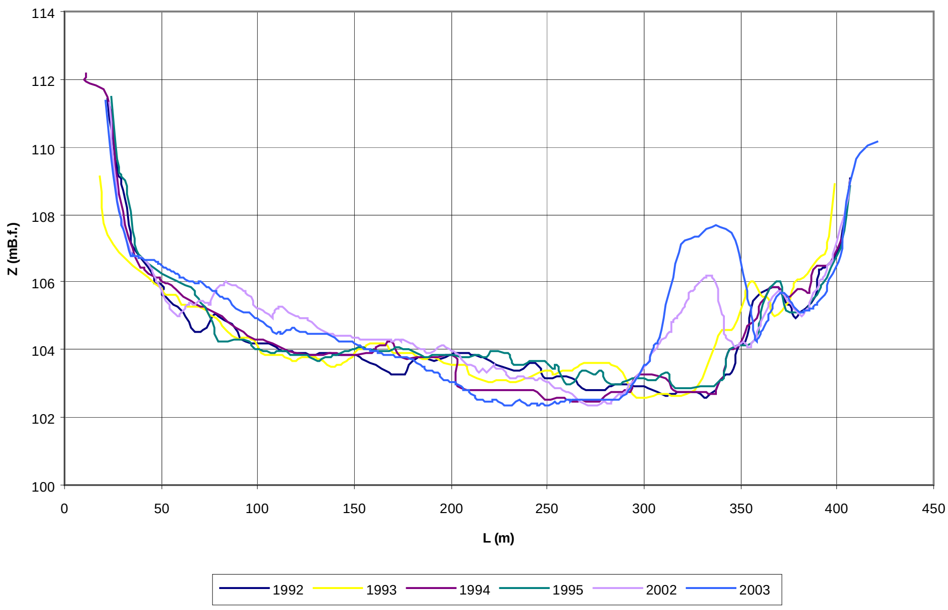


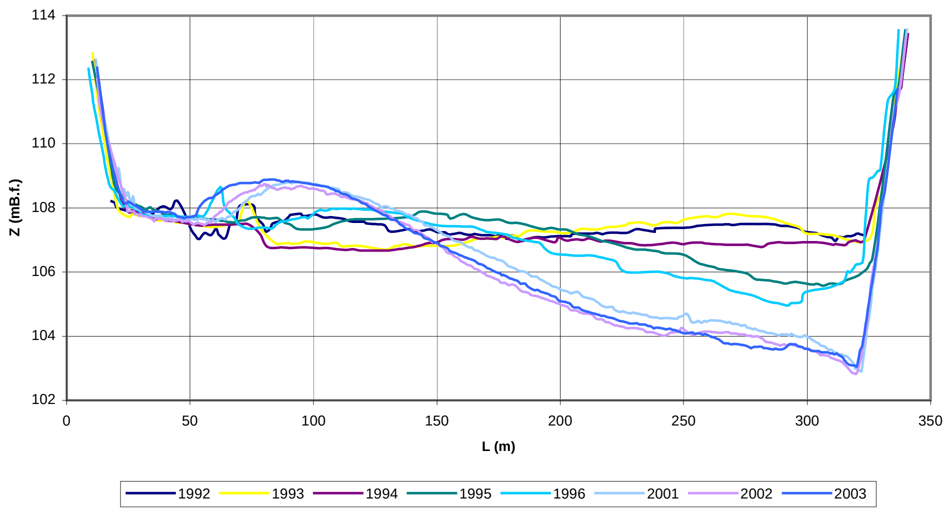
Figure 5-1 Siltation of side-arms and floodplain areas

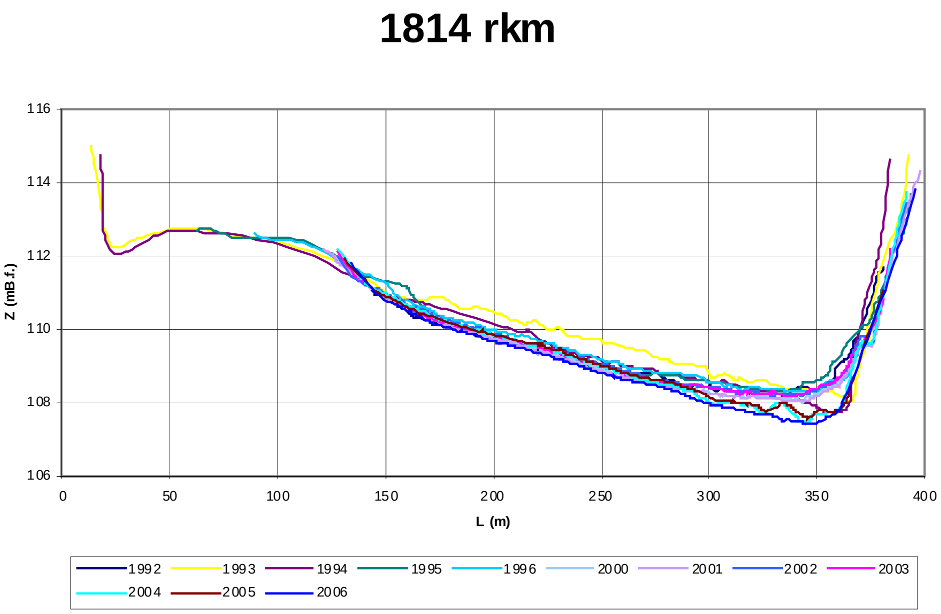
The Čunovo reservoir retains bed loads arriving from the Austrian section of the Danube and from the River Morava in its entirety, while suspended load is settled partially. For this reason a severe incision of the bed level occurs at the confluence amounting to 10 to 17 cm annually around Szap. Figure 5-2 shows a 3.5 m incision at rkm 1808 after 15 years of operation of the Gabčíkovo power station. Low stage water levels dropped in the Gönyü region by 1.4 metre since the water diversion of the Danube (1992) and 1.8 metre when compared to the levels in the 1960s and 1970s. According to the latest data the erosion of the channel ends upstream of Gönyű (1792 rkm). In the first years several hundred thousand cubic metres of sandy gravel was eroded from the right bank opposite of the confluence of the tailrace canal and started to move slowly moving downstream.

1795 rkm



1808 rkm





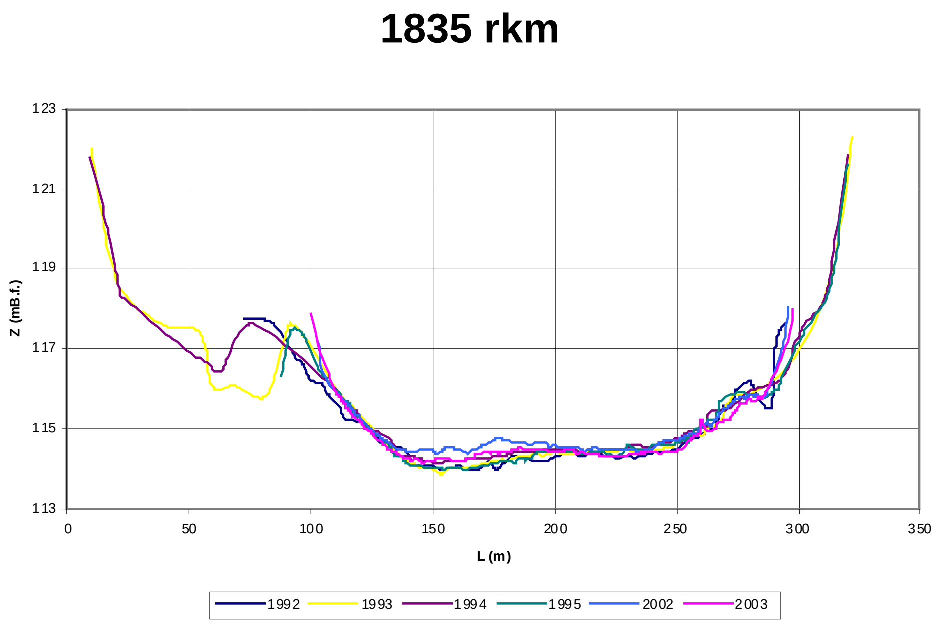


Figure 5-2 Development of cross-sections after diversion of the Danube in Oct. 1992 (confluence at rkm 1811)

Backward erosion started to cut into the river bed upstream of the confluence which is demonstrated at rkm 1814 in Figure 5-2. The cross-section at rkm 1835 near Cikolasziget in the upper part of the Old Danube clearly shows two effects typical for this reach: pronounced aggradation on the newly vegetated bars along the left bank of the river, and variable sediment heights above the former bed level indicating sediment movement above the armoured river bed as mentioned above.

The Sediment Issue Paper of ICPDR (20 November 2006) provides a general overview of the sediment quantity issues in the Danube River Basin, highlights initiatives outside ICPDR that deal with aspects of sediment issues in the Danube River Basin (SEDAN, Aqua Terra, UNESCO IHP International Sediment Initiative, SedNet, RISKBASE, CEDA), sets the operational conclusions, proposes the activities aimed at obtaining a greater insight into the problem of Danube sediments, and outlines a time plan for the proposed activities. Some of the conclusions of the paper are under heavy discussion. The key conclusions agreed and relevant to this feasibility study are as follows:

- To clarify the problem of sediment deficit in the Danube River as described in the Danube Basin Roof report 2004 it is necessary to further investigate the quantitative aspects of sediment transport in the Danube River Basin from a long-term perspective. The elaboration of a sediment balance is of primary importance.
- Special attention should be given to the role of floods in sediment transport since a substantial part of an annual sediment load can be transferred by this phenomenon.
- An appropriate assessment of the sediment balance necessitates the collection and analysis of long-term data sets. A consensus has to be reached on this issue.
- The intercomparability of the existing data sets on sediment quantity has to be investigated and respective quality assurance criteria have to be agreed. The sediment sampling methods in use in the Danube countries have to be compared with a view to achieving a common standard.
- The environmental aspects of dredging have to be discussed on a basin-wide level.
- It is needed to improve the understanding of the role of sediment in the functioning of the natural river-ecosystem in the Danube. The actions should be aimed at the assessing of the (combined) impact of sediment quantity and quality on the ecological status.

Table 5-1 Summary of deficiencies of the present morphodynamic regime

- Retention of bed load by upstream dams including the Čunovo reservoir causes **severe incision** of the river on a reach of several kilometres below the confluence as well as backward erosion in the Old Danube. Incision instead of aggradation is a **reversal of the natural process.** As a consequence low flow and mean water levels drop as well as groundwater levels in the adjacent floodplain.

- The basic ecological process of the **formation of new river beds**, and simultaneously the abandoning of other ones cease with river regulation in the 19th century creating a main channel and a side-arm system. Before degradation of the main channel the side-arms still experienced erosional processes to a certain extent and not just sedimentation or siltation as in the present situation.

- The **governing processes** of erosion, transport and deposition of sand and gravel in large quantities were completely stopped with the diversion of the river in 1992. The sharing of flood flows was inadequate for efficient transport processes. On the other hand suspended sediments were deposited in large quantities in side-arms especially in the lower reach of the Danube.
- Long-term solutions need to consider **compensation for the missing bed** load, e.g. by sediment management including transportation of sand and gravel through reservoirs.

5.1.2. Flow regime

Alteration before 1992

The effect of the various river regulation interventions can be observed in the flow regime. At the end of the 19th century the impact of flood protection measures and the construction of flood protecting embankments can be demonstrated on the hydrological behaviour of the river. The incoming sediment, which was spread out earlier on over the entire region of the Szigetköz and Zitny Ostrov, was subsequently seen filling up the unprotected land between the dam embankments rapidly, resulting in the growth of low, mean and high waters alike (Figure 5-3 and Figure 5-4).

Since the end of the 1960s mean flow levels and low flow reflect a diminishing tendency. Incision of the river bed is confirmed by the riverbed surveys. This process can be explained by the reduced amount of sediment entering the area, dredging activities and the increased transportation capacity due to river regulation.

At the beginning of the 20th century, the difference between low and mean flow levels at Gönyü (Figure 5-3) was 1.8 metres, while the difference between low and high flow levels was 4.3 metres. By the end of the period, i.e. the second part of the 1960s these values did not change significantly except that each of the trends has increased. Following this up to the present day the trend at low water was reduced significantly, by nearly two metres. However, high stage water levels kept on increasing.

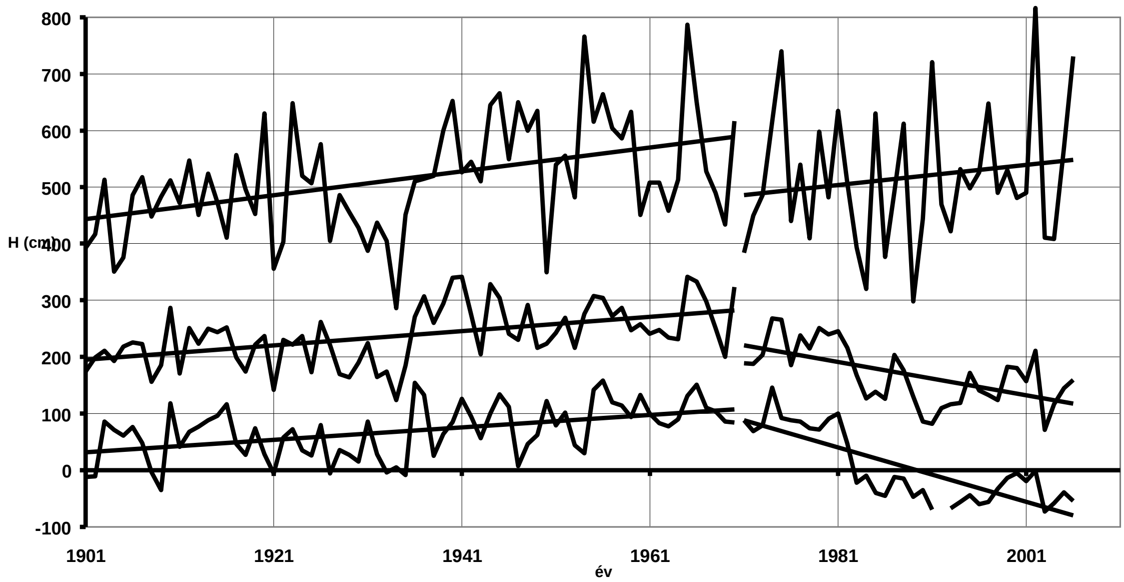


Figure 5-3 Trend analysis of typical annual levels of water, Gönyü

The same trend was observed in the case of the Dunaremete gauge (Figure 5-4). By the beginning of the 20th century the difference between low and mean water was merely 0.9-1.0 metre, the difference between low and high water 2.20 m.

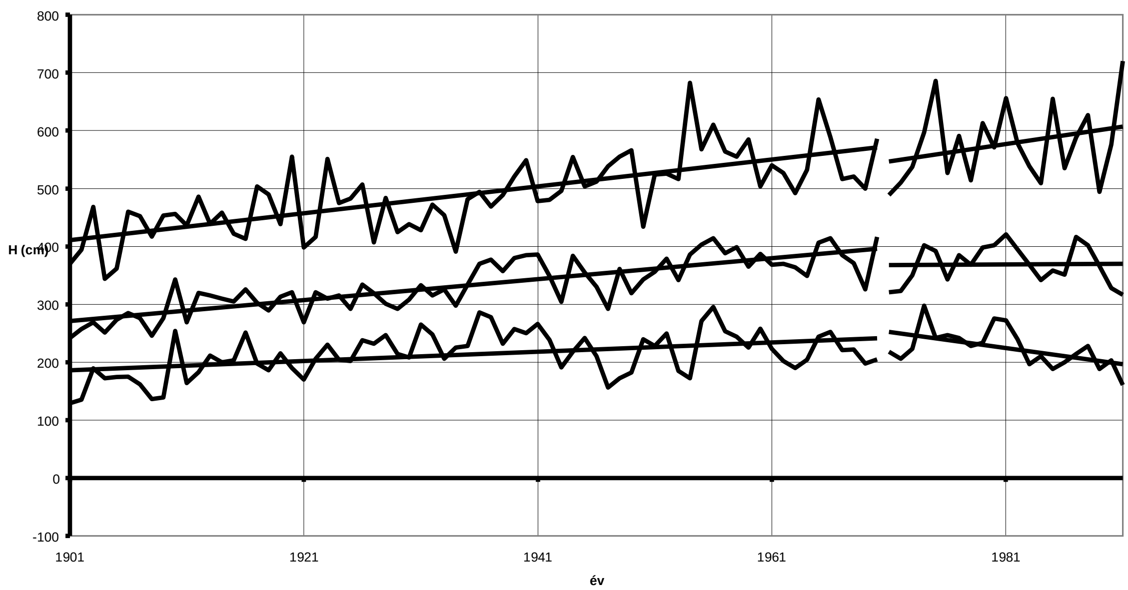


Figure 5-4 Trend analysis of typical annual levels of water, Dunaremete

The direction of the trend in low and mean water has changed, lowering from the seventies. By the end of the period (1991) the range between low and high water levels also approached 4 metres in Dunaremete.

Alteration after October 1992

Pursuant to the bilateral agreement of 1995 an average annual water flow of 400 m^3/s is discharged into the Danube at Čunovo. Water transfer takes place in accordance with the rules of procedure defined in the operation schedule, taking into account the natural hydrological regime of the Danube (Figure 5-5). The rules of procedure declare the discharge to be transferred in a monthly breakdown as a function of the Danube flow entering the area at the Devin profile. These flow rates vary between 400 and 600 m^3/s during the summer period and 250 and 600 m^3/s for the winter period.

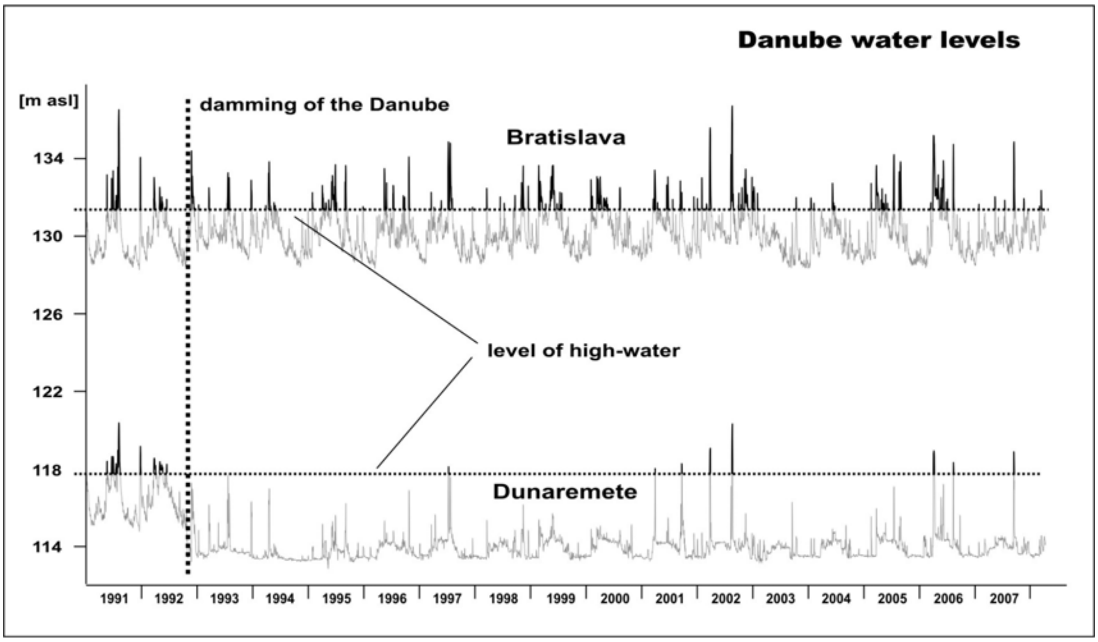


Figure 5-5 Hydrographs of Bratislava and Dunaremete gauges from 1991 to 2007

In certain places in the region of Rajka and Dunaremete, the water level of the Danube dropped, as a result of the diversion, by 4 m compared to the previous mean water levels and by 1.5 to 2 m compared to the previous minimum levels. Higher discharge than 600 m^3/s rates only occurred in the main channel when the total discharge rate of the river exceeded the maximum capacity of the Gabčíkovo Hydropower Station. The crest of such sudden and rapidly travelling “flood waves” barely reach the level of past mean flow levels. Figure 2-3, Figure 2-4 and Figure 2-5 represent the significant change in the flood flows. Only extraordinary events such as those in 2002 and 2006 cause full inundation of the floodplain. However, none of the flood flows lasted longer than 4 days due to the sudden closure of the Čunovo Barrage.

Furthermore, the dynamics of the flow regime have changed. Figure 2-2 demonstrates the small range of water level fluctuations in the Old Danube after 1992.

In the headwater section of the main channel the flow rate gradually decreases from 1.0 to 0.2 m/s while the water may even flow backwards at the beginning of flood waves between river-km 1811 and 1817 due to the mentioned backwater effect of the confluence.

After the diversion until the summer of 1993, most of the side-arms in the active floodplain were completely dried up. In order to establish a water supply system, the former closures were removed, new engineering structures were constructed and shortcuts were created. As a result a continous water supply, 20 to 110 m^3/s depending on the discharge received from the Čunovo Barrage is allocated to the side-arm system of the active floodplain resulting in an annual water level fluctuation of 0.5 to 1.0 m.

The approximately 36-km-long water supply system of the active floodplain is completely isolated from the main channel; water levels in the active floodplain are 2 to 4 m higher than in the main channel. Compared to the natural conditions, this represents a relative abundance of water corresponding to the previous mean water levels.

Table 5-2 Summary of the deficiencies of the present hydrological flow regime

- The natural **seasonal flow pattern** is reflected in the hydrographs of Rajka or Dunaremete (Fig. l). However, the ecological service associated with the natural flow regime in a large river system fails for several reasons.
- The average range of **water level fluctuations** was considerably smaller than under natural conditions. In addition, there are two separate flow systems: the side-arms with even smaller fluctuations of water levels and the main channel. The reduced range of fluctuations on a lower level combined with an irrigated floodplain represents a total change of the former riverine ecosystem.
- **Interconnecting the side-arms** with closures and cross-dykes to support the water level created abundant water bodies with running water experiencing little change due to inefficient flood pulses.
- The few **flood flows** exceeding the discharge capacity of the Gabčíkovo turbines were not able to trigger significant morphodynamic processes essential for the survival of the vital character of the river ecosystem. Any future concept will have to focus on an efficient flood regime capable of altering riverbed and rearranging floodplain deposits to a certain extent.

5.1.3. Groundwater regime

Results of a comparison of average groundwater level changes under low, mean and high water level conditions showed that groundwater levels markedly decreased after the diversion and remained still decreased after the construction of the underwater weir under mean and especially high water level conditions in the central part of the Szigetköz. In the region of Rajka groundwater levels have increased due to the impoundment of the Čunovo reservoir. After the construction of the underwater weir the increased level covered even larger areas under low water level conditions. In a 1-2 km wide zone next to the Danube in the section between Dunakiliti and Ásványráró, groundwater levels are lower by 1-3 m in the low-water condition, and by 2-4 m in the high-water condition. In some parts of the protected side the decrease is 1-2 m in the high-water period of spring and early summer which is significant from an agricultural point of view. (P. Scharek and I. Zsámbok, 1996).

Figure 5-6 shows mean groundwater levels following the diversion of the Danube. This figure demonstrates that groundwater recharge from the Danube bed has stopped between Rajka and Dunaremete. The role of the Danube was partly taken over by the Čunovo reservoir, the Mosoni-Danube, the seepage channel and the water supply system of the side-arms.

The lateral flow to the Szigetköz-aquifer from the reservoir is determined by two factors: (i) the clogging level of the reservoir and (ii) the level of impoundment upstream of the weir of Dunakiliti. (The clogging decreases the exfiltration from the reservoir, while the remaining lateral flow toward the Szigetköz is greater as the impoundment is higher).

The main part of the infiltration (artificial recharge) from the water courses in the protected side and from the side-arms in the floodplain flows to the Danube due to reduced water levels. The amount of water is important for stabilising the groundwater level in the protected side close to the original value. In the active floodplain, however, its increase has little impact on the groundwater level. This latter is rather determined by the mean water level in the Danube (as the other important boundary condition). The higher the average water level is in the Danube, the smaller the amount of water needed for artificial recharge is, or the greater part of the infiltrated water supplies the side channels.

As far as the origin of the groundwater is concerned, two main zones can be distinguished (before the diversion of the Danube the whole aquifer was filled by Danube water). The approximate border is at the line of water courses on the protected side, used for artificial recharge (see pink line in Figure 5-6). Between the Mosoni-Danube and the separating line the source is the infiltrated water from the reservoir while towards the Danube fresh water from the recharge system occur in the upper part of the aquifer.

From a quality point of view it is important whether the groundwater originates from infiltration by the reservoir or from seepage of irrigation channels or side-arm recharge. The silting up of the reservoir and as a consequence the infiltrated water becoming poor in oxygen and the increasingly reducing character of the groundwater flow is a question of time only. Due to the delayed silting of the reservoir and the travel time of several years, deterioration of groundwater quality may not be excluded for the future. On the other hand, the quality of artificial recharge with fresh water and with a small amount of suspended sediment is similar to the original quality. It is a general conclusion that from the qualitative point of view, it is more favourable if the ratio of the recharge from the water courses is higher.

The capillary moistening of the cover layer is essential for wetland ecology as well as for agricultural land on the protected side during the growing season. Figure 2-7 demonstrates the relative position of the average groundwater level to the lower surface of the cover layer in the 1980s. It is obvious that the sensitive areas are situated in the upper part of the Szigetköz. As far as the present situation is concerned the results of a recent analysis (Hajósy, A.; Liebe, P. and Szalai, J., 2008) is shown in Figure 5-7. The most sensitive areas are the ones which are covered by a cover layer of less than 4 m in thickness and experienced a significant drop of groundwater levels. In these areas capillary rise to the top soil layer is disrupted or endangered. The graph shows differences in groundwater levels of higher water flow between two five-year periods before and after the diversion of the Danube (1987-1991 and 1999-2003 respectively). The decrease of capillary moistening is predictable on the areas marked with parallel lines even in the floodplain area because of the lack of regular inundations. Surface and subsurface water levels of sampling sites indicated on this figure are presented in Figure 5-8.

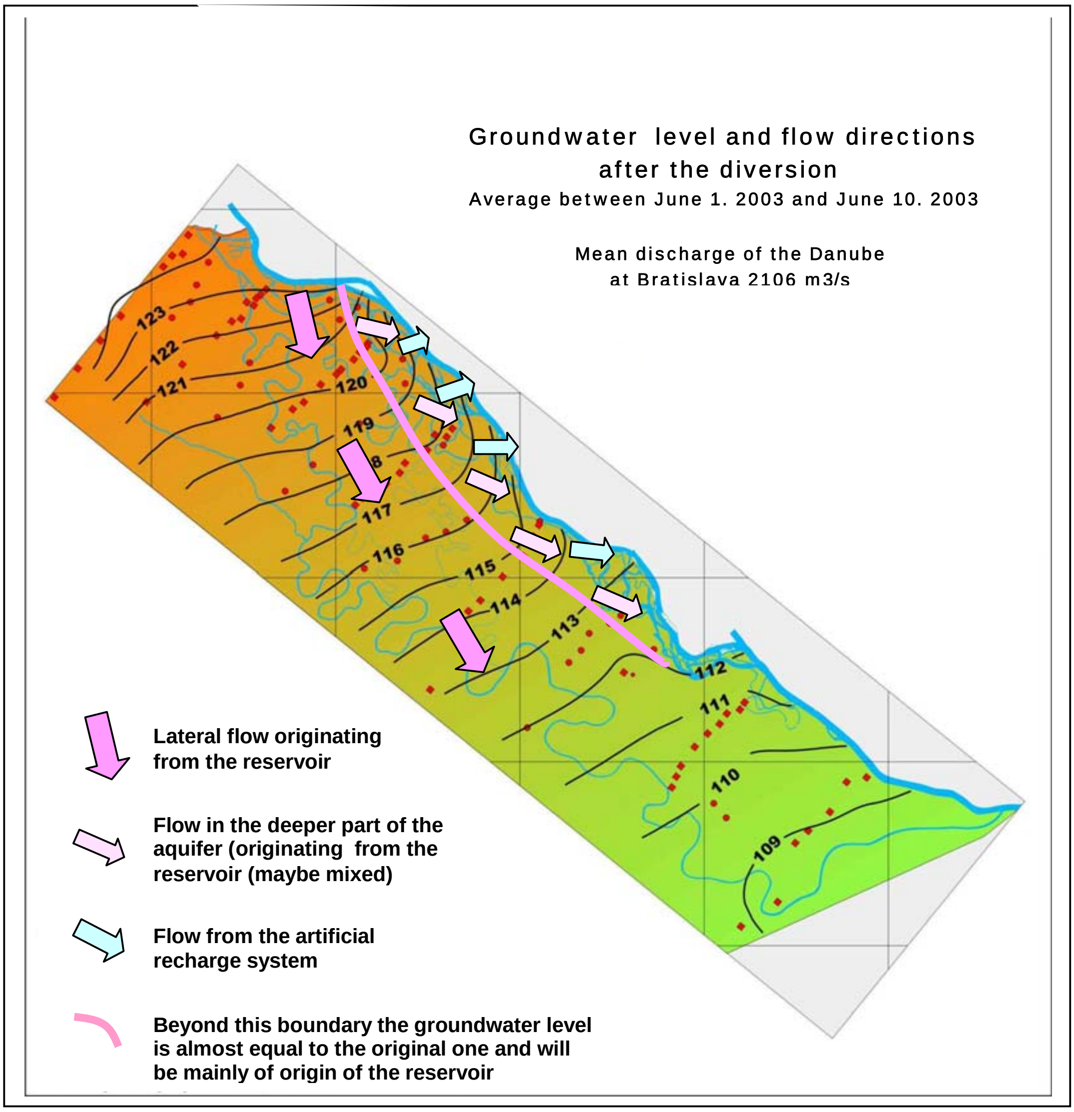


Figure 5-6 Groundwater level and flow directions after the diversion of the Danube

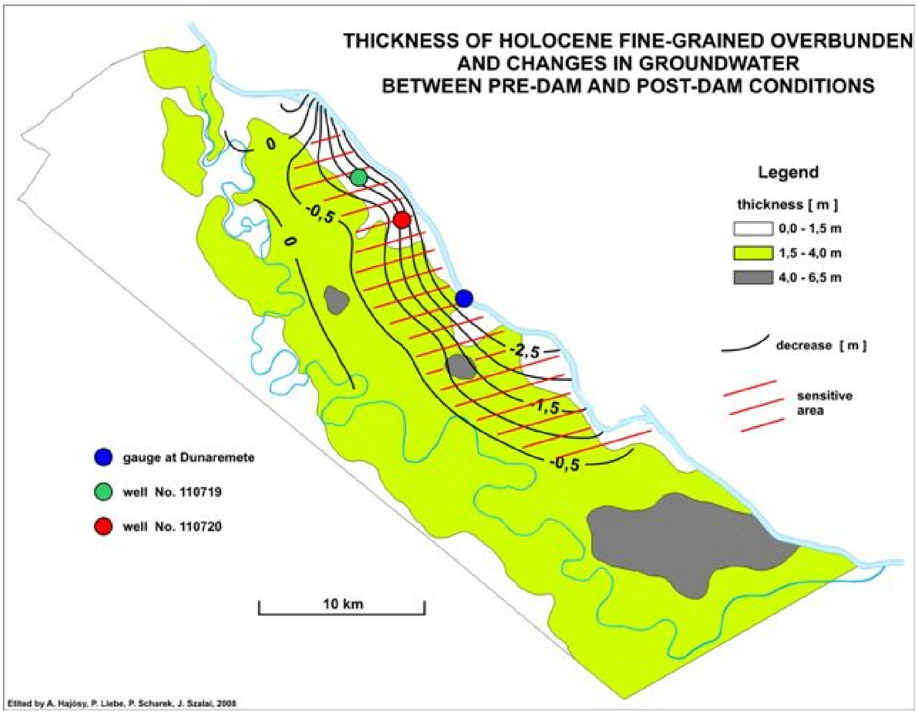


Figure 5-7 The thickness of the cover layer and the changes in groundwater levels comparing 1987-1991 and 1999-2003 respectively

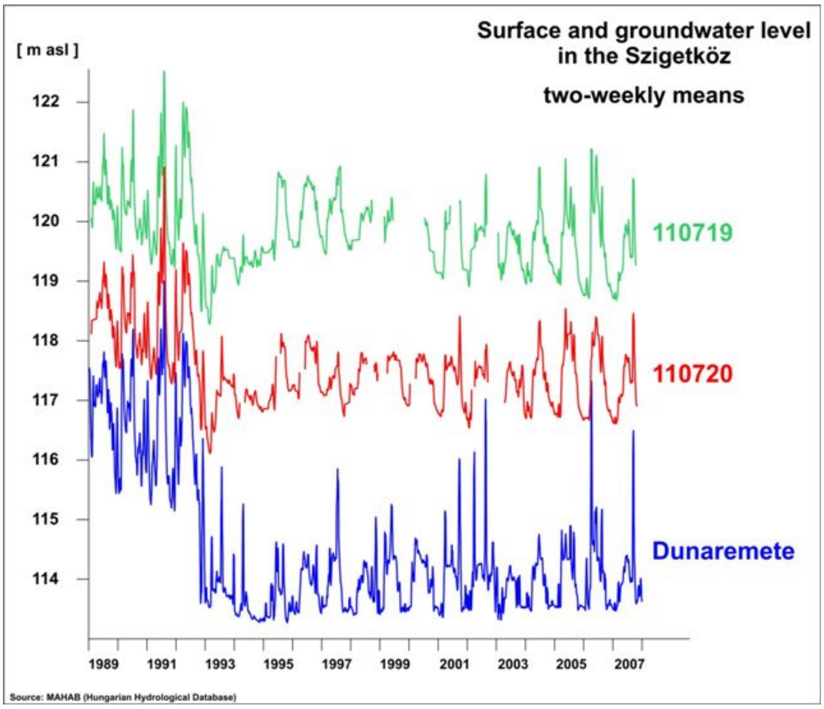


Figure 5-8 Two weekly means of surface (Dunaremete) and groundwater levels (wells No. 110719 and No. 110720). Sample locations are given in Figure 5-7.

Table 5-3 Summary of the deficiencies of the groundwater regime

- Recharge of the groundwater occurs mainly from the Čunovo reservoir and water courses receiving water from this structure. Since the reversal process of natural exfiltration no longer occurs there is a long-term danger of clogging and a subsequent reduction in rates of recharge associated with a risk of deterioration of water quality.
- The drop of groundwater levels in sensitive areas of the Middle Szigetköz endangers the capillary moistening of the cover layer of large parts of the floodplain including areas of the protected side.
- The overall change of the groundwater regime with areas of higher and lower groundwater levels at smaller ranges of fluctuations coupled with a considerably reduced flood flow regime has significantly altered the entire wetland ecosystem compared to its natural character and biological inventory.

5.1.4. Drinking water resources

The operating public water works abstract 50,000 m^3/d as an average, and additionally approximately 15,000 m^3/d abstractions for industrial and agricultural purposes are registered. Ten years ago bank filtered well-fields of a capacity of 235,000 m^3/d were delineated for future abstractions.

It is to be emphasised that the potential resource is much bigger. The Szigetköz was considered as the major drinking water resource of the country. *Before the diversion of the Danube* the gravel-terrace of the Danube potentially allowed approximately 1 million m^3/day bank filtered water abstraction and additionally 150,000 m^3/day could be considered in the inner part of the Szigetköz (the origin of the recharge being the Danube). In the South-Eastern part of the Szigetköz, the actually operating Waterworks of Győrújfalu and Szőgye show water quality problems due to the reductive character of the water (high iron and manganese content).

Since the diversion of the Danube the traditional (simple) bank-filtered water abstraction with wells drilled close to the river has ceased. Water abstraction is possible with artificial recharge ponds or by wells drilled aslope under the river bed. The potential bank-filtered resources decreased to approximately 600,000 m^3/day, which can be extended by 250,000 m^3/day quasi bank filtered water resources (only in the case of acceptable water quality conditions along the drainage canal between Rajka-Dunakiliti). The additional available groundwater resource in the inner part of the Szigetköz increased, it is estimated, to 230,000 m^3/day. Thus, the reduction in the available groundwater resource is not important, but the operational cost would be certainly bigger, because both the pumping and the treatment cost are expected to rise.

Table 5-4 Summary of the deficiencies of the drinking water resources

- The potential capacity of bank filtration for drinking water supply along the Danube decreased from 1 million m^3/day to 0.6 million m^3/day. The reduction is partially replaced by an additional bank filtration capacity along the drainage canal between Rajka and Dunakiliti (0.25 million m^3/day and by the increased resource in the upper part of the Szigetköz (0.23 million m^3/day).
- The water abstraction of bank filtration along the Danube would need more expensive techniques, compared to the simple wells along the main river bed.
- The probability of the reducing conditions and consequently the need for treatment is increased.
- The amount of available drinking water resources has not changed considerably, but the operational cost would likely be higher due to the increased pumping and treatment cost.

5.2. Landscape structure

5.2.1. Overall habitat development over time

Based on the historical GIS map evaluation (compare chapter 2.2.2) it is possible to directly compare the main habitats and their percentage and distribution in the system over time:

Water bodies

Figure 5-9 shows the development of water bodies since 1782. Prior to regulation (before 1890) a rather homogenous distribution of habitats with decreasing connectivity can be observed. However the habitats of a Plesiopotamon character, in particularly the Paleopotamon are not sufficiently represented since only the main river corridor not including the floodplain was evaluated. The differences showing a strong side-channel activity (Eupotamon B) are reflected in particular in the high values of 1834 and just prior to the main regulation (before 1890). These can be understood in the framework of the increasing channel activity during the small ice age (compare Pisut 2002) and the mean water regulation just upstream in Austria beginning in 1859 increasing bedload transport due to river straightening and side channel closures and affecting sediment balance in the Danube reaches downstream. Additionally the map specifications (no clear defined water levels for and during the historical map survey) meant that usually lower mean water levels were applied. The maps from 1840 and 1859 (Parsetti high resolution navigation map) not represented in Figure 5-9 confirm the above picture.

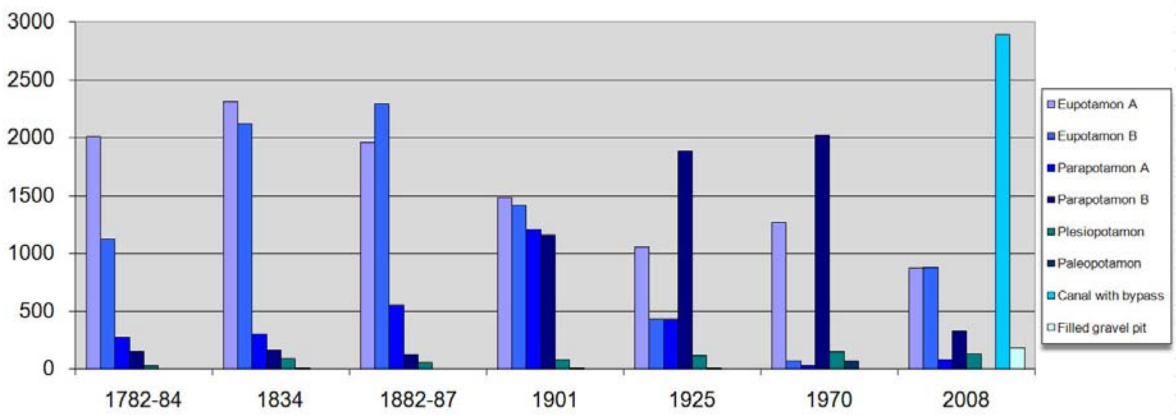


Figure 5-9 Overall spatial distribution of water bodies in hectares throughout the study period

In 1901 the mean water regulation changed the system dramatically, the Eupotamon A (main channel) decreased substantially and the side channel systems transformed into prevailing Parapotamon types. Within two decades (by 1925) and after further regulations (first low water regulation) the size of the main channel and the dynamically connected side channels further decreased whereas the disconnected channels upstream (Parapotamon B) increased. Until the 1970's an unspecified increase of the main channel could be recorded (further decrease of non-vegetated channel banks; most probably incision accelerated erosion in the main channel due to further low water corrections) and a strong decrease of side channel connectivity and of the size of the area related to this. With the construction of the Gabcikovo bypass canal the main channel further decreased (point bars and groyne fields became overgrown and bank length increased slightly) and the artificial water supply of the main side channel system increased the area of the permanently connected Eupotamon B.

The total water coverage before the regulation was reduced from some 5,000 ha to 3,600 ha in the 1970's. Due to the construction of Gabcikovo and the excavation of gravel pits the total size increased to 5,300 ha, however, the coverage of former natural waters further decreased to some 2,220 ha (-56% to that existing prior to the river regulation). The Eupotamon B is completely artificially managed today and not naturally connected, taking into consideration the fact that the Gabcikovo bypass canal takes 80% of the natural Danube discharge. The calculation shows that only 870 ha out of 4,700 ha Eupotamon A and B as well as Parapotamon A remained which is a loss of over 80%. This becomes much closer to the loss of the associated pioneer habitats (95%).

Due to the very complex development of the main channel(s) and side channels over the centuries and the small scale change from ana-branching (Nanson 1996), even in braiding to meandering stretches depending on local slope and sediment preconditions the waterbodies were subdivided into more ana-branching and more meandering types (shown in the maps where one category is split into two polygons). This means the morphodynamic characteristics of ana-branching and meandering channels are different, e.g. the width and depth variability is more uniform in meandering channels and more heterogeneous in ana-branching sections. The flow velocity and shear stress as well as lateral erosion forces are higher in ana-branching reaches.

Pioneer stands

Figure 5-10 demonstrates the nearly total loss of pioneer habitats in the altered river and floodplain system today. In the near-natural system about 60 bars and islands >5 ha which are non-vegetated or only colonised by incipient pioneer stands can be recorded.

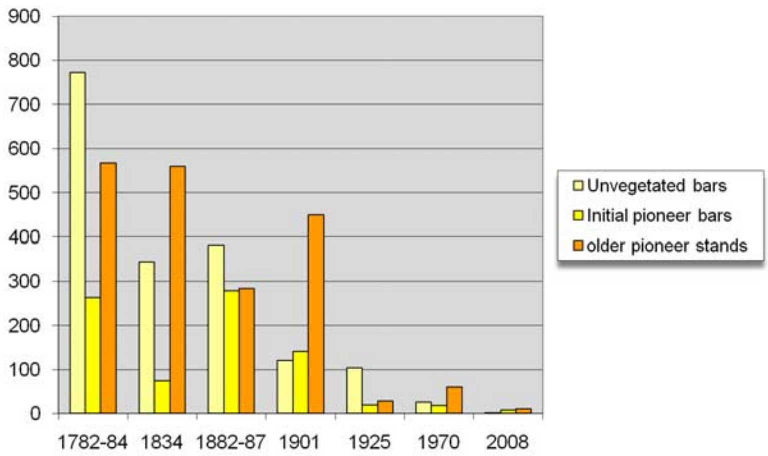


Figure 5-10 Overall spatial distribution of bars in hectares throughout the study period.

The size of 5-10 ha can be considered as typical for this Danube stretch.

The total size of all pioneer stands varies in the time period 1780-1890 from 1,000 ha to 2,000 ha indicating a high variability (some major floods are evident for this period, Pisut 2002) but, also taking into account a certain difference in water level during mapping however, most of the maps were prepared for lower mean water levels, and therefore the possible error is not so significant. Another factor could occur if prior to the mapping large floods occurred as described for several periods (Pisút, 2002). The system was already completely changed in 1925 (150 ha) and up to the present day pioneer stands are nearly “extinct” (20 ha).

Each pioneer stand was bound to the nearest waterbody and can therefore be characterized by individual erosive or deposition forces as well as habitat turnover/aging processes and characterisation. This is of relevance for the development of pioneer stands, in particular for initially non-vegetated banks in the main and side channels which will develop into matured pioneer and additional softwood stands. If those pioneer habitats are located in and along the main channel they have much longer development cycles or can even completely disappear after new bed formation stimulated by floods. However, those pioneer stands immediately resulting from huge floods in smaller side channel systems or far from the main channel tend to result in rapid succession and softwood stands.

Other floodplain habitats

Figure 5-11 gives an overview of the most important terrestrial habitats. Under natural conditions softwoods would prevail and wet grasslands and hardwood as well as smaller dry habitats on gravel would not be very widely distributed. However the usage as pasture and timber extraction for different purposes (softwood for fire and meshwork and hardwoods cut over centuries) were significant. Over time the intensity of pasture usage decreased and nearly disappeared prior to the 1970’s (the increase in 2008 includes all dykes with grass). Step by step the natural softwood forest was replaced by hybrid poplar plantations which today cover altogether at least 6,500 ha in both countries. Oxbow like backwaters with swampy vegetation in the large side branches existed prior to the regulation only to a very limited extent (most of this habitat can be found today in the morphological (former) floodplain and more distant from the river.

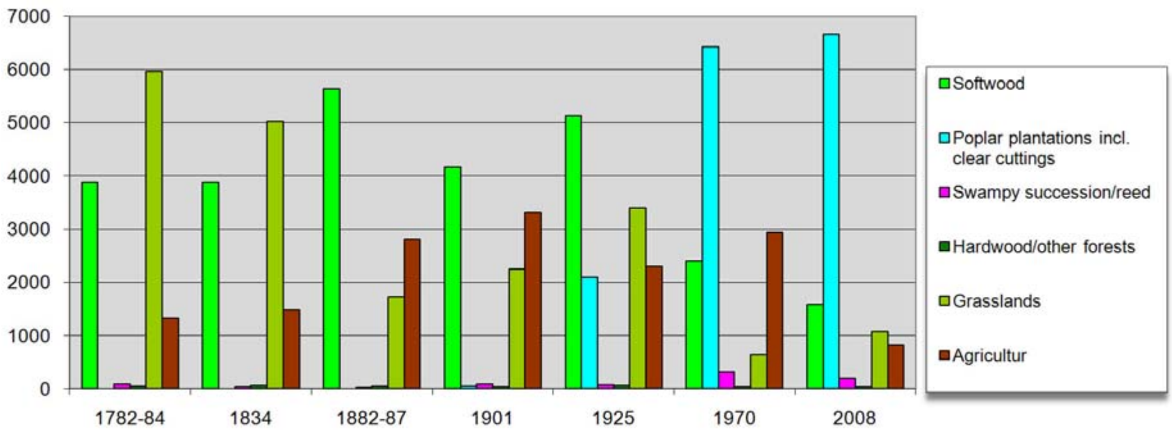


Figure 5-11 Overall spatial distribution terrestrial habitats in ha (hectares) throughout the study period

Agriculture has always been present in the area, however it increased significantly with the flood defence and the drainage works which went hand in hand with the river regulations at the end of the 19^{th} century. The strong decrease in 2008 is due to the fact that the Gabčíkovo bypass canal was built mostly on agricultural land.

As described above for pioneer stands the terrestrial habitats are also connected to their neighbouring water bodies. If a softwood stand is located along Eupotamon A or B (main channel, permanent side-channels) it reverts more probably to pioneer stand or even disappears (a major source of LWD (Large woody debris)). If the softwood is attached to Parapotamon or even Plesiopotamon water bodies (sporadically connected side channels or isolated floodplain waters) the softwood can develop further succession stadiums toward lower hardwood stadiums. Woods along Paleopotamic water bodies tend even towards swampy and other hardwood stadiums. Rejuvenation processes could also be different along the high dynamic bars and banks with different species colonising (e.g. Salix purpurea, Populus nigra) or with different stands maturing (Salix alba) whereas on remote floodplain waters vegetative propagation by rhizome can play a more important role.

Fluvial-morphological parameters

Basic fluvial-morphological parameters such as river and bank length (with sinuosity, bank-line index), number of islands and side-channel connections can support the general habitat and hydromorphological analysis (see also Schwarz, 2008).

The total river length in the research stretch was reduced from about 52 km to 43 km (17% shortening). The sinuosity declined from 1.3 (slightly meandering) to 1.1 following the mean water regulation at the end of the 19th century. Assuming that the sinuosity was calculated over the whole reach, the Danube can be characterized by shorter sections as meandering (1.5-1.7) in particularly in the lower reach with decreasing slope (currently rkm 1,833 -1,815). However, most of the entire reach was strongly ana-branching even with shorter braiding reaches.

Based on historical maps and the detailed longitudinal profile measurements prior to the mean water regulation at the end of the 19th century the shallowest stretches reached to around 2.3 m depth in the Thalweg (deepest part of the main channel) and the deepest pools could be estimated as up to 8.6 m. The mean flow velocity in the unmodified channel was 1-1.5 m/s - considerably lower than in the regulated stretch before the Gabcikovo barrage was built. Figure 5-12 highlights the high width variability of the main channel.

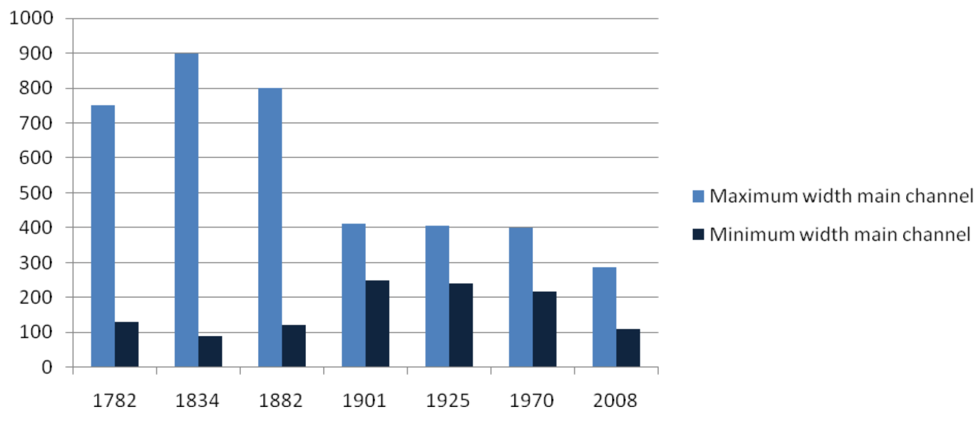


Figure 5-12 Width variability of the main channel throughout the study period

Figure 5-13 shows the number of major side channels connected to the main river. The increase from 1970-2008 can be explained by the permanent artificial water supply of the side-arm system. The differences prior to the regulation can be mostly explained by natural variability (different accumulation pattern leading to braiding but also meandering reaches with typically fewer side-channels) and to a lesser extent mapping uncertainties (different mapping water levels during historical survey, reduced detail accuracy in first Austrian military survey). The continuous "braiding and anabranching character" for the entire research stretch is evident from about 1830.

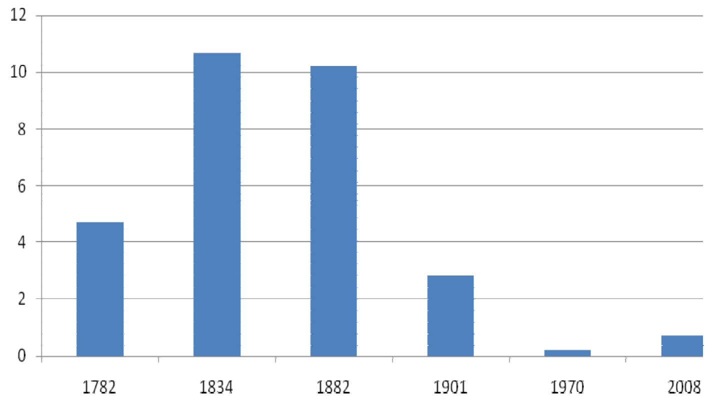


Figure 5-13 Connectivity of permanently connected side-arm channels (average numbers counted per 5 river km) throughout the study period

Banks

Steep banks could be detected only from selected maps but they clearly indicate a very frequent occurrence across the entire river course (at least 1/3 of the entire main channel bank lengths (104 km) can be described as steeply banked (even without including steep banks on major islands).

Habitat turnover

Prior to river regulation nearly 70% of the assessed inner floodplain corridor (the large morphological floodplain outside the flood protection dike was not assessed) was re-worked by the river within the 120 year period studied. Sample areas indicate the rapid development from Eupotamon to Parapotamon and the occurrence of pioneer bars and small islands on a time scale of between 5-15 years.

The lateral erosion rates along the main channel were generally estimated as 10 m/year (see the results of the sediment model of this Project and also Piszut 2002). Local analysis shows important variation of erosion pattern and rates over time and space. Major floods can shift the system within years locally for even stretches of 100 m or so whereas in other sections the banks are more or less stable over decades.

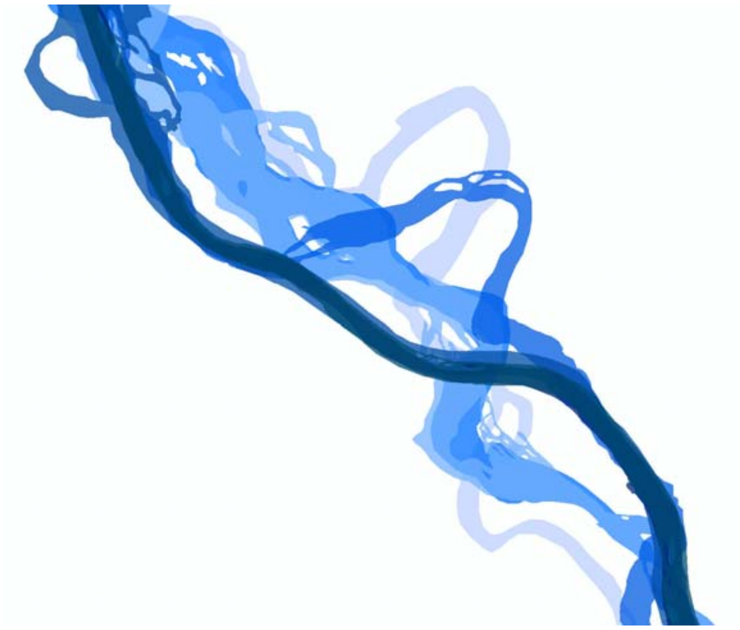


Figure 5-14 Example of qualitative habitat changes (example for Eupotamon A, oldest channel in light blue, recent in dark blue). It can be assumed that since about 1900 no major channel shifts occurred.

There is no indication in the active corridor for a succession from soft to hardwoods.

Considerable changes and long lasting habitat development can be observed especially following the mean water regulation: Most of the side channel habitats and associated lower floodplains were transformed into a rather stable habitat pattern. The variability and development stages declined considerably within some decades. The changes and turnover rates today exceed more than 90 years or are even halted by the artificial water supply. Vegetation models of this Project show the development of softwoods towards swampy vegetation or hard wood forests mainly depending on the level of groundwater and the reduction of flood events.

5.2.2. Habitat fragmentation

Habitat fragments are often completely isolated from each other by the extensive deteriorated or destroyed areas in between. In the case of fluvial ecosystems even small alterations e.g. weirs, cross-dykes, barrages, dykes can result in fragmentation.

Habitat fragmentation before the Danube diversion

- The flood protection dykes in the Szigetköz divided the floodplain into an inundated and an unflooded area and separated several side-arms from the main river.
- The creation and stabilization of the main channel and the blocking of upstream inlets of the side-arms altered the hydro-morphological dynamics and subsequently the structure of the aquatic habitats in the braiding branch system.
- Several cross-dykes were created by the regulation of the side-arms which restricted the longitudinal connectivity within the branch systems during low-water periods.
- A number of water level regulating structures stopped the connectivity within the water system on the protected side of the floodplain.

Changes of habitat fragmentation after the Danube diversion

- Longitudinal connectivity of the main riverbed has been interrupted at the Čunovo barrage since 1992.
- Tributaries of the floodplain side-arm system were completely closed when the temporary water recharge system in the active floodplain of the Szigetköz was created in the middle of the 1990s.
- Longitudinal connectivity of the main riverbed was restricted by the construction of the underwater weir at Dunakiliti in 1995, but it is not insurmountable for fish.
- Most of the cross dykes within the branch systems were opened to improve the flow of the water recharge system. The longitudinal connectivity within the branch system improved.
- A fish pass was constructed at the lower tributary of the Cikola side-arm system (Danube rkm 1832.5) in 1998. It provides a limited migratory passage for fish between the Danube and the floodplain side-arms.
- The water recharge system provides direct connections between the inundated and protected floodplain at two points (Dunakiliti and Dunaremete).

It is important to note, however, that the habitat quality has also changed significantly, e.g. the eupotamon water bodies in 1872 were characterized by a large diversity of substrates (gravel, sand, silt) while uniformity of mostly fine sediments prevails today (see below).

5.2.3. Deterioration of habitats

Habitat deterioration can be caused by several factors. Alterations of the water and sediment regime by the river regulations are indicated in the change of habitat structure.

Deterioration of habitats before the Danube diversion

- The creation of the main channel and the blocking of upstream inlets of the branch system changed the structure of the aquatic habitats. The main channel became a stable eupotamon type of habitat and advanced stages of the ecological succession of the aquatic habitats (parapotamon or plesiopotamon) were characteristic in the side-arms. The proportion of the eupotamon type of side-arms decreased and the area of the parapotamon type side-arms and stagnant waters increased at the beginning of the 20th century. These changes indicate the general trend of habitat modification in the central braiding sector of the Szigetköz area.

- The vertical range of water level fluctuation increased due to the narrow inundation area. The increased vertical water level fluctuation changed the habitat conditions in the Aquatic-Terrestrial Transition Zone (ATTZ). The biological functions of the ATTZ were affected by the modified water retention capacity of the floodplain.
- Abandoned branches in the unflooded side of the floodplain developed to paleopotamon type habitats due to their disconnection.
- Inshore formation of the main arm and in some sections of the branches was altered by the construction of several river regulation structures (rip-raps, wing-dams, etc.).
- Autogenic processes of habitat succession were accelerated by the declining trend of low and mean water levels due to the incision of the main river bed from the end of the 1960s. The siltation changed the patterns of aquatic vegetation.

Deterioration of habitats after the Danube diversion

- Since the operation of the temporary water recharge system the proportion of eupotamon type habitats increased and the area of parapotamic side-arms decreased in the floodplain area, however, the mitigation measures have not solved the problems of habitat deterioration. The absence of gravel bar formation and lithophilic species in the branches indicates the deficiencies of the natural hydro-morphological and ecological processes. The total area of the permanent aquatic habitats in the Bodak side-arm system has decreased by 40% since the pre-regulation situation (1872) and this change shows a general decline in the expanse of the water bodies in the central braiding channel sector of the Szigetköz.
- The narrow range of water level fluctuation and lack of inundations resulted in restrictions of biological functions of the ATTZ especially in the upper part of the Szigetköz area. Decrement of disturbances worsens the living conditions of pioneer communities.
- The vertical river-aquifer interconnection and interstitial pathways are limited by sedimentation at several side-arms and spawning and feeding habitats of fish have disappeared.
- The growing sediment layers along the shorelines provide good substrate for semi-aquatic and terrestrial macrophytes, or spontaneous forestation.
- The range and frequency of the daily water level fluctuations increased downstream of the Gabčíkovo bypass canal due to occasional peak operation of the hydroelectric power plant. The special communities of the shoreline are not able to adapt to repetitive daily peaks of the water level.
- The proportion of the floodplain forest increased in the Bodak side-arm system from the end of the 19th century andbut 60 % of the present woods are hybrid poplars (Limp, 2007).

Table 5-5 Summary of the deficiencies of the present habitat structures

- Habitat fragmentation:
- – Longitudinal connectivity of the main arm has been interrupted at Čunovo since 1992;
- – Lateral connectivity has been restricted: most of the tributaries of the floodplain side-arm system have been completely closed since 1993;
- – A number of water level regulating structures prevent longitudinal connectivity within the water system on the protected side of the floodplain;
- Deterioration of habitats:
- – The range of water level fluctuation became smaller in the Upper Szigetköz and a considerable decline in the frequency and duration of inundations resulted in further restriction of the biological function of the Aquatic-Terrestrial Transition Zone;
- – Inshore formation of the main arm and in some sections of the branches was altered by construction of several river regulation structures;
- – Fish spawning and feeding habitats have vanished due to the siltation and lack of competent flood flows;
- – The new sediment layers along the shorelines provide good substrate for semi-aquatic and terrestrial macrophytes, or spontaneous forestation;
- Disturbance of the Aquatic-Terrestrial Transition Zone along the lower part of the Szigetköz by the peak operation of the Gabčíkovo Power Plant.

5.3. Flora and fauna, biodiversity

5.3.1. Long-term change of the fish fauna

The long-term change of the fish fauna in the Eupotamon-A and Eupotamon-B type habitats of the anabranching sector is described in Figure 5-15 where species numbers are given per ecological categories (Schiemer & Waidbacher,1992). The pre-regulation composition of the fish fauna was estimated by expert judgment and by evaluation of the historical literature. The recent change of fish fauna (since the 1980s) was determined according to results of direct observations and data of ichthyologic literature.

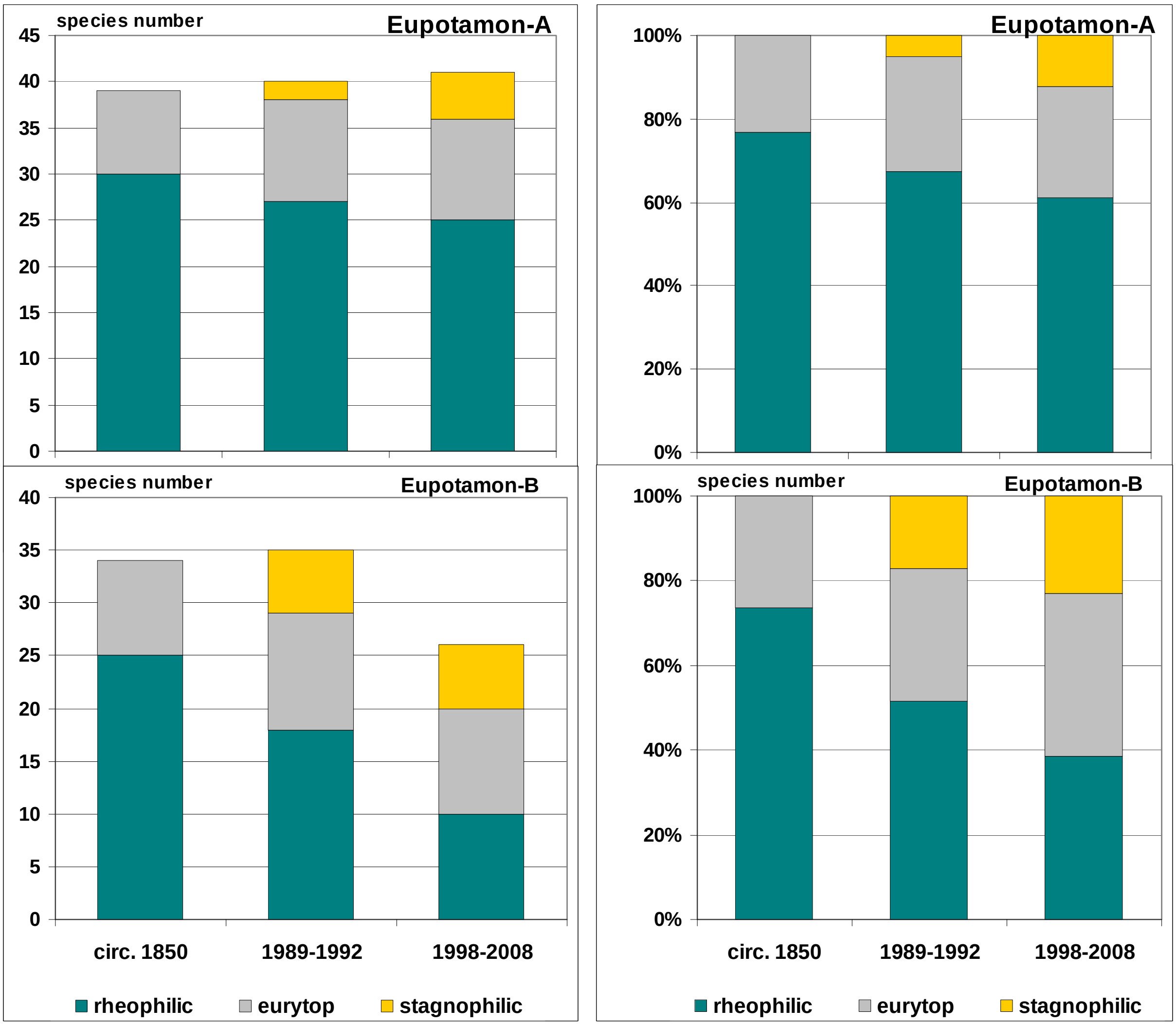


Figure 5-15 Long-term change in the proportions of rheophilic and stagnophilic fish species in the main arm (Eupotamon-A) and in the side arms with permanent flow (Eupotamon-B).

The long-term change of the fish assemblages is demonstrated by the increasing trend of the Habitat-specific Fauna Index (HFI) (See Appendix 3) in the Eupotamon-A (Figure 5-16 and Eupotamon-B (Figure 5-17) habitat. The quality grade of the HFI in the main arm is moderate recently, and it was good before the diversion of the Danube in the beginning of the 1990s.

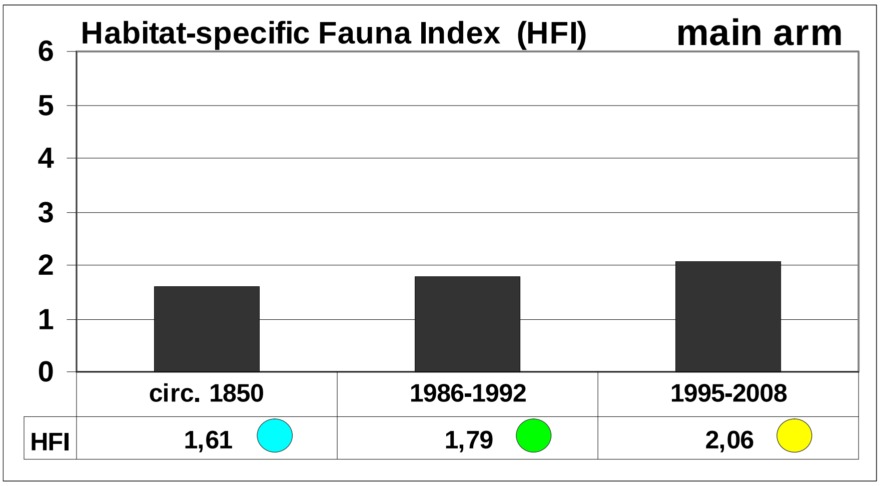


Figure 5-16 Long-term change of fish fauna is expressed by the habitat-specific fauna Index (HFI) in the main arm (Eupotamon-A type habitat). (The lower value of the HFI indicates the rheophilic character of the assemblages). Ecological (fish biological) quality grade is indicated by colours: Blue = excellent, Green = good, Yellow = moderate.

In the Eupotamon-B type side arms, the quality grade of the HFI is poor at present. It was moderate before the diversion of the Danube in the beginning of the 1990s.

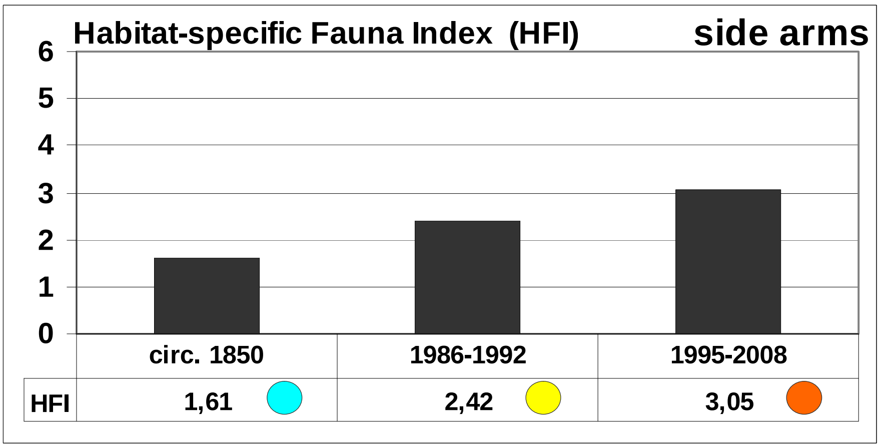


Figure 5-17 Long-term change of fish fauna is expressed by the Habitat-specific Fauna Index (HFI) in the Eupotamon-B type habitats of the floodplain branch system. (The lower value of the HFI indicates the rheophilic character of the assemblages). Ecological (fish biological) quality grade is indicated by colours: Blue = excellent, Yellow = moderate, Orange = poor.

5.3.2. Consequences of the habitat fragmentation

Fragmentation prevents the free movement, migration and spreading of species and their access to sources of nutrients and appropriate habitats. In isolated habitats species diversity is slowly reducing, due to changing conditions by natural succession. At the same time the isolation prevents the intrusion of competitors.

The dam at Čunovo is an insurmountable obstacle for migrating fish. The accessibility of the Dunakili bottom sill was investigated in a 'mark and recapture' experiment in 1996. Samples of different fish species were marked by floating tags and released below the underwater weir. Four out of 650 marked individuals were recaptured upstream of the underwater weir by professional fishermen; i.e. *Barbus barbus, Carassius gibelio, Chondrostoma nasus, Leuciscus cephalus*. This indicated that the underwater weir does not present an insurmountable barrier for these species. It does not, however, express a quantitative result.

The degree of ecological connectivity between the river and floodplain waters, as well as inundated terrestrial areas is an important factor influencing fish populations and communities (Amoros et al. 1987). The fish are especially sensitive to the fragmentation of water flows, as it may significantly restrict their migration or their optimal use of habitat. Many of the Danubian fish species migrate considerable distances during the spawning season looking for suitable spawning habitats. So obstacles on migration routes (cross-dykes, dams) prevent arrival onto the spawning grounds. This can have serious implications on the reproductive success of the migratory species and can lead to dicline in the stocks (Cowx & Welcome 1998). For numerous rheophilic fish species longitudinal migration means a feeding strategy which, by reducing competition, enables the development of fish populations containing a high number of individuals (Jones 1968). Due to migration independent from the spawning period the fish make a more efficient use of the food sources situated extensively in the riverbed. Comprehensive studies on the spawning and nursery grounds in the Danube and its backwaters (Schiemer & Spindler 1989, Schiemer & Waidbacher 1992) provide evidence that the various ecological groups of fish react differently to the longitudinal and lateral connectivity.

After the diversion of the Danube, interruption of the direct lateral connection between the main arm and floodplain side-arm system affected the composition of fish communities in the side-arms. According to the monitoring results in 1994, juveniles of 9 fish species were found in the upper part of the Cikola branch system, all of the rheophilic species diminished, and some phytophilic spawning species (*Carassius gibelio, Lepomis gibbosus*) appeared in high abundance. In 1995, an artificial temporary water replenishment system was implemented restricting direct connections to the main channel. In the next two years, juveniles of 10 species were detected, the number of phytophilic fish species decreased and some rheophilic species (*Abramis ballerus, Gobio albipinnatus, Leuciscus leuciscus, Vimba vimba*) reappeared which reflected the partial connectivity of the side-arm system (Guti 1998).

In a plesiopotamon-type side-arm (Schiesler side-arm) of the Cikola branch system 20 fish species were observed in 1992, but following the Danube diversion, between 1993 and 1996, when it was completely disconnected, species richness of fish assemblages decreased. The aquatic vegetation grew densely by steady separation (Table 5-6). In 1994 4 fish species (*Carasius gibelio, Rhodeus sericeus, Scardinius erythrophthalmus*, and *Leucaspius delineatus*) were observed. Juveniles of *C. gibelio* occurred in extreme abundance. Frequency of *L. delineatus* was relatively high considering that it had only been recorded once in the area during the previous six years. The number of collected species was 3 in 1995. Abundance of *L. delineatus* greatly declined, only an adult specimen was found and *R. sericeus* became rare. In 1996 only high abundance of *C. gibelio* was observed (Guti 1998).

Table 5-6 Changes of fish fauna of the Schiesler side-arm between 1992-1996 during its disconnection and intensive eutrophication

fish species	1992	1994	1995	1996
Abramis brama	+			
Alburnus alburnus	++			
Aspius aspius	+			
Blicca bjoerkna	+++			
Carassius gibelio	++	+++	+++	+++
Cobitis elongata	++			
Cyprinus carpio	+			
Esox lucius	++			
Gymnocephalus cernuus	+			
Lepomis gibbosus	++			
Leucaspius delineatus		++	+	
Leuciscus cephalus	+			
Misgurnus fossilis	++			
Perca fluviatilis	+++			
Proterorhinus semilunaris	+			
Rhodeus amarus	+++	++	+	
Rutilus rutilus	+++			
Sander lucioperca	+			
Scardinius erythrophthalmus	++	+		
Tinca tinca	++			

5.3.3. Consequences of the habitat deterioration

The Szigetköz section of the Danube produced most of its animal biomass from the floodplain. Aquatic organisms colonized the floodplain at rising and high water levels because of feeding and reproduction opportunities. The changes of extent and duration of the floods governed the biological function of the Aquatic-Terrestrial Transition Zone and thus the productivity of the fluvial hydrosystem. The restriction of spawning and feeding habitats due to a descending trend of the low water levels and increasing deposition of floating sediment in the floodplains affected the fisheries production of the Szigetköz area from the middle of the 1980s, as indicated by changes in the total annual catch of commercial and recreational fisheries between 1968 and 1996 (Figure 5-18). Since the diversion of the Danube the range of water level fluctuation became smaller in the Upper Szigetköz which reduced considerably the extent and duration of inundations.

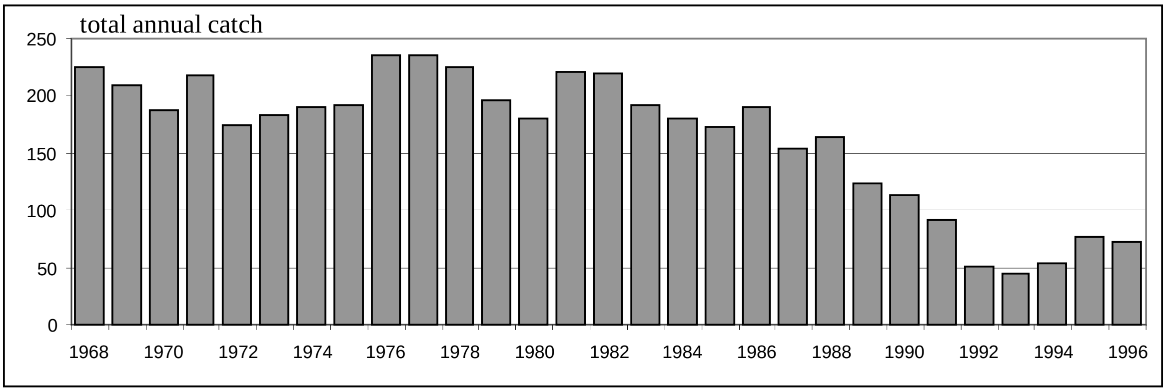


Figure 5-18 Changes of the total annual catch of commercial and recreational fisheries in the Szigetköz section of the Danube between 1968 and

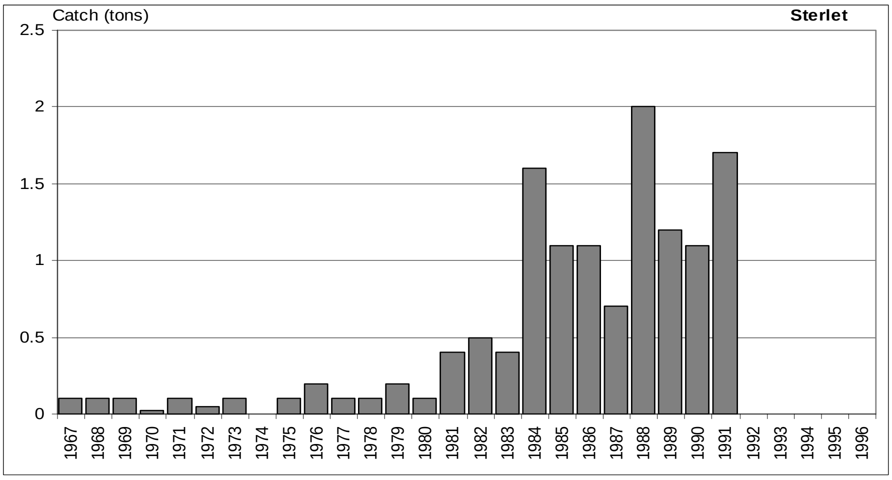


Figure 5-19 Changes of annual sterlet catch of commercial fishermen in the Szigetköz section of the Danube from 1967 and 1996 (Guti 2008)

The impact of deposition of suspended sediment on the fish habitats of the floodplain side-arms is indicated by the long-term changes of sterlet (*Acipenser ruthenus*) catch in the Szigetköz region (Figure 5-19). The sterlet catch was low in the 1960s and the 1970s, started to rise in the 1980s and it dropped to less then 10 kg/year from 1992. Sterlet were caught only in the lower part of the Bagomér side-arm and only during the spawning period. According to the fishery data, sterlet has disappeared over since the diversion of the Danube. When the sterlet catch started to increase a bed incision process happened. It seems that a low level of erosion process can maintain habitat quality for sterlet. The area of the side-arms of the Bagomér branch system increased by 2.1% from 1903 to 1962, while the area of the side-arms decreased at least 60% in the upper part of the Szigetköz (Doborgazsziget, Cikola and Bodak branch systems) (Csoma 1968).

The spawning site of the sterlet is in deep flowing arms at a depth of from 7 to 15 m. The eggs are laid on pebbles 1 to 7 cm in diameter (Sokolov & Vasilev 1989). The spawning habitat in the Szigetköz was altered following the diversion of the Danube, because the

Bagomér side-arm was filled by 346,000 m^3 silt from 1992 to 2005. The average sediment thickness on the spawning substrate is 60 cm, the upper third of which consists of fine mud fractions (Rákóczi & Sass 2005). Deterioration of the spawning ground would be a reason for the disappearance of sterlet in the Szigetköz section of the Danube.

River regulation in the 19th century, the diversion in 1992 and related bank protection with rip-rap have considerably degraded the natural shoreline configuration of the river, both in length and in habitat quality. In the 19th century regulation 3,5 million m^3 of stone were built in alltogether, that is 22 m^3 m^{-1}. The structural diversity and water retention of the inshore zone are significant for the physiographic microhabitat conditions of its biota, and for the productivity of riverine zooplankton and juvenile fish. Inshore retention is a key determinant of biological processes and biodiversity in large rivers (Schiemer et al. 2001).

Disturbance of the Aquatic-Terrestrial Transition Zone by the moderate peak operation of the Gabčíkovo Power Plant has not yet been investigated.

6. Legally binding obligations and stakeholder interests to be considered

6.1. Legal obligations

The legal framework of the implementation of the judgment of the International Court of Justice (ICJ) in the Gabčíkovo-Nagymaros Project Case of 25 September 1997 (henceforth: Judgment), forming the basis of all subsequent action including the joint Hungarian-Slovak Strategic Environmental Assessment as agreed by the Parties has been identified several times during the last decade[13].

No doubt, the accession of the negotiating Parties to the European Union has fundamentally affected the freedom of action of the Parties, setting constraints and imposing demands which derive neither from the Judgment nor from the 1977 treaty establishing the Gabčíkovo-Nagymaros Barrage System or from bilateral or multilateral treaties (and customary international law) binding them.

The text below relates both to the procedural and to the material requirements to be met when preparing and conducting the Strategic Environmental Assessment as well as when implementing its conclusions, in other words when adopting and realising the technical measures aimed at fulfilling the call of the ICJ "to negotiate in good faith in the light of the prevailing situation, and [to] take all necessary measures to ensure the achievement of the objectives of the Treaty of 16 September 1977, in accordance with such modalities as they may agree upon". (§ 155 (2)B).

6.1.1. The Judgement

As the Court noted, "the Parties together should look afresh at the effects on the environment of the operation of the Gabčíkovo power plant. In particular they must find a satisfactory solution for the volume of water to be released into the old bed of the Danube and into the side-arms on both sides of the river." (§ 140). "In order to evaluate the environmental risks, current standards must be taken into consideration" (ibid) – demanded the Court, adding that Variant C, "which it considers operates in a manner incompatible with the Treaty, should be made to conform to it. By associating Hungary, on an equal footing, in its operation, management and benefits, Variant C will be transformed from a de facto status into a treaty-based régime.

... Variant C could be made to function in such a way as to accommodate both the economic operation of the system of electricity generation and the satisfaction of

[13] See e.g. Annex 4 to the Protocol of the Plenary meeting held on 19 December 2006, summarising the applicable EU law

essential environmental concerns.” (§ 146) In that process “new norms have to be taken into consideration, and ... new standards given proper weight.” (§ 140).

So the task is to identify the current standards of environmental law and other branches of law, which have to be applied in the process in which Variant C is made to operate in a way which satisfies the essential environmental concerns, while not discontinuing electricity production and pursuing the other goals of the 1977 treaty (navigation, flood protection) as well. In the words of the Court: “It is for the Parties themselves to find an agreed solution that takes account of the objectives of the Treaty, which must be pursued in a joint and integrated way, as well as the norms of international environmental law and the principles of the law of international watercourses.”

6.1.2. International law

6.1.2.1.Environmental protection

The Convention on Co-operation for the Protection and Sustainable Use of the River Danube (Danube River Protection Convention) signed on June 29 1994, in Sofia forms the overall legal instrument for co-operation and transboundary water management in the Danube River Basin.

The main objective of the Convention is to ensure that surface waters and groundwater within the Danube River Basin are managed and used sustainably and equitably. This involves:

- the conservation, improvement and rational use of surface waters and groundwater
- preventive measures to control hazards originating from accidents involving floods, ice or hazardous substances
- measures to reduce the pollution loads entering the Black Sea from sources in the Danube River Basin.

The signatories obliged themselves to take "all appropriate legal, administrative and technical measures to at least maintain and where possible improve the current water quality and environmental conditions of the Danube River and of the waters in its catchment area, and to prevent and reduce as far as possible adverse impacts and changes occurring or likely to be caused."

The Convention on the Protection and Use of Transboundary Watercourses and International Lakes signed on 17 March 1992 in Helsinki with its **Protocol on Water and Health** signed on 17 June 1999 in London envisages that the Parties – applying the precautionary and "polluter pays" principles, and taking into account the interest of future generations – shall take all measures to prevent, control and reduce pollution of waters causing or likely to cause transboundary impact; and ensure that transboundary waters are used with the aim of ecologically sound and rational water management, conservation of water resources and environmental protection. The protocol demands effective protection of water resources used as sources of drinking water, and their related water ecosystems, from pollution from other causes, including agriculture, industry and other discharges and emissions of hazardous substances.

The **European Landscape Convention** signed on 20 October 2000 in Florence actions calls upon the Parties to conserve and maintain the significant or characteristic features of a landscape, justified by its heritage value derived from its natural configuration and/or from human activity. There is no doubt that several segments of the project area constitute “landscapes” according to the Convention’s definition.

The **Convention on Wetlands of International Importance Especially as Waterfowl Habitat** signed on 2 February 1971 in Ramsar obliges the Parties, among others, to formulate and implement all plans related to wetlands so as to promote and facilitate the wise use of the concerned sites and the conservation of their ecological character.

The **Convention on the Conservation of European Wildlife and Natural Habitats** of 19 September 1979, Bern obliges Parties to conserve wild flora and fauna and their natural habitats and to protect endangered migratory species and prohibits the deliberately causing of damage or the destruction of breeding or resting sites, or disturbing wild fauna, particularly during the period of breeding, rearing and hibernation.

The Convention on Biological Diversity signed on 5 June 1992 in Rio de Janeiro has also been signed by the European Union. Relevant obligations include (but are not limited to) the integration of conservation in sectoral and cross-sectoral policies and programmes; to make provisions for in situ conservation within and outside protected areas through appropriate measures, and to take measures in the interest of the recovery and reintroduction of threatened species. In the context of SEA it is of particular interest that Parties are obliged to carry out environmental impact assessments relevant to plans and programmes which are likely to have significant adverse effects on biological diversity.

Space limits do not allow for the detailed scrutiny of each agreement’s specific obligations. As a matter of fact that would be premature too, as the evaluation of the facts (planned interventions) against the legal limits can only be made effectively once the main features and impacts of those interventions are scientifically identified and assessed.

6.1.2.2.Navigation

Beyond doubt, the most important in this respect is the **European Agreement on Main Inland Waterways of International Importance (AGN)** signed on 19 January 1996 in Geneva as it is ratified by 15 European states, including Hungary and Slovakia and it sets standards for international waterways also acknowledged by the European Union. The AGN’s aim is to determine unified technical and operational parameters for the construction, modernization, reconstruction and operation of waterways destined for international river transport. Its Annex III contains the desired technical characteristics of waterways of international importance. Accordingly, “only waterways meeting at least the basic requirements of class IV (minimum dimensions of vessels 80 m x 9.5 m) can be considered as E waterways. Restrictions of draught (less than 2.50 m) and of minimum height under bridges (less than 5.25 m) can be accepted only for existing waterways and as an exception"; … When modernizing existing waterways and/or building new ones, vessels and convoys of greater dimensions should always be taken into account; inland waterways expected to carry a significant volume of container and ro-ro traffic should meet, as a minimum, the requirements of class Vb[14]. On waterways with fluctuating water levels, the value of the recommended draught should correspond to the draught reached or exceeded for 240 days on average per year (or for 60% of the navigation period).

The **Convention regarding the Regime of Navigation on the Danube** signed on 18 August 1948 in Belgrade is expected to be replaced by the new Danube Convention which has been negotiated now over a lengthy period. The Danube Convention does not set concrete parameters for the navigational channel and the legally non binding recommendations of the Danube Commission adopted before the AGN became binding on the riparian states will have lost their importance in their respect after the AGN has entered into force[15].

Neither the Judgment, not the 1977 Treaty sets any concrete parameter for navigation.

6.1.2.3.Bilateral co-operation

Whereas the above multilateral treaties are not subject to the will of the parties, but have to be applied as they had been adopted, there are a number of bilateral treaties between the parties regulating their co-operation in environmental, water-management and related matters which are not constituting limits to the goals to be achieved as the two parties can at any time amend or terminate them in agreement. These include the **Agreement between the Government of the Slovak Republic and the Government of the Republic of Hungary on certain temporary technical measures and discharges into the Danube and Mosoni branch of the Danube**, of 1995, the **Convention Regarding the Water Management Issues concerning Boundary Waters of 31 May 1976.** In fact the former is a provisional, technical agreement, meant to be in force until the judgment of the ICJ is passed and extended by a low level, essentially oral agreement until the end of the present negotiations between the parties. The latter was to be replaced by a new agreement between the Republic of Hungary and the Slovak Republic. The text of the new agreement has been agreed upon but expression of consent to be bound is delayed. The frame and spirit of the bilateral co-operation is enshrined in Article 9 of the **Treaty on Good-neighbourly Relations and Friendly Co-operation between the Republic of Hungary and the Slovak Republic of 1995** which states that "The

[14] Parameters of Vb: length of pushed convoys: 172-185 m. beam: 11.4 m. Draught: 2.50-4.50 m. Tonnage: 3,200-6,000

[15] Remarkably those old recommendations are not even included in the website of the Danube Commission see: http://www.danubecom-intern.org/GERMAN/Flag/flaginhalt.htm visited on 13 April 2008.

Contracting Parties, motivated by their interest concerning care for the natural environment and preservation of acceptable living conditions for future generations, shall co-operate in environmental and nature protection aiming at preventing and reducing environmental pollution, especially as regards trans-frontier pollution". Similar general, but trend-setting obligations are to be found in the **Agreement on cooperation in the fields of environmental protection and nature conservation between the Government of the Republic of Hungary and the Government of the Slovak Republic** (signed in Bratislava on 12 February 1999.[16]

6.1.3. European law

As the Slovak reaction to the preliminary version of this study confirms, the parties "agree that any proposed solution must comply with European Law".[17]

6.1.3.1.The Water Framework Directive

The fundamental principles, objectives and legal requirements relating to the EU's water policy are laid down by the **Water Framework Directive (WFD)**[18].

The WFD is a Community act of crucial importance for the resolution of the legal dispute, since the basic principles of the resolution of the legal dispute have to be defined with due consideration to environmental objectives set by the Directive, whilst the parameters of technical variants to be taken into account have to comply with the environmental parameters designated by the Directive, whereas the final solution has to be harmonised with, and included in, the plans for river basin management to be prepared in cooperation with the Slovak experts.

The main goal of Community water protection policy is to protect and enhance water quality. In the interests of that, (further) deterioration of water status has to be prevented; sustainable, balanced, equitable and reasonable water use has to be implemented, moreover aquatic ecosystems and directly dependent terrestrial and wetland ecosystems have to be protected[19]. Consequently, it is the Water Framework Directive that stipulates the applicable environmental objectives covering surface water and groundwater bodies and areas connected with water bodies. It means basically – in the case of surface waters and groundwaters – achieving at least "good water status", while in the case of protected areas it implies the parallel and integrated fulfillment of the connected protection objectives.

[16] See further: http://www.huskenv.org
[17] „The standpoint of the Governmental Delegation of the Slovak Republic on the Hungarian document named
'Preliminary Feasibility Study: The Rehabilitation of the Szigetköz Reach of the Danube' "Bratislava, December 14, 2009, p. 6
[18] Directive 2000/60/EC establishing a framework for Community action in the field of water policy
[19] WFD Preamble Sections (19), (26) and (23), Article 1. points (a)-(b)

Member States have to analyse, whether "good water status" can be achieved through adequate measures, moreover whether the actual solution has a technically and economically feasible, environmentally more favourable, alternative. This requirement in practice means that the Republic of Hungary and the Slovak Republic have to – within the river Basin Management (RBM) planning process – jointly or individually, review the interventions necessary for achieving good water status and also give consideration to whether the conjunctive conditions determining its designation as a "heavily modified water body" still prevail[20].

If these conditions prove to be existing in the case of a concrete water body, it has to be regarded as heavily modified, otherwise it has to be regarded as being of a natural status. In both cases, however, a system of interventions has to be prepared as a result of which good ecological status or (in the case of a heavily modified water body) good ecological potential can be achieved.

Concrete interventions at the related sections can be defined only after the definition of environmental objectives. In the case of interventions the environmental compatibility of all forms of uses connected to the existing and already operating installations, e.g. energy production, shipping and flood-prevention, moreover that of the facilities and their operation has to be ensured. This in any case should imply the comprehensive revision of the operation of the Gabčíkovo-Nagymaros Project and its adequate modification.

6.1.3.2.The Community's nature conservation regime

The Community's nature conservation regime, in particular the so-called Birds and Habitats Directives[21], lays down fundamental constraints as to physical modification of or other intervention into the favourable conservation status of protected sites pertaining to the EU's Natura 2000 nature conservation network. Even though the main focus of the Community nature conservation regime is the prevention of damage to or disturbance of habitats and species, it also provides for active management of sites, i.e. interventions by Member States. The aim of active management measures is to maintain or restore, at a favourable conservation status, the relevant habitat types and species and to maintain bird populations at a level which corresponds in particular to their ecological, scientific and cultural requirements.

The type of management measure can be chosen by Member States as they see appropriate, subject to the requirements of the Habitats Directive. The content of the management measures has to be established in the light of the particular ecological needs of the actual Natura 2000 site on the basis of available scientific information, taking

20 WFD Article 4 para.(3); detailed designation conditions and procedures are specified on pages 12-14., 19-23. and 19-59 of the Guidance Document on Heavily Modified Water Bodies

[21] Directive 79/409/EEC on the protection of wild birds ("Birds Directive"), Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora ("Habitats Directive")

account of the relevant economic, social and cultural requirements, as well as regional and local characteristics.

The obligations of the Parties with regard to the active management of Natura 2000 sites are not *prima facie* affected by the Gabčíkovo-Nagymaros Dispute. However, future changes to the operation of the installations in order to comply with applicable environmental objectives may necessitate the revision of existing management measures with regard to a number of sites.

6.1.4. International law as European law

Along with the Community secondary legislation it should also be remembered, that Member States are obliged to also apply international conventions adopted by the Community as Community law. As enforced by the International Court of Justice in the case *Commission v. Ireland* (C-459/03) in its judgement[22] on the 30th of May, 2006, "international conventions adopted by the Community form an integral part of Community law,.....in accordance with the standard judgement practice". As a consequence, the following conventions *inter alia* are to be taken into consideration:

- Bio-diversity Convention (Rio de Janeiro, 1992)
- Convention on the protection of migrating birds and wild fauna (Bonn, 1979)
- Convention on the protection and sustainable use of the Danube (Sofia, 1994)
- Convention on the protection and sustainable use of international cross-border and bordering fluvial waters and lakes (Helsinki 1992)

6.2. Stakeholder interests

Stakeholders' interests have not been assessed in this study. Further planning steps based on these results will include public participation and based on it will outline Stakeholder's interest.

Several assessments were already carried out on stakeholders' interests of local inhabitants like a recent study of a LIFE-III Community Programme[23].

[22] http://curia.europa.eu/jurisp/cgi-bin/form.pl?lang=hu&Submit=Keres%C3%A9s&alldocs=alldocs&docj=docj&docop=docop&docor=docor&docjo=docjo&numaff=C-459%2F03&datefs=&datefe=&nomusuel=&domaine=&mots=&resmax=100

[23] Implementation of an Innovative Decision Support Tool for the Sustainable Water and Land-use Management Planning and Flow Supplementation of the Hungarian-Slovakian Transboundary Danube Wetland Area: Szigetköz (LIFE04ENV/H/000382)) between 2004 and 2007. For more details please refer to www.szigetkozosen.hu

7. Delineation of environmental objectives

7.1. Introductory remarks

Human use and alteration of riverine landscapes and their catchments have led to their enormous degradation, especially in highly industrialised countries (Dynesius & Nilsson 1994, Schiemer 1999, Jungwirth et al. 2000). The related problems are increasingly recognised not only in the scientific community but also in the society. Therefore interest has grown in restoring ecosystem functions of regulated rivers. This recognition is emphasized in the EU Water Framework Directive (Water Framework Directive, 2000) in which the "ecological status" of river systems is one of the central considerations.

In large river remediation the definition of environmental objectives and the benchmarking of restoration variants have to be based on an analysis of the natural ecosystems prior to major human interventions ("reference standards", Henry and Amoros, 1995, "Leitbild concept", Kern 1992). These reference conditions are based on historical habitat analysis, a comparisons with undisturbed reference sites and on a general understanding of relationship between hydrological processes and conditions and the ecology of riverine landscapes.

Successful rehabilitation of river-floodplain systems requires knowledge of how hydrological dynamics and geomorphic processes lead to a dynamic equilibrium of habitat composition which determines the characteristic biodiversity and the ecological processes of the river ecosystem (Schiemer et al. 2007). Over the past two decades numerous concepts have been elaborated that explain the functioning of river ecosystems (see Thorp et al. 2006). These concepts represent a useful background for describing the natural river system of the Szigetköz section of the Danube and the formulation of an evaluation system for restoration and management variants.

Major impacts in the catchment and in the upstream sections of rivers, long-term impacts of past river engineering and the present social, economic and cultural demands of modern societies generally prevent a full return to original conditions. In addition, irreversible changes, e.g. extinction of species and last but not least the largely unknown impact of climate change, inevitably imprint the present ecosystems and have to be accepted as framework condition for rehabilitation planning. Thus, environmental objectives do not aim on the reconstruction of a historical landscape nor should the main effort concentrate on the fostering of selected species or species groups: the definition of environmental objectives rather focuses on the hydrodynamic and morphodynamic processes governing the natural riverine ecosystem with its resultant pattern of habitats and diversity of species. In general terms the goal is to foster hydrology and hydro-geodynamics, accepting irreversible changes and constraints. This general objective has to be put in practical terms of flow regime predicted geodynamics and the resulting habitat composition and diversity, habitat turnover and quality, which has to be ascertained by biotic indicators. In the definition of the environmental objectives we have to follow the cause–effect chain: the flow regime and flow diversion will define the hydrology and the hydro-morphological dynamics of the river-floodplain system. This will result in a dynamic state of habitat composition and landscape structure, which finally will result in a characteristic pattern of ecological integrity, biological diversity and ecological functions.

This approach attempts to restore the ecological integrity by allowing sustainable human use. It corresponds to the definitions of the WFD which bases its environmental objectives mainly on defined biological quality parameters and thresholds of chemical substances but uses hydro-morphological elements for auxiliary assessment. In the case of "heavily modified water bodies" these objectives are taking into account defined uses and refer to the good ecological potential.

In the following paragraphs the main objectives of rehabilitation and the respective evaluation criteria are outlined taking into account of the cause-effect chain of a) hydrological and hydro-morphological dynamics, b) the resulting landscape structure and c) the effects on biota and biodiversity.

The appraisal of variants is based on the degree of improvement in relation to the reference conditions focusing on tendencies rather than on absolute values:

--	considerably worse than present status	bad
-	status insufficient	poor
-+	status far from reference conditions but still acceptable	moderate
+	improvement of status acceptable but still far from reference conditions	good
++	considerable improvement or acceptable status compared to reference conditions	excellent
0	no change with increase of discharges	

7.2. Hydrological and hydro-morphological dynamics

The objectives outlined in Table 7-1 represent qualitative and quantitative cornerstones for rehabilitation scenarios. The general emphasis has to be put on an increase of hydrodynamics and morphodynamics in terms of water level fluctuations, diversity of flow velocities, erosion and sedimentation processes. The environmental objectives are competitive with the production of energy at Gabčíkovo. Therefore the criteria do not establish a certain threshold of discharge but rather focus on processes that might be initiated at different flows depending on technical solutions.

