Ecological comparison of the Gemenc and Lobau floodplains by Hydro-morphological indicators

SEVENTH FRAMEWORK PROGRAMME

WETwin

Deliverable D7.1
Draft version
Date 13/02/09

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Report of the WETwin project:
www.hydroinfo.hu/wetwin

Document Information

Title	Ecological comparison of the Gemenc and Lobau floodplains by Hydro-morphological indicators
Lead authors	Peter Winkler (WKL), István Zsuffa (VITUKI), Thomas Hein (WKL)
Contributors	
Deliverable number	D7.1
Deliverable description	Decision-support toolbox, performance indicators and decision criteria
Report number	D7.1_R1
Version number	D7.1_V1
Due deliverable date	4
Actual delivery date	4
Work Package	WP7
Dissemination level	PP
Reference to be used for citation	P. Winkler, I. Zsuffa, T. Hein, *Ecological comparison of the Gemenc and Lobau floodplains by Hydro-morphological indicators,* Report on the MOEL project (2009)

This project was exclusively funded by the Österreichische Forschungs-gemeinschaft (ÖFG) within the MOEL-program and was used as preparatory work to the project WETwin.

SEVENTH FRAMEWORK PROGRAMME

Grant Agreement no 212300 (7th Framework Programme)
Collaborative Project (Small or medium-scale focused research project)
Specific International Cooperation Action (SICA)

Start of the project: 01/11/2008
Duration: 3 years

Acronym: WETwin
Full project title: Enhancing the role of wetlands in integrated water resources management for twinned river basins in EU, Africa and South-America in support of EU Water Initiatives

Report on the MOEL-Project*

Ecological comparison of the *Gemenc* and *Lobau* floodplains by hydro-morphological indicators

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* This work was funded by Österreichische Forschungsgemeinschaft (ÖFG) within the MOEL program

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Contents

Introduction

The development of appropriate and sustainable management solutions for wetlands using adequate scientific tools has become a crucial task worldwide. Such ecosystems are exposed to high pressures by human activities like agriculture, land use change, water management and flood protection measures. Due to such local pressures, floodplains, especially in the proximity of human settlements, have been largely changed and degraded over the last 150 years. Today's global change aspects – like increasing temperature and meteorological extreme events – have lead to a change in appreciation of riverine wetlands' functions and services, as these ecosystems are known to increase the overall stability based on their buffering capacities. Therefore, it is highly important to maintain or ameliorate their ecosystem health by integrating functions and services like biodiversity, drinking water quality and the availability of water for agricultural use in a more holistic approach.

An important key prerequisite for applying such strategies is the development of so-called ecological indicators quantifying the status, health, functions and services of the ecosystems under consideration. Thereby, abiotic properties like hydro-morphology, and land-use and nutrient status have to be considered as well as the species and community level. Deriving the numerical values of such indicators for various possible future scenarios yields a basis for decision-making between different possible management options. An overview over various ecological indicators can be found in [1].

Our basic approach relies on the insight that ecological processes as well as community services (like drinking water supply) of wetlands are governed by their hydro-morphological properties to a large extent. A natural, largely undisturbed floodplain is characterised by frequent changes between flooded and dry periods and by a strong temporal and spatial variation in landscape character and species distribution. Therefore, ecological health and the similarity to a natural wetland can be assessed by purely hydro-morphological parameters like shallow water areas, shore line lengths and the variations of these quantities with respect to different water levels. Such interrelations have been shown by previous studies like the OPTIMA Lobau project [2, 3]. The above mentioned hydro-morphological parameters are used as ecological indicators in the present work. On the other hand, the drinking water quality and other community services are – of course – also closely related to the hydro-morphology of floodplains. Only ecologically healthy wetlands with sufficient landscape variability and species diversity can act as natural water-purification systems for rivers and serve for a sustainable drinking water supply.

The key task of the present work is to compare the structure-function-utilization-coupling of two riverine wetlands in Austria and Hungary by using hydro-morphological indicators. Gemenc and Lobau Danube-floodplains are two well-studied central European riverine wetlands along the Danube River showing different ecological and land-use characteristics. While in Gemenc forestry is being carried on, Lobau is not farmed at all. On the other hand, Gemenc has a stronger connection to the main stream channel of the Danube River, thus

being exposed to more frequent flooding than Lobau. For these two regions detailed data about both, biotic and abiotic properties are available. Therefore, an analysis of these two wetland systems with respect to their ecological functions and services seems to be a highly rewarding task. Thereby, the influence of different hydro-morphological and land-use characteristics on ecosystem health and water quality is of special importance.

Another task of this work is to investigate the nutrient dynamics in the Gemenc floodplain, being among the crucial processes in floodplains as regards ecology as well as community services. Such studies have not been carried out for this particular site until now. Nowadays, rivers and riverine wetlands are exposed to excessive nutrient input (mainly nitrate and phosphate) due to intensive agriculture and communal waste water. Therefore, the nutrient reduction capacity of floodplains belongs to the most important community services of such ecosystems. Nutrients can be removed from the river water, entering the floodplain during flood periods, via three pathways: Long-term burial in sediments, harvesting and de-nitrification by microbial communities. A study of de-nitrification requires extensive experimental investigations and was therefore beyond the scope of this project. For this reason the removal of Nitrogen and Phosphorous due to sedimentation and wood-felling has been investigated for the Gemenc floodplain. Comparison of the amounts of nutrients removed via these two pathways gives interesting insights into the nutrient dynamics of the studied system.

Objectives

- To find indicators measuring ecosystem health, landscape diversity and the similarity to a natural undisturbed ecosystem. These indicators should be based on structural hydro-morphological properties of the two studied sites.
- To calculate these indicators for Gemenc and Lobau by means of hydrodynamic simulations and statistical evaluation. In this way the two floodplains are compared to each other from an ecological point of view.
- To gain insight into the nutrient dynamics in the Gemenc floodplain by estimating quantitatively the amount of nutrients (nitrogen and phosphorous) removed due to sedimentation and harvesting.

Study sites

In this section the two study sites are briefly introduced. More detailed information about these regions can be obtained from the national park management authorities of "Nationalpark Donauauen" [4] and "Duna-Dráva Nemzeti Park" [5].

