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

-Executive Summary -

Prepared by

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Scope of the study

Growing awareness of threatened landscapes and wildlife in the last decades has resulted in a number of laws and programmes on international and national levels for the protection of endangered habitats and species. The Szigetköz wetland as a part of the former inland delta of the Danube still shelters numerous rare animals and plants despite fundamental interventions since the first regulation works at the end of the 19^{th} century.

It is the scope of this study

- to analyze the natural landscape and habitat conditions for flora and fauna before comprehensive river regulation
- to outline the impact of regulation works from the 19^{th} century regulation to the 1992 diversion of the river water to the Gabcikovo Hydro Power Plant (GHPP)
- to delineate environmental objectives and criteria for the preservation and rehabilitation of the diversity of flora and fauna
- to investigate the impact of present and potential mitigation measures on habitat conditions
- to assess the ecological performance of such measures based on defined thresholds of parameters (benchmarking)

It was beyond the scope of this study to present the *“ideal solution”*. Actually, none of rehabilitation measures investigated, proved to fullfil all essential environmental objectives and comply with constraints by energy production and flood protection at the same time.

The models established, however, and the results obtained represent an excellent data basis for further planning.

Procedure of the study

In accordance with international practice the natural functioning of the river floodplain ecoystem was analyzed (‘Leitbild-approach’, Chapter 2). This means that habitat conditions of the period before large river regulation works were studied together with dynamic changes of the landscape by river channel evolution. The resulting hydrological and morphological parameters, e.g. seasonal fluctuations of surface and groundwater levels, serve as reference basis for impact assessment of regulation works as well as for rehabilitation measures.

The impact of river regulation and flood protection as well as the use of natural resources from the 18^{th} century until today on the landscape, on flora and fauna and on the aquifer was studied in Chapters 3-5. Interventions in the past and land and river uses in present time constrain rehabilitation measures and thus the achievement of reference conditions. Associated legal obligations were outlined in Chapter 6.

Reference conditions and constraints are the framework for the delineation of environmental objectives which can be attained under present circumstances (Chapter 7). Criteria and benchmarks refer to aquatic habitat types, riparian habitats (‘transition zones’) and terrestrial habitats, e.g. softwood and hardwood forest.

After defining rehabilitation measures (‘variants’) including the present state, mathematical modelling was performed to explore the impact on surface water flows, groundwater levels and river channel evolution, i.e. erosion and sedimentation (Chapter 8). As far as possible the impact on fish and vegetation was investigated as well.

The natural character of the Szigetköz area before river regulation (Chapter 2)