The environmental objectives given in Table 7-1 fulfil the requirements of the hydromorphological quality elements defined by the WFD in annex V, table 1.2.1

Table 7-1 Environmental objectives / constraints for the hydrodynamic and morphodynamic regime of the Danube in the Szigetköz and appropriate benchmarking criteria

Parameter	Objectives	Benchmarking
Flow regime and its seasonal dynamics	Seasonal variations of the flow reflecting the natural run-off from the catchment. Full flood regime. *Constraints:* Water power production: (§ 146 of the Judgement).	Diversion of flow in relation to the flow of the Danube
Variations of flows and water levels at correct stage	High range of water level fluctuations throughout the year. Mean flow level should approach pre-dam conditions. *Constraints:* a) Water power production b) Flood protection barriers	Absolute water levels at low and high flow. Water level amplitudes predicted by the 1D- and 2D-surface water model (see Chapter 8.3.1, 9.4.1)
Bed load transport	The flow regime should allow effective bed load transport, *Constraints:* a) Water power production b) Availability of bed load material c). Possible river bed incision	Potential for morphodynamics evaluated on the basis of flow velocities and shear stress predicted by the 1d- and 2d-surface water model (see Chapter 8.3.4, 9.4.4)
Channel evolution	Morpho-dynamics allowing habitat rejuvenation up to long-term evolution of new born water courses. *Constraints* a) Availability of bed load material b). Possible river bed incision	As above plus results from morphological modeling (see Chapter as above)
Lateral, longitudinal and vertical connectivity	High lateral and longitudinal connectivity. Enhanced vertical connectivity.	Surface water connectivity derived from the 1d- and 2d-surface water model Fine sediment deposition assessed from flow velocity and shear stress pattern. Groundwater level dynamics (see Chapter as above)
Groundwater regime	Recharging of groundwater: sufficient infiltration of river water into the aquifer	Modeling of groundwater level dynamics (see Chapter

Parameter	Objectives	Benchmarking
	and exfiltration at falling flood stages. The range and level of ground-water fluctuations should provide moisture to the cover layer and maintain the wetland character.	8.3.3, 9.4.3)

7.2.1. Flow regime and seasonal dynamics

The ecology of river ecosystems is characterized by varying environmental conditions due to seasonal changes of water and groundwater levels and by irregular but frequent disturbance through flood pulses of different magnitude. The variety of habitats largely depends on competent flood flows which rejuvenate succession stages, initiate new water courses or side-arm development. For the ecological functioning it is necessary to re-establish the full flood regime which ensures the governing morphodynamic processes.

The natural flow pattern of the Danube over the year reflects the alpine flow regime with high discharges during the vegetation period due to snow melt. Flood flows are superimposed on this regular flow pattern and can occur at any time of the year. The variation of water and groundwater levels associated with this characteristic flow pattern is an essential factor for terrestrial wetland habitats. One of the key elements for biodiversity is the resulting mosaic of habitats with varying conditions of substrates, moisture and flood exposition providing habitat conditions for a high biodiversity of well-adapted and characteristic floodplain biota.

The only constraint for providing the natural flow regime is the diversion of river water to the power station at Gabčíkovo. The present rules of the Temporary Water Management Regime already provide residual flows based on the hydrograph at the Devin gauge. The dynamic flow regime in the Szigetköz system should however be enhanced in order to achieve a good ecological potential and higher sustainability. The proportion of the discharge necessary to sustain vital ecological functions also depends on other criteria, e.g. the range of fluctuations, and may vary with different technical solutions. The present regime is clearly insufficient especially in terms of flood flows.

Floods are important regulators of vegetation and cause habitat rejuvenisation and biotic successions. The cessation of floods inevitably leads to the loss of the floodplain character of the habitat.

Seasonal variations of the flow should reflect the natural run-off from the catchment. The discharge released into the Szigetköz system should be directly coupled with the flow rates measured at the Devin gauge. In order to initiate vital morphological processes the system must be exposed to the full flood regime.

7.2.2. Variations of flows and water levels at correct stage

Sharing flows with a dynamic regime does not support ecological functions as long as the associated varying water levels fail to reach the proper positions in elevation which characterized the natural dynamic environment. Therefore, it is essential to find technical solutions that compensate for the abstraction of discharge volume by raising water levels ensuring free flow and water level fluctuations of a nearly natural range and position.

Again, the main constraint is the abstraction of water for power production. In addition, for flood security the level of extreme flood flows may not be raised above the present stage. Additional measures for flood protection are necessary since the present system does not allow for the safe channelling of the design flood. Further constraints may represent the large quantity of appropriate material needed for raising bed levels in some solutions and/or financial constraints for investment.

The range of water level fluctuations throughout the year should comprise about 2 m not regarding extreme floods and droughts. The mean flow level of the dynamic residual discharge in the main channel of the Danube downstream of Čunovo should be at least on the level of pre-dam conditions.

7.2.3. Bed load transport

The basis of morphodynamic processes is the ability of the river to transport sand and gravel in a dynamic equilibrium. The alluvial cone forming the Szigetköz/Zitny Ostrov floodplain developed over hundreds and thousands of years until a long-term equilibrium of arriving bed load, local scouring, deposition, abrasion and transport of sediment in the downstream sector was nearly attained. Incision of the bed level of only a few centimetres per year can easily be acknowledged as man-induced when extrapolated on a geological time scale.

An obvious constraint of bed load transport is the availability of sand and gravel below the Hrusov reservoir. Although sediments exposed by lateral erosion and available in gravel bars may represent a substantial reserve there is a lack of bed load input from upstream which might have to be overcome by appropriate means of sediment management.

The flow regime should be able to allow effective bed load transport, i.e. movement of sand and gravel available in banks by lateral erosion, by movement of bars, or by added sediments (sediment management).

7.2.4. Channel evolution

A dynamic system is characterized by changing conditions. The formation of new channels, the movement of bends by lateral erosion, the siltation of abandoned arms receiving slow flows during floods only – all these processes are inherent in a vital riverine lowland ecosystem. The formation of a new channel bed or the mere transport of sediments can rarely be observed. Signals of vital river systems still experiencing these processes are the existence of irregular bare sand and gravel shores between water bodies and terrestrial habitats. For the biota the transitional zone or ecotone represents the most productive area of the ecosystem.

Lateral erosion, transport and deposition should have the chance to reshape channels up to the long-term evolution of new born water courses.

7.2.5. Lateral, vertical and longitudinal connectivity

Most of the objectives outlined above support lateral and vertical connectivity. Providing longitudinal connectivity is a legal obligation set out by the WFD. This includes the construction of migration routes at the Čunovo weir.

The undisturbed Danube provided mutual opportunities for exchange of water and biota. Depending on water levels the aquatic fauna should have ample access to branches in various stages of succession. Upstream and downstream migration has to be ensured avoiding impoundments.

7.2.6. Groundwater regime

Maintaining a groundwater reserve of a high potential in terms of quantity and quality is of prime importance for both bordering states. The natural fluctuation of surface water levels ensured a good passage of river water into the aquifer. Prevention of clogging was ensured in the natural system by exfiltration of groundwater into the main bed and active side-arms at falling flood stages. A sustainable solution should incorporate a similar process of self-maintenance of groundwater recharge. Any potential for the deterioration of groundwater quality should be avoided even if there is no evidence of deterioration at the present time.

Morphodynamic processes, inundations and groundwater level fluctuations combined with a pattern of different soils and substrates determine the biodiversity of the Danube wetland in its bio-geographical context. The rise and fall of groundwater levels at appropriate stages in relation to the regional distribution of the cover layer are essential factors in this respect. The assessment of technical solutions needs to consider quantitatively the dynamic regime of the groundwater.

The potential groundwater resource must be maintained at the level of 1.1 million m^3/day. No significant changes can be allowed in the availability of riparian zones for establishing future bank-filtration wells and in the quality of the river bed material (influencing the quality of the bank-filtered water), thus considerable sedimentation (silting) in the main channel must be avoided.

The hydrolpogical and hydro-morphological models applied for predicting the effects of measures of the different variants are outlined in chapter 7.

The system should ensure recharge of the groundwater in natural quantity and good quality. In the main branch no layer of silt should prevent infiltration of river water into the aquifer or the exfiltration of groundwater at falling flood stages. The range and level of ground-water fluctuations should correspond to the natural situation in order to provide moisture to the cover layer and maintain the wetland character.

7.3. Landscape structure

The Szigetköz floodplains are bearing an outstanding significance from the aspect of Hungarian nature protection. The Szigetköz area is the only place in Hungary where a braided river section developed on the alluvial fan. The landscape still shows a mosaic of the old floodplain elements. However, due to river engineering the original habitat composition has been considerably changed and habitat turnover became restricted. The trends in the landscape change are ongoing, in the direction of a general loss of aquatic areas, especially with respect to dynamic rejuvenation zones. Terrestrialisation, the process of loss of aquatic areas by the accumulation of organic and inorganic sediments but also by a lowering of the groundwater table in the floodplain, is strongly accelerated. The general environmental objective of restoration measures therefore has to be the enhancement of aquatic and transitional zones and their temporal turnover in direction of the “Leitbild” (see above).

Table 7-2 Objectives of restoration with regard to spatial extent, habitat quality and connectivity of characteristic landscape elements. Benchmarking criteria for the evaluation of restoration variants.

Landscape element	Objectives regarding physical and ecological characteristics of landscape elements	Benchmarking
Aquatic habitats		
Eupotamon A & B	Long-term maintenance and fostering of arms with permanent flow, near to natural flow dynamics, increased extent of inshore zones and ecotonal structure, exchange processes with the aquifer.	spatial extent of eupotamal zones, extent and structure of inshore zones, amplitude and temporal pattern of water level fluctuation

Landscape element	**Objectives regarding physical and ecological characteristics of landscape elements**	**Benchmarking**
	High significance for biological processes and biodiversity, essential habitat for rheophilic fish species	
Parapotamon	Long-term maintenance and fostering of side-arms with permanent connection to the flowing arms, improved connectivity to the river, improved ecotonal structure (as above) exchange processes with the aquifer, essential for biota of eupotamon as refuge during the flood events, wintering habitat, spawning ground and feeding area	Spatial extent of parapotamal zones. Temporal extent of connectivity to the eupotamon. Extent and structure of inshore zones. Amplitude and temporal pattern of water level fluctuation
Plesiopotamon	Long-term maintenance and fostering of permanent or temporary standing waters with temporary connection to the flowing arms. Intensified hydrogeomorphic processes by higher flow diversion in the floodplains for a sustained maintenance of this habitat type. *Essential habitat for limnophilic species, macrophyte dominated*	Spatial extent of plesiopotamal zones. Temporal extent of connectivity to the Eupotamon. Extent and structure of inshore zones, Amplitude and temporal pattern of water level fluctuation, Prognosis for long-term sustainability of this habitat type
Paleopotamon	Long-term maintenance and fostering of completely disconnected permanent standing waters *Indispensable habitat for some limnophilic species,* *intensive macrophytes growth*	Spatial extent of palaeopotamal water-bodies. Prognosis of long-term sustainability of this habitat type on the basis of hydro-morphological modelling.
Terrestrial habitats		
Low floodplain	Spatial extent of low floodplain terrestrial and pioneer habitats. Increased spatial extent of regular inundations. Soils are moistened with flood	Predictions on areal extent and development of low floodplain vegetation zones and terrestrial and ruderal and semi-ruderal habitats by vegetation model.

Landscape element	Objectives regarding physical and ecological characteristics of landscape elements	Benchmarking
	waters and by ground water. Improved growth conditions for the characteristic biota by larger flood pulses and higher groundwater fluctuations	Spatio-temporal extent of flooding: duration of regular inundation 1-2 month/year or more
High floodplain	Spatial extent of high floodplain habitatsfostered by an increased spatial extent of irregular inundations, by higher water diversion and higher amplitude of water level fluctuation. *Improved growth conditions for the characteristic biota by larger flood pulses and higher groundwater fluctuations*	Predictions on areal extent and development of high floodplain vegetation zones. Spatio-temporal extent of flooding, mean duration of irregular inundation is less than 1 month

7.3.1. Aquatic habitats

Aquatic habitats of the river ecosystem are determined by a range of hydraulic and morphological variables. Two different types of 'habitat sectors' characterize the alluvial river ecosystem of the Szigetköz according to its morphology: 1) braided sector (along the ridge of the alluvial cone), 2) meandering sector (on the edges and at the end of the alluvial cone). The braided sector is mostly unstable, which does not make complete development of ecological succession possible. The river-floodplain system includes aquatic, semi-aquatic and terrestrial habitats within the alluvial plain, that are interconnected with the river. The seasonal pattern of the hydrological regime is accompanied by a seasonal cycle of high and low water levels on major parts of the floodplain, which causes characteristic properties of various floodplain habitats The rejuvenation process is a prerequisite to maintaining the habitat elements and their dynamics and successional stages.

In the meandering sector channels migrate downstream and meander loops can become disconnected. The abandoned oxbow lakes (disconnected meander loop) gradually lose their connection with the river and get filled up over a few centuries. The relative stability of the meandering river section allows the full development of ecological succession.

The distinction of floodplain water bodies is based on the hydrological regime combined with hydro-morphological and ecological characteristics (Roux et al. 1982, Amoros et al. 1987; see Chapter 1.2.2 and Figure 7-1). We adopted the definitions of aquatic habitat types of Amoros & Roux in a version which was used by Hohensinner et al (2005) for the Austrian Danube.

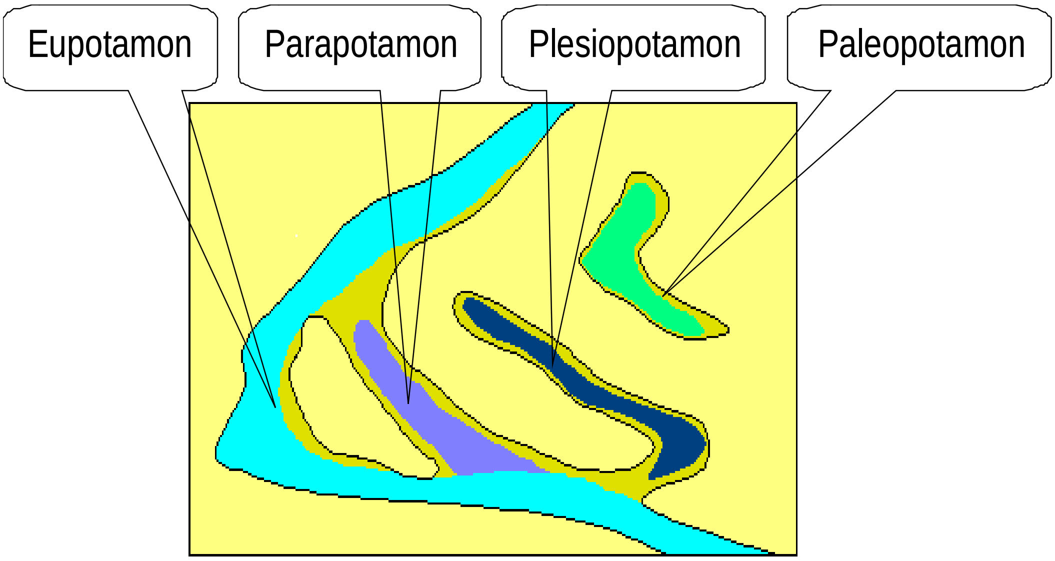


Figure 7-1 Schematic demonstration of the main types of functional sets within the Potamon hydro-system according to Amoros et al. (1987)

The ecological benchmark system of the diverse fluvial system of the Szigetköz is beyond the assessment methods of the WFD (see Appendix 1) and involves the "functional unit" concept of Amoros and Roux. The benchmarking is compiled using historical habitat and biological data. The main elements of the benchmark system are based on a quantitative assessment of the areal extent and proportion of aquatic habitats, with the reference of the historical habitat distribution. It is supported by habitat quality considerations based on the ecological requirements of characteristic biota, with the reference of the pre-regulation (19th century) biotic data.

The habitat types were determined according to the different modelled flow regimes in the side-arm system:

Eupotamon B upstream connection and throughflow at $40 m^3/s$;
Parapotamon A : throughflow at $80 m^3/s$;
Parapotamon B : throughflow at $120 m^3/s$;
Plesiopotamon upstream connection at flow regimes of above $180 m^3/s$ in the side-arm system.

A qualitative benchmarking is applied by contrasting the habitat features with the ecological requirements of the various fish guilds: (Schiemer & Waidbacher 1992)

7.3.2. Transition zone

Throughout the fluvial hydrosystem essential interactions take place across the land-water boundary. These Aquatic-Terrestrial Transition Zones (ATTZ) and their dynamic change with water level fluctuations are major ecological assets of floodplains and significant with regard to functional processes, i.e. production and decomposition processes, nutrient storage and turnover. They are significant for exchange processes with the groundwater aquifer and important microhabitats for characteristic floodplain biota.

The ecological integrity of the Szigetköz section of the Danube is dependent upon the strength of connectivity between the river and the floodplain. The pattern of flood-pulses are key elements for the maintenance of diversity of many taxonomic groups in a river floodplain system resulting in a gradient of plant associations adapted to seasonal inundation and an input of nutrients along the ATTZ. Enhanced primary production during the early stages of flooding provides essential conditions for reproduction and the feeding of fish and other animals which migrate from the river onto the floodplain with the rising water. Inundation provides aquatic animal’s access to allochthonous food sources. During flooding the littoral of the ATTZ provides nursery grounds for fish and a favourable habitat for aquatic invertebrates and adult fish. During the dry season terrestrial grasses and shrubs re-grow, terrestrial animals decolonize the floodplain and remaining aquatic vegetation is decomposed.

Certain floodplain habitats develop on surfaces continuously built up and washed away by the river. Purple willow bushes (Rumici crispi-Salicetum purpureae) established on gravel shoals, while in slower flowing sections where islands were formed of fine sand and silt almond-leaved willow bushes (Polygono hydropiperi-Salicetum triandrae) appeared. In the absence of formation of new islands the vegetation changes through the process of natural succession and ultimately becomes replaced by willow and poplar gallery forests, or by poplar plantations. Vegetation development on Transition zones in dependence on sediment type and the extent and temporal pattern of flooding – depending on the topography of the channels is discussed in context with the vegetation model.

A high areal extent of transition zones and a dynamic resetting of vegetation successions has been a characteristic feature of the natural situations. Therefore the development of transition zones should be a highly ranked evaluation criteria for variants.

7.3.3. Terrestrial habitats

In the terrestrial floodplain areas with a high inundation frequency the vegetation represents stages of an allochthonous succession. Along the gravel bars and shoreline of branches normally low willow scrubs are formed with species composition depending on the quality of the soil. On the gravel shallows purple willow scrubs (*Rumici crispi-Salicetum purpureae*) are settled. In the sandy sections almond-leaved willow scrubs (*Polygono hydropiperi-Salicetum triandrae*) are developed.

The low floodplain is affected by common floods and its average annual inundation lasts for 1 to 2 months or longer. Willow and poplar woods characterize its vegetation. The habitats inundated by smaller floods are generally forested by willow groves (*Leucojo aestivi-Salicetum albae*). Where the soil formed on the sand-gravel underlay black poplar groves (*Carduo crispi-Populetum nigrae*) are developed. On the higher terrain of the low floodplain which is only flooded for a shorter term, white poplar groves (*Senecioni sarracenici-Populetum albae*) are formed. In closed-drainage areas with good water supply willow and alder woods (*Calamagrostio-Salicetum cinereae, Carici elongatae-Alnetum*) range in.

The high floodplain is less exposed to the floods and the duration of its annual inundation is less than one month. Its vegetation is characterized by various hardwood associations: alder groves (*Paridi quadrifoliae-Alnetum*), oak ash elm groves (*Pimpinello majoris-Ulmetum*), hornbeam oak forests (*Majanthemo-Carpinetum*), closed and open dry oak forests (*Piptathero virescentis-Quercetum roboris, Peucedano alsatico-Quercetum roboris*), etc.

There are also swamp- and fen-meadows associations in the floodplain, such as the fen-meadow of calciferous ground (*Succiso-Molinietum hungaricae*) and mountain fen-meadow (*Carici flavae-Eriophoretum*). The first one prefers soils saturated with water.

The evaluation of variants is based on the trends of a long-term development of the different types of terrestrial vegetation. This is described in detail in the in the Appendix 2.

7.4. Biota and biodiversity

Morphodynamic processes within floodplains result in the characteristic composition and connectivity of habitat elements which finally are the arena on which the ecological processes and the characteristic biotic diversity are dependent. With respect to our present understanding of river-floodplain ecology and the requirements set by the legal frameworks especially the WFD, we have to aim for the good ecological status or potential with regard to trophic conditions of the water bodies, the functional limnological processes and the characteristic biota. Specific quality elements are listed and defined by FFH and other Directives. The WFD specifically recommends the consideration of Phytoplankton, Aquatic and Semi-aquatic Macrophytes (including Bryophytes), Macrobenthos and Fish as significant groups for the evaluation and benchmarking of the ecological quality. The environmental objectives aim at significantly improving the habitat extent and quality for characteristic floodplain associations, especially those which were severely endangered by the trends in landscape development following the regulation and damming of the area. Endangered biota are important indicators for both conservation status and benchmarking regarding the extent and quality of habitat elements.

The natural flora and fauna and biodiversity of the Szigetköz landscape are considered a significant value for nature protection. From the aspect of biogeography the Szigetköz belongs to the floral and fauna district of the region below the Devin Gate (*Arrabonicum*) within the floral province of the plain (*Eupannonicum*) within the Hungarian floral territory and the plane fauna province (*Pannonicum*)**.**

An assessment of species richness is not sufficient in itself. It is important to assess the diversity of species strongly associated with riverine floodplain habitats and dependent on the specific ecological conditions. If such species biotopes become rare or disappear, it is indisputably an unfavorable change. Furthermore, the establishment or dominance of drought tolerant species, even of protected ones, is unfavorable because it puts at risk the floodplain character of the landscape.

65 protected higher plant species were registered in the Szigetköz region. Two of them (*Pulsatilla pratensis ssp. nigricans*, *Myricaria germanica*) were recorded more than 50 years ago. Four of them are strictly protected. Most of the protected higher plants species (60 spp.) are terrestrial. One European Red listed and protected bryophyte species was found in the branch system. 3 saxicolous species characteristic of the Danube bryophyte flora are rare in Hungary will be including in the National Red list.

The diversity of the Macroheterocera fauna of the inner areas of the Carpathian Basin counts some 1300 species of which somewhat more than 550 species have been recorded from the flood plain of the Szigetköz area. Most of the species are connected to woodland habitats but the proportions of the arundiphilous and the species preferring humid grasslands are also considerable. The number of the species protected in Hungary ever recorded from the entire Szigetköz area is altogether 37; from this pool 26 are known from the flood plain. It is worth mentioning that ca 50% of them inhabits anthropogenically more influenced or degraded biotopes.

Occurrences of 76 fish species were observed in the Szigetköz section of the Danube, two of them (*Huso huso, Acipenser stellatus*) are extinct in the region and 18 of them are protected by Hungarian law. 11 amphibian species and 5 reptile species are also protected. There are about 200-220 bird species and 40 mammal species in the region, most of them are protected. The high number of bird species is maintained by the mosaicity and habitat diversity of the area, while the density of the species is increased by the dense shrub layer and the edge effect. The species-composition of the Szigetköz is similar to those of lower montane forests, but the density is higher (150-200%). The presence and co-occurrence of diverse habitat types allow the breeding of several strictly protected species (*Ciconia ciconia, Haliaetus albicila*).

The hydrological and geomorphologic changes resulted several ecological responses. The ecological assessment of the Szigetköz has to be based on the identification and quantification of these ecological responses and assessing the deviation from undisturbed reference conditions. The benchmark system is critical for the evaluation of the deviations, predicting the future changes, and assessment of rehabilitation measures. The benchmark is a reference point, which compared to measurements when quality is evaluated.

Table 7-3 Restoration objectives: biotic indicators with respect to habitat quality

Landscape element	restoration objectives	benchmarkings
Aquatic habitats		
Eupotamon	Near to natural flow dynamics, increased extent of inshore zones, and ecotonal structure because of its high significance as essential habitat for rheophilic species	Adequacy for characteristic rheophilic guilds of macrozoobenthos and fish (nursery-quality for rheophilic fish)
Parapotamon	Improved connectivity to the river, essential for biota of eupotamon as refuge during the flood events, wintering habitat, spawning ground and feeding area. Increased areal extent of this type because of its high significance as essential habitat for characteristic species guilds.	Adequacy of connectivity specialists of rheophilic fish, characteristic macrobenthos associations
Plesiopotamon	Long-term maintenance and fostering of permanent or temporary standing waters, significant habitats for macrophyte, macrozoobenthos and fish communities. Main breeding zone for Amphibians	Adequacy for characteristic macrophytes, fish and amphibian communities.
Paleopotamon	Long-term maintenance and fostering of disconnected water bodies, as a final aquatic successional stage in active floodplains. High biodiversity. Indispensable habitat for limnophilic fish species. Important habitat for amphibians	Adequacy for characteristic marophyte, fish and amphibian communities.

Landscape element	restoration objectives	benchmarkings
Transition zone		
	The aquatic-terrestrial transition zones are specific habitats of floodplains with a characteristic flora and fauna. Significant nursery zone for fish.	Extent of transition zones linked to the various aquatic habitat types. Adequacy for characteristic pioneer plant associations and bryophytes.
Terrestrial habitats		
Low floodplain	Improved growth conditions for the characteristic vegetation by larger flood pulses and higher groundwater fluctuations	Extent of autochtonous softwood forest: riverine willow shrubs, willow and poplar forests, reeds and sedge communities
High floodplain	Improved growth conditions for the characteristic vegetation by higher groundwater fluctuations	Extent of autochthonous hardwood A high diversity of hygrophilous Lepidoptera is a good quality indicator for this habitat type.

The following biotic indicators have been taken into account and the assessment focused on properties of variants with respect to

- conditions for rheophilic guilds of fish (rheophilic A&B, Schiemer and Waidbacher,1992), maintenance of stagnophilic guilds;
- conditions for rheophilc guilds among macrozoobenthos (Ephemeroptera, Odonata)
- conditions for amphibians as biotic indicators for parapotamic and palaopotamic water bodies;
- potential for a development of pioneer vegetation on gravel, sand and silt (transition zones according to Amoros-Roux habitat types);
- habitat quality of the bryophyte vegetation as an indicator of the aquatic-terrestrial ecotones;
- long-term development of terrestrial vegetation based on predictive habitat modelling, maintenance of pioneer associations, soft wood and hard wood alluvial forests in proportions comparable to reference standards
- maintenance of good habitat conditions for lepidopterans as quality indicator of terrestrial habitats

Details of benchmarking methodologies for fish, macrozoobenthos, lepdidopterans, and Amphybia, are presented in Appendix 3, 4, 5, and 6.

8. Investigation of rehabilitation measures

For the rehabilitation of the Danube floodplain habitats in the Szigetköz several suggestions have been made by different stakeholders over the last 15 years. Some of them have been studied and planned to a greater detail than others which existed only as general concepts. In this study it was not possible to elaborate plans at the same level for all variants selected. Efforts were made, however, to investigate the principle performance of all variants with respect to key parameters and processes as defined in Chapter 7.

8.1. Technical description of rehabilitation measures ("variants")

At the beginning of the study [see the preliminary version of this study: VITUKI (2009)] a broad variety of measures, e.g. with different numbers of weirs in the main channel, had been considered for testing. With increasing knowledge of model results, however, a few basic variants were selected for the final runs.

Table 8-1 Basic variants selected for model tests

Variant	Description of measures
Present channel network Increase of discharge / Variation of flow regime	- No additional measures, present network - A series of increased discharges in the main channel and in the side branches were run in model tests The release of increased flood flows close to natural conditions was investigated for morphodynamic processes and for economic (energy production) consequences
SZITE	Measures: 3 weirs in the main channel, dredging of point bars-, clear cutting of defined floodplain areas, additional check dams in side branches, removal of some side-arm closures
Narrowing	Measures: Raising level of existing vegetated point bars by 2 m comprising 1/3 of the channel area, side-arm closures left (an additional version included the removal of side-arm closures)
Optimum filling	Measures: Raising the bed level by 3-4 m in order to obtain average water levels of the 1950s at a discharge of 350 m^3/s in the main channel + 80 m^3/s in side branches
Widening[24]	Measures: Broadening the channel by 100 m + raising bed levels by gradual widening + filling (self adjustment)
Meander (INTERREG)	Measures: Construction of 7 more bottom sills in the main channel and connecting selected side branches on both sides of the Danube in order to create a single meander channel (in the simulation a version without weirs in the meander branch was adopted)
Meander (400)	Measures: Creating a new meander channel with a capacity of >400 m^3/s associated with 8 sills in the main channel (including the existing one at Dunakiliti)

[24] Several proposals were made for the widening (and lifting) of the main channel: Martin Jaeggi (1994), Péter Molnár (2004), VITUKI (2005); after first investigations only the Widening variant proposed by Jaeggi was kept as a concept.

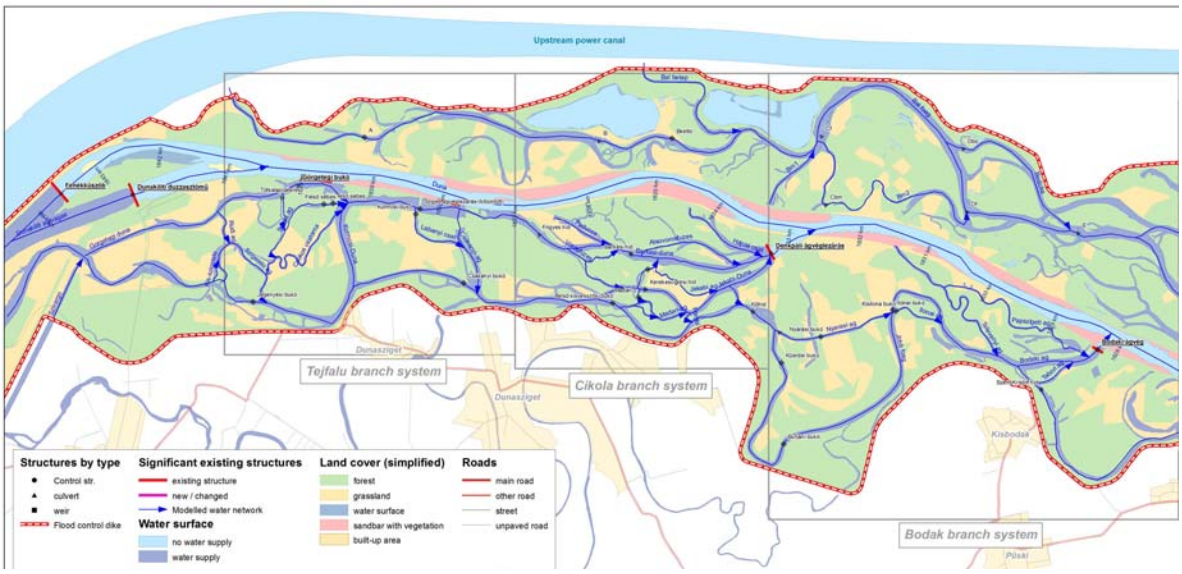
Present channel network / Increase of discharge / Variation of flow regime

The present situation of the Danube channel and the floodplain is the essential basis of all other variants. The channel network, the floodplain topography and the technical structures are defined in this “zero stage”.

For the Hungarian side the channel network is implemented in a previous MIKE 11 model that has the geometry data from the 1995-2000 period. The cross-sections are updated. The most remarkably affected ones are the Danube riverbed cross-sections, where geodetic survey results from 2004 have been applied. In the Hungarian side-arm system only those connected riverbeds were taken into account that had real geometric data. However, only channels that do not contribute to the discharge conveyance, mainly channels receiving backwater, were left out from the model. The structures in the side-arms (check dams, closures, culverts etc.) were also introduced in the model.

For the Slovak side only a Danube Atlas was available that has its cross-sections from the 1970’s. The technical parameters of the structures in the branches were taken from operational guidelines of the hydropower system. Where available, updated cross-section data from 2004 were used.

The present network and all other variants were investigated in 1D- and 2D-hydrodynamic models with a series of discharges (Chapter 8.2.5).



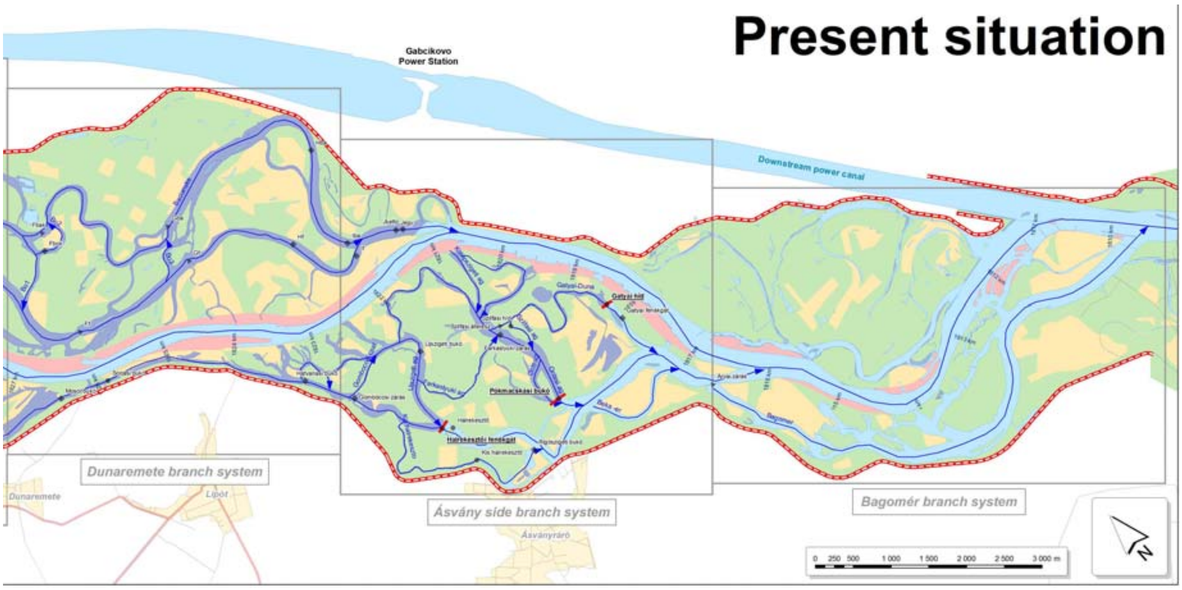


Figure 8-1 Present channel network

1D- and 2D-surface water models, a groundwater model and ecological models were applied to the project area with the existing channel network in order to study the impact of the flow regime without structural rehabilitation measures (for model details see Chapter 8.2, results are presented in Chapter 8.3). Some model investigations used time series of flows instead of steady state flow analysis.

Since October 1992 the flow regime has only rarely been able to provide efficient flood flows for sediment transport. Morphodynamic processes, however, are a key element in the ecology of large rivers. Therefore, a specific study was carried out reversing the discharge distribution between the Danube and the power canal above a certain threshold of flood flows.

SZITE variant (construction of 3 weirs in the main channel)

The so-called SZITE variant, promoted by the Szigetköz Environmental Protection Association of the Szigetköz (Szigetközi Természetvédelmi Egyesület, SziTE), a local Hungarian NGO, had already been produced as a draft plan by the Regional Water Management Unit (ÉDUKÖVIZIG).

Therefore, this variant has the most detailed designed interventions and structures. The main idea of the plan is to construct 3 new complex weirs in the Danube to raise the water level in order to re-connect side-arms, that had been obstructed by closures (Figure 8-2).

This solution defines the measures for the low water regime and for design flood conveyance as well; such as dredging side-arms, opening closures (dams), creating ice/flood-conveyance lanes and removing sediment deposits from the main river bed. In detail:

- ~175 ha conveyance lanes in both floodplains (defined locations) - The flood ways (conveyance lanes) are woody areas in the floodplain which will be cleared from ligneous vegetation to provide the suitable conveyance capacity to transmit the design flood and ice volume.
- ~140 ha dredging in the Danube main riverbed (defined elevation)
- ~380 ha cleaning of vegetation on shallows along the Danube main riverbed (defined locations) - The cleaning of vegetation in the channel means partly the same areas as dredging vegetated shallow ponds in the main riverbed, and on the other hand small islands in the side-arms that appeared due to the decrease of the water levels.
- Danube 1835,000 rkm opening side-arm closure (119,00 mBf, 24m width)
- Danube 1834,150 rkm complex dam: fixed crest + shiplock + fish path (119,10-119,50 mBf crest height 260 m, 3x24+10 m opening 116,40 mBf, 118,10 mBf riverbed 20m width)
- Danube 1827,700 rkm opening side-arms closures on both sides (117,40 mBf, 24m)
- Danube 1826,200 rkm complex dam: fixed crest + shiplock + fish path (119,10-119,50 mBf crest height 183 m, 3x24+10 m opening 114,40 mBf, 116,10 mBf riverbed 20m width)
- ~50 ha dredging of side-arms on the Slovakian side, 8,6 km upgraded channels, 111,00-110,50-110,00 mBf levels + small dams to keep a certain water level (defined crest heights and locations)
- Connecting “Morvaszigeti” side-arm to “Halrekesztő” side-arm
- Danube 1816,500 rkm opening the “Árvai” closure (“Bagamér” side-arm) on 111,00 mBf, 11m width
- Danube 1814,900 rkm complex dam: fixed crest+ shiplock + fish path (112,80-113,20 mBf crest height 104 m, 3x24+10 m opening 110,10 mBf, 111,80 mBf riverbed 20m width)
- ~75 ha dredging of side-arms in the Hungarian side, 8,3 km upgraded channels, 110,50-109,50 mBf levels + small dams to keep a certain water level (defined crest heights and locations)
- Danube 1809,700 rkm fixed crest dam with fish path at the end of “Bagaméri” side-arm (112,80 mBf, 15m fish path 111,00 mBf)

In the simulations the gates at the three weirs were opened above a threshold of 750/180 m^3/s (2D-modelling).

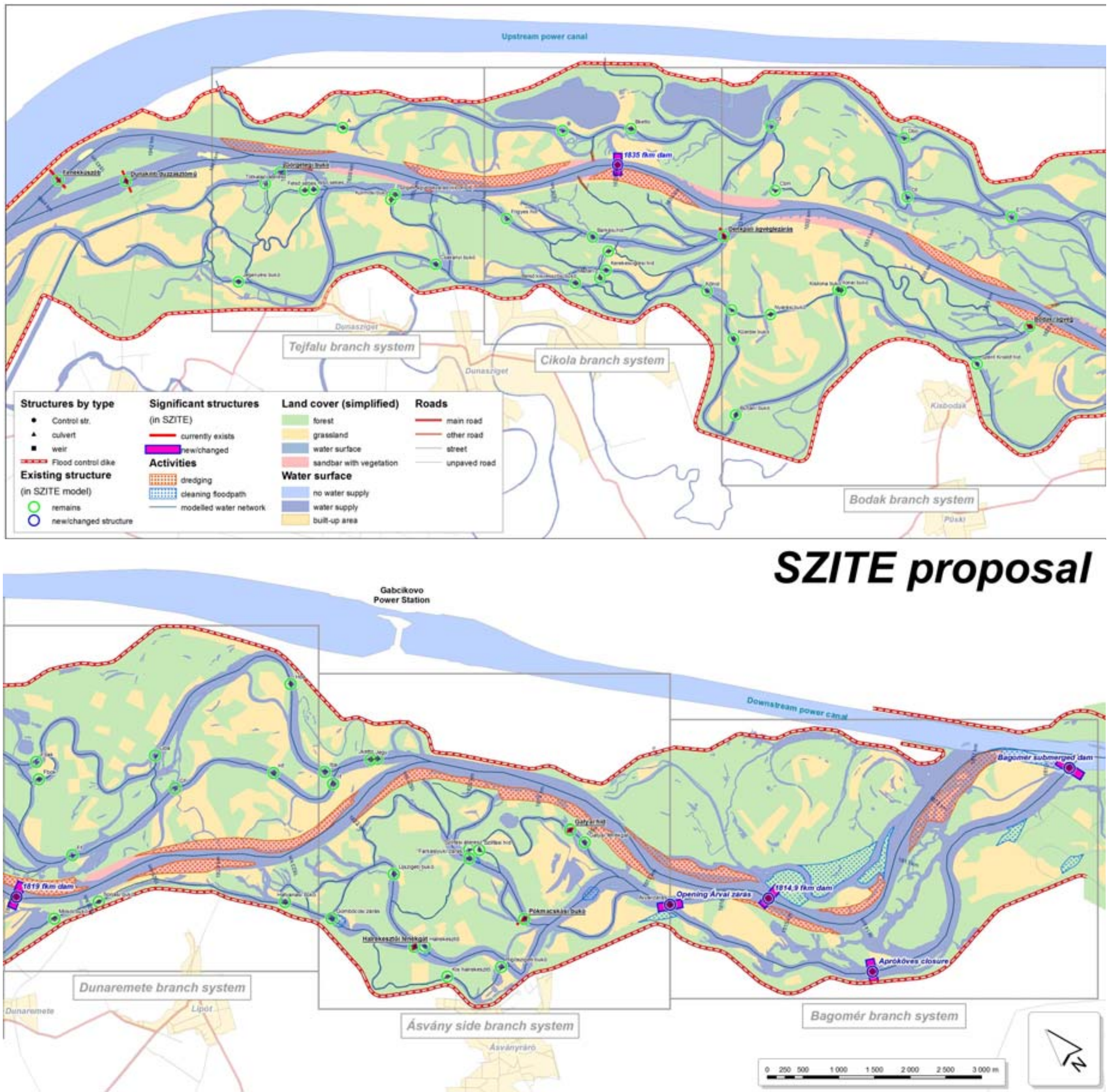


Figure 8-2 Plan view of the SZITE variant

Narrowing the main channel by raising point bars

Narrowing the main channel bed in order to raise water levels was a concept published by WWF Austria (1994, 1997). The original concept envisaged a narrowing of the bed by creating islands and decreasing the width of the channel. In order to restore lateral connectivity, it was suggested increasing the discharge to meet the water level of disconnected side-arms. The plan was not worked out in detail, neither was its hydraulic performance nor the appropriate source of material.

As a basic approach it was decided to use the existing point bars forming roughly 1/3 of the total channel surface area. These point bars experienced a fast growth of softwood forest following the diversion of the river water. The increased roughness enhanced the accumulation of sand and silt during flood flows. In the model runs it was assumed that the 2004 elevation of the point bars was raised by about 2 m (Figure 8-3 and Figure 8-4).

In order to avoid depletion of the side-branches at lower flows, the side-arm closures had to be left in the model. Early model runs were carried out without side-arm closures.

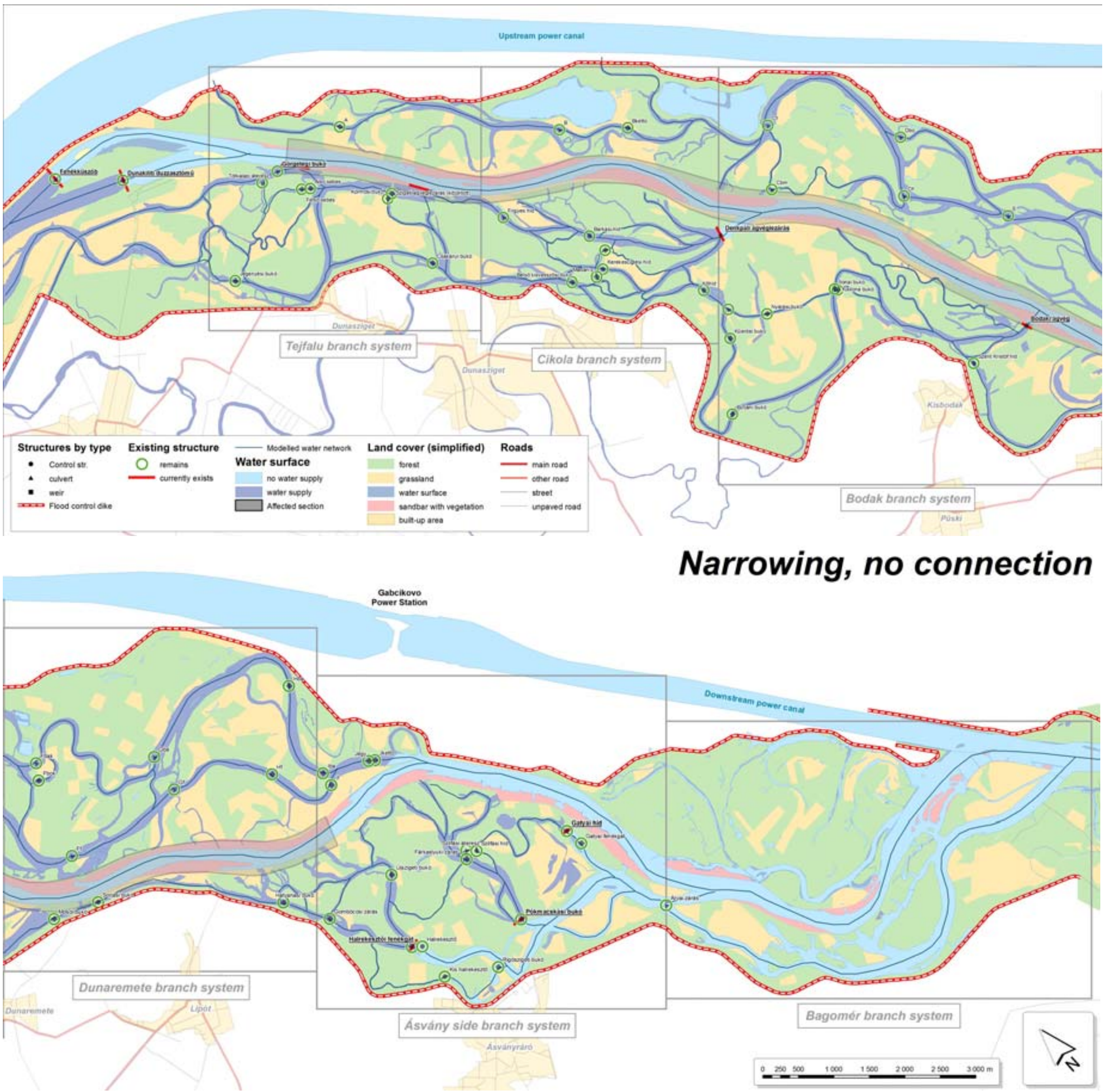


Figure 8-3 Plan view of the “Narrowing” variant

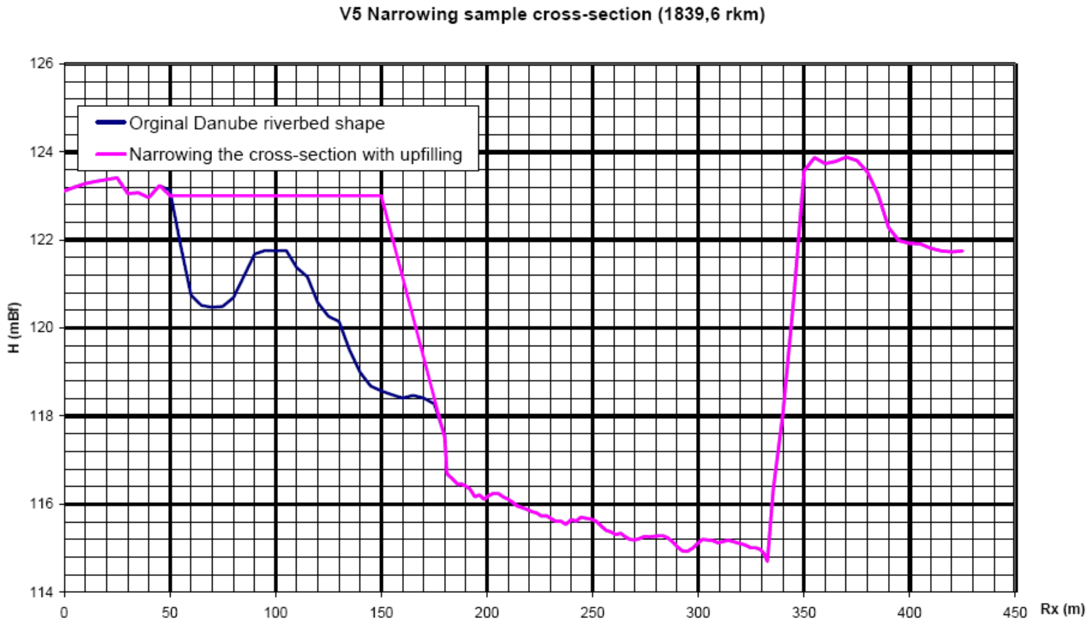


Figure 8-4 Channel narrowing by raising point bars, example of cross-sections

Optimum filling

There were several ideas on how to raise water levels in the main channel. One option was to fill in material from the river banks. There was no detailed plan, however, where exactly this could be done and which volumes of material would be available, not to mention the suitability of sediments. No clear indication was given as to which level the bed should be filled up.

Therefore it was decided to investigate a basic "optimum filling" variant which reproduces the pre-dam mean water level of 2,000 m³/s of the 1950s at a discharge of 350 m³/s in the main channel + 80 m³/s in the side-branches. The resulting bed filling amounted to 3-4 m uplifting of the main channel bed requiring about 16 mio. m³ bed material. The source of the material was not considered in this investigation since this is subject to a planning phase. This variant included the removal of side-arm closures.

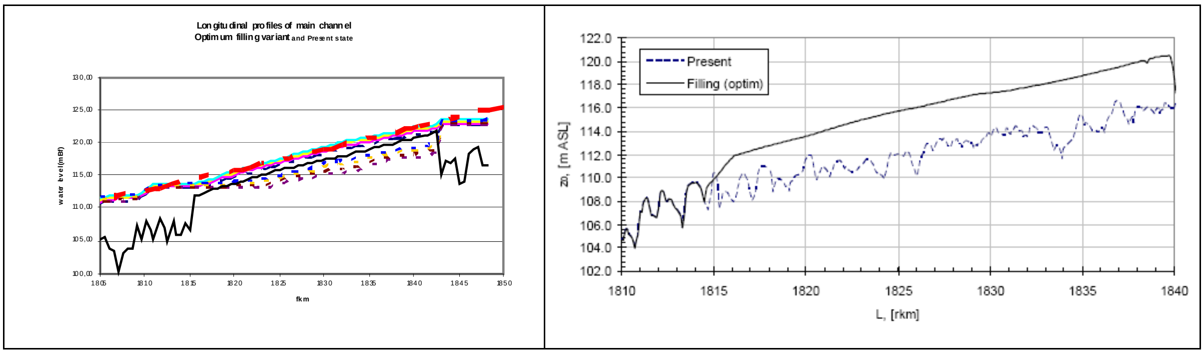


Figure 8-5 Longitudinal profile of bed levels for the "Optimum filling" variant (compared with present situation water levels for Q = 200 / 350 / 550 and 750 m³/s)

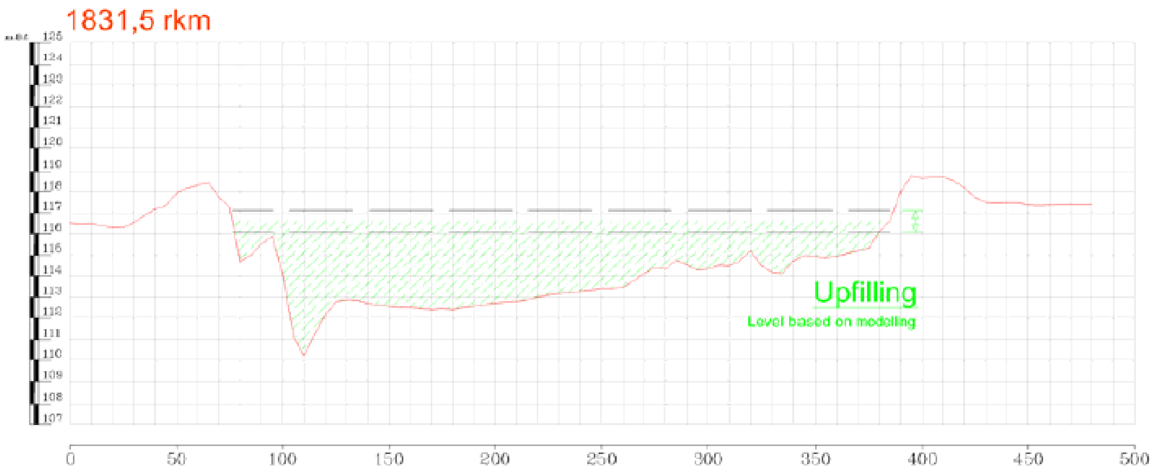
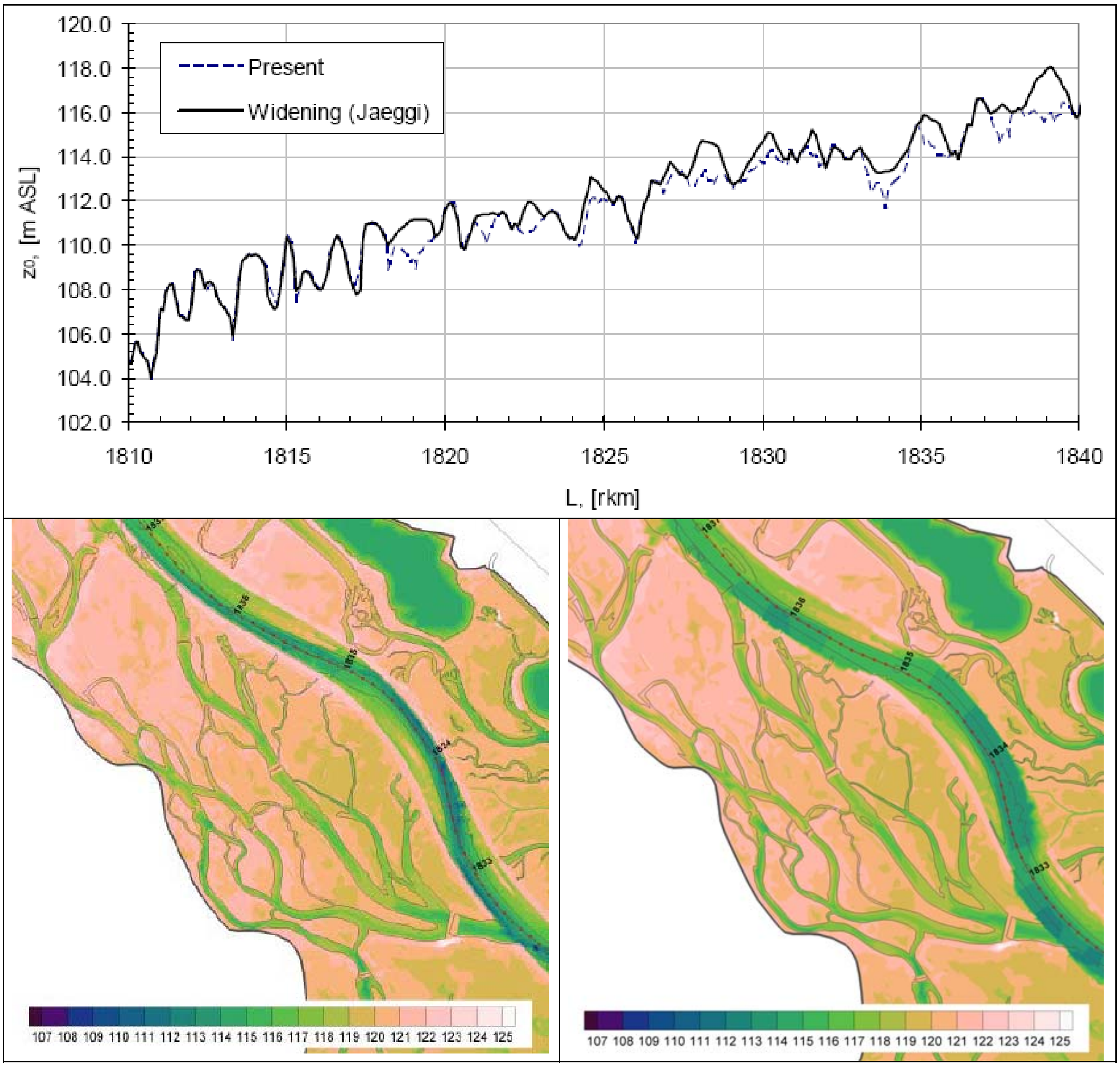


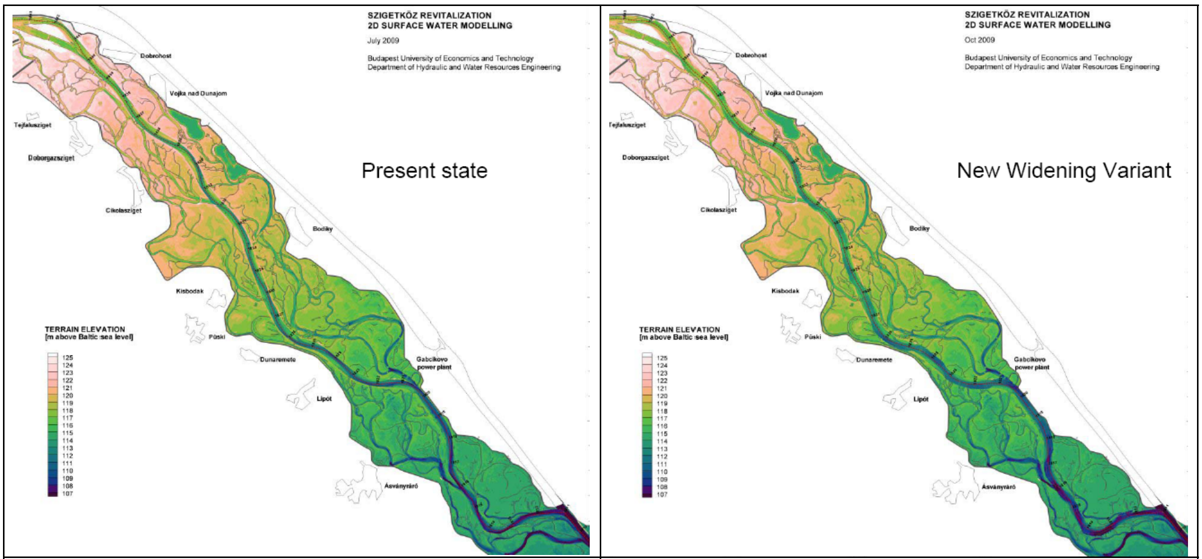
Figure 8-6 Sample cross-section of the "Optimum filling" variant

Widening + self-adjustment of bed levels (Proposal M. Jaeggi)

From fluvial geomorphology it is known that the broadening of river channels by lateral erosion produces higher bed levels. This phenomena was used as a planning concept for a variant which assumed river bed widening by lateral erosion after the removal of bank protection at defined locations. Based on simplified assumptions of lateral erosion rates and grain sizes of bank material, basic model runs were carried out to investigate the expected raising of bed levels over time. The results suggested that 0.9 to 1.8 m raising of bed levels could be expected after several decades if 100 m widening was assumed. Further investigations would need to analyze bank materials, refine model techniques and explore suitable measures for accelerating lateral erosion processes at appropriate locations on both sides of the river.

The widening variant assumed an endpoint of channel adjustment with 100 m lateral channel broadening at outer banks between rkm 1843 and rkm 1811. Bed level raising was assumed to be 1.8 m. Side-arm closures had to remain in order to avoid depletions of the branches.





Present state topography	*Widening of the main channel*

Figure 8-7 Topography of the widened main channel (widening at outer banks)

Meandering on floodplain level with secondary main channel

This variant proposes the construction of a meandering channel at floodplain level crossing the regulated Danube at several locations. At the intersections with the Danube, bottom sills have to be constructed raising the upstream water level to the required elevation of the crossing meander. The free flowing meander channel uses parts of the side branch network (with removed check dams) and newly dredged connecting channels.

Two meander versions have been modelled. One of them followed the planning concept of the INTERREG IIIA / HUSKUA/05/02/94 project (2007) which used the existing network of side branches plus additional connecting channels. The channel system was not modified except for the removal of all control structures (which was not planned in the INTERREG project).

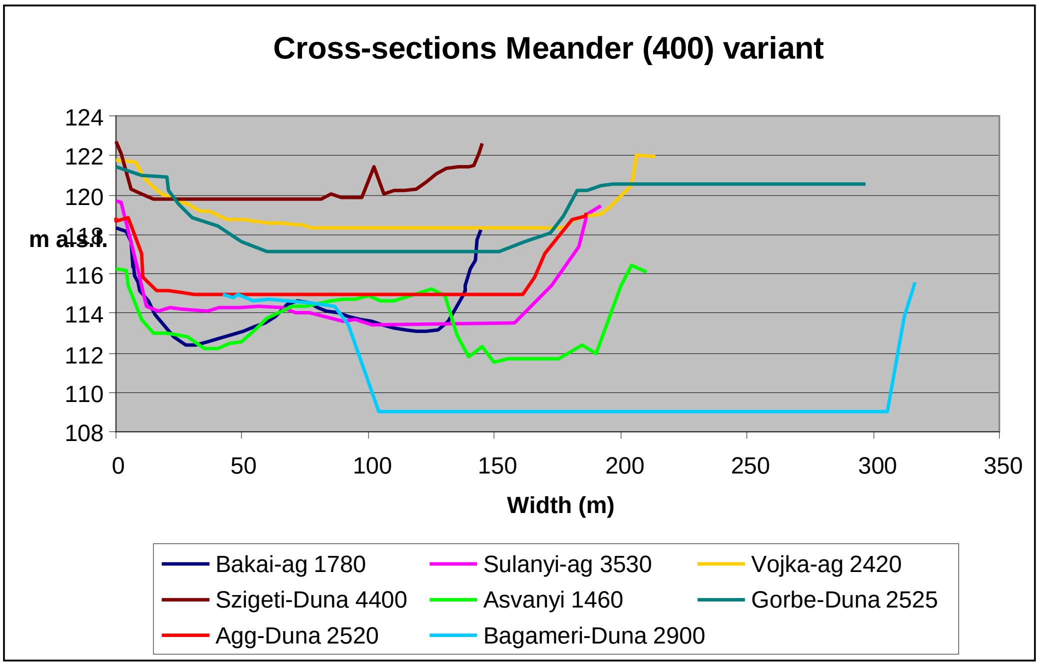
The Meander (400) version used the same channel pattern but enlarged the main meander branch to convey at least 400 m^3/s at bankful flow thus replacing the former main channel for prevailing flows. In order to convey the full discharge of about 400 m^3/s from one side of the floodplain to the other the crest elevations of the sills in the Danube had to be adapted.

Both versions used the same channel network with the same number and locations of sills. Modification at the existing weir at rkm 1843 will additionally be needed.

Distribution of flows. The Meander (INTERREG) version will have to be operated with the same distribution of flows between the main Danube channel and the branch system as other variants. The Meander (400) version, however, substitutes the main channel and needs to receive the main flow. Based on an average of 400 m³/s only a residual discharge of about 50 m³/s should be channelled into the regulated Danube. 300-350 m³/s should be diverted into the side branches above Dunakiliti which represent the upper end of the new meandering river course.

Table 8-2 Locations of bottom sills in the main channel and highest crest elevation of both versions

Main channel Danube	Meander (INTERREG) version	Meander (400) version
rkm	mBf	mBf
1814.9	113.40	114,00
1820.3	115.45	116,25
1825.1	117.25	118,05
1829.8	118.95	119,05
1831.8	119.85	120,55
1836.3	121.25	123,00
1838.3	122.10	122,80
1843.0	124.50	124,50



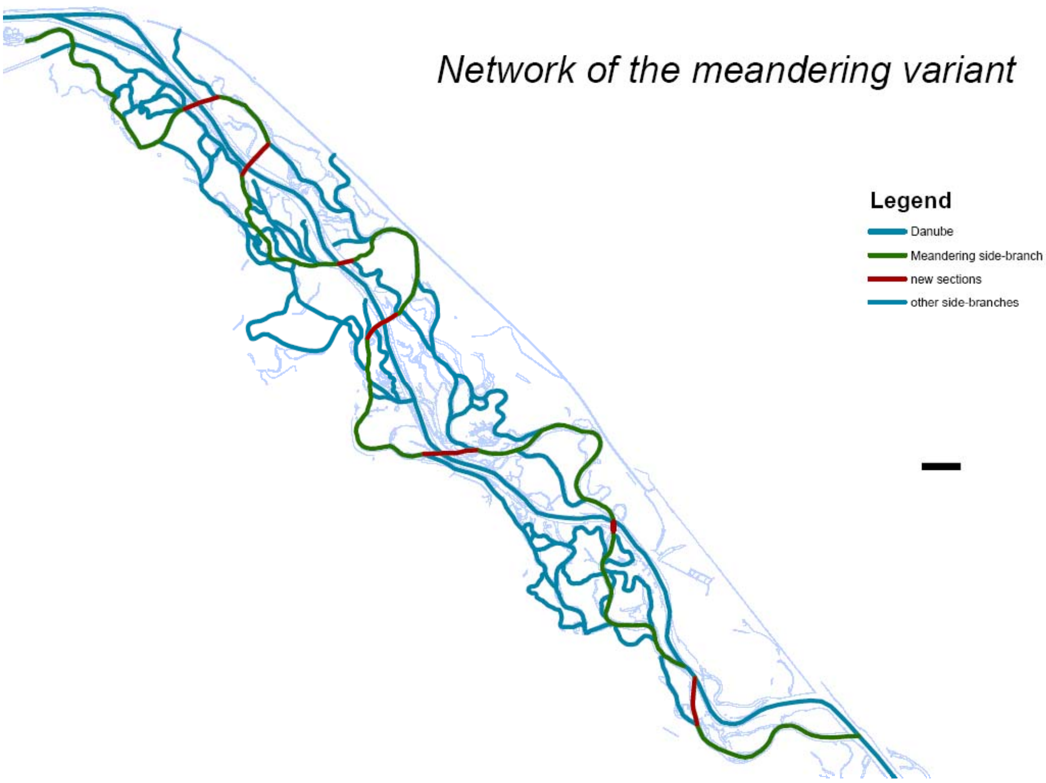


Figure 8-8 Network of the meander variant (both versions) and Cross-sections of the Meander (400) variant

8.2. Hydro-morphological modelling methods and simulation runs

8.2.1. One-dimensional modelling with MIKE11[25]

For 1D-modelling the version 4.01 of the hydrodynamic module of MIKE-11 developed by the Danish Hydraulic Institute (DHI) was used. The model considers every state variable (free surface elevation, discharge, velocity, concentrations, wetted cross-sectional area, free surface width) as cross-sectional integral or mean quantity. The numerical solution of physically based partial differential equations (Saint-Venant equations, advection-dispersion equations, etc.) is obtained by appropriate implicit finite difference technique. The main control parameters of the model are the Manning-type roughness (which can be modified even within a cross-section) as well as the head loss formulae of the various hydraulic structures and the infiltration intensity relevant to the bed surface.

An important limitation of the 1D model is the way of handling the computational cross–sections beyond bankful flow regime. In fact, when defining the discrete points of the cross–sections, the model implies an impervious vertical wall at the left and right hand side edges, as no information is provided on the topography of the adjacent floodplain to be inundated. Model results for discharges overtopping the banks have to be considered accordingly Therefore, realistic results for flows above the bankful level can only be expected from the 2D model.

Model boundary conditions: The planned interventions of the variants extend to the reach between Dunakiliti dam at 1841 rkm and the tailrace canal junction at 1811 rkm. The modeled area includes the open floodplain in this reach with all side branches between the Hungarian and Slovak levees. The model boundaries have been extended upstream and downstream to form a convenient implementation of inflow and outflow boundary conditions.

[25] Preliminary feasibility study of the restoration of Szigetköz - 1D surface modelling and groundwater modelling. Research report. North Transdanubian Directorate for Environmental Protection and Water Management, Emil Janák, Gabriella Mohácsiné Simon, Zoltán Molnár, Johanna Ficsor, 15 Dec. 2009.

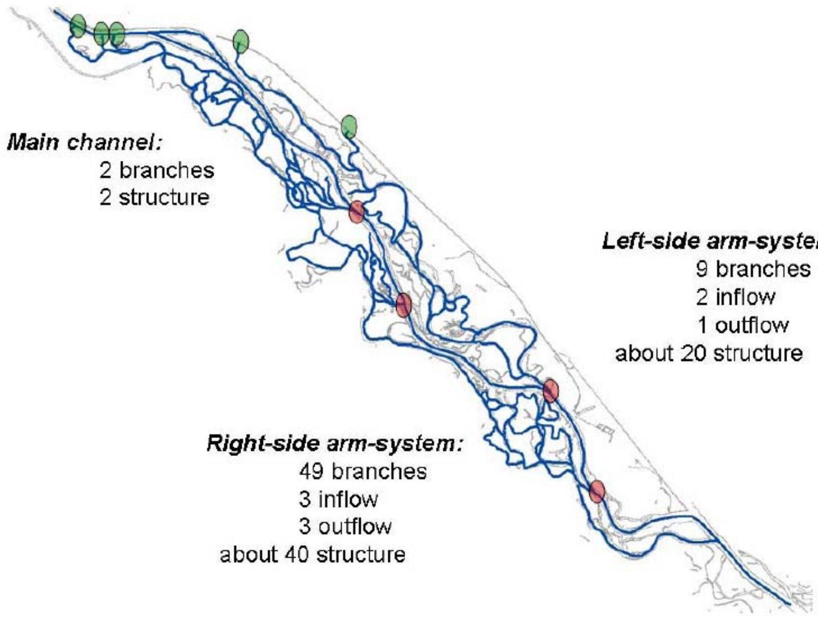


Figure 8-9 Channel network for the 1D-modelling

Calibration: The model was calibrated for the summer period of 2008 which covered the largest possible range of the regulated flow regime. The period of assessment was from 1 June 2008 until 31 July 2008. In this period the water discharge of the Danube released at Cunovo varied between 400 and 600 m^3/s.

In the calibration procedure model parameters such as bed roughness, groundwater infiltration and head loss at hydraulic structures were adjusted. The hydraulic system in the Szigetköz is dominated by transmissibility and backwater effects by hydraulic structures. The results of discharge measurements performed on 17 and 18 June 2008 were available for the correct internal distribution of the water. Thus the calibration of the system could be performed based on measured data available in as many as 33 cross-sections for discharge and 37 cross-sections for water level. The following graphs (in which the model calculations are indicated in black, the measurements in other colours) demonstrate some of the calibration results at selected reference cross-sections (Fig. 7.8).

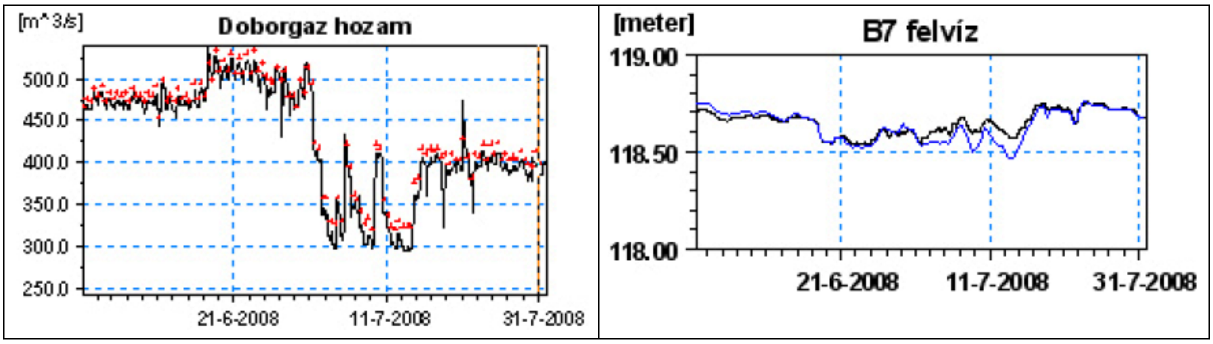


Figure 8-10 Measured and calculated (black) discharges and water levels respectively at two locations

8.2.2. Two-dimensional modelling with MIKE 21 FM[26]

Model characteristics

The model applied is a two-dimensional approximation to a flow system that may exhibit three-dimensional flow characteristics, particularly near abrupt changes in flow direction or depth. Further, the model is intended for the far field problem in which vertical accelerations are negligible and velocity vectors generally point in the same direction over the entire depth of the water column at any instant of time. The main purpose is the modeling of overbank flows. Infiltration was not included in the computations and only steady-state conditions are considered at this stage in model implementation.

The adopted hydrodynamic model, MIKE 21 FM, is based on the integral form of the 2D shallow water equations (DHI 2009). A triangular mesh is laid over the computational domain and the governing equations are solved on that mesh using the finite volume method. In the channels the mesh resolution was 60 m streamwise and as fine as 15 m crosswise. Away from the channels and embankments the mesh was made coarser and more isotropic.

Model boundary conditions: - as in 1D modelling

Topographical Information: The digital elevation model (DEM) was built using the most recent survey data available. This data comprised river cross sections, a scattered survey of the floodplain, sounding survey of the main riverbed, and aerial photography covering the whole area:

- **Cross sections of the main branch from a 2006 survey, extending between the two banks. These sections were spaced 100 m on the reach 1826–1810 rkm. An older set**

[26] Preliminary feasibility study of the restoration of Szigetköz - 2D hydrodynamic modelling of the impact on surface waters. Research report. Budapest University of Technology and Economics, Department of Hydraulic and Water Resources Engineering, János Józsa, Tamás Krámer, László Rákóczi, 30 Nov. 2009.

of scattered survey points was available for the rest of the main branch and the Ásványi and Bagaméri branches as well as for the point bars.

- **The same 250 cross sections were used for the Hungarian side branches as in MIKE 11. These extend only to the river bed.**
- **Cross-sections for the Slovak side branches were digitised from a printed survey documentation made in 1971. Although new data collected in 2009 was also available, these were sparse and covered only selected side branches; therefore they were not included in the DEM.**
- **The floodplain, excluding river beds, was covered by a survey with points spaced approximately 30 m on average. The survey originates from before 2004. This was the main data source for embankments and the water border of the side branches.**
- **The geometry of the weirs and sills was taken from the MIKE 11 model which has been validated for low flows.**

However accurate the river cross sections are, the bed shape must be estimated by interpolation for the gap between the sections. Because of this only the main bathymetry features in the cross sections were kept, such as the lines defining the thalweg or the base of flat cross sections. This reasonable simplification obviously leads to differences with the 1D cross sections.

The elevations were set in the flow model by first triangulating the scattered survey points, assuming breaklines along embankments, water borders and other linear terrain features. This led to a continuous surface model with plane faces within each triangle. Finally the average elevation of each element of the flow model was computed by averaging the triangulated surface analytically.

Experience with the hydrodynamic model also confirmed that predicting the shallow flooding of the floodplain and the distribution of the flow in the side branch system is very sensitive to the accuracy of the topography. Assembling the topographical data represented a major work in this project; it resulted in a comprehensive digital elevation model of the Szigetköz reach preserving most of the information in the available data. However the 2D model could have benefited much from a more accurate areal survey of the side branches, weirs and inner embankments.

Flow division: For lower flows (930 and 2000 m^3/s) the inflow was explicitly divided between the main branch (denoted from hence with the subscript *mb*) and the Hungarian side branch system (*sb*) upstream of the Dunakiliti dam.

For higher flows (3000 m^3/s and above) the main branch and the side branches become connected over the floodplain below Dunakiliti. In this case their discharge is not imposed explicitly, instead the modelled domain is extended sufficiently upstream till Rajka and the total discharge is imposed at a single inflow boundary.

Calibration and validation

Evaluating the hydrodynamic impact of the planned variants was undertaken with a different modelling approach for the low-flow and high-flow regime:

- **Inbank flows were modelled in as a network of 1D river channels connected at junctions. Weirs and gates are represented in great detail.**
- **Overbank flows where channels are connected through the flooded floodplain are modelled in 2D. This extends from the artificial flooding of the side branches to the extreme floods.**

The 2D model was calibrated for a wide range of flows.

Calibration of the main branch: The model was adjusted to reproduce water surface profiles measured during inbank flow conditions. A detailed profile was recorded along the main branch in September 2008 by the hydrographic team of ÉDUKÖVIZIG (Q_{mb}= 255 m³/s, $Q_{power\ canal}$ = 895 m³/s). This steady-state data set was selected for calibration, though it was for the low-flow regime. No measurements were taken in the side branches at the same time.
The model was more sensitive to the mesh layout than to the Strickler coefficient. With the coarser and less flow-aligned mesh of the initial runs the bed should have been excessively smooth to match the measured surface profile.
The finally accepted model has a conservative Strickler *k* of 40 $m^{1/3}/s$ but its mesh is more refined in the main bed and better aligned to the contours of the point bars. The smallest cell dimensions were close to 15 m.

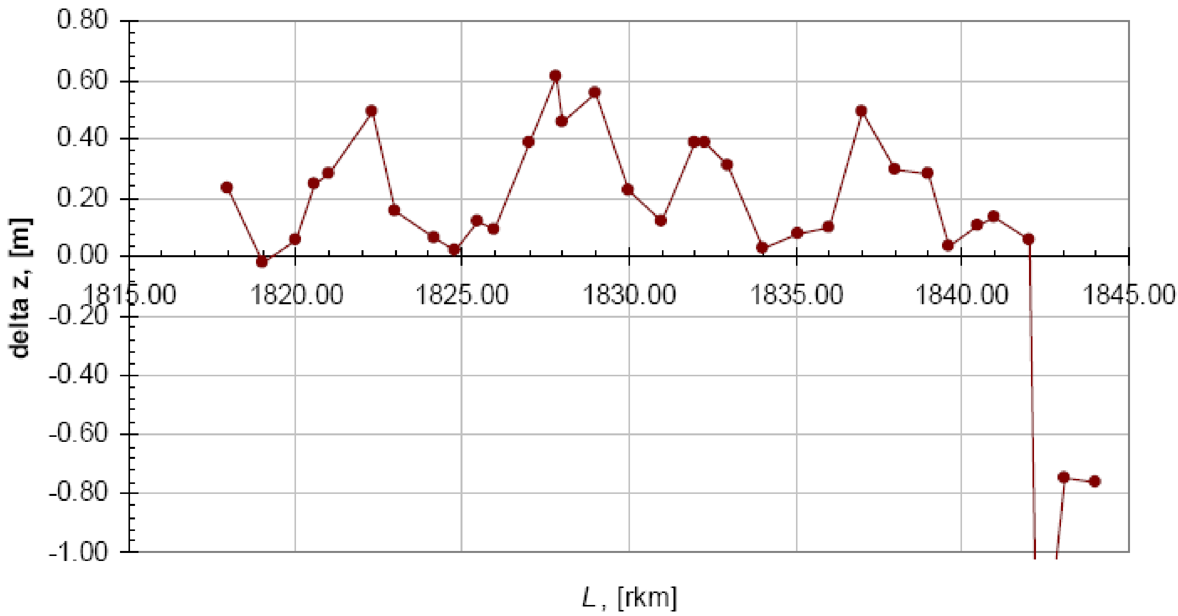


Figure 8-11 Deviation of the modelled water surface profile from the measurements

With detailed profiles measured in the discharge range of 750 to 1000 m^3/s, it would be possible to validate the 2D model's accuracy in the targeted flow regimes.

Calibration of the side-branches: Discharges and water levels were measured in the side-branch system in May 2009 (Q_{mb} = 690 m³/s, Q_{sb} = 210 m³/s, $Q_{power\ canal}$ = 1380 m³/s). Mesh editing and local adjustments of weir and embankment elevations were necessary to prevent connections that contradicted the measurements. A major issue was the proper sealing of the side branches from the main branch. Some branches could not be modelled because no survey data is available there.

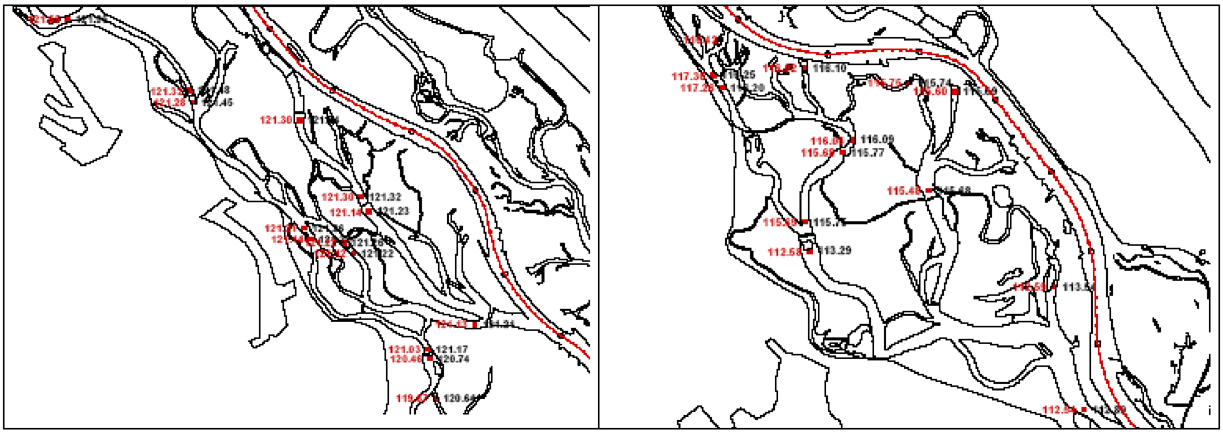


Figure 8-12 Measured (red) and modelled water levels in the side branches (May 2009)

The 2D model cannot discretise the weirs and gates as accurately as the 1D model because it would require a too fine mesh at those structures, resulting in prohibitively long computations. Therefore, "effective" weir heights were calibrated that resulted in the measured vertical steps in the water surface. It is only by overriding the weir crest elevations that we could affect water levels and the distribution of the discharge in the side-branch network. These were little sensitive to the Strickler smoothness, which is understandable since most of the side branches are presently impounded by weirs. The modelled water surface elevations are within 0.2 m of the measurements in most of the two focus areas (Figure 8-11)

Calibration for extreme floods: The 2D hydrodynamic model was also calibrated for the record flood of August 2002. The peak discharge was estimated at 6590 m^3/s at Dunakiliti, 6130 m^3/s at Medved'ov (1806 rkm) and 3080 m³/s in the tailrace canal.
The model was run in steady-state, with the lower and upper bound of the discharge specified at the inflow boundary. It is expected that the resulting steady-state profiles will define the range that contains the peak of the unsteady water surface profile.

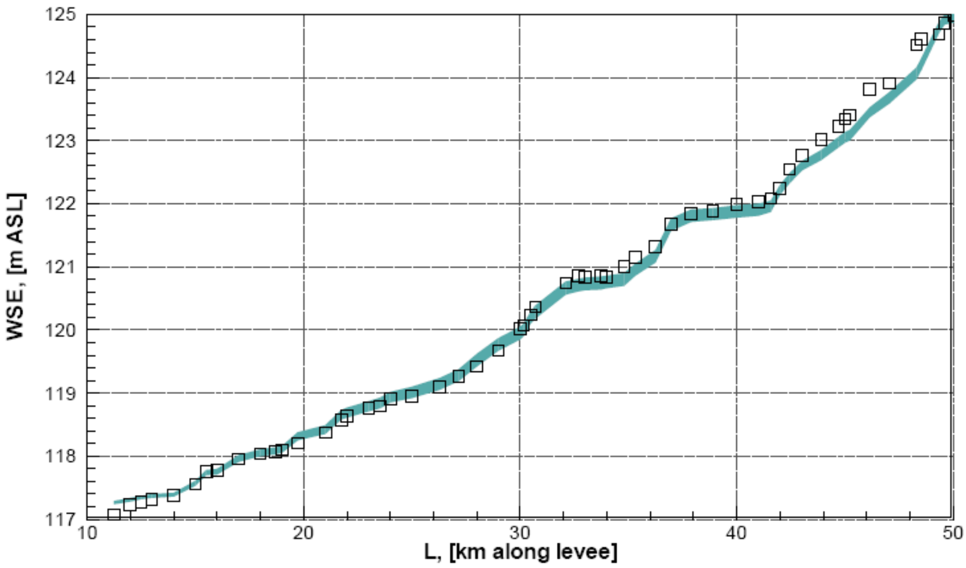


Figure 8-13 Measured (dots) and modellled (shading) water surface profiles along the Hungarian levee for the August 2002 flood. The shaded area bounds the profiles in the range Q_{mb+sb} = 6130 and 6590 m^3/s.

The modelled and the measured profiles are shown in Figure 8-13. Varying the discharge by about 6% causes a 0.2 m difference in the modelled profiles (this is the height of the shaded area). The observed stages mostly fall into this range. It is only in the upper Szigetköz that the model deviates consistently in the negative direction, but the deviations do not exceed 0.3 m in magnitude.

Table 8-3 Strickler *k* [m$^{1/3}$/s] values adopted in the 2D model.

Roughness class	Mean flow and minor floods	Extreme floods
Riverbed	40	40
Open terrain	20	20
Forest	5	4
Point bars	20	15
Weirs and sills	12	12
Cleared floodways*	20	15
Cleared point bars*	30	30
Dredged point bars*	40	40
Removed weirs*	12	12

Accepted Strickler values: Table 8-3 lists the Strickler *k* values applied to roughness classes uniformly in all variants. The star denotes new roughness classes imposed by some variants for the dredged and cleared areas (obviously these could not be calibrated).

Vegetated zones have lower smoothness because resistance due to vegetation increases with depth.

8.2.3. Morphological modelling with MIKE 11[27]

Model boundary conditions:

a) Upper edge of the modelled section – discharge Čunovo (km 1848,33);
b) Lower edge of the modelled section - discharge releases from Gabcikovo (km 1811); discharge rating curve in Medveďov on the lower edge of the modelled section (km 1806,4);
c) Grain size distribution curves – 2002, 2003, 2009;

Hydromorphological model – MIKE 11

A one-dimensional numerical model with a morphological module (MIKE 11 – commercial software developed by the Danish Hydraulic Institute) was used for building a model of the Danube (km 1848.3 – km 1806.4).

Sediment transport formulas: MIKE 11 offers five sediment transport equations for the calculation of bedload transport or total sediment transport (bedload + suspended load):

- the Engelund-Hansen, Ackers-White, and Smart-Jaeggi models – for the calculation of total sediment transport ('total load');
- the Sato-Kikkawa-Ashida model – pure bedload model for the calculation of bedload transport and morphological changes;
- the Engelund-Fredsoe and Van Rijn models – for the calculation of bedload transport and suspended load transport separately.

A similar bedload transport model (MIKE 11) was set up and used for the Sap - Komárno section of the Danube, where a wide range of field bedload measurements were carried out. The best agreement between the measured and calculated values of bedload transport in this river section was achieved when the morphological calculations were carried out on the basis of a numerical model using the Sato-Kikkawa-Ashida formula.[28] Since the main morphological characteristics of the river channel in the two sections are comparable (bed material size, B/H, bed slope), this formula can also be recommended for the Old Danube. In order to compare the results of model simulations the Ackers & White formula was also used for some of the scenarios.

[27] Holubová, K., M. Lukáč & Z. Capekova (2009) Morphological numerical model (MIKE 11) impacts of restoration scenarios on the development of the Danube river bed (rkm 1848,33 – 1806,40), final report, Nov. 2009.
[28] Model details are given in the research report (Holubova et al. 2009).

Morphological model calibration and validation

The morphological model was calibrated and validated against a topography model based on data from 2001. First, the hydrodynamic part of the model was calibrated and verified under various flow conditions, then its morphological part (on the basis of data from 2003).

For model simulations, hydrological data from the period 2001-2003 (from Rajka and Medveďov gauging stations) were used. A hydrograph for this period was selected in particular with regard to the occurrence of floods in 2002.

Figure 8-14), which could cause extreme morphological changes in the Old Danube (considering the period since 1992). Flow conditions from 2001-2002 were mainly used for model calibration, as well as for the basic evaluation of the restoration scenarios in terms of effectiveness.

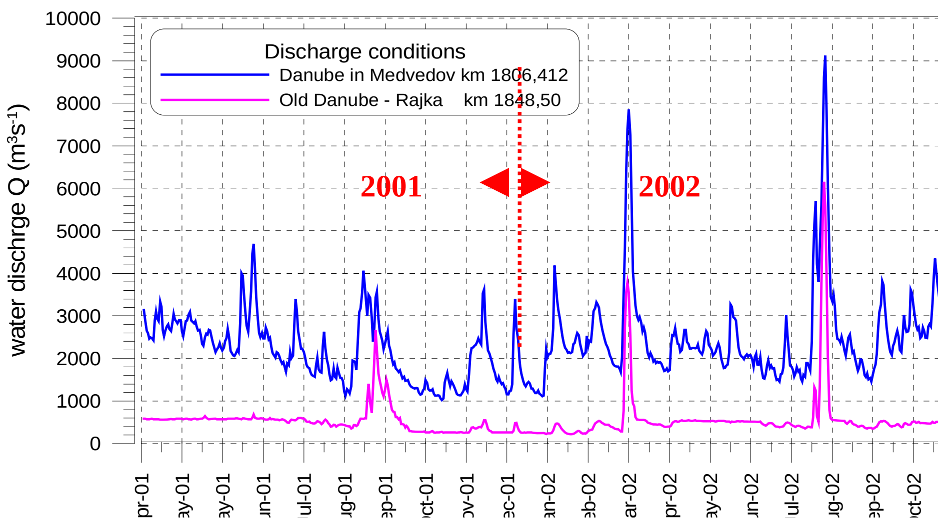


Figure 8-14 Hydrological conditions for the simulation of morphological changes – 1D model

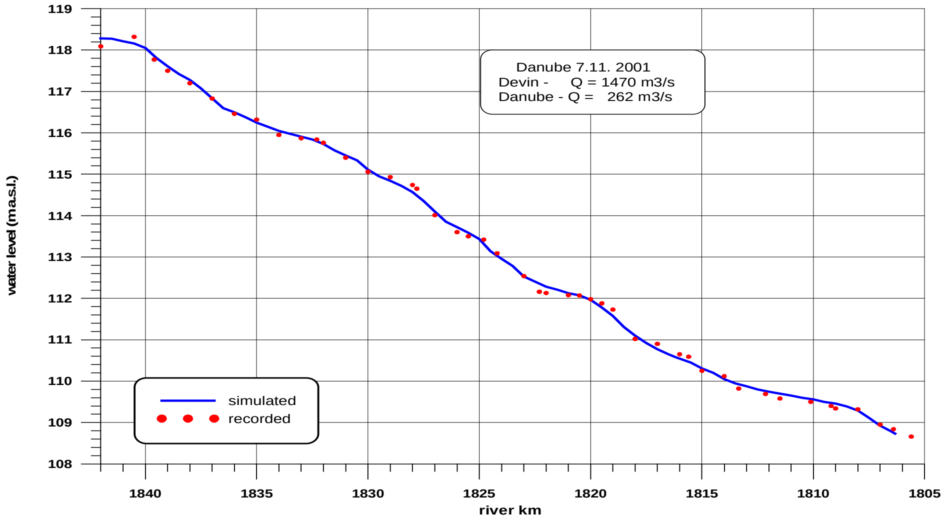


Figure 8-15 Results of hydrodynamic model calibration for low flow conditions

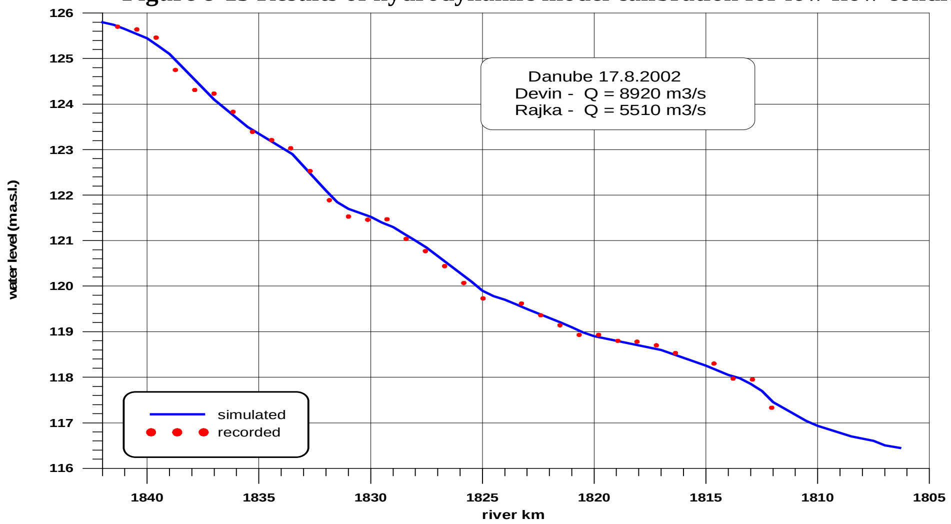


Figure 8-16 Results of hydrodynamic model calibration for flood flow conditions

Hydrodynamic model – the model was calibrated on the basis of field data, i.e. measured water levels and discharges. Its validation was based on a comparison of the simulated and calculated water levels. In the topography model, the river channel was divided into three parts: left-side flood plain, right-side flood plain, and the main river channel.

The roughness coefficient (Manning's n) was estimated for each compartment individually in order that the best agreement is achieved between the simulated and measured values. The results of hydrodynamic model validation for low flow and flood conditions are shown in Figure 8-15 and Figure 8-16. Good agreement was achieved in both cases. The differences between the measured and simulated water levels reached max. ± 15 cm for low flow water levels and max. ± 25 cm for flood water levels.

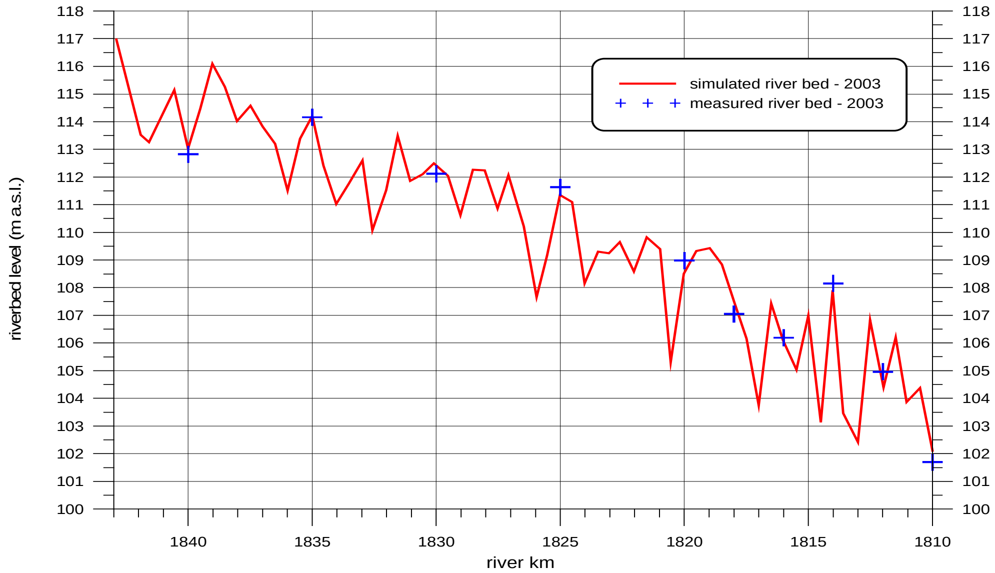


Figure 8-17 Results of morphological model calibration (period: 2001-2003)

Morphological model – the model was built using the Sato-Kikkawa-Ashida method (described above) and verified against data on river channel geometry from 2003. The differences between the simulated and measured river bed levels in the cross sections (using the Sato-Kikkawa-Ashida model) ranged from 5 cm to max. 40 cm. With regard to the complex river processes and complicated morphological and flow conditions in the Old Danube, this range of errors represents a very good agreement between the calculated and measured values (Figure 8-17). Therefore, the Sato-Kikkawa-Ashida method was used for a major part of the calculations and simulations (morphological changes, transport capacity, evaluation of the scenarios in terms of effectiveness).

Experiences from the lower part of the Danube (downstream of Szap) provided good results using the Ackers & White formula (Holubová, Capeková, Szolgay, 2004). Therefore, a comparison of both approaches was carried out to evaluate the effectiveness of widening restoration scenario “4”.

8.2.4. Groundwater modelling with MODFLOW [29]

For the groundwater responses of the variants the software package Visual Modflow version 4.2 developed by the Canadian software company Waterloo Hydrogeologic Inc. was applied. Visual Modflow is one of the most common 3D numerical models for subsurface flows.

[29] Preliminary feasibility study of the restoration of Szigetköz - 1D surface modelling and groundwater modelling. Research report. North Transdanubian Directorate for Environmental Protection and Water Management, Emil Janák, Gabriella Mohácsiné Simon, Zoltán Molnár, Johanna Ficsor, 15 Dec. 2009.

It describes unsteady groundwater flows (piezometric heads and 3D velocity vector field) in geologically stratified systems by means of the 3D governing partial differential equation, the numerical solution of which is achieved by using implicit finite difference technique on a Cartesian non-equidistant grid.

Model boundary conditions: In a localised, refined grid, on the southern side the boundary of the modelled area is the Hanság main canal, river Rábca, Mosoni Danube, on the western and south-western sides the boundary goes along the country border of Austria and Hungary, whereas on the northern and north-eastern side the boundary is the main channel of the river Danube. As external and internal boundary conditions the free surface profiles obtained by the 1D hydrodynamic model MIKE 11 were used in the 3D groundwater model. The secondary branches on the floodplain were included in the model as additional internal boundary conditions, with water levels determined also by the 1D model. Figure 8-18 presents the study area and the conductivity parameters of the 2^{nd} out of ten layers of the aquifer.

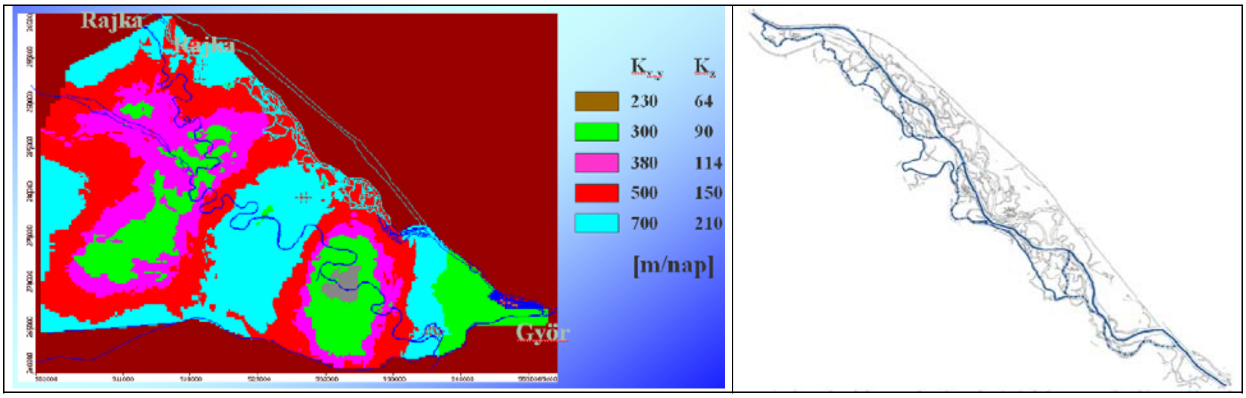


Figure 8-18 Boundaries and conductivity parameters of the study area and channel network used as internal boundary condition

Calibration: The model was calibrated for unsteady conditions. As long-term groundwater stage time series were available, calibration could be performed by comparing measured and computed water (or piezometric) levels at characteristic reference points. The present situation in Szigetköz is the one developed after the diversion of the Danube and the implementation of the Floodplain Water Supply System that is why the time series of the period between 1996 and 1998 were used for calibration. The model was also verified by comparing computed flow directions to the ones derived from measurements.