The *Lobau* is an urban floodplain region, partly within the city limits of Vienna. Together with the adjacent floodplains of Orth, Regelsbrunn and Hainburg, it is part of the "Nationalpark Donauauen". The Lobau has a total area of approximately 40km^2 excluding the main stream. Due to its proximity to Vienna the region is used for recreational purposes and for additional drinking water supply ion case of water shortage. However, in contrast to the adjacent Marchfeld where intensive agriculture is being carried on, the Lobau is not farmed at all. A detailed digital terrain model (DTM) of the floodplain showing the terrain elevations can be found in Figure 1. Along the south-western fringe of the region there is the Danube river while the north-eastern one borders on the Marchfeld.

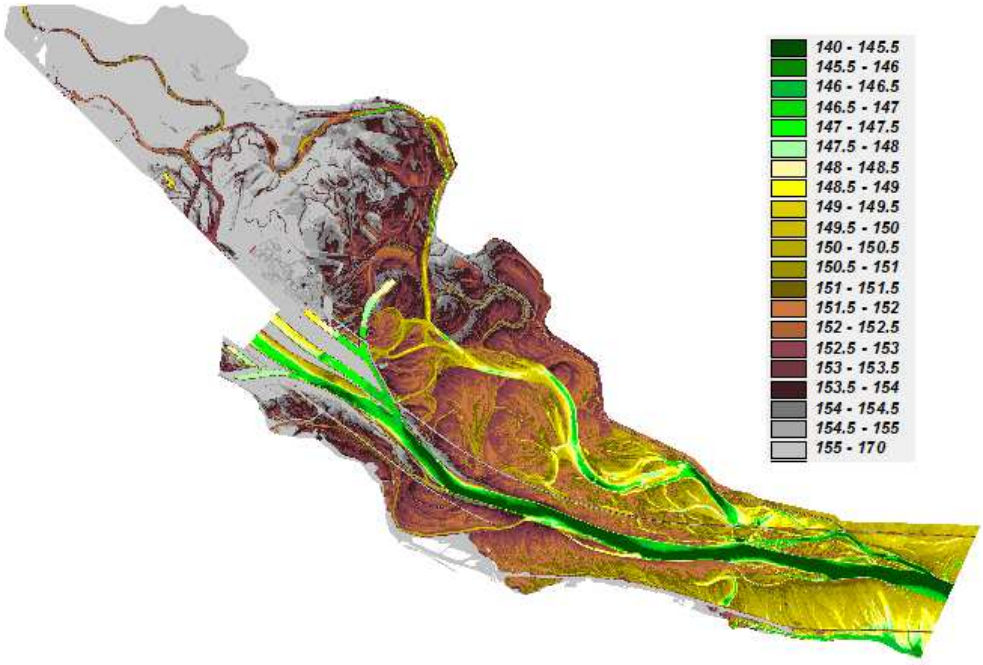

Figure 1: DTM of the Lobau. The terrain elevations are given in metres above Adriatic sea level.

One of the most important characteristics of the Lobau is its separation from the main channel by a flood protection dike. This artificial engineering measure has serious consequences for hydro-morphology and ecology of the system: As the only connection between the Danube and the floodplain is the so-called "Schönauer Schlitz" at the downstream (i.e. south-eastern) end of the system, the Lobau is a back-flooded system receiving river water only at water levels

higher than middle water. While the lower part of the Lobau is inundated during flood events, its upstream (i.e. north-western) part is permanently dry. As a consequence, the system is threatened by continuous aggradation and will ultimately lose its floodplain character as well as many characteristic and endangered species, if no restauration measures are carried out. Therefore, in the project OPTIMA Lobau different future management and engineering measures have been investigated in order to preserve and ameliorate the ecological character of the system. It has been found that an additional opening of the dike will lead to a situation which is much closer to the largely natural character of the system 150 years ago.

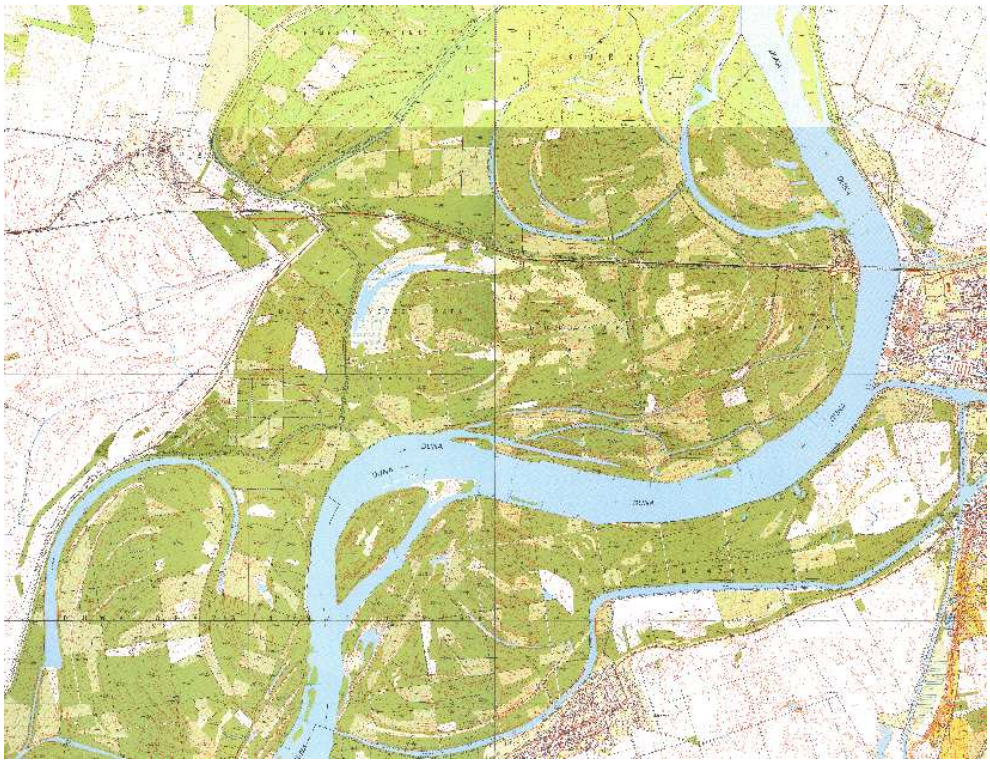

Figure 2: Topographic map of the Gemenc on the scale of 1:10000. On the right hand side, the city of Baja.