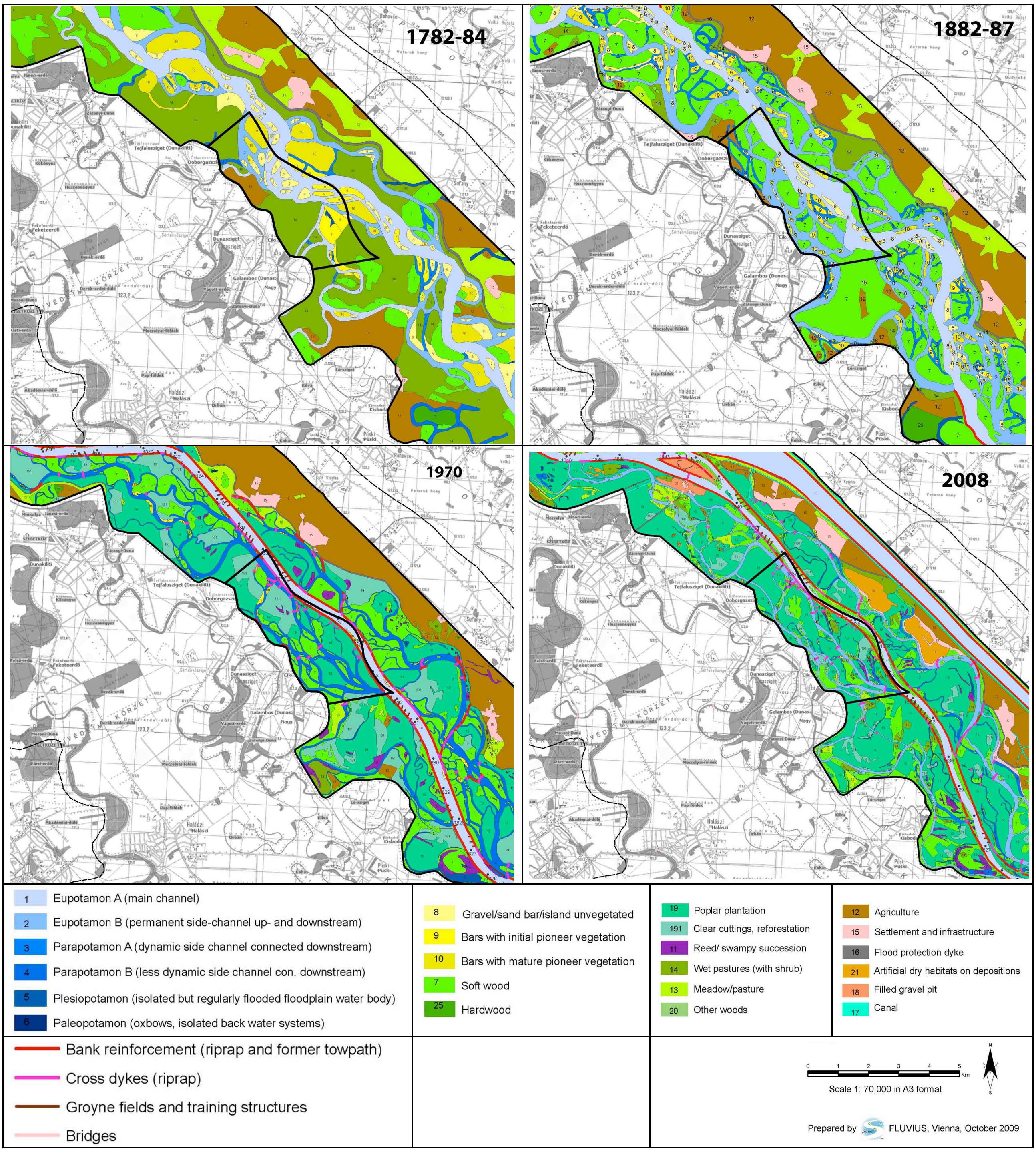


Fig. 1 Analysis of landscape elements for different periods in the Szigetköz area

The appraisal of the present state and variants was carried out in Chapter 9. The evaluation focused on physical habitat conditions concentrating on the criteria and parameters outlined in Chapter 7. Summarizing conclusions on the ecological performance of different scenarios (‘concepts’) terminate the study.

With each flood flow the Danube used to carry a huge amount of sand and gravel from its alpine basin through the Carpathian gate to the Small Hungarian Plain. The drop in gradient resulted in a continuous accumulation of sediments with the formation of a large alluvial cone from Bratislava to Gönyu. A single flood flow was able to congest the main channel with large deposits of sand and gravel, and divert the main flow into former secondary branches. The Mosoni Duna in Hungary and the Maly Duna in Sovakia are the remnants of the former inland delta.

An analysis of period maps revealed that dramatic channel changes occurred even within a few decades. Periods of channel widening changed with periods of channel narrowing indicating changes in the hydrological regime, i.e. the frequency of flood flows of different magnitudes. Fig. 1 (upper part) shows the central part of the Szigetköz reach between 1782/84 and 1882/87. It is obvious that nearly every squaremetre of the floodplain had experienced transitions from terrestrial habitat to aquatic habitat and vice versa.

Reworking of floodplain sediments by lateral erosion and gradual or sudden relocation of channels was the most characteristic feature of the natural system. Channel beds were covered with sand and gravel and large gravel bars, some of them with pioneer vegetation, were spread all along the reach. Very few short branches were not connected to the main channel system at low and mean flows. Fine sediment deposits rarely occurred in a few isolated channel reaches. The unregular channel pattern was associated with a large diversity of flow velocities, water depths and substrates including fallen trees. The Szigetköz wetland was a highly dynamic environment with habitats in rather young succession stages. Consequently very few patches in greater distance from the main channel corridor consisted of hardwood forest.