Considering that the curves of water level time series calculated by the model and originating from the measurement data show a very similar tendency and the calculated flow vectors as well as the flow directions that can be read from the contour-line maps edited on the basis of the measured data describe a similar flow system, the model approximates the real situations of the region.

8.2.5. Simulation runs

Hydrodynamic surface water modelling

Generally, it was decided to base the modelling on steady state discharge scenarios applying discrete steps of discharges from low flow to flood flows. In low-flow regimes the discharges were split between the main channel and the side branches on the Hungarian floodplain.

Table 8-4 Discharge distribution for the low-flow regime, 1D-modelling (m^3/s)

$Q_{main\ branch}$	$Q_{side\ branches}$		
	40	80	120
200	1D	1D	1D
350	1D	1D	1D
550	*	1D	1D
750	*	1D	1D

In flood conditions the main channel and the branches are connected. Therefore one single discharge was applied entering the main channel at the upstream border of the project area.

Table 8-5 Model discharges for flood flows, 2D-modelling (m^3/s)

Short reference		***Q* = 930**	***Q* = 2000**	***Q* = 3000**	***Q* = 4000**	***Q* = 5000**
Discharge in the main branch	Q_{mb}	750	1800	N/A	N/A	N/A
Discharge in the side branch	Q_{sb}	180	200	N/A	N/A	N/A
Total discharge at Dunakiliti	Q_{mb+sb}	930	2000	3000	4000	5000
Discharge in the tailrace canal	Q_{Gabc}	1070	2000	2000	2000	2000
Total outflow discharge	Q_{out}	2000	4000	5000	6000	7000

The discharges 4000 and 5000 m^3/s were only investigated for the present state. In addition, the peak discharge from Aug. 2002 was simulated for several variants.

Morphological modelling

Morphological simulations were done with hydrological data from the year 2001 (calculation of bedload transport under the current situation) and simulations of the morphological changes for all specified restoration variants including present state with hydrological data of 2001 and 2002. In 2002, the high flood occurred on the Danube, so this year represents extreme flow conditions which can not be considered as representative. Nevertheless, these high flow conditions (so rare in the Old Danube) are appropriate for morphological modelling because they would provide the maximum possible effect on river processes (bedload transport, bank erosion, morphological development – erosion/sedimentation). This year provides a wide range of high discharges important not only for river processes but also for the evaluation of the positive/negative effects of restoration scenarios. For a comparison of the effect of "common" and "extreme" hydrological conditions on morphological development simulations with the years 2001 and 2001-2002 were made as well.

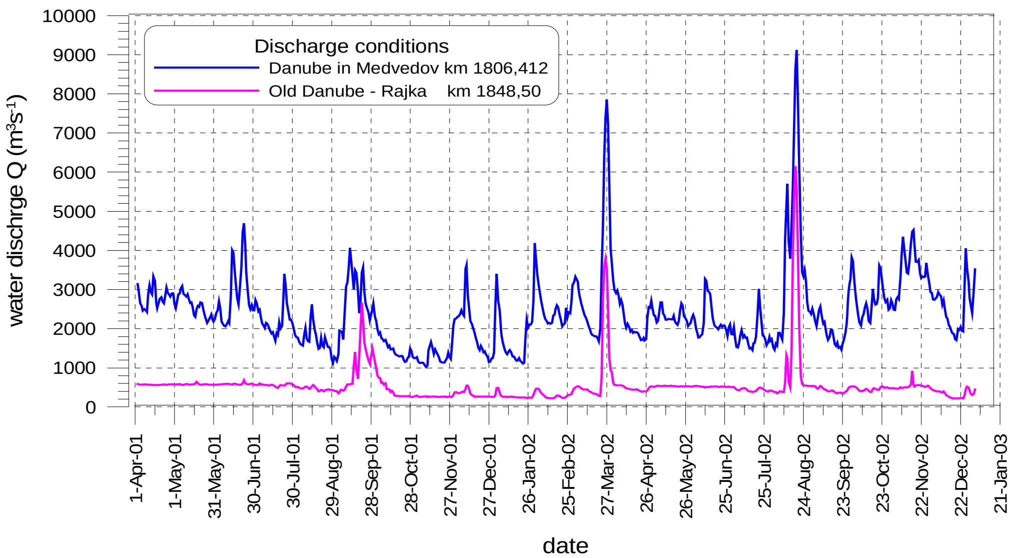


Figure 8-19 Hydrological conditions for the selected period 2001-2002

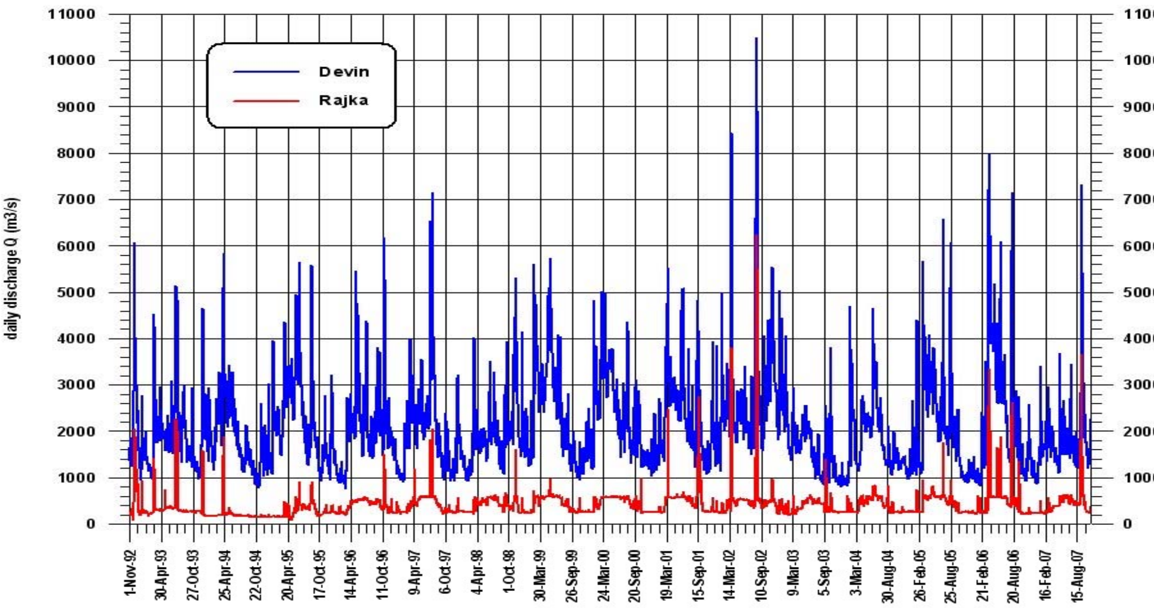


Figure 8-20 Hydrological conditions for the selected period 1995-2005

A longer period, i.e. the 1995-2005 decade, was used for a more detailed analysis of the long-term impacts of the present situation and some of the restoration scenarios.

For the exploration of the long-term evolution of the river bed a time series consisting of competent flows of the period 1995-2005 was repeatedly used to simulate a 40 year time span (applied for the widening variant).

Groundwater modelling

The variants were analysed for the following discharge scenarios:

Table 8-6 Discharge scenarios for groundwater modelling

	Discharge (m^3/s)			
Main channel	200	350	550	750
Secondary branch system	40	80	120	120
Identifier in the figures	Q200	Q350	Q550	Q750

8.3. Results of hydro-morphological modelling

8.3.1. Surface water level dynamics

The drop of water levels and insufficient water level fluctuations were an immediate impact of the diversion of the river water in 1992 affecting the entire floodplain eco-system. 1D-modelling produced water levels for all variants and discharges up to 750 m³/s. Figure 8-21 displays water levels in the main channel for each variant at varying discharges. Figure 8-22 shows water levels for one discharge and different variants.

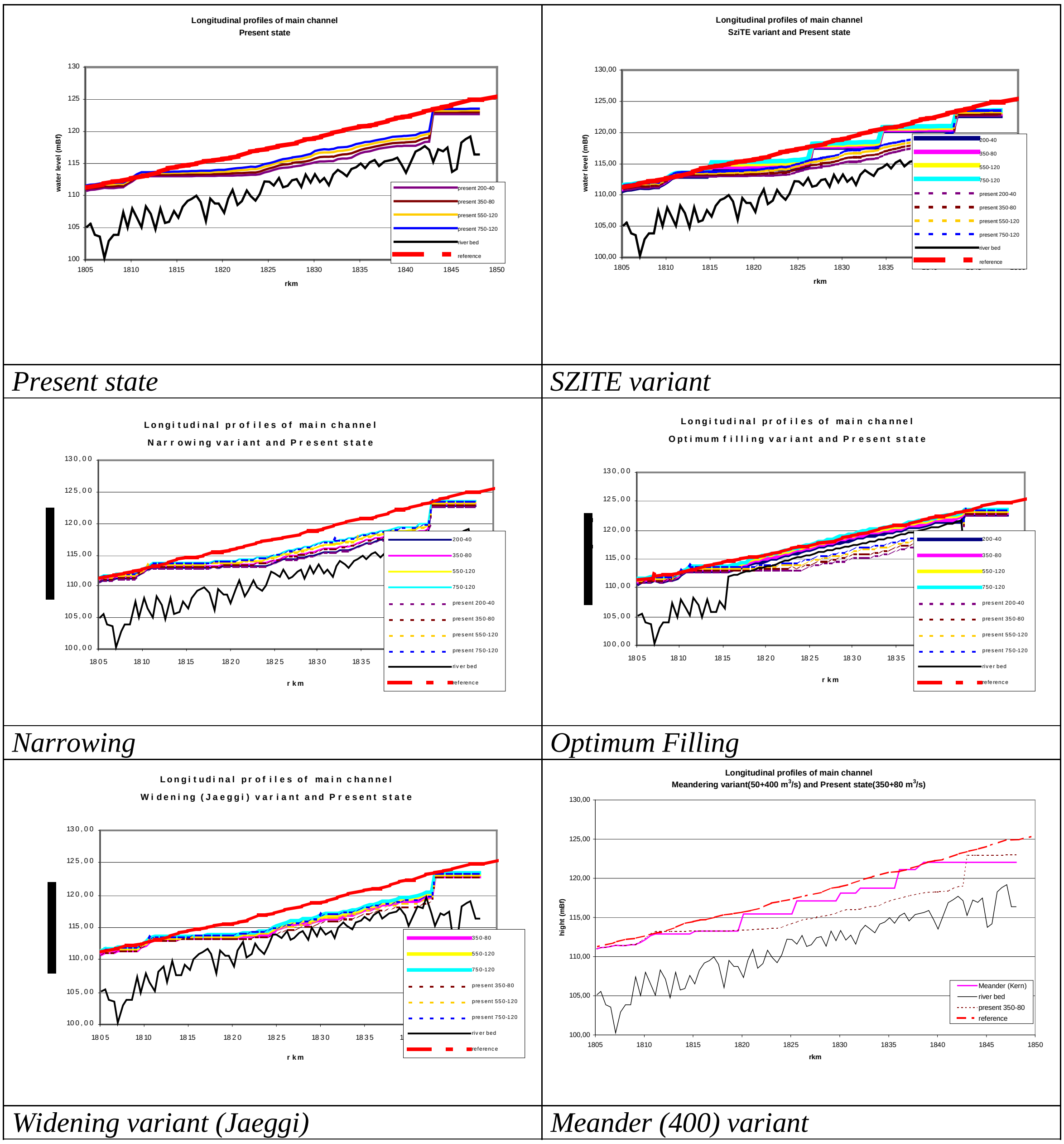
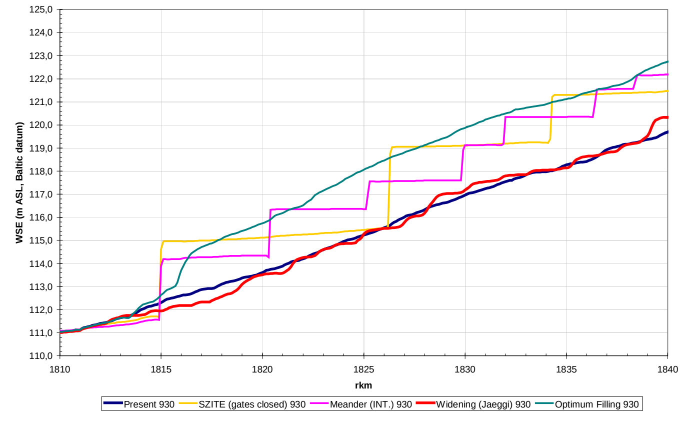
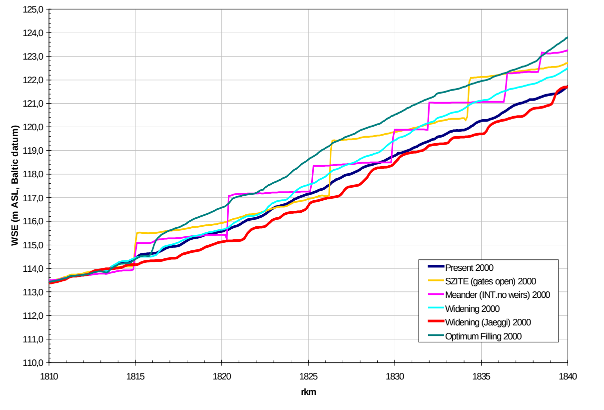


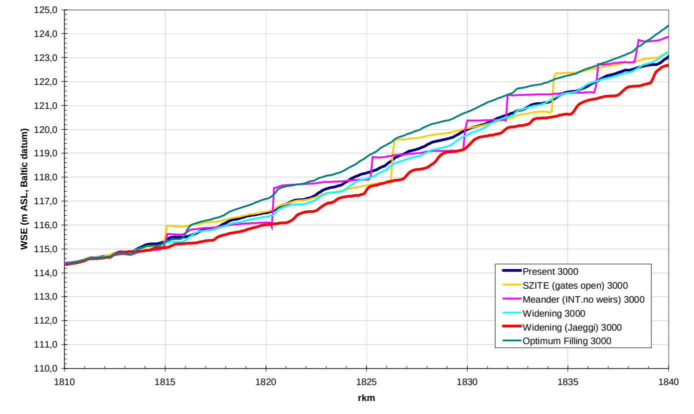
Figure 8-21 Water levels in the Danube for discharges from 200 to 750 m³/s compared to the mean water level in the 1950s as reference level (red line); Meander (400) variant with 400 m³/s in meander branch and 50 m³/s in main channel



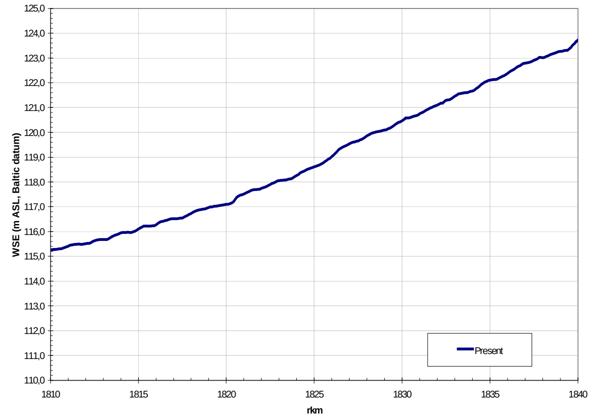
$Q = 930\ m^3/s$



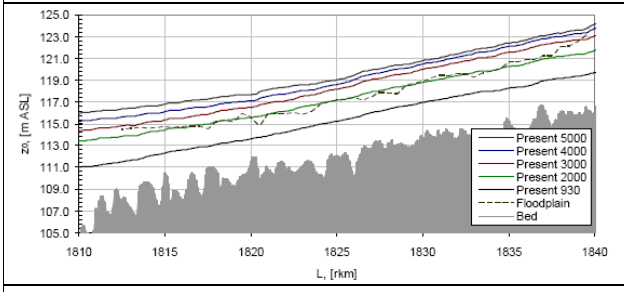
$Q = 2000\ m^3/s$



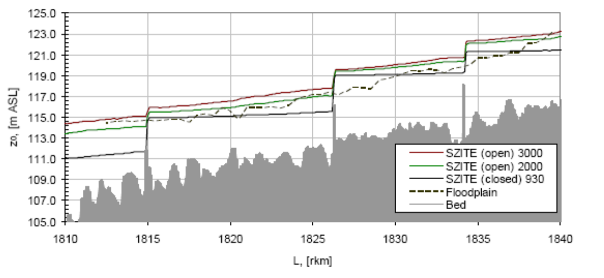
$Q = 3000\ m^3/s$



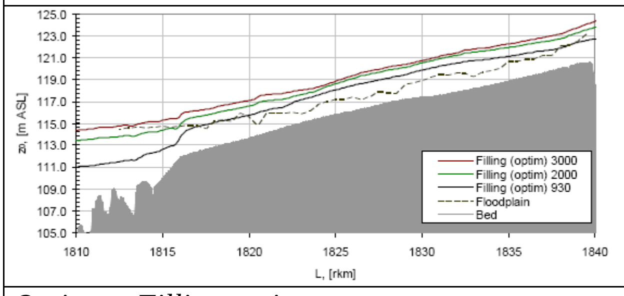
$Q = 4000\ m^3/s$ (Present)



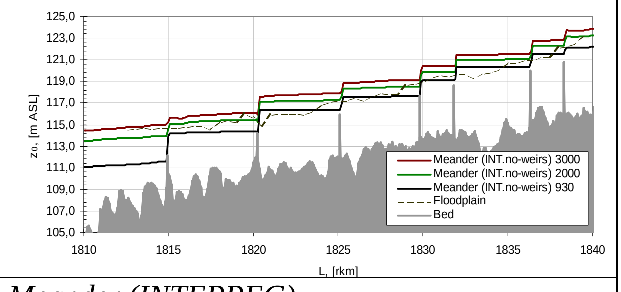
Present state



SZITE variant



Optimum Filling variant



Meander (INTERREG)

Figure 8-22 Water levels in the Danube main channel for discharges from 930 to 5000 m³/s

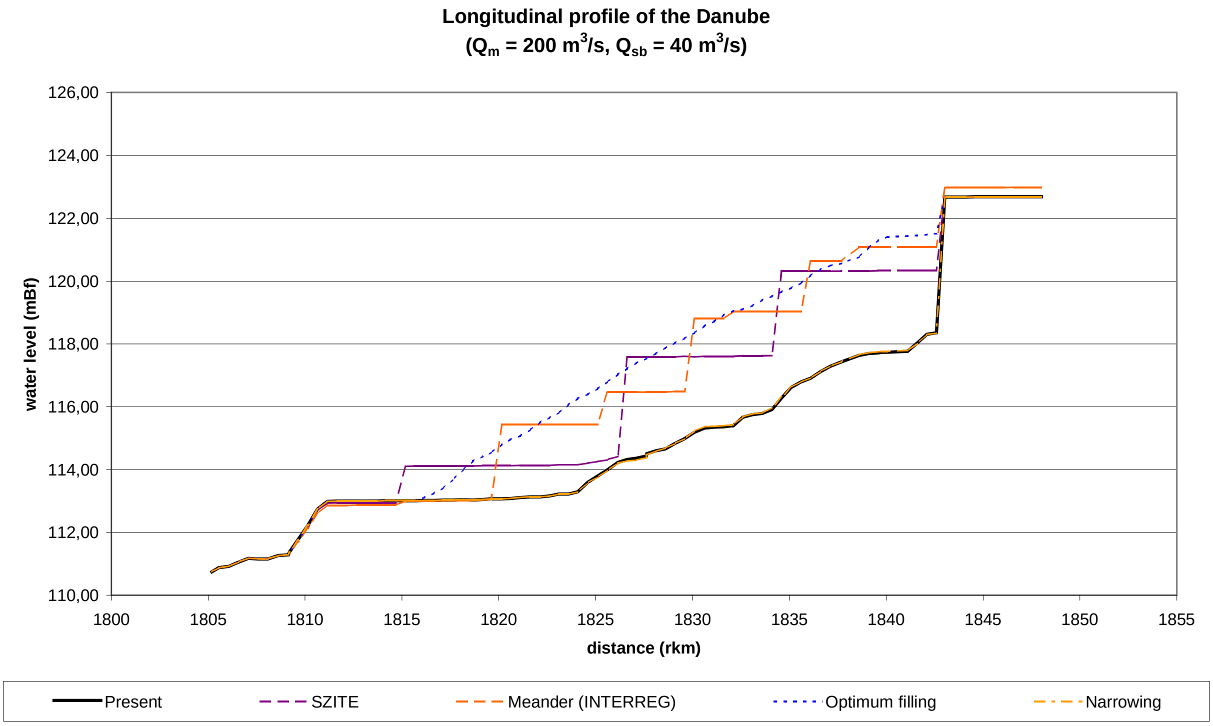


Figure 8-23 Water levels in the Danube main channel for 200/40 m³/s and different variants

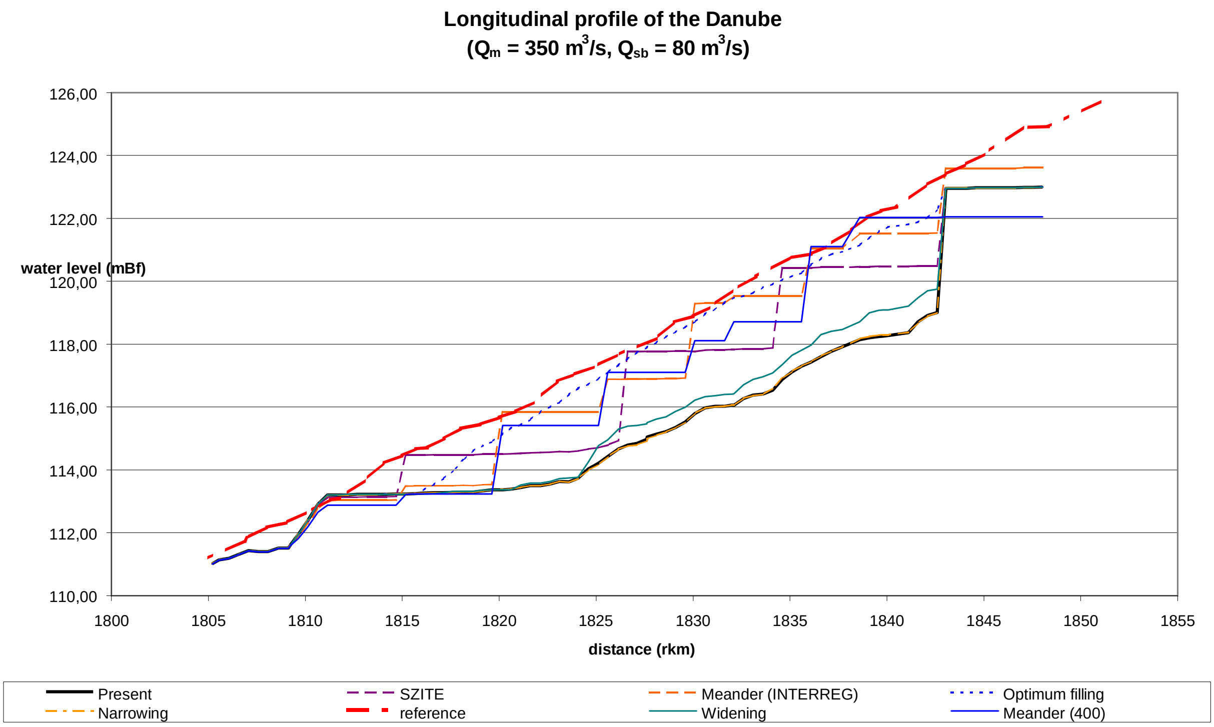


Figure 8-24 Water levels in the Danube main channel for 350/80 m³/s and different variants; Meander (400) variant: Q_m = 50 m³/s, Q_{sb} = 400 m³/s

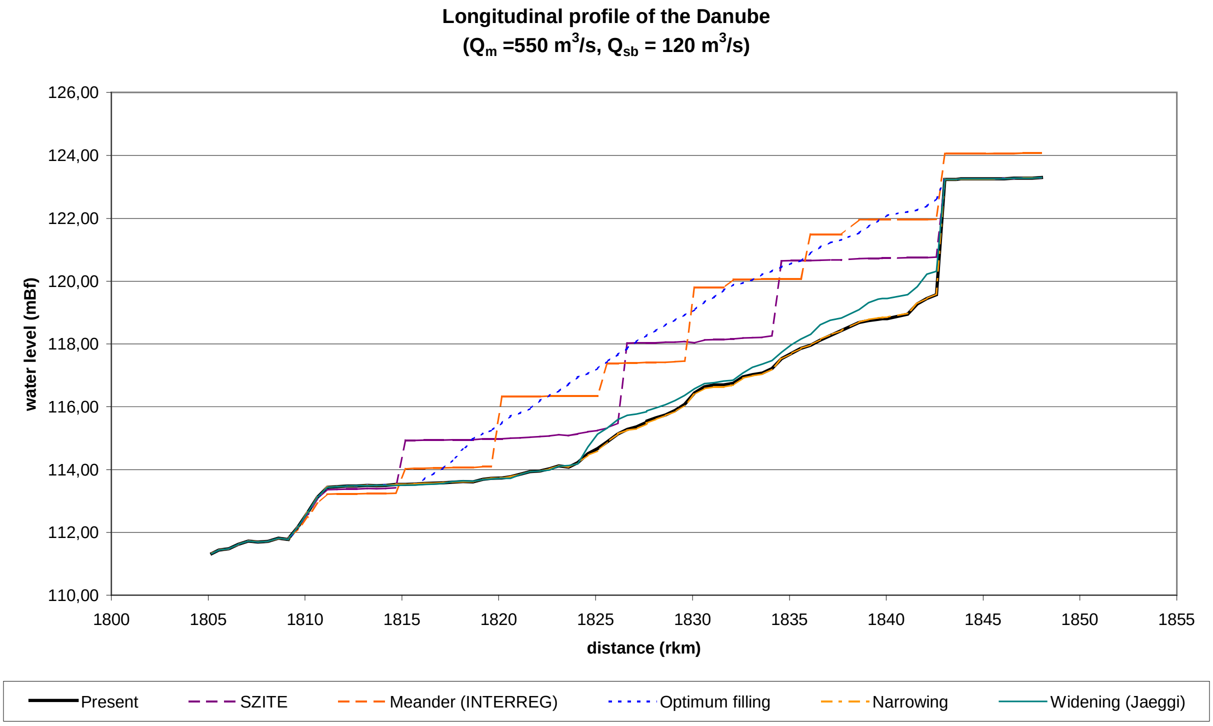


Figure 8-25 Water levels in the Danube main channel for 550/120 m³/s and different variants

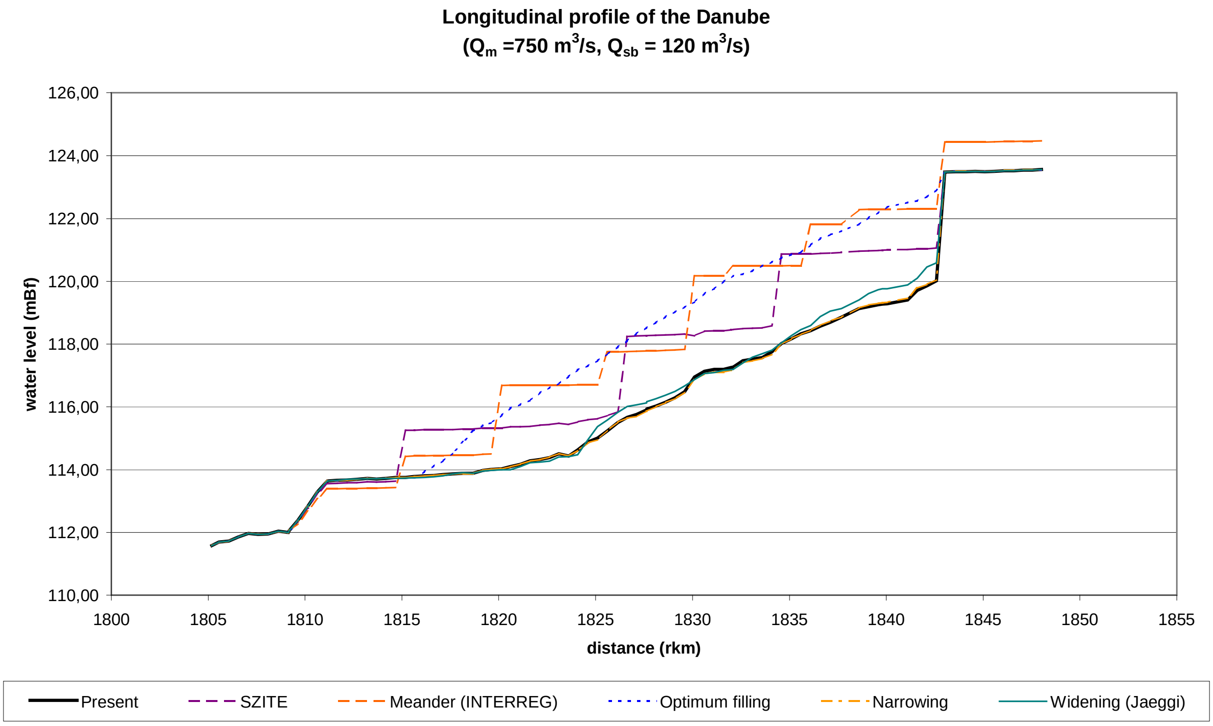
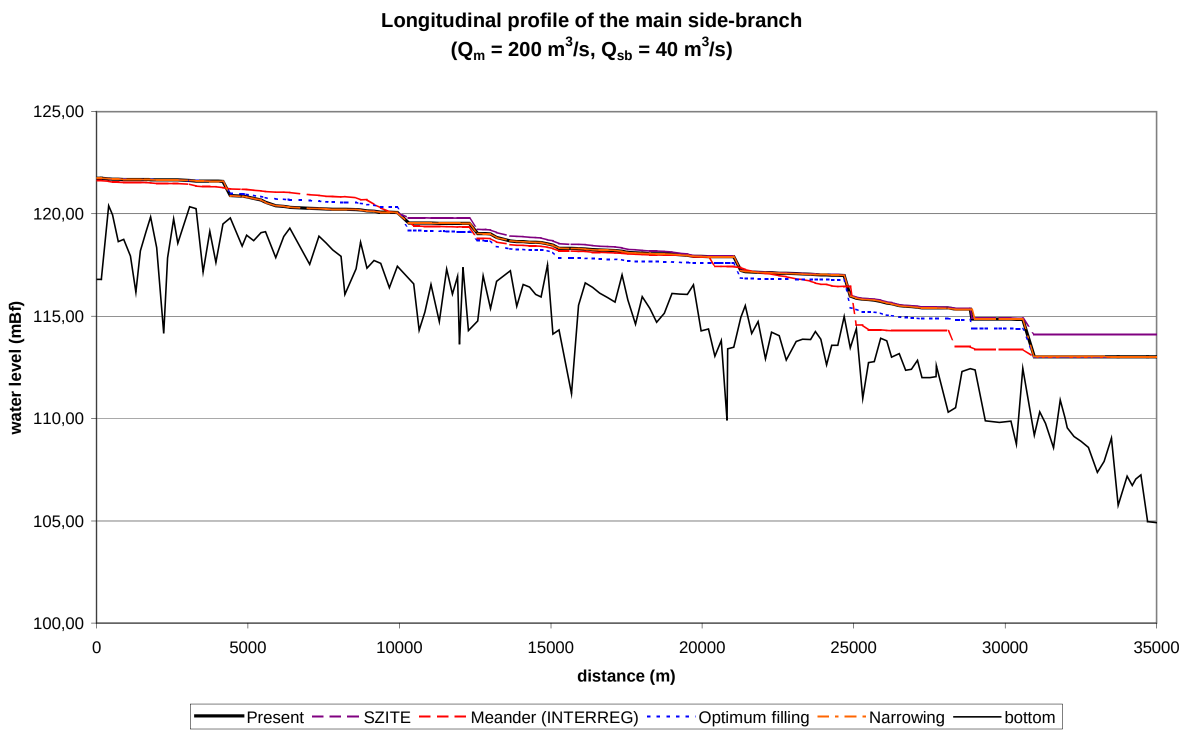
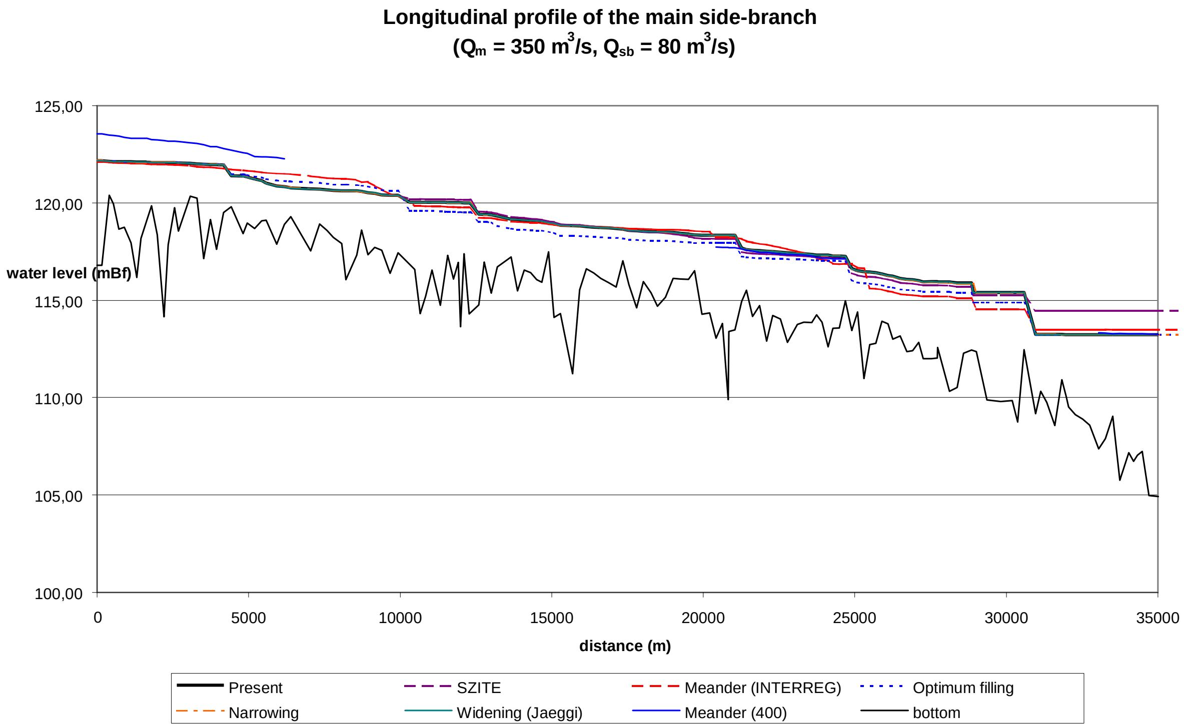


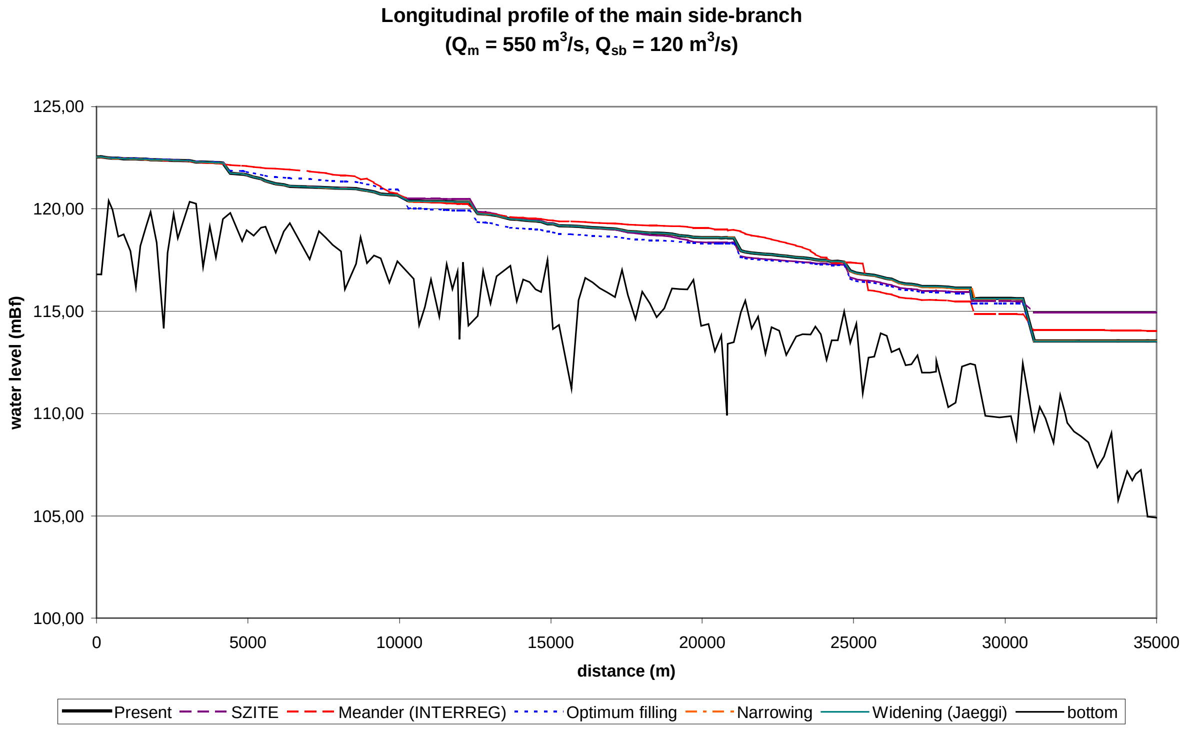
Figure 8-26 Water levels in the Danube main channel for 750/120 m³/s and different variants



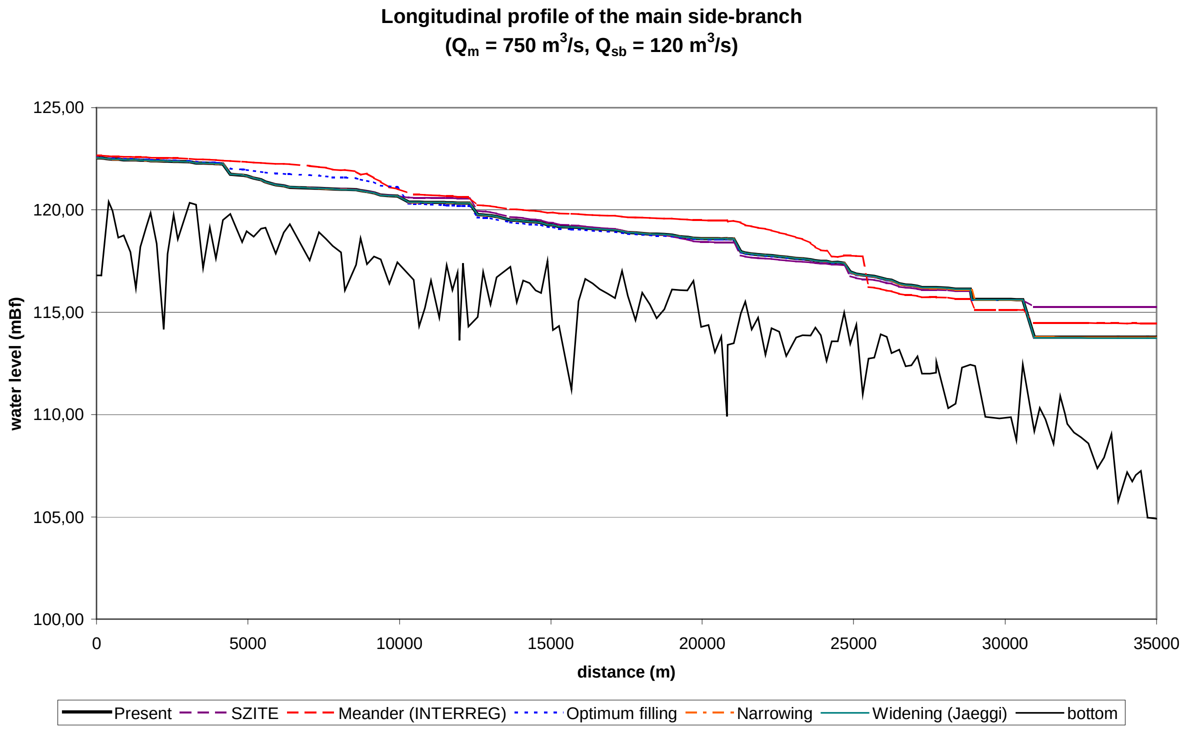
8-27 Water levels in the main side branch for 200/40 m³/s and different variants



8-28 Water levels in the main side branch for 350/80 m³/s and different variants; Meander (400) variant with 400 m³/s in meander branch and 50 m³/s in main channel

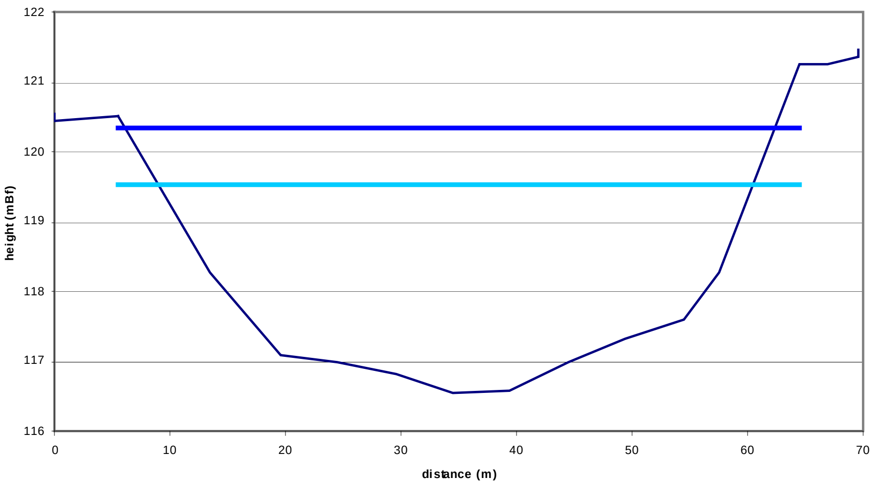


8-29 Water levels in the main side branch for 550/120 m³/s and different variants

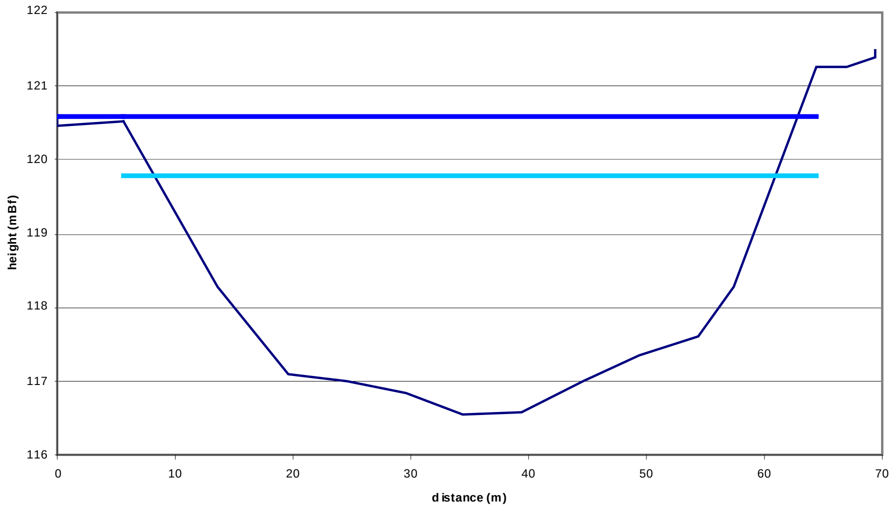


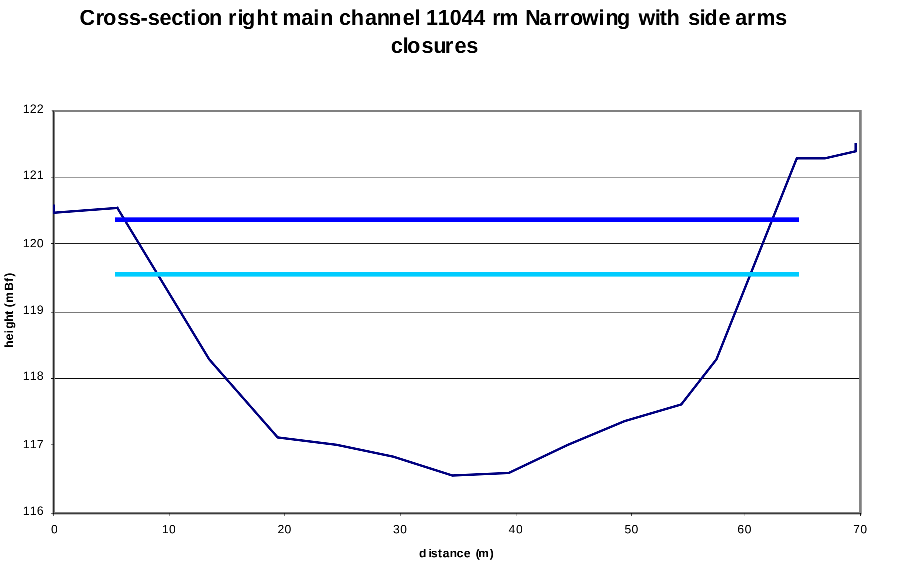
8-30 Water levels in the main side branch for 750/120 m³/s and different variants

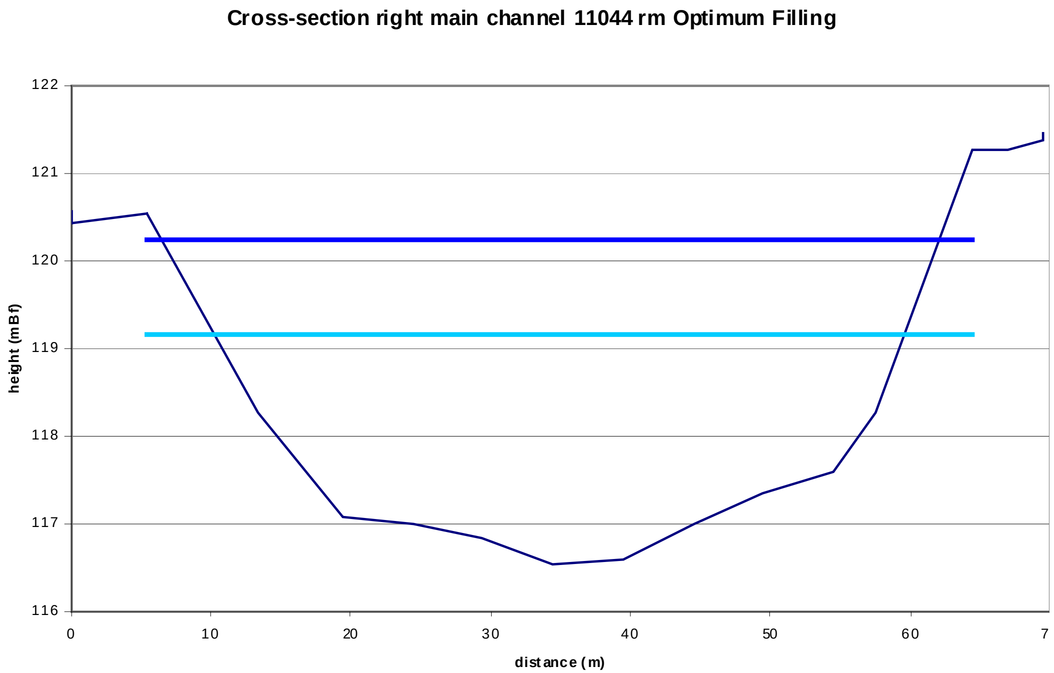
Cross-section right main channel 11044 rm Present

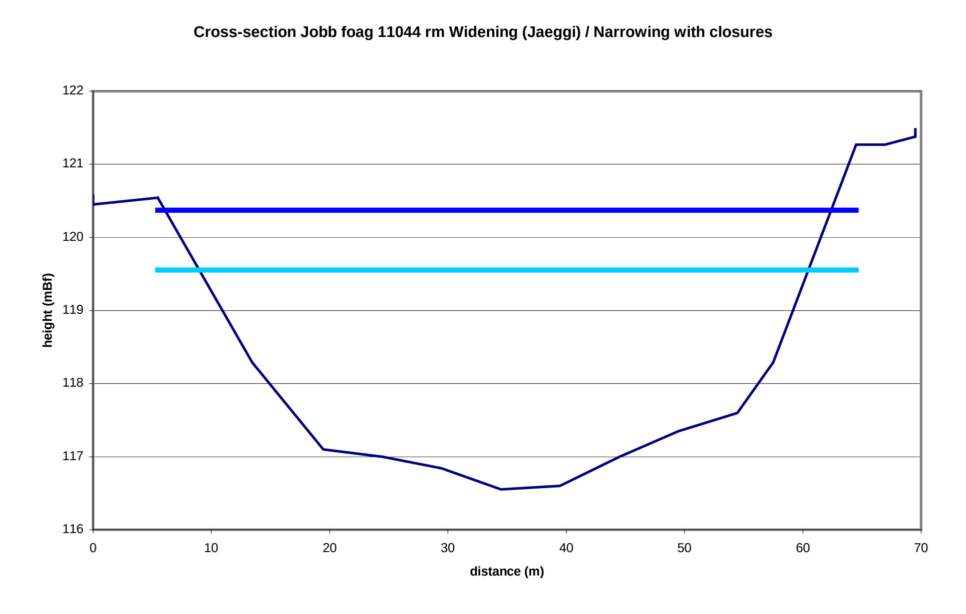


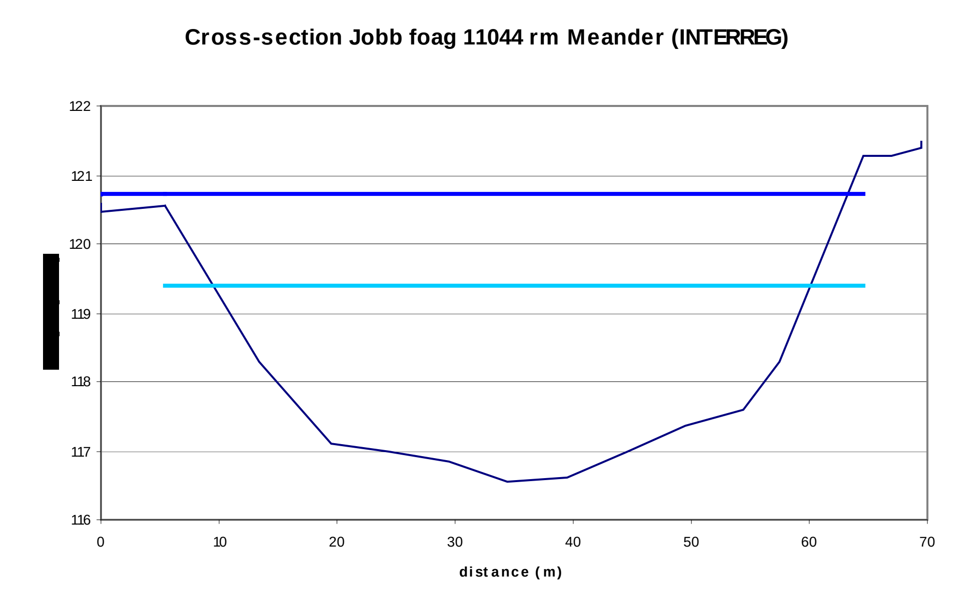
Cross-section right main channel 11044 rm SZITE



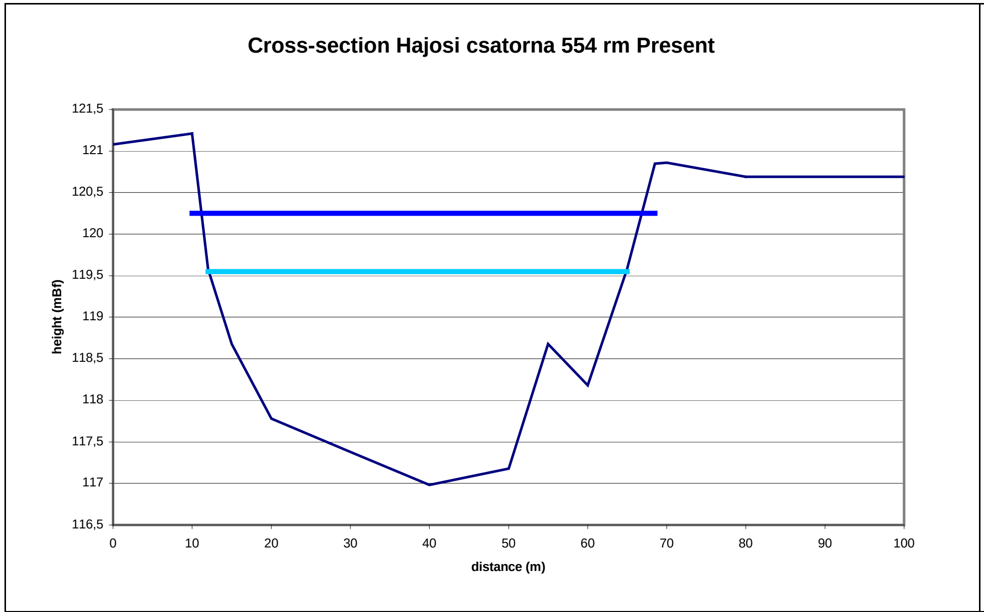

Cross-section right main channel 11044 rm Narrowing with side arms closures
height (mBf)
122
121
120
119
118
117
116
0
10
20
30
40
50
60
70
distance (m)

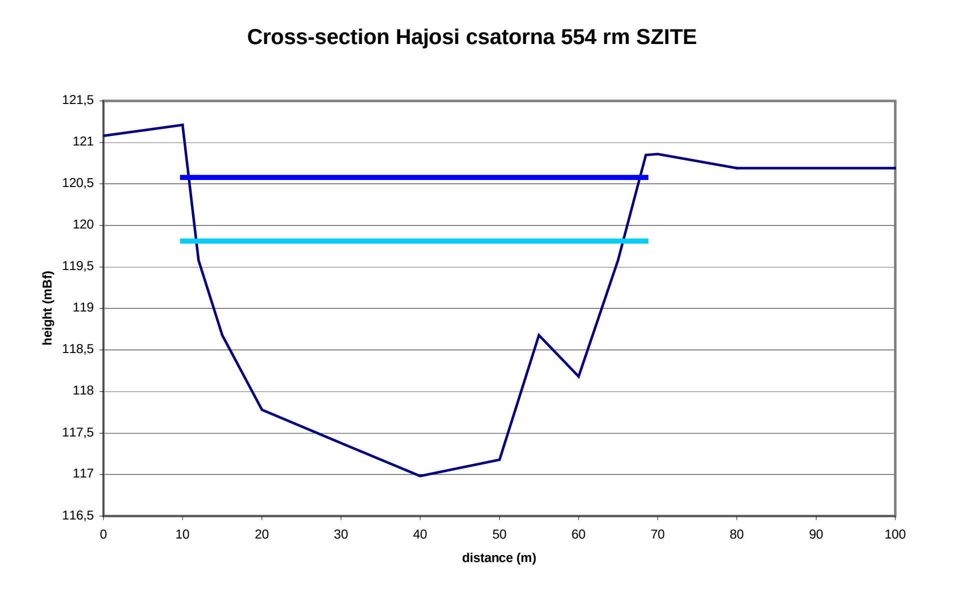

Cross-section right main channel 11044 rm Optimum Filling
height (mBf)
122
121
120
119
118
117
116
0
10
20
30
40
50
60
7
distance (m)

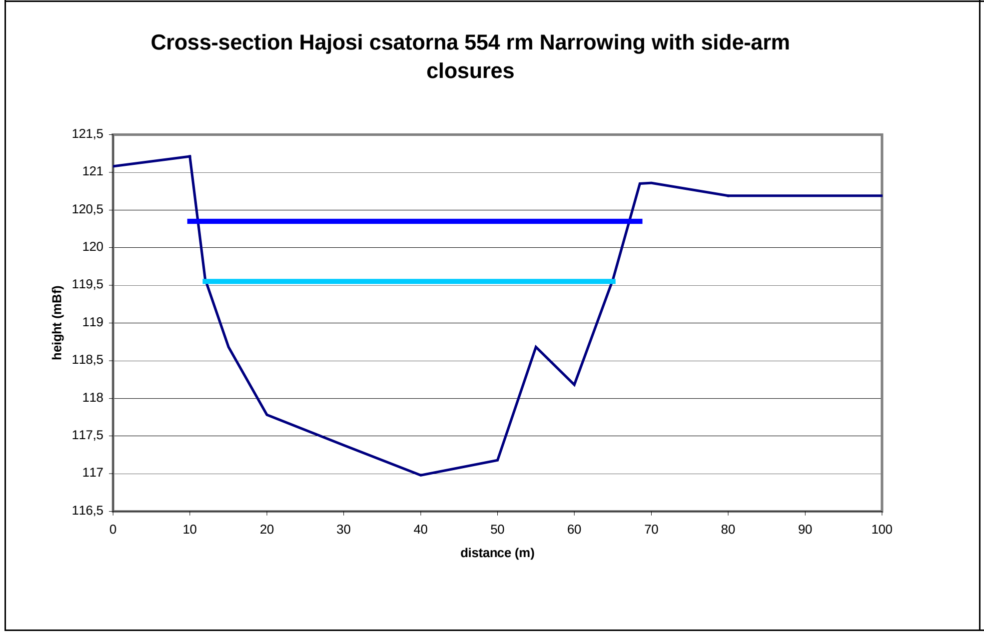


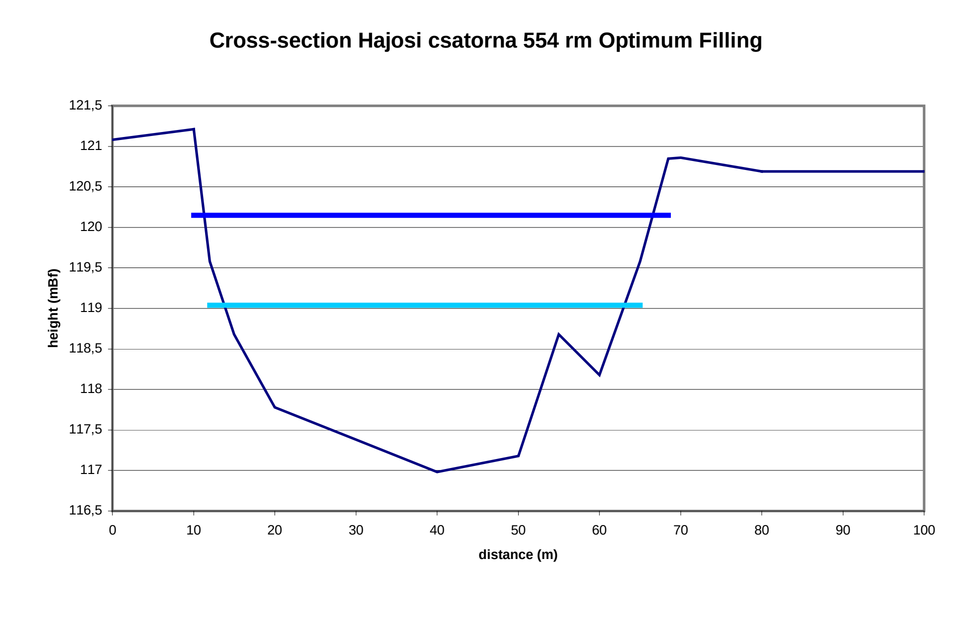


a) Water level differences in the main side branch of the Hungarian floodplain (above)


Cross-section Hajosi csatorna 554 rm Present
height (mBf)
121,5
121
120,5
120
119,5
119
118,5
118
117,5
117
116,5
0 10 20 30 40 50 60 70 80 90 100
distance (m)


Cross-section Hajosi csatorna 554 rm SZITE
height (mBf)
121,5
121
120,5
120
119,5
119
118,5
118
117,5
117
116,5
0 10 20 30 40 50 60 70 80 90 100
distance (m)


Cross-section Hajosi csatorna 554 rm Narrowing with side-arm closures
height (mBf)
121,5
121
120,5
120
119,5
119
118,5
118
117,5
117
116,5
0 10 20 30 40 50 60 70 80 90 100
distance (m)


Cross-section Hajosi csatorna 554 rm Optimum Filling
height (mBf)
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120,5
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119,5
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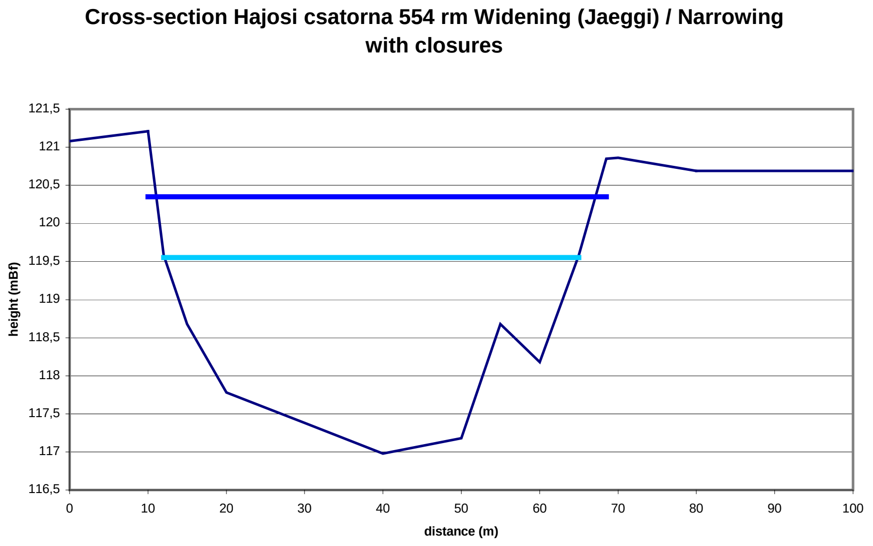
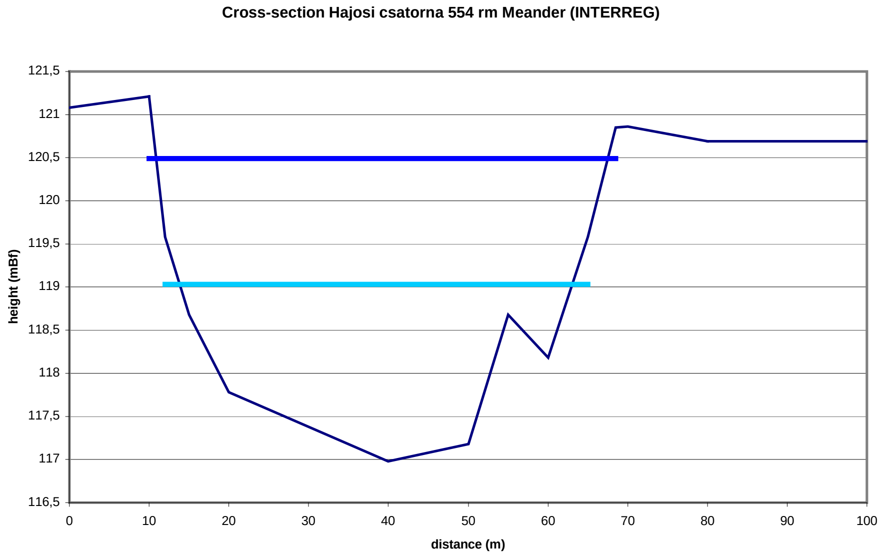
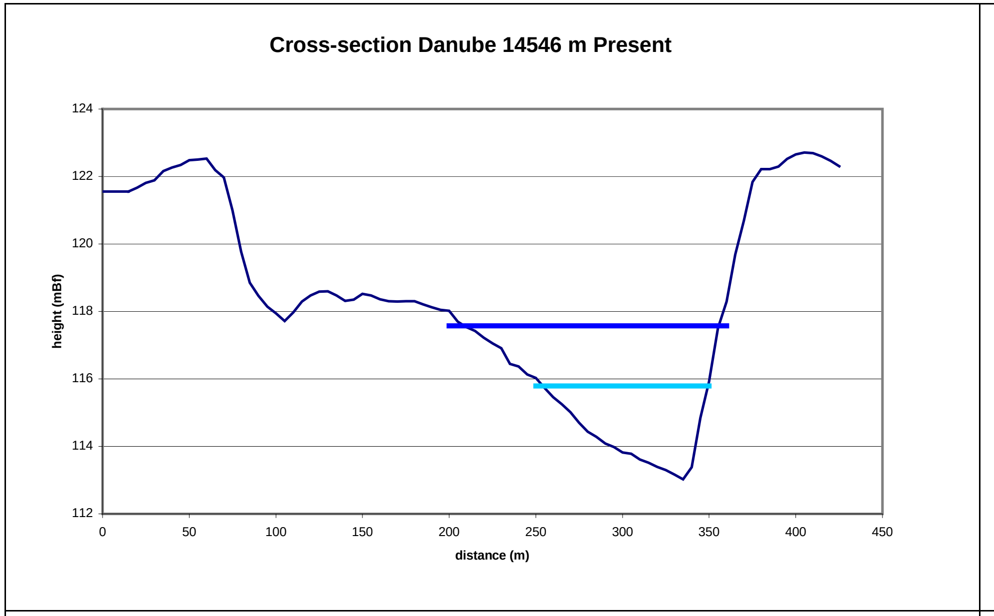
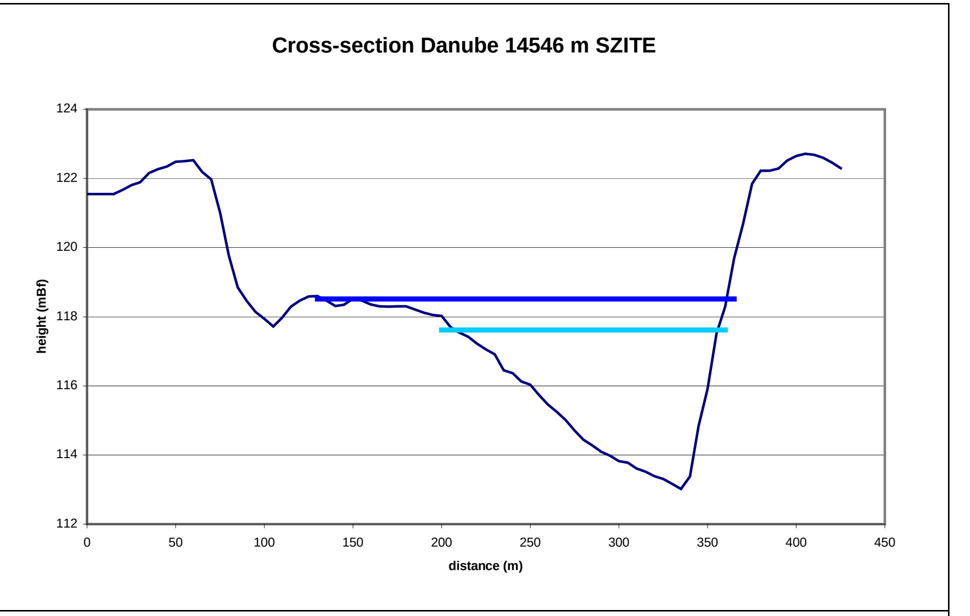
117,5
117
116,5
0 10 20 30 40 50 60 70 80 90 100
distance (m)

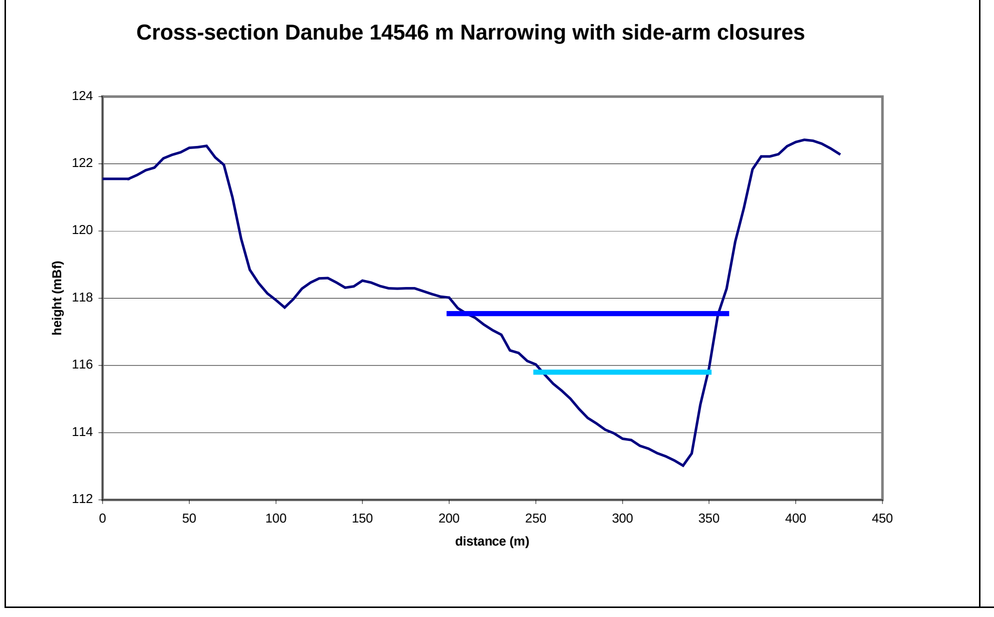


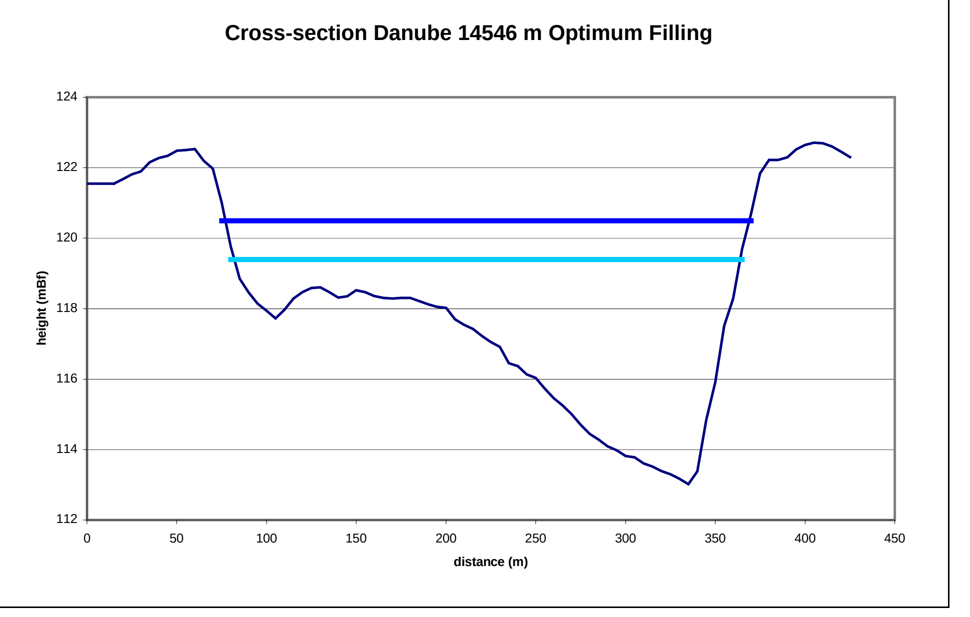


b) Water level differences in the Hajósi Csatorna branch of the Cikola region (above)


Cross-section Danube 14546 m Present
height (mBf)
distance (m)
124
122
120
118
116
114
112
0
50
100
150
200
250
300
350
400
450


Cross-section Danube 14546 m SZITE
height (mBf)
distance (m)
124
122
120
118
116
114
112
0
50
100
150
200
250
300
350
400
450


Cross-section Danube 14546 m Narrowing with side-arm closures
height (mBf)
distance (m)
124
122
120
118
116
114
112
0
50
100
150
200
250
300
350
400
450


Cross-section Danube 14546 m Optimum Filling
height (mBf)
distance (m)
124
122
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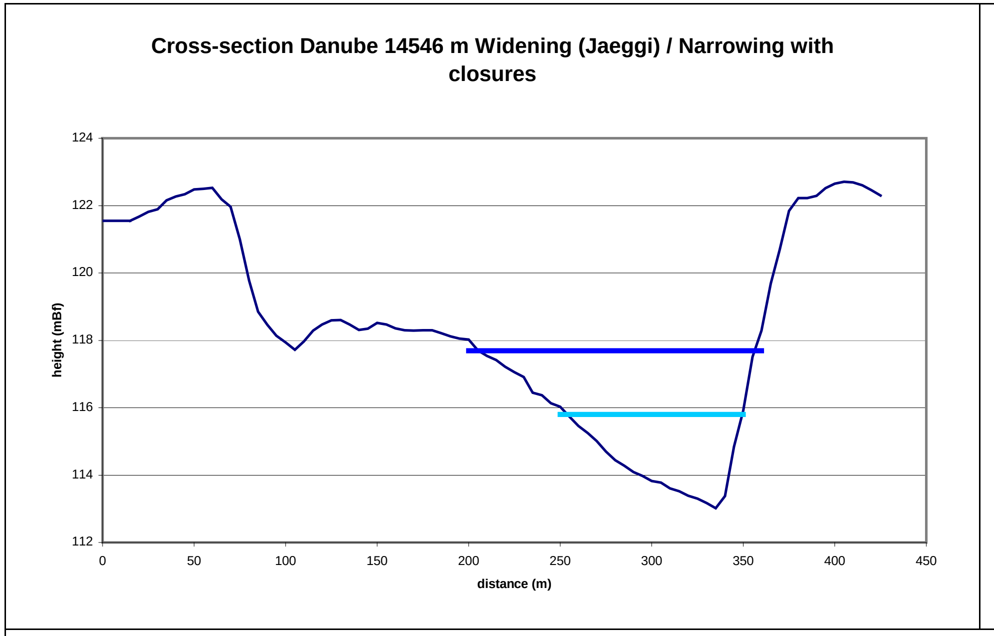
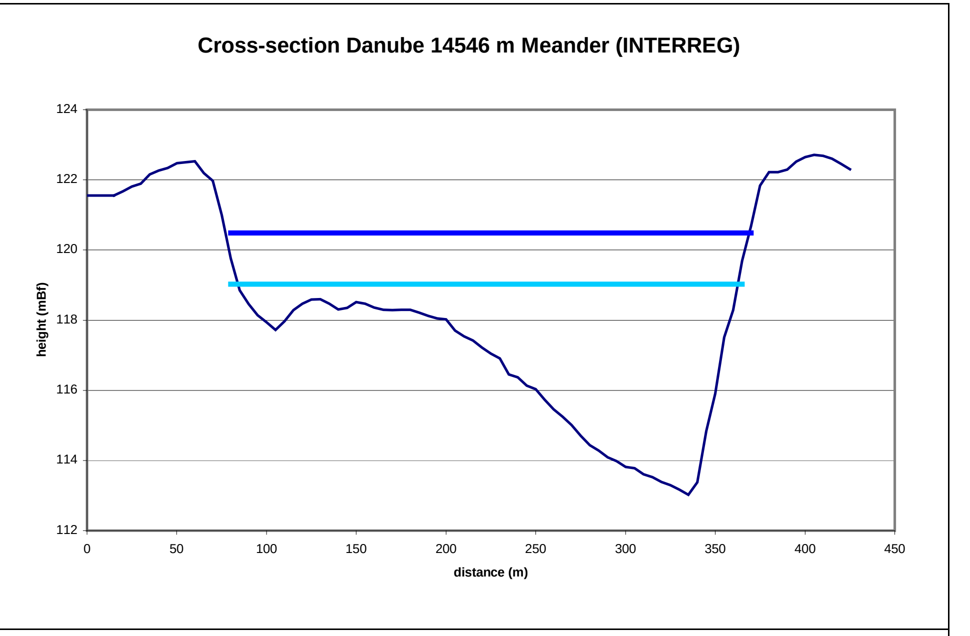
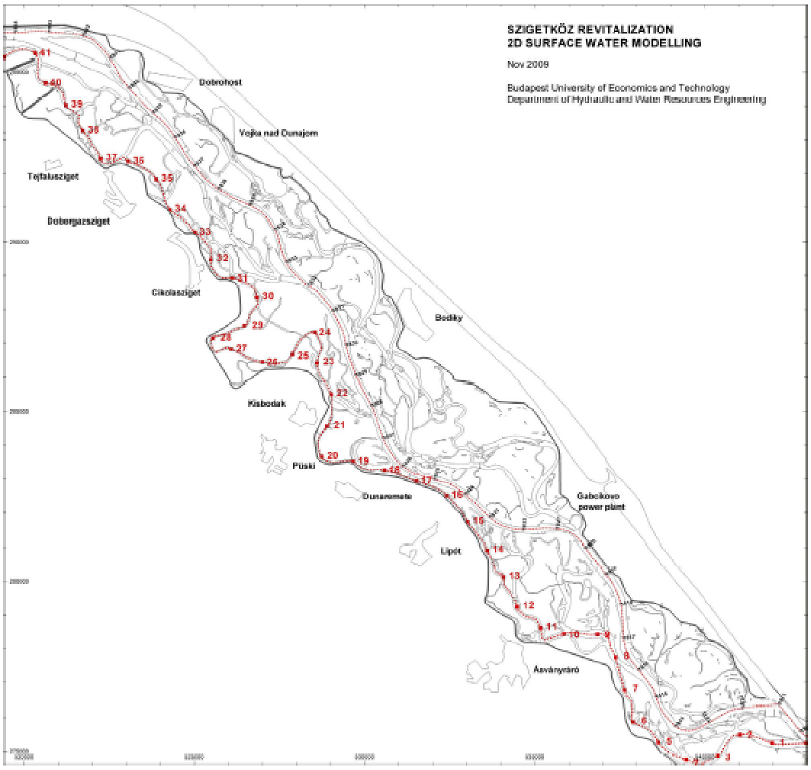
400
450

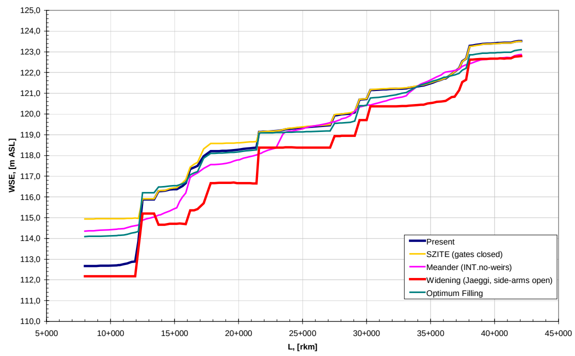




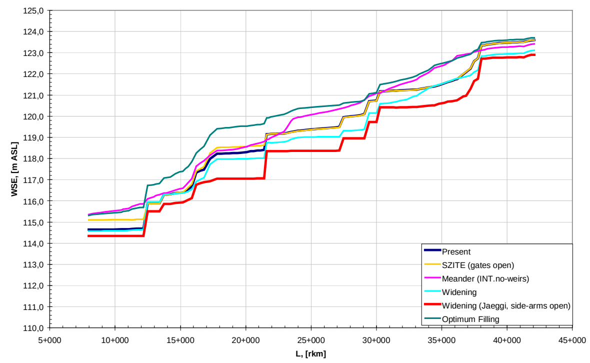
c) Water level differences in the main channel of the Danube

8-31 Water level difference in selected cross-sections in the main channel and in side branches between 750/120 m³/s and 200/40 m³/s (Widening (J.) compared to Narrowing since 200/40 was not included in the modellling)

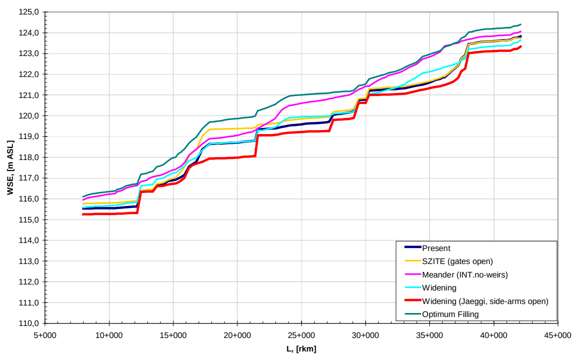




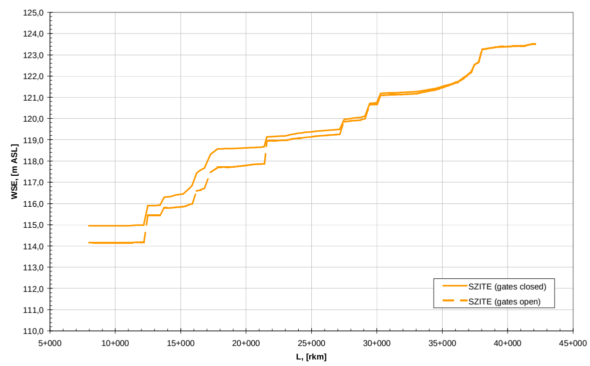
Q = 930 m³/s



Q = 2000 m³/s

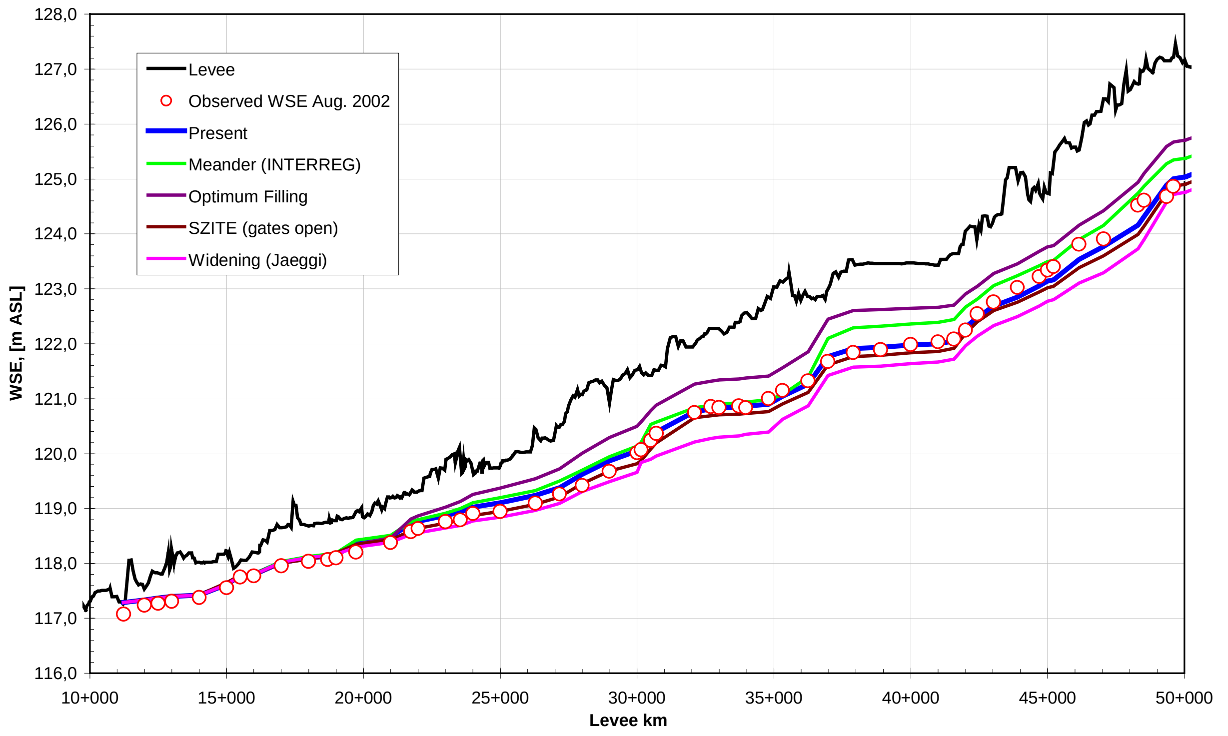


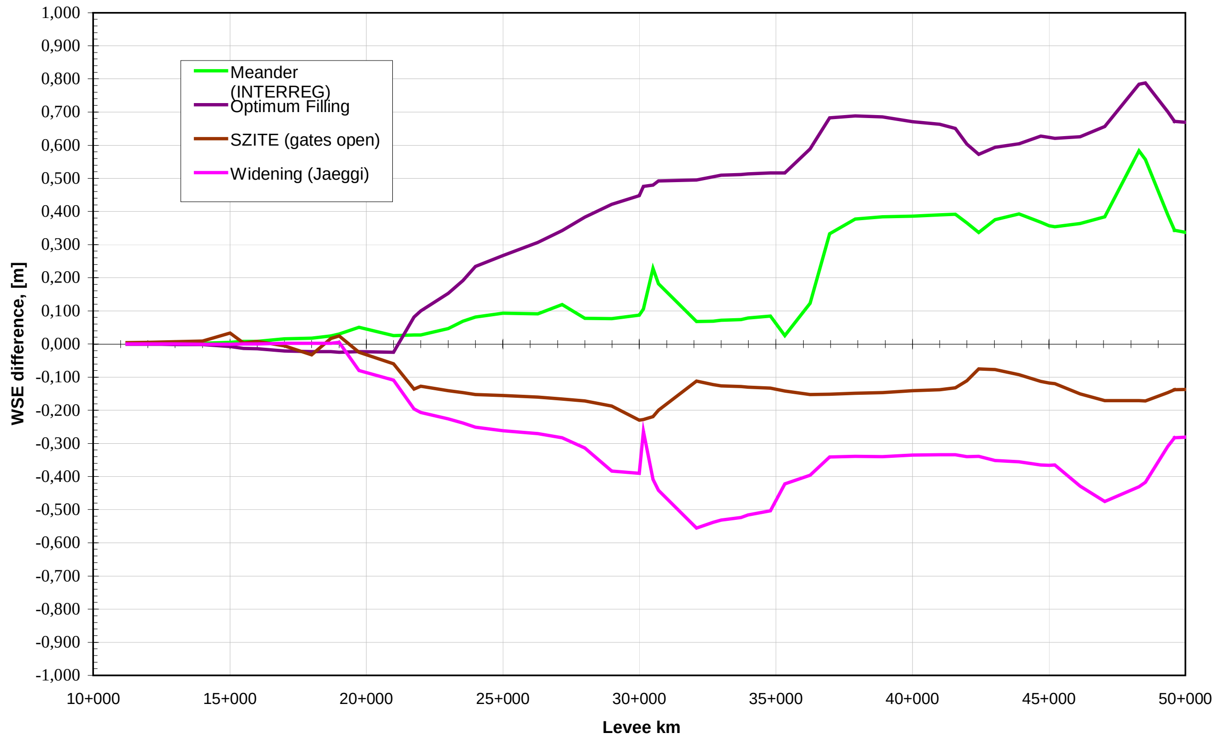
Q = 3000 m³/s



SZITE (gates open/closed) 930 m³/s

8-32 Layout and water levels of the main side branch channel for different variants

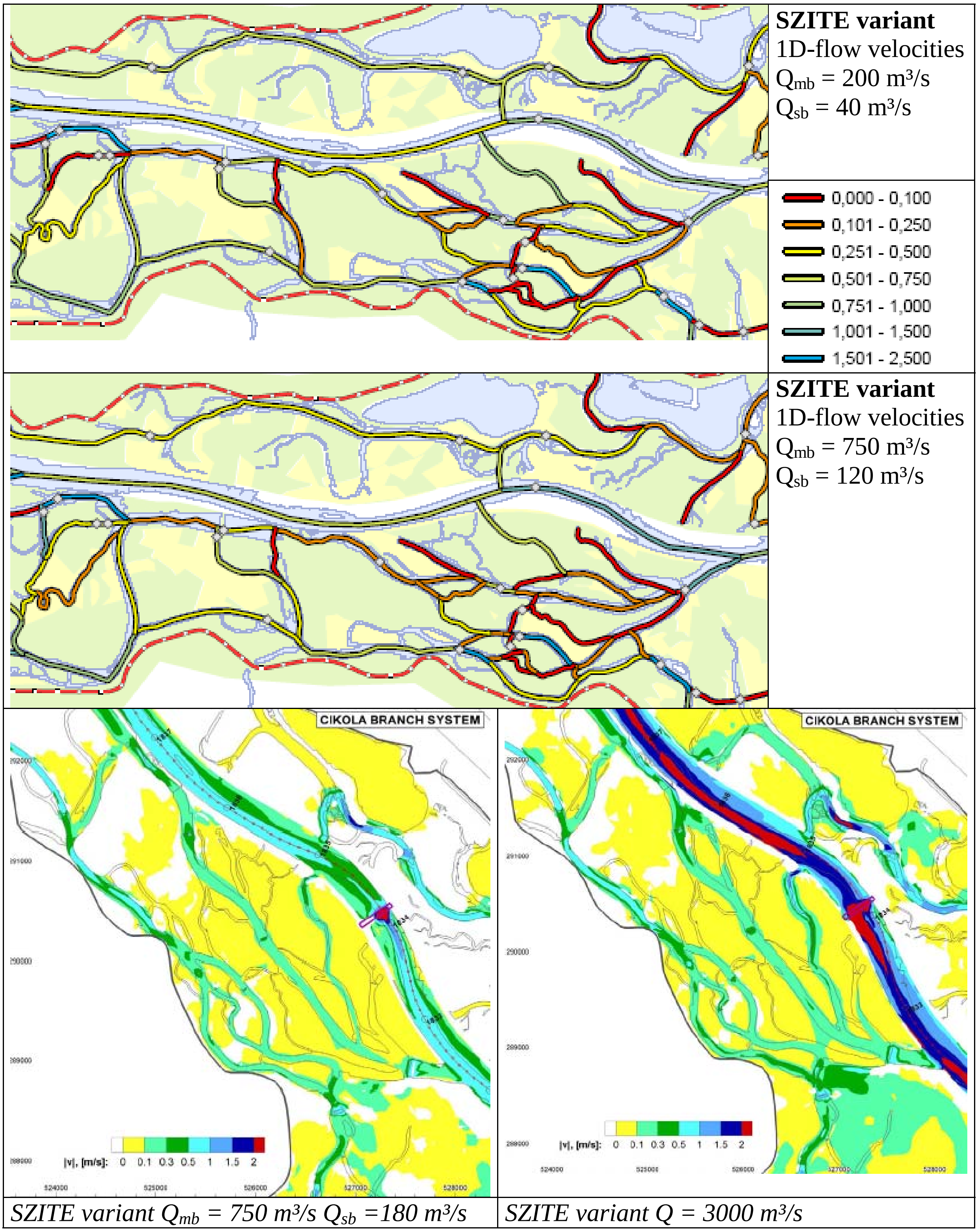




8-33 Water level profiles for the 2002 flood (Q_{Devin} = 10,370 m³/s, Q_{Rajka} = 6590 m³/s, $Q_{Gabcikovo}$ = 3080 m³/s, $Q_{outflow}$ = 9670 m³/s)

8.3.2. Flow velocities

Flow velocities were calculated for all discharge scenarios. The distribution of flow velocities over space and time is an important factor for the composition of the aquatic fauna. Graphs for the SZITE variant may demonstrate the results obtained in a similar way for most of the variants.

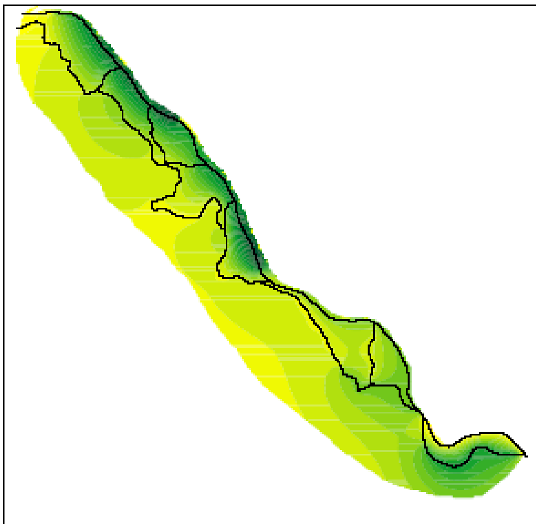


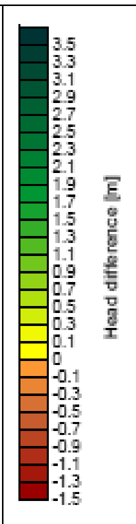
8-34 Spatial distribution of flow velocities for the SZITE variant at different discharges

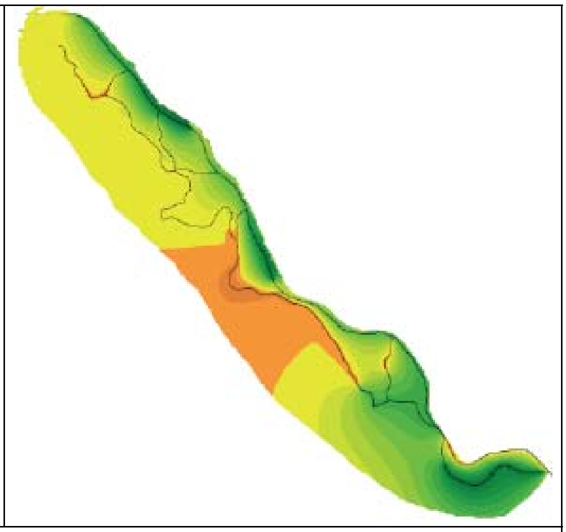
8.3.3. Groundwater level dynamics

Groundwater levels were calculated for all variants and discharges from 200, 350, 550 and 750 m³/s in the main channel. Difference maps over the project area were created showing the rise or fall of groundwater levels for different variants compared to the present situation at particular flows (Figure 8-35). These maps give an impression of groundwater level changes associated with certain measures. Yellow and yellow ochre indicate “no significant change”.

The Meander (INTERREG) variant tends to overestimate the rise of groundwater levels to a certain extent. This is caused by over-bankful flows which result in higher surface water levels in the 1D-model than in nature. Nevertheless, the general trend is correct.