The *Gemenc* floodplain is situated in Southern Hungary close to the small city of Baja and belongs to the "Duna-Drava" national park. The system contains oxbow lakes and is – in contrast to the Lobau – fed from upstream by a side channel of the Danube. Up to the beginning of the 20^{th} century, the Gemenc has been used for fishery. For this purpose, so-called "fok" channels have been dug in order to retain fish when water was retreating after flood events. Up to now, these channels are the preferred flow-pathes of water during high water periods. Nowadays, fishery plays only a minor role, however, forestry – primarily for the purpose of paper production – is being carried on in this region. Due to numerous fok-channels and several weirs the water levels in the Gemenc are not strictly connected to the ones in the Danube. In addition to this, during

the summer months, evaporation plays a major role for the water balance in the system. Many ponds and other water bodies dry out during the summer season. Figure 2 shows a topographic map of the region on a scale of 1:10000.

As in the Lobau, aggradation is a huge problem in the Gemenc. However, here the reason for the ongoing aggradation process is different: While –as mantioned above – in the Lobau it is due to the artificial separation by a dike, in the Gemenc the channelisation of the main stream as well as low flow velocities lead to a huge accumulation of sediment which will ultimately fill up the present oxbow lakes. These low flow velocities stem from the small slope of the river bed – 0.5cm/km versus 1m/km in the Lobau. Also in the Gemenc, engineering measures are being discussed in order to maintain and ameliorate the ecological values and functons of the system.

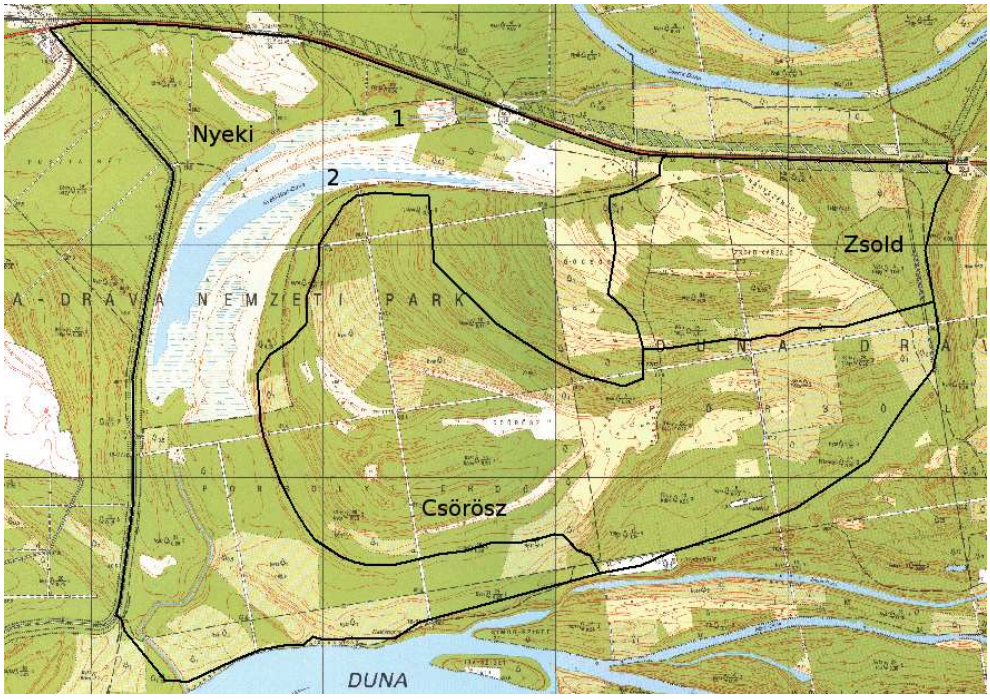

Figure 3: Topographic map (1:10000) of the Nyeki-Csörösz-Zsold subsystem investigated within this work. The three main hydrological cells are indicated by black lines. The inflow is indicated by "1" and the south-eastern branch of Nyeki by "2".

Within this work a hydrologically self-contained subsystem of the Gemenc, the *"Nyeki-Csörösz-Zsold"* lake system has been investigated. This system is fed indirectly by another oxbow lake in the north and drains directly into the Danube on its southern border. It consists of three major hydrological cells, indicated in Figure 3.

It should be mentioned, that Lobau and Gemenc belong to the few floodplain regions in the Danube river basin that are still existent. Around 80% of the original floodplains have been destroyed in the past 150 years by human inter-

ventions like flood protection measures, river channelisation, power plants, and drainage of terrain for agriculture and for building settlements. The remaining 20% of the original floodplain regions are, however, of utmost importance for the ecology and water quality in the whole Danube river basin and the Black Sea.

Methods

In this section the methods used within this work are presented. This includes software tools like GIS programs and hydrological simulation software as well as statistical evaluation tools.

Digital Terrain Model (DTM)

As a first step, geographical and topographical information about the Nyeki-Csörösz-Zsold-system has to be acquired and transformed into a digital terrain model (DTM) which forms the basis of all our investigations. Each grid-point of such a DTM contains the terrain elevation – and optionally other information e.g. land cover data – and can be displayed graphically. To achieve this, the topographical 1:10000 map from 1985 has been scanned and digitalised by manually tracing its contour lines using the GIS software ArcView. Additionally, the geometric shapes of fok channels, weirs and other artificial constructions have been added manually to the digital map. ArcView allows to interpolate between the contour lines in order to obtain continuous information about the terrain elevation and to transform the digital map into a DTM.

Nutrient dynamics – sedimentation and forestry

More recent topographical information is available about lake Nyeki only: A DTM was developed in 2005 by the national park research centre in Baja and in 1993 the same institution has measured seven cross-sections across the lake. By geo-referencing these cross-sections and creating approximate contour lines another DTM of lake Nyeki has been created using ArcView. This information about the ground of the lake from different years makes it possible to estimate the amount of sediment that has been deposited between 1993 and 2005. With the availability of the DTMs from these two years it is straight-forward to create a sedimentation map by subtracting the 1993 elevations from the 2005 ones for each grid point. This map shows the amount of sediment which has been deposited within these twelve years for lake Nyeki. Its grid-size is 1 by 1 metre.