The impact of river regulation and use of resources (Chapters 3-5)

Clearing of forest in the basin and in the floodplain were the first interventions affecting the river system. River regulation at the end of the 19th century with a main channel of defined width and protected banks, however, marked a first fundamental turning point in the functioning of the natural system. The reworking of floodplain sediments was terminated and consequently the rejuvenation of terrestrial and aquatic habitats had come to an end as well.

At the beginning of the 20th century about one third of the channel area receiving permanent flow (Eupotamon) was turned into branches with downstream connection only (Parapotamon, Fig. 2). After low water regulation (1925) a further decrease of Eupotamon channels was recorded. By 1970, most side branches received flow only at flood events. This further change was mainly caused by lowering of the riverbed induced by channel dredging and reduced bed load supply from the upstream catchment.

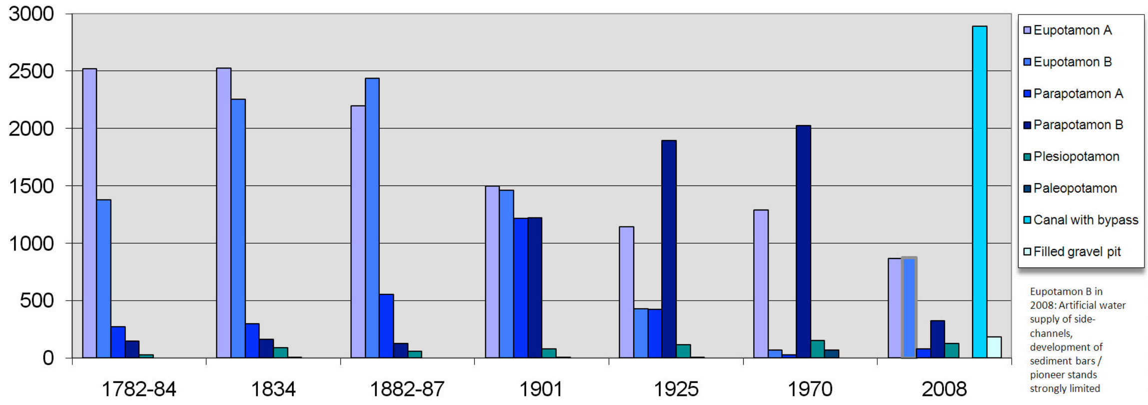


Fig. 2 Change of aquatic water body types since the 18th century (total area in ha)

The second fundamental turning point in the ecological functioning of the natural system occurred in 1992 when 80% of the water was diverted into the power canal for energy production at the GHPP. The subsequent drop of water levels in the river by 2-3 m resulted in a reversal of groundwater flows in the vicinity of the main channel. Mitigation measures in 1995 created a new side-branch system with permanent flow competely separated from the main channel (Fig. 1, lower part). The increase in Eupotamon B in Fig. 2 documents the interconnected branch system with permanent flow.

Aquatic habitat quality, however, deteriorated considerably at the same time. Fig. 3 shows the decline of sand and gravel bars of different succession stages. The total area of bars is a good indicator for the dynamic character of the system as well as for the diversity of aquatic habitat conditions. The dramatic decline occurred already at the first river regulation and the following low water regulation works. With the latest intervention the remaining point bars in the main channel were turned into permanent softwood stands.