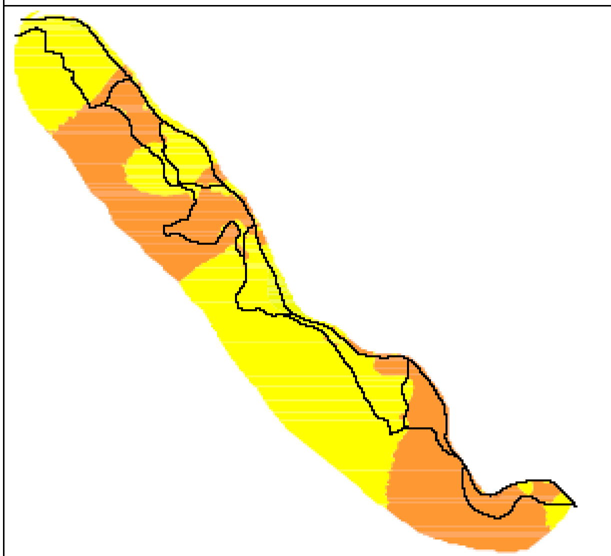




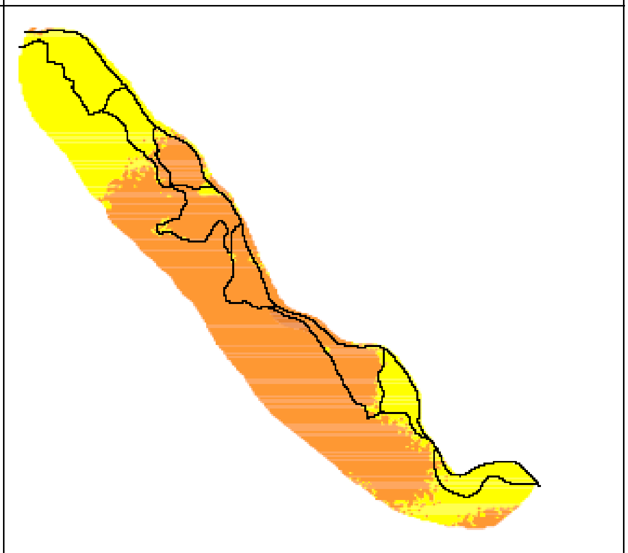


SZITE minus Present at 200/40 m³/s

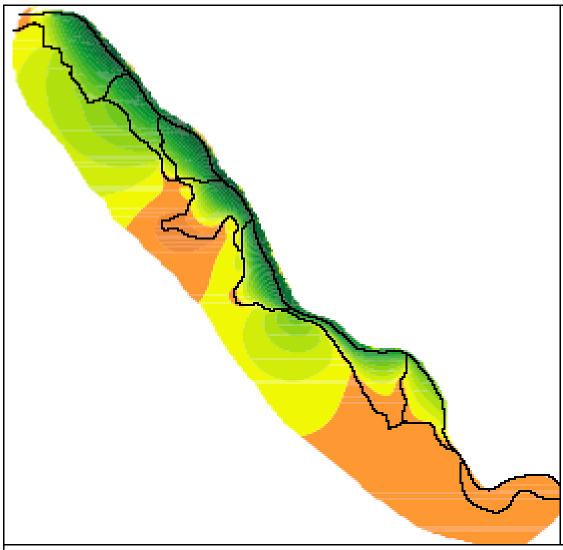
SZITE minus Present at 750/120 m³/s

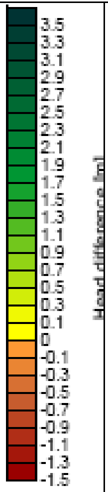


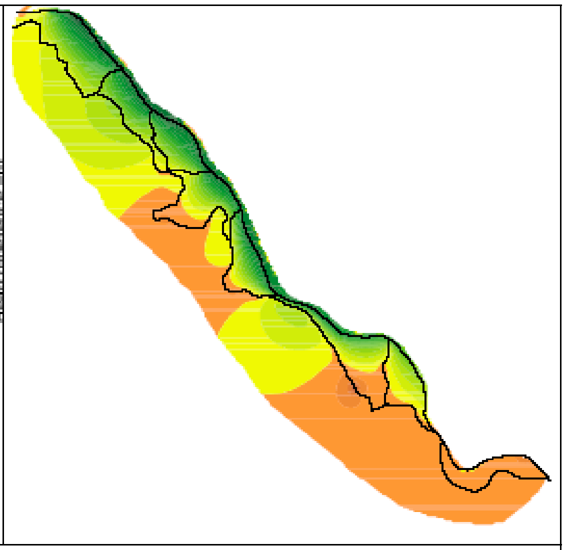
Narrowing (no connection) minus Present at 200 m³/s



Narrowing (no connection) minus Present at 750 m³/s

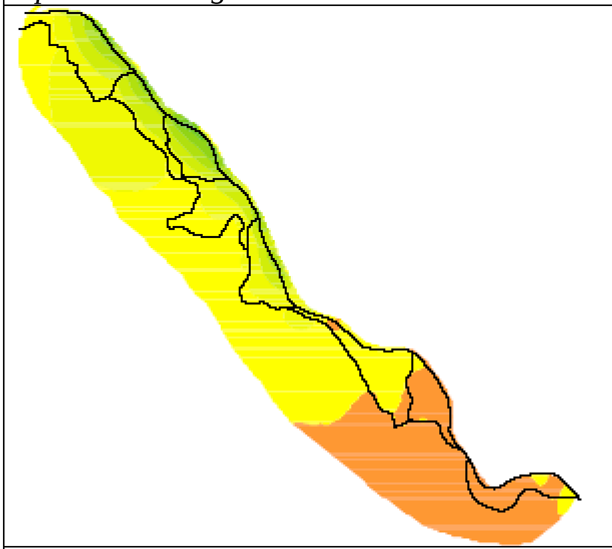




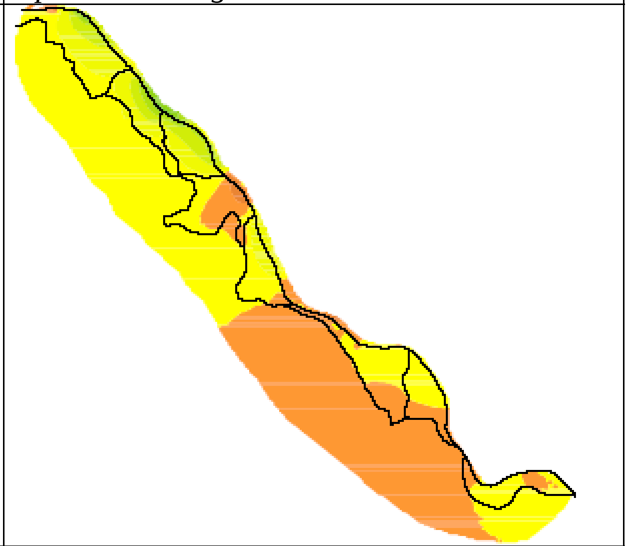


Optimum Filling minus Present at 200 m³/s

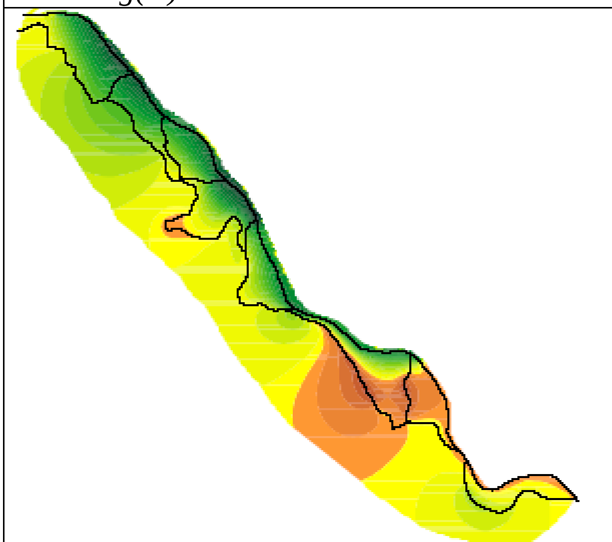
Optimum Filling minus Present at 750 m³/s



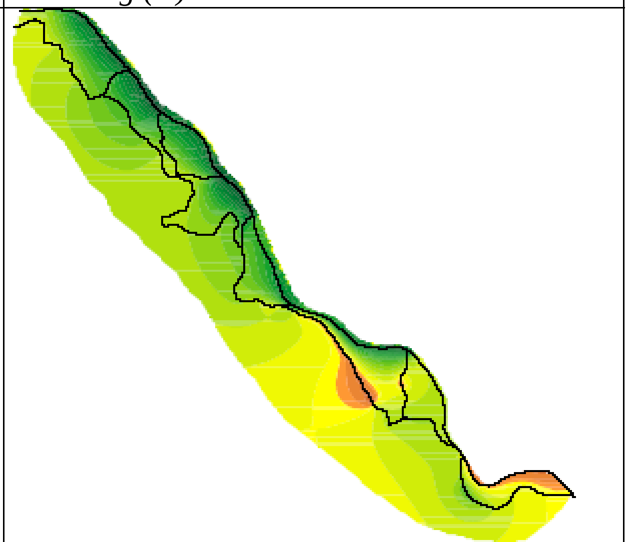
Widening(J.) minus Present at 350 m³/s



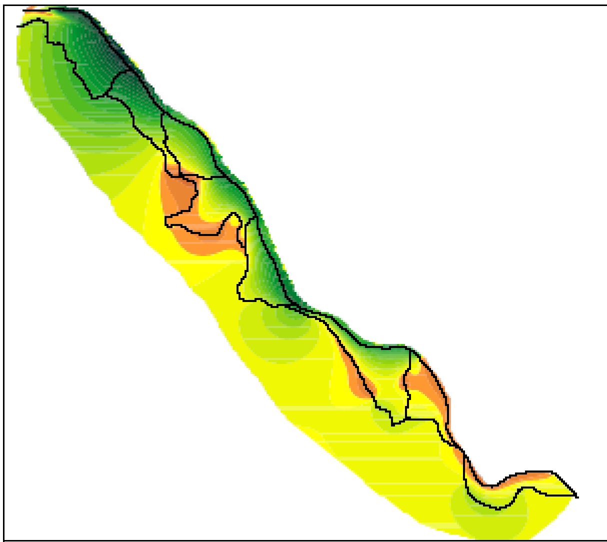
Widening (J.) minus Present at 750 m³/s



Meander (INTERR.) minus- Present at 200 m³/s



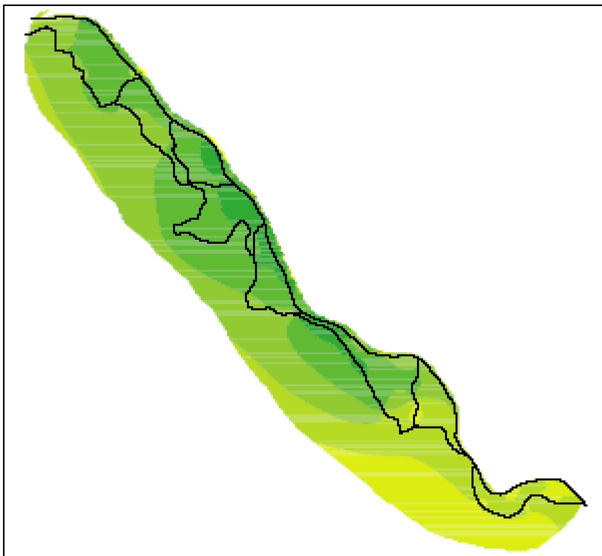
Meander (INTERR.) minus Present at 750 m³/s

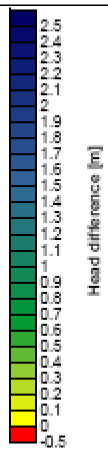


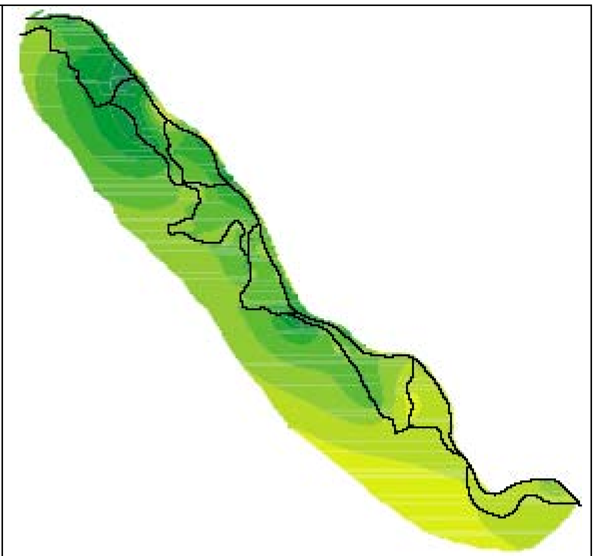
Meander (400) minus Present at 400 m³/s

Figure 8-35 Difference maps of groundwater levels relative to present conditions

Since groundwater fluctuations are an important parameter for terrestrial habitats, difference maps for varying discharges (350–200/550-350/750-550 and 750-200 m³/s) were established (Figure 8-36).

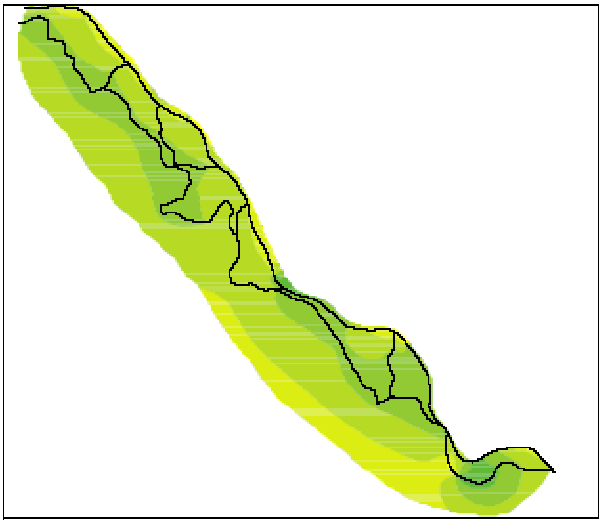


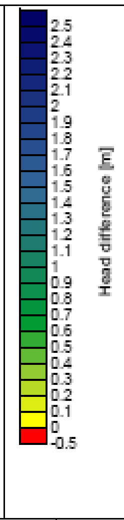


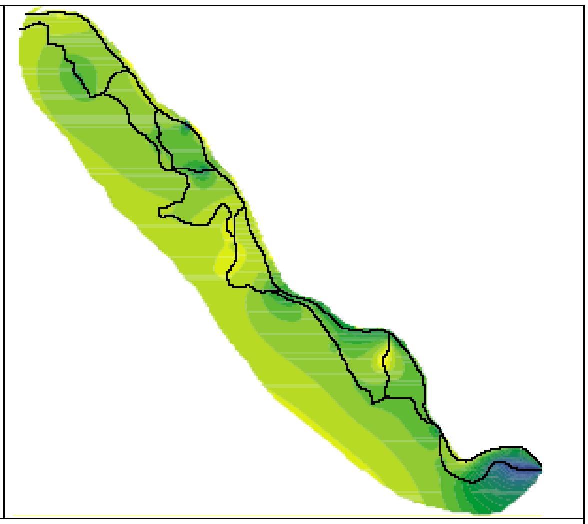


Present: 350 minus 200 m³/s

Present: 550 minus 350 m³/s

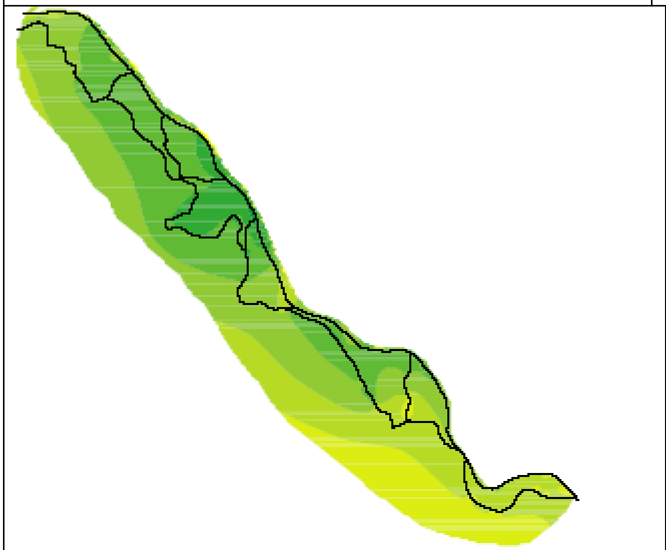


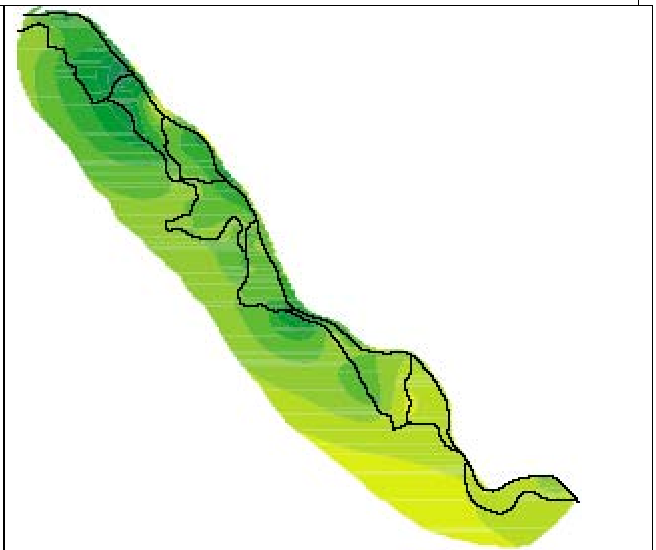




SZITE: 350 minus 200 m³/s

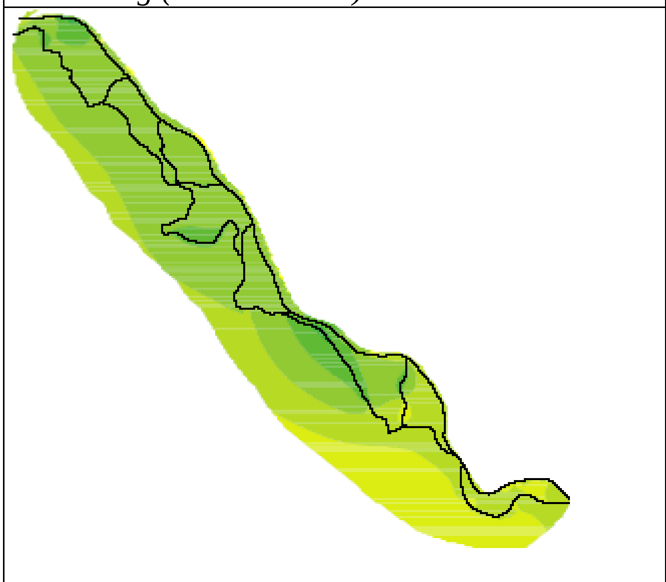
SZITE: 550 minus 350 m³/s

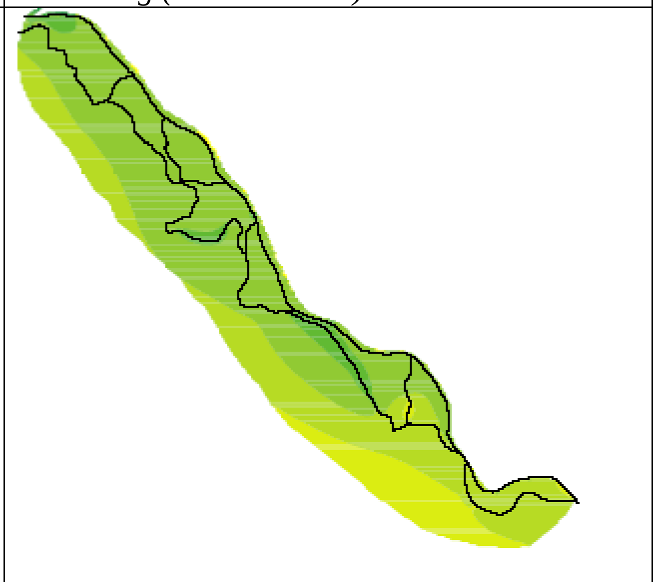




Narrowing (no connection): 350 minus 200 m³/s

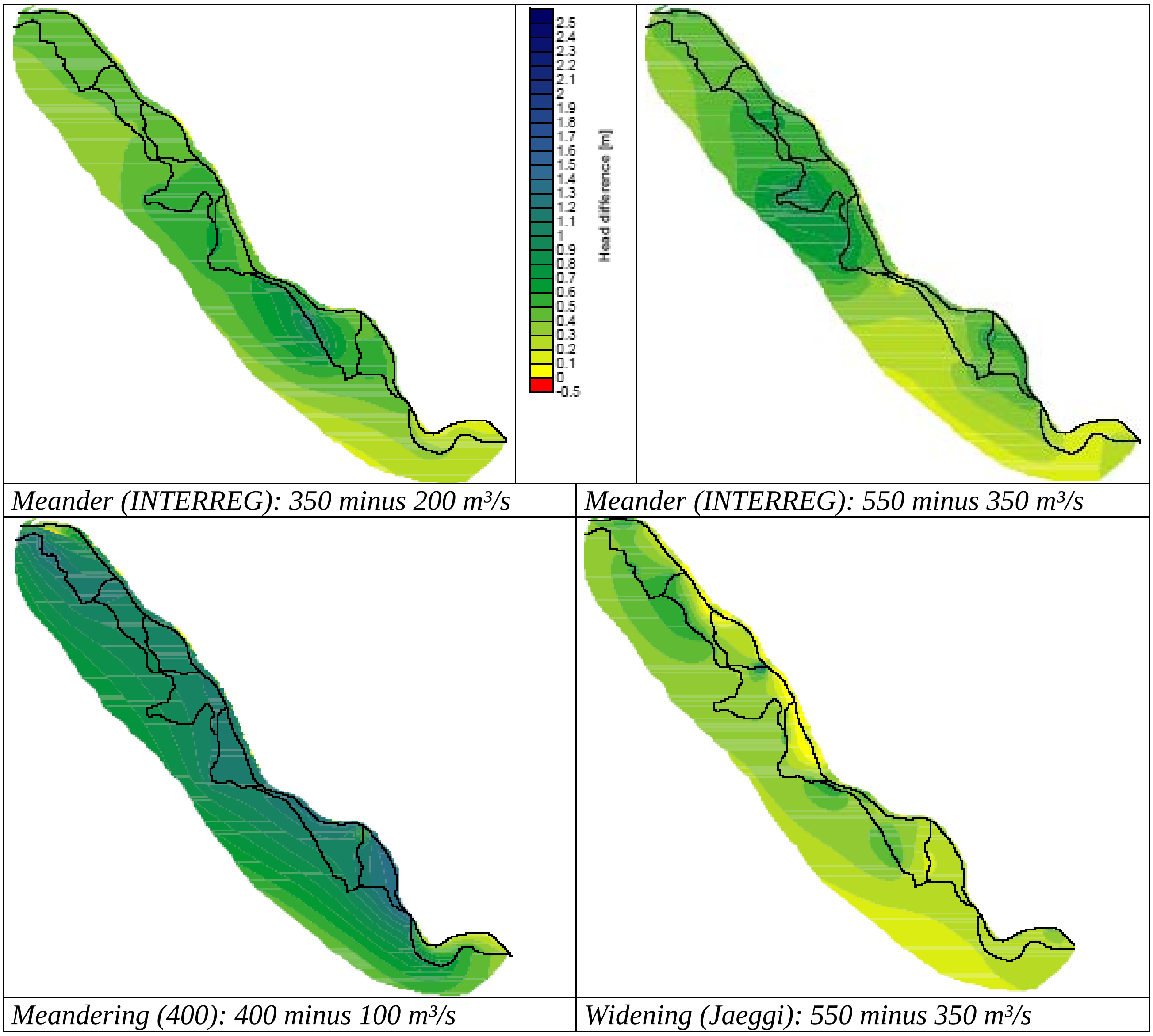
Narrowing (no connection): 550 minus 350 m³/s





Optimum Filling: 350 minus 200 m³/s

Optimum Filling: 550 minus 350 m³/s



Meander (INTERREG): 350 minus 200 m³/s

Meander (INTERREG): 550 minus 350 m³/s

Meandering (400): 400 minus 100 m³/s

Widening (Jaeggi): 550 minus 350 m³/s

Figure 8-36 Fluctuation of groundwater levels for selected discharges and variants

Figure 8-36 shows groundwater level fluctuations between 550/120 m³/s and 350/80 m³/s for the present state and for all variants except for the Meander (400) variant which conveys 400 m³/s and 100 m³/s in the enlarged meander branch while keeping a residual discharge in the Danube channel of 50 m³/s only. This explains the pronounced difference in the groundwater response of this particular variant.

Again, it is important to keep in mind that groundwater fluctuations depend on both structural measures *and* the variation of the discharge by the imposed flow regime.

8.3.4. Morphodynamics

a) Interpretation of steady state model results

1D- and 2D-modelling provides information on the spatial distribution of flow velocities and shear stress in the channel network and over the floodplain. From grain size distributions of sediments and expert knowledge on the incipient motion of sediments conclusions can be drawn on the spatial distribution of channel reaches with silt, sand and gravel and at locations where morphodynamic processes of erosion, deposition and lateral movement may be expected. The overall channel stability in terms of long-term incision and aggradation was investigated by non-steady state modelling (Chapter 8.3.4 b).

Morphodynamic processes are strongly related to the magnitude and duration of flood flows. Therefore, aside from structural rehabilitation measures the flow regime is a key parameter for initiating channel evolution. In addition, bedload supply is another important element, especially for the long-term channel evolution.

The assessment of sediment motion was based on critical shear stress values after Shields (1936)[30] given in Table 8-7 and Figure 8-37.

Table 8-7 Critical shear stress for incipient motion of different grain sizes

	Gravel	**Sand**	**Silt**
Diameter (mm)	20	0.25	0.05
Critical shear stress (Pa) or (N/m²)	15	0.2	0.1

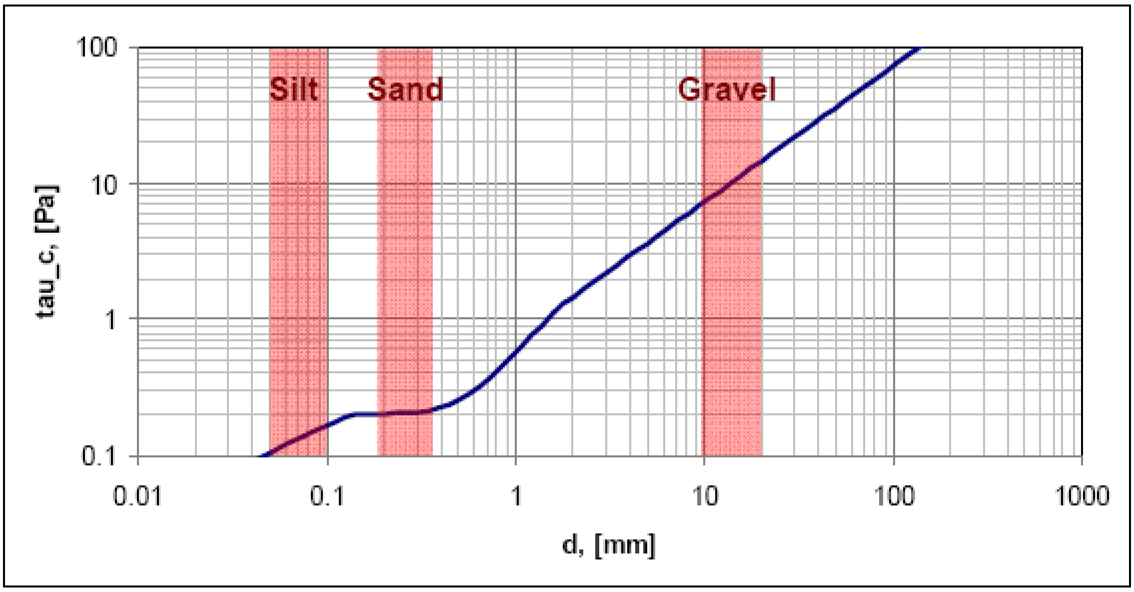


Figure 8-37 Critical shear stress tau for incipient motion of grain sizes after Shields

In the 2D-model the total area was calculated that exceeded a particular critical shear stress for the present state and each variant. The resulting graphs can be read in a similar way to

[30] Shields, A. (1936) "Anwendung der Aehnlichkeitsmechanik und der Turbulenz -Forschung auf die Geschiebebewegung." Mitt. der Preussische Versuchanstalt für Wasserbau und Schiffbau, Berlin, Germany, No. 26.

flow duration curves; it is important, however, to consider the variation of the total area for each result. It is obvious that variants incorporating the construction of weirs are less capable of moving gravel and larger areas are prone to siltation (Figure 8-38).

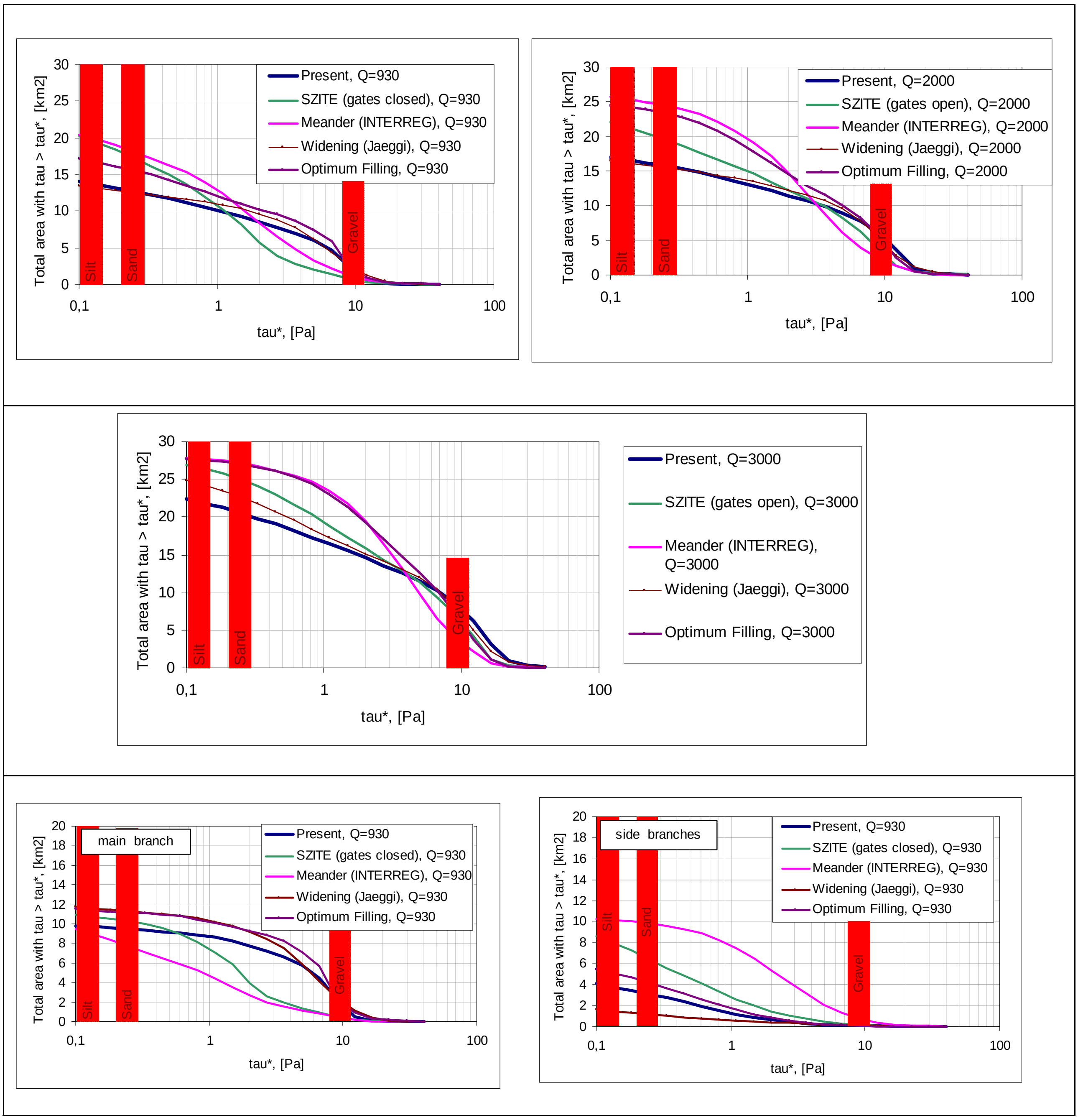


Figure 8-38 Areal extent of critical shear stress for 930, 2000 and 3000 m³/s (2D-modelling)

From Figure 8-39 to Figure 8-48 channel reaches can be identified that are likely to be covered with silt while others that are exposed to higher flow velocities still have a sandy gravel bed. Channel reaches likely to experience local scouring can be assessed as well, especially when comparing different variants.

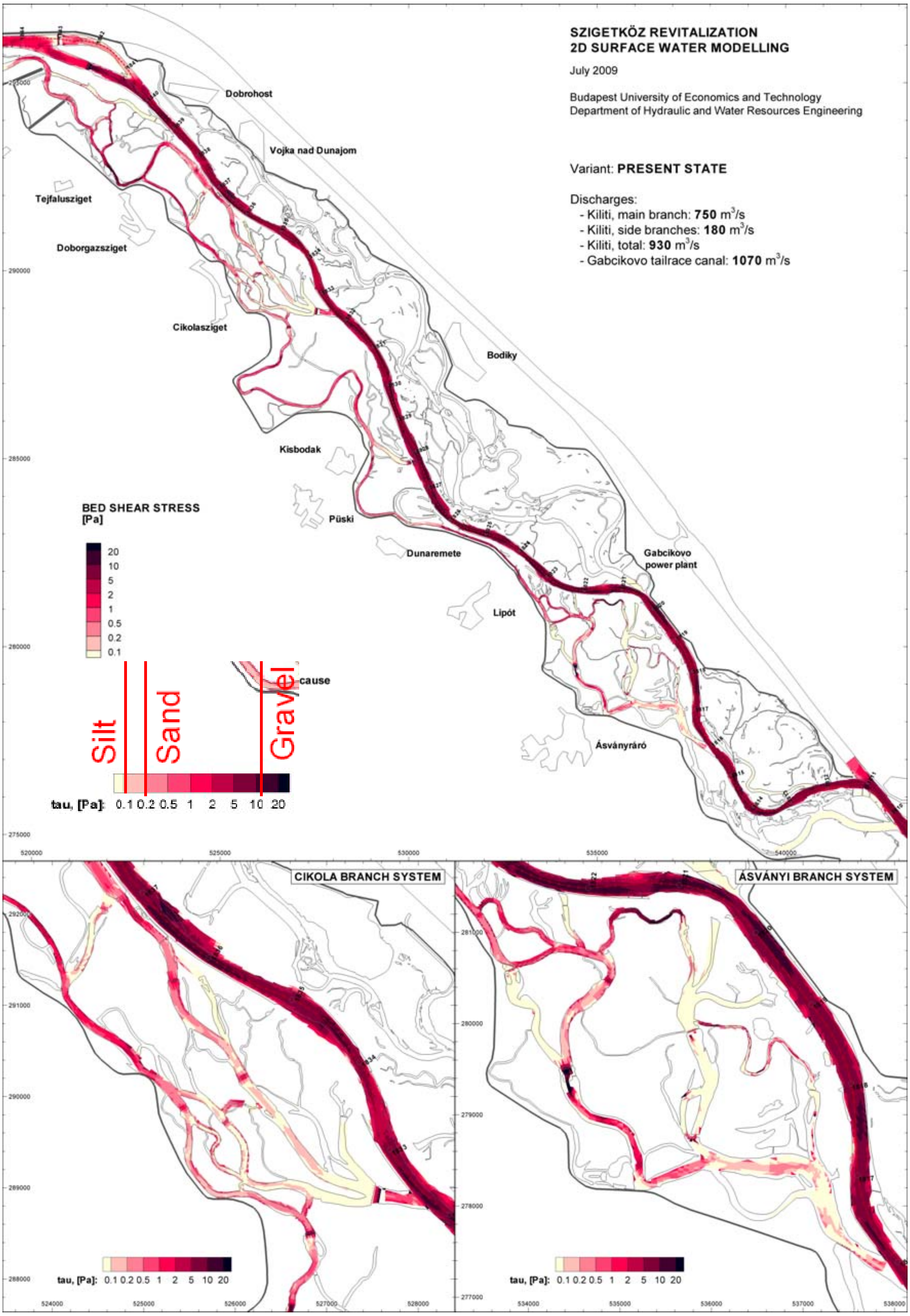


Figure 8-39 Spatial distribution of shear stress for the Present State at 930 m³/s

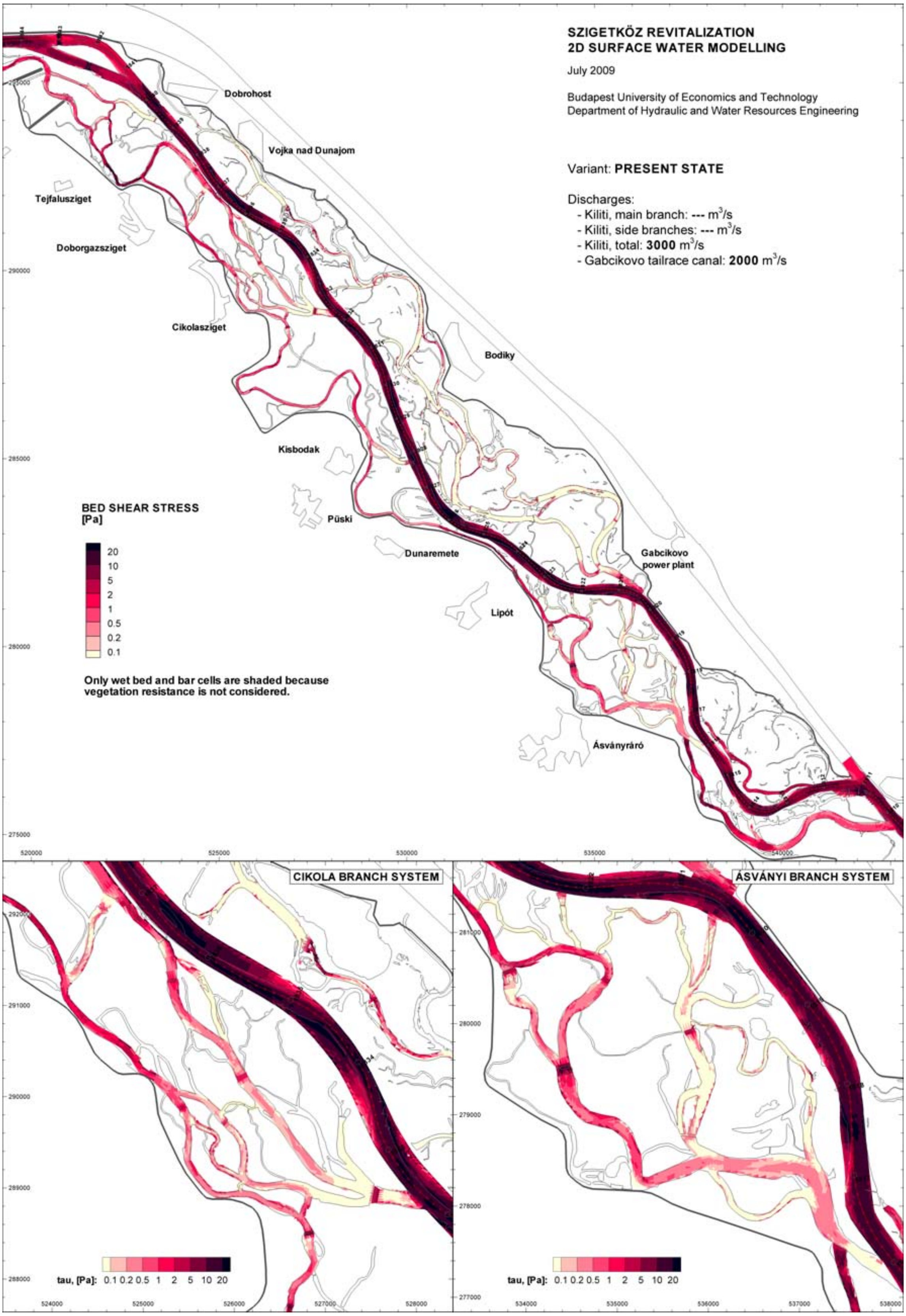


Figure 8-40 Spatial distribution of shear stress for the Present State at 3000 m³/s

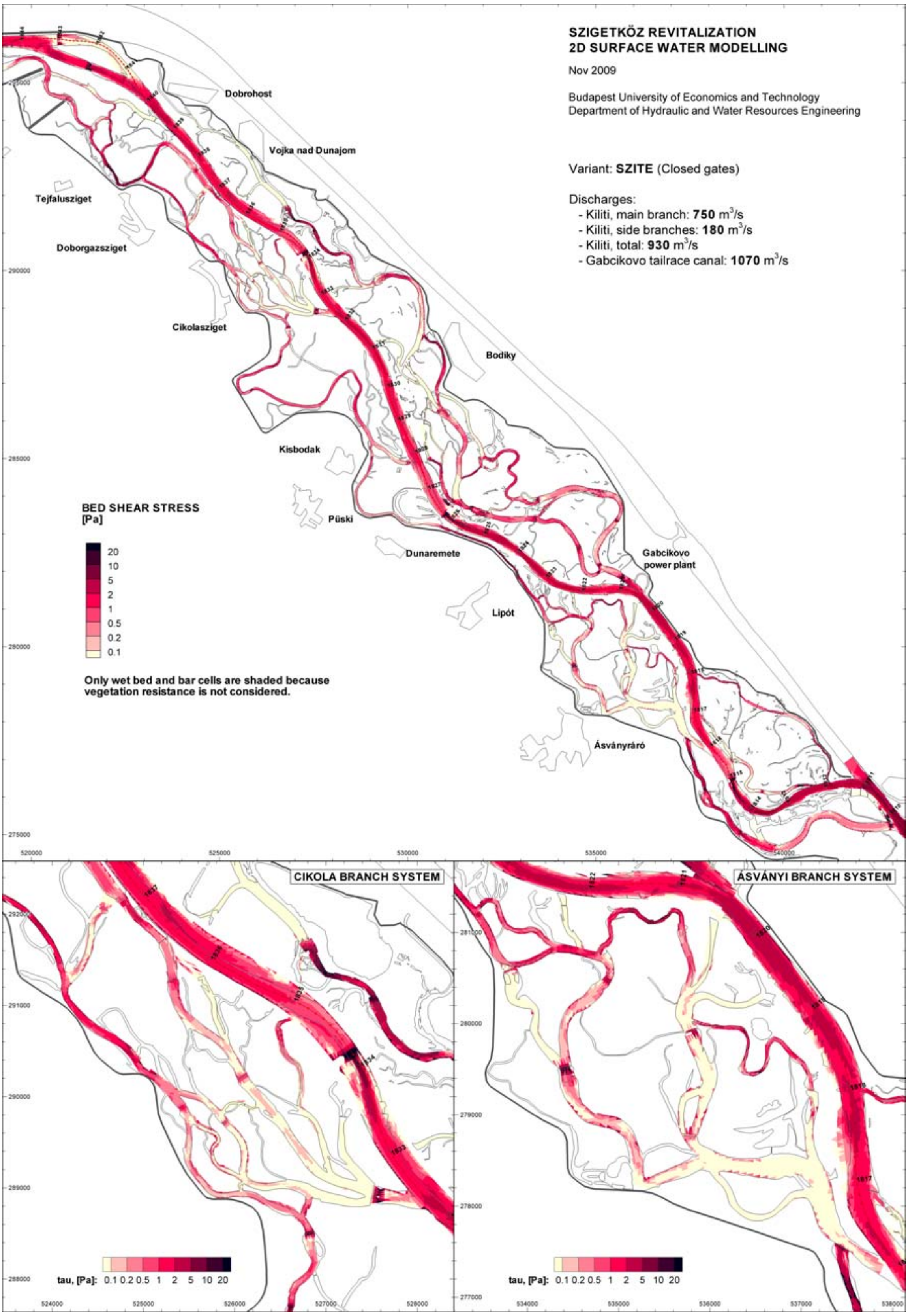


Figure 8-41 Spatial distribution of shear stress for the SZITE variant at 930 m³/s (gates closed)

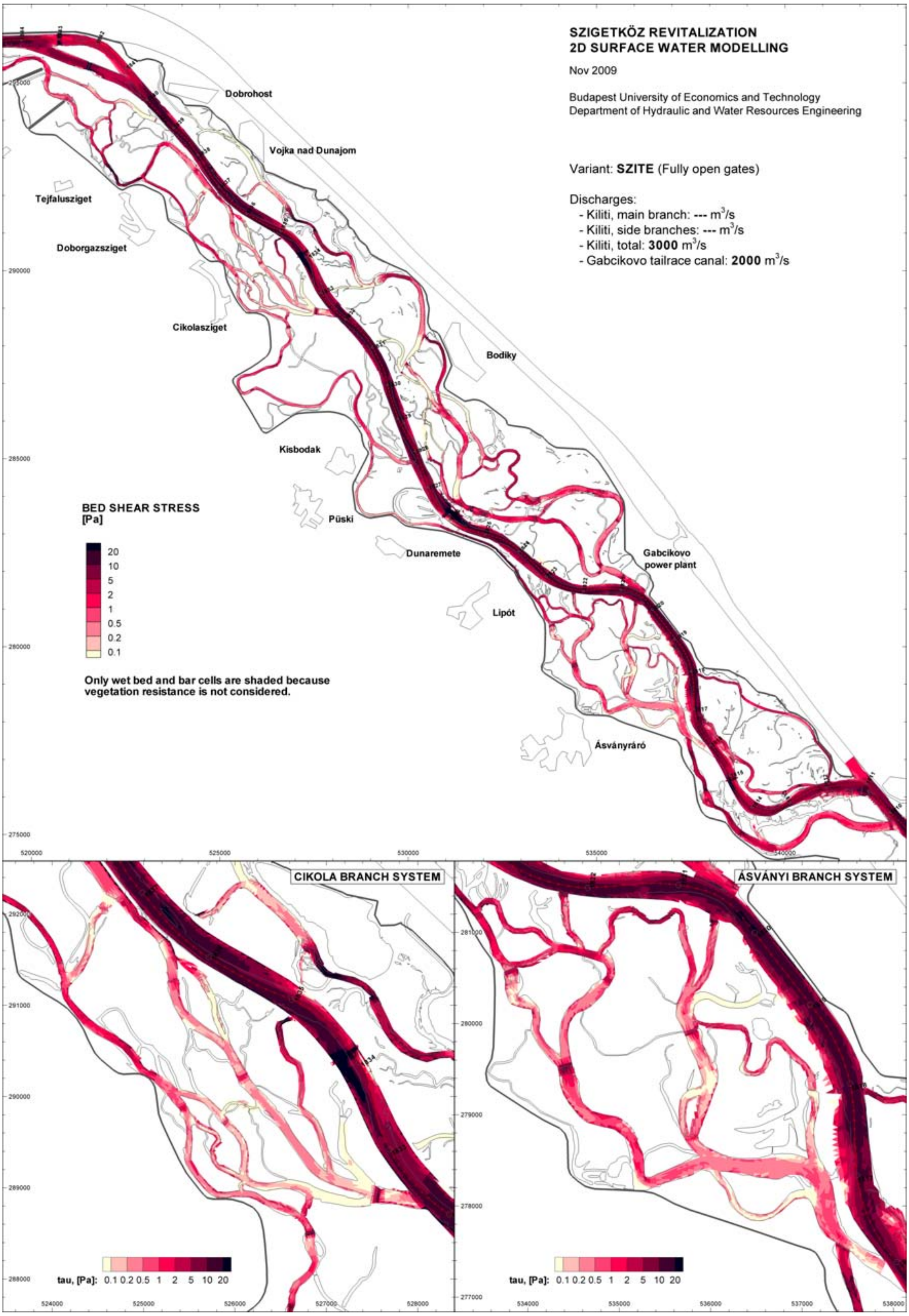


Figure 8-42 Spatial distribution of shear stress for the SZITE variant at 3000 m³/s (gates open)

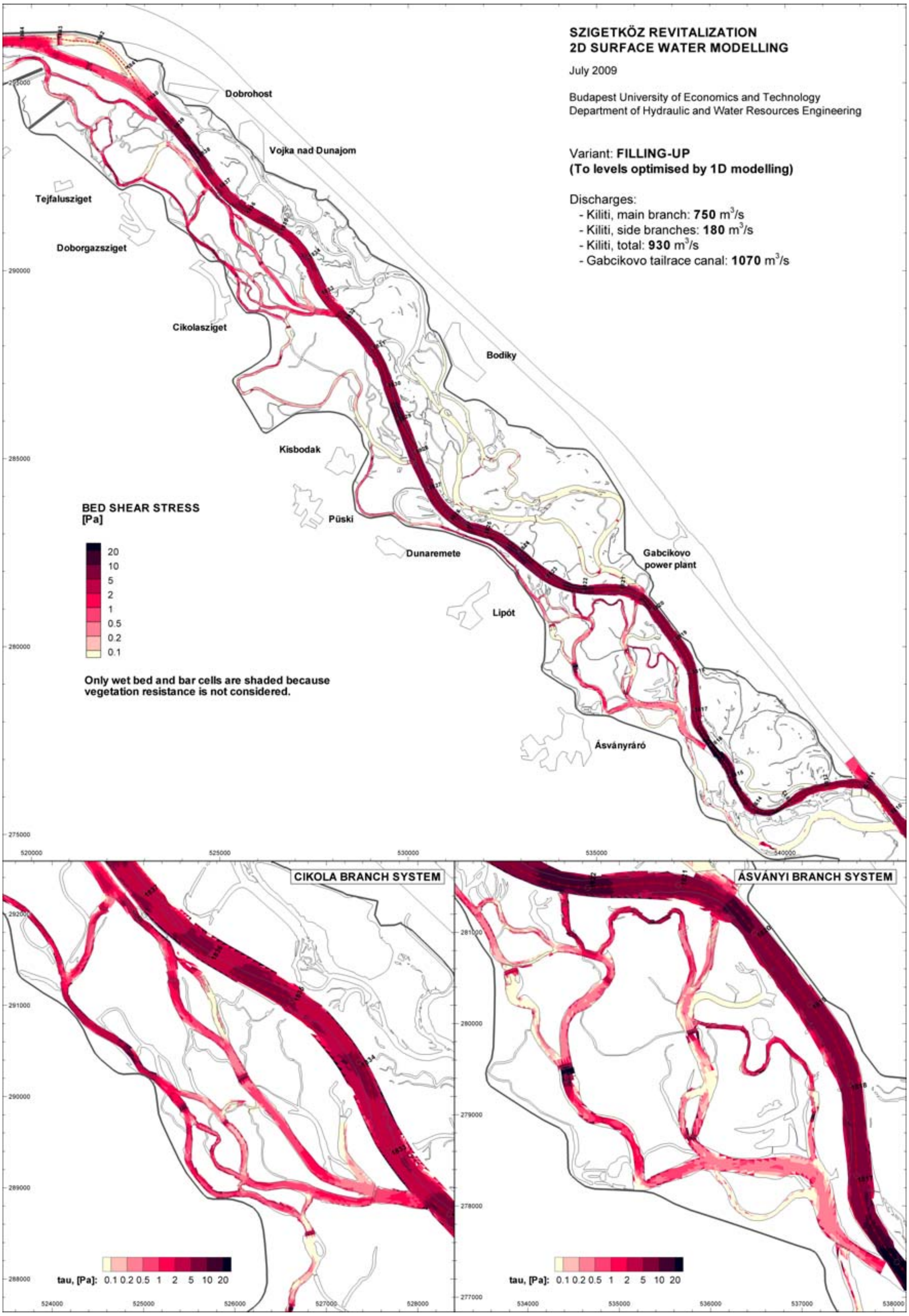


Figure 8-43 Spatial distribution of shear stress for the Optimum Filling variant at 930 m³/s

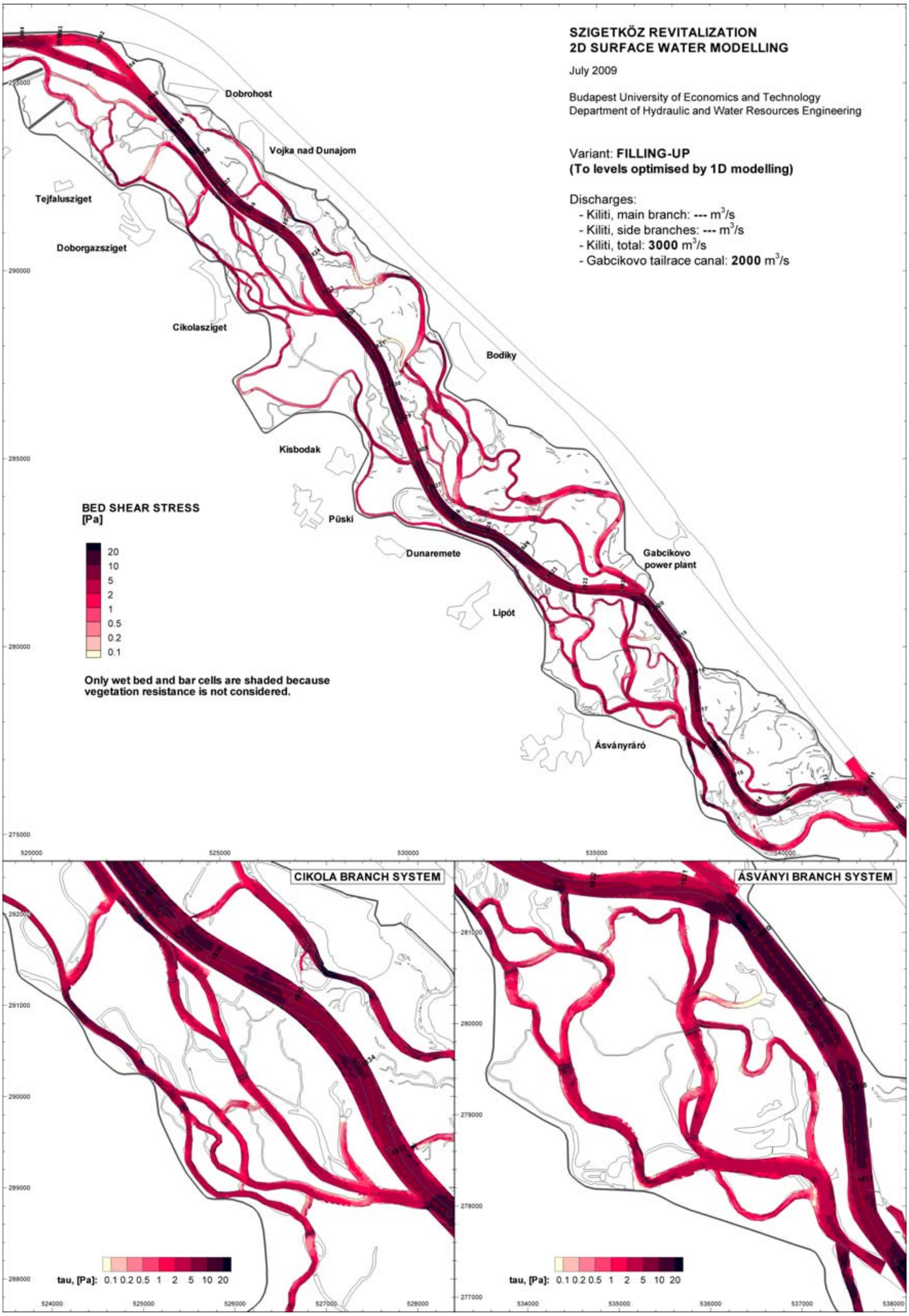


Figure 8-44 Spatial distribution of shear stress for the Optimum Filling variant at 3000 m³/s

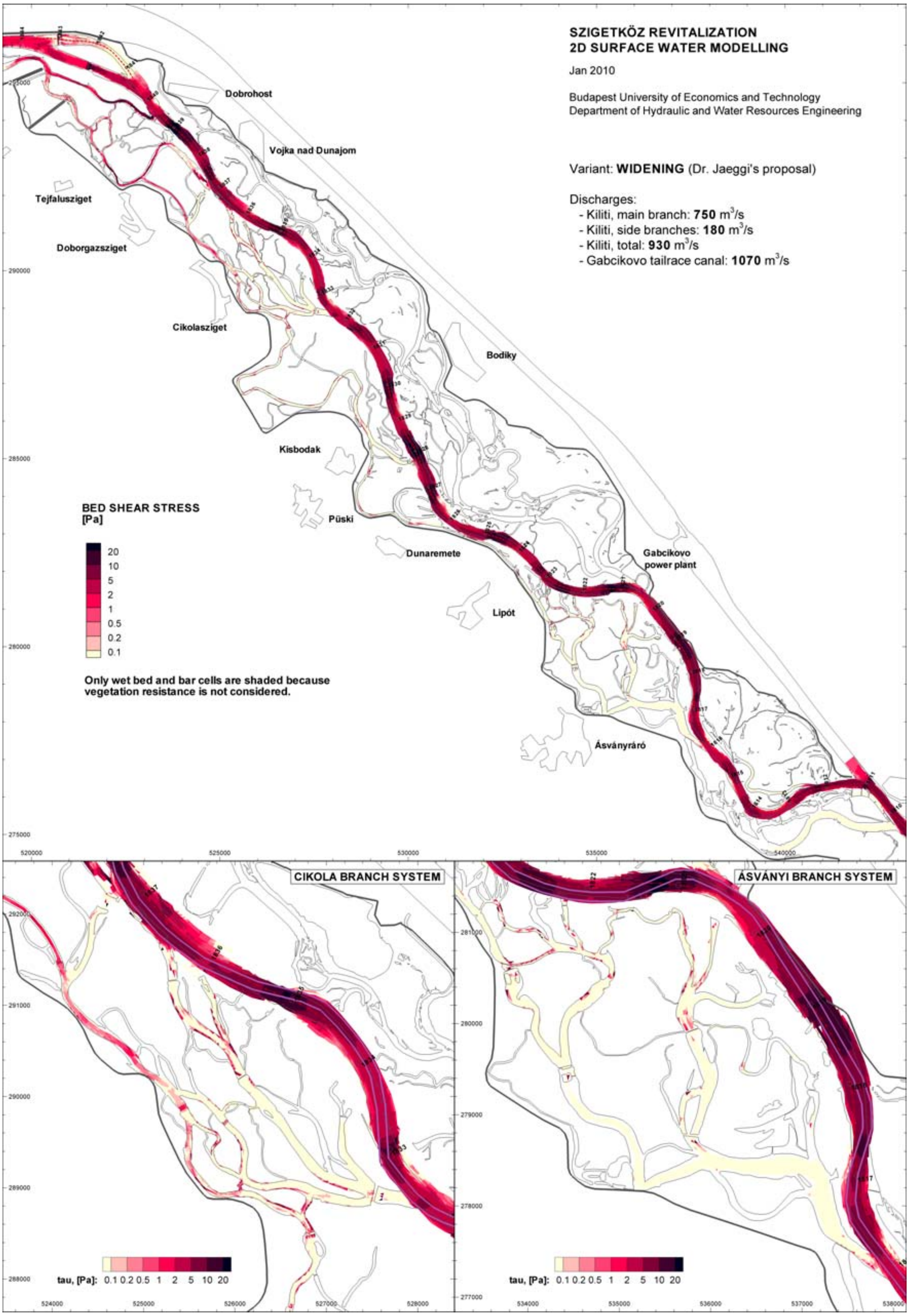


Figure 8-45 Spatial distribution of shear stress for the Widening (Jaeggi) variant at 930 m³/s

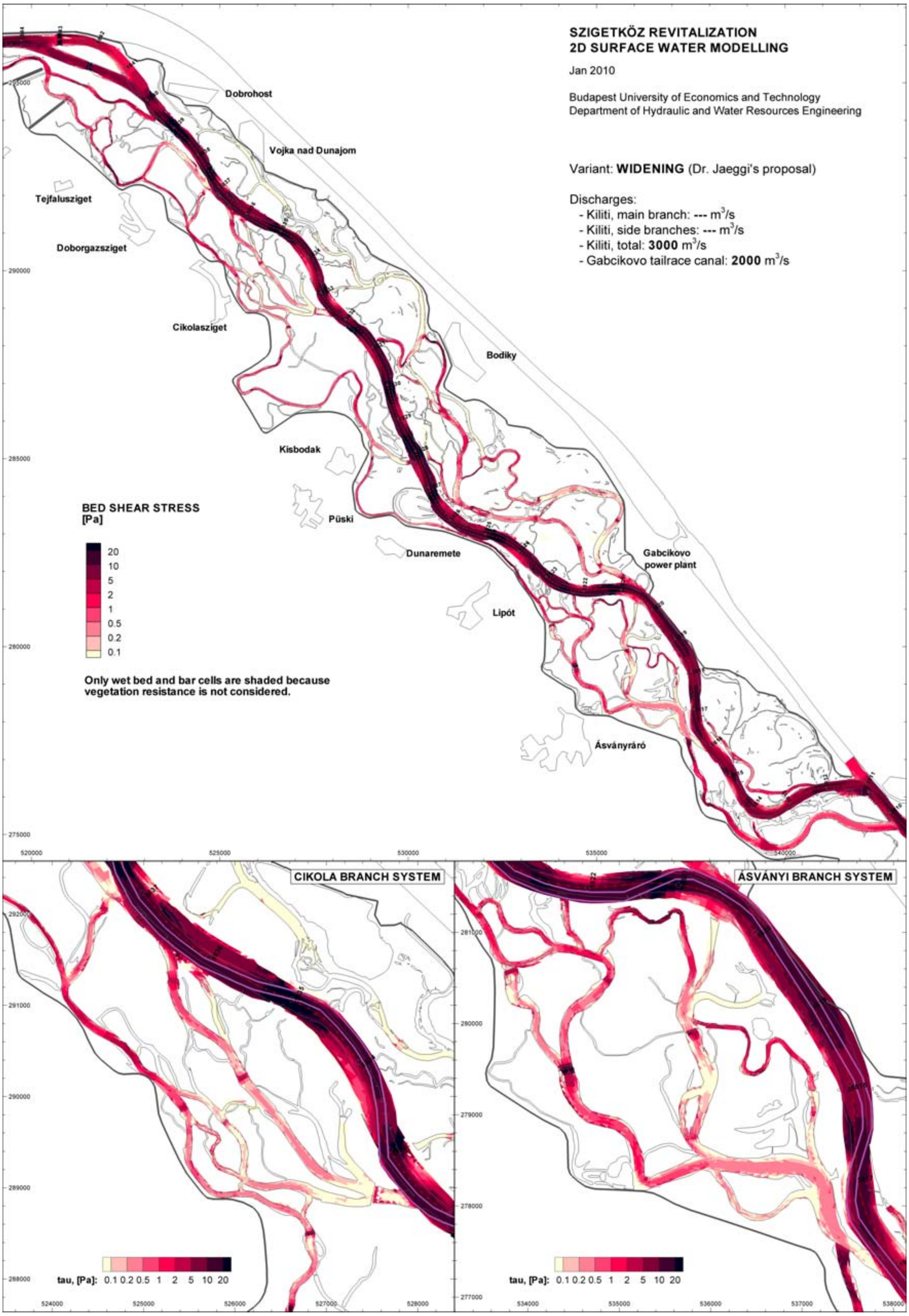


Figure 8-46 Spatial distribution of shear stress for the Widening (Jaeggi) variant at 3000 m³/s

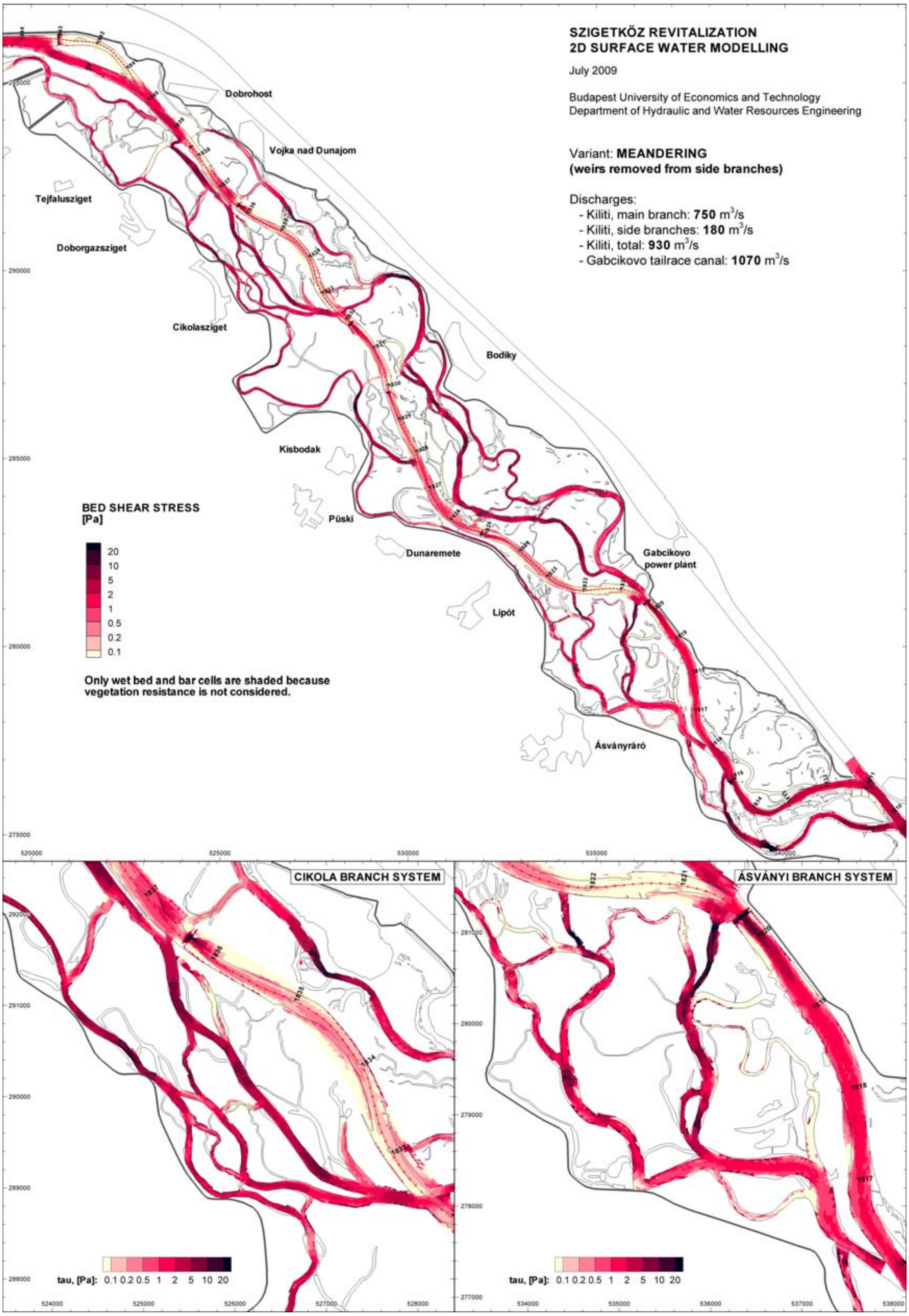


Figure 8-47 Spatial distribution of shear stress for the Meander (INTERREG) variant at 930 m³/s, no weirs in side branches

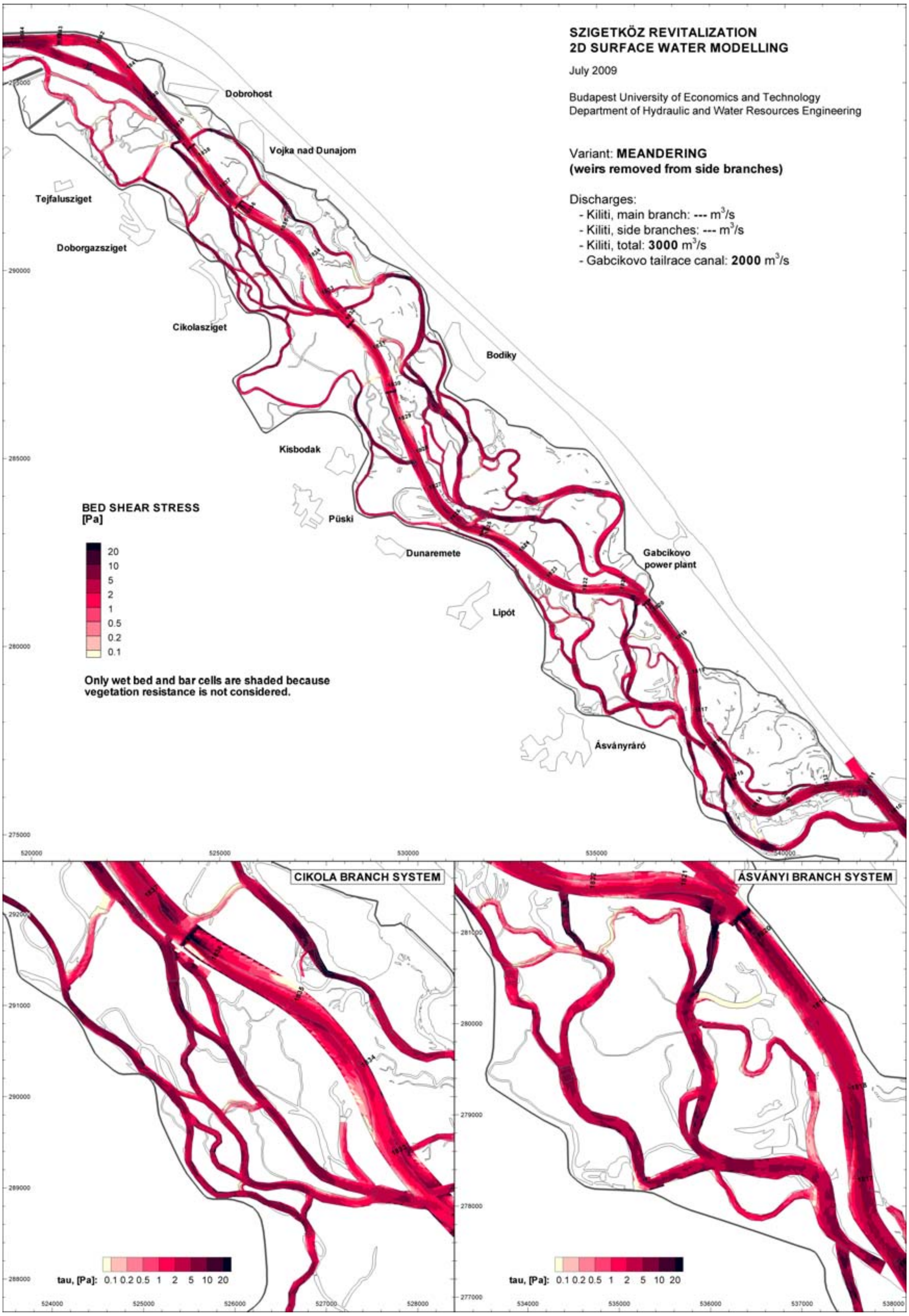


Figure 8-48 Spatial distribution of shear stress for the Meander (INTERREG) variant at 3000 m³/s, no weirs in side branches

b) Morphological modelling[31]

For those variants that did not incorporate weirs in the main channel a 1D-morphological model was used in order to investigate the impact of measures on the longitudinal profile of the Danube.

Grain size distributions of the channel from different sources and periods were analyzed including samples from 2009 (Figure 8-49). For the model runs d_{50} = 10 mm was taken. No analysis of bank materials was available; information from boreholes of groundwater wells indicated inhomogeneous layers of sand and gravel that could not be used as representative samples. So it was assumed that $d_{50, banks}$ = 8 mm, and two versions of bank material layers were tested.

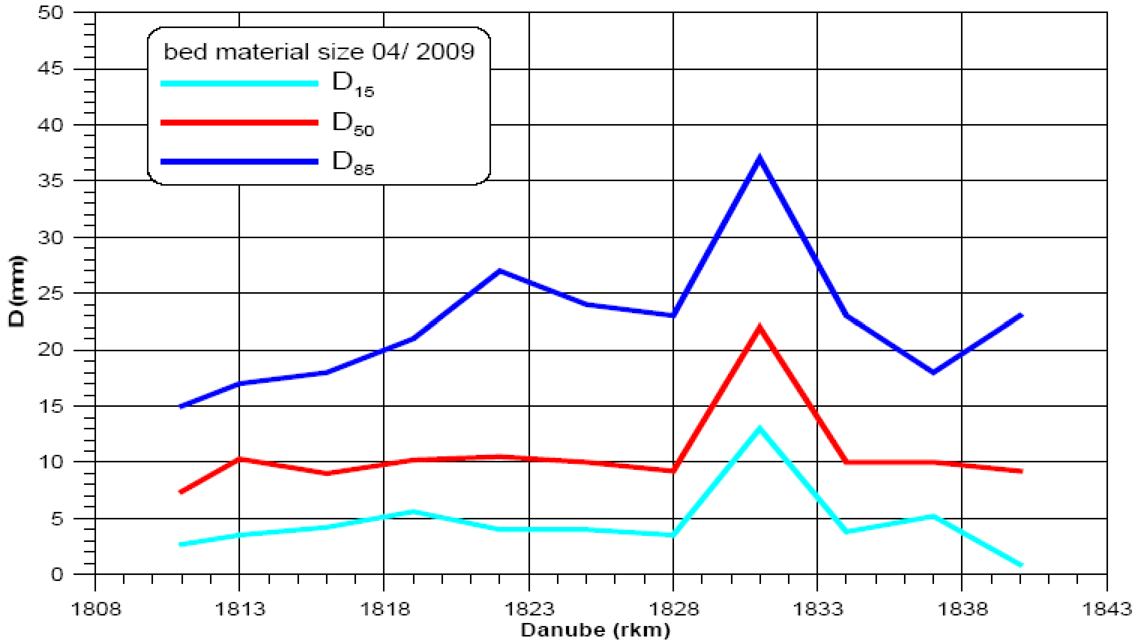


Figure 8-49 Results of the survey of channel materials in April 2009

[31] Holubová, K., M. Lukáč & Z. Capekova (2009) Morphological numerical model impacts of restoration scenarios on the development of the Danube river bed (rkm 1848,33 – 1806,40), final report, Nov. 2009..

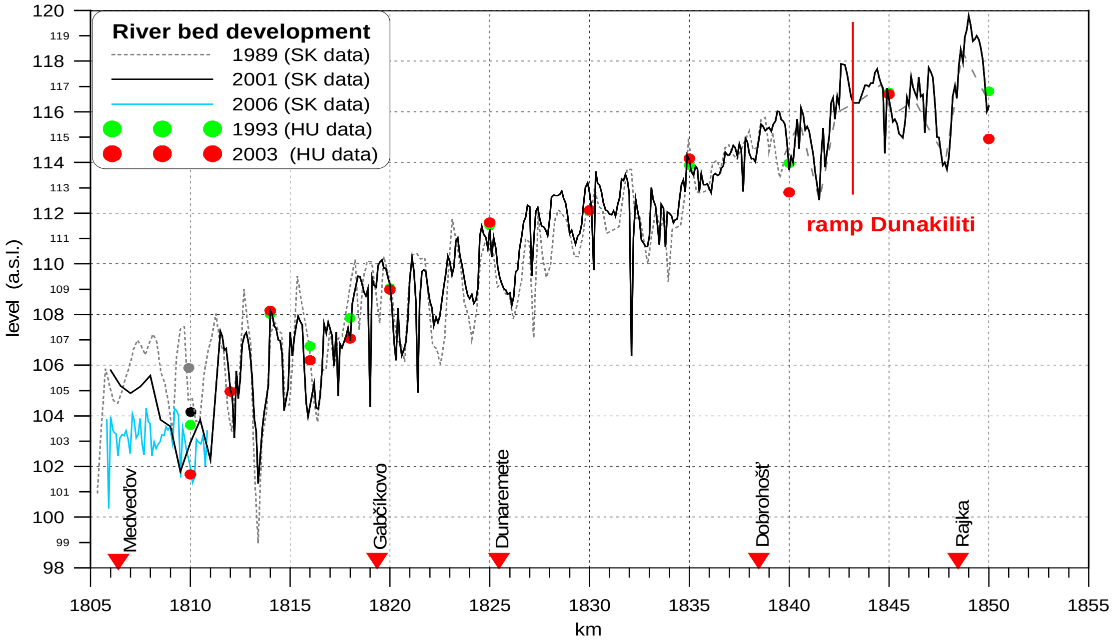


Figure 8-50 Development of the Danube river bed (1989-2003)

According to Figure 8-50 pronounced incisions of several meters occurred below the confluence triggering backward erosion in the Danube channel up to about rkm 1822.

First model runs showed that bedload movement starts at a discharge of 900-1200 m³/s. Continuous transport, however, occurs at a discharge range between 1400 and 1800 m³/s. Maximum transport rates are reached at bankful flow of about 3000 m³/s.

The morphological modelling used time series of daily flows simulating the years 2001 and 2002, the latter including two major flood flows. Additionally, the time series 1995-2005 was used for simulation. For the Widening scenario (see below) a period of 40 years was simulated by repeated cycles.

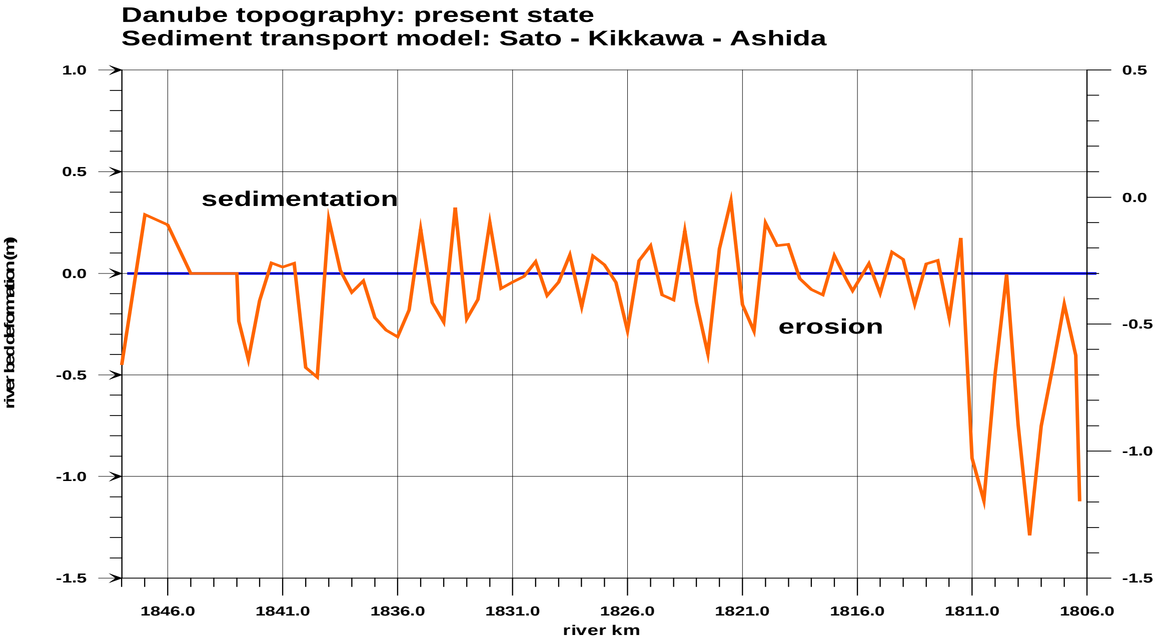


Figure 8-51 Relative changes of bed levels for the present state modelling the period 2001-2002

Present state modelling was used as calibration as well as reference condition for the simulation of variants. The results shows rather stable conditions with a tendency of bed level lowering below the weir at Dunakiliti (rkm 1843) and pronounced incision at the confluence. This is evident from Figure 8-52 showing the tendency after 10 years simulation.

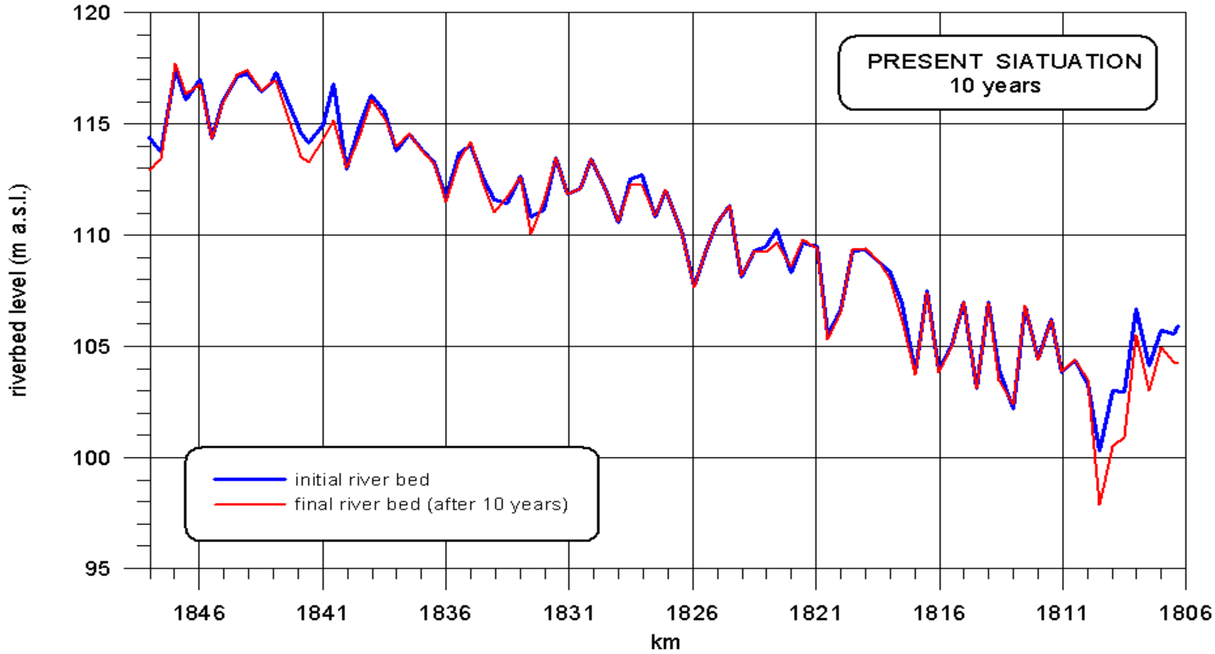


Figure 8-52 Morphological changes in the river bed – present state (10 years)

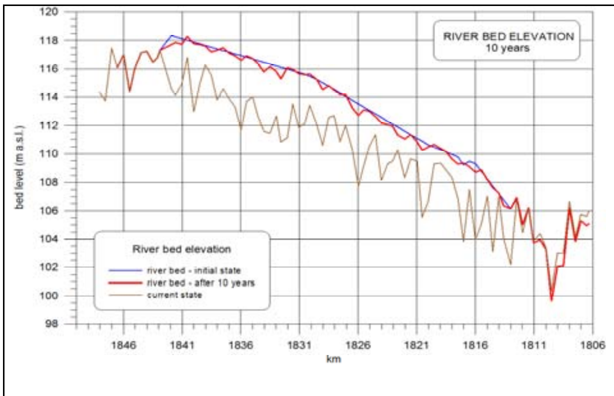
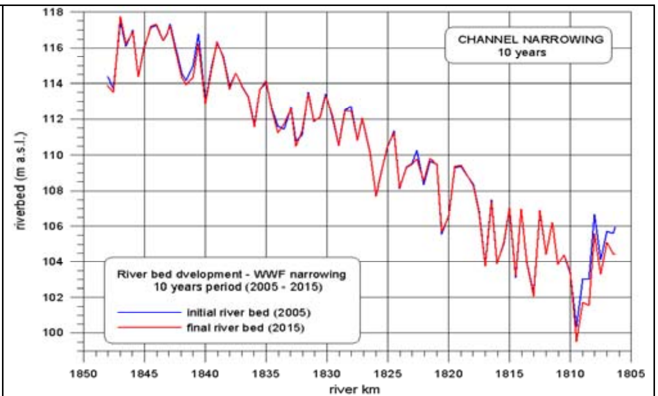
	
River bed filling (2 m)	*Narrowing (raising point bars by 2 m)*

Figure 8-53 River bed development for Riverbed Filling (2 m) and Narrowing (1995-2005)

The version **"Riverbed Filling"** is a sub-variant of "Optimum Filling" and refers to an average raising of bed levels by 2 m (locally up to 5 m). It is assumed that the bed material of the raised bed level corresponds to natural conditions. The changes recorded in the longitudinal profile after 10 years (Figure 8-53) point to an increase in local erosion (max. 120 cm). Even if the river bed slope is still maintained there are some evident indications of systematic river bed erosion. The higher variability of the river bed level can be partly ascribed to the rather uniform level of the river bed at the beginning of the simulation process (flat river bed).

“Narrowing” refers to the variant with point bars raised by 2 m as described in Chapter 8.1. Figure 8-53 shows that under the present flow regime the longitudinal profile would stay rather stable. The morphological changes are very similar to those recorded under the ‘present state’ scenario. Only a few areas were affected by local erosion (max. 60 cm). In order to increase the effectiveness of this scenario, more significant river channel narrowing is required and adequate discharges.

Widening of the Danube channel by lateral erosion along outer banks was implemented in the morphological model on a test reach between rkm 1840 and 1830. Since lateral erosion processes could not be handled in the model several approaches were tested varying lateral erosion rates and profile adjustment, composition of bank material, localities of sediment supply and the simulation of “dry” and “wet” years.

After successfully testing the functioning of the morphological model with the period 2001-2002 a longer simulation run was carried out under the following assumptions:

Geometry: It was assumed that the widening had already occurred at the beginning of the simulation. Total widening is 100 m, the modification will be obtained by shifting the steeper bank (usually concave part of the river bend) by 100 m to the outside. The thalweg is thus widened by 100 m (Figure 8-54).

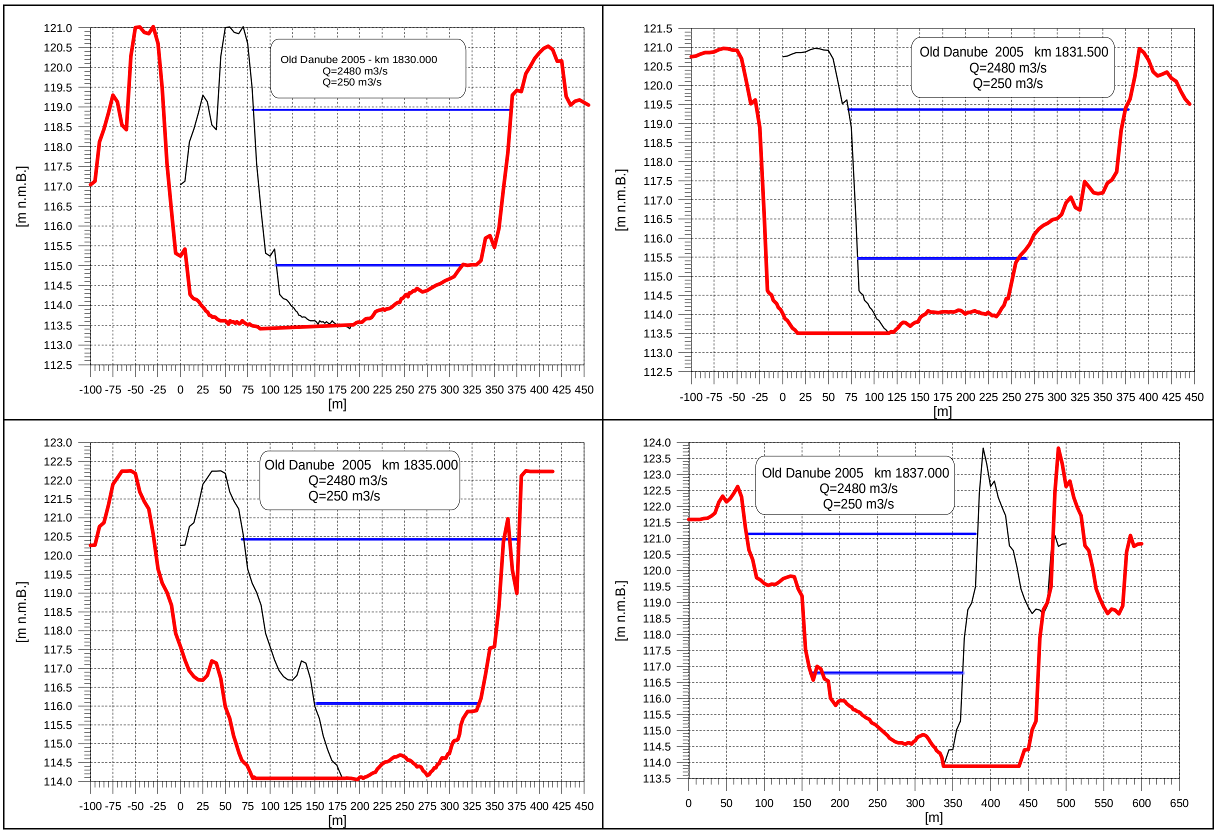
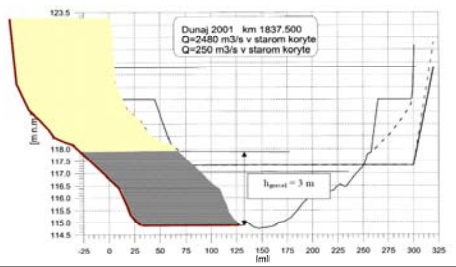
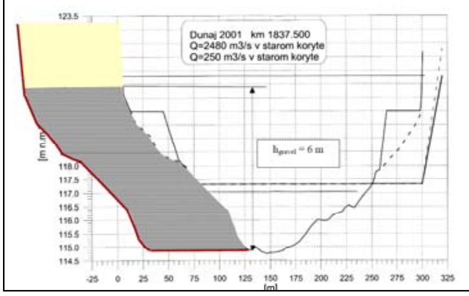


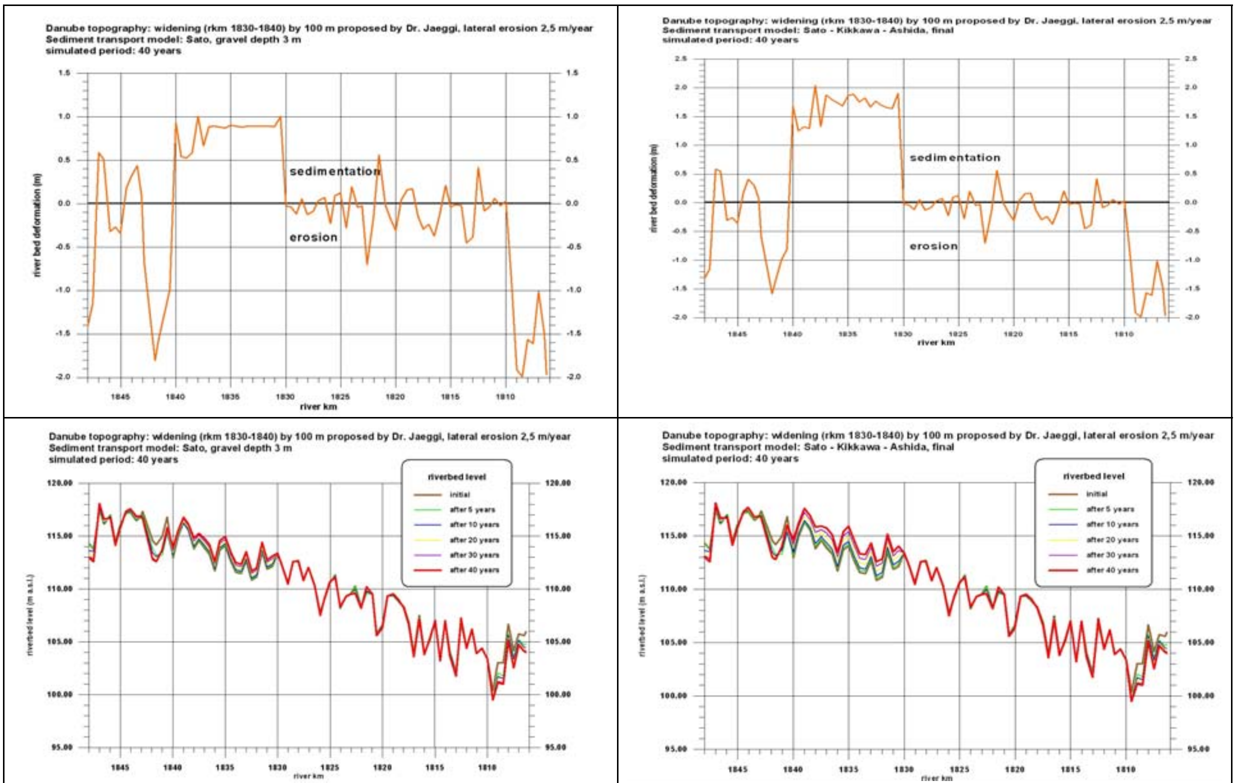
Figure 8-54 Geometry modification for widening scenario

Hydrograph: the series between 1995 – 2005 was used and repeated in order to obtain a 40-year simulation period. The exceptional 2002 flood would normally be reduced when repeated. In order to somewhat compensate the simplification concerning transport capacity computation, the flood hydrograph was left as it is also when repeated.

Sediment input - two sub-variants are envisaged:

	**Figure 8-55 Assumption of 3 m of gravel depth – which represents widening of 100 m on 10 km with total volume of 3 million m^3, which corresponds to the value of 75,000 m^3/a. The lateral erosion rate amounts to 2.5 m/a. The reduced sediment input compared to Figure 8-56 corresponds at the same time to the hypothesis of a higher cover of fine sediment in the floodplain.**
	**Figure 8-56 Assumption of 6 m depth of gravel – which represents the same type of widening. Regularly distributed over a simulation time of 40 years, this represents a total sediment input of 150,000 m^3/a (or approx. 300,000 t/a). This was regularly distributed along the 10 km of the widened reach. This corresponds to a lateral erosion of 2.5 m/a on one bank which is a rather small value, but is justified by the actual flow regime and rather low flood frequency.**

Grain size distribution and bedload supply: For the bed material a corresponding value of D_{50} was used (10 mm). For bank material D_{50} = 8 mm was used. It was assumed that no bedload arrives from upstream; i.e. the only source of bedload is bank material.



3 m bank height of sand and gravel below 3 m fine cover layer	*6 m bank height of sand and gravel*

Figure 8-57 Long-term evolution of the bed level assuming 100 m widening at outer banks and annual bank retreat of 2.5 m. Widening between rkm 1840 and 1830. Simulation period: 40 years.

After 10 years the changes in the longitudinal profile within the widened section indicate a maximum river bed elevation of +17 cm and +35 cm respectively on average (except for two localities exposed to systematic erosion). The river section downstream of the widened section shows very stable conditions without any significant changes.

The model test generally proved that a raising of bed levels could be expected after effective lateral erosion. The amount of lifting and the temporal evolution of the bed profile depends on many factors, e.g. composition of bank material, competence of the future flood flow regime and additional measures (construction of groynes, additional supply of bedload, mechanical widening at appropriate locations etc.).

For hydrological performance the “Widening variant” was extended over the entire project reach with a 100 m-broadening of the channel as demonstrated in Figure 8-7 and a final elevation of the bed level amounting to 1.8 m.

8.4. Flow regime

The flow regime is a key parameter for the restoration of the Danube wetland in the project reach. With the 1995 Agreement on a Temporary Water Management Regime the prevailing seasonal flows were increased with a dynamic flow regime correlated to the natural flow at the Devin gauge. The share of flood flows, however, was governed by the work capacity of the power station at Gabcikovo.