As this sedimentation map is for lake Nyeki only, an extrapolation to the whole Nyeki-Csörösz-Zsold-system has to be established. However, as for the largest part of this system the only available topographic information stems from the 1985 map, this extrapolation can only be a rough estimation which should yield the correct order of magnitude of deposited sediment. To achieve this, the correlation between the terrain elevations of all grid points (within a well-defined region) and their amounts of sedimentation has been investigated. Thereby, the crucial task is to choose a region, characteristic and representative for the

whole system. Here, the south-eastern branch of lake Neyki (indicated by "2" in figure 3) has been chosen, based on the following considerations: As the inflow channel to lake Nyeki ("1" in figure 3) is connected to its north-western branch, high flow velocities can be expected here. For most other parts of the system, however, rather low flow velocities are typical because of their indirect connection to the inflow channel. Therefore, the hydrological situation in the more isolated south-eastern branch is characteristic for the system as a whole. The correlation between sedimentation and elevation in this region turned out to be almost linear and has been extrapolated to the whole system. Thus, an approximate sedimentation map for the whole Nyeki-Csörösz-Zsold-system could been created.

In order to assess the amount of nutrients captured in the sediment, sediment samples were taken at three sites in lake Nyeki. The sampling was carried out by the Duna-Drava National Park Research Institute. The total content of nutrients in the sediment was measured by VITUKI using titrimetry in the case of N and specrophotometry in the case of P. Only material from more than thirty centimetres below the ground of the lake has been investigated, in order to exclude the variable amount of nitrogen in the upmost layer where de-nitrification takes place. It is assumed that the amount of nutrients 30 centimetres or more below the ground is stable or quasi-stable and can be released only during extreme floods with exceptionally high flowing velocities. The knowledge of nitrogen and phosphorous content in the sediment and the total amount of sediment in the system makes it easy to assess the total amount of nutrients removed by sedimentation between 1993 and 2005.

The amount of nutrients removed by forestry – harvesting of poplars, oaks and other trees – has been estimated from wood-felling data (solid cubic metres per km^2) provided by the National Hungarian Forestry authority. For the nutrient content in wood from different species, average values for oaks and poplars have been taken from different literature sources [6, 7, 8] and from recent measurements [9]. Comparing the amounts of nutrients removed by sedimentation and by forestry, respectively, gives interesting insight into the nutrient dynamics of the investigated system.

Hydrodynamic simulation – water levels – ecological indicators

A long-term hydrodynamic simulation is the basis for the investigation of hydromorphological and ecological properties of the studied system. From such simulations, three characteristic water-levels can be derived for each water body of the system. They are defined in the following way:

- LW (low water) is the water level, which is surpassed at 94% of the whole time-period considered.
- SMW (summer mean water) is the mean water level in the months from April to September
- HW1 (one-yearly high water) the water level which is reached – on average – once a year.

For each of these water levels and for each water body in the system, the *total water surface area* and the *total shore line length* are calculated. In addition to these six quantities, the relative increase (variation) of water area and shore line length between LW and SMW and between SMW and HW1, respectively, are used as hydro-morphological parameters in this work, describing the hydrological variability and habitat diversity of the studied system [10].

For the Lobau, these quantities have already been calculated within the project OPTIMA Lobau. For the Gemenc a hydrodynamic simulation has been performed from which the characteristic water levels as well as the hydro-morphological indicators have been derived. As the hydrological situation and the number of floods differs strongly between different years, a one-dimensional (1-D) long-term simulation of 21 years has been chosen. The Nyeki-Csörösz-Zsold system is divided into the three hydrological cells indicated in figure 3. In a 1-D simulation, the topology of the terrain enters the calculation via the so-called elevation-volume-function. This function yields the volume of water stored in the cell as a function of the present water level (elevation). It has been derived from the DTM for each of the three cells before starting the simulation. Additionally, the geometries of the inflow- and outflow-fok-channel as well as of the natural boundaries between the three cells have been used as input for the simulation. The average monthly precipitation and evaporation have also been considered. The boundary conditions are a daily time-series of water levels at the Danube from 1975 to 1995. The simulation program was written by István Zsuffa [11] and finally yields daily water levels for the three system cells Neki, Csörösz and Zsold over this period of 21 years.

In order to arrive to the above-mentioned characteristic water-levels, this time-series has been evaluated statistically using the statistics software "Technical Hydrology" which is specially designed for hydrological problems. The hydro-morphological parameters described above have been derived from the DTM and the characteristic water-levels using ArcView and smaller FORTRAN programs written for this purpose.

Error analysis

It must be mentioned that part of the available data were very inaccurate: For geo-referencing the seven cross-sections of lake Nyeki, we had to rely on hand-drawn sketches without knowing the coordinates of the starting- and end-points of the cross-sections. Nevertheless, considering the topology and character of the landscape, it was possible to locate the cross-sections on the DTM approximately. This inaccuracy leads – of course – to a considerable error in the results of the sedimentation study (while the hydrological simulation and the hydro-morphological parameters are not affected by this inaccuracy.) It was still possible to obtain correct orders of magnitude for the amounts of sediment and nutrients in the system.

Results

In this section the main results found within this project are presented:

The DTM

The DTM of the Nyeki-Csörösz-Zsold-system, developed from the 1985 topographical map, is shown in figure 4. Here, it can be seen clearly that the studied region consists of three cells which are hydrologically separated from each other at low- and mean-water. Each of the three cells consists of a depression which is surrounded by higher grounds. The boundaries of these cells have been derived from this DTM by choosing a path with the highest possible elevation. This DTM forms the basis for all further hydrological and sedimentation studies carried out during this project.