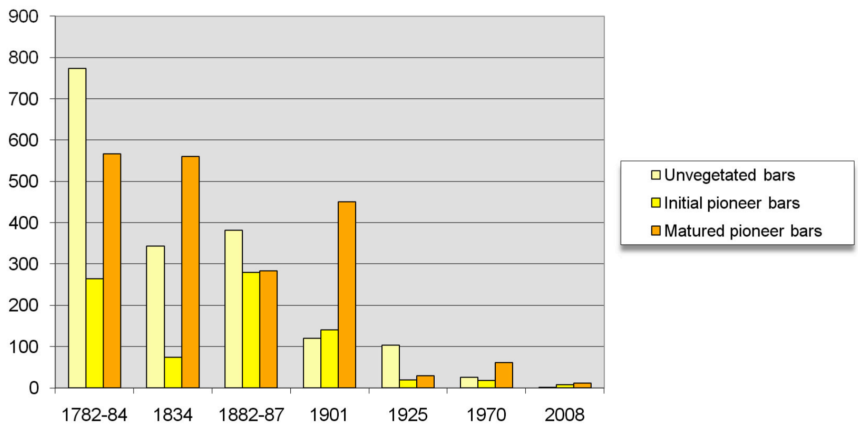


Fig. 3 Change of total area of unvegetated and vegetated sand and gravel bars in ha

The main deficiencies of the present ecosystem in the Szigetköz reach of the Danube are:

- Residual flow of 400 m³/s (temporarily 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
- 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

The missing access from the main channel to the side branch system is a major deficiency for many fish species which depend on spawning and feeding grounds in the floodplain, on winter habitats in stagnant side arms and on shelter during flood events. The interconnected side-branch system itself does not provide suitable habitat conditions for rheophilic fish guilds since flow velocities are too low for many rheophilic species and substrates are dominated by fines covering the gravel of the channel beds. This is clearly reflected by recent fish sampling. In addition, the decline of instream structures, demonstrated in Fig. 3 for bars, refers to the side branches as well as to the main channel. Therefore, the recovery of water body areas receiving permanent flow in the side branches from 1970 to 2008 in Fig. 2 (Eupotamon B) must not deceive over the fact that aquatic habitat conditions remains poor for the indicative group of rheophilic fish.

Flood flows are essential for channel forming processes and for the transport of sand and gravel as well as for regular inundations of terrestrial floodplain habitats. As a consequence of the high turbine capacity of the GHPP there was a lack of regular seasonal floodings in the Szigetköz and a shortage of competent bankfull flows, both in frequency and in duration. This is to say that the present flow regime does not support essential functions of the former river-floodplain ecosystem.

Legal Framework (Chapter 6)

Any intervention in the Szigetköz area has to comply with international and European law as well as with the judgement of the International Court of Justice ICJ of 1997. The Court ruling noted in § 140 and § 146 that "*in order to evaluate the environmental risks, current standards must be taken into consideration*", the Parties "*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*" and "*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 essential environmental concerns*".

The most important environmental law for the future development of the region may be the EU Water Framework Directive WFD which defines certain procedures, environmental objectives and a time schedule for implementation and achievement. This study is following the general procedure and complies with the steps to be taken for its implementation. It furthermore adapts criteria and benchmarking of quality parameters to the ecology of large floodplain rivers.

Environmental objectives and criteria (Chapters 7 and 9)

Environmental objectives and criteria were delineated for physical habitat conditions, i.e. hydrodynamics and morphodynamics (Table 1), and for characteristic habitat types, i.e. different aquatic habitat types (Fig. 4), transition zones between water and land, lower floodplain areas (softwood stands and marshes) and higher and less dynamic areas (hardwood stands).

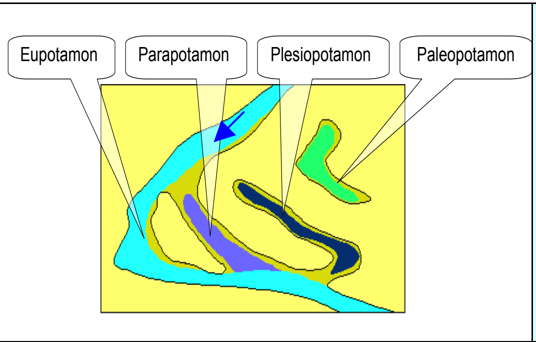
Table 1 Environmental objectives and indicators for physical habitat conditions