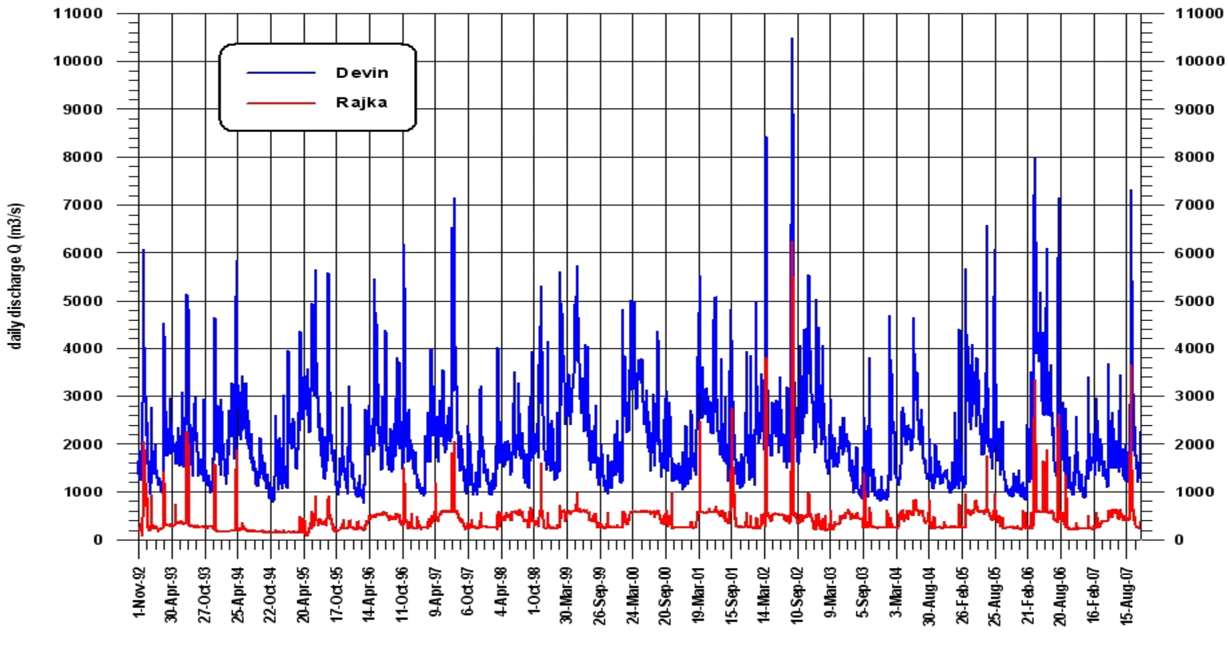


Figure 8-58 Hydrograph Devin and Rajka gauge (1992-2007)

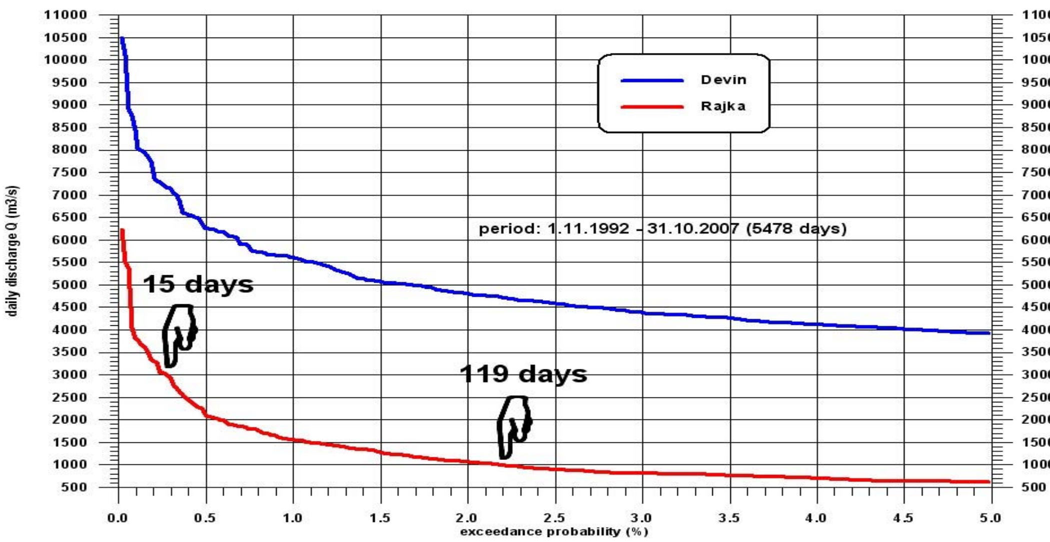


Figure 8-59 Total duration curves of Devin and Rajka gauge (period 1992-2007)

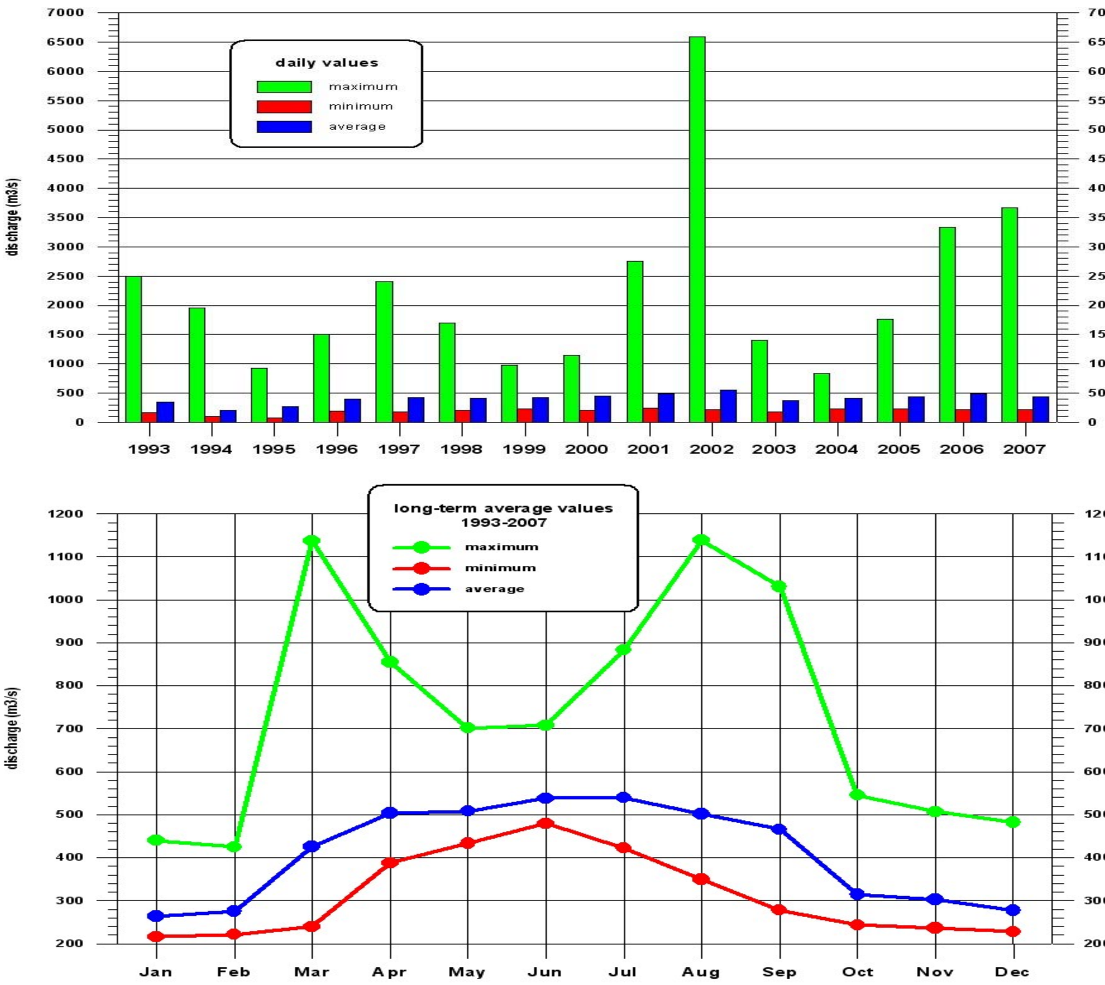


Figure 8-60 Analysis of annual flows at Rajka

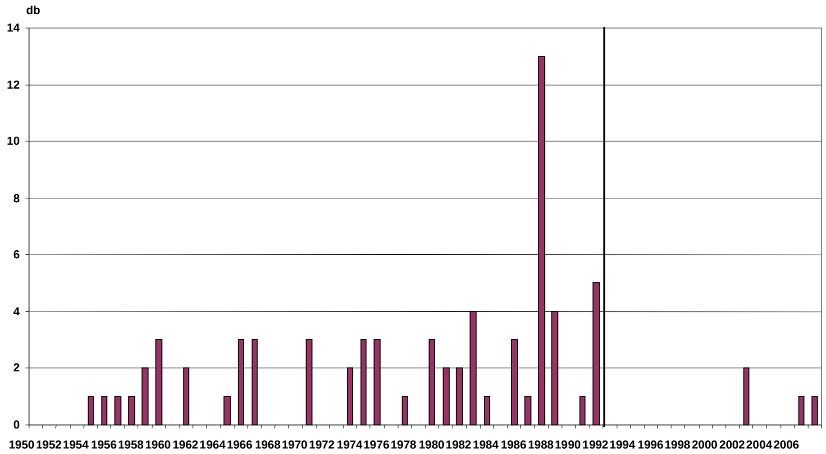
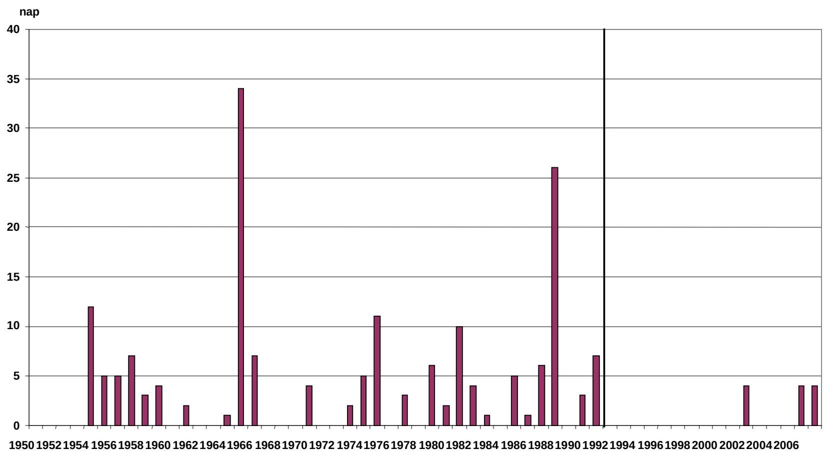
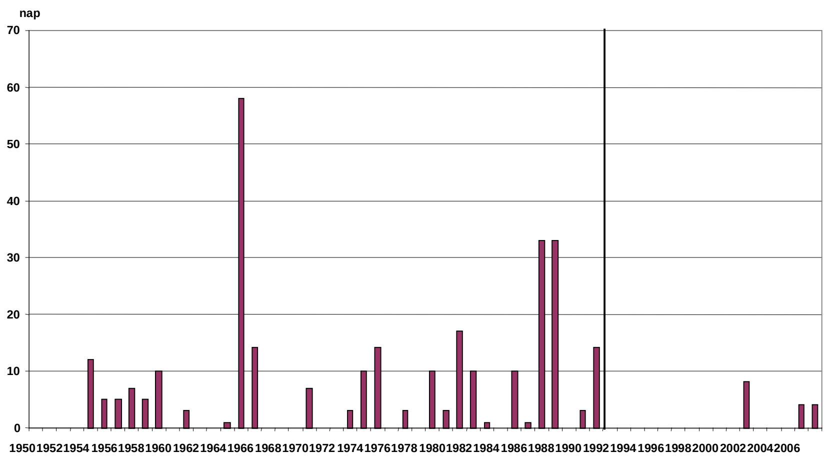
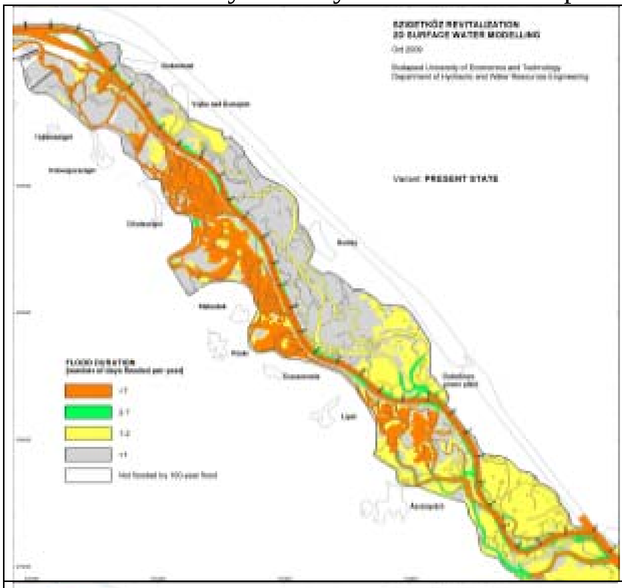
	***a)*** *Number of flood waves causing complete inundation of the floodplain in the Szigetköz section of the Danube between 1950 and 2007 (Danube, Dunaremete 530 cm)*
	***b)*** *Duration of the longest flood waves causing floodplain inundation in the Szigetköz section of the Danube between 1950 and 2007 (Danube, Dunaremete 530 cm)*
	***c)*** *Number of days with floodplain inundation in the Szigetköz section of the Danube between 1950 and 2007 (Danube, Dunaremete 530 cm)*

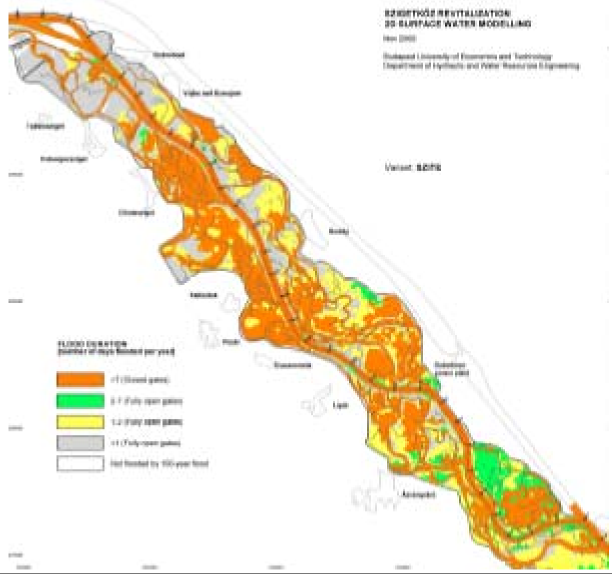
Figure 8-61 Analysis of flood flows in the Szigetköz floodplain

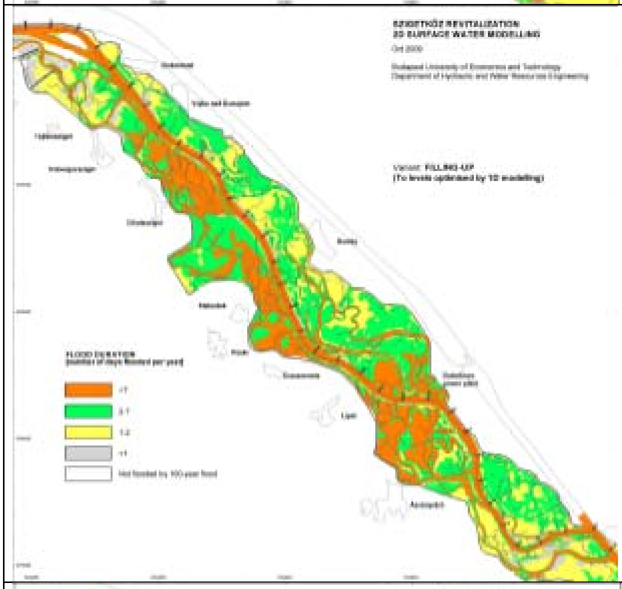
The figures above (Figure 8-58 - Figure 8-61) demonstrate, that compared to pre-dam conditions

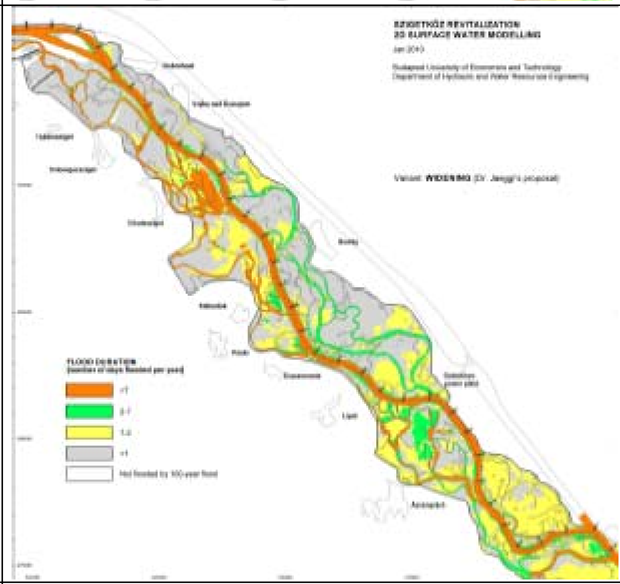
- flood flows are less frequent
- have a shorter duration
- rarely inundate the entire active floodplain

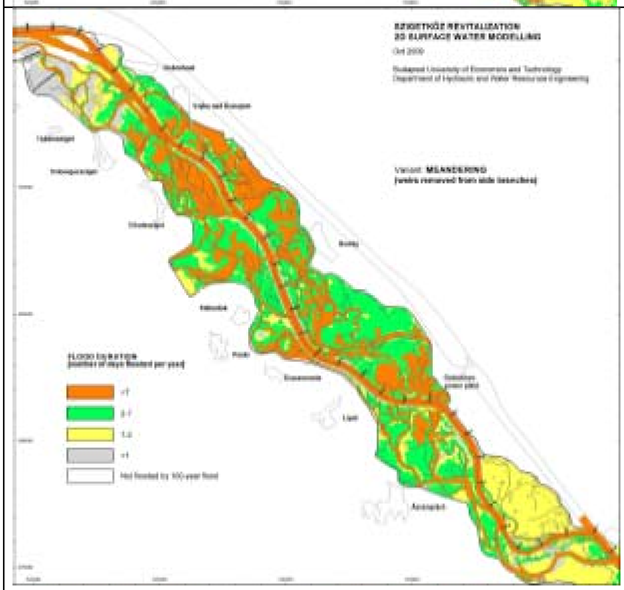
The number of bankful flows which are responsible for channel changes considerably decreased. In the first 15 years after the diversion of the water only 15 days experienced over-bankful flow. And on about only 120 days were flows competent to initiate any bedload transport at all.

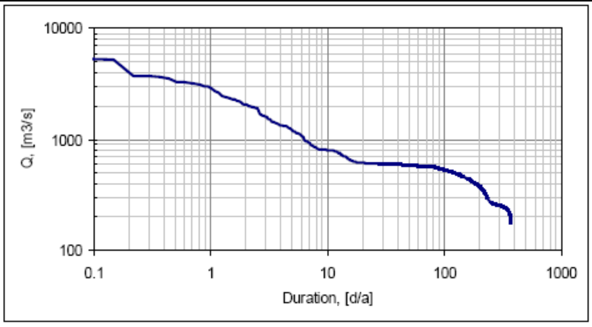






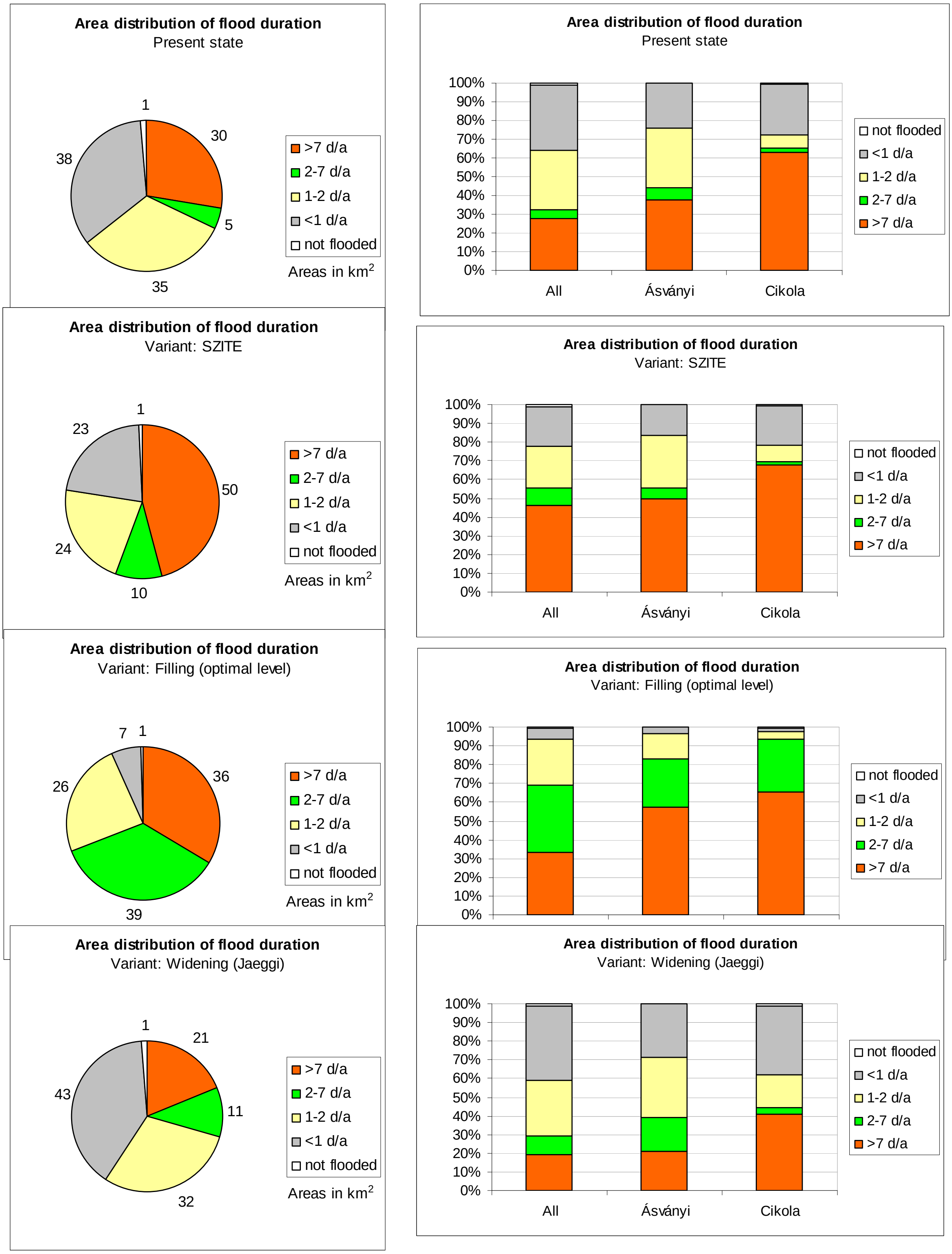


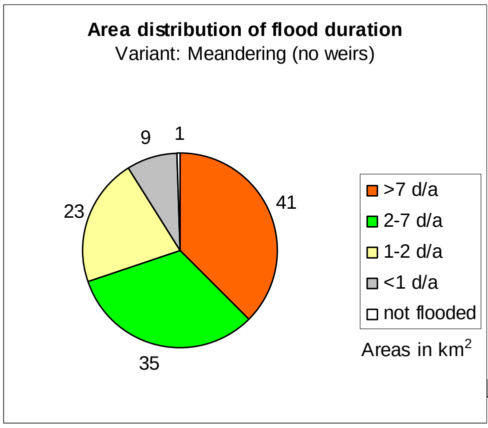


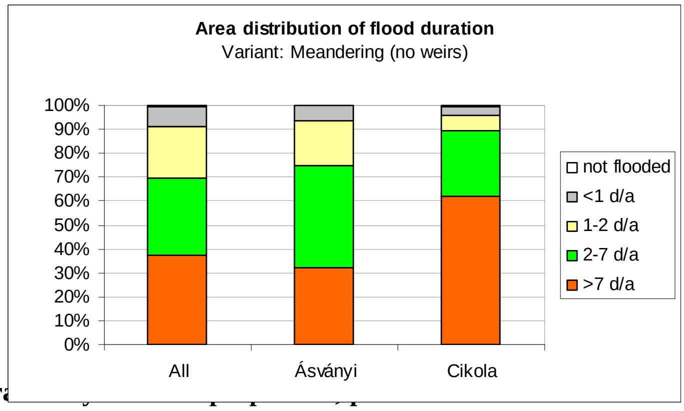


Q_{mb+sb}, [m^3/s]	Duration [d/a]
930	7.0
2000	2.2
3000	0.9

Figure 8-62 Spatial inundation of floodplain areas in number of days per year (Present state and variants), period analyzed: 1995 – 2008







8.5. Restoration effects of different variants on biota

8.5.1. Quantitative evaluation of aquatic habitats

The Szigetköz section of the Danube has undergone hydrological and geomorphologic modifications due to waterway development, flood protection works, gravel dredging and dam constructions. The hydrological and geomorphologic changes resulted in several ecological responses. The ecological assessment of the Szigetköz has to be based on the identification and quantification of these ecological responses and by assessing the deviation from undisturbed reference conditions.

The central part of the anabranching sector upstream of Sap was characterized by multiple channels, bars, and unstable islands with a dominance of Eupotamon-A habitat before extensive regulation measures took place. The inshore zones of the main arm were altered by the construction of rip-raps and groynes and became stabilized.

At the end of the 20th century, when the Danube was diverted to the bypass canal, the water level of the main arm decreased by 3 m and a significant part of the river bed became dry. On the dry gravel bars an intensive development of terrestrial vegetation started. The growing vegetation changed the flow and shear stress distribution in the main arm and this process resulted in the accumulation of fine sediment along the shoreline. The increasing sediment layer provided a substrate for semi-aquatic and terrestrial plant growth. The increasing sedimentation restricts the spawning, nursery and feeding habitats of several rheophilic fish species. Fish biological surveys have indicated these changes since the end of the 1980s (See Chapter 5.3).

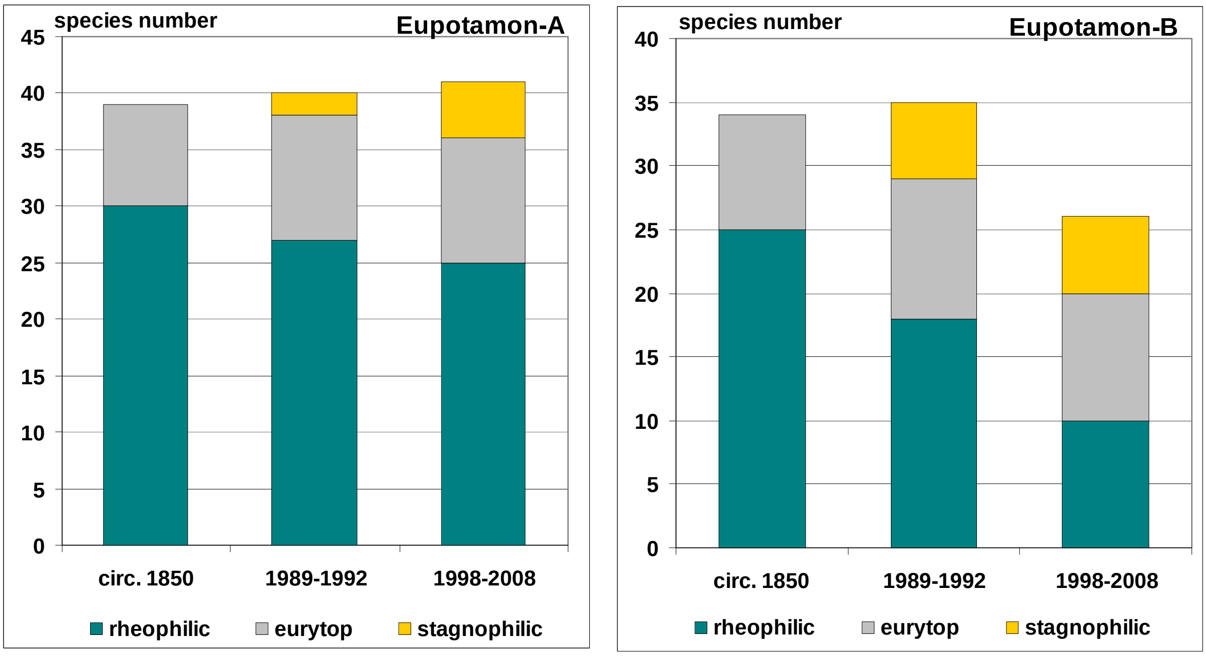


Figure 8-64 Long-term change of species number and proportion of rheophilic, eurytopic and stagnophilic fish species in the main arm (Eupotamon-A) and in a side arm in the Cikola branch system. The side arm was Eupotamon-A habitat in the middle of the 19th century. It was a Parapotamon-A type habitat before the diversion of the Danube (from the end of 19th century to1992) and recently it is Eupotamon-B habitat.

Only stretches with gravel substrate where shear stress is higher provide important refuge areas for the endangered rheophilic guild.

The habitat distribution as presently existing was described by direct field observations and analysis of aerial photographs. The high resolution aerial photographs were taken in 2007 and 2008 by VITUKI. The definitions of different types of aquatic habitats were based on the classification scheme introduced by Amoros and Roux (Roux et al. 1982, Amoros et al. 1987) (See Chapter 5 and 7).

Habitat map preparation and calculation of areal extent of aquatic habitats were accomplished by the ArcView 3.3 software. The variation of areal extent of the aquatic habitats at different discharge inputs was calculated from data of 1D hydrological model produced by the MIKE-11 software. The 1D hydrological model was developed in 2009 by EDUKÖVIZIG. The 1D hydrological model does not cover all side arms, 18% of them are outside of the model (mainly the parapotamon-B and the plesiopotamon type habitats).

The calculated total area of the aquatic habitats on the right side of the active floodplain between Rajka and Sap is 2,360 ha (main arm included) at the present time. The Eupotamon-A habitat type has the largest areal extent (50%), followed by the Eupotamon-B (28%), Parapotamon-B (13%), Plesiopotamon (5%) and Parapotamon-A (4%).

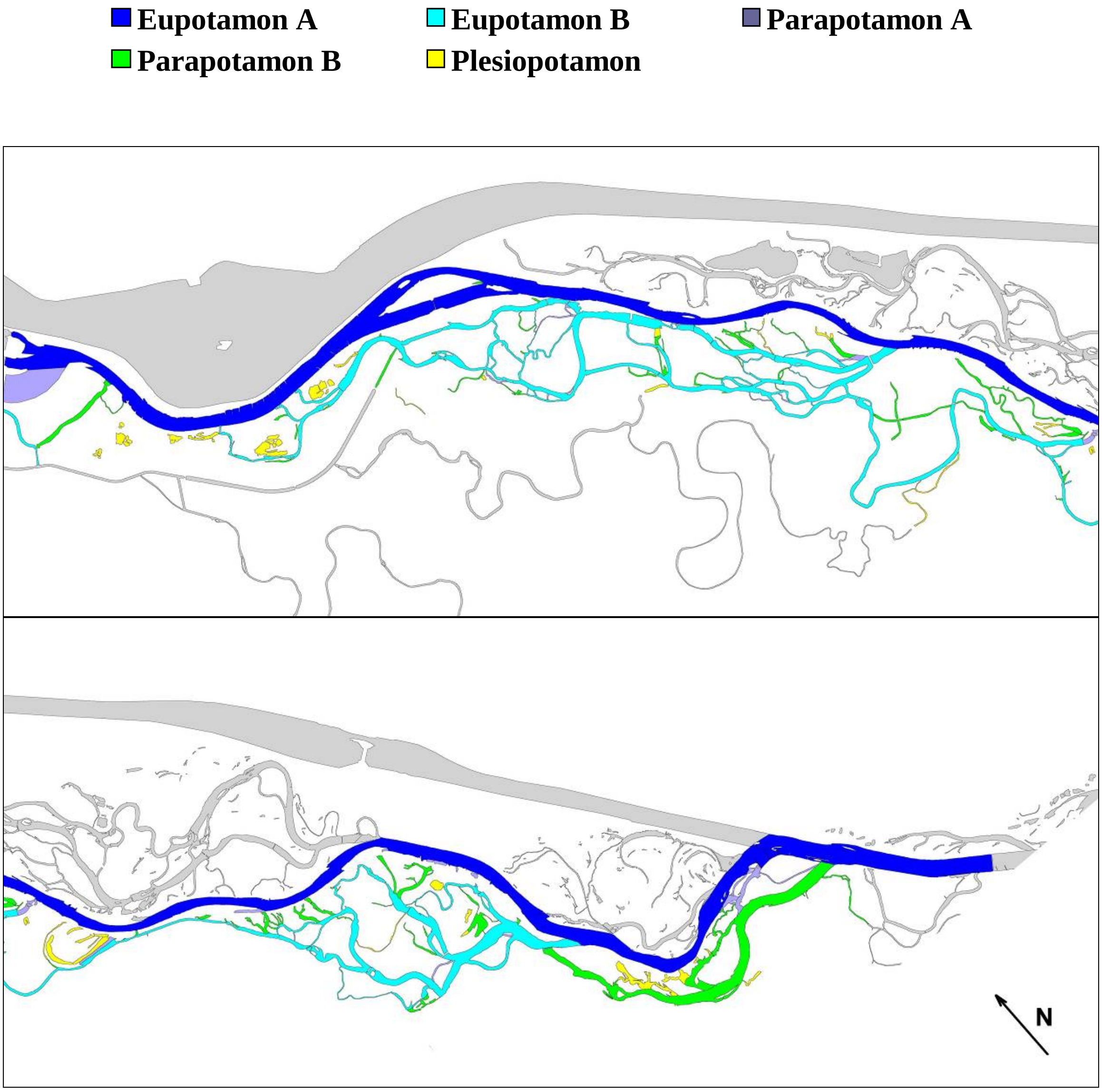


Figure 8-65 Aquatic habitat types along the active floodplain of the Szigetköz at the Present state

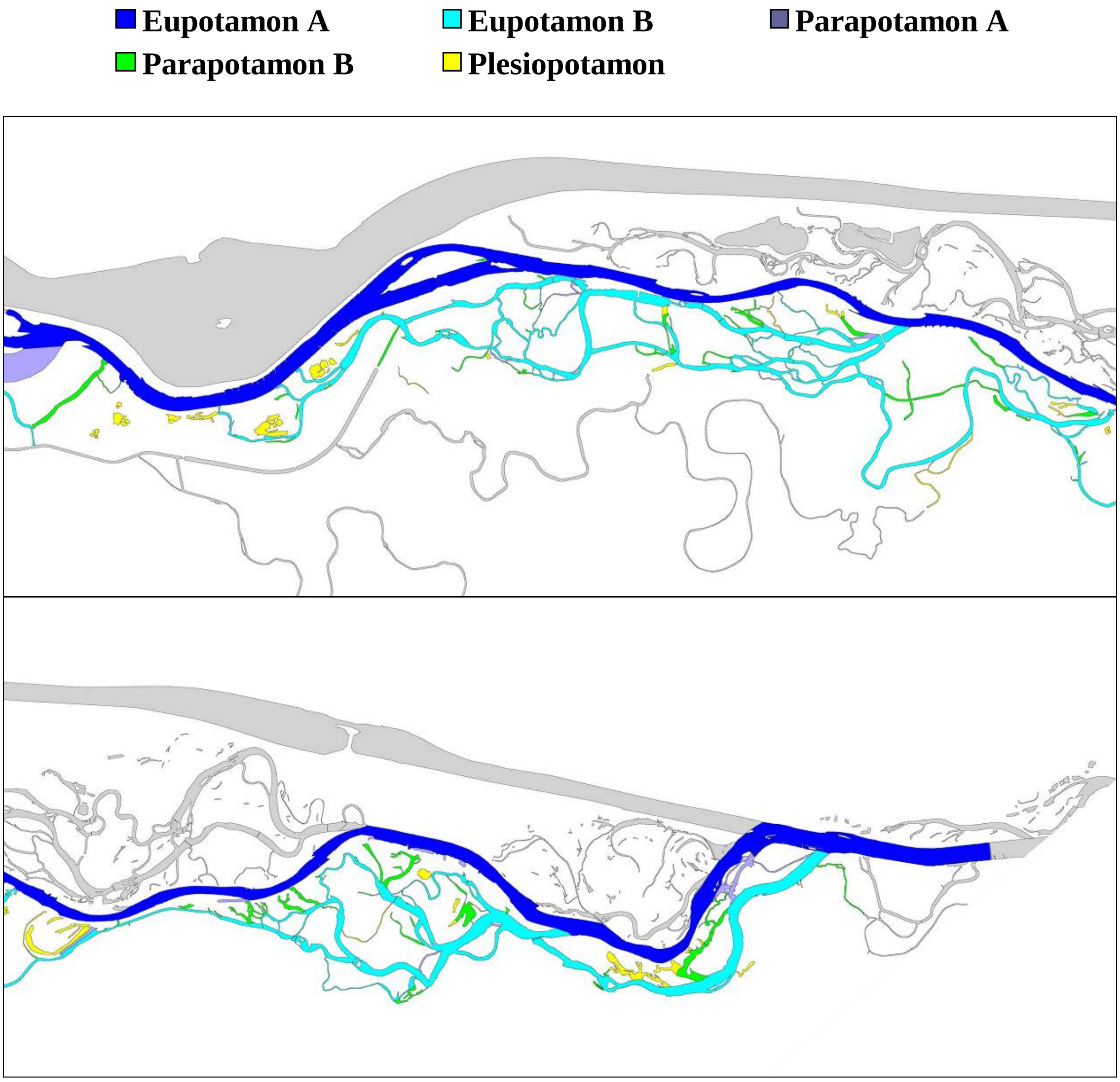


Figure 8-66 Aquatic habitat types along the active floodplain of the Szigetköz at the SZITE variant

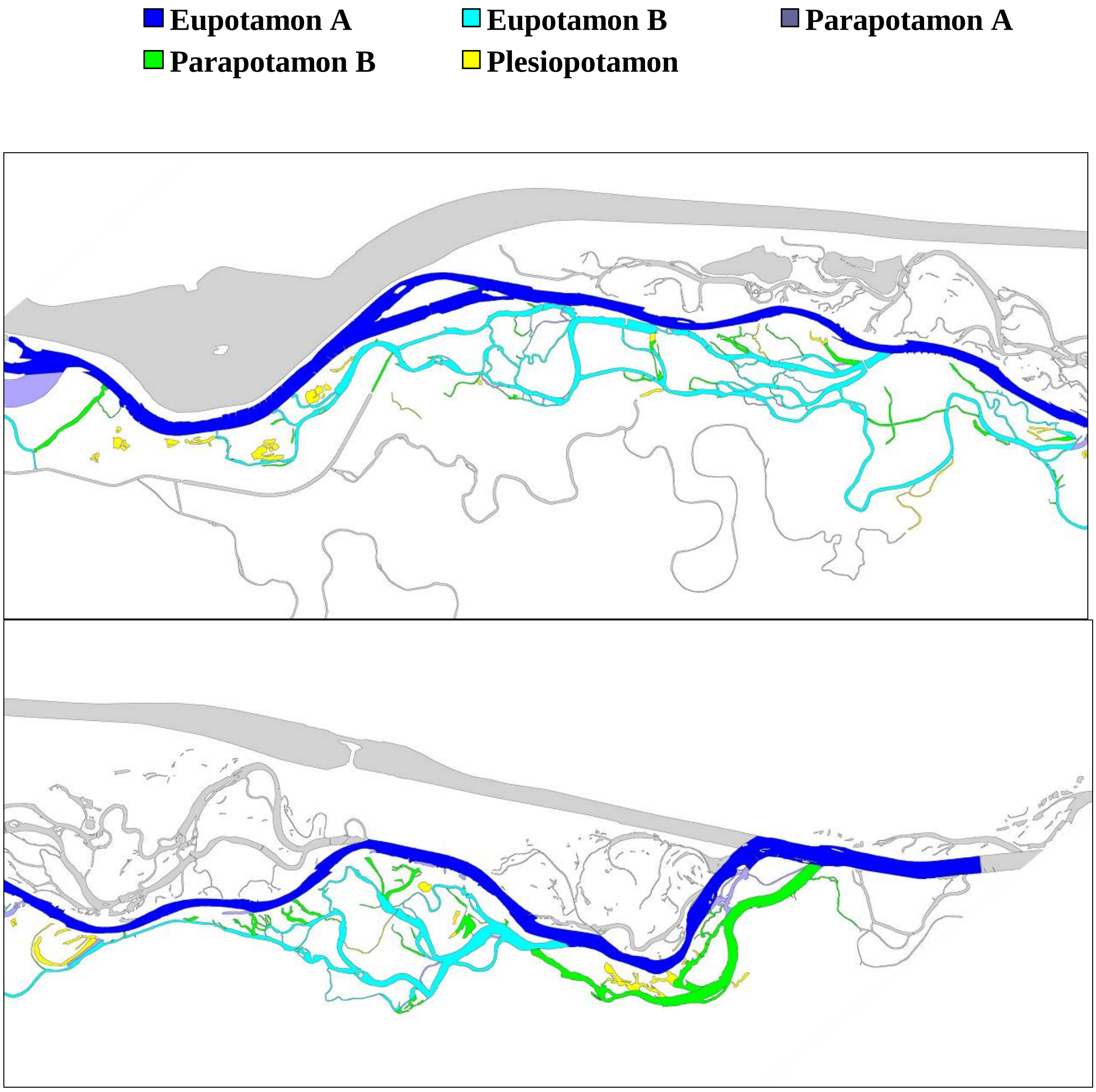


Figure 8-67 Aquatic habitat types along the active floodplain of the Szigetköz at the Narrowing variant.

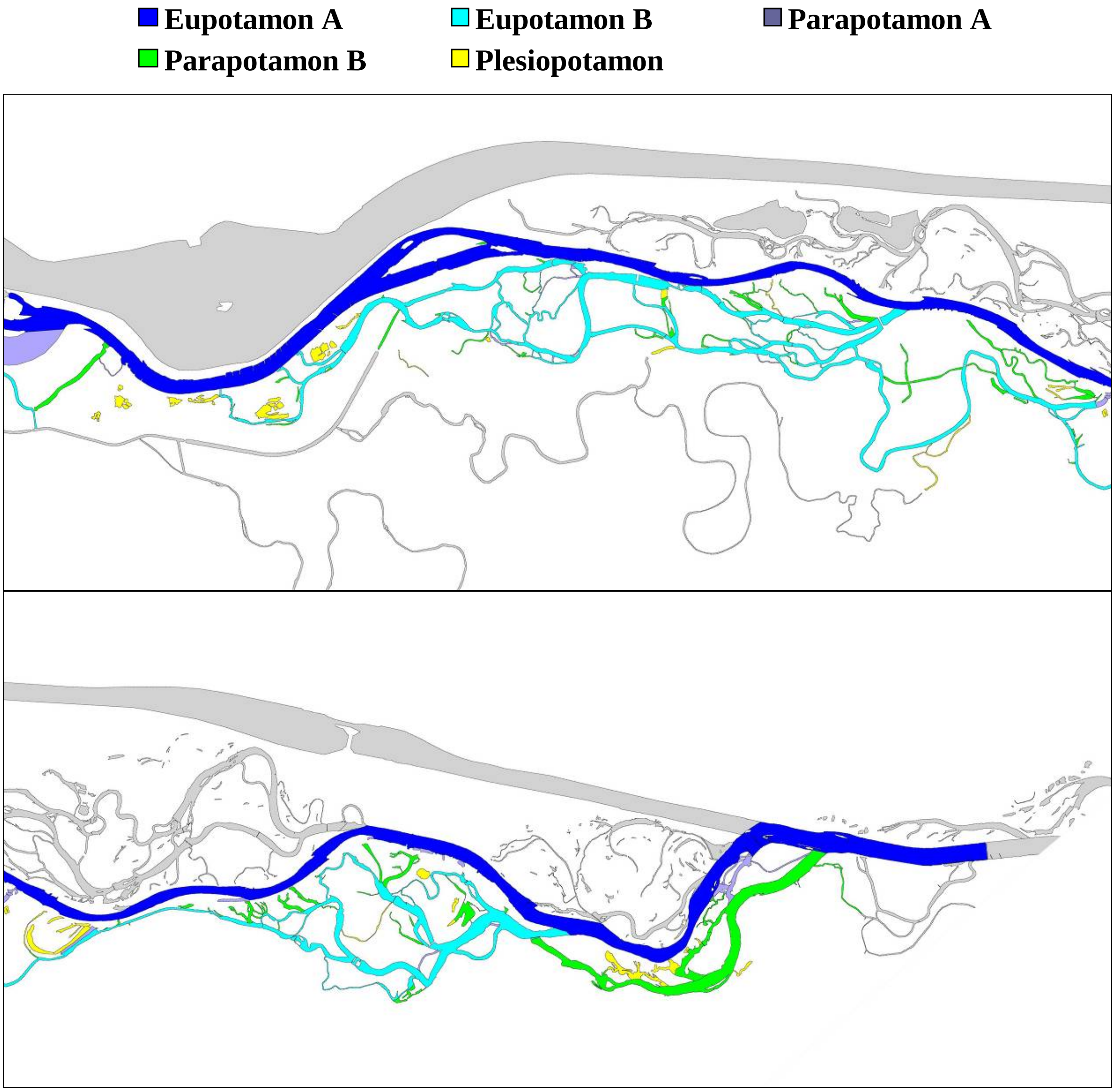


Figure 8-68 Aquatic habitat types along the active floodplain of the Szigetköz at the Optimum filling variant

8.5.2. Qualitative evaluation of fish habitats

Flow velocity and shear stress distributions in the main arm were calculated on the basis of 1D hydrological model results in the range from 200 m^3/s to 750 m^3/s discharge input. The values were calculated at 104 cross sections in a 43 km long stretch of the main arm from Rajka to Sap. In the branch system, flow velocity and shear stress distributions were calculated in the 10 km long Cikola study area on the basis of 1D hydrological model results. Discharge inputs range from 40 m^3/s to 120 $m^3\ s^{-1}$ in the analysis. Flow velocity and shear stress values were calculated at 176 cross sections in the ‘eupotamon B’ type side arms, at 18 cross sections in the ‘parapotamon A’ type side arms and at 28 cross sections in the ‘parapotamon B’ type side arms.

The habitat quality is estimated by the shear stress distribution data of the 1D hydrological model. The relationship between the habitat quality and the shear stress was examined according to the results of the fish biological surveys in the recent situation (1989-2008; see Appendix 3). The expected ecological (fish biological) quality grade of the eupotamon A habitat is bad if the shear stress is very low (<0,2 Pa). The ecological (fish biological) quality grade is probably good if the shear stress is high (> 7 Pa). The expected ecological (fish biological) quality grade of the eupotamon-B habitat is bad if the shear stress is very low (<0,2 Pa). The ecological quality grade is likely moderate if the shear stress is high (> 5 Pa).

The areal extent of the locations with a different value of shear stress was calculated according to the discharge regime in the case of the rehabilitation scenarios. Since rheophilic fish are a major indicator the effects of the variants are considered for the main arm (Eupotamon A) and the Eupotamon B type habitats of the side-arm system separately.

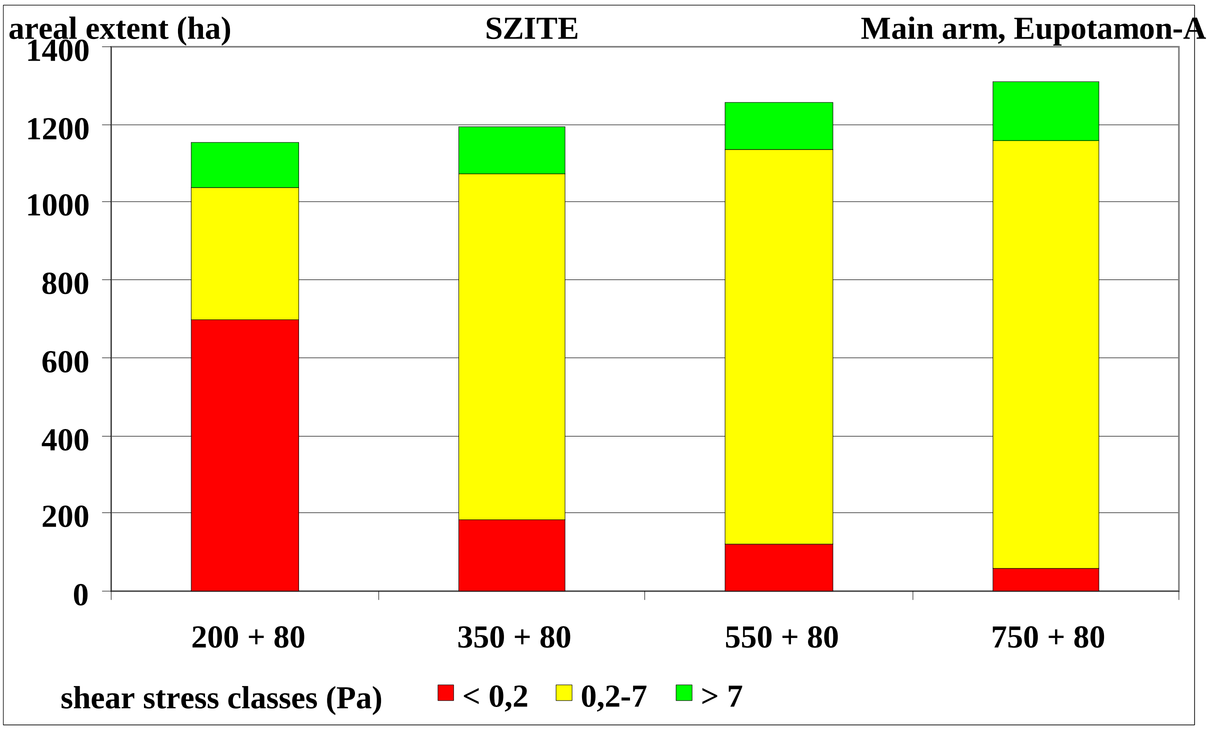
Eupotamon A:

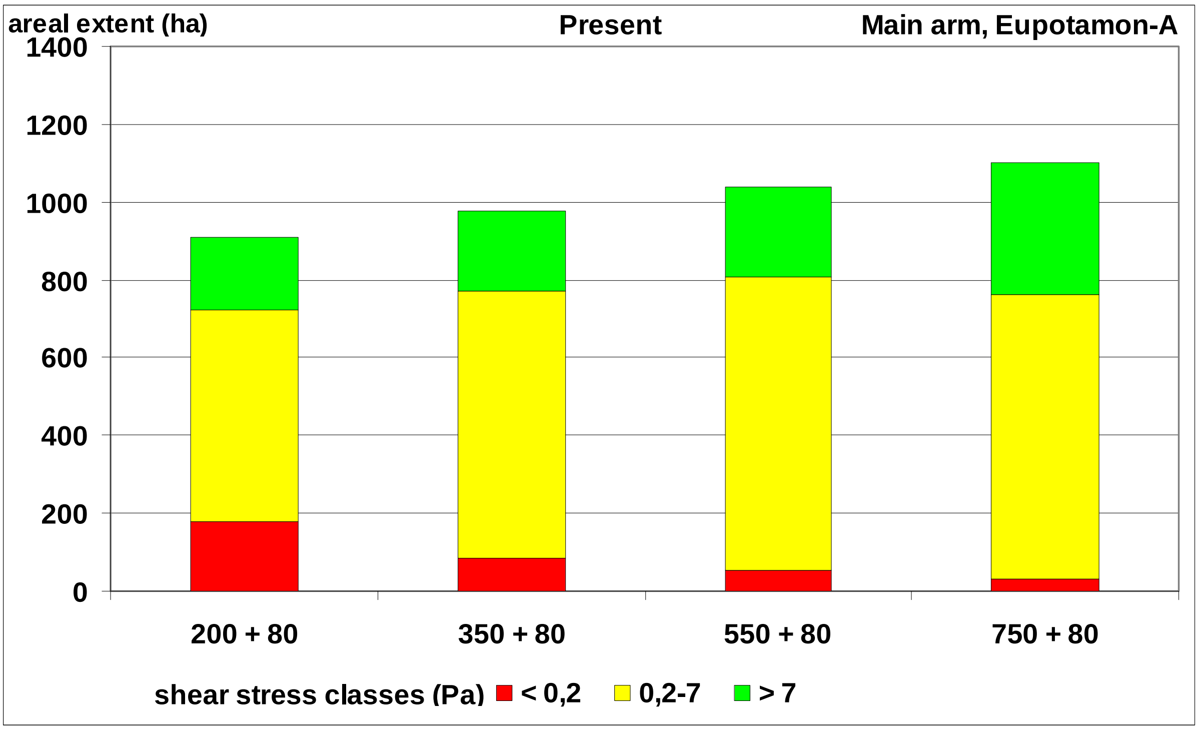
In the case of the Present state the areal extent of the locations with very low value of shear stress (low quality grade) decreases from 177 ha (20 %) to 31 ha (3 %) by the change of discharge input from 200 m^3/s to 750 m^3/s. The areal extent of the locations with low value of shear stress, where the quality grade is moderate, increases from 545 ha (60 %) to 729 ha (66%) by the increase of discharge. The area of the reaches with high value of shear stress, where the quality grade of the HFI is good, increases from 186 ha (21%) to 340 ha (31 %).

In the case of the SZITE variant, the extent of the locations with a low value of shear stress decreases from 696 ha (60 %) to 60 ha (5 %) by the increase of discharge input from 200 $m^3 s^{-1}$ to 750 $m^3 s^{-1}$, and the area of the reaches with a high value of shear stress extends from 117 ha (10%) to 154 ha (12 %). The locations with a moderate value of shear stress are the most extensive, their area increases from 343 ha (30 %) to 1098 ha (84 %) by the rise of discharge.

In the case of the Narrowing variant, the extent of the locations with a low value of shear stress declines from 173 ha (19 %) to 31 ha (3 %) by the rise of the discharge input. At the same time, the area of the reaches with a high value of shear stress increases from 186 ha (21%) to 323 ha (31 %). The locations with a moderate value of shear stress are the most extensive, their area increases from 536 ha (60 %) to 680 ha (66 %) by the increase of discharge.

In the case of the Optimal filling solution, the extent of the locations with a low value of shear stress lessens from 274 ha (22 %) to 93 ha (7 %) by the increase of the discharge input. At the same time, the area of the reaches with a high value of shear stress extends from 125 ha (10%) to 251 ha (18 %). The locations with a moderate value of shear stress are the most extensive, their area increases from 839 ha (68 %) to 1030 ha (75 %) by the rise of discharge.


areal extent (ha)
SZITE
Main arm, Eupotamon-A
1400
1200
1000
800
600
400
200
0
200 + 80
350 + 80
550 + 80
750 + 80
shear stress classes (Pa)
< 0,2
0,2-7
> 7


areal extent (ha)
Present
Main arm, Eupotamon-A
1400
1200
1000
800
600
400
200
0
200 + 80
350 + 80
550 + 80
750 + 80
shear stress classes (Pa)
< 0,2
0,2-7
> 7

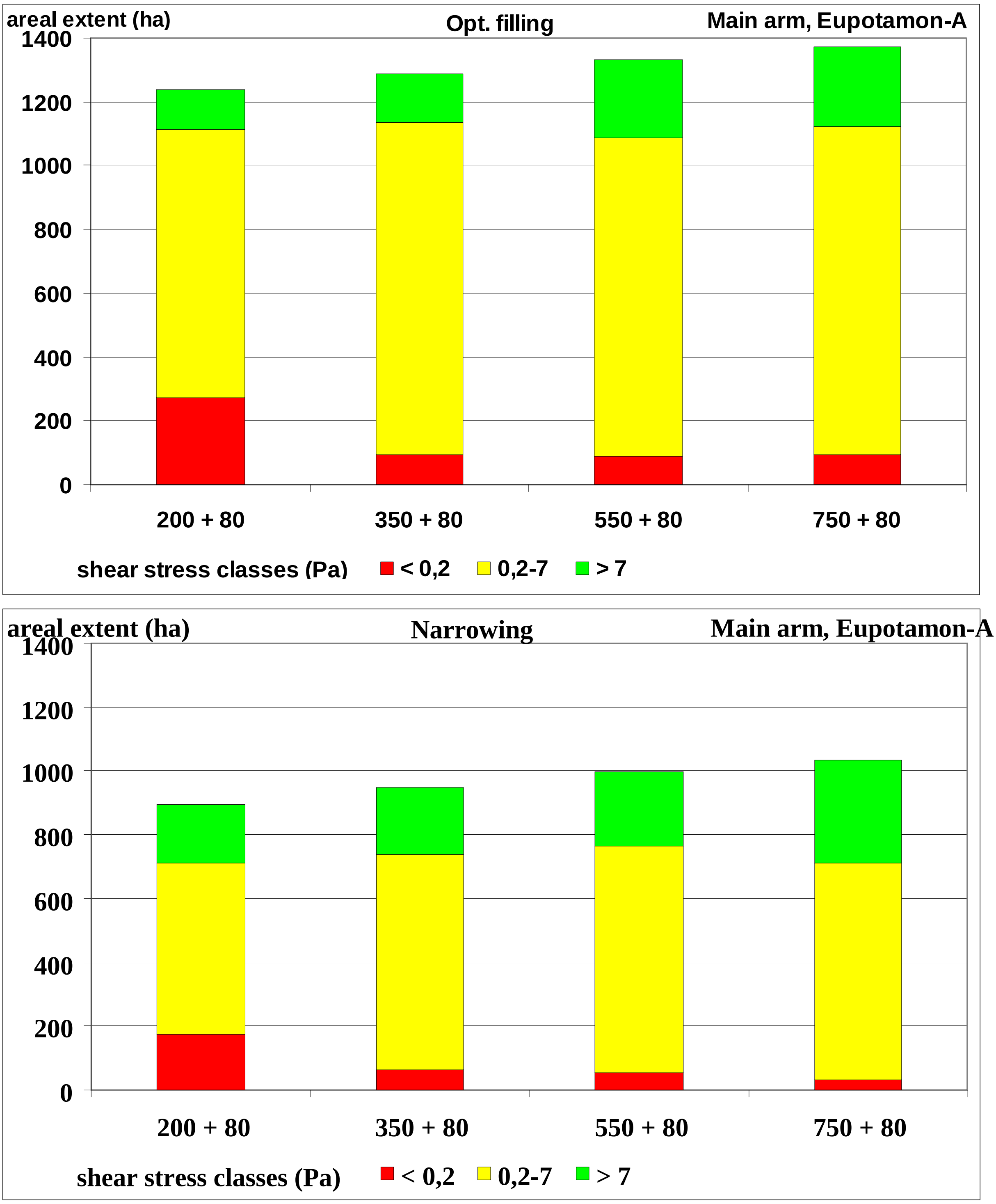


Figure 8-69 Areal extent of the shear stress classes (< 0,2 Pa, 0,2-7 Pa, > 7 Pa) in the main arm (Eupotamon-A) in the case of the present situation, the 3 weirs (SZITE) scenario, the narrowing scenario and the optimum filling scenario . The predicted ecological (fish biological) quality grade is indicated by colours: Red = bad, Yellow = moderate, Green = good

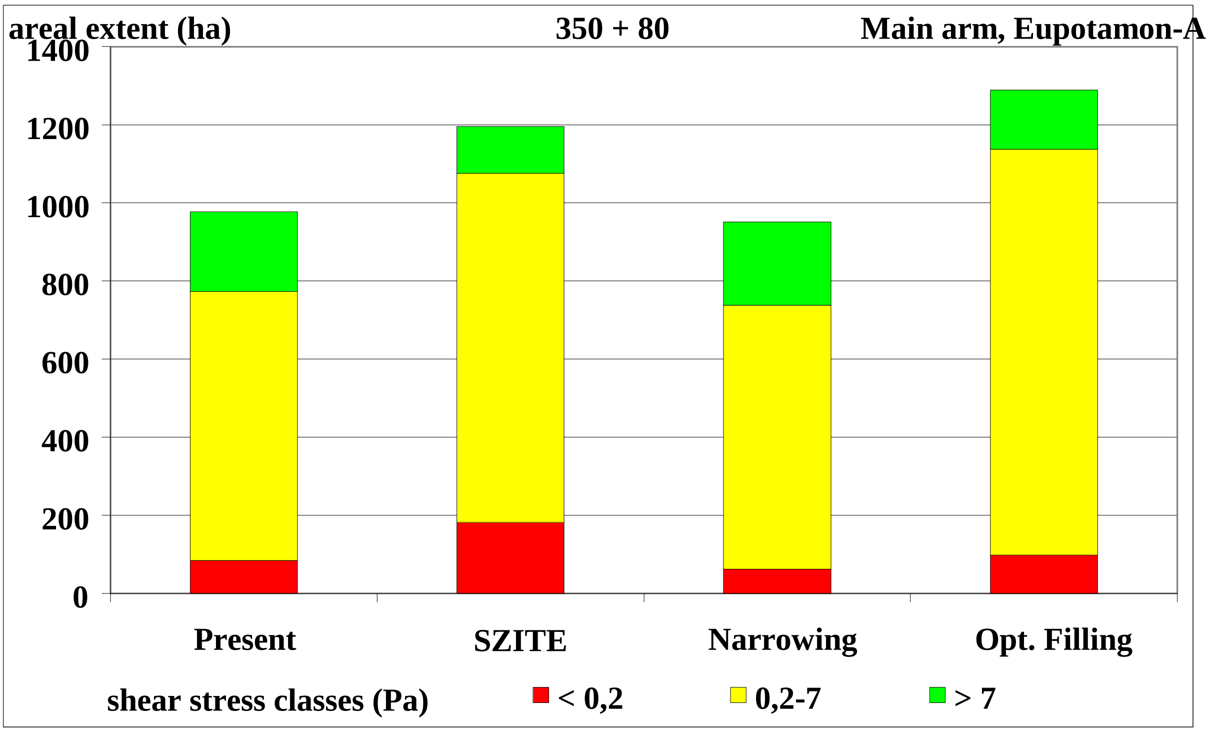


Figure 8-70 Comparison of areal extent of the shear stress classes (< 0,2 Pa, 0,2-7 Pa, > 7 Pa) in the main arm (Eupotamon-A) in the case of different rehabilitation scenarios at 350+80 $m^3 s^{-1}$ discharge. The predicted ecological (fish biological) quality grade is indicated by colours: Red = bad, Yellow = moderate, Green = good.

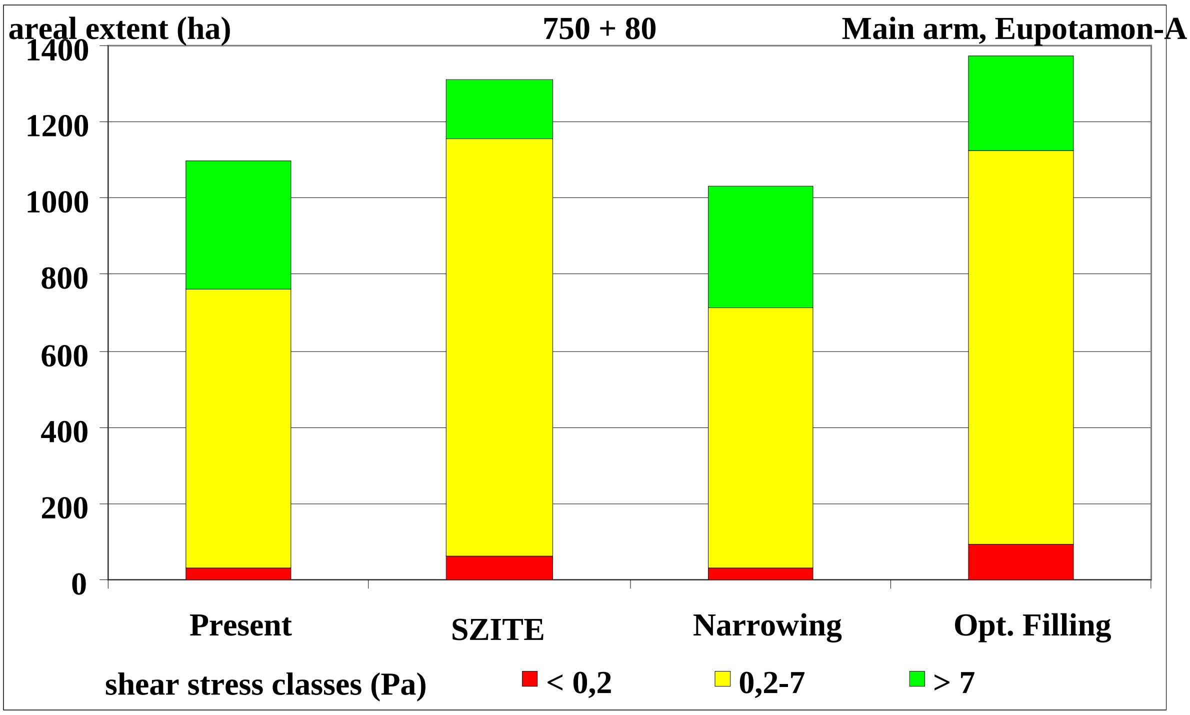


Figure 8-71 Comparison of areal extent of the shear stress classes (< 0,2 Pa, 0,2-7 Pa, > 7 Pa) in the main arm (Eupotamon-A) in the case of different rehabilitation scenarios at 750+80 $m^3 s^{-1}$ discharge. The predicted ecological (fish biological) quality grade is indicated by colours: Red = bad, Yellow = moderate, Green = good.

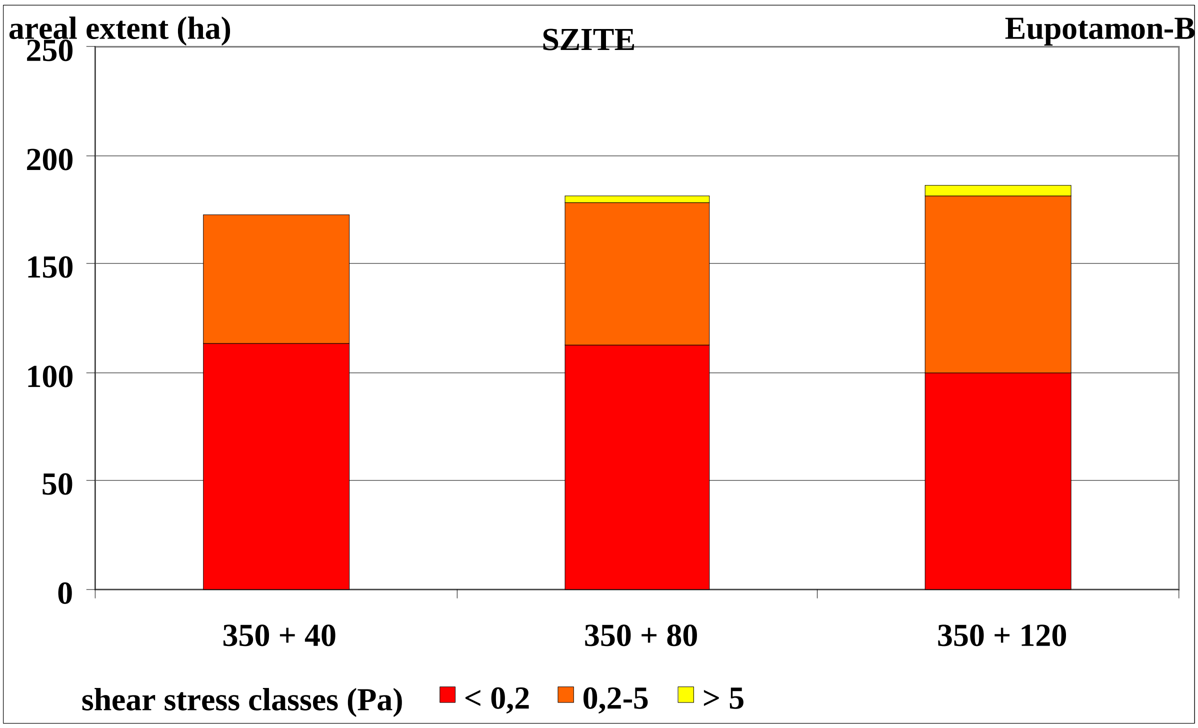
Side arm system (Eupotamon-B):

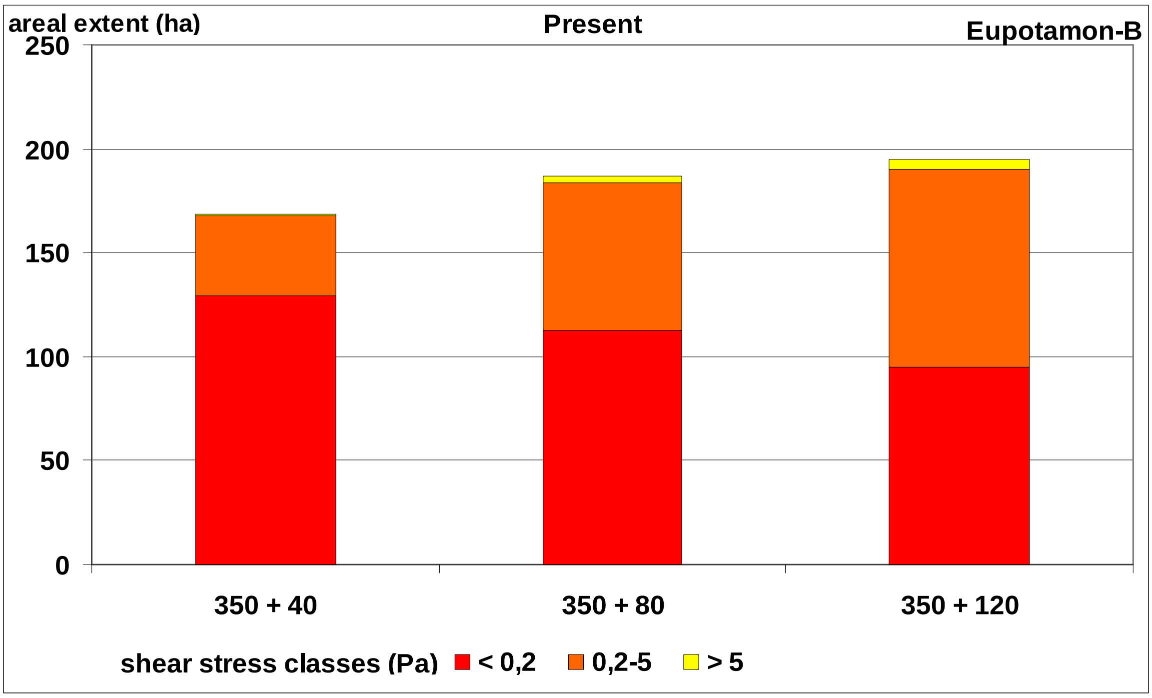
In the case of the Present state the areal extent of the locations with very low value of shear stress(low quality grade), decreases from 129 ha (76 %) to 95 ha (49 %) by the increase of discharge input from 40 m^3/s to 120 m^3/s. The extent of the reaches with low value of shear stress, where the quality grade of the HFI is poor, increases from 39 ha (13 %) to 95 ha (49 %) by the rising discharge. The area of the locations with high value of shear stress, where the quality grade of the HFI is moderate, extends from 1,2 ha (1 %) to 4,7 ha (2 %)

In the case of the SZITE variant, the extent of the locations with a low value of shear stress decreases from 113 ha (66 %) to 100 ha (53 %) by the increase of discharge input from 40 $m^3 s^{-1}$ to 120 $m^3 s^{-1}$. At the same time, the area of the reaches with a high value of shear stress extends from 0 ha (0%) to 5 ha (3 %). The locations with a moderate value of shear stress are the most extensive, their area increases from 59 ha (34 %) to 82 ha (44 %) by the rise of discharge.

In the case of the Narrowing solution, the locations with a low value of shear stress are the most extensive, their area decreases from 131 ha (77 %) to 106 ha (54 %) by the increase of the discharge input from 40 m^3/s to 120 m^3/s. At the same time, the area of the reaches with a high value of shear stress extends from 0,3 ha (0,2 %) to 6 ha (3 %). The extent of the locations with a moderate value of shear stress increases from 39 ha (23 %) to 83 ha (43 %) by the increase of discharge input.

In the case of the Optimal filling variant, the extent of the locations with a low value of shear stress decreases from 22 ha (12 %) to 19 ha (10 %) by the increase of discharge input from 40 $m^3 s^{-1}$ to 120 m^3/s. At the same time, the area of the reaches with a high value of shear stress extends from 4 ha (2 %) to 6 ha (3 %). The locations with a moderate value of shear stress are the most extensive, their area increases from 162 ha (86 %) to 168 ha (87 %) by the rise of discharge.


areal extent (ha)
SZITE
Eupotamon-B
250
200
150
100
50
0
350 + 40
350 + 80
350 + 120
shear stress classes (Pa)
< 0,2
0,2-5
> 5


areal extent (ha)
Present
Eupotamon-B
250
200
150
100
50
0
350 + 40
350 + 80
350 + 120
shear stress classes (Pa)
< 0,2
0,2-5
> 5

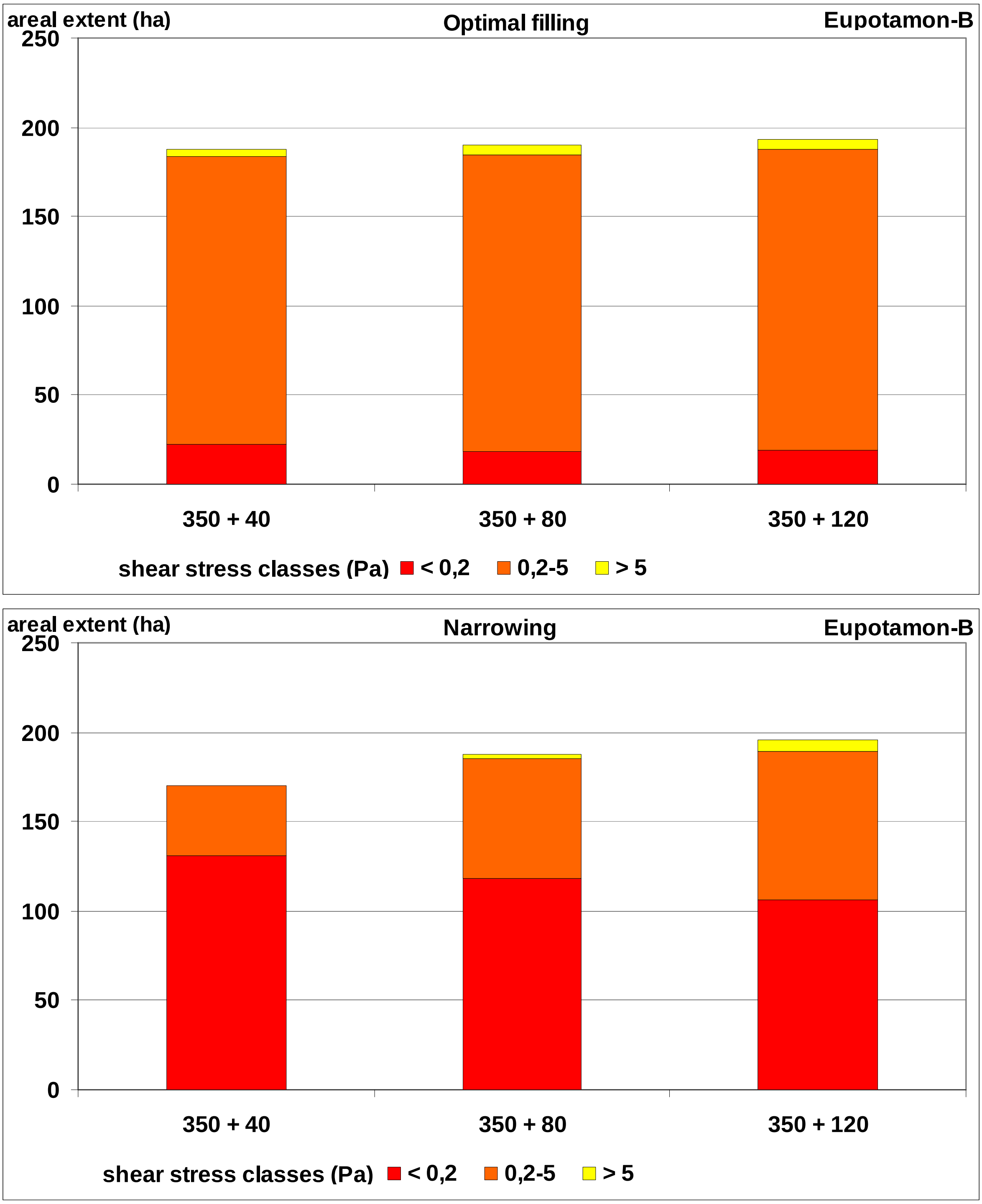


Figure 8-72 Areal extent of the shear stress classes (< 0,2 Pa, 0,2-5 Pa, > 5 Pa) in Eupotamon-B type side arms of the Cikola branch system in the case of the present situation, the SZITE scenario, the narrowing scenario and the optimum filling scenario . The predicted ecological (fish biological) quality grade is indicated by colours: Red = bad, Orange = poor, Yellow = moderate quality grade. The quality grade is evaluated according to the Eupotamon-B reference.

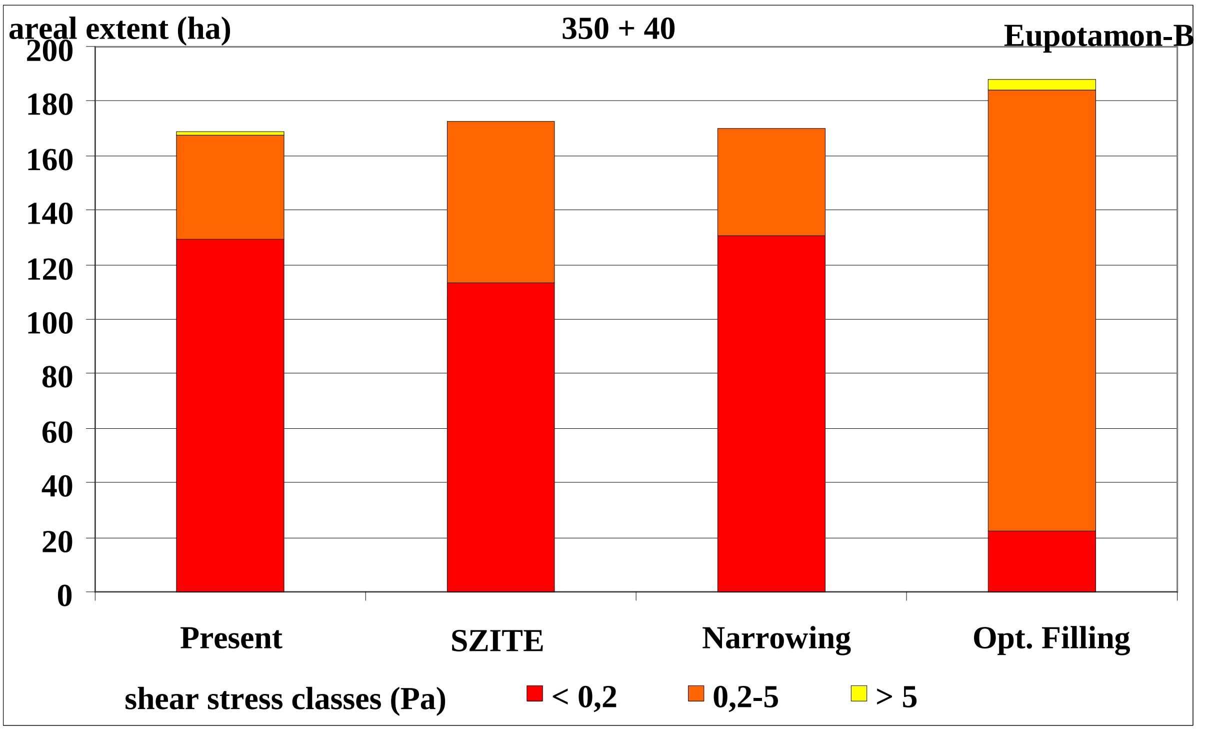


Figure 8-73 Comparison of areal extent of the shear stress classes (< 0,2 Pa, 0,2-5 Pa, > 5 Pa) the Eupotamon-B type side arms in the Cikola branch system in the case of different rehabilitation scenarios at 350+40 $m^3 s^{-1}$ discharge. The predicted ecological (fish biological) quality grade is indicated by colours: Red = bad, Orange = poor, Yellow = moderate quality grade. The quality grade is evaluated according to the Eupotamon-B reference.

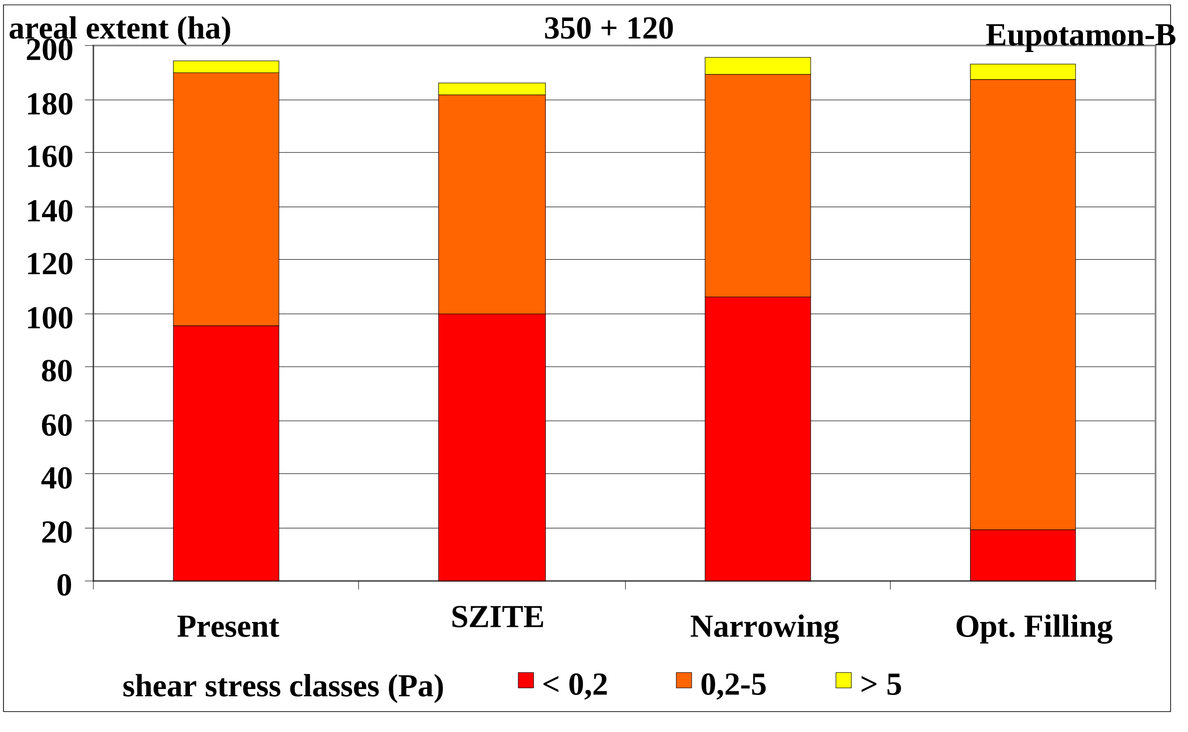


Figure 8-74 Comparison of areal extent of the shear stress classes (< 0,2 Pa, 0,2-5 Pa, > 5 Pa) the Eupotamon-B type side arms in the Cikola branch system in the case of different rehabilitation scenarios at 350+120 $m^3 s^{-1}$ discharge. The predicted ecological (fish biological) quality grade is indicated by colours: Red = bad, Orange = poor, Yellow = moderate quality grade. The quality grade is evaluated according to the Eupotamon-B reference.

The flow velocity distribution shows a shifting to higher values by the increasing discharge input of the main arm. The most frequent (freq. >10%) flow velocity classes range from 0,25 m^3/s to 1,0 m/s at 200 m^3/s discharge input, and they range from 1,0 m/s to 2,25 m/s at 750 m^3/s discharge input. The discharge input variation to the branch system has no significant impact on the flow velocity of the main arm.

A shifting to higher values in the shear stress distribution is detectable by the increasing discharge input of the main arm. The most frequent (freq. >20%) shear stress classes are 0,5 Pa and 10 Pa at 200 m^3/s discharge input, and they range from 2,0 Pa to 10 Pa at 750 m^3/s discharge input. The discharge input variation to the branch system has no significant impact on the shear stress distribution in the main arm.

According to the analysis of hydrological variables in the main arm, the frequency of the stretches with >7 Pa value of tau (critical for incipient motion of 10 mm grain sized gravel) increases from 30% to 50% by change of discharge input from 200 m^3/s to 750 m^3/s. The flow velocity at these stretches usually surpasses the value of 1.7 m s^{-1}. At the same time, the frequency of the stretches with <0.2 Pa value of tau (critical for silt deposition) decreases from 17% to 3%.

In the case of the SZITE variant, the areal extent of aquatic zones and the proportion of Eupotamon improve, but the habitat quality strongly decreases.

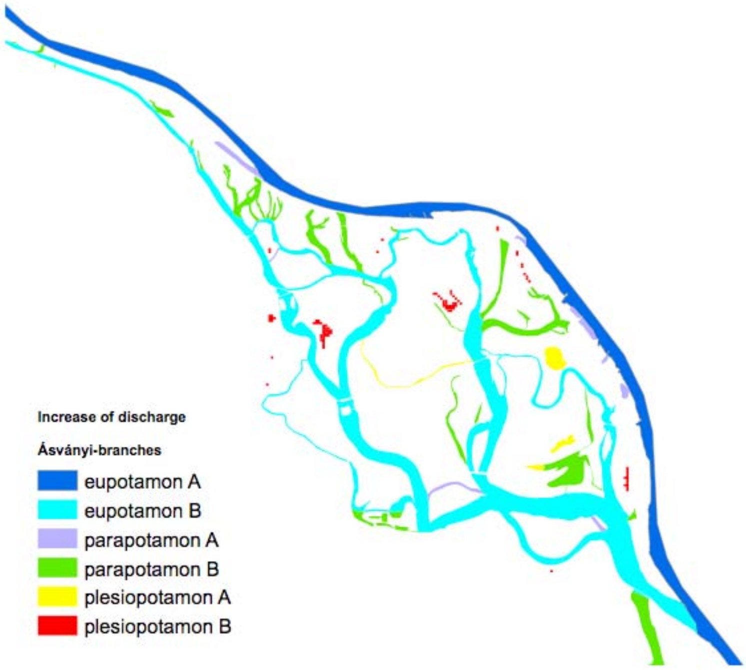
The Present state and the Optimum filling variant provide better habitat conditions for reference fish fauna than the other scenarios. This evaluation disregards the condition of the longitudinal connectivity.

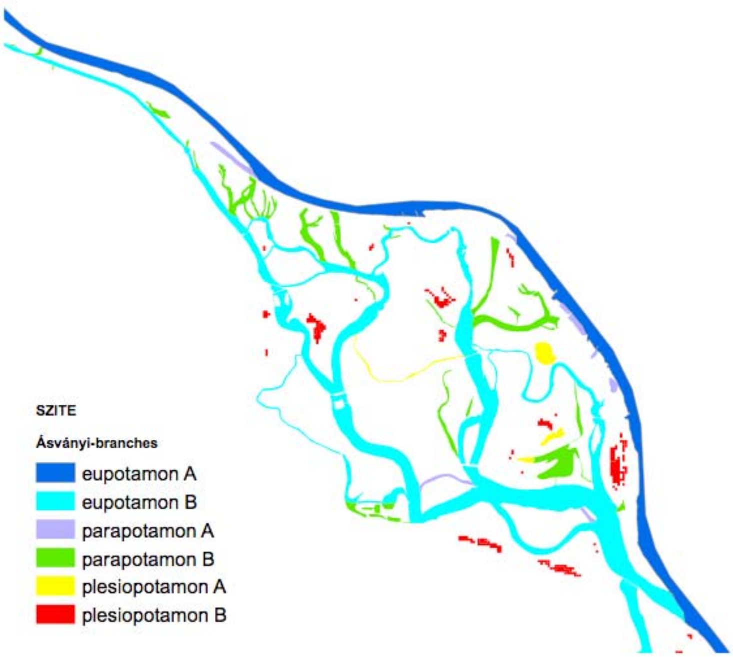
8.5.3. Amphibia

While the fish and macrozoobenthos assemblages are especially indicative for the availability and quality of eupotamal habitats, for the amphibian fauna the existence of plesiopotamic and palaeopotamic water bodies as reproduction sites is particularly significant.

In the determination of habitat types based on the data of 1D hydromorphological model produced by the MIKE 11 software a considerable amount of branch elements have remained as uncategorized water type. They were ranked manually and most of them put into Plesiopotamon A habitat type.

Based on the five grade benchmark system (see chapter 7) the variants “Optimal Filling“ and “SZITE“ showed the highest values (3.5 and 4.0, respectively). It should be emphasized that the ratio of Parapotamon B/ Parapotamon A type habitat seems to be considerable higher in the case of variant “Optimum filling” compared to “SZITE” (19.2 and 8.8 respectively) resulting in ultimately more suitable spawning sites for amphibians in the floodplain.


Increase of discharge
Ásványi-branches
eupotamon A
eupotamon B
parapotamon A
parapotamon B
plesiopotamon A
plesiopotamon B


SZITE
Ásványi-branches
eupotamon A
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parapotamon A
parapotamon B
plesiopotamon A
plesiopotamon B

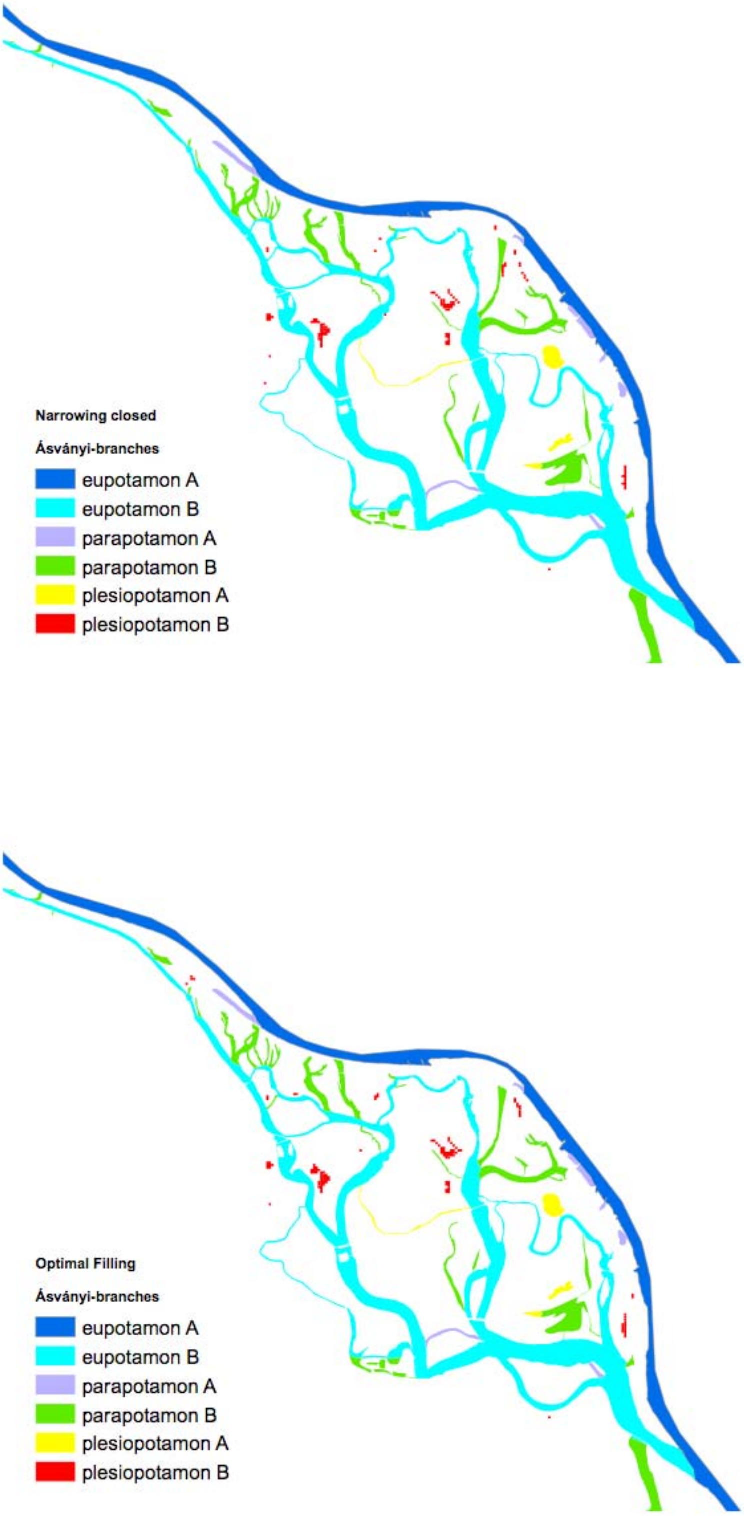
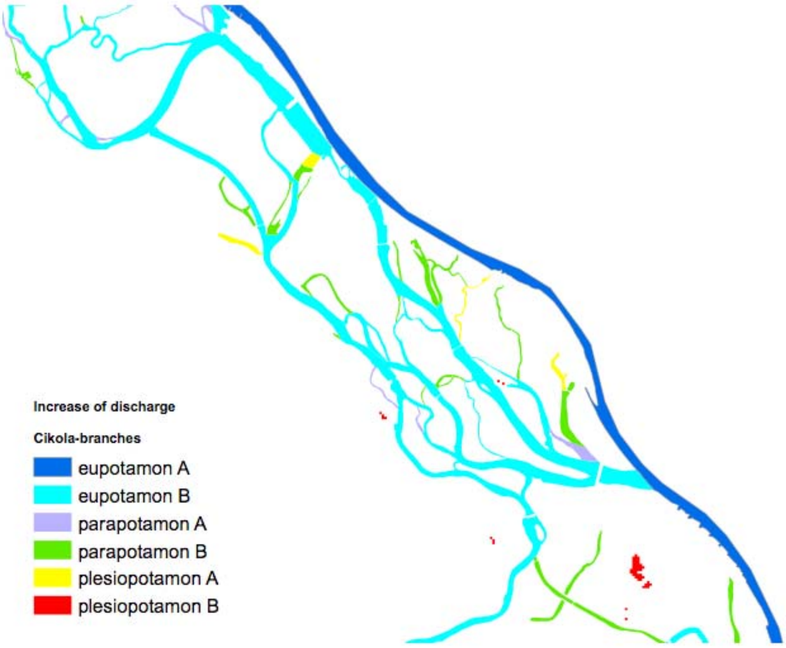
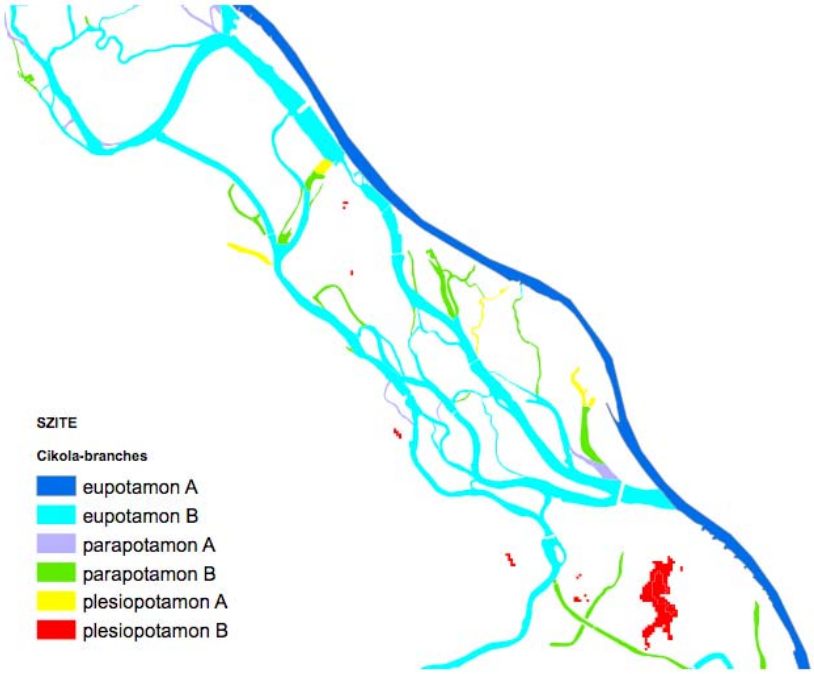
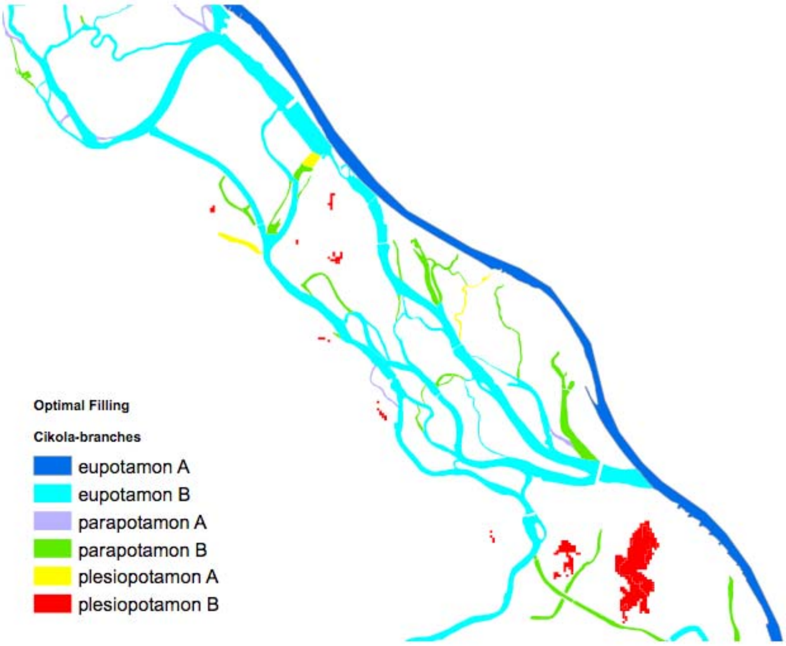


Figure 8-75 Distribution maps of aquatic habitat types for Amphibians by variants in the Asványi branch system and its surroundings


Increase of discharge
Cikola-branches
eupotamon A
eupotamon B
parapotamon A
parapotamon B
plesiopotamon A
plesiopotamon B


SZITE
Cikola-branches
eupotamon A
eupotamon B
parapotamon A
parapotamon B
plesiopotamon A
plesiopotamon B



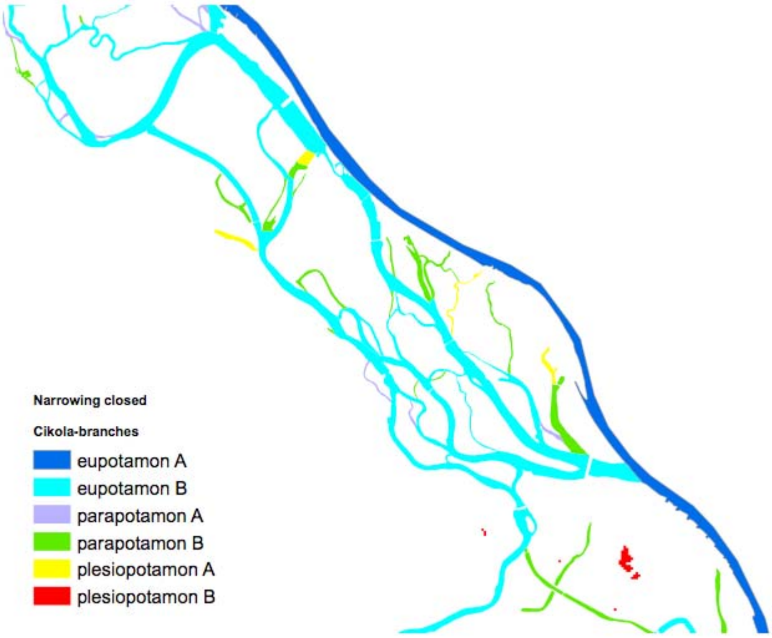


Figure 8-76 Distribution maps of aquatic habitat types for Amphibians by variants in the Cikola branch system and its surroundings

Table 8-8 Evaluation of aquatic habitats using Amphibian benchmarking system

	Increase of discharge	SZITE	Narrowing closed	Optimum Filling
% Plesiopotamon B	1.3	4.0	1.2	3.0
Plesiopotamon Index (B/ A)	0.3	0.9	0.3	0.7
% Parapotamon B	19.2	8.8	18.4	19.2

Benchmark variable	Increase of discharge	SZITE	Narrowing closed	Optimum Filling
% Plesiopotamon B	2	4	2	3
Plesiopatamon Index (B/ A)	2	5	2	4
% Parapotamon B	4	2	4	4
Score of benchmark variable	2.66	3.66	2.66	3.66
Ranking by benchmarking	-+	+	-+	+
Status by benchmarking	status far from reference conditions but still acceptable	improvement but still far from reference conditions	status far from reference conditions but still acceptable	More improvement but still far from reference conditions

8.5.4. *Vegetation development in the terrestrial zones*

The first set of maps presents the habitat type distribution predicted by the vegetation model (see Appendix 2) for the different variants.

Bar charts are provided for each variant presenting the proportions of habitat type frequencies for the 16 categories considered as predicted by the model at four discharge levels. This is followed by a table summarizing the calculated area proportions of five habitat classes (softwood forests, hybrid poplar plantations, ruderal and semiruderal riverine communities, wetlands and hardwood forests) with their actual proportions in the year 2008 as a reference. This data is also presented in a table and are shown in graphs and are shortly interpreted.