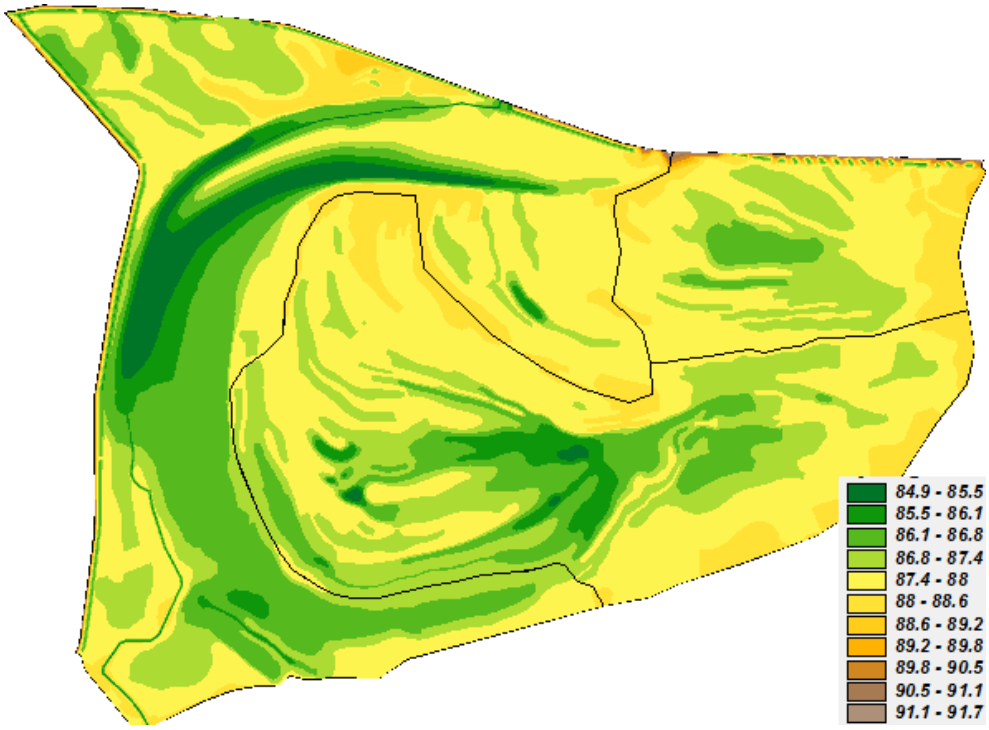

Figure 4: DTM of the Nyeki-Csörösz-Zsold-system.

Correlation between sedimentation and elevation

As the south-eastern branch of lake Nyeky was found to be approximately representative for the whole system, the correlation between the amount of sedimentation and the terrain elevation has been investigated for this region. The result in figure 5 shows a fairly linear correlation. This means that deeper grounds experience more sedimentation than higher ones. At more than 87m above sea level the sedimentation becomes almost zero.

This correlation allows an extrapolation to the rest of the system, which is shown in figure 6. Thereby, the data for lake Nyeki stem from the comparison between the 2005 DTM and the 1993 cross-sections, whereas the rest of the

sedimentation map relies on the correlation presented above. Here, it is striking, that the region in and around lake Nyeki shows a very fragmented sedimentation pattern: The thickness of the sediment layer varies strongly over short distances. This behaviour is due to the inaccuracies in the positioning of the cross-sections described in the previous section. As this inaccuracy was inevitable due to the lack of data, a more accurate investigation of the sedimentation in the studied region will only be possible by carrying out extensive new measurements. Nevertheless, our investigations allow to assess the spatial distribution and total amount of sediment in an approximate way.

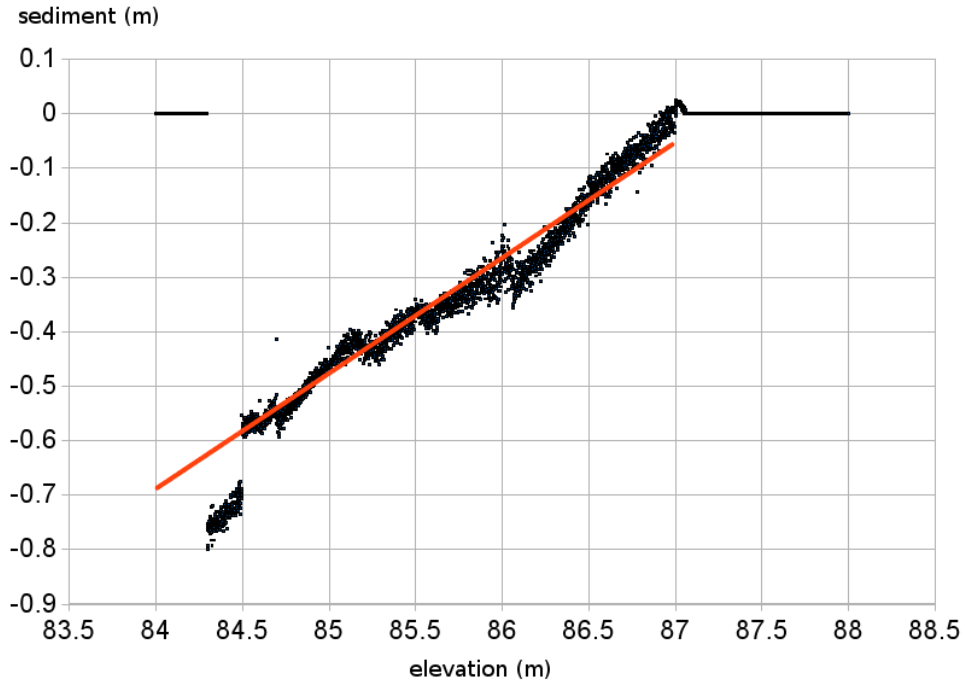

Figure 5: Correlation between elevation and sedimentation for the south-eastern branch of lake Nyeki. The quantity on the abscisa is the terrain elevation in 1993. The quantity on the ordinate is the change in elevation due to sedimentation between 1993 and 2005. Therefore, negative numbers on the ordinate correspond to a growth of the sediment layer. The red line is a linear least squares fit.

The highest amounts of sediment can be found in lake Nyeki. Here, the thickness of the sedimentation layer is up to almost one metre. Csörösz and Zsold show considerable lower amounts of sediment (10 to 50 cm). In approximately half of the total system, sedimentation is low or even negligible (below 10 cm, the white and light red parts in figure 6). Nevertheless, the strong sedimentation going on in the deepest lake of the system (Nyeki) supports the process of aggradation which may eventually lead to a loss of the floodplain character of the system. The amounts of sediment in Nyeki and in the total system, respectively, can be found in table 1.