Parameter	Objective	Indicator
Flow regime and seasonal dynamics	Natural variations of the flow, full flood regime	Discharge compared to the flow records at Devin gauge
Water level variations at correct stage	High range of water level fluctuations at pre-dam position	Position of mean water level, range of seasonal water levels
Flow velocity and diversity	Flow velocities according to water body type (Fig. 4); diversity of flow velocities associated with channel variability	Longitudinal range of flow velocities, local diversity of currents in cross-sections and river patches
Bed load transport	Competent flow regime for potential transport of sediment	Distribution of critical shear stress for movement of sand and gravel, duration and frequency of competent flood flows
Channel evolution	Rejuvenation of habitats by channel evolution and relocation of channels by lateral erosion	
Lateral and longitudinal connectivity, permeable channel bed substrates	High connectivity along the river and towards side arms, prevailing sand and gravel bed	Position of mean water level; length of free flowing river reach, type of weirs and sills; distribution of crit. shear stress
Groundwater regime	Sufficient groundwater fluctuations to maintain the wetland character and its biota; sufficient groundwater recharge	Spatial range of seasonal groundwater fluctuations; distribution of critical shear stress

The assessment of the present state and of potential rehabilitation measures was based on a set of indicators resulting from mathematical modelling (Table 1). The selection of parameters and indicators was guided by the former highly dynamic environment resulting in specific habitats and associated biota. The *flow regime* as the governing factor does not only refer to the prevailing sharing of the natural discharge but to the distribution of flood flows which are important for morphydynamic processes. *Variations of water levels* from seasonal low flow levels to flood stages are a key factor for habitat conditions in transitions zones and terrestrial floodplain habitats. Surface water level variations are controlling the *groundwater regime* impacting large areas on the protected side of the floodplain. *Flow velocities* at prevailing low and mean flow conditions are essential for the diversity of the rheophilic fish guild.

In the natural sytem the river and its floodplain was a unit with numerous transitions of different habitat types and free exchange of the aquatic fauna and open gravel beds (Fig. 1). Regulation works resulted in separate systems of river channels, flooded areas and protected sites preventing migration and exchange of biota in many ways. Therefore, re-establishing *connectivity* is a prime objective. The magnitude and spatial distribution of shear stress at bankfull flows together with the flood regime is governing the potential *evolution of channels* and thus the rejuvenation of habitats.

Aquatic habitats can be distinguished in different water body types with specific habitat conditions and associated biota (Fig. 4). Unvegetated sand and gravel bars or pioneer stands on bars and the natural shore length can be quantified in landscape analysis from period maps to compare the areal extent of transition zones. Fig. 1 demonstrates the change in composition of landscape elements from the 18th century until the present time reflecting the impact of river regulation and the change in land use on the floodplain.



Eupotamon: channels with permanent flow; essential habitat for rheophilic fish species; high significance of habitat quality
Parapotamon: channels receiving flow at higher discharges below bankfull flow; essential refuge, wintering, spawning and feeding habitat for fish from Eupotamon channels; high significance of habitat quality
Plesiopotamon: permanently connected channel with stagnant water; essential habitat for limnophilic species and water plants
Paleopotamon: isolated water bodies affected by changing water levels; indispensible habitat for some limnophilic species, intensive growth of water plants

Fig. 4 Water body types in large floodplain rivers as criteria for aquatic habitat conditions

In addition to the ecological criteria the impact of large flood flows on water levels was investigated for the assessment of flood protection compatibility.

Outline of rehabilitation measures

The *present channel network* and discharge distribution is the result of mitigation measures after the diversion of 80% of the water to the GHPP. The former floodplain area is divided into four separated sectors: the main channel with a residual discharge, the Slovak floodplain with water supply from the power canal, the Hungarian floodplain with supply from the headwater of the Dunakiliti weir and the protected side. On the Hungarian floodplain all side-arm entrances were closed after 1992, and the branches were interconnected with the exception of the Bagomer branch. Drop structures control water levels in the branch system. A dynamic flow regime is imposed on the Hungarian 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.