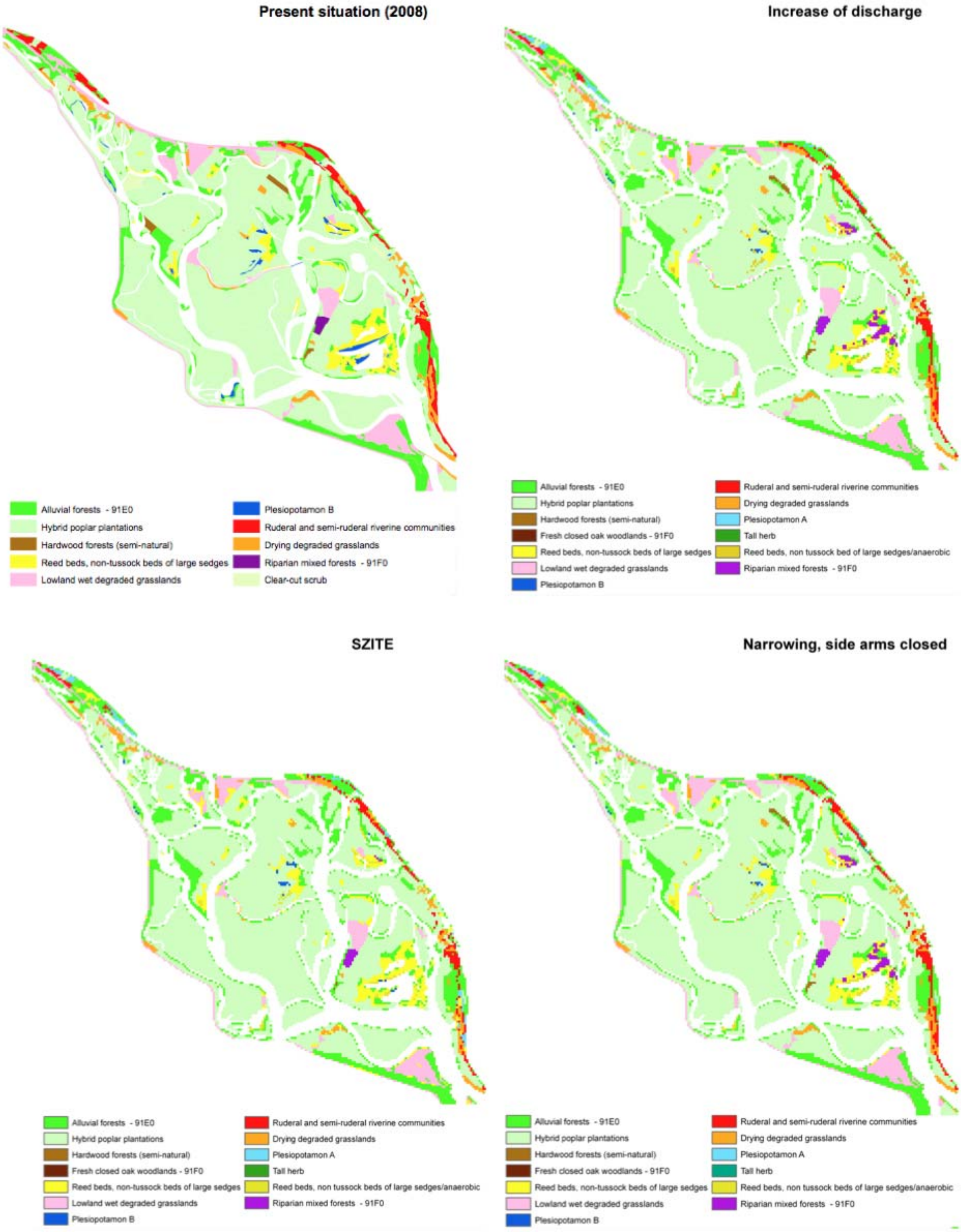


Figure 8-77 Results of habitat modelling by variants in the Ásványi branch system using a 50 year long simulation period and a 770 m^3/s average discharge level in the vegetation season

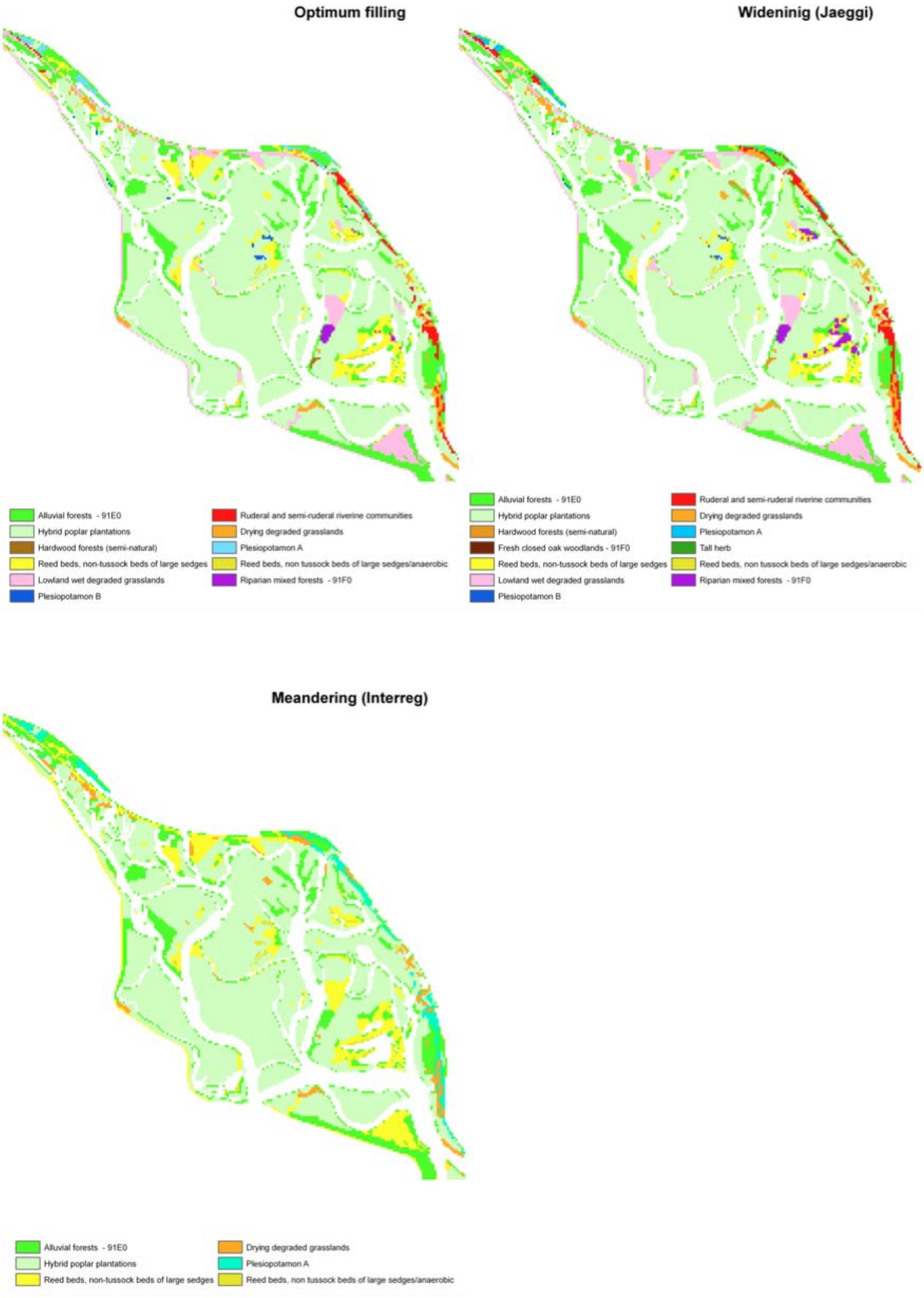


Figure 8-78 Results of habitat modelling by variants in the Ásványi branch system using a 50 year long simulation period and a 770 m³/s average discharge level in the vegetation season

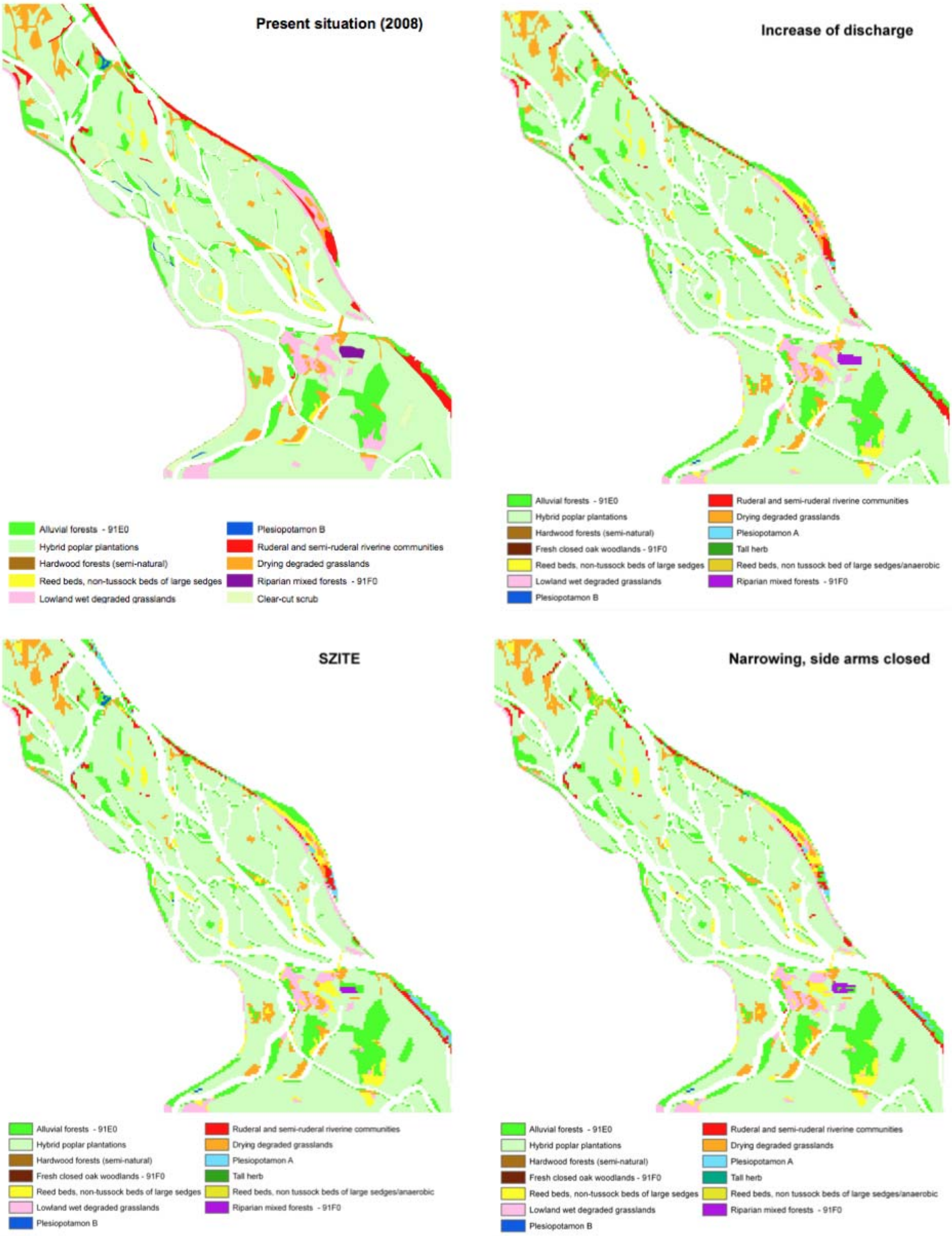


Figure 8-79 Results of habitat modelling by variants in the Cikola branch system using a 50 year long simulation period and a 770 m^3/s average discharge level in the vegetation season

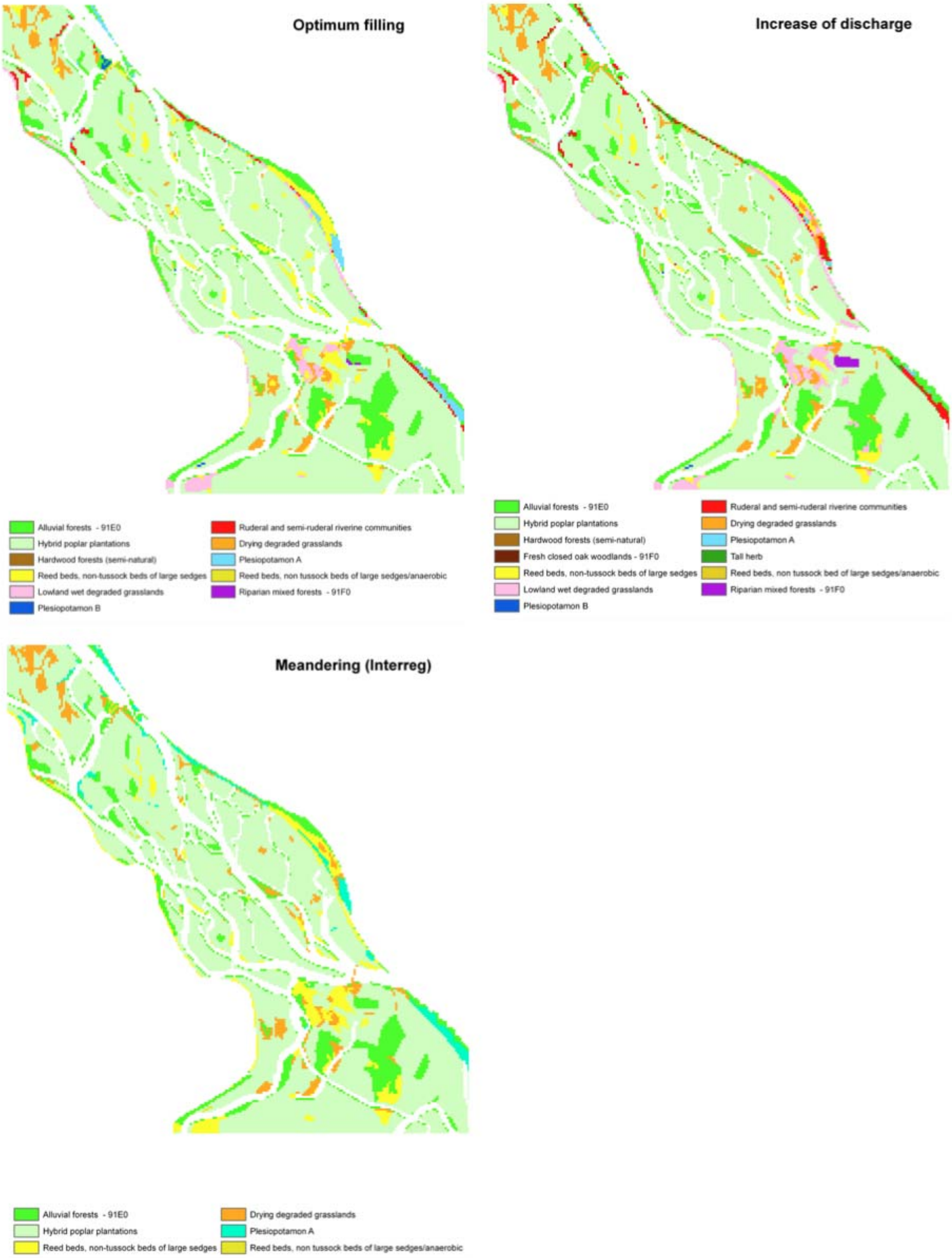
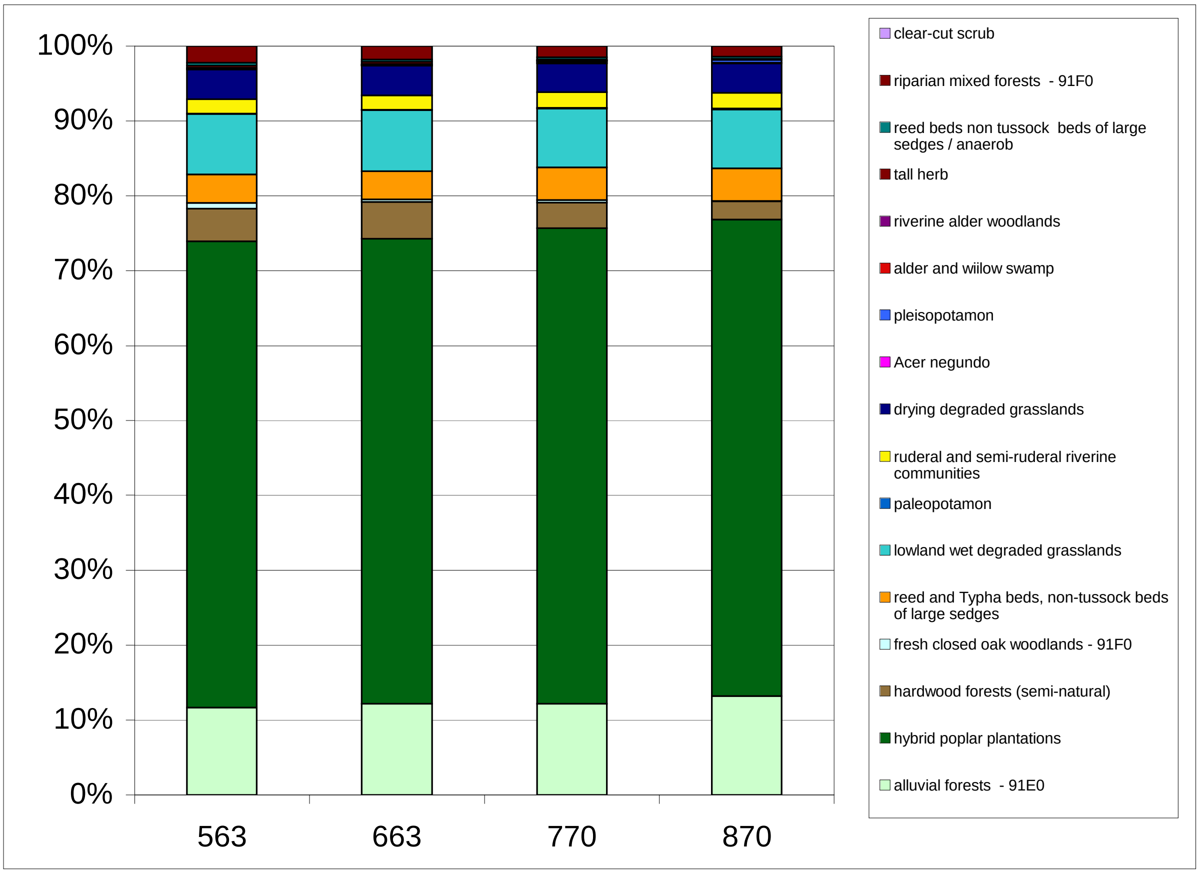
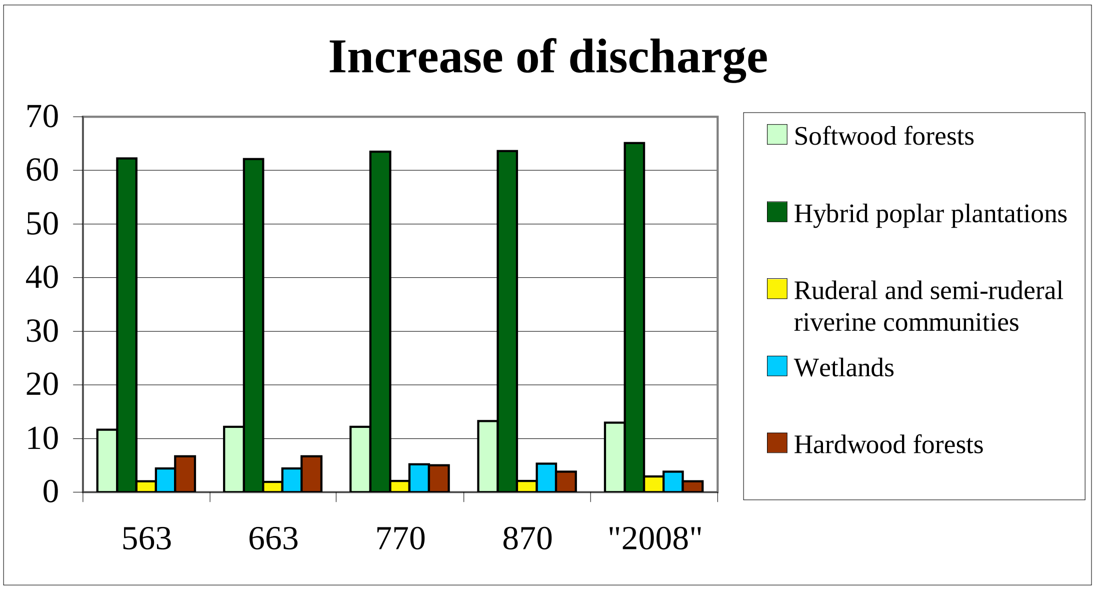


Figure 8-80 Results of habitat modelling by variants in the Cikola branch system using a 50 year long simulation period and a 770 m^3/s average discharge level in the vegetation season

INCREASE OF DISCHARGE



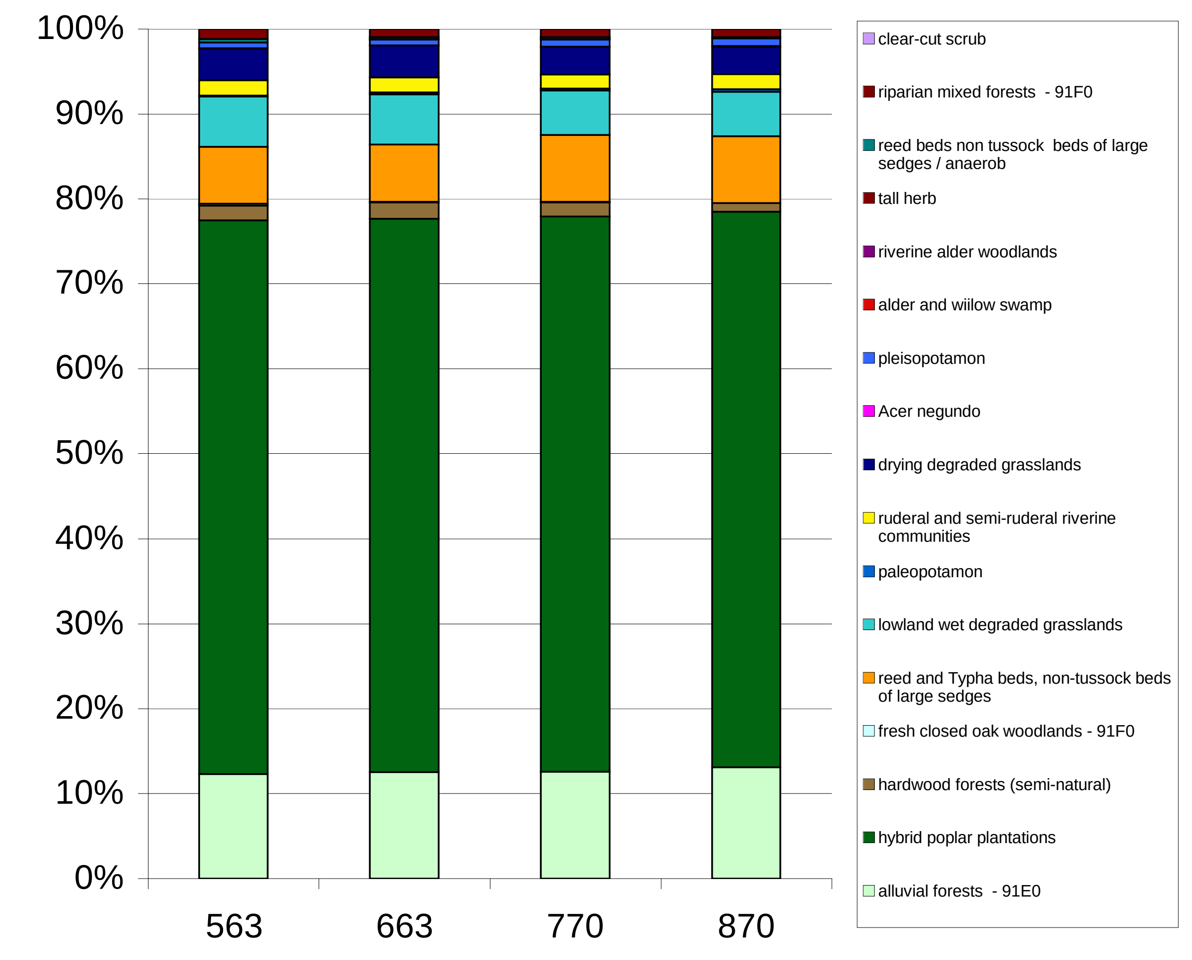
Increase of discharge (%)	563	663	770	870	"2008"
Softwood forests	11.67	12.14	12.14	13.20	12.98
Hybrid poplar plantations	62.25	62.14	63.53	63.65	65.08
Ruderal and semi-ruderal riverine communities	1.95	1.93	2.07	2.11	2.89
Wetlands	4.35	4.35	5.13	5.27	3.76
Hardwood forests	6.63	6.70	4.93	3.80	2.02



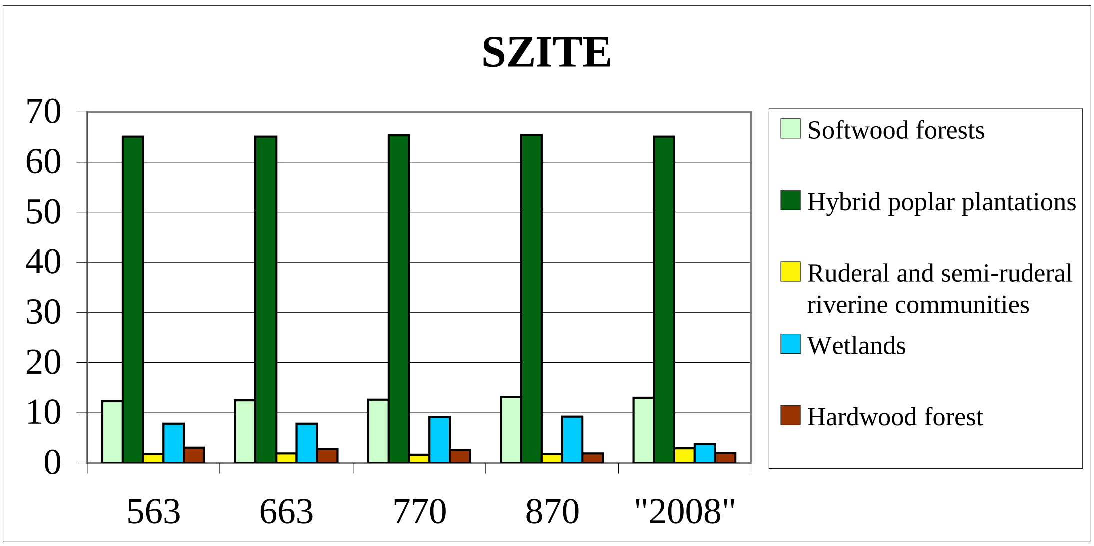
The following observations are made with regard to the Increase of discharge variant:

- the area of softwood forests grows when the rate of flow is 870 m^3/s (favourable), and it decreases in the case of other flow rates (unfavourable)
- the area of hybrid poplar forests decreases regardless of the flow rate (unfavourable)
- the area of floodplain ruderal and semi-ruderal communities diminishes regardless of the flow rate (unfavourable)
- the wetland area increases regardless of the flow rate (favourable)
- the area of hardwood forests *significantly* increases regardless of the flow rate (unfavourable)

SZITE



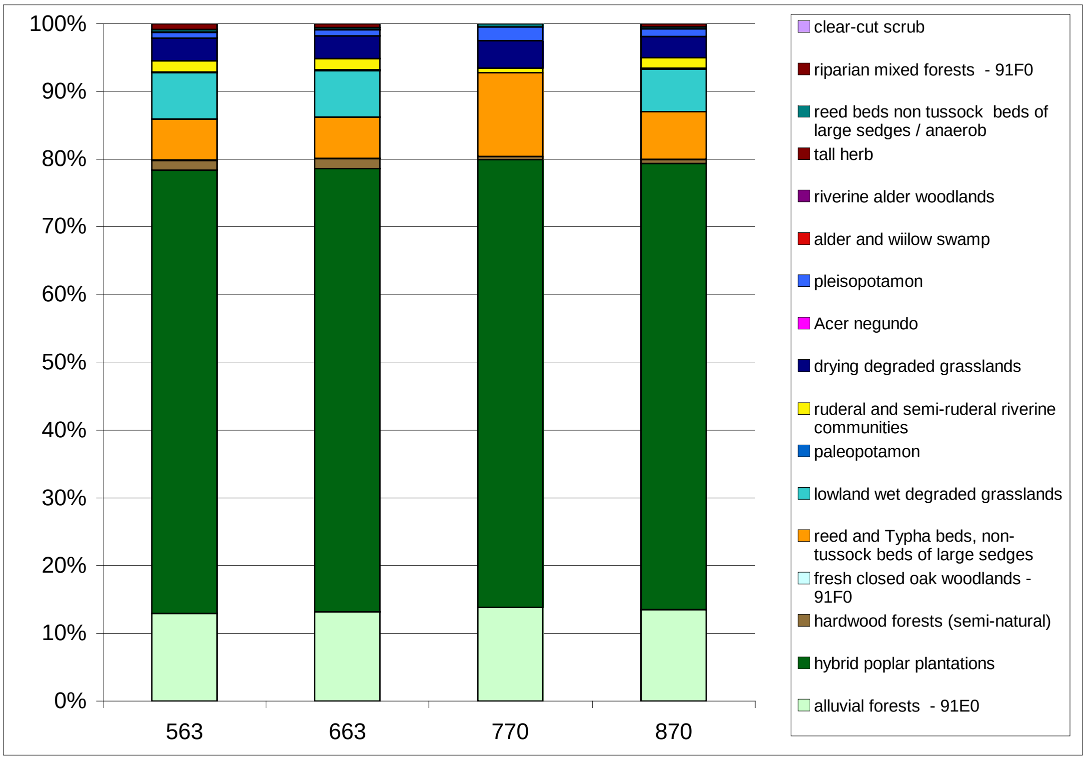
SZITE (%)	563	663	770	870	"2008"
Softwood forests	12.32	12.55	12.57	13.12	12.98
Hybrid poplar plantations	65.11	65.09	65.34	65.38	65.08
Ruderal and semi-ruderal riverine communities	1.79	1.82	1.66	1.74	2.89
Wetlands	7.85	7.86	9.16	9.25	3.76
Hardwood forest	2.98	2.86	2.61	1.90	2.02



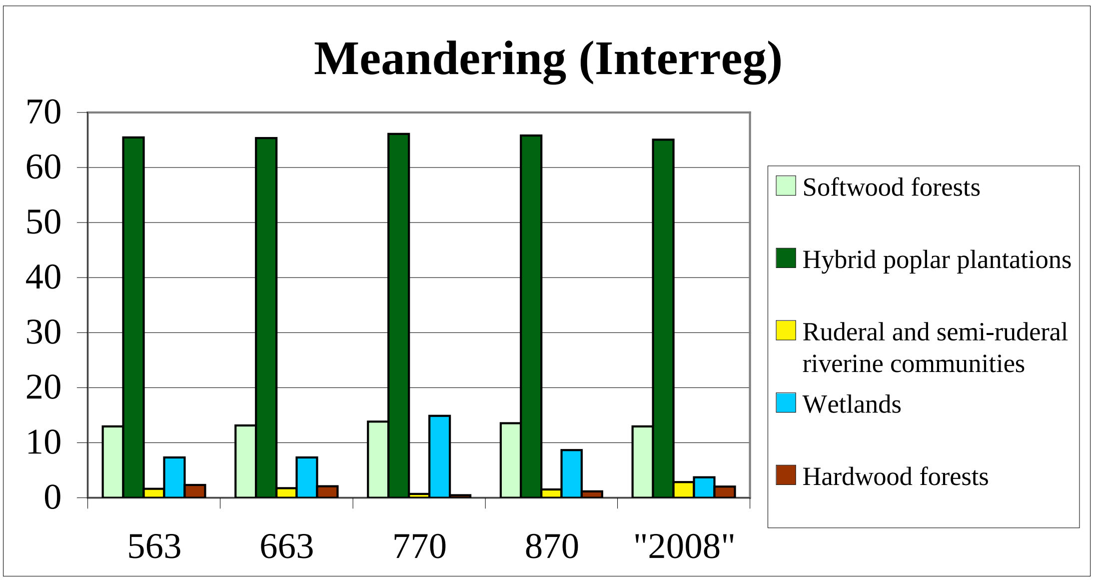
The following observations are made with regard to the SZITE variant:

– the area of softwood forests increases at a flow rate of 870 m^3/s (favourable) and it decreases in the case of other flow rates (unfavourable)
– the area of hybrid poplar forests increases regardless of the flow rate (favourable), the change is *negligible* at 563 and 663 m^3/s
– the area of floodplain ruderal and semi-ruderal communities diminishes regardless of the flow rate (unfavourable)
– the wetland area *significantly* increases regardless of the flow rate (favourable)
– the area of hardwood forests decreases at a flow rate of 870 m^3/s (favourable) and it increases in the case of other flow rates (unfavourable)

MEANDERING INTERREG



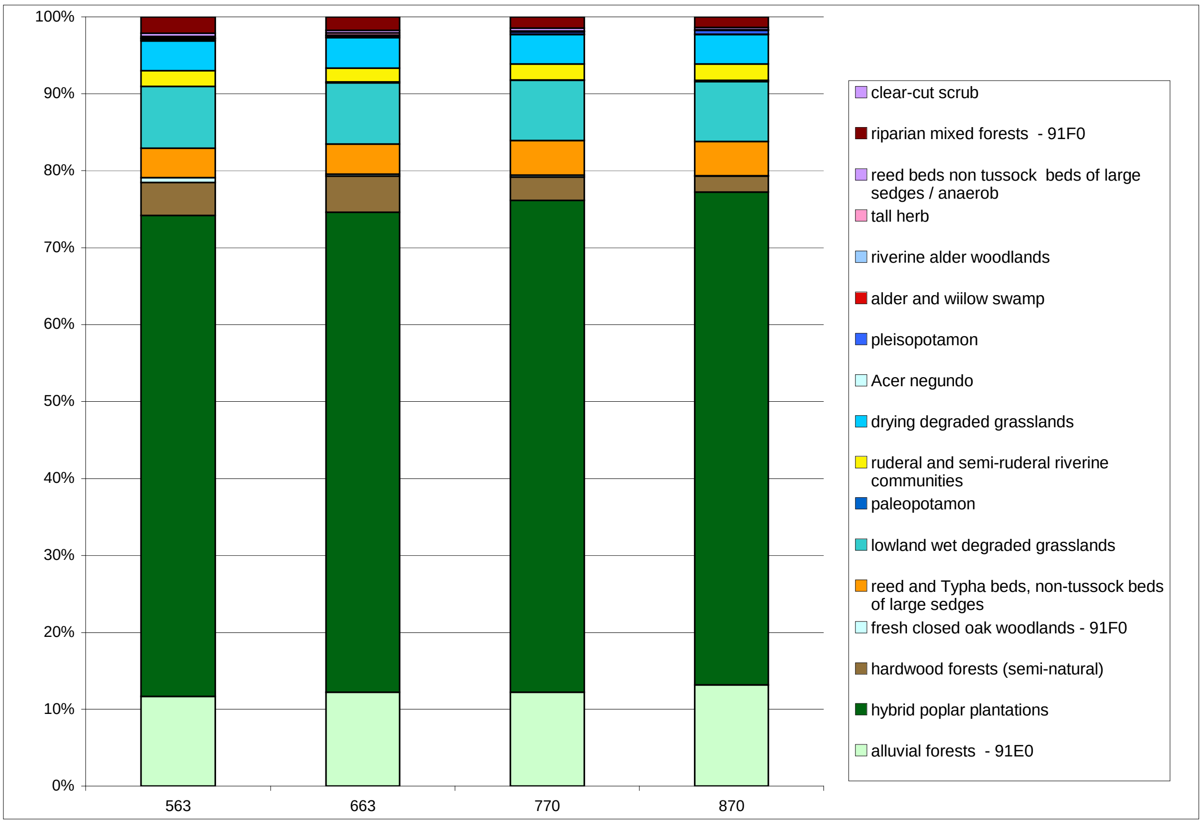
MEANDERING INTERREG (%)	563	663	770	870	"2008"
Softwood forests	12.95	13.18	13.83	13.49	12.98
Hybrid poplar plantations	65.39	65.37	66.09	65.82	65.08
Ruderal and semi-ruderal riverine communities	1.63	1.67	0.70	1.54	2.89
Wetlands	7.37	7.37	14.87	8.66	3.76
Hardwood forests	2.31	2.10	0.44	1.11	2.02



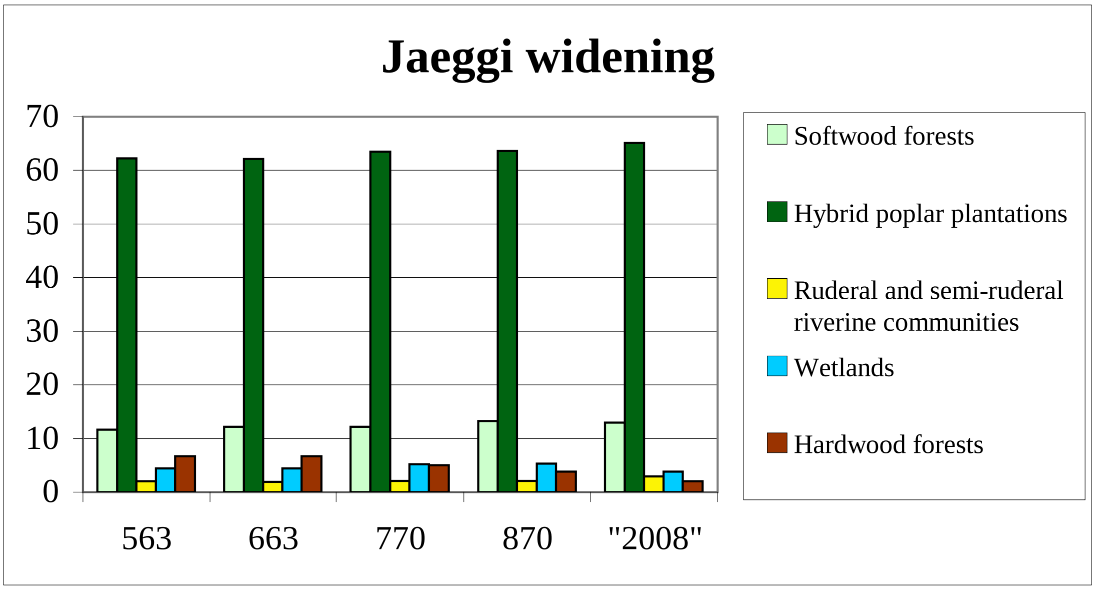
The following observations are made with regard to the MEANDERING variant:

- the area of softwood forests decreases at a flow rate of 563 m^3/s (unfavourable), but the change is *marginal*, and it increases in the case of other flow rates (favourable)
- the area of hybrid poplar forests increases regardless of the flow rate (favourable)
- the area of floodplain ruderal and semi-ruderal communities diminishes regardless of the flow rate (unfavourable)
- the wetland area increases *significantly* regardless of the flow rate (favourable), at a flow rate of 770 m^3/s the increase is outstanding
- the area of hardwood forests increases at flow rates of 770 and 870 m^3/s (unfavourable), at flow rates of 563 and in particular at 663 m^3/s it decreases (favourable)

WIDENING (JAEGGI)



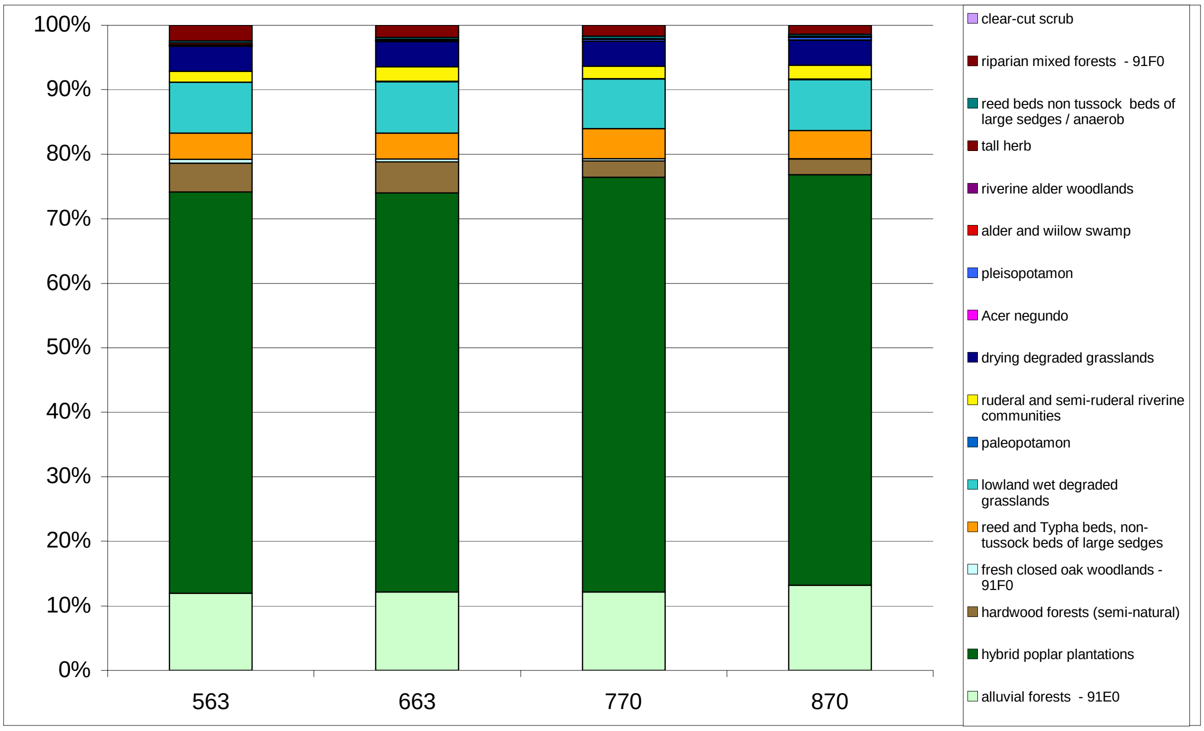
Widning (Jaeggi) (%)	563	663	770	870	"2008"
Softwood forests	11.67	12.14	12.14	13.20	12.98
Hybrid poplar plantations	62.25	62.14	63.53	63.65	65.08
Ruderal and semi-ruderal riverine communities	1.95	1.93	2.07	2.11	2.89
Wetlands	4.35	4.35	5.13	5.27	3.76
Hardwood forests	6.63	6.70	4.93	3.80	2.02



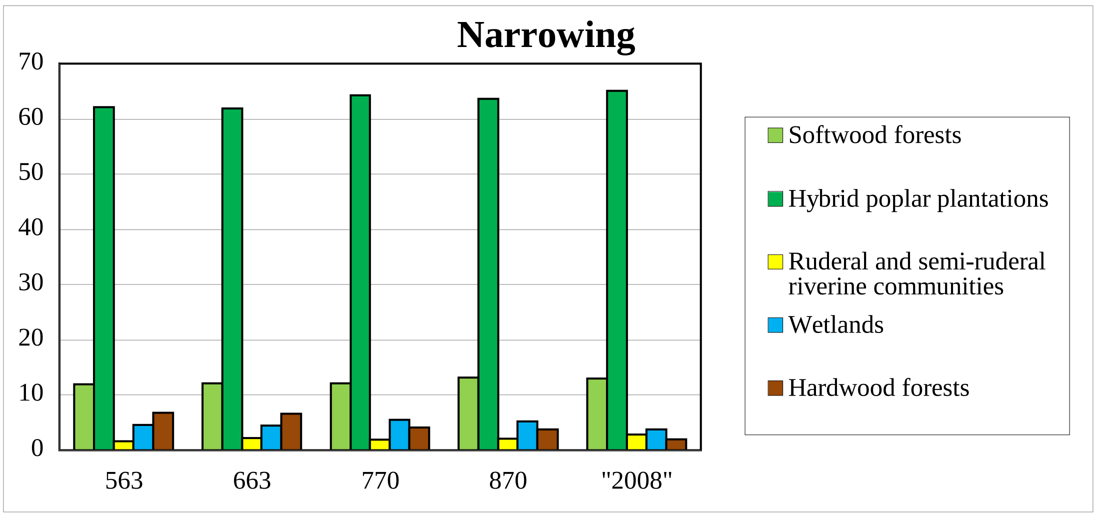
The following observations are made with regard to the widening Jaeggi variant:

- the area of softwood forests grows when the rate of flow is 870 m^3/s (favourable), and it decreases in the case of other flow rates (unfavourable)
- the area of hybrid poplar forests decreases regardless of the flow rate (unfavourable)
- the area of floodplain ruderal and semi-ruderal communities diminishes regardless of the flow rate (unfavourable)
- the wetland area increases regardless of the flow rate (favourable)
- the area of hardwood forests *significantly* increases regardless of the flow rate (unfavourable)

NARROWING (SIDE-ARMS CLOSED)



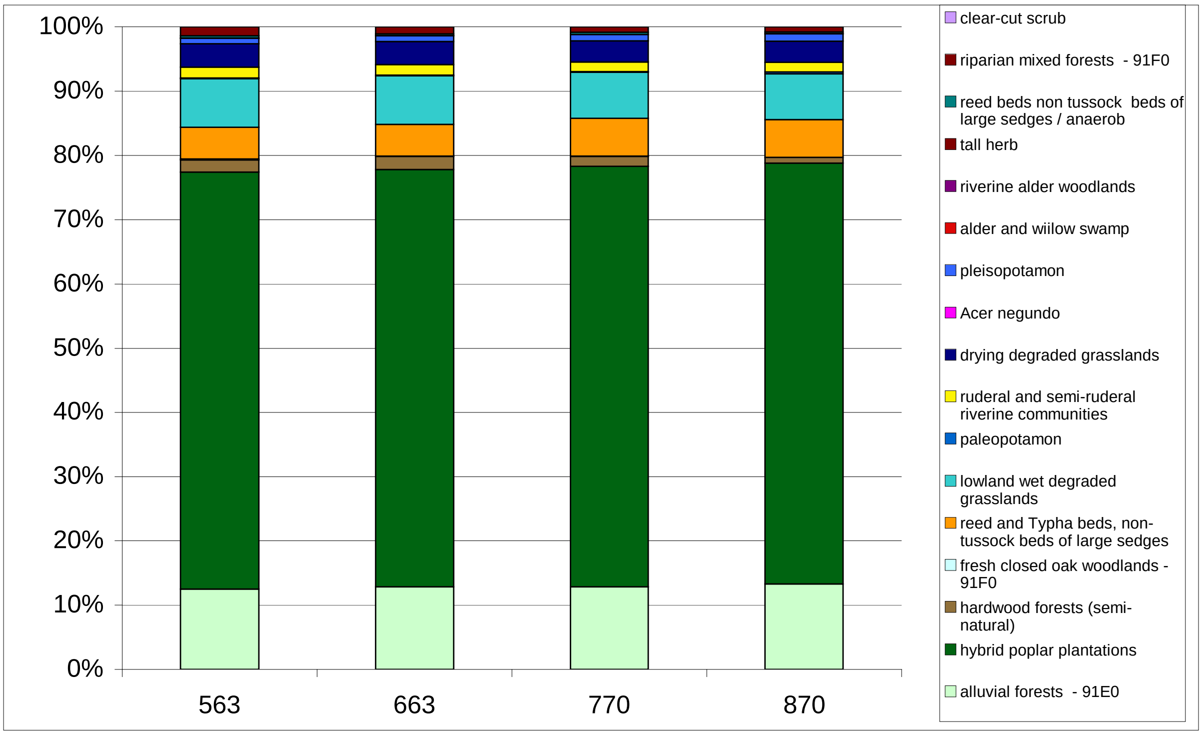
NARROWING (SIDE-ARMS CLOSED) (%)	563	663	770	870	"2008"
Softwood forests	11,96	12,15	12,12	13,19	12,98
Hybrid poplar plantations	62,23	61,90	64,33	63,64	65,08
Ruderal and semi-ruderal riverine communities	1,69	2,24	1,97	2,12	2,89
Wetlands	4,59	4,54	5,50	5,26	3,76
Hardwood forests	6,77	6,61	4,18	3,81	2,02



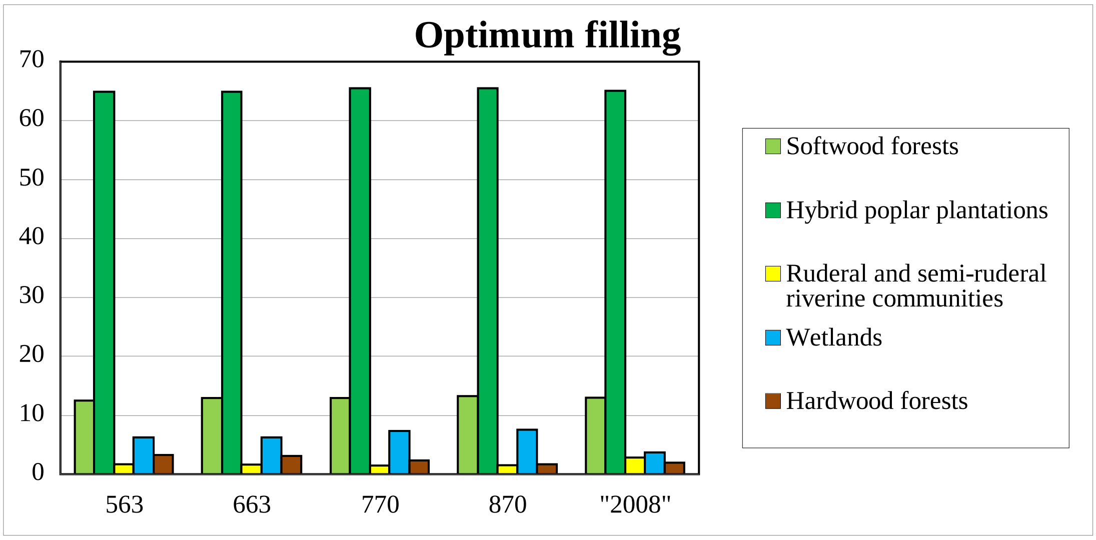
The following observations are made with regard to the Narrowing, side-arms closed variant:

- the area of softwood forests increases at a water discharge of 870 m^3/s exclusively (favourable), otherwise decreases (unfavourable)
- the land covered by hybrid poplar plantations decreases at any water discharge (unfavourable)
- the area covered by ruderal and semi-ruderal floodplain associations declines for each water discharge level (unfavourable)
- wetland habitats expand at each water discharge level (favourable)
- the area of hardwood forests significantly increases (unfavourable)

OPTIMUM FILLING



OPTIMUM FILLING (%)	563	663	770	870	"2008"
Softwood forests	12,47	12,88	12,88	13,29	12,98
Hybrid poplar plantations	64,91	64,89	65,47	65,51	65,08
Ruderal and semi-ruderal riverine communities	1,71	1,63	1,49	1,53	2,89
Wetlands	6,23	6,24	7,35	7,53	3,76
Hardwood forests	3,33	3,10	2,32	1,70	2,02



The following observations are made with regard to the OPTIMUM FILLING variant:

- the area of softwood forests slightly increases at a water discharge of 870 m^3/s only (favourable), otherwise moderately decreases (unfavourable)
- the area of hybrid poplar plantations increases at 770 and 870 m^3/s water discharge (favourable), while decreases at lower water discharges (unfavourable)
- the area covered by ruderal and semi-ruderal floodplain associations declines for each water discharge level (unfavourable)
- wetland habitats expand at each water discharge level (favourable)
- the area of hardwood forests becomes smaller at 870 m^3/s water discharge (favourable), but at smaller water discharges it increases (unfavourable)

9. Preliminary evaluation of rehabilitation measures

by Klaus Kern & Fritz Schiemer

9.1. Introductory remarks

Comprehensive river regulation in the Szigetköz reach of the Danube dates back to the late 19th century. Creating a single main channel in the former inland delta prevented the evolution of new river courses on the large alluvial plain as well as channel forming processes in the braided or anabranching pattern. This major intervention had fundamental consequences for the fluvial ecosystem and landscape development. In addition land use and the construction of dams in the alpine catchment area as well as river training measures and dredging interfered with the natural processes of erosion and sedimentation with severe consequences for habitats, riverbed stability and flood security.

The most recent intervention was the damming and diversion of 80-90% of the discharge for energy production at the hydropower plant at Gabcikovo and subsequent mitigation measures for the preservation of the floodplain ecosystem.

Compared to pre-dam conditions the most important pressures on the floodplain ecosystem in the Szigetköz reach of the Danube are:

- Residual flow of 400 m^3/s (agreed annual average) with a consequent lowering of water levels in the Danube by 2-3 m
- Disconnection of the main channel and side branches
- Reduction of bedload to nearly zero after the diversion of the river in October 1992
- Incompetent flood flows in terms of (erosive) morphodynamic processes and duration
- Insufficient floodplain inundation in terms of frequency and duration
- Degradation of aquatic habitats, transition zones and floodplain habitats due to loss of hydro- and morphodynamic processes
- Riverbed incision downstream and upstream of the confluence with the tailrace canal

It is well understood that rehabilitation measures cannot restore the natural system. In accordance with the Water Framework Directive, however, any rehabilitation effort which can be reconciled with existing water uses must be taken to revive ecological functions.

The complexity of the system and given constraints present a real challenge for rehabilitation. Simple solutions like raising water levels in the main channel may not be able to restore vital ecological functions supporting essential floodplain habitats and inherent biota. A combination of measures and evolutionary processes may be required for the long-term sustainable development of the fluvial ecosystem taking into consideration upstream and downstream reaches as well.

Any solution requires a joint effort with contributions from both bordering states. The results from simulations and the expert assessment of habitat quality represent a data base for future discussions and planning procedures in a common panel with Hungarian and Slovak experts and stakeholders. For this reason the evaluation of variants and the appraisal of studies and expert judgements must not result in final assessments and conclusions. More important than establishing a ranking list is to analyze the success and failure of restoration measures in terms of rehabilitating ecological functions identified in benchmarking parameter systems (Chapter 7).

9.2. Review of variants and data base for evaluation

Variant selection

The results of the hydrodynamic models presented in Chapter 8 have to be critically reviewed taking into account the underlying assumptions of the models and the boundary conditions of the variants.

The SZITE variant was the only proposal that had already reached the stage of a pre-planned project including detailed measures for the improvement of flood protection. All other variants consisted of conceptual ideas without technical data for changes of channel pattern, filling or widening of the cross-section, the installation of new structures or removal of others. Since the necessary steps of field data collection and planning had to be omitted these variants were implemented in the models by applying simplified geometric data for channel changes, simple installing or removal of structures and associated assumptions of roughness, transmissivity etc. This means that arbitrary decisions were taken in terms of raising of bed levels or channel narrowing.

Several modifications of variants were proposed after the first results of modelling. The removal of side-arm closures at too low water levels, for instance, would lead to a depletion of the branch system; subsequently side-arm closures had to be re-introduced for those runs. One variant envisaged raising bed levels with bank material by schematic channel widening at 1:60 bank slope angles. Obviously this procedure would result in a broad devastation of riparian forest without providing suitable bed material. It was replaced by a variant which focuses on long-term lateral erosion processes with eventual raising of bed levels depending on competent flood flows of sufficiently long duration and the composition of bank material. In this case riparian forests would also be affected but in a gradual adaptation process of bed evolution resulting in new habitat conditions.

The selection of variants included measures with

- riverbed lifting or narrowing (unspecified external source of material)
- riverbed widening + lifting (using bank material)
- raising water levels by impounding (1+3 weirs or 1+7 weirs plus meandering floodplain channel)

These variants covered the most important proposals presented by different authors or institutions. According to the assigned task rehabilitation measures concentrated on the common border reach of the Danube. Ensuring the longitudinal migration of fish may require additional measures on Slovak territory.

Data base

Topographical information was more recent and more detailed on the Hungarian floodplain than on the Slovak side. For further studies an up-date of cross-section measurements and the use of recent DEM data are recommended. While bed material samples provided a good insight into the grain-size distribution of bed sediment, insufficient information was available on the composition of bank materials.

Model discharges

Most of the model runs were carried out with a fixed discharge. In order to assess the performance at a particular flow regime, a series of different discharges and discharge distributions between the main channel and the (Hungarian) side-branch system was investigated in the model runs (Chapter 8.2.5). The impact of the present flow regime on future measures has to be assessed by comparing indicative parameters with model results of the present system. In a similar way potential changes of the flow regime will have to be evaluated.

9.3. Evaluation method

The evaluation of variants is based on criteria outlined in Chapter 7. In the following chapter the performance of each variant in terms of hydrodynamics, morphodynamics, lateral and longitudinal connectivity etc. will be discussed. The impact of an altered flow regime is another important aspect to be addressed with each variant.

Since the variants were not fully planned at this stage they are open to modifications in future planning phases. This is another fact that needs to be considered in the assessment. Nevertheless the modelling results allow the outlining of similarities, differences and tendencies with regard to supporting ecological functions.

For each field of assessment the functioning of the natural system before major human intervention will be characterized. In some cases parameters of the 1950s will be used for comparison with present conditions. This is before the period of intensive gravel dredging which destabilized the riverbed. It is well understood, however, that rehabilitation measures have to take into account present river uses according to WFD article 4.3. as well as the legal obligations of the Judgement. Therefore, the description of reference conditions indicates rather the direction of change than the final parameter value pursued.

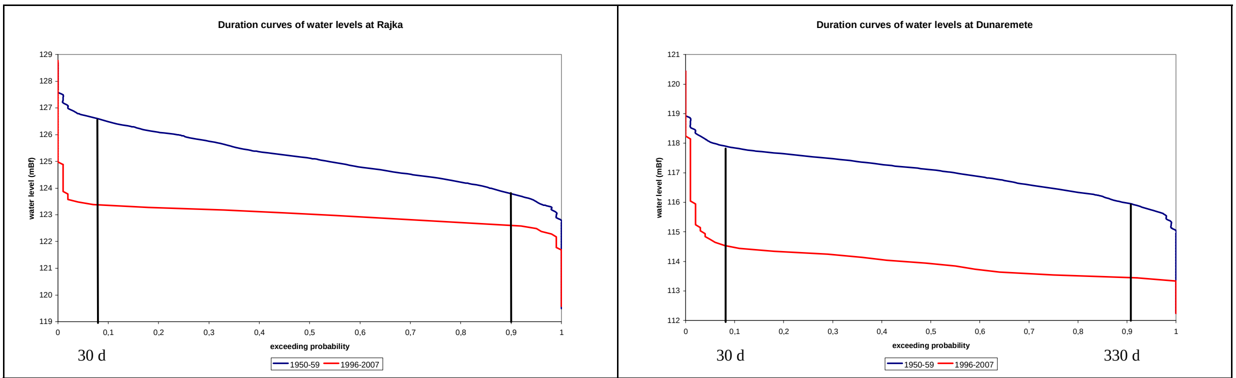
The evaluation of hydrodynamics and morphodynamics will refer to reference conditions in the full knowledge that the natural system cannot be re-established. The appraisal will be based on the degree of improvement focusing on tendencies rather than on absolute values:

--	considerably worse than present status
-	status insufficient
-+	status far from reference conditions but still acceptable
+	improvement of status, acceptable, but still far from reference conditions
++	considerable improvement or acceptable status compared to reference conditions
0	no change with increase of discharges

9.4. Assessment of habitat conditions

9.4.1. Surface water level dynamics and connectivity

Seasonal surface water level fluctuations are a key element for floodplain habitat conditions. They govern the spatial extent of transition zones between aquatic and terrestrial habitats representing the most productive landscape element in floodplains. In natural systems surface water level fluctuation also determine the rise and fall of groundwater levels ruling over the composition of floodplain vegetation. Water level fluctuations are characterized by extremes of drought and flood but more important may be the prevailing seasonal changes in water level which may be represented by water levels exceeding 30 days and 330 days per year on average.



Water level difference 30 day$_{exceeding}$ minus 330 day$_{exceeding}$	Rajka gauge	Dunaremete gauge
Reference period 1950 - 1959	2.4 m	1.9 m
Period 1996 – 2007 (after construction of the weir at rkm 1843)	0.8 m	1.1 m

Figure 9-1 Average duration curves of water levels at Danube gauges Rajka and Dunaremete from 1950-1959 and from 1996-2007; comparison of water level differences

Present situation compared to reference conditions

Figure 9-1 shows water level duration curves of the river gauges at Rajka (rkm 1848,4) and Dunaremete (rkm 1825,5). The period of the 1950s may serve as a reference period before further degradation of the riverbed occurred due to reduced bed load transport caused by upstream dams and intensive gravel mining. At that time many side arms were still connected at least with the downstream end.

At the Rajka gauge the difference between water levels exceeded on 30 and 330 days decreased from 2.4 m to 0.8 m. This pronounced difference is not only caused by the diversion of the Danube but also by the construction of the bottom sill at Dunakiliti in 1995 which impounds the upstream section of the Danube. At Dunaremete which is just not influenced by the backwater effect of the tailrace canal the same indicator is 1.9 m (reference) and 1.1 m (present situation).

Table 9-1 Discharges related to 30 d and 330 d exceeded water levels at Dunaremete gauge

W-Q-relation Dunaremete	30 d exceeding		330 d exceeding	
	W (m)	Q (m^3/s)	W (m)	Q (m^3/s)
1950 - 1959	117.9	3380	116.0	1080
1996 - 2007	114.6	570	113.5	230

The reference discharges related to the given water levels amounted to 1080 m^3/s (330 days exceeding) and 3380 m^3/s (30 days exceeding). After the implementation of Gabčíkovo these values dropped to 570 and 230 m^3/s respectively. The corresponding discharges in the model runs could be selected to 550/80 m^3/s and 200/40 m^3/s.

Variants compared to present conditions (main channel)

Raising water levels by impounding produces considerably smaller water level differences in the first and second impoundment of the SZITE variant. In the lower section, however, the range of fluctuations is even increased with the SZITE variant. This hydraulic paradox is caused by the governing backwater effect of the tailrace canal in the lower third of the project reach.

Table 9-2 Water level difference Δh (m) between 200/40 and 550/80 m^3/s for the Present state and variants in the main Danube channel

Location Danube	**Present**	**SZITE*)**	**Narrowing** (with clos.)	**Opt.Filling**)	**Widening**	**Meander** (INTERR.)	**Meander** (400)
Discharges	**550/80-200/40**	**550/80-200/40**	**550/80-200/40**	**550/80-200/40**	**750/80-350/40**	**550/80-200/40**	**50/400-50/100**
1842,1	1.14	0.42	1.15	0.91	0.76	0.81	0.97
1838,6	1.04	0.38	1.03	0.72	0.69	0.80	0.97
1834,6	1.23	0.32	1.21	0.73	0.69	0.95	1.11
1834,1	1.27	0.59	1.20	0.75	0.73	0.95	1.11
1830,6	1.26	0.48	1.17	0.71	0.72	0.91	1.17
1826,6	0.92	0.40	0.93	0.59	0.61	0.85	1.11
1826,1	0.88	0.98	0.89	0.59	0.54	0.84	1.11
1820,6	0.64	0.81	0.64	0.68	0.63	0.83	1.27
1815,2	0.46	0.75	0.46	0.46	0.50	0.95	1.41

*) Weirs at rkm 1834,15/1826,2/1814,9

**) For technical reasons the Widening variant was not calculated with 200/40 m^3/s

The way it was constructed the **Narrowing** variant turned out to have very little effect on water levels. Therefore, the water level fluctuations more or less correspond to the present situation. Filling up the riverbed to the **Optimum** level for lateral connectivity would reduce water level fluctuations by 30-40% which can be explained by the "smoothened" channel geometry. A similar effect is observed with the **Widening** of the channel. Quite surprising is the impact of constructing more weirs in the Danube as envisaged in the **Meander** variants: only a slight reduction in the range of water level fluctuations is observed in the upper and central reach. In the lower project reach, again, the fluctuations increase above the present level. The more pronounced fluctuations of the Meander (400) version are explained by high water level fluctuations in the meander branch which is imposed on the Danube channel at the crossings.

Variants compared to present conditions (side branches)

Before October 1992, the water level dynamics in the side branches depended on the natural flow regime of the Danube and the conveyance capacity of the main channel. Since 1992 the flow dynamics of the secondary branch system has depended on the discharge provided at Čunovo Dam and the water supply conditions. Nowdays the supply of the system is based on the available amount of water, in a dynamism following the natural flow regime of Danube. In 1995, the construction of the bottom sill at Dunakiliti and the closure of all side-arm connections enabled the water supply of the Hungarian side branch system even at very low flows in the main channel. With the operation of the gates at Dunakiliti the amount of water supplied to the branch system can be controlled within certain limits.

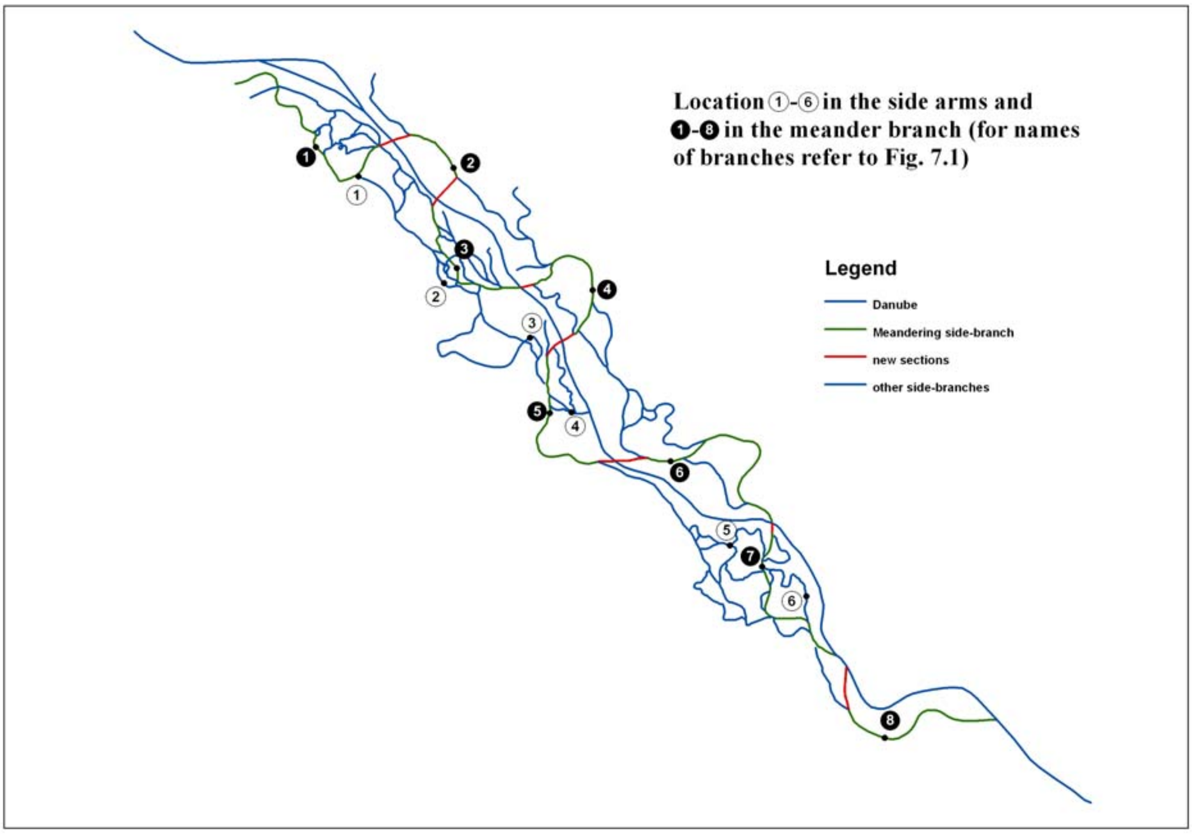


Figure 9-2 Location of calculated water level differences in the side arms and in the meander branch

Table 9-3 Water level differences Δh (m) between 200/40 and 550/120 m³/s in the Hungarian side-arm system

Profile	**Side branch**	**Present**	**SZITE**	**Narrowing** (with clos.)	**Opt.Filling** *)	**Widening**	**Meander** (INTERREG)
6381	① Right main branch	0.79	0.80	0.79	0.81	0.80	0.87
11044	② Right main branch	0.82	0.70	0.82	0.82	0.82	0.92
18487	③ Right main branch	0.76	0.53	0.76	0.81	0.76	1.18
662	④ Tabori branch	0.69	0.41	0.69	0.72	0.69	1.55
1670	⑤ Ujszigeti branch	0.69	0.52	0.68	0.98	0.70	1.58
2700	⑥ Gatyai Duna	0.14	0.83	0.14	0.21	0.12	0.95

*) Values for Widening calculated with 350/40 m³/s instead of 200/40 m³/s

Figure 9-2 shows locations ①-⑥ where water stages were calculated to demonstrate the surface water level fluctuations in the Hungarian side-arm system. Table 9-3 shows the water level differences for the Present state and variants between a flow of 200 + 40 m³/s (main channel + side-arm system) and 550 + 120 m³/s. The present situation shows 70 – 80 cm water level fluctuations except for the lowest location influenced by the backwater effect.

The two variants Narrowing and Widening, that did not allow the opening of side-arm closures, do not deviate from the Present state which was expected. Filling the bed to a level allowing side-arm connection (Optimum Filling) increases the range of water level fluctuations by about 30% in the lower project reach. The SZITE variant which allows re-connection of a part of the side arms shows heterogeneous results: nearly maintaining the range of fluctuations in the upper part, lowering by 30% in the middle section and a sharp increase at the lower end. The highest fluctuations are obtained for the Meander (INTERREG) variant; they may be overestimated to a certain degree since overflowing banks cannot be simulated by the 1D-model so that the cross-sections are assumed to be bounded by vertical walls at the banks.

Table 9-4 Water level differences Δh (m) in the meander branches

Location meander branch	Meander (INTERREG)	Meander (400)
Discharges	**550/120 - 200/40**	**50/400 – 50/100**
4400 ❶Szigeti	0.92	1.39
2420 ❷Vojka	0.87	1.10
2525 ❸Gorbe	0.88	1.09
3530 ❹Sulany	1.00	1.22
2520 ❺Agg	1.52	1.18
1780 ❻Bakai	0.97	1.23
1460 ❼Asvani	1.14	1.13
2900 ❽Bagameri	0.76	0.88

The meander branch is a free flowing river channel on the floodplain crossing the Danube at weir intersections. In the case of the INTERREG version only the drop structures were removed from the branches integrated into the concept and some connecting channels were installed. For the Meander (400) version, however, all side arms used for the meander branch were enlarged to 150-200 m of width for a conveyance capacity of about 400 m³/s (ref. Figure 8-9). In this version the water level difference between 100 and 400 m³/s flowing in the branch was calculated. Table 9-4 shows similar results for the water level fluctuations in the meander channel for both Meander versions. The range of fluctuations is considerably higher than in the Present stage in the side arms (as seen in Table 9-3).

Raising water levels – lateral connectivity

Both variants, Narrowing and Widening, fail to raise water levels at the given flow regime to allow the reconnection of side arms. The Narrowing variant is an interpretation of the WWF proposal (1994, 1997) which included a request for about 2/3 of the natural discharge. Filling up the vegetated point bars (covering about 1/3 of the riverbed) by 2 m had no effect on the water levels at flows of up to 750 m³/s. Subsequently 2800-3000 m³/s, i.e. 25-30% above the mean flow, would be needed to re-establish full connectivity which is the same as in the present condition. Even if the entire riverbed were to be raised by about 2 m water levels at prevailing flows would only rise by 1.0-1.3 m.[32]

The variant "Optimum Filling" was selected to explore the amount of material necessary to re-establish side-arm connectivity at the given flow regime. 16 million m³ of bed material would be needed to reach the level of the side arms at the present flow regime. Any solution involving a lower levbočných ramenáchel of bed filling would have to increase discharges to an adequate level.

The raising of bed levels by lateral erosion (Widening) was investigated under basic assumptions which need more exploration in future investigations. From the results it can be

[32] These results were obtained in model runs which used bank material for raising the deepest part of the bed by 2 m on average.

concluded that long-term raising of bed levels can be expected by processes of lateral erosion and bed load transport. The evolution of the riverbed profile depends on the composition of bank materials and on competent flood flows. It is obvious that additional measures, e.g. additional supply of bed material and more frequent and higher discharges by reducing water diversion during flood periods (Chapter 9.4.7) would be needed to accelerate the raising of the river bed. But even in this case the target of lateral connectivity with the existing side-branch system could not be achieved. The long-term objective of the Widening variant, however, would be rather to initiate natural lateral erosion processes with the gradual evolution of a new river-floodplain-system with terraces formed by the present floodplain and a recent floodplain on a lower level. For this reason the Widening variant represents a special option which has to be considered accordingly.

The SZITE variant as well as the Meander variants (INTERREG and Meander (400) versions) raise water levels to a similar extent. The SZITE variant provides connectivity to some of the side branches and connects the Bagomér branch to the upstream system. The Meander (INTERREG) variant was modified during the investigation and all weirs and drop structures in the side-arm system were removed. Consequently a free migratory corridor would exist along the impounded main channel. Details, e.g. connectivity with other side branches and controlling crest heights and components of dams in the main channel, are the subject of further steps in planning. The Meander (400) version also provides a migratory corridor along the main channel; connectivity with other branches could be provided implementing appropriate structures.

Impact of increase of discharges on range of water levels

The effect of increased discharges from 550/80 to 750/120 m³/s on the range of water level fluctuations is tested for the present state and most variants (Table 9-5).

Table 9-5 Water level ranges between 200/40 and 750/120 m³/s [incr.] at selected cross-sections compared to 200/40 and 550/80 m³/s (550/120 m³/s for branches) [pres.]

Location	Present		SZITE		Narrowing (with clos.)		Opt.Filling		Widening*)		Meander (INTERREG)	
	pres.	incr.	pres.	incr.	pres.	incr.	pres.	incr.	pres.	incr.	pres.	incr.
1838,6 Danube	1.04	1.50	0.38	0.64	1.03	1.49	0.72	1.04	0.69	0.69	0.80	1.19
1830,6 Danube	1.26	1.81	0.48	0.80	1.17	1.69	0.71	1.04	0.72	0.75	0.91	1.37
1820,6 Danube	0.64	1.01	0.81	1.24	0.64	1.01	0.68	1.00	0.63	0.67	0.83	1.26
6381 ① Jobb foag (branches)	0.79	0.79	0.80	0.80	0.79	0.79	0.81	1.05	0.80	0.80	0.87	1.19
11044 ② Jobb foag (branches	0.82	0.82	0.70	0.78	0.82	0.82	0.82	1.10	0.82	0.82	0.92	1.32
662 ④ Tabori ag (branches)	0.69	0.69	0.41	0.48	0.69	0.69	0.72	0.98	0.69	0.69	1.53	2.04
2700 ⑥ Gatyai Duna (branch.)	0.14	0.33	0.83	1.16	0.14	0.33	0.21	0.40	0.12	0.29	0.95	1.36

*) Values for Widening calculated with 350/40 m³/s instead of 200/40 m³/s and 750/80 m³/s instead of 550/80 m³/s

In the Present state an increase of the seasonal flow peaks from 550 to 750 m³/s would improve the water level fluctuations in the main branch by about 50% but do not reach reference values; the branches would not profit from the change. This is similar for the Narrowing variant. No effect is noted for the Widening variant. The SZITE would profit in the main channel, but not in the branches except at the lower end. The increased range of fluctuations in the main channel would, however, still remain far below the present values in the upper and middle section of the project. The increase of discharges would again improve the range of water level fluctuations for the Meander (INTERREG) variant in both, the main channel and the side branches. Since the Meander (400) variant pursues a different concept it was not included in the investigation.

Preliminary conclusions on surface water level dynamics and connectivity

Compared to reference conditions of the 1950s none of the variants would improve reduced water level fluctuation of the present situation in the main channel; three variants would even deteriorate the seasonal range of rise and fall of water levels (Table 9-6). In the branches there is not much difference between most variants and the present situation, except both Meander variants which improve the seasonal variation on most of the project reach.

Field of assessment	**Present**	**SZITE**	**Narrowing** (with clos.)	**Opt.Filling**	**Widening**	**Meander** (INTERREG)	**Meander** (400)
Water level dynamics: Danube	-	--	-	--	--	-	-
Water level dynamics: Branches	-	-	-	-	-	++	++
Improvement of water level dynamics with higher flows **(Danube / branches)**	+ / **0**	+ / +	+ / **0**	+ / +	**0 / 0**	+ / ++	not relevant
Lateral connectivity	-	+	-	+	-	+	+
Longitudinal connectivity*)	+	-+	+	+	+	**(-)**	**(-)**

*) Not including the missing fish path at the Cunovo weir

Increased summer flows from 550 to 750 m³/s would improve the situation for most variants, especially in the main Danube channel. The Meander (INT.) variant would profit considerably in both the main channel and the side branches; the Optimum Filling variant as well to a smaller extent. Since the Meander (400) version pursues a different concept the increase of flows is not relevant.

The Present state and the Narrowing variant do not allow lateral connectivity. The Widening variant could - in a perspective of several decades - develop a secondary floodplain with side branches on a lower level allowing lateral connection. Lateral connectivity is provided with the SZITE variant, the Optimum Filling variant and both Meander variants although control structures are still required in the remaining branches.

The present riverbed and all variants without weirs provide free migration for fish although the bottom sill at Dunakiliti presents an obstacle for some species. The Meander variants provide a free migration corridor in the meander channel on the floodplain level. It does, however, prevent migration for those fish that try to use the impounded Danube main channel. The SZITE variant implements new weirs in the Danube and in the branches which – compared to a free flowing section – represent migration obstacles despite fish paths or similar measures. For full rehabilitation all options would need the construction of a fish path at the Čunovo Barrage on Slovak territory.

9.4.2. Flow velocities

The variability of flow velocities over space and time is a key parameter for the composition of the aquatic fauna. Most fish species require a variety of different habitats for suitable spawning grounds, for juvenile life stages and for the adult phase. The natural richness of unregulated rivers provides shallow still water areas near the shore along with deep pools, fast flowing shallow sections of bars and deep central flow corridors with strong currents within a short distance. Grain sorting processes during falling flood stages result in a diverse pattern of substrates from silt to sand and pebbles depending on the general and local gradient. The associated diversity of sediment substrates is characteristic for natural river reaches.

Present situation compared to reference conditions

The historical analysis of landscape elements (Chapter 5.2) demonstrates the extent and diversity of aquatic habitats before regulation.
Figure 9-3 shows the remarkable reduction in total area of water bodies in the 20th century from about 5,000 ha to less than 2,500 ha. With the river regulation at the end of the 19th century there was a sharp reduction of channels receiving permanent flow (eupotamon type, Chapter 2.2.2) since many branches were cut off and turned into parapotamon types of water bodies which did not receive discharge at mean and low flow stages. The disconnection of side branches in the 20th century resulted in a considerable increase of side arms that received flow at the upstream end only at higher flood stages (parapotamon B). Before 1992, only a few branches were left that experienced flowing water even at low flow stages (eupotamon B). With the construction of the Gabcikovo HPP the total area of the main channel decreased due to reduced width at lower discharges. At the same time the former partially disconnected side branches received discharge by mitigation measures on both sides of the Danube turning them into eupotamon B types.

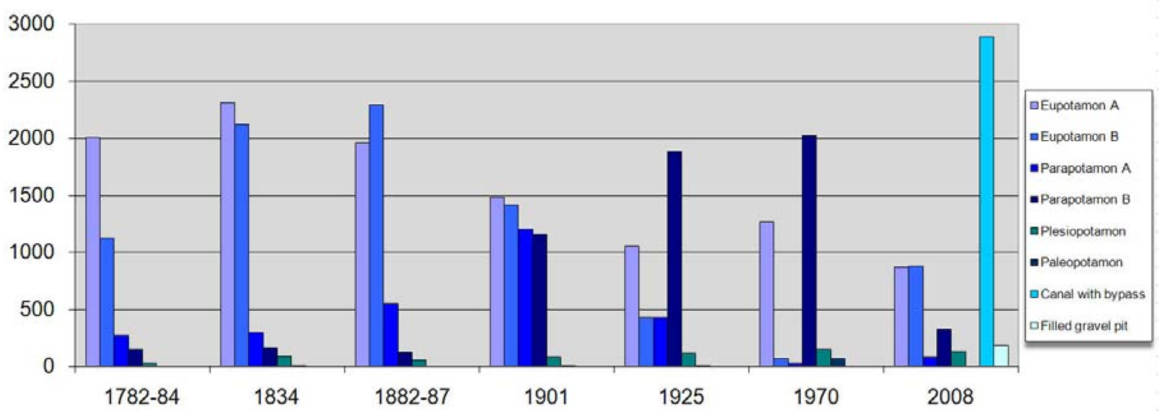


Figure 9-3 Distribution of water body types since the 18th century

What does this mean translated into flow velocities? Eupotamon types of water bodies experience a permanent flow even at times of drought while parapotamon types receive discharge at flow stages overtopping the upstream deposition of sediments at the entrance of the branch. In natural rivers this may even occur at mean flow levels when gravel and sand accumulations blocking the entrance are overspilled (parapotamon A). With growing crest height sediment bars carry woody vegetation and prevent the entrance of water for most of the year (parapotamon B).

For the aquatic fauna prevailing flow conditions with seasonal variations determine habitat conditions. Again, this may be seen within the range of 30 to 330 days of exceedance. Figure 9-4 shows on the left side the distribution of flow velocities in the main channel for 200 to 750 m³/s for the Present state. Even at 200 m³/s none of 104 cross-sections exhibit flow velocities below 0.25 m/s. With increasing discharges there is a clear shift towards flow velocities above 0.5 m/s suitable for rheophilic species. In the Cikola branch system about 85% of 222 cross-sections are characterized by flow velocities below 0.5 m/s at a flow of 80 m³/s in the branches. Compared to the main channel the eupotamon B type represents only a narrow range of suitable flow velocities for rheophilic species.

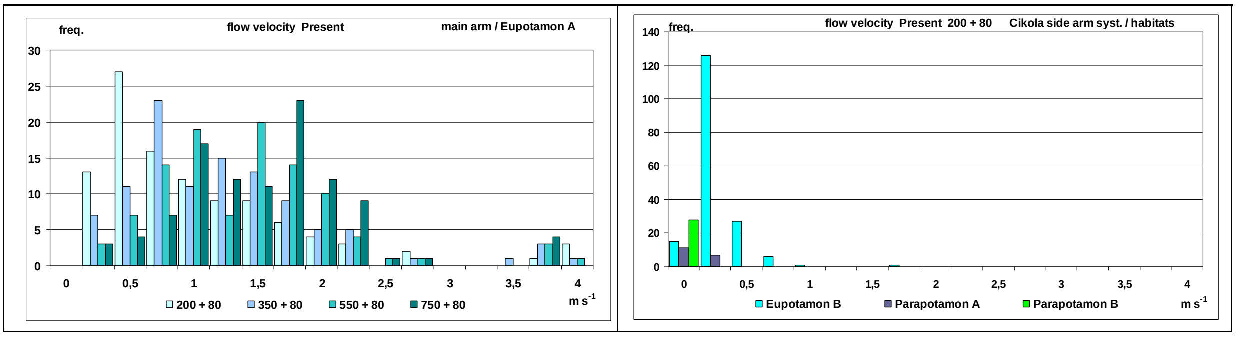


Figure 9-4 Distribution of flow velocities in the main channel (left) and in the Cikola side-arm system[33]

As outlined before, the spatial variability of flow velocities on a local level is a key parameter for aquatic habitats. The occurrence of instream habitats such as gravel bars and large woody

[33] Flow velocities above 3 m/s are attributed to a section of the Danube below the confluence which was included in the analysis.

debris indicates the diversity of flow conditions. Figure 9-5 shows the decline of larger gravel bars from 780 ha in 1782-84 to just 20 ha with only 1 ha of gravel bars in 2008. This total loss of vegetated and non-vegetated bars may be more significant than the absolute loss of total area of water bodies.

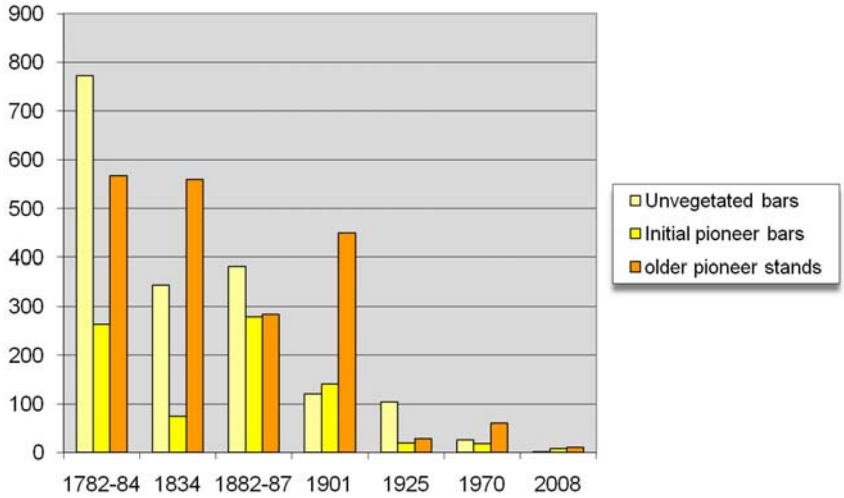


Figure 9-5 Total size of bars and pioneer stands since the 18th century (in ha)

Variants compared to present conditions

Danube: All variants that maintain the free flowing character of the river produce similar flow velocities in the main channel as prevail today (Table 9-10). Even at low-flow conditions cross-sectional mean velocities stay above 0.5 m/s reaching 1.5 m/s at some locations except for the lowest 6 km which slow down to 0.3-0.4 m/s due to the backwater effect of the confluence. The Optimum Filling variant generally equalizes the velocities since the riverbed is raised to the same level. The Widening variant shows a slight decrease of flow velocities at larger flows compared to the Present stage, regarding total averages.

The SZITE variant reduces the cross-sectional mean flow velocities for low flows in the first impoundment below 0.2 m/s, 2/3 of the length of the second impoundment stays below 0.3 m/s; the third impoundment is dominated by currents of 0.3-1 m/s. At 350 m³/s in all reaches the prevailing velocities are between 0.3-0.7 m/s, at 550 m³/s above 0.5 m/s. The total average is based on all profiles above the confluence with the tailrace canal.

The Meander (INTERREG) variant exposes flow velocities below 0.3 m/s for 200 m³/s in the impounded Danube sections and between 0.25 and 0.5 m/s for 550 m³/s which is below the SZITE results. This is also expressed by the averages. The Meander (400) version carries only 50 m³/s into the Danube channel as a residual flow producing nearly stagnant flow conditions in the impoundments. Since the model did not provide discharge in the main channel in the low-flow scenario 50/100, the flow velocities are 0 in Table 9-6. Actually, gates would be needed to provide a residual flow and about 0.1 m/s could be expected in the impounded sections of the main channel.

Table 9-6 **Cross-sectional mean flow velocities in selected locations of the main channel and the branch system for the Present state and for different variants**

Location	Present			SZITE[a)]			Narrowing (with clos.)			Opt.Filling			Widening[b)]			Meander (INTERREG)[c)]				Meander (400)[d)]	
Main channel – average flow velocities in cross-sections (m/s)																					
Discharge (m³/s)	200/40	550/80	750/120	200/40	550/80	750/120	200/40	550/80	750/120	200/40	550/80	750/120	350/40	550/80	750/120	Location	200/40	550/80	750/120	50/100	50/400
1842,1 Danube	0.72	1.39	1.68	0.11	0.68	0.90	0.73	1.38	1.64	--	1.10	1.30	0.92	1.62	1.86	1842,1	0.00	0.29	0.44	0	0
1838,6 Danube	0.57	0.88	1.00	0.19	0.47	0.61	0.66	1.05	1.21	0.64	1.01	1.12	0.86	1.05	1.20	1838,6	0.16	0.37	0.48	0.04	0.03
1834,6 Danube	1.56	1.49	1.59	0.15	0.40	0.53	1.53	1.54	1.66	0.75	1.01	1.13	1.05	1.23	1.38	1834,6	0.11	0.25	0.30	0	0.06
1834,1 Danube	1.61	2.33	2.14	0.52	1.05	1.16	1.55	2.43	2.53	0.78	1.12	1.27	1.49	1.60	1.64	1834,1	0.10	0.23	0.28	0	0.06
1830,6 Danube	0.66	1.17	1.29	0.24	0.62	0.80	0.63	1.09	1.29	0.84	1.23	1.41	0.60	0.80	0.96	1830,6	0.05	0.17	0.20	0	0.05
1826,6 Danube	0.79	1.40	1.64	0.22	0.57	0.73	0.63	1.24	1.52	1.02	1.55	1.78	0.64	0.88	1.09	1826,6	0.27	0.51	0.62	0	0.04
1826,1 Danube	1.08	1.61	1.82	0.91	1.38	1.59	1.05	1.46	1.65	0.95	1.33	1.50	1.67	1.81	2.01	1826,1	0.27	0.48	0.57	0	0.04
1820,6 Danube	0.72	1.42	1.64	0.42	0.85	0.97	0.72	1.41	1.64	0.93	1.25	1.42	0.69	0.92	1.10	1820,6	0.06	0.19	0.26	0.01	0.07
1815,2 Danube	0.41	0.86	1.09	0.22	0.48	0.60	0.41	0.86	1.09	0.41	0.86	1.09	0.39	0.56	0.70	1815,2	0.04	0.39	0.49	0	0.07
Total average	***0.74***	***1.21***	***1.40***	***0.31***	***0.70***	***0.86***	***0.75***	***1.23***	***1.43***	***0.70***	***1.15***	***1.32***	***0.77***	***0.98***	***1.14***		***0.17***	***0.37***	***0.46***	***0.01***	***0.06***
	Side arms – average flow velocities in cross-sections (m/s)															Meander channel – flow velocities (m/s)					
① Jobb foag 6381	0.33	0.38	0.35	0.33	0.38	0.34	0.33	0.40	0.38	0.37	0.42	0.42	0.34	0.36	0.36	❶Szigeti	0.46	0.45	0.52	0.62	1.12
② Jobb foag 11044	0.17	0.28	0.35	0.16	0.24	0.32	0.17	0.26	0.35	0.37	0.56	0.63	0.16	0.26	0.35	❷Vojka	0.30	0.59	0.71	0.50	0.80
③ Jobb foag 18487	0.26	0.38	0.46	0.34	0.47	0.55	0.26	0.38	0.46	0.14	0.34	0.42	0.26	0.38	0.46	❸Gorbe	0.94	1.06	0.96	0.88	1.24
④ Tabori ag 662	-0.01	-0.01	-0.02	0.00	0.00	0.01	0.01	0.01	0.02	0.00	-0.01	-0.02	-0.01	-0.01	-0.02	❹Sulany	0.35	0.52	0.65	0.29	0.56
⑤ Ujszigeti 1670	0.18	0.30	0.35	0.18	0.26	0.31	0.18	0.31	0.38	0.14	0.28	0.35	0.17	0.30	0.35	❺Agg	0.82	1.23	1.34	0.66	1.00
⑥ Gatyai D. 2700	0.31	0.33	0.24	0.10	0.04	0.02	0.31	0.33	0.24	0.27	0.33	0.24	0.31	0.34	0.25	❻Bakai	0.65	0.87	0.98	0.54	1.05
Average Jobb f.	***0.31***	***0.43***	***0.50***	***0.33***	***0.43***	***0.50***	***0.31***	***0.43***	***0.50***	***0.25***	***0.43***	***0.51***	***0.31***	***0.43***	***0.50***	❼Asvani	0.65	0.92	1.00	1.12	1.52
a) Weirs at rkm 1834,15/1826,2/1814,9 b) Values for Widening calculated with 350/40 m³/s instead of 200/40 m³/s																❽Bagom	0.31	0.46	0.52	0.20	0.42
c) The actual discharge distribution changed at every meander reach d) The model did not provide the required discharge in the main channel for the low-flow situation 50/100																***Average***	***0.44***	***0.60***	***0.69***	***0.48***	***0.78***

Side arms: In the Present state the side-arm system experiences flow velocities below 0.3 m/s at 40 m³/s; increasing discharges result in a moderate rise of flow velocities only. None of the variants produce a significant change in flow velocities compared to the present situation. The total average of the main right branch with a length of 35 km is slightly above the values of the selected cross-sections. This result indicates sub-optimal habitat conditions for rheophilic fish species.

Meander branch: For the Meander (INTERREG) version the flow velocities vary from 0.3 to 0.9 m/s for 40 m³/s. At 80 m³/s in the meander branch the velocity rises to 0.45-1.2 m/s, and at 120 m³/s the range of velocities is 0.5-1.3 m/s. Actually the distribution of flows varied according to the capacity of the branches increasing flows up to 220 m³/s in meander branch sections. At 400 m³/s flowing in the branch, the Meander (400) version produces velocities similar to the Present state in the Danube at 200 m³/s (Figure 9-6). At 100 m³/s with an average of 0.48 m/s suitable habitat conditions for rheophilic species still prevail except for the lower end influenced by the backwater effect of the Bagameri arm mouth.

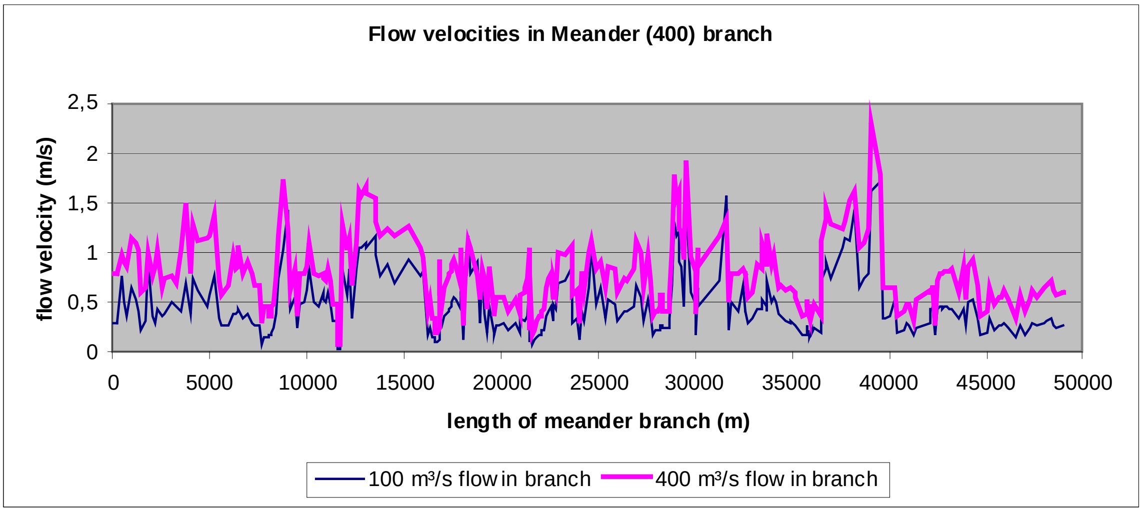


Figure 9-6 Distribution of flow velocities in the Meander (400) branch

Impact of increase of discharges on flow velocities

In the Danube channel only the Meander variants and in the upper and central reach the SZITE reduce flow velocities below a critical threshold for rheophilic fish at low flows. In order to maintain suitable conditions for rheophilic fish minimum seasonal discharges should be raised to about 300 m³/s in the case of the SZITE variant. For the Meander variants the ecological function of the free flowing river are transferred to the meander channel. For the Meander (INTERREG) version the discharge channelled into the meander course should be at least 80 m³/s and vary according to seasons.

To ensure suitable habitat conditions for rheophilic fish in the side arms a seasonal minimum of 80 m³/s should be fed into the branch system in the case of the SZITE variant.

Preliminary conclusions on flow velocities

Except for the SZITE and the Meander variants none of the measures improve or deteriorate flow conditions compared to the present situation. It must be mentioned that the Optimum Filling variant increases flow velocities in the present backwater reach at the lower end. Compared to reference conditions, however, a considerable improvement of aquatic habitat conditions, i.e. instream structures must be accomplished. Any plan for rehabilitation needs to include suitable measures to increase the diversity of aquatic habitats beyond the typology given with the Amoros-Roux-system. The absence of gravel bars is associated with uniform flow conditions leading to a degradation of the aquatic fauna.

The Meander variants increase flow velocities in the meander branch but not quite to the level of the main channel at present conditions. The increase of the discharge would foster rheophilic species in the main channel as well as in the side branches for the Meander (INT.) version.

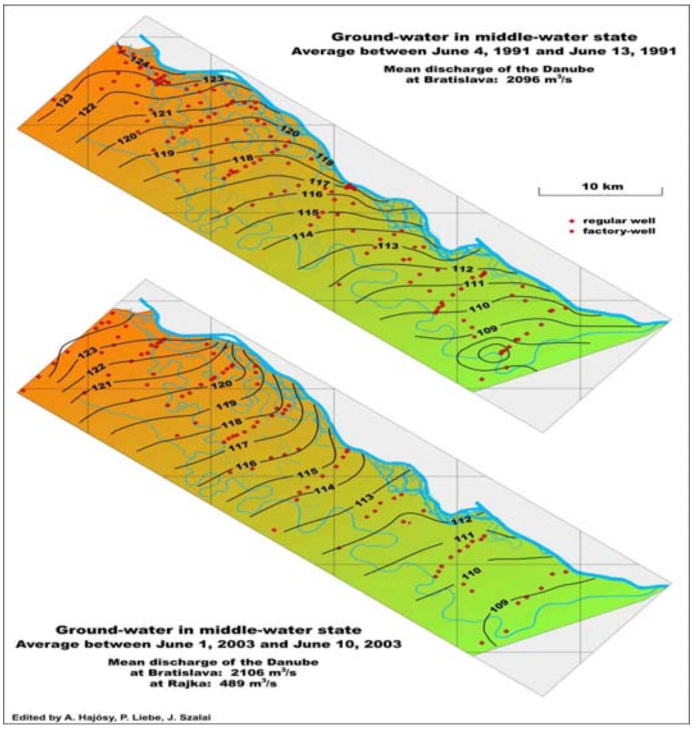
Field of assessment	**Present**	**SZITE**	**Narrowing** (with clos.)	**Opt.Filling**	**Widening**	**Meander** (INTERREG.)	**Meander** (400)
Flow velocities: Danube	**-+**	**-**	**-+**	**-+**	**-+**	**--**	**--**
Flow velocities: Branches	**-**	**-**	**-**	**-**	**-**	**++**	**+**
Improvement of flow velocities with higher flows **(Danube / branches)**	**0** / +	+ / +	**0** /+	**0 / +**	**0 / +**	**(+)** / +	0/+

9.4.3. Groundwater level dynamics

The position and the seasonal variation of the groundwater level together with regular inundations and substrates determine terrestrial habitat conditions in the active floodplain as well as on the protected side. In addition, morphodynamics are an important factor for terrestrial habitat conditions. The continuous settling of alpine sediments resulted in the formation of a large alluvial cone in the Szigetköz with an elevated (“hanging”) bed of the river. Therefore, the groundwater was always fed by the river at average flows.

Present situation compared to reference conditions

This relationship between the river and the groundwater fundamentally changed in 1992 when the average water level of the Danube dropped by 2-3 m and the main channel became a permanent drain (Figure 9-7). At the same time the upstream reservoir was impounded representing a permanent source of infiltration for the upper project area since then. In 1995, the supply of the side branches commenced which had an additional impact on groundwater levels.



(For more details on groundwater flow directions refer to Chapters 2.1.2 and 5.1.3)

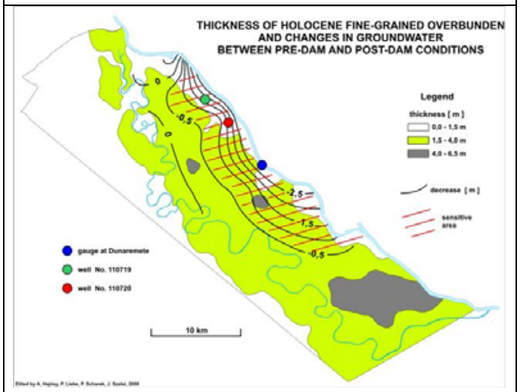


Figure 9-7 Change in the groundwater regime before and after the diversion of the water to Gabcikovo in Oct. 1992

Even before river regulation in the late 19th century the groundwater regime, recharge and dynamics were similar to pre-dam conditions in 1991. The most significant impact is the decrease of groundwater levels in the central project reach between Dunakiliti and Ásványráró mainly affecting the active floodplain and to a smaller degree the protected side. Associated with a drop of groundwater levels is the decrease of groundwater level fluctuations which amounted to 2-3 m in the active floodplain and near the Mosoni Danube to 0.5-1 m.

Variants compared to present conditions

Figure 9-8 shows changes of groundwater levels in the Hungarian floodplain for the SZITE, the Optimum Filling and the Meander variants. The Optimum Filling variant continuously raises groundwater levels along the Danube by up to 2.5 m. The impact is limited to the narrow strip of the channel corridor of the side branches. The location of the three weirs is governing the impact on groundwater levels at the SZITE variant. Along the Danube groundwater levels are raised by 1.5-2.5 m. It is the only variant that raises groundwater levels at the lower end of the project reach. Again the impact does not significantly affect the protected side. The Meander variants raise groundwater levels along the Danube by 2-3.5 m. The impact is far more reaching than any other variant amounting up to 0.5 m on the protected side. Local differences by the two versions are caused by different crest heights of weirs implemented. In addition, the modelling of the Meander (400) version did not provide discharge to the other side arms. The Widening variant raises groundwater levels up to 0.5 m at the Danube and the Narrowing variant does not affect the groundwater.