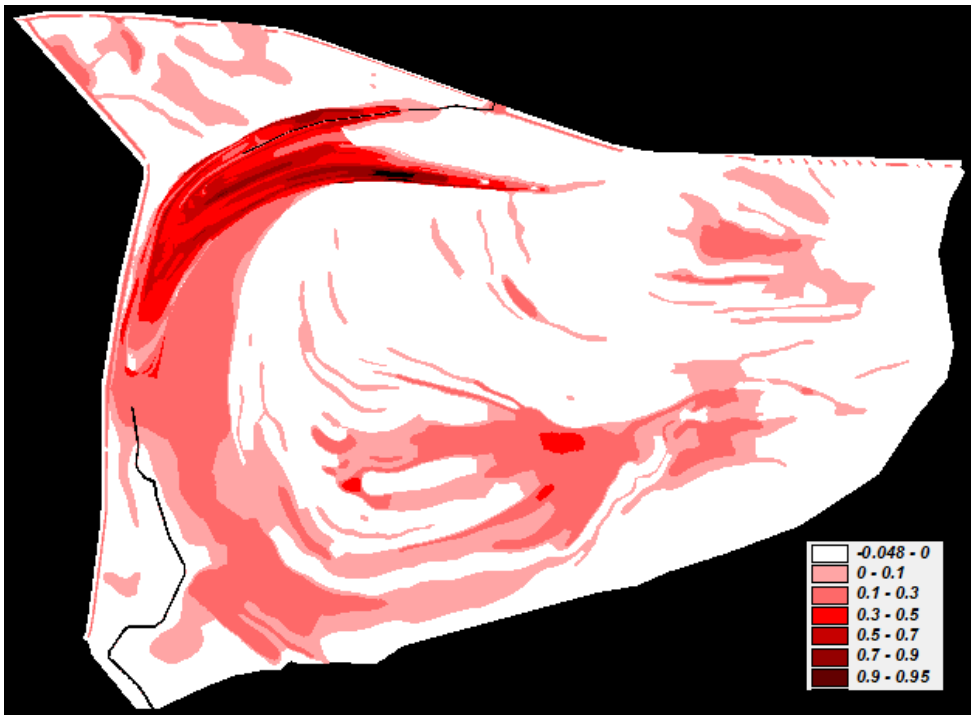

Figure 6: Sedimentation map of the Nyeki-Csörösz-Zsold-system. The thickness of the sediment layer from 1993 to 2005 is given in metres.

Nutrient removal by sedimentation and forestry

Laboratory measurements of the nitrogen and phosphorous contents of the Nyeki sediment allow to estimate the amount of nutrients reduced by sedimentation between 1993 and 2005. The average nutrient content of the three wet sediment samples was found to be 1.654 g/l nitrogen and 0.745 g/l phosphorous. The total amounts and the amounts per unit area of nutrients are given in table 1.

Sedimentation:	total system	Nyeki
sediment (m^3)	376213.4	187580.3
N (t)	622.4	310.3
P (t)	280.1	139.7
sediment (cm)	5.4	44.6
N (g/m^2)	88.9	737.6
P (g/m^2)	40	332

Forestry:	total area
wood (m^3)	33375
N (t)	34.3
P (t)	3.1

Table 1: Nutrient removal in the Nyeki-Csörösz-Zsold system from 1993 to 2005: Total amounts and average amounts (per unit area) of nutrients buried in the sediment (left). Total amounts of nutrients removed by forestry (right).

The quantity of nutrients removed by sedimentation has been compared to the nutrient reduction by forestry (wood-felling). The result of the analysis of forestry data is given on the right hand side of table 1. Comparing the total amounts of nutrients removed between 1993 and 2005, it can be seen clearly

that removal through sedimentation exceeds the effect of forestry by a factor of 18 for nitrogen and by a factor of 90 for phosphorous.

This means that in the Gemenc floodplain sedimentation is a much more efficient nutrient removal process. This observation is in accordance with previous findings, showing that the Gemenc system is exposed to extraordinarily strong sedimentation which even threatens its ecological character (see section Study Sites). The well-known fact that phosphorous storage is in sediments is much more efficient than nitrogen storage (relative to the total available amounts of P and N) is also mirrored in our results.

Hydrological simulation

The hydrodynamical simulation performed for the Nyeki-Csörösz-Zsold-system directly yields a series of daily water levels in the three cells of the system (Nyeki, Csörösz and Zsold) for the period between 1975 and 1995. In the following, the water level changes during one whole year will be discussed in greater detail. In order to show the hydrological characteristics of the studied system, we have chosen the year 1977 as example. The water levels in all three cells are shown in figure 7 depending on the date.

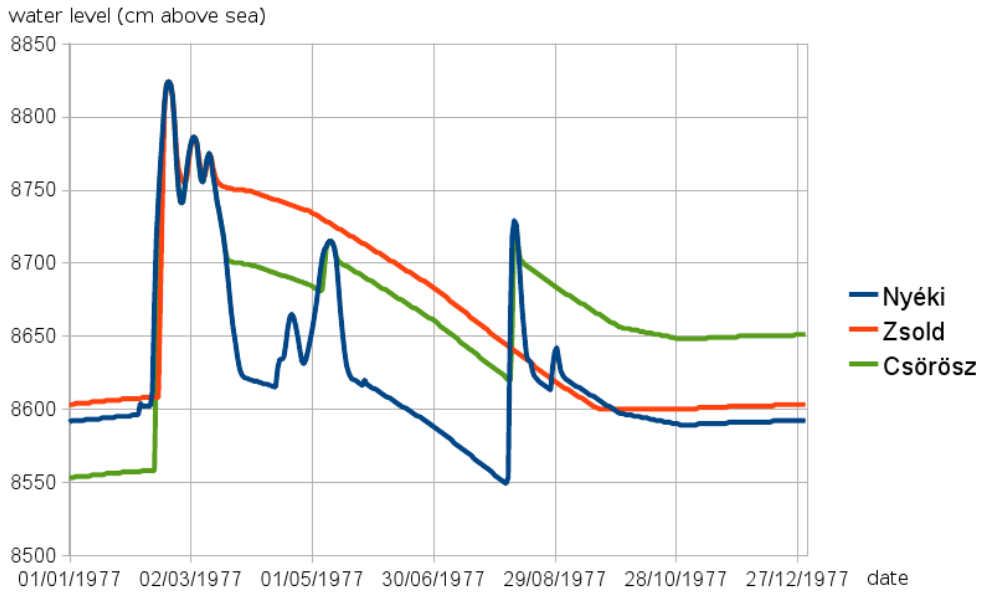

Figure 7: Simulated water level time-series in Nyeki, Csörösz and Zsold.