About a dozen rehabilitation proposals have been published by various authors since 1992, but only a few plans had been worked out to a greater detail. This includes the proposal of the so-called SZITE variant, promoted by the Environmental Protection Association of the Szigetköz (Szigetközi Természetvédelmi Egyesület, SziTE) and a meander variant which was subject of the INTERREG IIIA / HUSKUA/05/02/94 project (2007). Other proposals envisaged the narrowing and raising of the bed level (WWF 1994, 1997), the widening of the bed by lateral erosion (Jaeggi, in Neue Züricher Zeitung, 12 Jan. 1994), the raising of the channel bed by using bank material (Molnár 2004) and the construction of different number of weirs in the main channel (various sources). None of them was elaborated to greater detail. For the implementation of these proposals in numerical models simplified planning assumptions were taken for channel geometry and structures.

In the course of the study a number of variants were selected for further detailed investigations representing four different rehabilitation concepts (Table 2). The variants selected covered different concepts of rehabilitation and avoided duplication of time-consuming model runs. The *first concept* accepts the present separation of the main channel from the side-branch system of the floodplain and envisages a general increase of discharges for improvement of aquatic habitats as well as an improvement of the flood regime.

Table 2 Rehabilitation concepts and associated measures

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, two Meander variants + AFR
4	Creating a lower secondary floodplain by lateral erosion	Widening variant + AFR

AFR = Altered Flow Regime

The *second concept* envisages the raising of water levels by lowering the discharge capacity of the main channel thus achieving lateral connectivity with floodplain water bodies. The **"Narrowing variant"** raised the surface of the former point bars in the main channel, which cover about 1/3 of the total channel area, by 2 m. Since this measure proved to be rather ineffective in terms of raising water levels, an **"Optimum Filling variant"** was implemented which filled up the channel bed by 3-4 m in order to obtain average water levels of the 1950s in the main channel. The variants selected represent the lower and the upper limit of the channel filling concept and the results have to be interpreted accordingly. Increased average discharges to achieve connectivity below the optimum filling level and an altered flow regime with effective flood flows are part of the concept.

The *third concept* includes the raising of water levels by impounding main channel sections with different numbers of weirs or bottom sills. Raising of water levels also restores lateral connectivity on full length or at least on a part of the project reach. The "**Szite variant"** includes the construction of three weirs in the main channel with fish passes, movable flood gates and small ship locks for sports boats. It plans to extend the side-branch system to the Bagomer branch. In addition, side-arm closures will be opened at two locations upstream of planned weirs and channels will be dredged on both sides of the Danube. In the main channel clearing of vegetation and dredging of point bars plus clearing of defined location in the floodplain is planned for the lowering of flood levels and ice release.

Seven bottom sills are envisaged in the two "**Meander variants"** creating a series of impoundments along the river. The main idea of these variants is to create a new free flowing river on floodplain level crossing the impounded Danube at the headwater of the bottom sills. Both versions use the same meander course which makes use of existing branches adding some connecting reaches. The INTERREG version does not enlarge the existing branches; consequently the discharge distribution between the main channel and the meander branch varies along the reach. The Meander (400) version envisages enlarging of the meander branch up to a discharge capacity of about 400 m³/s. The resulting meander branch would have a similar width as the present main channel at residual discharge, i.e. about 150-200 m. This last version requires higher bottom sills than the INTERREG version.

In the *forth concept* the raising of bed levels by lateral erosion **("Widening variant")** was investigated. 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.

The evolution of the riverbed profile depends on the composition of bank materials and on competent flood flows. In this concept it is accepted that the main channel and the present floodplain remain separate systems. Lateral connectivity would not be possible.For this reason the Widening variant represents a special option which has to be considered accordingly.

Model investigations

The investigation of potential rehabilitation measures was based on mathematical modelling using 1-dimensional and 2-dimensional models for surface water flows and a 3-dimensional model for the groundwater response. All models could be calibrated with existing observations of surface and groundwater levels at different discharges. With 1-dimensional morphological modeling the long-term channel bed stability was investigated for selected variants. A vegetation succession model was used to predict future changes in vegetation stands based on groundwater level results for different rehabilitation measures and discharge scenarios.