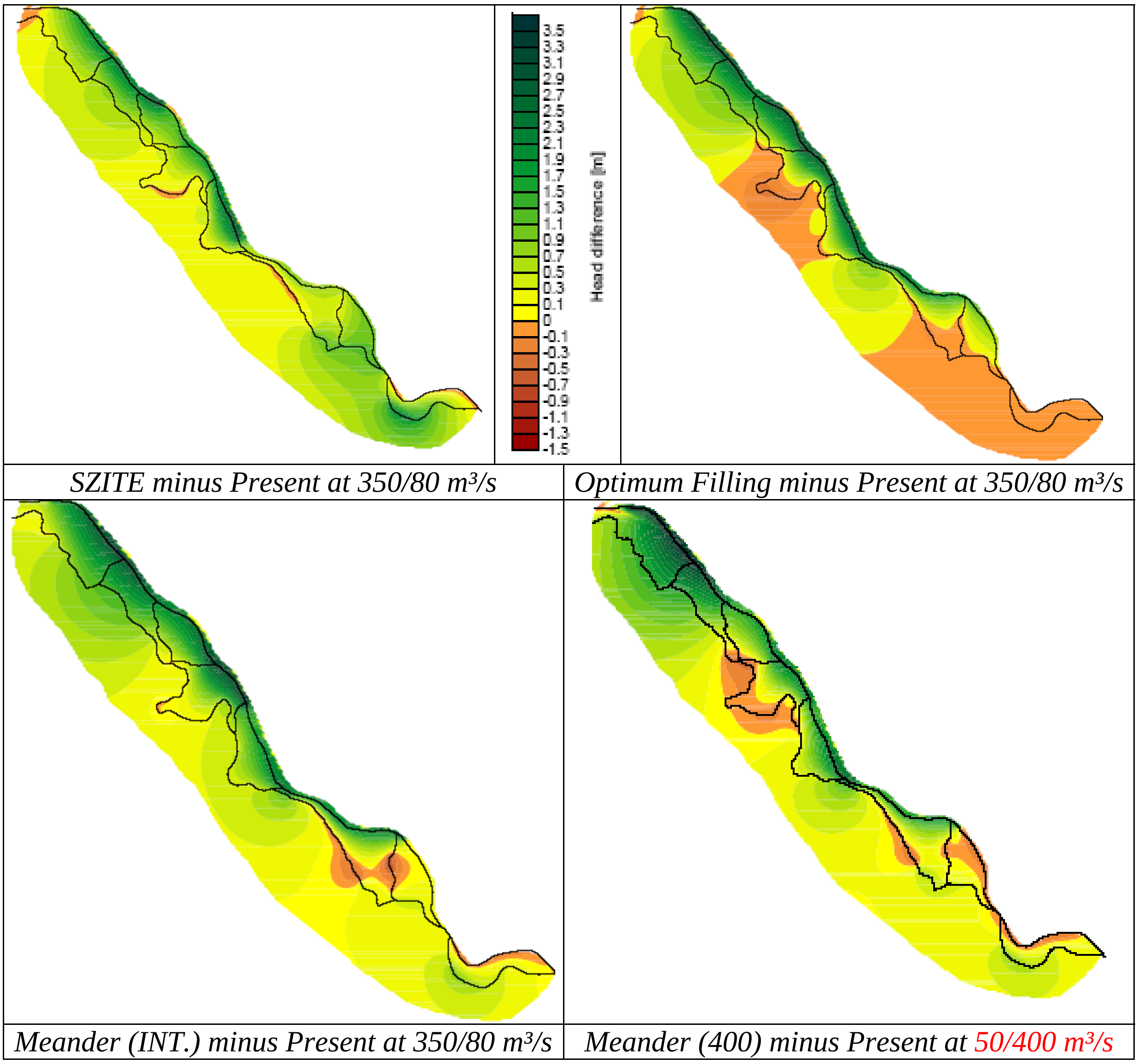
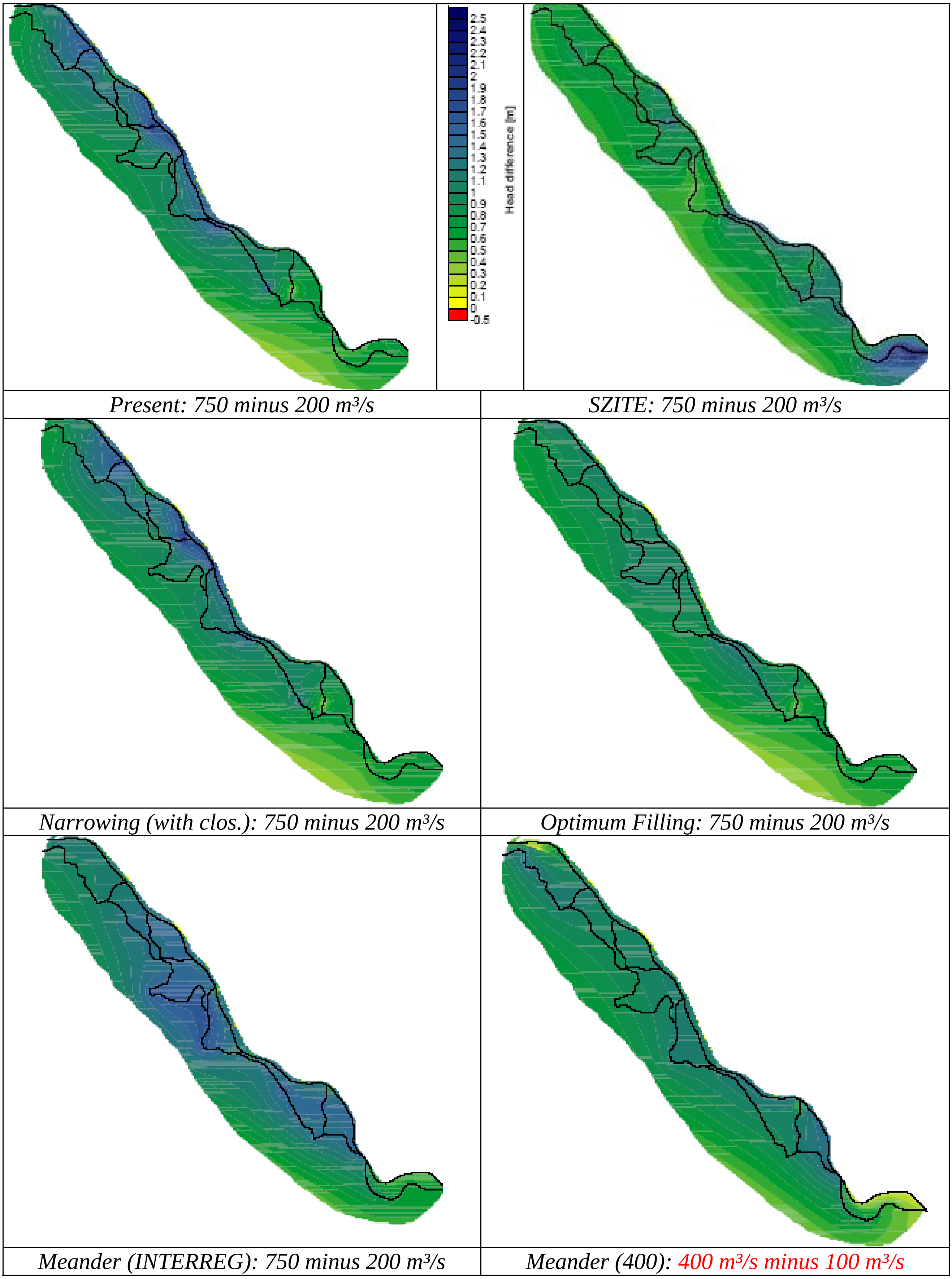


Figure 9-8 Groundwater level changes by implementation of variants



Present: 750 minus 200 m³/s

SZITE: 750 minus 200 m³/s

Narrowing (with clos.): 750 minus 200 m³/s

Optimum Filling: 750 minus 200 m³/s

Meander (INTERREG): 750 minus 200 m³/s

Meander (400): 400 m³/s minus 100 m³/s

Figure 9-9 Range of groundwater level fluctuations between 750/120 and 200/40 m³/s for the Present state and variants

Figure 9-9 shows groundwater level differences between a low flow and a high flow condition. These results assume that high water situations prevail long enough to produce the groundwater response predicted in the steady state model. This effect becomes more significant with increasing distance from the river; i.e. groundwater fluctuations on the protected side may be lower than suggested in the model.

In the Present state most of the area shows a groundwater level difference of about 1 m; near the Danube the range is 1-2 m except for the lowest reach which is influenced by the backwater effect of the tailrace canal. The Narrowing variant shows the same results. Considerably smaller surface water level fluctuations result in a corresponding groundwater response with differences of just 0.5-1.2 m for the Optimum Filling variant. For the SZITE variant most of the area shows groundwater level differences of 0.5-1 m, in a small area at the lower project reach 1.2 m are attained. Higher fluctuations might be attained for the SZITE variant with an adequate operation mode of the weir gates. Similar results are obtained for the Widening variant.

The results of the Meandering (INTERREG) variant are rather surprising. Obviously the meander branch is controlling the groundwater level fluctuations resulting in extended fluctuations over most of the area of 1-1.5 m. The result may be somewhat overestimated by data input from the 1D-model which cannot calculate realistic values for water levels exceeding bankfull stages. The Meander (400) version produces groundwater level fluctuations of 0.8-1 m on most of the area. More investigations are needed to explain the difference between the two Meander versions probably caused by excluding side arms in the model runs for the Meander (400) version.

Impact of increase of discharges on groundwater level dynamics

The modelling of groundwater level differences was already done for an upper discharge of 750/120 m^3/s. In the case of the Present state, the Narrowing, the SZITE and the Optimum Filling variants an increase of discharges generally enhances groundwater level dynamics. For the Meandering version the fluctuation in the branches seems to be more important than in the Danube.

Preliminary conclusions on groundwater level dynamics

Only the effective raising of Danube water levels by filling the bed or impounding river sections would signicantly raise the groundwater table. In terms of groundwater level fluctuations only the INTERREG version of the Meander variants produced higher ranges which can be explained by the exclusion of side arms in the model runs for the 400 version. The model results for the SZITE variant were based on the assumption that the gates are closed at low and mean-flow conditions. In this case groundwater fluctuations would be reduced compared to the Present state. The range of groundwater levels could be increased with another mode of operation (see Chapter 9.7.3). All variants except for the Meander variants would profit from increased discharges.

Field of assessment	Present	SZITE	Narrowing (with clos.)	Opt.Filling	Widening	Meander (INTERREG)	Meander (400)
Compensating drop of groundwater levels	-	+	-	+	-	+	+
Groundwater level fluctuations	-	(--)	-	--	--	(+)	-
Improvement of groundwater level fluctuations with higher flows	+	+	+	+	(+)	0	0

*⁾ Results not comparable due to different discharges.

9.4.4. Morphodynamics

Lateral erosion and deposition with subsequent changes of the channel pattern, local scouring of the riverbed and the formation of sand and gravel bars in widened sections were characteristic processes of the natural river landscape in the Szigetköz. The overall accumulation of sediments resulted in the evolution of a large alluvial cone producing the unique inland delta of the River Danube with shifting main channels in historical times. Reference conditions rather refer to the rapidly changing pattern of river channels documented in Chapter 5.2.

Present situation compared to reference conditions

With the construction of barrage systems in the upstream basin and intensive gravel dredging the bedload was already reduced, but with the operation of the Hrusov reservoir all the gravel and most of the sand load settles and no longer enters the project reach. Due to the peak operation capacity of the turbines at Gabčíkovo only large flood flows are shared with the Danube delivering discharges above bankfull flow. After 1992, only three flood flows inundated the project area, and bankfull flows of 3000 m³/s competent for bedload transport lasted less than one day (Chapter 8.4). Even discharges above 1200-1400 m³/s initiating transport of sediments only occurred about 20 times between 1992 and 2007. At the same time the bed level was eroded by about 3 m in the Danube below the confluence (rkm 1811-1805), also initiating bed degradation of the bed in the lowest part of the upstream project reach by backward erosion.

In the Present state morphodynamic processes are characterized by

- reduced bedload transport capacity at the prevailing flow regime
- weaker siltation of floodplain and isolated water bodies

- backward erosion at the lower end of the project reach
- moderate bed scouring and lack of lateral erosion
- occasional and weak transport of sand and fine gravel over the armoured coarse gravel bed material

with the consequence of

- no rejuvenation of pioneer stands
- no rejuvenation of water bodies (fixed channel pattern)
- lack of diversity of substrates
- lack of instream structures, e.g. gravel bars (ref. Figure 9-5)
- general uniformity of habitat conditions

Figure 9-10 shows the distribution of bottom shear stress at a flow of 3000 m³/s in the channel beds of the Cikola and Asvanyi neighbourhood. The two darkest red colours indicate shear stress values >10 Pa that are competent to move loosely embedded pebbles coarser than 10 mm; the second lightest red shows areas with initial transport of sand grains >0.25 mm. It is obvious that effective bedload transport of sand and gravel can only occur in the main channel bed and only if flood flows persist long enough. In the branch system, however, even a flow of 3000 m³/s would only move sand and silt. Local scouring is restricted to the vicinity of structures where overspills produce enough energy to move bed material in small areas.

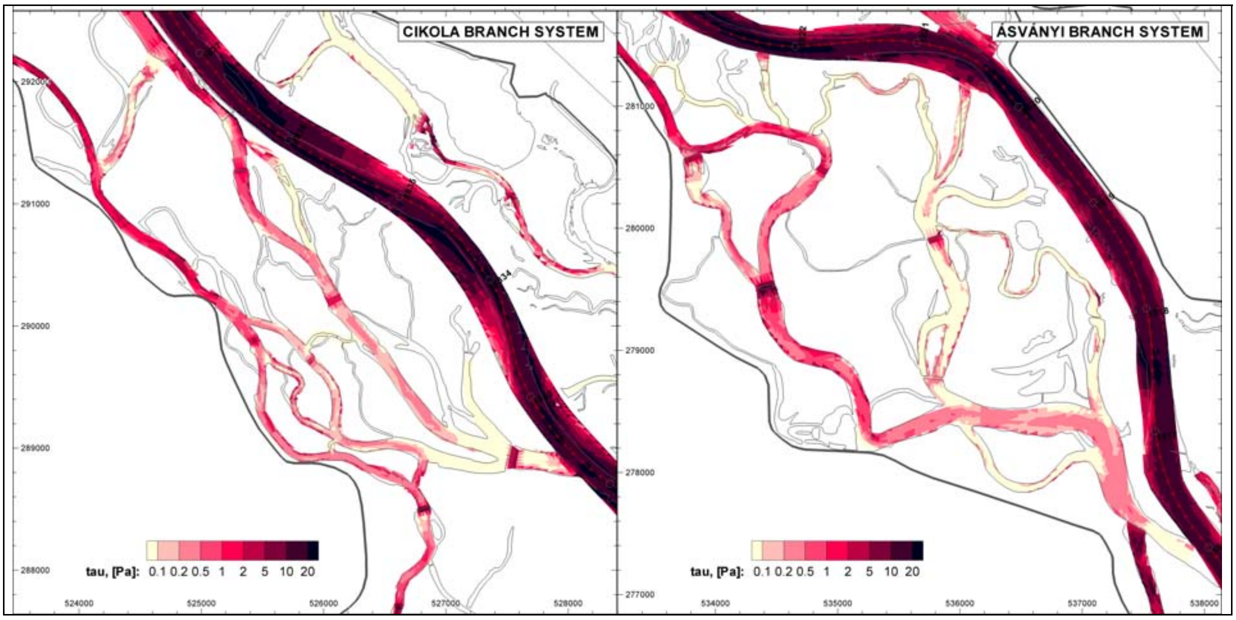


Figure 9-10 Distribution of shear stress at 3000 m³/s in channel beds

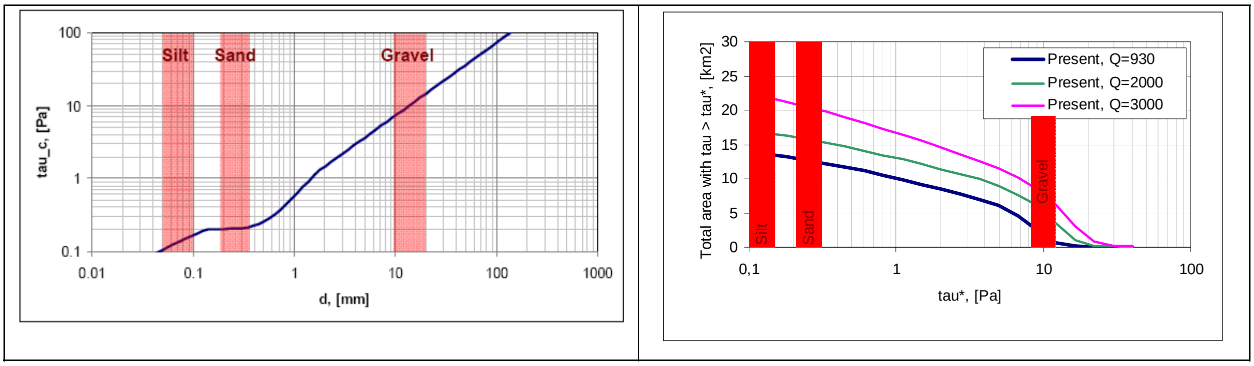


Figure 9-11 Thresholds of incipient motion of grain sizes (left) and area distribution of bed shear stress for Present state at discharges from 750/180 to 3000 m³/s (Example: At 3000 m³/s about 6.5 km² out of 22 km² channel area experience shear stress values competent to initiate gravel transport. At 930 m³/s (= 750 m³/s in main channel + 180 m³/s in side branches) this area is reduced to about 1 km²)

Figure 9-11 sums up the total area of shear stress in channel beds over the entire project area, including the Slovak floodplain. Effective bed load transport is restricted to the central part of the main channel covering about 6.5 km².

In terms of morphodynamics the Present state is far from the historical situation before river regulation. On the top of all interventions by river regulation the river ecosystem suffers from the lack of competent flood flows initiating erosive processes and from the lack of bed load supply from upstream.

Variants compared to present conditions

Figure 9-12 shows the longitudinal distribution of cross-sectional mean bottom shear stress along the Danube from Rajka to the confluence for the Present state and for variants at 750 m³/s. From the morphological modelling it is known that effective bed load transport starts at discharges between 900 – 1200 m³/s. Actually only a few values exceed the threshold of 10-15 Pa for incipient motion of gravel (mean grain size of 10 mm). The graph demonstrates that in the upper and central reach the shear stress performance is quite similar for the Present state, the Narrowing, the Optimum Filling and even the Widening variants. In the lower reach the Optimum Filling variant maintains the shear stress level of the central part by compensating the backwater effect due to higher bed levels.

The SZITE variant shows generally somewhat lower shear stress values with variations according to the location of weirs. The closed chain of weirs in the Meander (INTERREG) variant produces very low shear stress values in the main channel. The deposition of fines is more likely in the impounded sections of the Meander than in SZITE variant. Similar small values are found above the weir at Dunakiliti (location no. 13) and in the vicinity of the confluence – reaches where siltation is observed today.

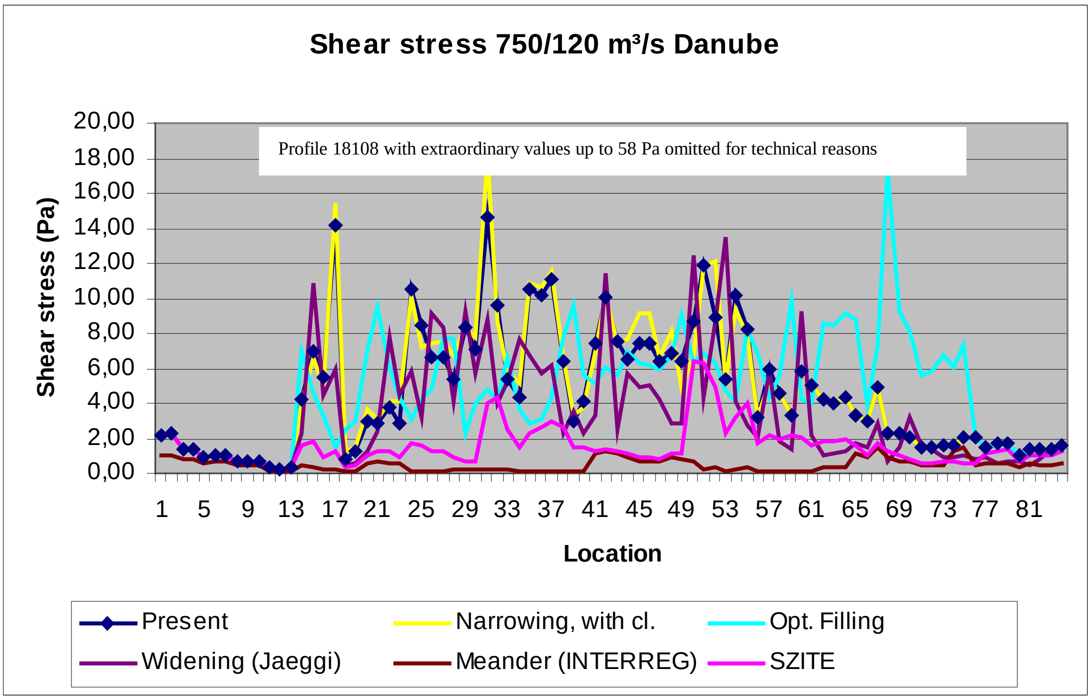


Figure 9-12 Bottom shear stress distribution along the main channel as averages in cross-sections (1D-model data)

The 2D-model results for the main channel (Figure 9-13 top left) confirm the conclusions from the 1D-modelling. Below 3 Pa the Meander variant significantly deviates from the SZITE indicating that larger areas are exposed to smaller shear stress values with a risk of siltation. Both variants, however, are not capable of moving larger pebbles which contrasts with all other measures and the Present state. For the SZITE variant it must be noted that the gates at the three weirs are closed at a flow of 750/180 m³/s and open gates at higher discharges would produce higher values.

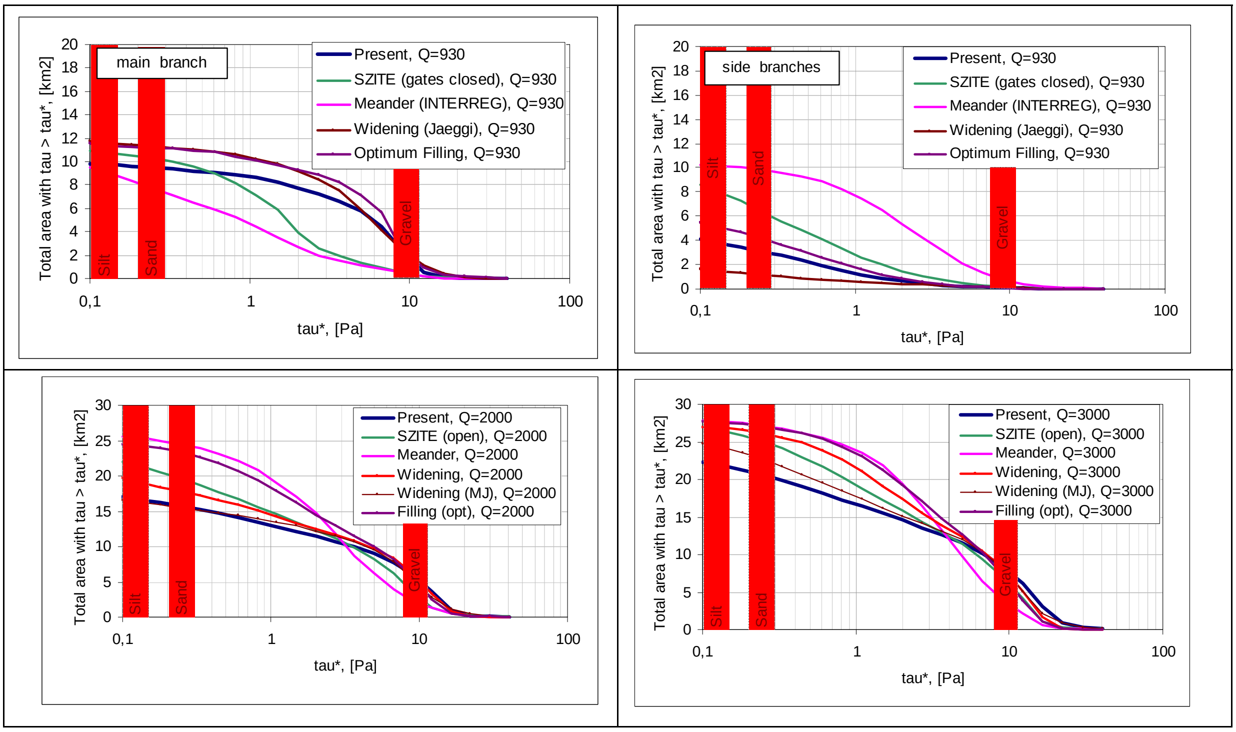


Figure 9-13 Areal distribution of bottom shear stress in the main channel and in the side branches for 750/180 m³/s (2D-model data); Meander (400) version not included in 2D-modelling

Channel forming morphodynamic processes can only be expected at bankfull flows somewhere between 2000 and 3000 m³/s for the present state (Figure 9-13, bottom). Looking at thresholds above 8-10 Pa, which more or less represent the main channel and not the side branches, the Meander (INTERREG) variant is associated with the smallest area with competent hydraulic forces while the other variants have similar values as the Present state, the SZITE being marginally lower. It is due to the higher shear stress values in the branches that the Meander variant produces larger areas with higher shear stresses below a threshold of 3-4 Pa at 3000 m³/s.

In the branches the picture is completely reversed Figure 9-13, top right). There, the Meander (INTERREG) variant is the only one in which most of the channel beds are not prone to siltation. Since 180 m³/s are fed into the branches already exceeding bankfull flow of most channels no significant increase of shear stress can be expected at higher flows. The increase in total area for the Meander and SZITE variant is due to the flooding of branches on the Slovak floodplain.

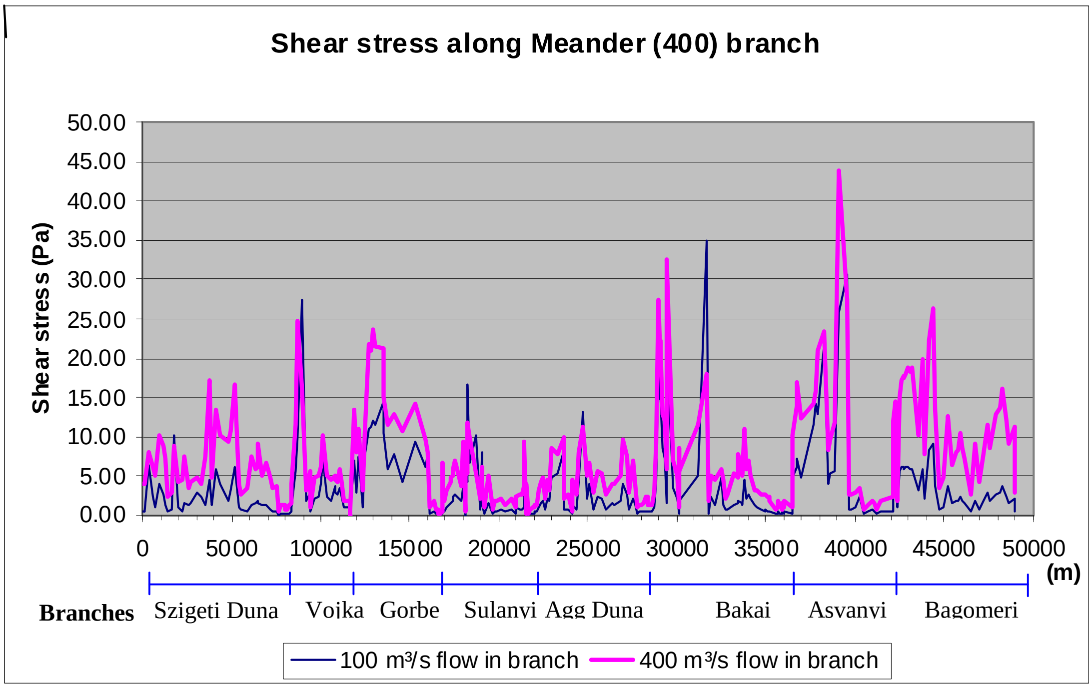


Figure 9-14 Distribution of cross-sectional mean bottom shear stress along the meander channel of the Meander (400) variant (1D-model data)

Figure 9-14 shows average shear stress values in cross-sections along the meander branch of the Meander (400) version. 10 Pa may be accepted as a threshold for channel evolution by scouring and local transport since higher peaks will occur in individual cross-sections and in parts of cross sections. Therefore, morphodynamic processes with local scouring and formation of bars, i.e. channel forming processes, can be expected all along the meander branch except for the Sulanyi and Agg branches. Short reaches of incision and accumulation can develop but an overall degradation of the meander branch can be excluded. Only the mouth at the Bagameri Duna needs to be protected against backward erosion.

Impact of increase of discharges on morphodynamics

The rehabilitation of channel forming morphodynamic processes certainly requires a fundamental change in the flow regime towards higher and longer lasting flood flows (Chapter 9.4.7). The increase of prevailing seasonal discharges would not be important for morphodynamic processes.

Preliminary conclusions on morphodynamics

Main channel: With a competent flood regime the Present state and all but the Meander variants have the potential of channel forming processes; this is clearly indicated with shear-stress distributions for 3000 m^3/s (ref. to Figures 8-39 to 8-48). The Optimum Filling variant considerably improves the morphodynamic potential in the backwater reach of the tailrace canal. With fixed weirs neither Meander variant would be able to transport gravel-size bed load.

The greatest capacity to make use of the channel forming potential is coupled with the Widening variant and the Optimum Filling variant. The Widening concept of providing bed material by lateral erosion would certainly lead to a new evolution of low-flow channels in the (over-)widened riverbed. Accumulated material would form bars and vegetated islands in the first decades of development. Eventually a new floodplain with terrestrial habitats would develop on a level of 1.5-2.5 m above the present channel bed leaving the present floodplain as a terrace. In a similar way the Optimum Filling variant would provide a wide channel bed with a large potential for the evolution of a smaller channel adapted to the prevailing flow regime. The unconsolidated sediment would rather rapidly form bars and islands in irregular cross-sections.

Side branches: In the side branches only the Meander variants have a morphodynamic potential. The Meander (INTERREG) variant may be able to maintain large areas of sand and fine gravel substrates. Considerable channel evolution can be expected with the Meander (400) version in long reaches of the meander branch. The substrate diversity of all other variants including the Present state is expected to be rather low; i.e. uniform conditions of channel substrates dominated by fines will prevail.

The natural Danube wetland was characterized by rapidly changing channels systems as demonstrated in Chapter 5.2. Today’s constraints delimit the opportunities to reactivate morphodynamic processes to a large extent. The channel forming potential of small-scale scouring, lateral movement, bar formation, diversity of substrates, flow velocities and water depths is an important criteria of evaluation. The potential depends on the hydraulic forces exerted on channel beds by the imposed flow regime and the inherent concept of restoration.

Field of assessment	**Present**	**SZITE**	**Narrowing** (with clos.)	**Opt. Filling**	**Widening**	**Meander** (INTERREG.)	**Meander** (400)
Morphodynamic Potential: Danube	-+	-+	-+	++	++	--	--
Morphodynamic potential: Branches	-	-	-	-	-	+	++
Improvement of morphodynamics with higher flows **(Danube / branches)**	+ / 0	+ / 0	+ /0	+ / 0	+ / 0	0 / 0	0 / 0

9.4.5. Aquatic habitat evaluation

The morphodynamic processes of the natural situation in the Szigetköz resulted in continuous, flood-driven changes of the landscape. High landscape dynamics, with a characteristic habitat turnover and spatial dislocation of landscape elements resulted in a dynamic equilibrium in habitat composition. These hydrologically driven geomorphic processes cause a characteristic ecotonal structure and habitat mosaic and initiate continuous habitat rejuvenation and successions. The landscape dynamics result in high biodiversity as expressed in the "Intermediate disturbance hypothesis" (Ward and Stanford, 1995, Schiemer, 1999)

The historical analysis in Chapter 5.2 illustrates that the total area of flowing water with wide ranges of current velocity and associated ecological gradients was remarkably high. These conditions favoured the requirements of rheophilic biota e.g. fish and macrozoobenthos. Periodically disconnected side-arms (parapotamon and plesiopotamon) and aquatic areas flooded only occasionally at high floods (palaeopotamon) resulted in the broad range of aquatic habitat conditions as the basis for a highly diverse and well adapted biota characteristic for river-floodplain landscapes.

A quantitative comparison of the historical with the present habitat availability with respect to the areal extent of aquatic habitats (AE) and the proportion of the eupotamon habitat (PEu) (see Chapter 7) elucidate the ecological deterioration compared to reference conditions. Consequently the fostering of these habitat types and the conservation of parapotamon – palaeopotamon water bodies has to be a specific scope of restoration programmes.

The decrease between the historical and recent areal extent of the aquatic habitats is 48 % and the proportion of the eupotamon habitat has decreased to 70% (Table 9-7); all main types of the aquatic habitats of the ana-branching sector, however, still exist.

Table 9-7 The decreases of areal extent of the aquatic habitats and the proportion of eupotamon habitat

areal extent (AE)	**Reference**	**Present**
Eup. + Parap.+ Plesiop. (ha)	4500	2360
change (%)	0	-48
proportion of eupotamon (PEu)	**Reference**	**Present**
Eup. A + Eup. B (%)	85-90	70

With respect to the interconnectivity between the side-arm system and the main channel the Present, Narrowing and Widening variants fail to achieve appropriate conditions even at higher flow.

SZITE, Meandering and Optimum Filling variants achieve this lateral interconnectivity and provide an increased extent of aquatic habitats and a high proportion of eupotamal zones. In the SZITE variant, due to the effect of weirs the longitudinal connectivity in the main arm is restricted and the shear stress and velocity gradients in the Eupotamon A are suboptimal. The longitudinal connectivity in the branch system remains unsatisfactory from an ichthyological point of view because of the necessity to maintain weirs.

Besides this general assessment of aquatic habitats the evaluation of variants requires more detailed analysis of the habitat conditions for characteristic rheophilic biota, especially fish and macrozoobenthos.

The deterioration of conditions over the past 160 years can be most explicitly shown by the change in the guild composition of fish in the main arm and in the side arm system (Figure 9-15)

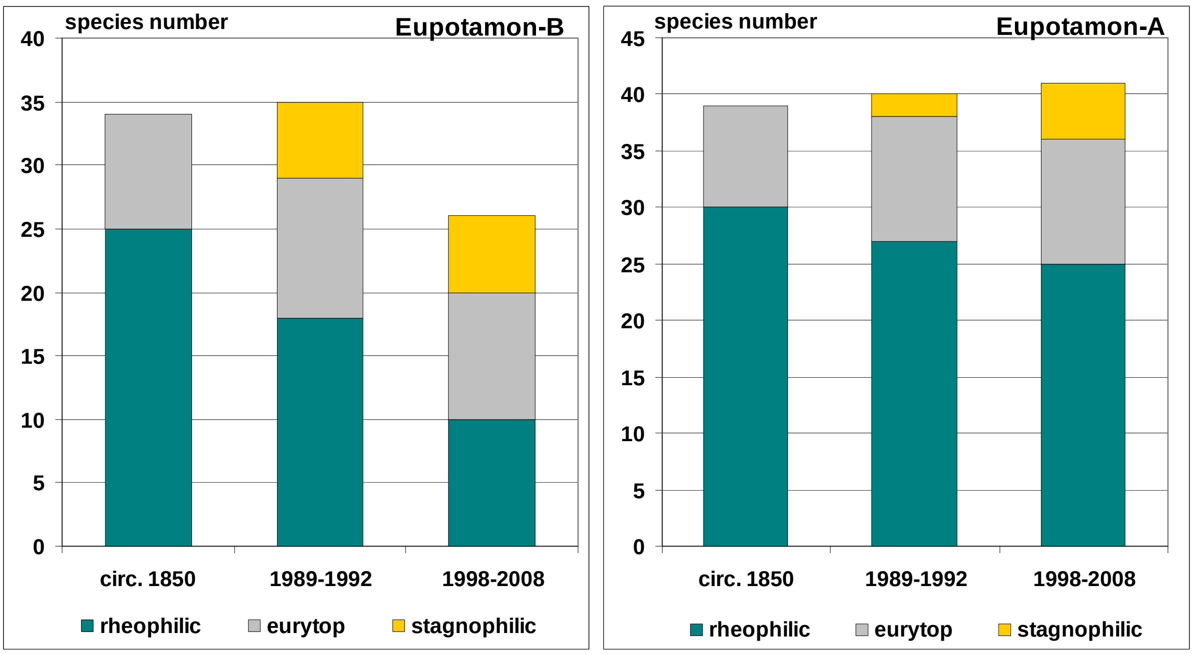


Figure 9-15 Long-term change of species number and proportion of rheophilic, eurytopic and stagnophilic fish species in the main arm (Eupotamon-A) and in a side arm in the Cikola branch system. The side arm was Eupotamon-A habitat in the middle of the 19th century. It was a Parapotamon-A type habitat before the diversion of the Danube (from the end of 19th century to1992) and recently it is Eupotamon-B habitat.

The assessment of the fish assemblage is considered separately for the main arm *(Eupotamon-A)* and the side arm system *(Eupotamon B)* in order to demonstrate the differential effect of possible management measures on the two systems. In terms of habitat quality the relationship between the requirements of characteristic fish guilds and shear stess classes is used as a quality indicator. It is relevant for the rheophilic fish guilds which form the prime biotic indicator for the eupotamal habitats. Three characteristic shear stress classes can be distinguished: good (shear stress > 7 Pa), medium (0,2-7 Pa) and bad (<0,2 Pa) conditions for rheophilic fish. This habitat quality assessment does not consider the life conditions for the early life history stages of fish but is based on electro fishing experiences of predominantly adult fish.

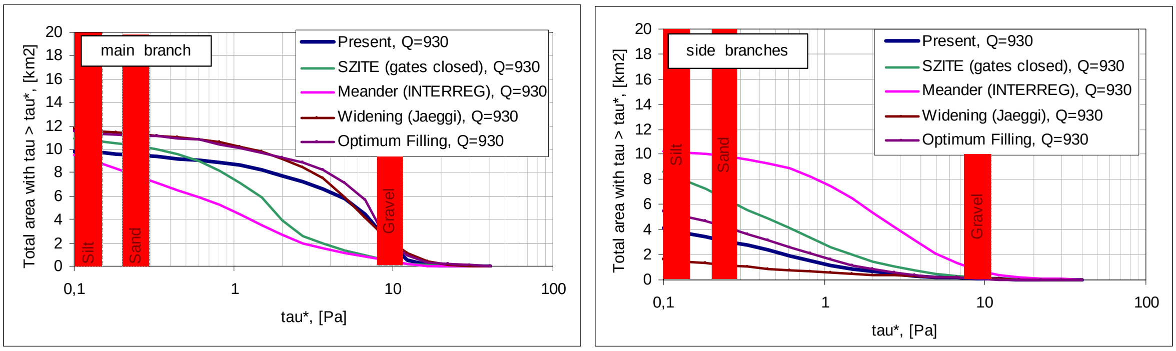


Figure 9-16 Shear stress distribution for different variants in the main arm (Eupotamon-A) and in the side branches (Eupotamon B) for different rehabilitation scenarios at 750+180 m^3/s discharge.

For the main channel conditions of all variants including the Present situation are improved at higher flow. The areal extent of high shear stress classes is increased.

In the Eupotamon-B habitat type of the floodplain branch system the fish assemblages have deteriorated in historical times more strikingly - from excellent to moderate before the diversion of the Danube to very poor under the present situation. The present composition of fish assemblages varies with the spatial habitat conditions expressed by the shear stress distribution.

Table 9-8 provides an overall appraisal of the variants with respect to development of high quality habitat zones for rheophilic fish taking into account the shear stress distribution in Figure 9-16.

Table 9-8 Appraisal of variants from the point of view of rheophilic fish guilds

	Present	SZITE	Narrowing	Optimum filling	Widening	Meandering
High quality zones Eupotamon A	+	-	+	+	+	-
High quality zones Eupotamon B	-	-+	-	-	-	+

The quantitative and qualitative evaluation of the other aquatic habitat types in the side-arm system – parapotamon, plesiopoatmon and palaeopotamon requires a detailed assessment at a later stage. According to the 1D model assessment the continued existence of these habitat types is secured for all variants (see Chapter 8, areal graphs, quantitative composition). Its respective habitat quality, which is of particular importance for characteristic biota, e.g. aquatic and wetland vegetation, stagnophilic fish (see Chapter 7) and amphibians (see Chapter 7) requires a more detailed assessment at a later stage in combination with modeling of the dynamic seasonal hydrology pattern.

While the fish and macrozoobnethos assemblages are especially indicative for the availability and quality of eupotamal habitats, for the amphibian fauna the existence of plesiopotamic and palaeopotamic water bodies as reproduction sites is particularly significant.

Based on the five grade benchmark system (see chapter 7) the variants “Optimum Filling” and “SZITE” showed the good values. It should be emphasized that the ratio of Parapotamon B/ Parapotamon A type habitat seems to be considerable higher in the case of variant “Optimum filling” compared to “SZITE” resulting in ultimately more suitable spawning sites for amphibians in the floodplain.

9.4.6. Transition zones and terrestrial habitat evaluation

The potential development of the **terrestrial vegetation** of the floodplain area over a prolonged period of time for the variants was assessed by a model based on the water requirement of different vegetation types and the calculated groundwater levels for the different scenarios and for fixed flow rates. Of course, this can only provide a very broad comparison of vegetation development since the key factor for habitat rejuvenation, flood induced disturbances, has not been taken into account. Therefore the development of pioneer associations especially in the transition zones of the floodplain, which are the characteristic “terrestrial” habitat type of active floodplains, cannot be predicted by the model. However the model provides some insight into two further habitat elements which are significant from a conservation point of view, the areal extent of softwood forests, and the areal extent of wetlands such as Phragmites stands (Figure 9-17).

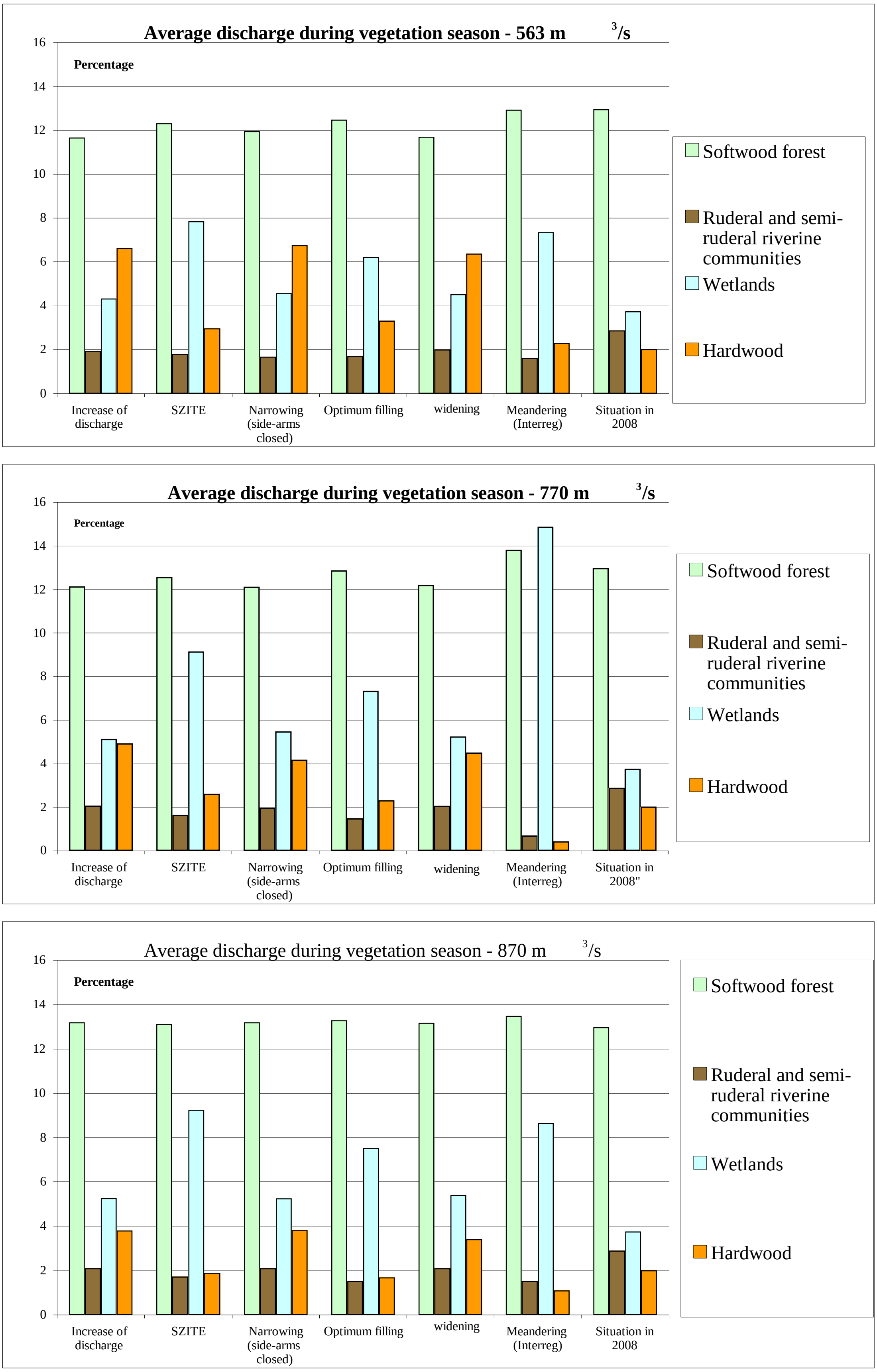


Figure 9-17 Comparison of the predictions on long-term development of characteristic vegetation types at 3 levels of simulated flows

Pioneer associations of the vegetation on frequently “disturbed” **transition zones** are a characteristic feature of active floodplains. These communities are of high conservation values and contain characteristic FFH elements and endangered biota (vegetation, invertebrates) and are important breeding habitats for birds.

Their specific ecological conditions depend on the flood disturbances and the extent of water level fluctuations. The vegetation model applied does not incorporate the disturbance regime of floods nor the water level dynamics.

Therefore the areal extent of transition zones linked to the Amoros-Roux aquatic habitat types and the predicted water level fluctuations is an important ecological asset for the future landscape development. A more detailed account has to be given to these landscape elements in the further discussion and planning of variants. They are not identical with the "Ruderal" and "semi-ruderal" riverine communities as predicted by the vegetation model (see Chapter 7)

Table 9-9 gives an overview on the effect of variants with respect to habitat conditions in the terrestrial zone and the transition zone (For evaluation of Lepidopterans see chapters 7 & 8)

Table 9-9 Evaluation of variants according to a bioindication of transition zones and terrestrial habitats

	Present	SZITE	Narrowing	Optimum filling	Widening	Meandering
Ecology of transition zones	-+	-+	-+	+?	+?	+
Ecology of terrestrial habitats	-	-+	-	-+	-	+

9.4.7. Assessment of the flow regime

Although seasonal variations were established in the 1995 agreement on a Temporary Water Management Regime flood flows were not sufficiently shared. It is demonstrated in Chapter 8.4 that

- only three floods between 1993 and 2007 inundated the entire floodplain,
- these three floods lasted only a few days, due to the operational schedules of the upstream barrages,
- bankfull flows of 3000 m^3/s occurred on 15 days only,
- 2000 m^3/s occurred 2.2 times per year,
- 930 m^3/s occurred on 7 days per year,
- in a couple of consecutive years the flow did not reach 1000 m^3/s.

The ecology of floodplain rivers fully depends on effective flood flows, which

- support morphodynamic processes enabling the rejuvenation of habitats (habitat turn-over),
- provide seasonal fluctuations of surface and groundwater levels,
- inundate the floodplain regularly.

Changes in the flow regime

Changes in the flow regime could apply to seasonal low and peak flow values as well as to the sharing of flood flows between the Gabčíkovo diversion canal and the Danube.

The **seasonal flow regime** is governing the average annual fluctuation of surface and groundwater levels together with water depths, flow velocities, extent of transition zones and terrestrial habitat conditions. Most variants and the Present state would benefit from an increase of summer discharges in the main channel and/or in the branches. The increase of flood flows of sufficient duration would improve all status in the main branch except for the Meander variants. The side branches would not benefit from an improved flood regime.

Field of assessment	**Present**	**SZITE**	**Narrowing** (with clos.)	**Opt. Filling**	**Widening**	**Meander** (INTERREG)	**Meander** (400)
Improvement of **water level dynamics** with higher flows (Danube / branches)	+ / **0**	+ +	**+ / 0**	+ / +	**0 / 0**	+ / ++	not relevant
Improvement of **flow velocities** with higher flows (Danube / branches)	**0** / +	+ / +	**0** /+	**0** / +	**0** / +	**(+)** / +	0/+
Improvement of **groundwater level fluctuations** with higher flows	+	+	+	+	**(+)**	**0**	**0**
Improvement of **morphodynamics** with higher flows (Danube / branches)	+ / **0**	**+ / 0**	+ /**0**	+ / **0**	+ / **0**	**0 / 0**	**0 / 0**

9.5. Impact on flood security

Flood conveyance

The performance of flood conveyance was tested with the August 2002 flood flow which had a discharge of 10,370 m³/s at the Devin gauge and equalled the flood peak of the 1954 flood flow[34]. Statistical analysis results in values of HQ_{50} = 10,100 m³/s and HQ_{100} = 11,000 m³/s.

Figure 8-38 shows the water levels of the Present state and the variants. In Figure 9-18 the freeboard allowance along the Hungarian dyke system is displayed, i.e. the vertical distance between the crest of the levees and the water level. In this study 1 m freeboard allowance is suggested as a reference value for assessing variants.

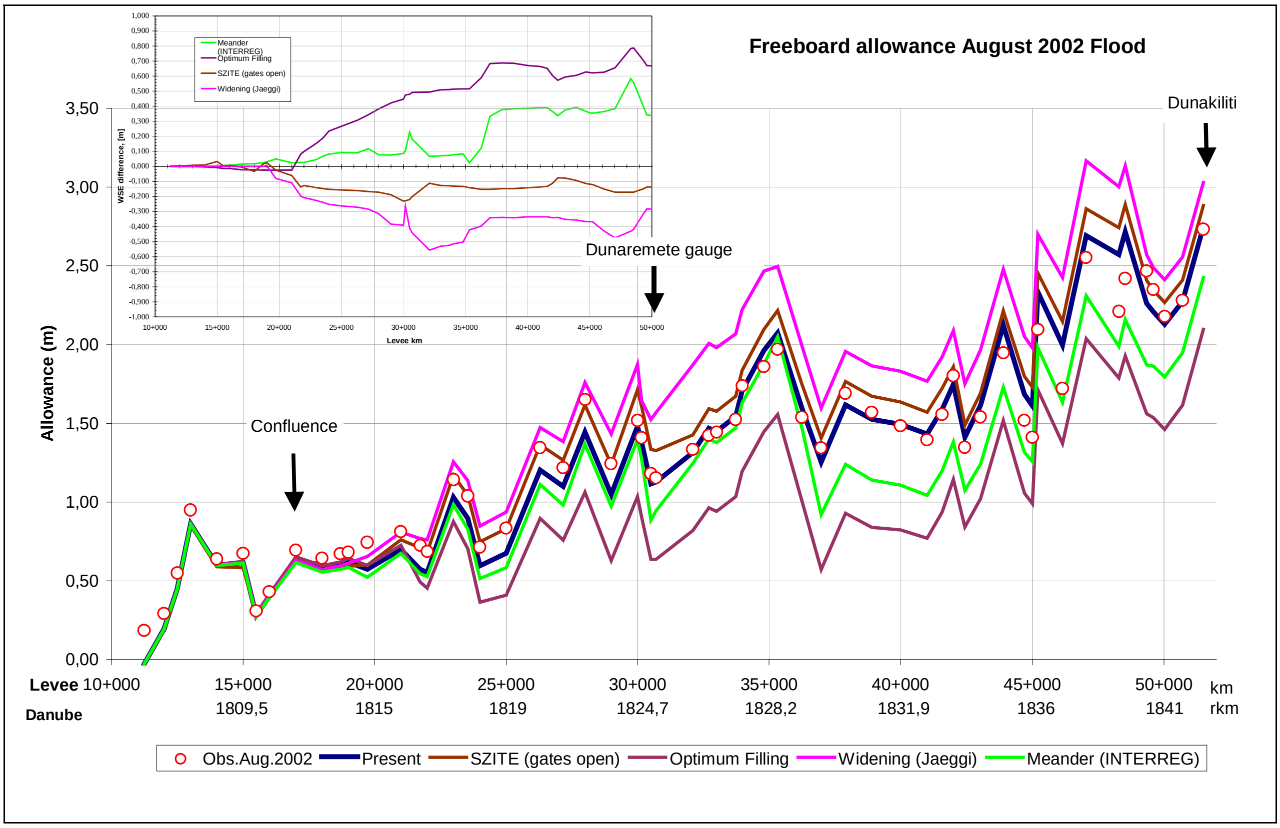


Figure 9-18 Observed and calculated freeboard allowances for the Present state and variants; (difference map “variants minus present” inserted)

From both figures it is obvious that the Danube reach below the confluence has an insufficient flood conveyance capacity with freeboard allowances of 0.5 m and less. Due to the backwater effect this propagates about 10 km upstream into the project reach. Between Danube km 1820 and 1834 the freeboard at the Present state amounts to 1.0–1.5 m, in the remaining 9 km up to Dunakiliti the freeboard increases to 1.5–2.5 m. Of course, none of the variants can mitigate the flood deficiencies of the downstream reach.

[34] Miklánek, P. & P. Pekárová (2008) Flood regime of the Danube River in Bratislava, Slovakia. Institute of Hydrology SAS, Bratislava, Web publication: *147.213.145.2/pekarova/WEBClanky/AEC01.pdf*

The SZITE variant which envisaged dredging of point bars in the main channel, clearing of certain floodplain forest areas and movable flood gates at the three weirs increases the freeboard by 10-20 cm mainly in the Danube reach which has a freeboard allowance of more than 1 m in the Present state. The Widening variant which envisaged a 100 m broadening of the channel with an elevated bed level, increases the channel capacity considerably: in the lower reach up to rkm 1822 water levels decrease by 20-30 cm, in the upper reach by 30-50 cm compared to present conditions. Again, the increase in freeboard mainly extends to reaches which are above 1.0 or 1.5 m already.

The Meander (INTERREG) variant produces a light increase of water levels in the lower and central reach of 10 cm with a local maximum of 20 cm. A sharp rise to 40 cm water level difference at rkm 1829 produces levels with a local maximum of 60 cm (at rkm 1838,7). The freeboard allowance decreases accordingly; a minimum of 1 m, however, is preserved all along the reach above rkm 1820 with some minor deviations. The Meander (400) variant was not implemented in the 2D-model. Its flood performance may deviate considerably since the crest levels of the weirs are higher on one side and the meander branch is enlarged on the other.

The Optimum Filling variant considerably decreases the conveyance capacity of the main channel. The resulting water level is 30-55 cm above the present stage and violates the 1 m freeboard allowance below rkm 1834.

Ice conveyance

Besides natural flood flows the conveyance of ice is also a concern in terms of flood security. The conveyance of drifting ice may be hampered by shallow and vegetated bars and by fixed weirs. Ice jams may build up raising water levels above natural flood levels. The bottom sill at Dunakiliti is not suitable for ice conveyance; the Dunakiliti weir, however, can manage ice flows and even break up the ice cover by operational modes. Generally, the optimum solution is to leave the fixed cover of ice and let it decay.

The Present state is characterized by an increased risk of ice formation in the impounded reach upstream of Dunakiliti. Below Dunakiliti the strong infiltration of groundwater combined with low winter discharges prevents the formation of an ice cover. Conveying floating ice may be hampered by vegetated point bars. The SZITE variant installs three impoundments increasing the risk of ice formation. The movable gates, however, can discharge floating ice over the weirs and ice breaking vessels can pass through the ship locks. The point bars are cleared and dredged or impounded. Clear cutting of defined areas in the floodplain mitigates the conveyance of floods and floating ice.

The Narrowing variant further restricts the channel area increasing the risk of ice jams. The Optimum Filling variant is likely to develop vegetated bars and islands thus impeding ice conveyance. Both variants, however, refrain from impounding the reach and do not include the construction of weirs with the inherent risk of ice jams and structural damage. The Widening variant may be assessed similarly to the Optimum Filling variant with one difference: groundwater influence is more likely to prevent ice formation. The Meander (INTERREG) variant includes 7 impoundments with even lower flow velocities than the SZITE proposal; ice formation can be expected at the same frequency as in the upstream reservoir. Fixed weirs are unsuitable for ice conveyance and no vessels can reach the impoundments. The meander branch is too narrow in some locations to convey floating ice without risking jammed cross-sections. The Meander (400) variant may have the advantage that ice breaking vessels can use the enlarged meander branch at bankfull flow. Floating ice is more likely to pass the meander channel without getting caught by channel constrictions.

Preliminary assessment of flood performance

The assessment is divided into three parts:

- impact on flood levels
- violation of freeboard requirements
- risk of ice formation and conveyance of floating ice

Field of assessment	**Present**	**SZITE**	**Narrowing** (with clos.)	**Opt.Filling**	**Widening**	**Meander** (INTERREG)	**Meander** (400)
Impact on flood levels	**0***)	+	**-**	**--**	++	**-**	**-**
Violation of freeboard requirements	**0**	**0**	**-**	**--**	**0**	**(-)**	**-**
Risk of ice formation**)	**0**	**-**	**0**	**0**	**0**	**--**	**--**
Conveyance of ice**) **(Danube / branches)**	**0 / 0**	**+ / 0**	**- /0**	**- / 0**	**- / 0**	**- / 0**	**- / +**

*) "0": No change compared to the Present state   **) Compared to present conditions

Flood levels. None of the variants can resolve the flood protection deficiencies that are caused by insufficient conveyance capacity in the Danube below Szap. Compared to pre-dam conditions the only variant that produces unacceptable results is the Optimum Filling variant. Even the Meander (INTERREG) variant nearly maintains a minimum of 1 m freeboard allowance along the reach which is not influenced by the backwater effect. Further planning could avoid these deficiencies. Special flood protection measures associated with the SZITE variant largely produce lower flood levels where sufficient freeboard allowance exists already. The Narrowing and the Meander (400) variants were assessed by expert judgement.

Ice formation and conveyance. The free flowing variants and the Present state have a similar risk of ice formation as the Danube had before the diversion. Reduced flow velocities by impounding increase the risk of ice formation which is the case for both Meander variants and to a smaller extent for the SZITE variant. Compared to present conditions all variants deteriorate ice conveyance in the Danube main channel with the exception of the SZITE variant. For the free flowing situations this is caused by vegetated bar formation. The Meander variants with fixed weirs would need a more sophisticated design to enable ice discharge.

9.6. Investment and operation costs

Investment and operation costs have not been calculated in this study. The scope of this study was rather to explore the impact of various rehabilitation measures on the environment. Further planning steps based on these results will outline rehabilitation measures in more detail and associated costs can be analyzed.

9.7. Conclusions and recommendations

The first fundamental intervention in the natural river eco-system dates back to the late 19th century with the construction of a fixed single main channel in the former anabranching and meandering channel pattern (Chapter 3). Earlier human impact such as deforestation in the catchment had not disturbed the governing processes of erosion and sedimentation as did the river regulation. Landscape analysis (Chapter 5.2) indicates that changes in channel pattern occurred within a few decades probably triggered by climatic fluctuations. After the overall regulation a new system of a single main channel and side arms with limited potential for habitat rejuvenation was established. Since then, morphodynamic processes were delimited to aggradation and degradation of main channel reaches, point bar formation and to minor local scouring in side arms. Gradual sedimentation of branches and overall siltation of floodplain areas were the dominating processes. Intensive dredging in the main channel along the entire reach below the Austrian border coupled with reduced bed load supply from the upstream catchment destabilized the channel. With the degradation of the river bed more and more side arms lost connection to the main channel (Chapters 4.1 and 5.1).

The construction of the Gabčíkovo HPP in 1992, represented another major intervention with further fundamental changes of the eco-system. The diversion of more than 80 % of the discharge to the power canal lowered the mean water level by 2-3 m. The subsequent drop of groundwater levels was partially compensated for by interconnecting side arms, controlling water levels in branches with drop structures and the construction of a bottom sill at Dunakiliti to raise upstream water levels in the Danube in 1995. The implemented artificial flow regime only provides those flood flows that exceed the capacity of the Gabčíkovo HPP.

All these interventions resulted in a severe lack of hydrodynamic and morphodynamic processes which used to characterized the floodplain ecosystem and produced its rich pattern of habitats and its biodiversity.

Rehabilitation measures need to address the deficiencies in the ecological functioning of the river ecosystem. Key parameters were defined and benchmarks described in Chapter 7. The impact of rehabilitation measures on the surface water and groundwater was investigated through hydrodynamic models. The biological response of measures was assessed for floodplain vegetation and fauna indicator groups, namely for fish. Results were summarized in Chapter 8. A detailed evaluation was carried out in Chapter 9.

Rehabilitation concepts

The variants described in Chapter 8 can be assorted into four rehabilitation concepts:

Concept		Measures
1	Accepting the separation between main channel and side-arm system	Present state + Increased discharge
2	Connecting systems by raising of bed levels in main channel	Narrowing variant, Optimum Filling variant + AFR
3	Connecting systems by raising of water levels (weirs with gates and sills in main channel)	SZITE variant, both Meander variants + AFR
4	Creating a lower secondary floodplain by lateral erosion	Widening variant + AFR

AFR = Altered Flow Regime

The definition of concepts indicates that none of the rehabilitation measures unambiguously serves all ecological functions expressed in the indicative parameter evaluation. The grouping into different rehabilitation concepts should rather emphasize the idea of combining variants in order to enforce ecological functioning based on model results and biological response.

Table 9-10 indicates the evaluation of key parameters and variants which will be discussed below.

Table 9-10 Evaluation of key parameters and measures

Concept	**1**	**2**		**3**			**4**
Measures / **Criteria**	**Present** mitig. meas. + AFR	**Narrowing**	**Opt. Filling**	**SZITE**	**Meander** (INTER.)	**Meander** (400)	**Widening** (lateral erosion)
Groundwater level increase	+	-	+	+	+	+	-
Groundwater dynamics	+	-	-	(-)	+?	-	-
Surface water level dynamics	(+)	-	+	-	+	+	-
Morphodynamics (habitat rejuvenation)	-	-	(+)	-	+	+	+
Lateral conncectivity	-	-	+	+	+	+	-
Longitudinal connectivity	+	+	+	-+	(-)	(-)	+
Rheophilic guilds*	-	-	-+	+	-+	-+	-
Flood conveyance		-	-	+	-	-	+

AFR = Altered Flow Regime (in this case it involvs a general increase of discharges for the Present state)

*) A comprehensive appraisal of the habitat conditions of rheophilic guilds of fish has to take the habitat quality criteria for adult (and juvenile) stages but also the habitat connectivity in form of lateral and longitudinal connectivity into account (Schiemer & Waidbacher, 1992). These aspects have been considered in the evaluation in Table 9-12.

9.7.1. Concept 1: Present state + Increased discharge

Rationale and measures

Since the lateral connectivity cannot be restored under the present conditions without the full discharge, this concept accepts the separation of the Danube and the floodplain with the branch system.

Measures. By engineering measures after the diversion the old side-arm pattern was changed into an interconnected system of branches with drop structures controlling water levels. The discharge released at the Čunovo barrage is divided at Dunakiliti between the Danube channel and the floodplain branches. A dynamic flow regime is imposed on the branch system with average discharges from 30 –150 m³/s and occasional peak flows above 200 m³/s which cause inundations mainly in the reach between Cikolasziget and Dunaremete and to a smaller extent in the Asványi branch system. The concept is based on optimizing the flow regime independently in the two systems.

Altered flow regime. A general increase of the discharge in the main *Danube channel* improves aquatic habitat conditions for certain rheophilic fish species. A considerable improvement, however, would be the large-scale restoration of gravel bars in the main channel (see below). This could only be achieved by an effective flood regime with competent flood flows rejuvenating habitats; i.e. reworking of bar sediments, establishing of pioneer vegetation and reworking again before the full development of softwood stands. Without further interventions, increased flows in the *branch system* would not significantly improve aquatic habitat conditions since the present flow regime already provides bankfull flows at seasonal variations.

Effective sharing of flood flows with regard to peak flows as well as to duration would also increase annual groundwater level fluctuations and inundations of terrestrial habitats emphasizing the dynamic character of the riverine wetland ecosystem.

Predictions on effects

Aquatic habitats: Although the diversity of aquatic habitats declined compared to reference conditions, the *main channel* still provides adequate flow velocities and substrates to support the rheophilic guilds of macrozoobentos and fish, despite the lower flows. The missing connectivity to the side branches remains as a major deficiency for the aquatic fauna. In the *branch system,* however, despite an average annual flow of 85 m³/s and occasional flushing, the habitat conditions are not suitable for rheophilic guilds. This is not only due to low flow velocities but to dominating fine sediments. Even higher flood flows are not competent to effectively mobilize fine deposits in the branch system. The potential for increasing flow rates into the branch system is limited by the channel geometry.

Transition zones. In 1970, the point bars in the *main channel* still existed with or without pioneer vegetation. These formed important transition zones especially since the river banks are protected by rip-rap (see Chapter 2.2.2, Map 2-6). By 2008, all point bars have been turned into terrestrial habitats carrying soft wood forest and shrubs (see Chapter 2.2.2, Map 2-7) and transition zones in the main channel are restricted to a narrow shore along the former point bars. In the *branch system* the reduction in gravel bars is similar to that in the main channel. Since most of the banks in the branches are not covered with rip-rap they represent an important transition zone. Even at higher flow the seasonal water level fluctuations (70-80 cm) would result in rather small areas compared to reference conditions. The potential for the development of pioneer associations is low. The key factor for habitat rejuvenation, flood induced disturbances, have not been taken into account in the vegetation model. Therefore the development of pioneer associations especially in the transition zones of floodplains – which are the characteristic “terrestrial” habitat type of active floodplains cannot be predicted by the model.

Terrestrial habitats. The model on the potential development of terrestrial vegetation is based on the water requirement of different vegetation types and the calculated groundwater levels (see Chapter 8). The model predictions for this variant with respect to the development of softwood forests - important from a conservation point of view - showed an improvement only at increased flow rates. All terrestrial and semi-terrestrial habitat types would certainly profit from frequent flood flows inundating the floodplain for at least some days.

Aspects of flood conveyance. Deficiencies in freeboard allowance in the lower project reach are caused by a lack of conveyance capacity of the Danube below the confluence. No measures in the project reach can effectively contribute to the lowering of flood levels in the reach near the confluence because of the backwater effect.

Possible improvements of the concept

In the *main channel*, a lowering of the vegetated point bars to the prevailing water level could re-establish gravel bars and pioneer stands if this measure were to be coupled with an effective flood regime. A certain area of the vegetated point bars should always be left as a natural river bank. Feeding an appropriate amount of sediments into the main Danube channel may be necessary to support and maintain the envisaged processes. At selected locations in outer banks the rip-rap should be removed on short reaches to initiate local scouring and small-scale lateral erosion to increase habitat diversity and provide bed material. Regular monitoring could assist to control undesired effects.

In the *branch system* the removal of drop structures should be considered in order to improve flow velocities and possibly the composition of substrates in some reaches. At the lower project reach the Bagameri branch should be integrated into the system and the construction of a drop structure considered at the last junction into the Danube.

Long-term perspective

In the long term, the *main Danube channel* could probably shelter most species of the present aquatic fauna if habitat improvement measures were carried out. The missing connectivity with the floodplain will reduce the carrying capacity of rheophilic guilds and – on a long-term perspective - will reduce its species richness. The functional aspects of floodplains, e.g. nutrient retention and carbon sequestering will be reduced. In the *branch system* some short reaches still provide suitable habitat conditions for rheophilic species but the majority of the branches experience deposition of fine sediments. Parapotamon and plesiopotamon water body types would be endangered by siltation and gradually turn into terrestrial habitats. The long-term development of terrestrial habitats will mainly be groundwater dependent with a lack of rejuvenation.

9.7.2. Concept 2: Connecting systems by raising of bed levels

Rationale and measures

The concept “Raising of bed levels” envisages raising bed levels and discharges in order to re-establish side-arm connectivity. The raising of bed levels is equivalent to a narrowing of the channel. Both measures diminish the conveyance capacity of the channel.

Measures. Modelling included a Narrowing variant which increased the height of the existing point bars, - covering 1/3 of the riverbed -, by 2 m. In the Optimum Filling variant, the entire riverbed was filled up by 3-4 m raising the water level at 350 m³/s to the mean flow level of the 1950s. At this stage of investigation it was not explored from which source the material would come.

Altered flow regime. Any filling or narrowing variant producing water levels below the Optimum Filling variant would need to increase discharges. Otherwise the lateral connectivity would not be re-established. In addition, the sharing of flood flows would be needed to initiate channel forming processes including natural armouring as described below.

Predictions on effects

The Narrowing variant proved to be ineffective for the raising of water levels since the top of most points bars was above the prevailing water levels. With the Optimum Filling variant it was explored as to which level the bed would be needed to be filled up in order to reach side-arm connectivity. Actually, the two variants represent border conditions of the concept “Raising of bed levels”, and rehabilitation measures according to this concept would need to define both, bed levels and increased discharges. It is obvious that the level of filling (and/or narrowing) would need to be close to the “optimum” level in order to maintain adequate energy production at Gabčíkovo HPP. Nevertheless, expected habitat conditions can be discussed based on existing results.

Aquatic habitats. With the filling of the *main channel* new point bars would develop rapidly at the same locations and on a similar length as the existing ones. Erosion, transport and deposition would eventually result in a riverbed adapted to the prevailing flow regime and available sediments. Channel forming processes would increase habitat diversity: deeper channel sections would occur as well as shallows. In the *branch system* aquatic habitat conditions will not change compared to the Present state. With the Optimum Filling variant the enhanced lateral connectivity to the *branch system* could be reached at higher flow rates representing a considerable improvement.

Transition zones. New bar formation would improve transition zones in the *main channel.* In the *branch system* no change can be expected. With filling of the main channel reduced water level fluctuations were observed which could be avoided by the use of adequate techniques (see below).

Terrestrial habitats. Groundwater levels would be raised considerably all along the main channel. A decrease of groundwater fluctuations was observed, however, due to smaller ranges of surface water level fluctuations. This is a disadvantage for the long-term development of terrestrial vegetation in this variant.

Aspects of flood conveyance. The Optimum Filling variant violates freeboard requirements on most of the project area. Providing the necessary freeboard allowances for flood protection will considerably restrict the freedom of channel elevation and narrowing.

Possible improvements of the concept

Water levels can be increased by raising bed levels or by a narrowing of the bed. Effective narrowing of the bed would result in higher water level fluctuations with changing discharges than would the raising of the channel bed. In practical planning a compromise of narrowing and raising bed levels would have to be found similar to the envisaged channel form of the WWF proposal. This would also increase groundwater level fluctuations.

Morphological modelling results indicated that riverbed stability may not be endangered. Natural armouring of the bed could be expected by grain sorting processes. The long-term behaviour would need to be verified in further planning phases.

Long-term perspective

The long-term evolution of the main channel may need to compensate loss of sediments by input of material. An effective flood regime would be necessary to prevent the development of softwood forest stands on higher elevations. For floodplain habitats and the branches the long-term perspectives remain unchanged compared to the Present state.

9.7.3. Concept 3: Connecting systems by raising of water levels

Rationale and measures

Raising water levels by impounding instead of diminishing the conveyance capacity of the channel is another concept. The main objective of this concept is to raise surface and groundwater levels by impounding the main channel and restore connectivity with the side branches. The Meander variants seek to maintain the free flowing character of the river and transfer ecological functions from the main channel to the meander branch, i.e. suitable habitat conditions for all life stages of rheophilic fish. This requires a broad range of flow velocities not only along the meander course but also on reach level in the close neighbourhood. Associated with different flow velocities is the diversity of substrates from coarse gravel to fine sand on local areas (patches).

Measures. In the course of the study several proposals with a different numbers of weirs (weirs with gates and/or bottom sills) were discussed and finally three variants were selected for further investigations, i.e. the SZITE variant with 3 weirs with gates and two Meander variants with 7 bottom sills and different capacities in the meander branch. The Meander (INTERREG) version still maintained the present flow distribution between the side branches and the main Danube channel. The Meander (400) version would reverse the flow distribution and carry up to 400 m^3/s in the meander branch leaving only a residual flow in the main Danube channel which was assumed to be 50 m^3/s in modelling. Supporting 400 m^3/s across the Danube requires higher crest elevations of the sills for this variant (Table 9-2). All variants in this concept included the Bagomer branch either as part of the meander channel or as a connected side branch.

Altered flow regime: For the SZITE variant, especially in the main channel, habitat conditions could be improved with higher discharges. In addition, an effective flood regime would support floodplain habitats and prevent siltation of the impoundments to a certain extent. The Meander (INTERREG) variant would also profit from higher discharges. The Meander (400) version does not depend on discharge increase if a small residual discharge in the main channel can be accepted. Sharing of flood flows mainly supports terrestrial habitats.

Predictions on effects

Aquatic habitats. In the *main channel* the SZITE variant leads to rather uniform flow conditions especially in the upper impoundments. Sand sediments will dominate the substrate. Most of the point bars will be impounded and cannot contribute to habitat diversity. Altogether, aquatic habitat conditions will deteriorate compared to the Present state. In the *branch system* the enhanced lateral connectivity of the SZITE variant compared to the Present state however represents a considerable improvement.

The Meander (400) variant fully impounds the main channel turning it into a nearly stagnant water body with flow velocities of 5-10 cm/s and fine sediment deposition. In the Meander branches both versions produce flow velocities that are similar to the Present state at 200 m³/s in the main channel (Table 9-6). The width of the Meander (400) branch is similar to the actual width of the present Danube channel at prevailing flows (150-200 m, Figure 9-6). The shear stress distribution along the branch indicates a high potential for channel evolution on most of its length (Figure 9-14). Point bar development, scouring along outer banks, aggradation and degradation in short reaches can be expected rendering diverse habitat conditions for the aquatic fauna. Undesired evolution of channel pattern can be controlled by appropriate measures.

Transition zones. The SZITE variant produces considerably smaller water level fluctuations in the *main channel* and in the *branch system* than the Meander variants. With appropriate operation of the gates the range of fluctuations could be increased with SZITE variant (see below). At the elevated impoundment levels in the *main channel*, however, the water level fluctuations occur at the channel banks covered with rip-rap which is unfavourable for the ecological functions of transition zones.

For the Meander variants the range of fluctuations in the branches by far exceeds the present values[35] and the resultant transition zones are situated along unprotected banks (for most of the branches). In addition, the expected channel evolution with point bars in the meander branch of the Meander (400) version would contribute to the extent of transition zones.

Terrestrial habitats. The predictions for the long-term vegetation development dependent on the groundwater level are clearly better for the Meander variants compared to the SZITE variant: this concerns the characteristic soft wood forests and wetlands. The range of groundwater level fluctuations could be increased for the SZITE variant with an adequate

[35] The total range may be overestimated for technical reasons, but the tendency is correct.

operation mode of the gates (see below). Only the Meander variants have a limited potential for terrestrial habitat rejuvenation in the meander branch corridor.

Aspects of flood conveyance. The SZITE variant increases the freeboard allowance by 10-20 cm in the central and upper reach where no deficiencies exist today. For reasons explained above it cannot contribute to increase flood safety in the lower reach influenced by the backwater effect. The Meander variants would violate freeboard requirements without increasing the discharge capacity of the bottom sills by gates (see below).

Possible improvements of the concept

In the SZITE variant the removal of drop structures should be considered in the *branch system* in order to improve flow velocities and possibly the composition of substrates. The implementation of a branch crossing the Danube at the weirs ("small meander solution") could be associated with the SZITE variant and provide new opportunities for the branches.

The operation of the gates in the SZITE variant could be used to increase the range of surface and groundwater level fluctuations. An appropriate operation mode could be worked out which includes the opening of the gates to create lower water levels. Adapations in the side branches would be needed to prevent depletion at open gates.

In further planning the location and number of weirs could be reconsidered for the Meander variants. For better flood performance the weirs of the Meander variants should be constructed in a similar way to the SZITE weirs. In further planning steps the integration of the side-arm system in the case of the Meander (400) version needs to be worked out.

Long-term perspective

It is likely that fine sediments accumulate in the impoundments of the Meander variants deteriorating aquatic habitat conditions in the main channel. On the other side the Meander variants are the only options for rejuvenation of habitats in the branch system within certain limits, e.g. the fixed points of the meander branch crossings at the main channel.

9.7.4. Concept 4: Creating a secondary lower floodplain by lateral erosion

Rationale and measures

In this concept it is accepted that the main channel and the present floodplain remain separate systems. Lateral connectivity would not be possible. The long-term development of a lower secondary floodplain was evaluated as an ecosystem in itself. The envisaged evolution of a lower secondary floodplain is a long-term concept developing over decades. This concept had not been studied in detail. Some principal investigations were carried out in morphological modelling, and - based on assumptions of a future bed level – its hydrological response was explored. Its long-term consequences on the landscape and ecology of the study area need further investigations. Nevertheless, the concept is worthwhile to be presented and considered in future discussions.

Its general idea is to re-establish channel evolution forces by the removal of lateral constrictions. With an effective flood regime channel forming processes could be expected similar to the natural system, but on a smaller scale. Eventually, landscape elements of a new floodplain would develop on a lower level in a widening river corridor.

Measures. At appropriate locations the bank protection would be removed in order to trigger lateral erosion at flood flows. With bankfull flood discharges above 3,000 m^3/s occurring a few times per year for several days or even weeks it is expected that bank sediments gradually fill up the bed to a certain level during the process of widening. Over decades a secondary floodplain would develop with channels and gravel bars and vegetated islands leaving the present floodplain as a terrace. The side-arm system would still be supplied, and with continuous widening adaptations would have to be carried out. The change of the flood regime is a prerequisite for this variant, as detailed next.

Altered flow regime. Sharing flood flows to provide bankfull discharges of sufficient duration in the main channel is an essential element of this concept. Effective lateral erosion providing material for channel evolution only occurs at near bankfull flows with longer durations. Habitats on the higher floodplain would also profit from larger and more frequent and larger fluctuations of the flow.

Predictions on effects

Aquatic habitats. Gradual widening, transport and deposition and local scouring of the *main channel* would eventually result in a riverbed adapted to the prevailing flow regime and according to available sediments from bank materials. Channel forming processes would increase habitat diversity: deeper channel sections would occur as well as shallows. The development of islands over decades would increase the length of the productive shoreline. The aquatic fauna would profit from habitat diversity. The missing connectivity to the former floodplain water bodies would be compensated in a perspective over many decades. The *branches in the old floodplain* would not change compared to the Present state. Habitat conditions will remain suboptimal for rheophilic fish.

Transition zones. With the formation of bars and vegetated islands transition zones of high quality would develop in the *main channel*. Smaller ranges of water level fluctuations would find equivalent differences in elevation on the new level of the secondary floodplain. No change compared to the Present state could be expected in the *side branches*.

Terrestrial habitats. As long as the supply of the side-arm system is not changed the long-term development of terrestrial habitats over the present Szigetköz floodplain area would be similar as in the Present state. Predictions depend on the average flow rates. Groundwater levels would be maintained, fluctuations of the groundwater level would be reduced mainly in the upper part of the project reach. The advantage and quality of this concept would be the potential of creating new terrestrial and semi-terrestrial habitats and habitat successions within the main channel. Their persistence and quality largely depends of the imposed flow regime.

Aspects of flood conveyance. The widened channel would provide additional freeboard allowance for flood protection. As outlined above the deficiencies in freeboard of the lower reach cannot be resolved by measures in the area above the confluence.

Possible improvements of the concept

Lateral erosion processes may be inhibited by cohesive sediments built up to great height on the floodplain. Erosion could be enforced by mechanical removal of bank material which will be distributed over the river bed, and by guiding structures (groynes) built from rip-rap removed from the banks in order to accelerate channel formation. Adequate techniques would need to be explored in the field. Mechanical removal of the cover layer in short reaches along the banks may also facilitate widening and would avoid additional load of fine sediments.

Long-term perspective

In a long-term perspective the secondary floodplain could represent a broad corridor within the present floodplain sheltering similar habitat diversity as the natural river system but on a smaller scale. In the long run sediment management including available deposits from the upstream reservoir may be needed to maintain the system. The surplus of sediments that will be carried continuously to the Danube reach suffering from incision below the confluence is another positive aspect to be considered in this concept.

9.7.5. Concluding remarks

The purpose of this study was to provide a sound data basis for future decisions on rehabilitation measures on the Danube reach affected by the Gabčíkovo Hydro Power Plant. Environmental objectives were delineated and a benchmarking system with indicative parameters was established based on an analysis of reference conditions. Constraints by water use and flood protection were taken into account. The hydrodynamic and morphodynamic performance of the present state and of selected measures was studied with surface water and groundwater modelling. Biological indicator groups were investigated based on monitoring results.

None of the measures investigated proved to be the “ultimate variant”; the greatest challenge remains: re-activating of morphodynamic processes which could rejuvenate river and floodplain habitats. This driving force which used to govern the natural system was deprived of annual competent flood flows and of bed load supply from the catchment. **Any measure which fails to initiate competent hydraulic forces for bed load transport and lateral erosion and which fails to allow for such processes will not maintain the biodiversity of the Szigetköz floodplain ecosystem in a long-term perspective.**

This is the reason why “non-traditional” measures were included in the study and presented as a basis for discussion, i.e. the “Widening variant” which envisages the long-term evolution of a lower secondary floodplain and the “Meander (400) variant” which creates a new large meandering channel on the floodplain level.

Any further planning should make use of this valuable resource of data produced in hydrodynamic models and ecological investigations. On this basis the impact on habitat conditions and biota can be assessed using the criteria outlined and applied in this study.

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11. Appendices

Appendix 1 - The evaluation of the present state of the Szigetköz system applying the WFD scheme (G. Guti)

The Water Framework Directive strives for good ecological conditions in all surface waters, and it implemented a monitoring network and standardised assessment methods to observe the ecological status of the water bodies. The ecological status of the water bodies in Hungary were evaluated according to the WFD and ECOSTAT protocols in 2008. The quality classes of the ecological potential in the heavily modified water bodies have not yet been described, and their classification was based on the assessment of the ecological status.

Most of the surveys were executed from 2007 to 2008. Assessments of the quality classes were based on the ecological evaluation of the biological objects (phytobenthos, phytoplankton, macrophyta, macroinvertebrate and fish) and physico-chemical elements of the WFD, as well as chemical evaluation of priority hazardous substances and other components considered by ICPDR. Classification does not include the results of hydro-morphological evaluation.

Table 11 Assessment of the ecological status in the Rajka – Gönyű (Szigetköz) section of the Danube. Quality grades: 5 = excellent, 4 = good, 3 = moderate, 2 = poor, 1 = bad; Confidence levels: 3 = high, 2 = medium, 1 = low.

vt-VOR NAME	**AEP443** **Rajka - Gönyü**
average of phytobethos grade in the water body	3,9
phytobenthos grade by expert judgement	4,0
confidence of the phytobenthos grade	3,0
average of phytoplankton grade in the water body	5,0
confidence of the phytoplankton grade	2,2
average of macroinvertebrate grade in the water body	3,6
maximum of macroinvertebrate grade	5,0
confidence of the macroinvertebrate grade	2,0
average of fish grade in the water body	3,2
maximum of fish grade	4,0
confidence of the fish grade	3,0
physico-chemical grade	4
confidence of the physico-chemical grade	3
priority parlous substances in excess of limit	1
Integrated grade (ECOSTAT)	**1**
Integrated grade (weighted average)	**3,9**

The Szigetköz section of the Danube is one water body (AEP 443) in the Hungarian surface water typology system. It ranges from Rajka to Gönyü and it is a heavily modified water body. An evaluation based on macrophytes has not been carried out so far. The assessment of the ecological status in the Rajka – Gönyű river section is summarised inTable 11.

The integrated quality class of the ecological status was determined by the worst of the standards (one bad all bad principle) according to the WFD and ECOSTAT. An indicative alternative evaluation has been carried out, which determines the final quality class by the confidence-weighted average of the standards, but this method does not conform with the WFD.

The integrated grade of the ecological potential was bad because of the fact that the priority hazardous substances were in excess of the limit and the integrated grade. However the final quality class by the confidence-weighted average indicates good ecological potential.

According to the final result of the assessment, the WFD evaluation system is not indicative of environmental problems for the Szigetköz section of the Danube. Another problem of the evaluation system is that it does not distinguish the several types of floodplain aquatic habitats.

Appendix 2 - Habit Model Description (András Gubányi and Richárd Wohlfart)

Prior to the development of the simulation model for the floodplain of the River Danube in the Szigetköz region the following (pre)conditions were to be met: (i) assessment of the status of habitats along with the determination of the different types thereof; (ii) specification of the optimal water supply of habitats indicating the favourable groundwater level that satisfies the water demand of vegetation; (iii) follow up of changes in groundwater levels most characteristic of the ecological status of habitats; (iv) defining the succession scheme showing the conversion of the certain habitat types, as a function of changes in the water supply (Fig. 3); (v) determination of the upper gravel surface layer on the floodplain of the river Danube in the Szigetköz region; (vi) computation of the Digital Surface Model (DSM) of the floodplain using a 25m × 25m grid structure; (vii) analysis of the collected data using a wrapper program (powered by Clarion PE 6.0) being able to create the input matrix of the simulation program.

Assessment of the present status of habitats along with the determination of their types

For determining the initial conditions of the spatial distribution of habitats the high resolution, infrared aerial photos by Vituki-Argos in 2008 were used. Data gathered from former vegetation surveys and results of recorded filed excursions were also used. Habitats were demarcated by a 25m × 25 m sized grid equal to the resolution of data on the upper gravel surface layer. The methods used in habitat mapping were based on the classification system of ÁNÉR (Figure 1). These categories were simplified and pooled into 10 main habitat types (Figure. 2).

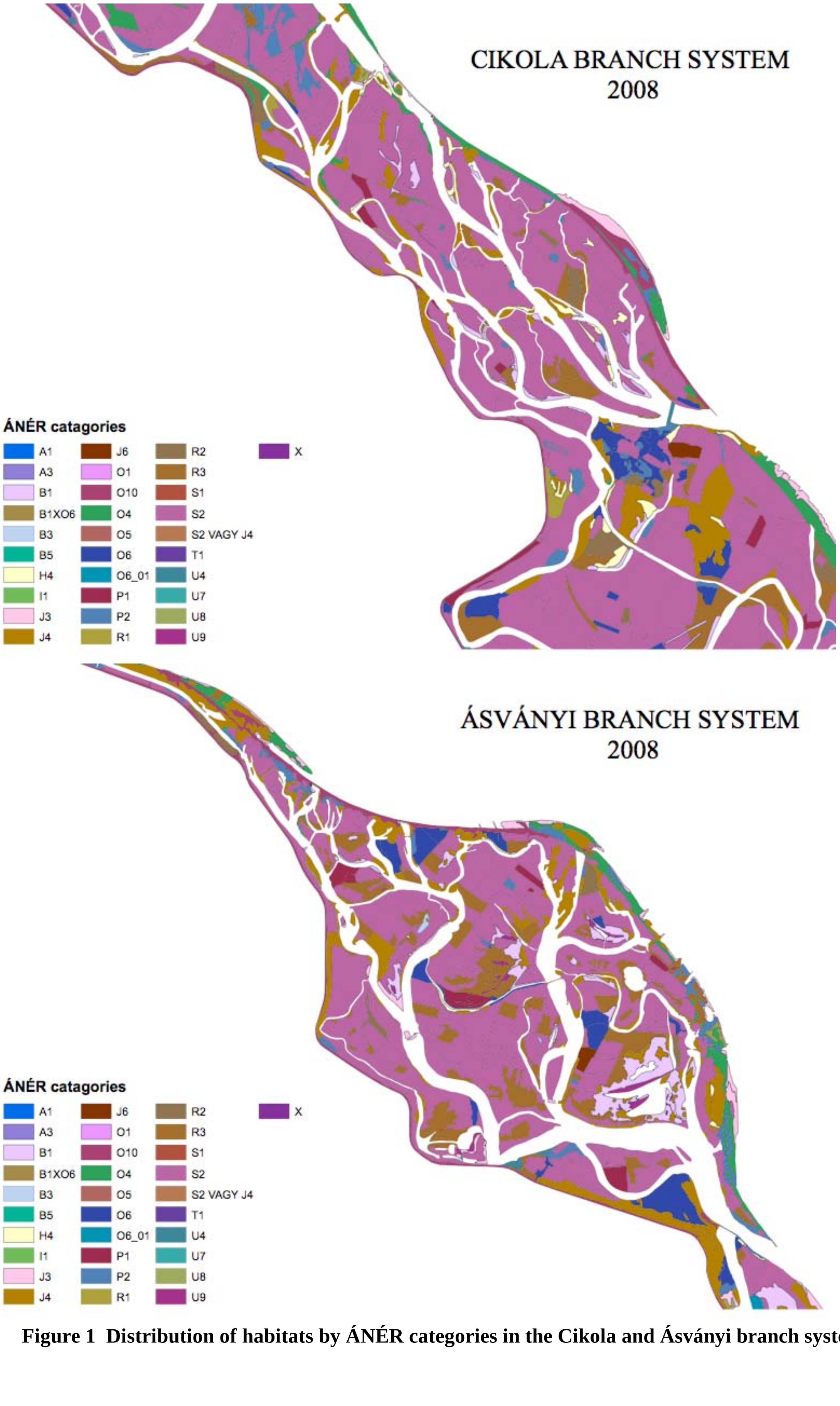


Figure 1 Distribution of habitats by ÁNÉR categories in the Cikola and Ásványi branch systems

Based on the data from the mapping and succession scheme, as well as on the theoretically predicted forms of vegetation, the following 17 potential aggregated habitat types (Figure 14) were set up for the model:

0. Alluvial forests - 91E0
1. Hybrid poplar plantations
2. Hardwood forests (semi-natural)
3. Fresh closed oak woodlands - 91F0
4. Reed and Typha beds, non-tussock beds of large sedges
5. Lowland wet degraded grasslands
6. Paleopotamon
7. Ruderal and semi-ruderal riverine communities
8. Drying degraded grasslands
9. Acer negundo
10. Pleisopotamon
11. Alder and willow swamp
12. Riverine alder woodlands
13. Tall herb
14. Reed beds non tussock beds of large sedges / anaerobic
15. Riparian mixed forests - 91F0
16. Clear-cut scrub

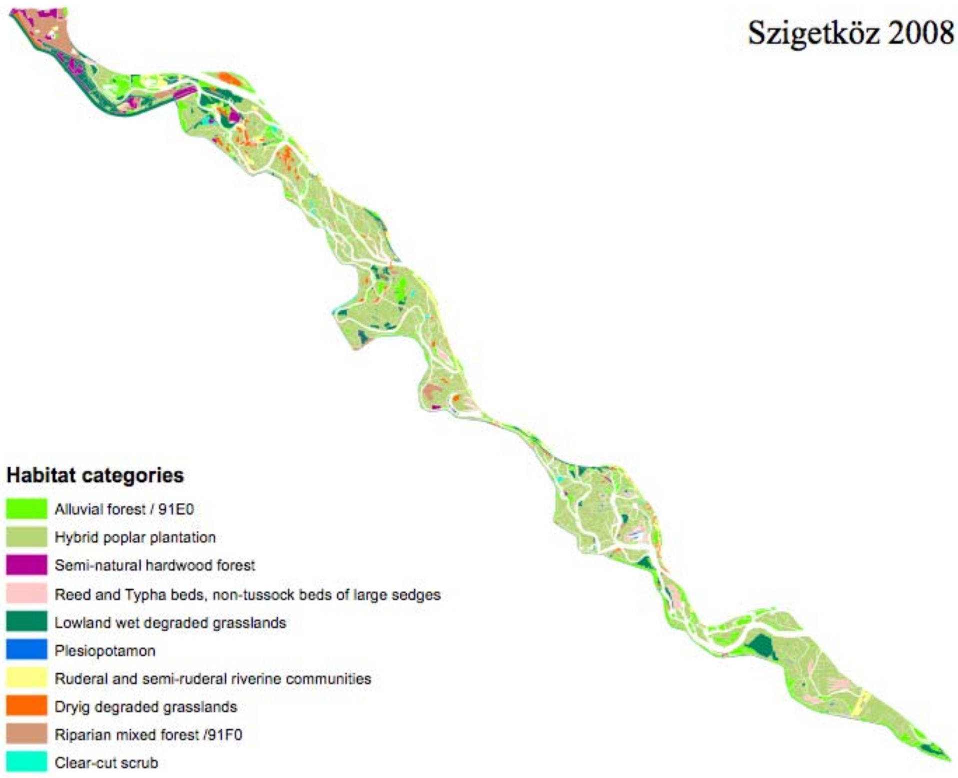
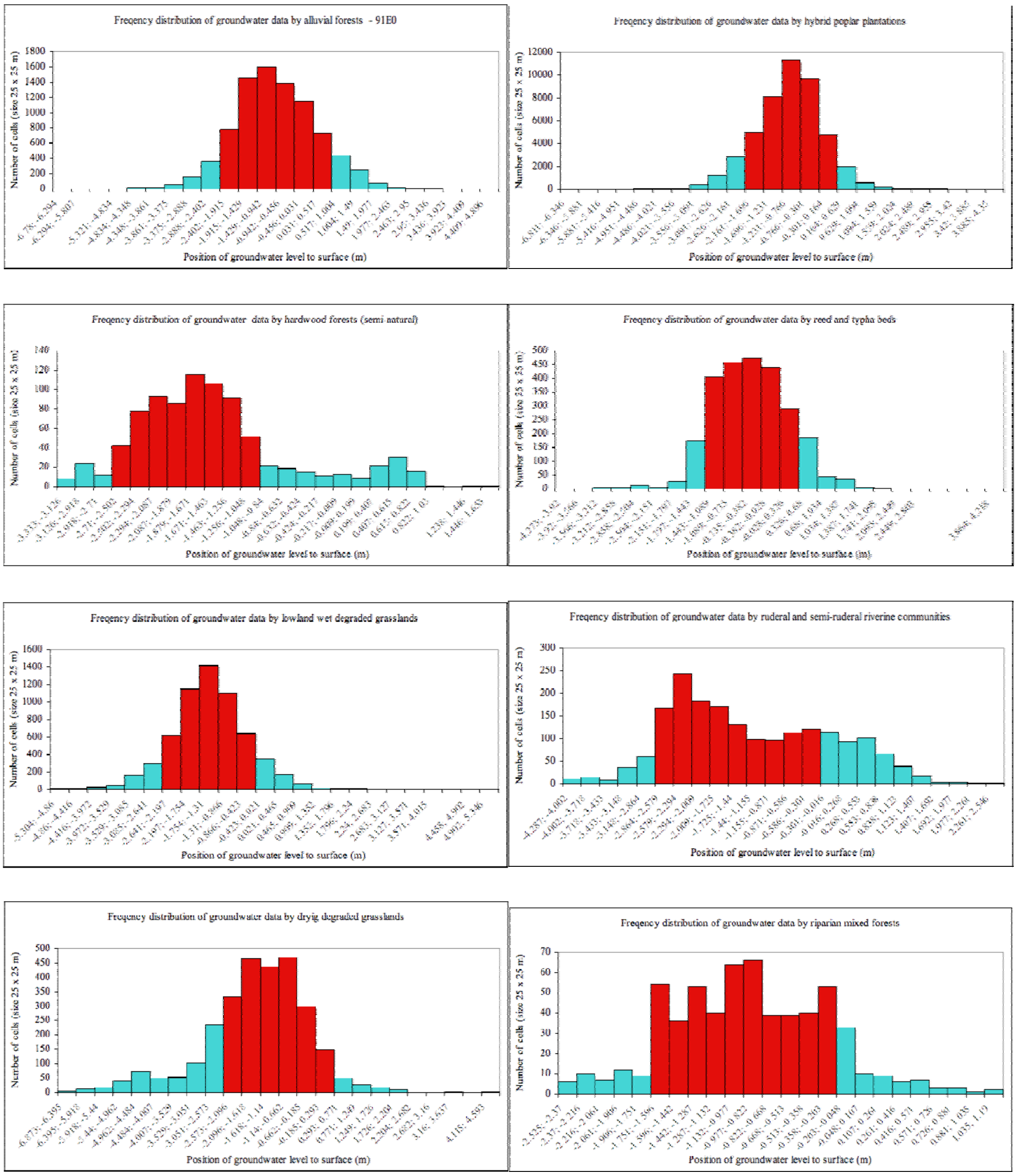


Figure 2 Aggragated habitat types of the floodplain of the Szigetköz

Specification of optimal water supply

The frequency of groundwater level distribution of the particular aggregated habitat types was determined using the data gathered from habitat mapping and the distribution of groundwater levels (data on groundwater of the "present" variant 750+120) follows a theoretically quasinormal distribution. For the determination of the optimal range of a given habitat type the 70-75% range of the distribution curve was considered (see Figure 3). Lower and upper thresholds of the optimal range were used for generating the input matrix of the simulation calculations hereafter. Values for predicted habitat types were extrapolated from the distribution pattern of groundwater levels by aggregated habitat types.