At the beginning of the year, in January, rather low water levels are predominant: The surface of lake Nyeki is at 85.9 m above sea level, which means that the maximum depth of the lake is not more than one metre. In this period, Csörösz and Zsold do not have water at all, because the (hypothetical) water levels are identical with their lowest terrain elevations. The first flood in 1977 arrived in the first half of February. As, of the three cells, Nyeki is the closest one to the inflow, it is the first one where the water level begin to rise. Within few days 88.25 m are reached. The water levels in Csörösz and Zsold follow

with a short delay. This is due to the fact, that these two cells receive water from Nyeki via overland flow. The lowest passage between Nyeki and Csörösz is at 87 m and the lowest one between Nyeki and Zsold at 87.5 m. On the other hand, Nyeki receives water from the Danube at a water level of 86.2 m already, due to its connection via a fok channel. Consequentially, only above these water levels the respective cell is connected to inflowing water. At the peak of the first flood, mid of February, all three cells are connected, hence their water levels are identical for a short period of time.

As the water level starts to fall between mid and end of March, Zsold and Csörösz become disconnected at the water levels mentioned above, i.e. the three lines separate from other. In 1977 there were two more flood events in the Gemenc region: one in May and one in August. However, these floods are much weaker than the one in February. Especially the flood in May has a profound effect on the water level in lake Nyeki only, whereas the water level in Csörösz is raised by approximately 30 cm only. Zsold is not effected at all by these two smaller floods, as the water level does not surpass its critical elevation of 87.5 m. The overall picture is clear: Only lake Nyeki is affected by smaller water level fluctuations in the Danube river. Csörösz has a significant response to small floods and Zsold is largely separated from the Danube river. Its water level is raised only during strong flood events.

Another important observation from the simulation results in figure 7 is the continuous decrease of water levels from mid of March (after the end of the first flood) to end of September. In the Zsold cell this steady decrease is without interruptions, whereas in the other two cells it is interrupted by the two subsequent flood events. This decrease of water levels is due to the strong evaporation in the Gemenc region. In this arid region the precipitation surpasses evaporation only in the winter months November to February. Therefore, it can be stated that the evaporation during summertime is one of the most important factors governing the water-regime in the Gemenc floodplain. On the other hand, it can be seen from figure 7 that the largely separated Zsold cell may receive sufficient water during one flood event in February, in order not to dry out until end of September.

Characteristic water-levels

The previous considerations take one year as example for the hydrological situation in the Nyeki-Csörösz-Zsold system. The availability of a water level time-series for 21 years, however, makes it possible to calculate long-term averages.

Within this work the characteristic distribution between water and land in the system is described by the three characteristic water levels, defined in the Methods section: low water (LW), summer mean water (SMW) and one yearly high water (HW1). These water levels, found by statistical evaluation of the simulation results are given in table 2.

A visualisation of this characteristic water distribution in the studied system depending on the water level can be found in figure 8. Here, the areas flooded

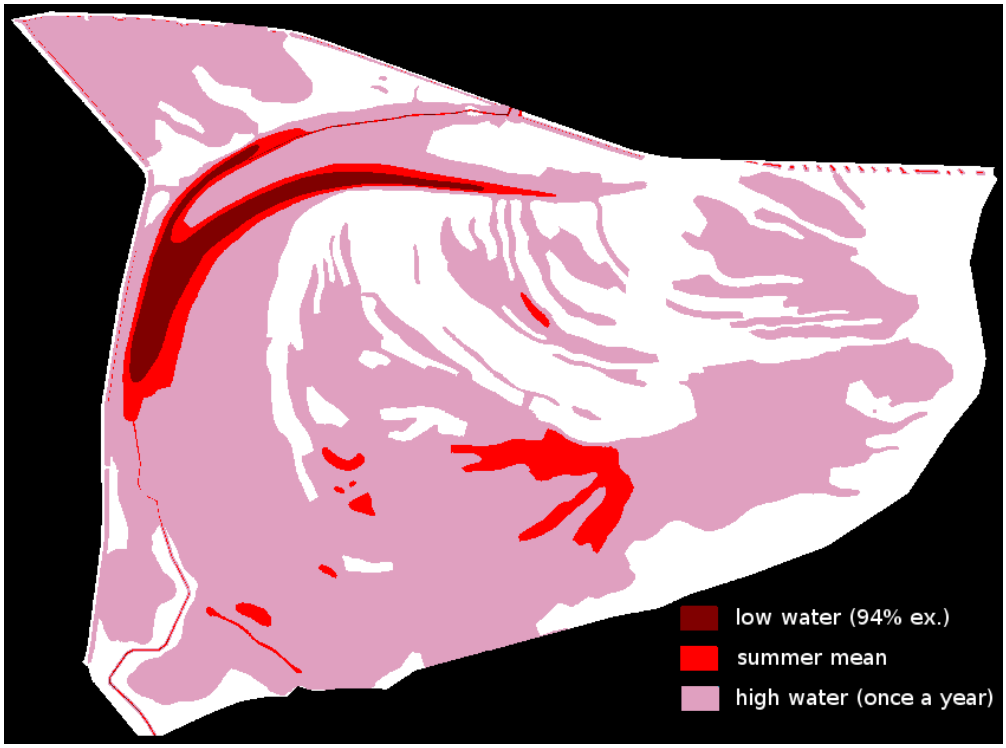

Figure 8: Flooded areas in the Nyeki-Csörösz-Zsold-system at the three characteristic water-levels.

at different water levels are indicated by different colours: Water areas at LW are in dark red, at SMW in bright red and at HW1 in violet. This figure gives a clear picture of the hydrological situation in the system: At LW only lake Nyeki carries water whereas the other two cells are entirely dried out. At SMW, summer mean water, Nyeki approximately doubles its surface area, Csörösz is also partly inundated, whereas Zsold is still dry. On average, Csörösz is dry for 53 days and Zsold for 85 days per year. Therefore, only Nyeki can be termed as lake, whereas Csörösz and Zsold are partly flooded depressions. At HW1, the high water that arrives once a year on average, also Zsold receives water, Nyeki and Csörösz are merged together and more than half of the total system area is inundated. Note, that even higher floods occur in the Gemenc, where almost the total Nyeki-Csörösz-Zsold system is inundated.

water level	Nyeki	Csörösz	Zsold
LW	85.43	85.43	85.43
SMW	86.09	86.32	86.50
HW1	87.60	87.60	87.50

Table 2: Characteristic water levels in Nyeki, Csörösz and Zsold in metres above sea level: low water (LW), summer mean water (SMW) and one yearly high water (HW1) as defined in the Methods section.