Table 3 Results of hydrodynamic and morphodynamic modeling

Model	Parameter results
1-D surface water model	- flow velocity, bottom shear stress (mean values in cross-sections) - water levels, water depth (in cross-sections) - discharge distribution among channels (below bankfull stages)
2-D surface water model	- flow velocity, direction of flow, bottom shear stress, water levels, water depth (at each knot of the mesh, i.e. 15 x 60 m in channels) - discharge distribution on the floodplain (overbankfull stages) - spatial extent and duration of inundations (by analysis of time series)
1-D morphological model	- erosion/accumulation of bed sediments, i.e. evolution of the longitudinal profile (by mean values in cross-sections) - assessment of bed load transport capacity - assessment of threshold for competent flows for bed load transport
3-D groundwater model	- contour lines of groundwater levels, direction of groundwater flow, groundwater level differences for comparison of discharges or variants

The surface water models were restricted to the active floodplain between the upstream border section at Rajka (rkm 1850) and the confluence with the Gabcikovo tailrace canal (rkm 1811). The groundwater model extended from the main channel in south-west direction far beyond the Mosoni Danube.

Most models runs were carried out with a constant discharge input for the main channel and the Hungarian side-branch system. In order to explore the effect of variable flows a series of discharges from 200 to 750 m³/s and higher flows from 2000-4000 m³/s and the flood flow of August 2002 were investigated. In the Hungarian side-branch system 40-180 m³/s were supplied coupled with different main channel flows. The morphological model and the vegetation succession model used time series of discharges in the simulation.

Table 3 contains the list of parameters from model results that were used as indicators for the interpretation of habitat conditions and habitat quality in the assessment of the present situation and variants (also compare to Table 1). The model simulations produced a huge amount of data in graphical and numerical form especially due to the large number of discharge scenarios for each variant and the present situation. Results included

- Maps with the distribution of discharges, water depths, flow velocities and shear stress (1-D, 2-D)
- Exceedance curves for shear stress values by area (2-D)
- Longitudinal water level profiles of the main channel and of the (main) side-branch channel for discharges from 200+40 to 750+10 m³/s (1-D) and 930 - 4000 m³/s plus flood flow Aug. 2002 (2-D)
- Graphs with water levels in cross-sections, main channel, side branches (1-D)
- Longitudinal bed level profiles, variants compared to present state (morph. model)
- Groundwater potential maps for present state and variants for different discharges
- Groundwater difference maps between different discharges for present state and variants
- Groundwater difference maps between present state and variants for different discharges
- EXCEL-files with 1-D data for all cross-sections
- Shape files with 2-D data

Method of assessment

For habitat conditions the assessment was based on analysis of indicators listed in Table 3. Additional assessment included aquatic habitats, fish fauna, lateral and longitudinal connectivity and terrestrial habitats (mainly based on vegetation development). The analysis was carried out for the present situation and for rehabilitation measures (variants) mentioned in Table 2.

- **Surface water level fluctuations**
  The range of water level fluctuations was analyzed at representative cross-sections in the main channel, in the side branches and in the meander branch for the following discharge scenarios[1]: 550+80 minus 220+40 (main channel), 550+120 minus 200+40 (side branches), 750+120 minus 200+40 (main channel and side branches), 550+120

[1] 550+80 means 550 m³/s flowing in the main channel and 80 m³/s supplied to the Hungarian branch system above Dunakiliti.

minus 200+40 (meander branch, Meander-INT. version), 50+400 minus 50+100 (meander branch, Meander-400 version).

- **Flow velocities**
  At the same cross-sections mean flow velocities from 1-D modelling were analyzed for discharge scenarios: 200+40, 550+80, 750+120 (main channel, side branches, meander branch for Meander-INT. version), 50+100, 50+400 (meander branch, Meander-400 version); in addition, total averages for channel reaches were compared.

- **Groundwater level dynamics**
  The assessment of the groundwater response was based on difference maps of groundwater levels between variants and the present state for discharge scenarios: 200+40, 350+80, 550+120, 750+120 and 50+400 (only Meander-400 version). Groundwater fluctuations were assessed on the basis of difference maps for the following discharge scenarios: 350+80 minus 200+40, 550+120 minus 350+80, 750+120 minus 550+120, 750+120 minus 200+40 and 50+400 minus 50+100 (only Meander-400 version).