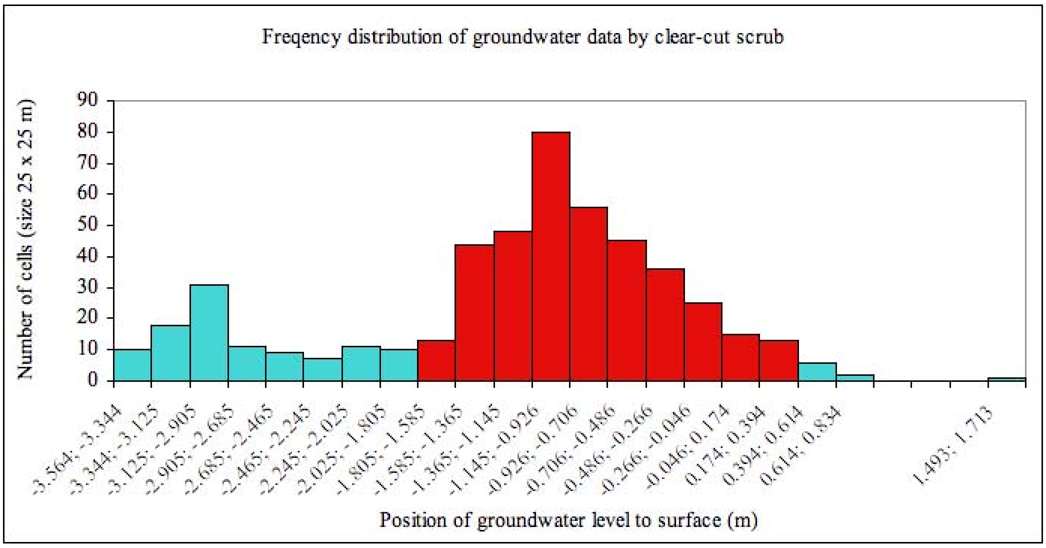


Figure 3 Frequency distribution of groundwater data by different terrestrial habitats (red bars represent the optimal range of groundwater level distribution for a given habitat type)

Table 1 Optimum range of groundwater level by terrestrial habitats

Habitat type	Min (m)	Max (m)
Alluvial forests - 91E0	-2.4	0.5
Hybrid poplar plantations	-2.2	0.2
Hardwood forests (semi-natural)	-2.7	-1.1
Fresh closed oak woodlands - 91F0	-6.0	-2.7
Reed and Typha beds, non-tussock beds of large sedges	-1.4	0.3
Lowland wet degraded grasslands	-2.6	-0.4
Ruderal and semi-ruderal riverine communities	-2.9	-0.0
Drying degraded grasslands	-2.6	0.3
Acer negundo	-3.0	-1.0
Alder and willow swamp	-0.5	1.5
Riverine alder woodlands	-1.7	-0.2
Tall herb	-1.5	-0.4
Reed beds non tussock beds of large sedges / anaerobic	-0.5	0.5
Riparian mixed forests - 91F0	-1.7	-0.2
Clear-cut scrub	-1.8	0.4

Simulation of the changes in the ground water level was carried out for four different water discharges (200 + 40, 350 + 80, 550 + 120, 750 + 120 m^3/s), taking the factors of leakage of the 1D hydromorphological model into account. In cases where the simulated levels of the ground water reached the surface, data (750 + 180 m^3/s) from 2D hydromorphological model were also taken into account in order to fix the parameters of different background variables.

Four different yearly water discharge profiles were constructed and used for the further computation, based on the hydrological data sets provided by EDUKOVIZIG and ecological water requirements of terrestrial habitats (Figure 4). Type "A" and "B" profiles mapped the years 2007 and 2005, when the total water discharge shows min and max values, respectively. Type "C" was calculated by theoretical dynamics of water requirement of terrestrial habitats. The last variant, type "D" represented the maximum water discharge that was implemented by the groundwater model analyses. Vegetation season was fixed between April 15 and October 15, and water discharge levels were defined by two-week periods.

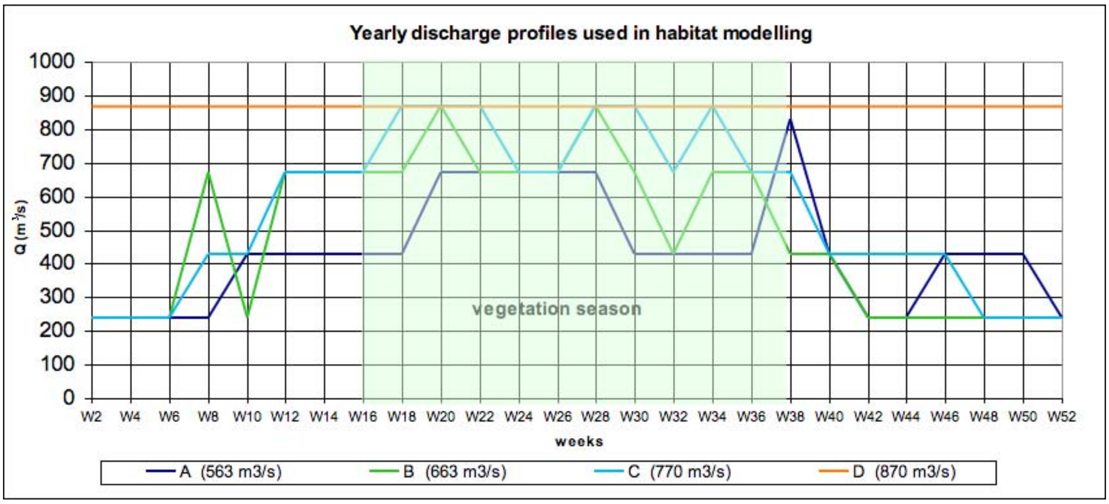


Figure 4 Yearly discharge profiles used in analyses (green area represents the vegetation season).

The following programmes were used for the evaluation of basic data: Q-GIS, LandSerf and Clarion PE 6.0.

Computation of the digital elevation model (DEM) of the floodplain

The digital elevation model was built by the Department of Hydraulic and Water Resources Engineering (Budapest University of Technology and Economics) using the most recent survey data available. This data comprised river cross-sections, scattered survey of the floodplain, sounding survey of the main riverbed, and aerial photography covering the whole area. A detailed description of the model was presented in a research report on 2D hydrodynamic modelling of the impact on surface waters (Józsa et al. 2009)**.**

Determination of the upper gravel surface layer in the floodplain of the river Danube in the Szigetköz region and interaction between the groundwater level and soils

Based on the evaluation of the data of the Geological Institute of Hungary (MÁFI) and on aerial photos, the map of the gravel layer was manually constructed initially at 0.5 m resolution. This document was then digitalized using MicroStation95, and finally processed with the aid of Intergraph Co.MGE software package.

As expected, the resolution of the surface model defining the upper gravel surface layer did not reach the limit value of the digital surface model as a consequence of the uneven distribution of the drilling data, though it could still be applied with acceptable accuracy for control calculations. In addition to these results the data series of actual geological monitoring carried out at nine points since 1995, were also used in order to construct the proper graph of the surface. In the present study, ArcGIS 9.2 was applied to convert data into ESRI shape format and to compute the 25m grid model for the floodplain. For reference, the data of the geological map made by MÁFI and the Geological Institute of Bratislava (Štátny geologický ústav Dionýza Štúra – ŠGÚDŠ) were used within the framework of DANREG in 1997, digitally published in 2000, representing the 25km-wide track along both sides of the river Danube. Having been calibrated several times, the grid model computed in this way was finally crosschecked with the digital surface model, thus resulting in the model of the upper gravel surface layer (Figure 5).

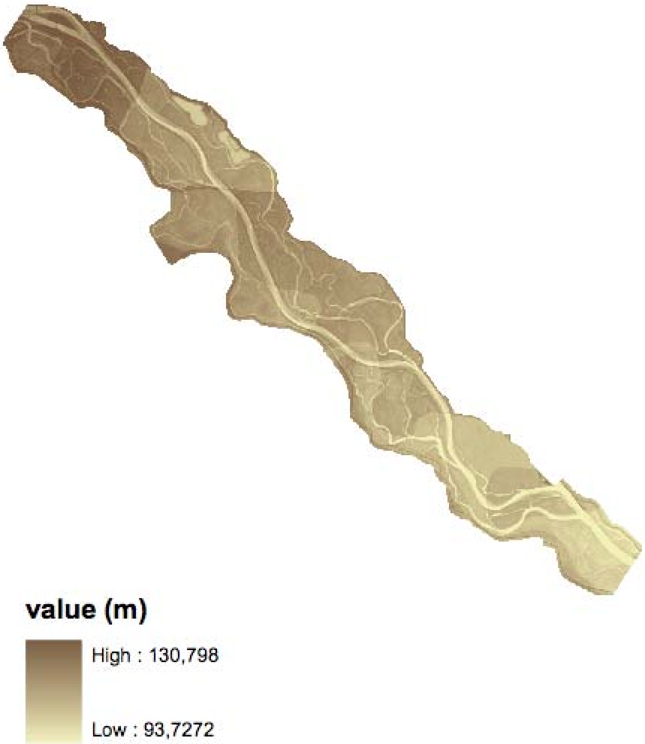


Figure 5 The upper gravel surface layer in the floodplain

The piesometric head of groundwater by a 25m grid have usually been situated above the upper gravel surface layer for all 8 tested variants (increase of discharge, SZITE, meandering (400), meandering INTERREG, widening, widening (Jaeggi), optimum filling, narrowing side-arms closed, see Figure 6-13).

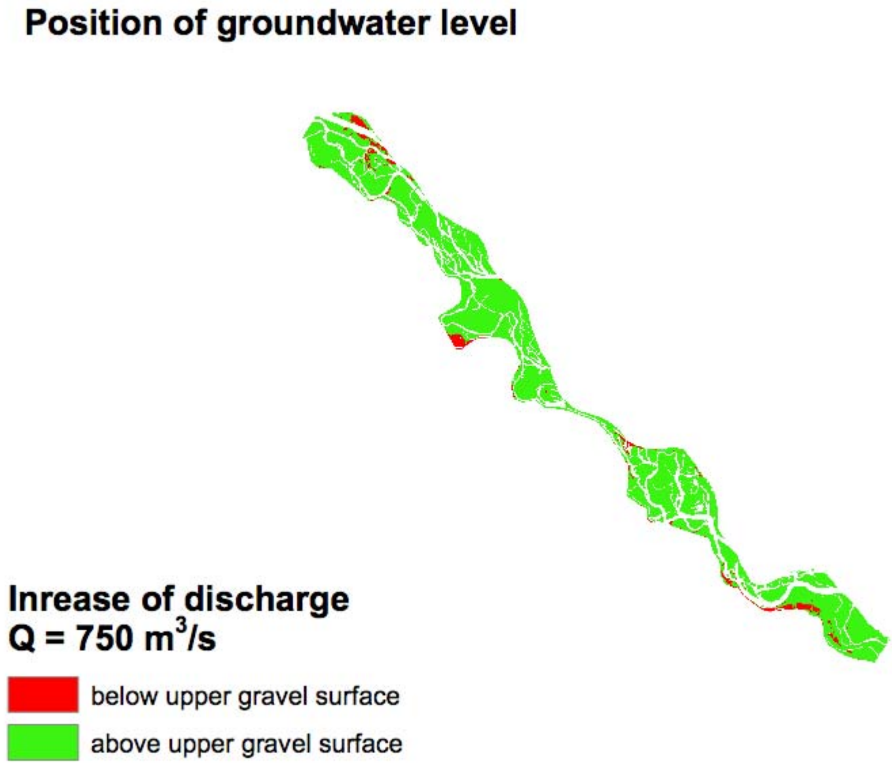


Figure 6 Increase of discharge - Interaction between the groundwater level and soils

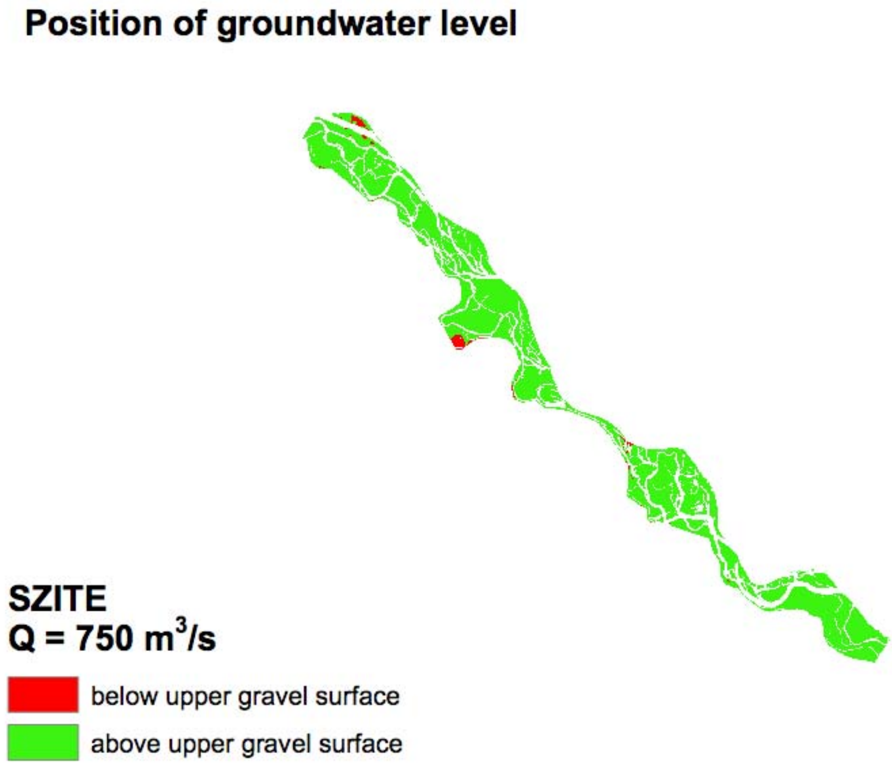


Figure 7 SZITE - Interaction between the groundwater level and soils

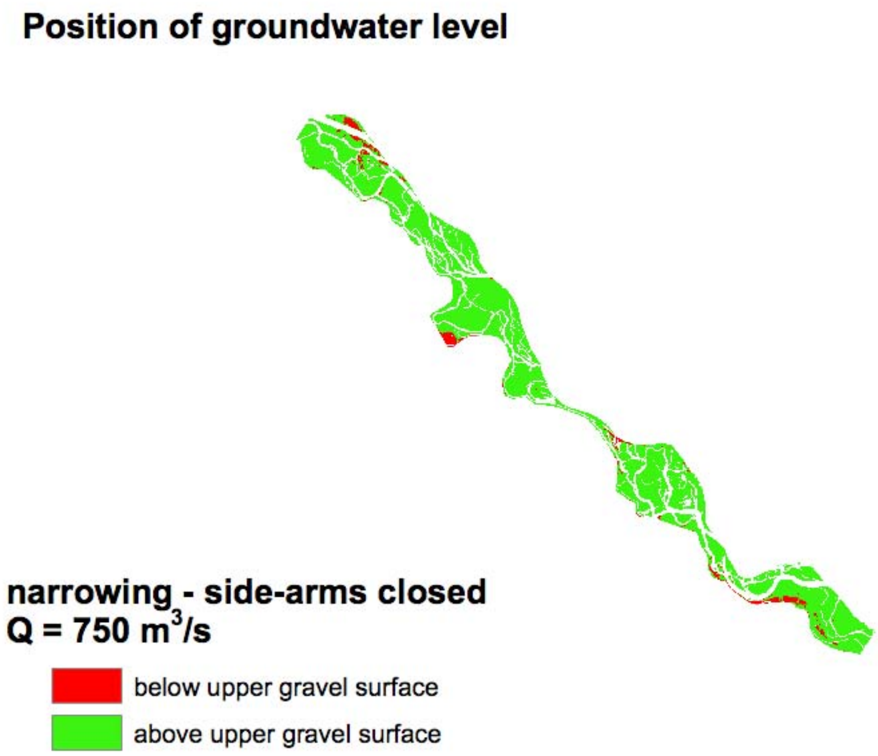


Figure 8 Narrowing, side-arm closed - Interaction between the groundwater level and soils

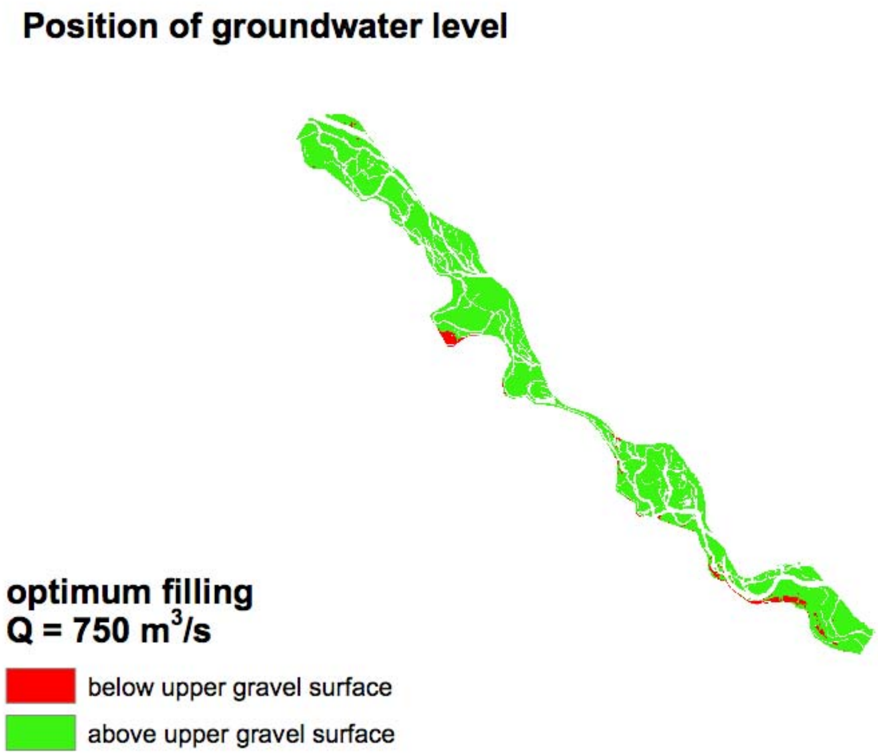


Figure 9 Optimum filling - Interaction between the groundwater level and soils

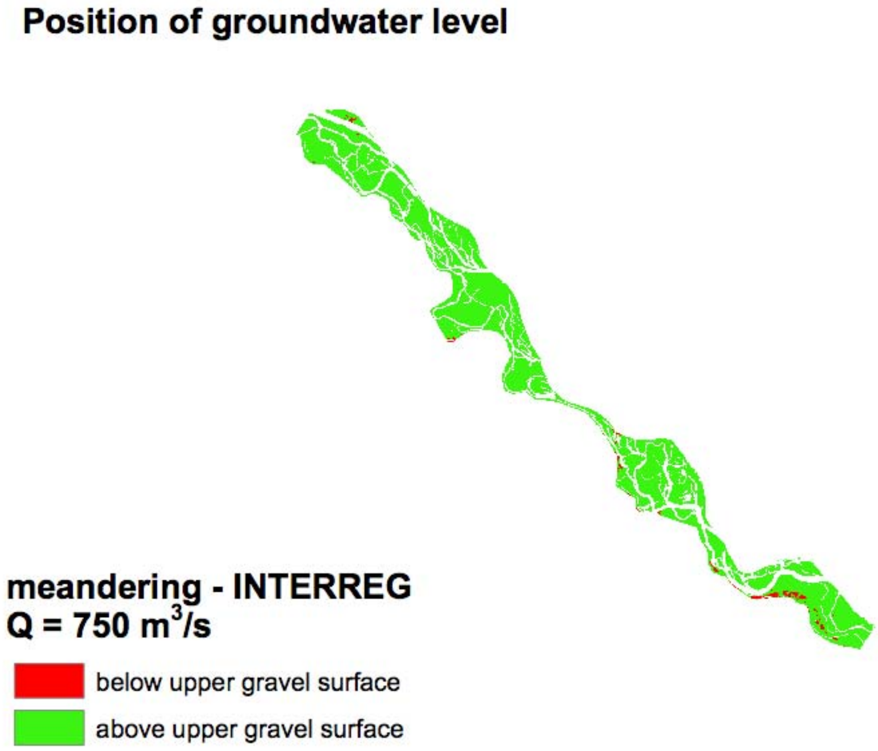


Figure 10 Meandering (INTERREG) - Interaction between the groundwater level and soils

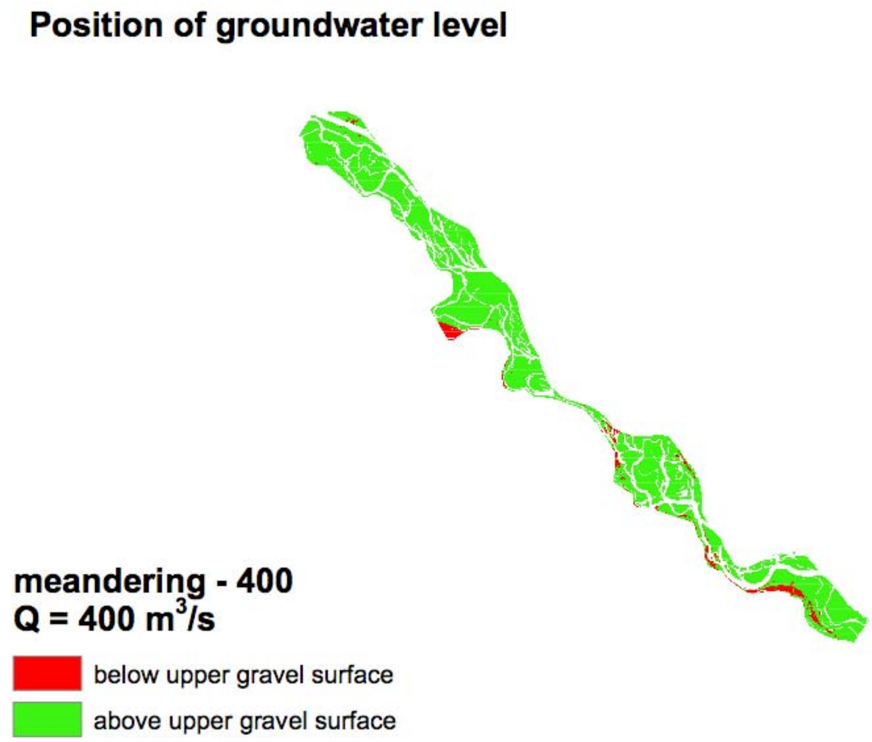
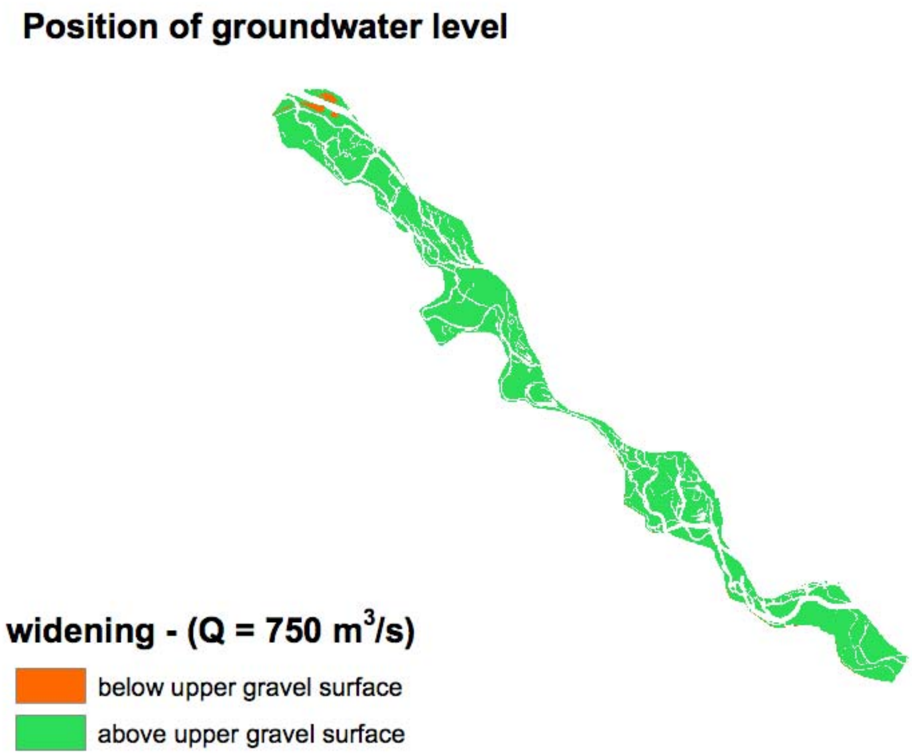
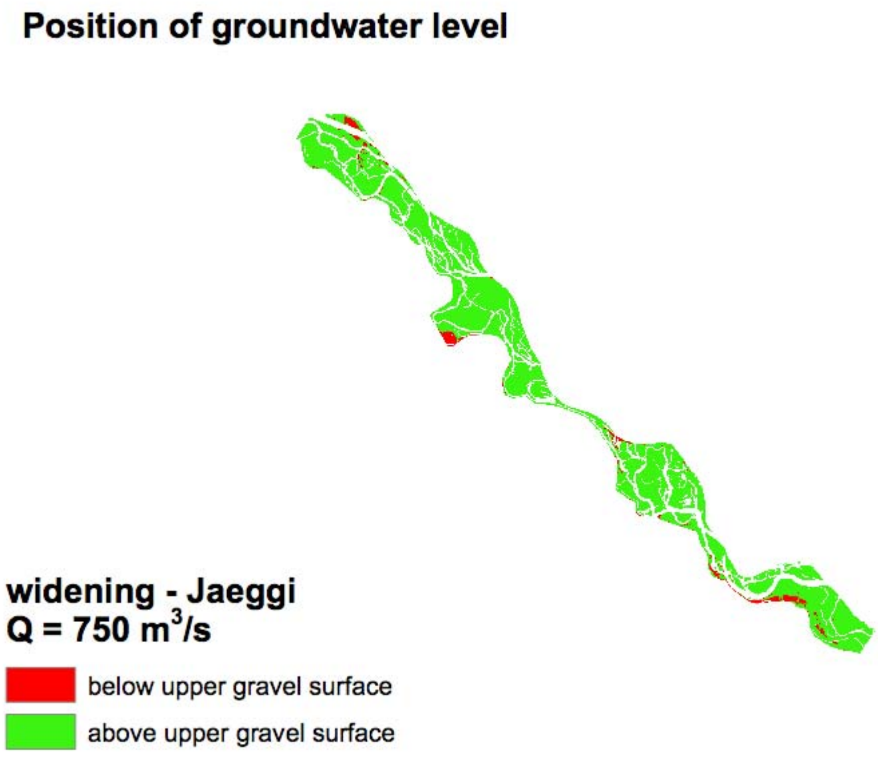


Figure 11 Meandering () - Interaction between the groundwater level and soils



Figuer 12 Widening - Interaction between the groundwater level and soils



Figuer 13 Widening (Jaeggi) - Interaction between the groundwater level and soils

Evaluation of basic data with the aid of a wrapper program

Resolution of the habitat simulation was identical to the 25m×25m grid used in habitat mapping. Such a highly detailed analysis needed a simulation using the data of more than 70,000 cells. For the simulation all those variables were required to be incorporated by the input matrix which were needed to solve the differential equations during the simulation. This required the generation of a 100,000 × 60 input matrix constructed by a specific program.

Determination of the succession scheme representing the interconversion of certain habitat types and description of the habitat simulation model

The following general aspects were taken into account in the construction of the scheme showing the interconversion of certain habitats: changes brought about by the effects of (i) aridification or (ii) humidification can be (iii) spontaneous or (iv) anthropogenic. It is a characteristic of the time-scale (temporal resolution) of changes that (v) the succession of humid habitats is faster in general than that of the arid ones and (vi) regeneration requires a longer period of time than degradation.

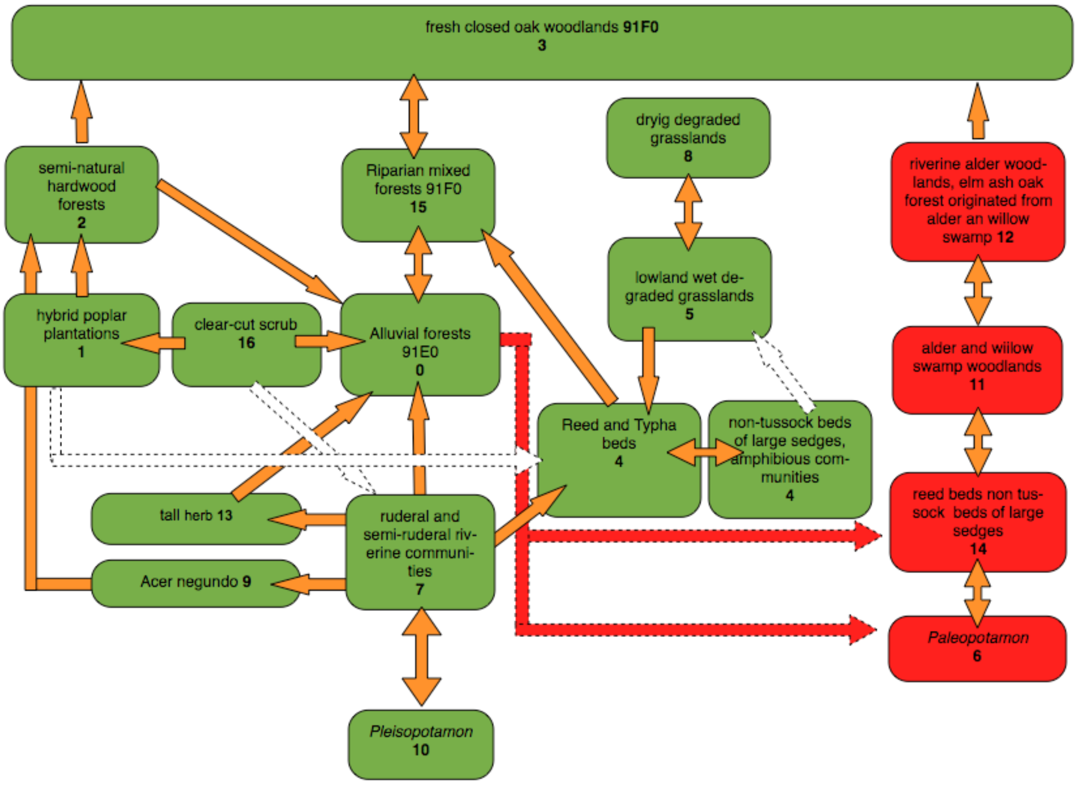


Figure 14 Process flow of the habitat simulation model

The starting point of the simulation model was the determination of the so-called integrated habitat types and their transitional matrix, based on the succession scheme presented above (Figure 3). The following factors may influence the direction of the processes: (i) natural factors, (ii) anthropogenic factors, (iii) aridification and (iv) humidification. The time-scale of the changes can range from years to centuries. Table 2 shows the quantified estimations of the temporal change of processes, based on former studies (IID Gazdasági és Tanácsadó Kft, 2001) and field experiences.

Table 2 Transitional matrix for integrated habitat types

Y = time-scale of the changes, transition time in years
L = The percentage of the groundwater level that should be below the optimal range during the vegetation period that the transformations start.
M= The percentage of the groundwater level that should be within the optimal range during the vegetation period that the transformations start.
H = The percentage of the groundwater level that should be above the optimal range during the vegetation period that the transformations start.

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0		Alluvial forests - 91E0	Hybrid poplar plantations	Hardwood forests (semi-natural)	Fresh closed oak woodlands - 91F0	Reed and Typha beds, non-tussock beds of large sedges	Lowland wet degraded grasslands	Paleopotamon	Ruderal and semi-ruderal riverine communities	Drying degraded grasslands	Acer negundo	*Pleisopotamon*	Alder and willow swamp	Riverine alder woodlands	Tall herb	Reed beds non tussock beds of large sedges / anaerob	Riparian mixed forests - 91F0	Clear-cut scrub
0	Alluvial forests - 91E0							Y=7								Y=70	Y=100	
		M=50															L = 98	
								H= 100								H = 50		
1	Hybrid poplar plantations			Y=100												Y=60		
				L=100														
																H=50		
2	Hardwood forests (semi-natural)	Y=70			Y=80													
					L=49													
		H=3																
3	Fresh closed oak woodlands - 91F0																	
4	Reed and Typha beds, non-tussock beds of large sedges						Y=7										Y=100	
							L=50-70										L=70	
5	Lowland wet degraded grasslands					Y=7				Y=7								
										L=100								
						H=25												

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Alluvial forests - 91E0	Hybrid poplar plantations	Hardwood forests (semi-natural)	Fresh closed oak woodlands - 91F0	Reed and Typha beds, non-tussock beds of large sedges	Lowland wet degraded grasslands	Paleopotamon	Ruderal and semi-ruderal riverine communities	Drying degraded grasslands	Acer negundo	*Pleisopotamon*	Alder and wiilow swamp	Riverine alder woodlands	Tall herb	Reed beds non tussock beds of large sedges / anaerob	Riparian mixed forests - 91F0	Clear-cut scrub
6	Paleopotamon															Y=20		
																L=20		
7	Ruderal and semi-ruderal riverine communities	Y=8				Y=7					Y=9	Y=4			Y=8			
		L = 10				L = 1					L=75				L=50			
		M=50				M=75												
		H = 10									H=10	H=90			H=10			
8	Drying degraded grasslands						Y=7											
							L=25											
							L=25											
9	Acer negundo			Y=60														
				L=10														
				H=10														
10	*Pleisopotamon*								Y=7									
									L=90									
11	Alder and wiilow swamp													Y=100		Y=70		
														L=20				
																H=50		

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Alluvial forests - 91E0	Hybrid poplar plantations	Hardwood forests (semi-natural)	Fresh closed oak woodlands - 91F0	Reed and Typha beds, non-tussock beds of large sedges	Lowland wet degraded grasslands	Paleopotamon	Ruderal and semi-ruderal riverine communities	Drying degraded grasslands	Acer negundo	*Pleisopotamon*	Alder and wiilow swamp	Riverine alder woodlands	Tall herb	Reed beds non tussock beds of large sedges / anaerob	Riparian mixed forests - 91F0	Clear-cut scrub
12	Riverine alder woodlands				Y=80								Y=60					
					L=80													
													H=80					
13	Tall herb	Y=15																
		H=10																
14	Reed beds non tussock beds of large sedges / anaerob							Y=20					Y=70					
													L=49					
								H=50										
15	Riparian mixed forests - 91F0	Y=70			Y=80													
					L = 70													
		H = 10																
16	Clear-cut scrub	Y=7	Y=20						Y=7									
		M=50-80	M=50															
									H=70									

The following restrictions had to be made when constructing the computerized model taking the available data and expectations into consideration:

1. As agreed, the runtime for the model is 50 years.
2. Forestry activity cannot be involved as the duration of forestry management plans is a period of 10 years.
3. Usage of grasslands is permanent.
4. Groundwater level fluctuation is the most important factor in the development of succession;
5. Development of new habitat types are permitted
6. Interaction of neighbourhood cells are only permitted in the case of ruderal and semi-ruderal riverine communities, see the schema of the model.
7. Resolution of the simulation is 25x25 m cell size

Background variables used are:

- Yearly water discharge profiles (2000-2008)
- Groundwater modelling data of Q=200, 350, 550, 750 m^3/s) by cells
- 2D Model data of Q=930 m^3/s by cells
- Position of upper gravel surface by cells
- Vegetation data by cells
- Optimal range of the groundwater level by habitat types

The different invasion strategies of particular habitat types were described by ordinary differential equation system. The basic equation was that of 1st order, second-degree time dependent.

$$H'_{k,i}(t) = c_{i,j} * H_{k,i}(t) - \frac{c_{i,j} * r_{i,j}}{H_{k,i}(t) * H_{k,j}(t)} * H_{k,i}^2(t)$$

$H'_{k,i}(t) = - H'_{k,j}(t)$

Where:

$H_{k,i}$ = the percent ratio of the habitat type i in the cell k,

c_{ij} = coefficient depending on speed of transformation of habitat type i to habitat type j

r_{ij} = resistance or buffer capacity of habitat type i against of habitat type j

Coefficients of the differential equations describing the certain transitions were determined by the values shown in Table 2.

There are basically two different succession strategies significantly amending the values of the coefficients of the differential equations: one producing fast, the other producing slow transition. OCTAVE 3.2.3., an open source, Matlab-like numerical analysis software package was used for determining the coefficients. The values of the coefficients are presented for both strategies in Table 3 taking into account the duration of the transitions.

“Rapid” strategy “Soft” strategy

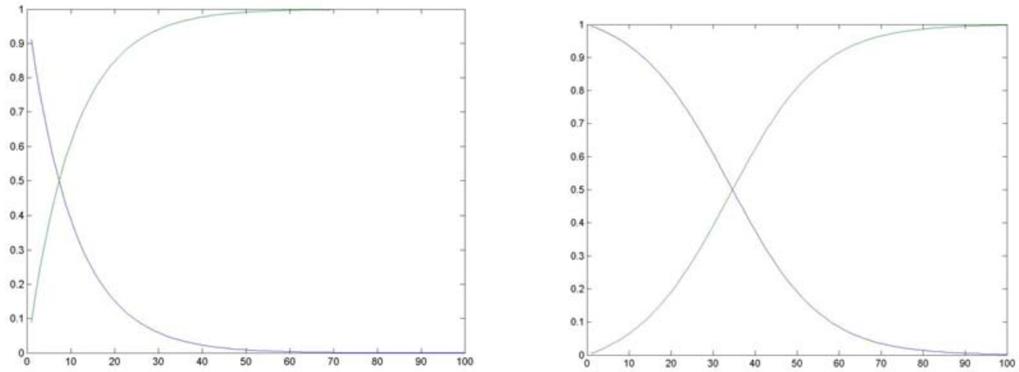


Table 3 The values of the coefficients for rapid and soft strategies calculated by OCTAVE 3.2.3 numerical analysis software package

Years	Rapid		Soft	
	c	r	C	r
2	-	-	0.7	0
3	-	-	0.5	0
7	0.7	0.95	0.3	0
10	0.5	0.95	0.2	0
20	0.27	0.95	0.1	0
25	0.21	0.95	0.09	0
30	0.17	0.95	0.075	0
50	-	-	0.045	0
60	0.09	0.95	-	-
70	0.075	0.95	0.032.	0
80	0.065	0.95	0.029	0
100	0.055	0.95	-	-

Ordinary differential equation systems were extended by the condition system of the above mentioned background variables and solved numerically using a SIMSZIG program written in MS Visual Basic 6.0 calculating the changes on cell-level using the conditions of the model. Data were saved in generic point raster file format (.txt), plotted by LandSerf 2.3. and converted to files compatible to ArcGIS 8.3.

Input structure of the comma delaminated file of the SZIGSIM habitat-modelling program:

1 : Identification number of the cell
2 : X coordinate in Hungarian GIS format
3 : Y coordinate in Hungarian GIS format
4 : Initial type number of the habitat in a given cell, if it is homogenous (0-19)
5-21: Ratio (0.0-1.0) of the different habitat types (n=17) in a given cell.

22 : 0 < water depth of standing water < 0.5 m = 1;
water depth of standing water > 0.5 m =2;
all other situation = 0
23: Multiple cell interaction in the case of “Ruderal and semi-ruderal riverine communities” (0 = there is no “Reed and Typha beds” in the neighbourhood cells; 1=there is “Reed and Typha beds” in the neighbourhood cells
24: Position of groundwater level compared to upper gravel surface (0 = above, 1 = below)
26-38: Par of percentage values of the groundwater level by habitat types (n=17), situating below and above the optimal range.
39-45: Unused (0)

1,520700,295975,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,100,0,100,0,0,0,100,100,0,
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3,520750,295975,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,100,0,100,0,0,0,0,100,0,0,0
,0,0,0,100,100,0,100,0,0,0,0,0,100,0,0,0,0,0,0,0,0,0,0,0
4,520775,295975,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,100,0,100,0,0,0,0,100,0,0,0
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7,520850,295975,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,100,50,0,0,0,100,0,0,0,
0,0,0,0,100,0,100,0,0,0,50,0,100,0,0,0,0,0,0,0,0,0,0,0

Output structure of the comma delaminated file of the SZIGSIM habitat-modelling program:

1 = identification number of the cell
2 = X coordinate in Hungarian GIS format
3 = Y coordinate in Hungarian GIS format
4 = Initial type number of the habitat in a given cell, if it is homogenous (0-19)
5-24 = ratio (0.0-1.0) of the different habitat types (n=20) in a given cell.

4485,520125,294500,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
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08,0,0,0,0,0,0,0,0,0,0,0,0,0,0
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08,0,0,0,0,0,0,0,0,0,0,0,0,0,0
4489,520225,294500,5,0,0,0,0,.99999998201535,1.79846504264741E-
08,0,0,0,0,0,0,0,0,0,0,0,0,0,0
4490,520250,294500,1,0,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

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Appendix 3 - Benchmarking of fish assemblages (G. Guti)

The key factors of the qualitative benchmarking are the discharge-controlled geomorphologic processes which create the characteristic patch dynamics and spatial distribution of flow velocity, shear stress and substrate grain size. These hydrological and geomorphologic variables provide the specific habitat conditions for characteristic floodplain species assemblages. The composition of the specific assemblages can be characterized by the proportion of the rheophilic and stagnophilic species (Chovanec & Waringer 2001, Waringer & Graf 2002, Chovanec et al. 2005). A qualitative benchmarking is applied by contrasting the habitat features with the ecological requirements of the various fish guilds according to Schiemer & Waidbacher (1992).

The proportion of the rheophilic and stagnophilic species can be expressed by the ***Habitat-specific Fauna Index*** (HFI). The HFI is based on summation of species habitat preference metrics (habitat value and indication weight). Since species compositions vary according to the hydrological and geomorphologic conditions, the ecological quality of the aquatic habitats can be characterized by the HFI.

In order to describe the species' habitat preferences numerically, 10 valency points were distributed among five habitat types. The valency point distribution is based on autecological knowledge, field observations as well as literature data. Species-specific habitat values (HV) are calculated according to the following equation:

$$HV = (1*H_1 + 2*H_2 + 3*H_3 + 4*H_4 + 5*H_5 + 6*H_6) / 10$$

The criterion for the differentiation of the habitat types was lateral connectivity with the main channel: H_1 = Eupotamon A, H_2 = Eupotamon B, H_3 = Parapotamon A, H_4 = Parapotamon B, H_5 = Plesiopotamon, H_6 = Paleopotamon.

Indication weights (IW) ranging from 1 for eurytopic species to 6 for stenotopic species have been allocated to each species in order to identify sensitive species (indication weight ≥ 4).
The indication weight is calculated from the valency point distribution:

Favoured habitat is scored 8-10 valency points:	*IW = 6*
Favoured habitat is scored 6-7 valency points:	*IW = 5*
Favoured habitat is scored 5 valency points:	*IW = 4*
Favoured habitats are scored 3-4 valency points, sp. occurs at 4 habitat types:	*IW = 3*
Favoured habitats are scored 3-4 valency points, sp. occurs at 5 habitat types:	*IW = 2*
Favoured habitats are scored 1-2 valency points	*IW = 1*

The HFI is based on the summation of the habitat values and indication weights of all native species occurring at a given location. It is calculated using the following equation:

$$HFI = \Sigma (HV * IW) / \Sigma IW$$

where HV is the habitat value and IW is the species-specific indication weight. The method is based on a presence / absence approach, thus, abundances are not considered in the formula.

The FI is calculated for locations and results in a number between 1 and 6, indicating habitat preference of the assemblage at the given location.

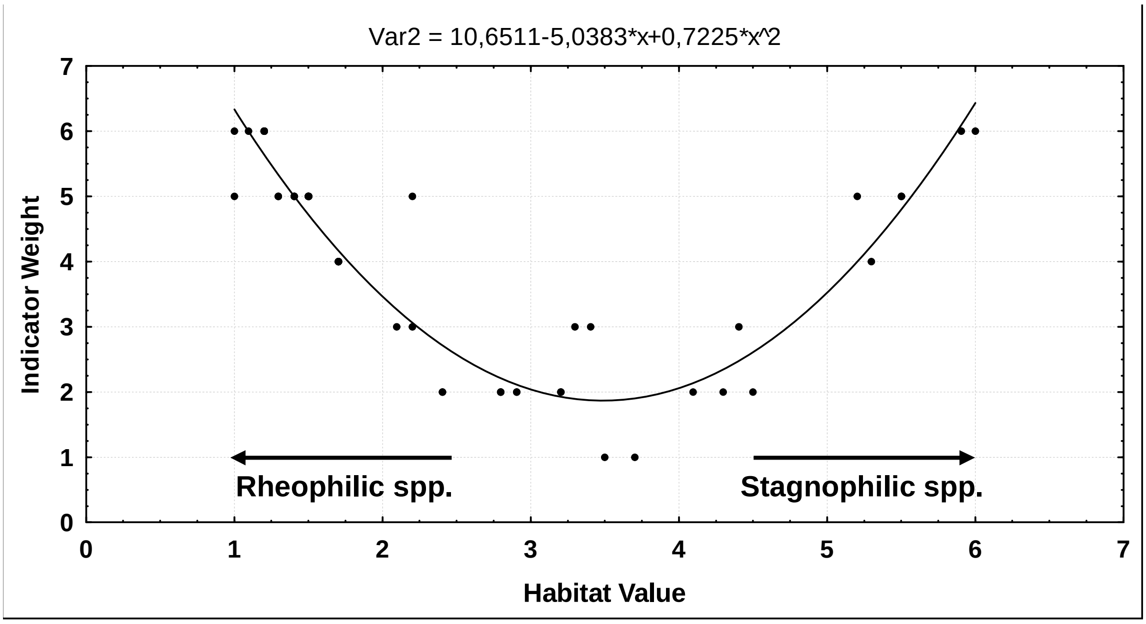

Figure 11-1 Relationship between the habitat value and the indicator weight of fish species. (Calculated on the Habitat Value and Indicator Weight data of the Szigetköz fish fauna)

Table 1 Habitat preference of the native fish species in the river/floodplain system of the Szigetköz considered in the Habitat Specific Fauna Index (HFI). HV: species-specific habitat value, IW: indication weight. Rheophilic (HV < 2,5) spp. are indicated by light blue, stagnophilic (HV > 4) spp. are indicated by apricot colour.

fish taxa	eu A	eu B	Para A	Para B	Plesio	Paleo	HV	IW
Abramis ballerus	5	3	2				1,7	4
Abramis brama	2	2	3	2	1		2,8	2
Abramis sapa	5	3	2				1,7	4
Acipenser gueldenstaedtii	8	2					1,2	6
Acipenser nudiventris	7	2	1				1,4	5
Acipenser ruthenus	7	2	1				1,4	5
Acipenser stellatus	8	2					1,2	6
Alburnoides bipunctatus	10						1	6
Alburnus alburnus	1	2	3	2	2		3,2	2
Anguilla anguilla	2	2	3	2	1		2,8	2
Aspius aspius	3	3	2	1	1		2,4	2
Barbatula barbatula	8	2					1,2	6
Barbus barbus	6	3	1				1,5	5
Blicca bjoerkna	2	2	3	2	1		2,8	2
Carassius carassius					1	9	5,9	6
Carassius gibellio			2	3	3	2	4,5	2
Chondrostoma nasus	6	3	1				1,5	5
Cobitis elongatoides			2	3	4	1	4,4	3
Cottus gobio	10						1	5
Cyprinus carpio	1	2	3	2	2		3,2	2
Esox lucius		1	2	3	3	1	4,1	2
Eudontomyzon mariae		8	2				2,2	5
Gobio albipinnatus	5	3	2				1,7	4
Gobio gobio	3	4	2	1			2,1	3
Gobio kesslerii	6	3	1				1,5	5
Gymnocephalus baloni	5	3	2				1,7	4
Gymnocephalus cernuus		2	3	4	1		3,4	3
Gymnocephalus schraetser	7	3					1,3	5
Hucho hucho	9	1					1,1	6
Huso huso	7	3					1,3	5
Leucaspius delineatus				1	6	3	5,2	5
Leuciscus cephalus	3	3	2	1	1		2,4	2
Leuciscus idus	3	3	3	1			2,2	3
Leuciscus leuciscus	5	3	2				1,7	4
Lota lota	5	3	2				1,7	4
Misgurnus fossilis				1	3	6	5,5	5
Pelecus cultratus	6	3	1				1,5	5
Perca fluviatilis	1	1	2	3	2	1	3,7	1
Rhodeus amarus		1	1	3	4	1	4,3	2
Rutilus pigus	8	2					1,2	6
Rutilus rutilus	1	2	2	2	2	1	3,5	1
Sabanejewia balcanica	6	3	1				1,5	5
Salmo trutta fario	7	2	1				1,4	5
Sander lucioperca	1	3	3	2	1		2,9	2
Sander volgensis		2	4	3	1		3,3	3
Scardinius erythrophthalmus				1	5	4	5,3	4
Silurus glanis	1	3	3	2	1		2,9	2
Tinca tinca				1	3	6	5,5	5
Umbra krameri						10	6	6
Vimba vimba	5	3	2				1,7	4
Zingel streber	8	2					1,2	6
Zingel zingel	8	2					1,2	6
FI	1,61	1,80	2,18	3,85	4,29	5,23		

The assessment of the ecological quality is based on a comparison between the pre-regulation river-type-specific reference assemblage and the recent assemblage or the predicted future assemblage. The pre-regulation (middle of the19th century) reference assemblage was taken into account by a study of historical literature and autecological knowledge.

The ecological quality is classified by a five grade sorting scheme corresponding to the WFD evaluation system. A preliminary qualitative benchmark system has been developed on fish data and is focused on changes of fauna in the Eupotamon-A and -B type habitats.

1) Calculation of HFI by change of fish fauna in the Eupotamon-A type habitat

- change of rheophilic sp. num. < -4 and
  change of stagnophilic sp. num. 0 **HFI < 1.70** fish biol. quality grade = 5
- change of rheophilic sp. num. < -9 and
  change of stagnophilic sp. num. < +3 **HFI < 2.00** fish biol. quality grade = 4
- change of rheophilic sp. num. < -15 and
  change of stagnophilic sp. num. < +6 **HFI < 2.45** fish biol. quality grade = 3
- change of rheophilic sp. num. < -22 and
  change of stagnophilic sp. num. < +8 **HFI < 3.10** fish biol. quality grade = 2
- change of rheophilic sp. num. >-21 and
  change of stagnophilic sp. num. > +7 **HFI >= 3.10** fish biol. quality grade = 1

2) Calculation of HFI by change of fish fauna in the Eupotamon-B type habitat

- change of rheophilic sp. num. < -4 and
  change of stagnophilic sp. num. 0 **HFI < 1.90** fish biol. quality grade = 5
- change of rheophilic sp. num. < -9 and
  change of stagnophilic sp. num. < +3 **HFI < 2.30** fish biol. quality grade = 4
- change of rheophilic sp. num. < -15 and
  change of stagnophilic sp. num. < +6 **HFI < 2.90** fish biol. quality grade = 3
- change of rheophilic sp. num. < -22 and
  change of stagnophilic sp. num. < +7 **HFI < 3.50** fish biol. quality grade = 2
- change of rheophilic sp. num. >-21 and
  change of stagnophilic sp. num. > +6 **HFI >= 3,50** fish biol. quality grade = 1

Table 2 Five grade evaluation system for the ecological quality of the Eupotamon-A and Eupotamon-B habitats based on Habitat-specific Fauna Index (HFI) calculated from fish data in the Szigetköz section of the Danube and its floodplain branch systems

Eupotamon-A	Eupotamon-B	Ecological (fish biological quality grade)
FI < 1.70	FI < 1.90	excellent
FI < 2.00	FI < 2.30	good
FI < 2.45	FI < 2.90	moderate
FI < 3.10	FI < 3.50	poor
FI >= 3.10	FI >= 3.50	bad

A more detailed analysis of habitat quality for fish is based on the eco-hydrological relationship between fish assemblages and shear stress classes. Occurrence of fish species at monitoring sites grouped in different classes of shear stress have indicated significant difference in species richness and proportion of rheophilic and stagnophilic species.(see Figure 3)

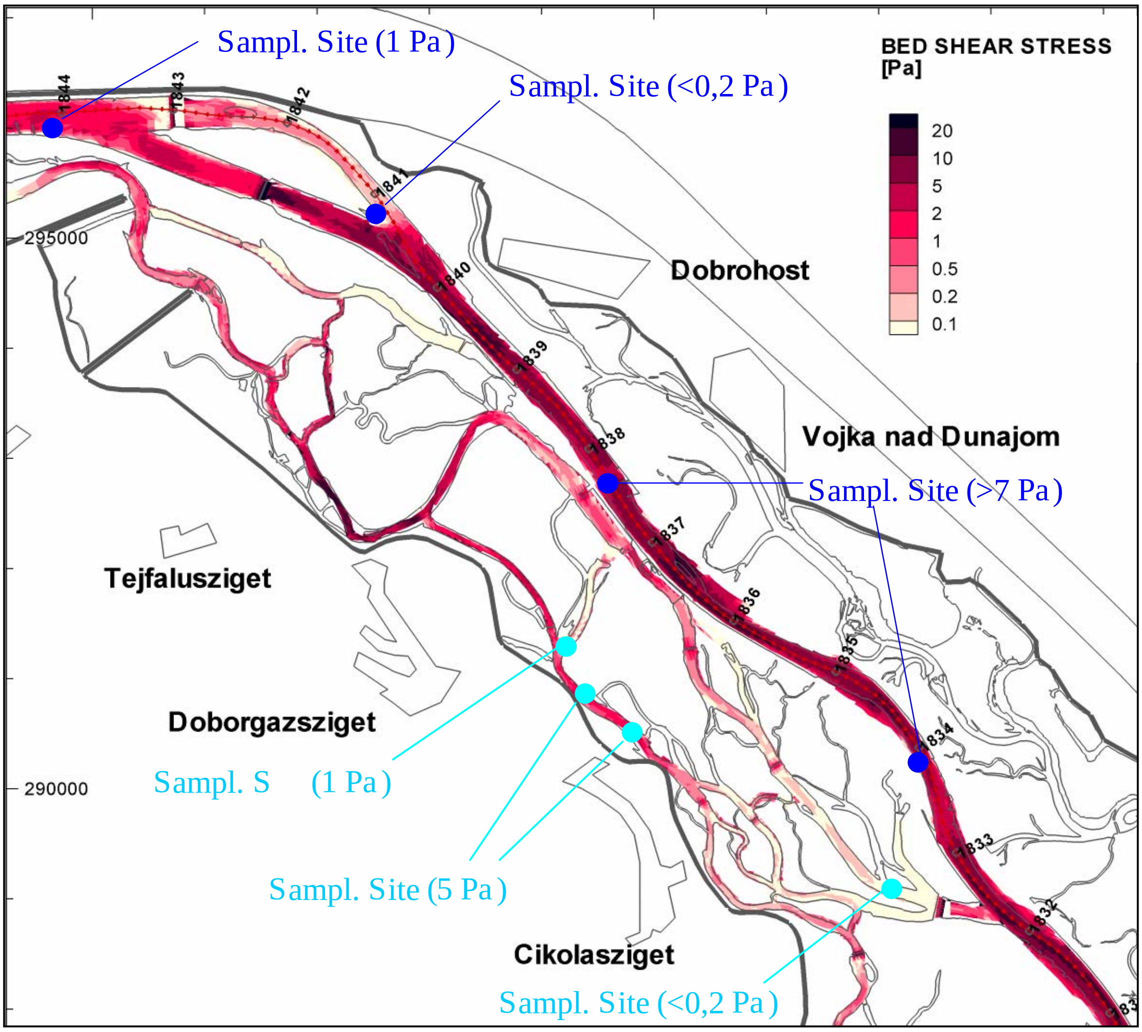

Figure 2 Fish biological sampling sites in the Eupotamon-A (dark blue spots) and -B habitats (light blue spots) and the spatial distribution of the bed shear stress in the upper part of the Szigetköz at 750 + 180 $m^3 s^{-1}$ discharge input.

Spatial distribution of fish species in the Eupotamon-A and Eupotamon-B type habitats of the anabranching sector is described in Figure 4 and 5 where fish species are ranged according to their habitat value. Fauna elements of locations with low, moderate and high shear stress were determined by direct surveys (from the end of 1980s) and expert judgement. The spatial distribution of the bed shear stress was calculated by 2D hydrological model (Figure 2).

Based on the available data set on flow velocity and shear stress effect on distribution of fish in the main arm of the Szigetköz section of the Danube, three shear stress classes (>7 Pa, 1 Pa, <0,2 Pa) can be characterized by fish fauna data. High number of the native species (34 spp.) was verified at the locations of high (>7 Pa) shear stress class. The number of the native species decreases by the decline of the shear stress, it is 23 spp. at the moderate (1 Pa) and 21 spp. at the low (<0,2 Pa) shear stress class. The proportion of the rheophilic species drops by the decrease of the shear stress. Their ratio is 74 % and 29 % at the high and the low value of shear stress, correspondently. Stagnophilic species absent at the high shear stress stretches and their proportion is 24% at the low value locations.

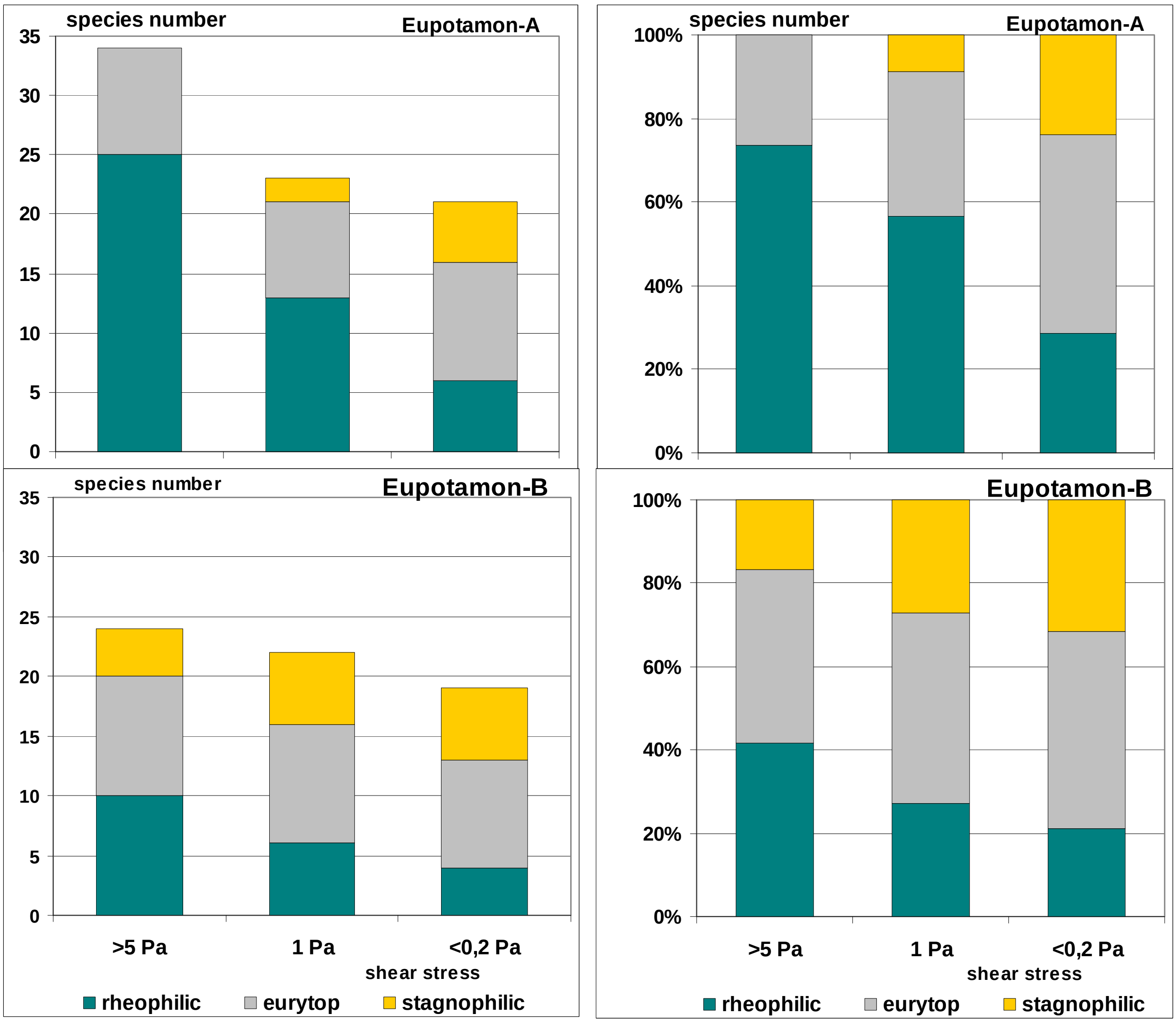

Figure 3 Variation of species number and proportion of rheophilic, eurytop and stagnophilic fish species at locations with different values of shear stress in the main arm (Eupotamon-A) and in the Eupotamon-B type side arms of the Cikola branch system.

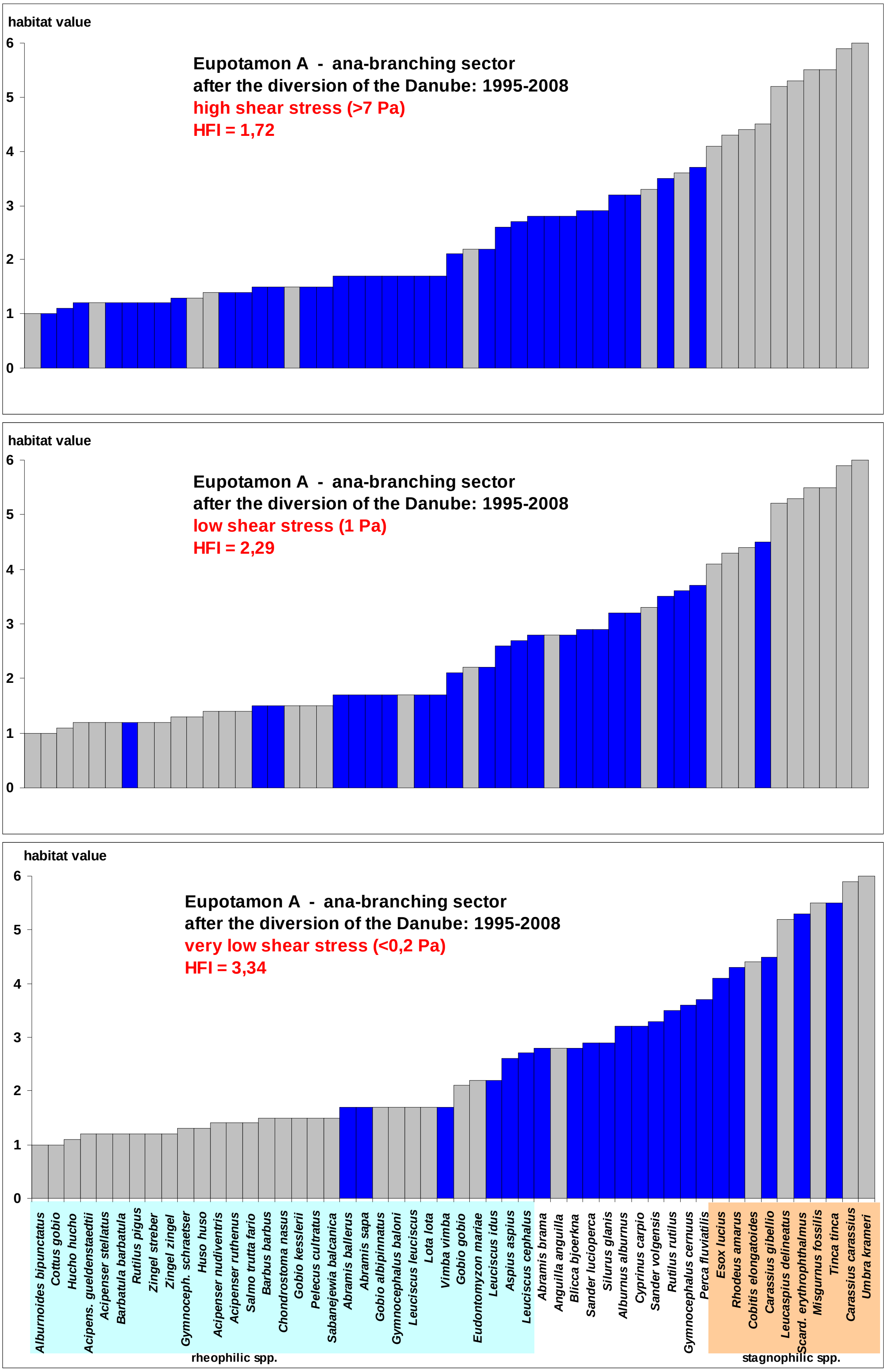

Figure 4 Occurrence of fish species at locations with different shear stress class in the Eupotamon-A habitat of the anabranching sector.

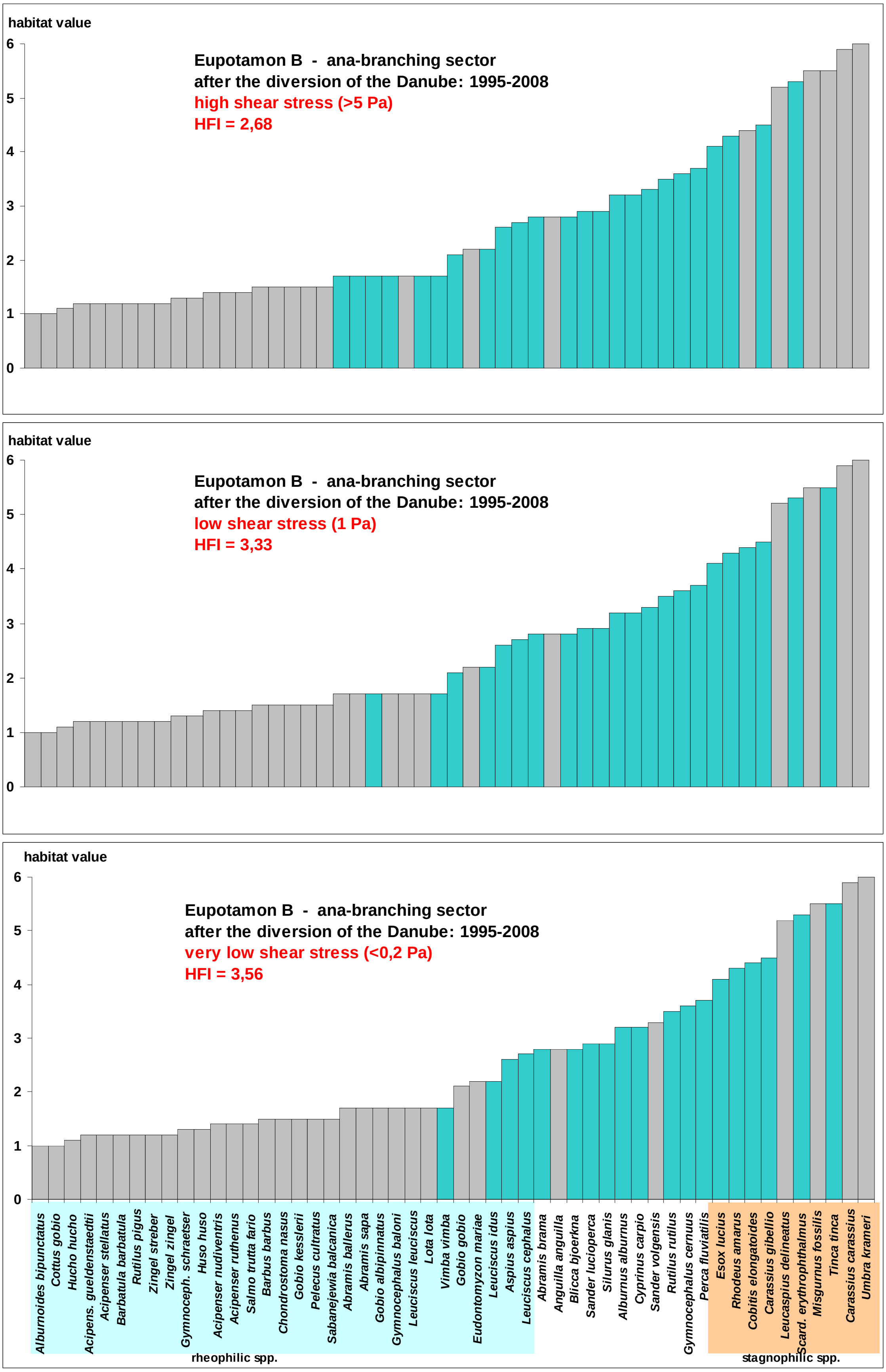

Figure 5 Occurrence of fish species at locations with different values of shear stress in the recent Eupotamon-B habitats of the Cikola arm system.

The differences in the fish assemblages structure emphasize that the decrease in areal extent of stretches with high value (>7 Pa) of shear stress endangers the conservation of the natural biodiversity in the eupotamon-A habitat.

In the Eupotamon-B type side arms, 24, 23 and 19 native species were verified at the locations of high (>5 Pa), moderate (1 Pa) and (<0,2 Pa) low shear stress classes, correspondently. The number of the rheophilic species drops from 10 (42 %) to 4 (21 %) by the decrease of the shear stress. The occurrence of the stagnophilic species shows an opposite trend, their number increases from 4 (19 %) to 6 (32 %) by the decrease of the shear stress.

Change of the Habitat-specific Fauna Index (HFI) indicates the differences in the spatial distribution of the rheophilic and stagnophilic species by the alteration of the shear stress. (Fig. 6 and 7). This relationship between shear stress classes and fish associations allows a habitat evaluation of the various variants especially with respect to rheophilic fish as the most significant single biotic indicator group for floodplain rehabilitation (Schiemer, 1999).

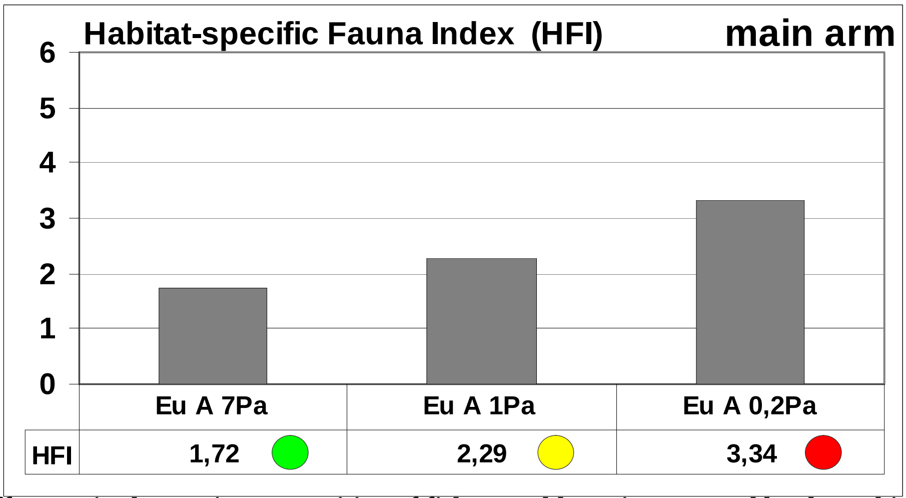

Figure 6 Difference in the species composition of fish assemblages is expressed by the Habitat-specific Fauna Index (HFI) at locations with different values of shear stress in the main arm (Eupotamon-A type habitat). Ecological (fish biological) quality grade is indicated by colours: Green = good, Yellow = moderate Red = bad.

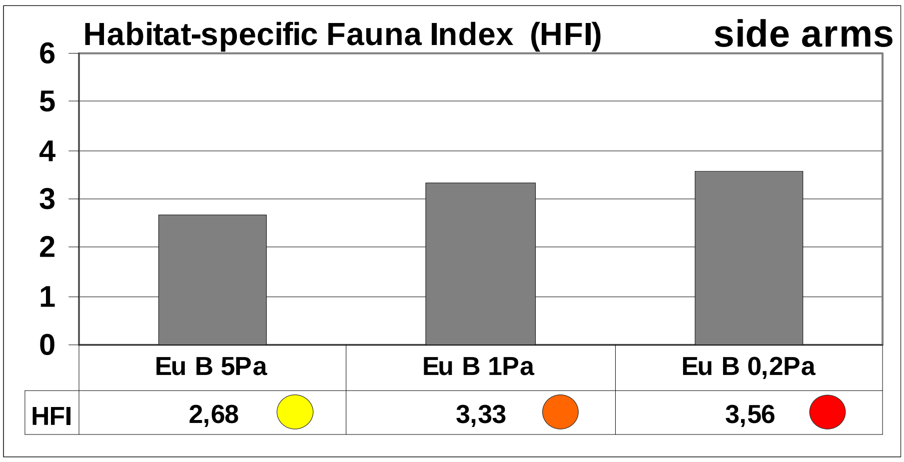

Figure 7 Difference in species composition of fish assemblages is expressed by the Habitat-specific Fauna Index (HFI) at locations with different values of shear stress in the Eupotamon-B type side arms. Ecological (fish biological) quality grade is indicated by colours: Yellow = moderate, Orange = poor, Red = bad.

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Appendix 4 – Benchmarking of selected macrozoobenthos groups (Ephemeroptera, Plecoptera, Odonata)

The characteristic fauna of the reference state of the Danube and the waterbodies of its floodplains have been fortunately assessed in the case of Ephemeroptera and Plecoptera (Mocsáry 1900, Pongrácz 1914), providing a realistic picture of the communities at the end of the 19th century and at the beginning of the 20th century. These early records show that at that time the Danube was very rich in species and contained a number of Ephemeroptera and Plecoptera species that have become extinct as a consequence of the hydromorphological interventions and the deterioration of the quality of water during the past century. Although we have no accurate data concerning Odonata, it should be assumed that two of the rheophilic species – *Ophiogomphus cecilia*, and *Onychogomphus forcipatus* – must also have been wide-spread along the Danube. Despite regular larva surveys these species cannot be found today in the Danube habitat (Kovács & Ambrus 2009).

By extrapolating data from the earlier sources and in view of findings of more recent research - conducted in the past two decades (Andrikovics *et al.* 2006, Kovács & Ambrus 2009) - we have selected the Ephemeroptera, Odonata and Plecoptera taxa for an evaluation.

Table 1 Habitat preference of characteristic macrozoobenthos species related to the Amoros-Roux types of aquatic habitats. The preference is given in a scale of 0 -10.

Ephemeroptera taxa	**Eu A,B**	**Para A**	**Para B**	**Plesio**	**Paleo**
***Ametropus fragilis* †**	10				
Baetis buceratus	10				
Caenis horaria		1	1	2	6
Caenis robusta				3	7
Cloeon dipterum	1	1	1	2	5
Cloeon simile				10	
Ecdyonurus aurantiacus	10				
Ephemera lineata	10				
Ephoron virgo	10				
Heptagenia coerulans	10				
Heptagenia flava	10				
Heptagenia sulphurea	10				
***Oligoneuriella pallida* †**	10				
Potamanthus luteus	10				
Siphlonurus lacustris	10				
Torleya major	10				
Plecoptera taxa	**Eu A,B**	**Para A**	**Para B**	**Plesio**	**Paleo**
Isogenus nubecula †	10				
***Taeniopteryx araneoides* †**	10				
***Taeniopteryx nebulosa* †**	10				
***Brachyptera braueri* †**	10				
***Brachyptera trifasciata* †**	10				
***Oemopteryx loewi* †**	10				

***Marthamea vittripennis* †**	10				
***Isoptena serricornis* †**	10				
Xanthoperla apicalis	10				
Odonata taxa	**Eu A,B**	**Para A**	**Para B**	**Plesio**	**Paleo**
Aeshna affinis				10	
Anaciaeschna isosceles			1	1	8
Brachytron pratense					10
Calopteryx splendens	8	1	1		
Coenagrion puella		1	1	2	6
Crocothemis erythraea				2	8
Enallagma cyathigerum					10
Epitheca bimaculata		1	1		8
Erythromma najas					10
Gomphus flavipes	10				
Gomphus vulgatissimus	10				
Ischnura elegans	1	1	1	3	4
Ischnura pumilio				10	
Lestes sponsa				8	2
Lestes virens				8	2
Lestes viridis					10
Libellula fulva					10
Ophiogomphus cecilia	10				
Orthetrum brunneum	10				
Platycnemis pennipes	7	1	1		1
Somatochlora metallica	10				
Sympetrum vulgatum		1	1	1	7

Protected, rare or extinct - species are found only among the rheophilic Ephemeroptera and Plecoptera species characteristic for the Eupotamon. Flowing water, high dissolved oxygen content, modest nutrient supply and not excessively warm temperatures - restricted to the summer months - constitute the preferred environment for these species. For lack of vegetation in the water or on the river bank only a narrow patch of the water body in direct contact with the waterbed is suitable for Ephemeroptera as a habitat. The three protected river dragon flies are indicators of this type of habitat.

No Plecoptera are to be found in the other habitat types – Parapotamon, Plesiopotamon, Paleopotamon – as these accommodate only abundant and eurytopic Ephemeroptera. The good flying capability of dragonflies living in these areas provide largely for their re-colonisation or colonisation even perhaps from suitable water bodies outside the flood protection embankments. Thus the species living in these types of habitats are not included in the evaluation. Accordingly, from the aspect of Ephemeroptera, Odonata and Plecoptera the Eupotamon is a crucially important habitat.

The evaluation scheme therefore can be based on the relative significance of Eupotamon habitats and the currently available data on the existing fauna (Müller et al. 2009). At the present stage no comprehensive evaluation of variants can be carried out due to an insufficient data base of the side-arm system, however, the ecological requirements of the characteristic rheophilic group have been taken into consideration at the benchmarking of Eupotamon A (main arm) & B (side arms).

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Appendix 5 - Benchmarking system of Lepidopterans (László Ronkay)

This categorisation could be of special importance in nature conservation since non-specialists may obtain further biological information from a "simple" faunistic (and zoo-cenological) survey of a given area which is often difficult to interpret by nature conservation managers. The biogeographical categorisation is coherent and rather well established. The categories summarising bionomic information are less homogeneous, due to the far more complex nature of these data (e.g., phaenology, number of generations, etc.). Thus, the bionomical categorisation has not been used during this evaluation, in order to minimise the rather considerable uncertainty originating from the theoretically estimated faunal composition of the different vegetation types of the seven variants. However, subsequent efforts are worth making in order to provide this kind of information which best characterises the species for practical every day usage.

The estimated Macroheterocera fauna for the variants

		variants species numbers/protected species numbers/zoogeographic categories								
	Vegetation type	**Meandering (400)**			**Situation in 2008**			**SZITE**		
		Spec. No.	Prot.	Zoogeography*	Spec. No.	Prot.	Zoogeography*	Spec. No.	Prot.	Zoogeography*
1.	alluvial forests + poplar stands	57	3	Transpalaearctic: 75,44%; Boreo-Continental: 17,54%; Western Palaearctic: 7,02%.	57	3	Transpalaearctic: 75,44%; Boreo-Continental: 17,54%; Western Palaearctic: 7,02%.	57	3	Transpalaearctic: 75,44%; Boreo-Continental: 17,54%; Western Palaearctic: 7,02%.
2.	Alder woodlands	0	0	0	0	0		0	0	
3.	hardwood forests (oak-elm-ash woodlands	75	2	Extra-Palaearctic: 1,33%; Transpalaearctic: 59,85%; Boreo-Continental: 16,17%; Western	135	6	Extra-Palaearctic: 0,74%; Transpalaearctic: 51,98%; Boreo-Continental: 19,83%; Western	147	6	Extra-Palaearctic: 0,68%; Transpalaearctic: 53,74%; Boreo-Continental: 18,37%; Western

		variants species numbers/protected species numbers/zoogeographic categories								
	Vegetation type	**Meandering (400)**			**Situation in 2008**			**SZITE**		
				Palaearctic: 22,09%.			Palaearctic: 27,55%.			Palaearctic: 27,21%.
4.	oakwoods	0	0	0	0	0	0	0	0	0
5.	Reed and Typha beds, non-tussock beds of large sedges, amphibious communities on river gravel and sand banks	22	0	Transpalaearctic: 27,27%; Boreo-Continental: 68,18%; Southern Continental: 4,54%.	18	0	Transpalaearctic: 33,33%; Boreo-Continental: 61,11%; Southern Continental: 5,55%	20	0	Transpalaearctic: 30,07%; Boreo-Continental: 65,00%; Southern Continental: 5,00%
6.	lowland wet degraded grasslands	0	0	*a part of the typical fauna of this vegetation type change its habitats and survive partly in the small hardwoods fragments, partly in the riverine and drying grasslands	83	5	Transpalaearctic: 51,25%; Boreo-Continental: 34,94%; Southern Continental:4,81%; Western Palaearctic: 7,23%.	80	5	Transpalaearctic: 53,60%; Boreo-Continental: 34,40%; Southern Continental:4,80%; Western Palaearctic: 7,20%.
7.	ruderal and semi-ruderal riverine communities	31	9	Transpalaearctic: 66,66%; Boreo-Continental: 8,33%; Western Palaearctic: 25,00 %.	31	9	Transpalaearctic: 67,74%; Boreo-Continental: 3,23%; Western Palaearctic: 29,03%.	31	9	Transpalaearctic: 67,74%; Boreo-Continental: 3,23%; Western Palaearctic: 29,03%.
8.	drying degraded grasslands	80	1	Extra-Palaearctic: 2,5%; Transpalaearctic: 68,75%; Boreo-Continental:	75	1	Extra-Palaearctic: 2,66%; Transpalaearctic: 66,78%; Boreo-Continental:	75	1	Extra-Palaearctic: 2,66%; Transpalaearctic: 66,78%; Boreo-Continental:

		variants species numbers/protected species numbers/zoogeographic categories								
	Vegetation type	**Meandering (400)**			**Situation in 2008**			**SZITE**		
				2,5%; Southern Continental: 2,5%; Western Palaearctic: 23,75%.			2,66%; Southern Continental: 1,33%; Western Palaearctic: 26.60%.			2,66%; Southern Continental: 1,33%; Western Palaearctic: 26.60%

		variants species numbers/protected species numbers/zoogeographic categories								
	Vegetation type	**Inrease of discharge**			**Optimum filling**			**Narrowing**		
		Spec. No.	Prot.	Zoogeography *	Spec. No.	Prot.	Zoogeography *	Spec. No.	Prot.	Zoogeography *
1.	alluvial forests + poplar stands	57	3	Transpalaearctic: 75,44%; Boreo-Continental: 17,54%; Western Palaearctic: 7,02%.	57	3	Transpalaearctic: 75,44%; Boreo-Continental: 17,54%; Western Palaearctic: 7,02%.	57	3	Transpalaearctic: 75,44%; Boreo-Continental: 17,54%; Western Palaearctic: 7,02%.
2.	Alder woodlands	0	0	0	0	0	0	0	0	0
3.	hardwood forests (oak-elm-ash woodlands	140	2	Extra-Palaearctic: 1,42%; Transpalaearctic: 60%; Boreo-Continental: 17,38%; Western Palaearctic: 22,38%.	134	2	Extra-Palaearctic: 0,74%; Transpalaearctic: 49,58%; Boreo-Continental: 21,16%; Western Palaearctic: 28,52%.	137	2	Extra-Palaearctic: 0,73%; Transpalaearctic: 51,83%; Boreo-Continental: 20,44%; Western Palaearctic: 27.01%.
4.	oakwoods	0	0	0	0	0	0	0	0	0
5.	Reed and Typha beds, non-	18	0	Transpalaearctic: 33,33%; Boreo-	18	0	Transpalaearctic: 33,33%; Boreo-	18	0	Transpalaearctic: 33,33%; Boreo-

		variants species numbers/protected species numbers/zoogeographic categories								
	Vegetation type	**Inrease of discharge**			**Optimum filling**			**Narrowing**		
	tussock beds of large sedges, amphibious communities on river gravel and sand banks			Continental: 61,11%; Southern Continental: 5,55%			Continental: 61,11%; Southern Continental: 5,55%			Continental: 61,11%; Southern Continental: 5,55%
6.	lowland wet degraded grasslands	83	5	Transpalaearctic: 51,25%; Boreo-Continental: 34,94%; Southern Continental:4,81%; Western Palaearctic: 7,23%.	83	5	Transpalaearctic: 51,25%; Boreo-Continental: 34,94%; Southern Continental:4,81%; Western Palaearctic: 7,23%.	83	5	Transpalaearctic: 51,25%; Boreo-Continental: 34,94%; Southern Continental:4,81%; Western Palaearctic: 7,23%.
7.	ruderal and semi-ruderal riverine communities	24	8	Transpalaearctic: 66,66%; Boreo-Continental: 8,33%; Western Palaearctic: 25,00 %.	31	9	Transpalaearctic: 67,74%; Boreo-Continental: 3,23%; Western Palaearctic: 29,03%.	31	9	Transpalaearctic: 67,74%; Boreo-Continental: 3,23%; Western Palaearctic: 29,03%.
8.	drying degraded grasslands	75	1	Extra-Palaearctic: 2,66%; Transpalaearctic: 66,78%; Boreo-Continental: 2,66%; Southern Continental: 1,33%; Western Palaearctic: 26.60%.	75	1	Extra-Palaearctic: 2,66%; Transpalaearctic: 66,78%; Boreo-Continental: 2,66%; Southern Continental: 1,33%; Western Palaearctic: 26.60%.	75	1	Extra-Palaearctic: 2,66%; Transpalaearctic: 66,78%; Boreo-Continental: 2,66%; Southern Continental: 1,33%; Western Palaearctic: 26.60%.

		variants species numbers/protected species numbers/zoogeographic categories					
	Vegetation type	**Widening**			**widening (Jaeggi)**		
		Spec. No.	Prot.	Zoogeography *	Spec. No.	Prot.	Zoogeography *
1.	alluvial forests + poplar stands	57	3	Transpalaearctic: 75,44%; Boreo-Continental: 17,54%; Western Palaearctic: 7,02%.	57	3	Transpalaearctic: 75,44%; Boreo-Continental: 17,54%; Western Palaearctic: 7,02%.
2.	Alder woodlands	0	0	0	0	0	0
3.	hardwood forests (oak-elm-ash woodlands	155	8	Extra-Palaearctic: 0,64%; Transpalaearctic: 50,97%; Boreo-Continental: 20,64%; Western Palaearctic: 27,74%.	135	6	Extra-Palaearctic: 0,74%; Transpalaearctic: 51,98%; Boreo-Continental: 19,83%; Western Palaearctic: 27,55%.
4.	oakwoods	0	0	0	0	0	0
5.	Reed and Typha beds, non-tussock beds of large sedges, amphibious communities on river gravel and sand banks	18	0	Transpalaearctic: 33,33%; Boreo-Continental: 61,11%; Southern Continental: 5,55%	18	0	Transpalaearctic: 33,33%; Boreo-Continental: 61,11%; Southern Continental: 5,55%
6.	lowland wet degraded grasslands	83	5	Transpalaearctic: 51,25%; Boreo-Continental: 34,94%; Southern	83	5	Transpalaearctic: 51,25%; Boreo-Continental: 34,94%; Southern

		variants species numbers/protected species numbers/zoogeographic categories					
	Vegetation type	**Widening**			**widening (Jaeggi)**		
				Continental:4,81%; Western Palaearctic: 7,23%.			Continental:4,81%; Western Palaearctic: 7,23%.
7.	ruderal and semi-ruderal riverine communities	24	8	Transpalaearctic: 66,66%; Boreo-Continental: 8,33%; Western Palaearctic: 25,00 %.	31	9	Transpalaearctic: 67,74%; Boreo-Continental: 3,23%; Western Palaearctic: 29,03%.
8.	drying degraded grasslands	75	1	Extra-Palaearctic: 2,66%; Transpalaearctic: 66,78%; Boreo-Continental: 2,66%; Southern Continental: 1,33%; Western Palaearctic: 26.60%.	75	1	Extra-Palaearctic: 2,66%; Transpalaearctic: 66,78%; Boreo-Continental: 2,66%; Southern Continental: 1,33%; Western Palaearctic: 26.60%.

Evaluation process of the different variants

The evaluation of the different variants was made using the results of the new models where the average water profile was 750 m³. The ranking of the variants should be based on the evaluation of the more humid vegetation types, their predictable fauna, the balance of the softwood and hardwood stands approaching the ancient stages, and the feasibility (and also the impact) of the given variant.

The evaluation of the actual variants on a five-degree scale depends on the proportion of the "original" and the less humid, often more degraded vegetation types and the proportion of certain ruling faunal types within the different vegetation types.

Abbreviations:

Extra-Palaearctic (EP)
Trans-Palaearctic (TP)
Boreo-Continental (BC)
Southern Continental (SC)
Western Palaearctic (WP)

Vegetation type	Alluvial+poplar	hardwood	Reed-Typha-non-tussock	Lowland wet grassland	Riverine-ruderal	Drying grassland
Excellent (5)	Above 60%	Below 2%	Above 7%	Below 2%	Below 1%	Below 2%
Good (4)	Between 50-60%	Between 2-6%	Between 5-7%	Between 2-5%	Between 1-2%	Between 2-4%
Medium (3)	Between 40-50%	Between 6-10%	Between 3-5%	Between 5-8%	Between 2-3%	Between 4-6%
Poor (2)	Between 30-40%	Between 10-14%	Between 1-3%	Between 8-11%	Between 3-4%	Between 6-8%
Bad (1)	Below 30%	Above 14%	Below 1%	Above 11%	Above 4%	Above 8%

Vegetation type	Alluvial+poplar	hardwood	Reed-Typha-non-tussock	Lowland wet grassland	Riverine-ruderal	Drying grassland
Excellent (5)	TP+BC>90%	WP below 25%; BC above 20%	BC above 65%; WP below 5%	WP below 5%	No real sense	TP+BC above 70%; WP below 25%
Good (4)	TP+BC between 85-90%	WP between 25-28%; BC between 17-20%	BC between 60-65%; WP between 5-6%	WP between 5-8%	No real sense	TP+BC between 67-70%; WP between 25-28%
Medium (3)	TP+BC between 80-85%	WP between 28-31%; BC between 14-17%	BC between 55-60%; WP between 6-7%	WP between 8-11%	No real sense	TP+BC between 64-67%; WP between 28-31%
Poor (2)	TP+BC between 75-80%	WP between 31-34%; BC between 11-14%	BC between 50-55%; WP between 7-8%	WP between 11-14%	No real sense	TP+BC between 61-64%; WP between 31-34%
Bad (1)	TP+BC below 75%	WP above 34%; BC below 11%	BC below 50%; WP above 8%	WP above 14%	No real sense	TP+BC below 61%; WP above 34%

This is a proposed scheme which at the moment has not be comprehensively applied. However, the main aspects have been taken into consideration for the long-term development of the terrestrial ecosystems.

References

Varga, Z., Ronkay, L., Bálint, Zs., László, Gy.M. and Peregovits, L. (2005): Checklist of the Fauna of Hungary. Volume 3. Macrolepidoptera. – Hungarian Natural History Museum, Budapest, 114 pp.

Varga, Z., Ronkay, L., Bálint, Zs., László, Gy.M. és Peregovits, L. (2004): A magyar állatvilág fajjegyzéke. 3. kötet. Nagylepkék. – Hungarian Natural History Museum, Budapest, 108 pp

Appendix 6 - Amphibian fauna as bioindicator for para-to plesiopotamic water bodies

While the fish assemblages and the Macrozoobnethos is especially indicative for the availability and quality of eupotamal habitats, for the amphibian fauna the existence of plesiopotamic and palaeopotamic waterbodies as reproduction sites is particularly significant.

The accuracy of old maps proves to be a bottleneck in the data analysis especially in the case of isolated water bodies. After the main water regulation scheme (1901) a considerable decrease of the Eupotamon A type habitat and an increase of the Parapotamon and Plesiopotamon type occurred. This dramatic change created more suitable habitats for amphibians in the floodplain In the last two-three decades the ratio of Parapotamon B and Plesiopotamon type habitats showed a rapid decrease resulting a significant decline in population size.

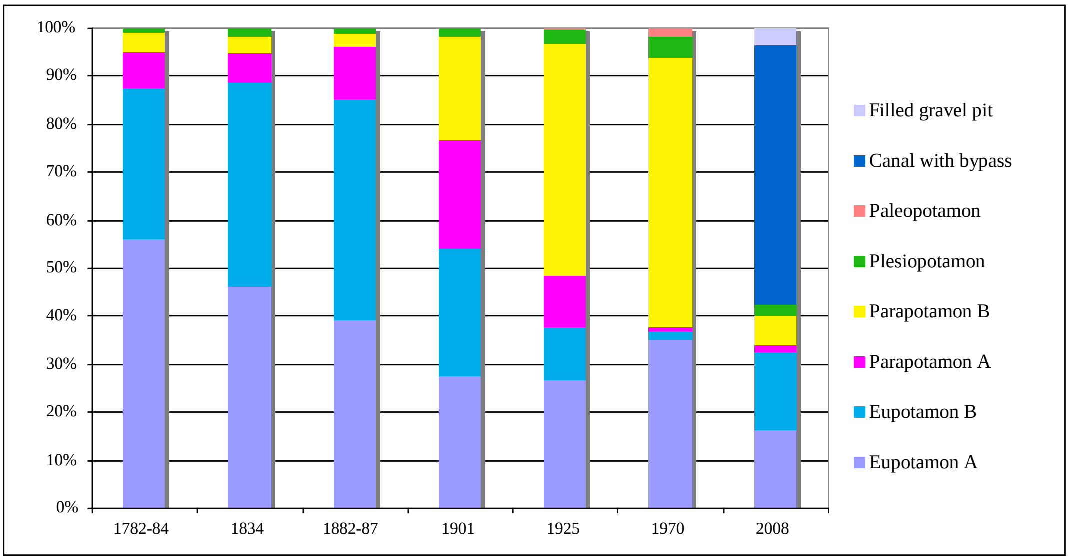

Figure. 1. Historical Landscape Element Analysis for the Szigetköz floodplain in Hungary (Schwarz, 2009)

Amphibians during breeding require warm, shallow and highly vegetated waters with small amplitudes of water level fluctuations as spawming habitats.

For the evaluation of variants with regard to amphibians it is necessary to distinguish two types of Plesiopotamon: Plesiopotamon A, water bodies close to the main channel with higher fluctuation and Plesiopotamon B - more isolated water bodies with lower amplitude of water level fluctuations (only flooded at high floods, modulated by groundwater, partially anaerobic processes).

Altogether 11 amphibian species (*Rana arvalis, Rana dalmatina, Lissotriton vulgaris, Triturus dobrogicus, Pelobates fuscus, Hyla arborea, Bufo bufo, Rana ridibunda, Rana esculenta, Rana lessonae, Bombina bombina*) have been found to regularly breed in the floodplain. The reproduction strategies adopted by anurans of the Szigetköz region fall into two basic categories: explosive and prolonged mating. Both breeding strategies require suitable biotopes. The following evaluation can be worked out on the basis of the available set of field faunistic data, binding to the different Amoros Roux classes and conservation status.

Table 2 Amphibians' breeding sites binding to the different Amoros-Roux classes and the conservation status

	Eupotamon B	Parapo-tamon A	Parapo-tamon B	Plesiopo-tamon A	Plesiopo-tamon B	HD Annex II.	Conservation status
Triturus dobrogicus				+	++	+	protected
Lissotriton vulgaris				+	++		protected
Bombina bombina			+	+	++	+	protected
Hyla arborea			+	+	++		protected
Bufo bufo			+	+	++		protected
Pelobates fuscus			+	+	++		protected
Rana arvalis				+	++		protected
Rana dalmatina				+	++		protected
Rana kl. esculenta	+	+	++	++	+		protected
Rana lessonae			++	+	++		protected
Rana ridibunda	+	++	+				Protected
Ratio of breeding sites	2/11	2/11	7/11	10/11	10/11		

+ = potential habitat in breeding season
++ = preferable habitat in breeding season

Table 3 Evaluation criteria for Amphibians defined by the proportion of Plesiopotamon B to Plesiopotamon A habitats.

Proportion of plesiopatamon B and A (B/A)		
> 0.8	considerable improvement on present state	++
0.61-0.8	improvement but still far from reference conditions	+
0.41-0.6	status far from reference conditions but still acceptable	-+
0.21-0.4	status insufficient	-
< 0.2	considerably worse than present status	- -

The study area was deliniated because of the limitation of the three different types of maps (groundwater distribution maps, digital elevation maps, aquatic habitat distribution maps) used for evaluation. As Figure 1 shows, the upper and lower parts of the Szigetköz as well as the Slovakian section of the floodplain could not be included in the evaluation.

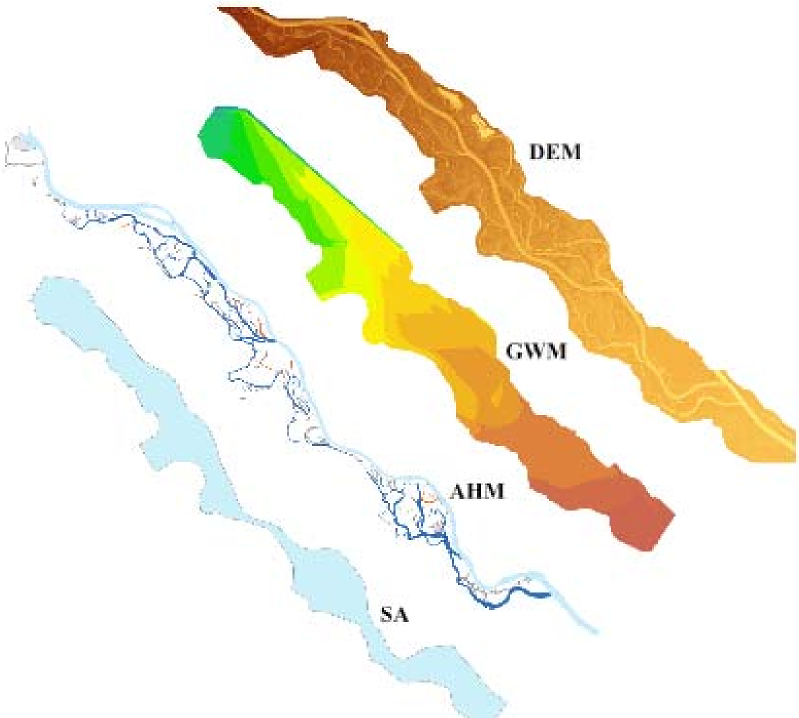

Figure 1 Delineation of the study area (Digital elevation map (DEM), groundwater distribution map (GWM), aquatic habitat distribution map (AHM), study area (SA)

References

Schwarz, U. (2009) Historical landscape element analysis for the Szigetköz floodplain in Hungary. Unpublished report, FLUVIUS, 31 p., Vienna, 4 Nov. 2009