- **Morphodynamics (shear stress)**
  The assessment was based on longitudinal profiles of bottom shear stress for the main channel at 750+120 (1-D results) and 50+100/400 for the meander branch (1-D result, Meander-400 version only). In addition, analysis of shear stress exceedance for 750+180, 2000 and 3000 was used as well as maps of spatial shear stress distribution (2-D results).

- **Flow regime**
  The flow regime imposed on the project reach since 1992 was analyzed on the basis of gauge data from Devin (Bratislava), Rajka and Dunaremete making use of duration curves (1992-2007), daily average discharges per year (1992-2007), number of floods per year causing complete inundation (1950-2007), duration of longest flood causing inundation for each year (1950-2007), number of days of inundation for each year (1950-2007), spatial inundation for present state and variants (1995-2008, 2-D results)

- **Connectivity**
  Lateral and longitudinal connectivity was assessed based on variant design and expert judgement.

- **Aquatic habitats**
  The assessment of aquatic habitat conditions concentrated on the fish fauna: change of total area of water bodies for different types, change of number of species for rheophilic, eurytop and stagnophilic fish in different water body types. The preference of rheophilic fish was also correlated to shear stress.

- **Transition zones and terrestrial habitats**
  The vegetation succession model distinguished between softwood forest, ruderal and semi-ruderal riverine communities, wetlands and hardwood stands and predicted long-term development of habitats for the present situation and for variants.

- **Flood protection**
  Water level profiles of the Aug. 2002 flood were calculated for the present state and for variants and a freeboard allowance of 1 m was used as reference for the assessment

of flood protection performance. In addition, ice conveyance was discussed based on expert judgement.

Assessment of rehabilitation concepts

The assessment of rehabilitation measures was carried out on a quantitative data basis but expressed in qualitative terms with "+" and "-". The results in Table 4 are summarizing more detailed results contained in Chapter 9 of the study. It is highly recommended to refer back to the detailed analysis for further planning and management decisions.

Table 4 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 involves a general increase of discharges for the Present state)

--	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

Concept 1: Present state + increase of discharge

Altered flow regime. A general increase of the discharge in the main *Danube channel* improves aquatic habitat conditions for certain rheophilic fish species. 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 would also increase annual groundwater level fluctuations and inundations of terrestrial habitats emphasizing the dynamic character of the riverine wetland ecosystem.

Effects on 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 m^3/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. By 2008, all point bars were turned into terrestrial habitats carrying soft wood forest and shrubs, 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.

Terrestrial habitats. Improvments with respect to the development of softwood forests - important from a conservation point of view – can only be expected at increased flow rates. But 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 possibly 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.

Concept 2: Connecting systems by raising of bed levels

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.

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.

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 combined narrowing and filling.

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 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.

Concept 3: Connecting systems by raising of water levels

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. Rehabilitation measures include 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 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. 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. 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.

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 while the Meander (INT.) version maintains velocities of 30-40 cm/s in most reaches. In the *meander branches* both versions produce flow velocities that are similar to the Present state at 200 m^3/s in the main channel. The width of the Meander (400) branch is similar to the actual width of the present Danube channel at prevailing flows (150-200 m). The shear stress distribution along the branch indicates a high potential for channel evolution on most of its length. Point bar development, scouring along outer banks, aggradation and degradation in short reaches can be expected rendering diverse habitat conditions for the aquatic fauna.

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. At the elevated impoundment levels in the *main channel*, however, the water level fluctuations for all variants in this concept 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* exceeds the present values 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 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 operation mode of the gates. 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. Non of the variants can 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.

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 as 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 accomplished.

Concept 4: Creating a secondary lower floodplain by lateral erosion

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.

The general idea if this concept 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.

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 fluctuations of the flow.

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 in the branches.

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. 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.

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 and earlier interventions. 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.

In line with the Water Framework Directive this study concentrated on reference conditions and on benchmarking for rehabilitation and on delineation of environmental objectives. Further planning is needed to assess associated costs and technical feasibility.

None of the measures investigated proved to be the “ideal solution”; 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 of envisaged measures on habitat conditions and biota can be assessed using the criteria outlined and applied in this study.