Hydro-morphological parameters – comparison to Lobau

Within our approach, the ecological situation and and ecosystem health are assessed by hydro-morphological parameters, derived from the relief (the DTM) of the studied systems and their characteristic water levels. Of course, the significance of these values themselves is limited. However, they allow *comparison* between two different floodplain regions or between two different (hypothetical) states or management options of one and the same floodplain. In the present work Gemenc and Lobau have been compared in this way.

The parameters calculated for the three characteristic water-levels are: the area of the water surfaces as percentage of the total system area, the shore line length related to the total system area and the variations of these quantities between different water-levels (as percentage of the value for the lower water level). As already mentioned in the introduction, these parameters are measures for strong variation and diversity in landscape character and water- and species-distribution. Therefore they are indicators for a high availability of habitats for diverse species and a for natural condition of the ecosystem. For example, many fish species require subsequent dry and wet periods for spawning. Their values for the Nyeki-Csörösz-Zsold system and for the Lobau are given in table 3. The Lobau values are results of the OPTIMA Lobau project.

indicator	water level	Gemenc	Lobau
water area (%)	LW	2.3	5.6
water area (%)	SMW	7.4	6.0
water area (%)	HW1	**66.9**	**21.5**
shore line (km/km^2)	LW	1.2	2.8
shore line (km/km^2)	SMW	3.9	3.4
shore line (km/km^2)	HW1	7.3	
variation area (%)	LW-SMW	**229.5**	**7.8**
variation area (%)	SMW-HW1	**799.3**	**258.2**
variation shore line (%)	LW-SMW	**229.9**	**21.1**

Table 3: Hydro-morphological indicators for the Nyeki-Csörösz-Zsold system (here referenced als "Gemenc") and Lobau. Significant differences between the two regions are indicated by bold numbers.

Comparing these indicators between the two floodplain regions under investigation leads to the following conclusions: Generally, at the same characteristic water level, water areas and shore line lengths have similar values for Gemenc and Lobau (the upper part in table 3). At LW, both indicators are bigger in the Lobau, whereas at SMW and HW1 they are slightly bigger in the Gemenc. The biggest difference can be found in the water area at HW1: Here the Gemenc value is more than three times bigger than the one in Lobau. Nevertheless, all other values lie roughly within the same order of magnitude. Consequentially, significant differences between the two studied sites cannot be observed using these indicators.

Considering the *variations* of water areas and shore line lengths between different water levels (the lower part of table 3) significant differences between Gemenc and Lobau have been found: Here the Gemenc values are throughout much bigger. For example, the variation of water area between LW and SMW is approximately 30 times higher than in Lobau. (Note, that these variations are always percentages of the *lower* indicator value. Consequentially, the variations may exceed 100 %.) Generally it can be stated, that smaller water level changes (from LW to SMW) as well as floods (from SMW to HW1) have a profound influence on the water regime in Gemenc, causing a drastic change in landscape character, water-land-distribution and consequentially in the species distribution. This dependency on the water level of the Danube river is much weaker in the case of Lobau due to the existence of the flood protection dike largely separating the floodplain from the river channel.

From these results we conclude, that the Nyeki-Csörösz-Zsold system shows a higher hydrological variability and hence a greater landscape diversity than Lobau. However, statements about the ecological situation in these two floodplains on the basis of the indicators discussed above, have to be considered carefully: On the one hand, the higher hydrological variability indicates a more natural floodplain character and higher habitat diversity in Gemenc. On the other hand, large-scale human interventions (forestry) are being carried on in Gemenc, whereas Lobau is not farmed at all and used for recreational purposes only. The results of this work also indicate that the strong separation between the Lobau and the Danube river channel leads to a low hydrological diversity and hence to the partly degraded character of the present floodplain system.

Conclusion

The following conclusions can be drawn from our investigation of the Gemenc and Lobau floodplain systems:

- The mean sediment deposition due to hydrological processes in lake Nyeki amounts to 45 cm in the twelve years from 1993 to 2005. An estimation of sedimentation in the whole Nyeki-Csörösz-Zsold system – based on a correlation between the terrain elevation and sedimentation – suggests a much lower rate of sedimentation in the rest of the system. However, the high rate of sedimentation in Nyeki supports the observation that the Gemenc floodplain is endangered by aggradation, as Nyeki is part of the main water-flow path in the system.

- Sedimentation has a profound effect on the nutrient capturing in the system. The retention of nitrogen by sedimentation exceeds the N-removal by forestry by a factor of 20. Phosphorous is stored even more effectively in the sediment: Here the effect of sedimentation exceeds the one of forestry by a factor of 90. An investigation of de-nitrification – the third important pathway of nutrient removal – was beyond the scope of this project.

- A long-term hydrological simulation and calculation of the characteristic water levels – low water, summer mean water and one-yearly high water – showed that only Nyeki carries water at low water conditions and responds very sensitively to water-level changes in the Danube river. Csörösz and Zsold are flooded during the largest part of the year, however, they also have dry periods of up to three months approximately. They have a lower connectivity to the main stream and therefore respond to higher floods only. During such higher floods, large parts (more than half) of the Nyeki-Csörösz-Zsold system are inundated. In the dry period from March to September, the water regime in the system – especially in Csörösz and Zsold – is mainly governed by strong evaporation.

- Hydro-morphological indicators have been calculated in order to compare the hydrological and ecological situation between the Nyeki-Csörösz-Zsold system and Lobau. The percentages of water areas as well as the shore line length densities have similar values in both systems. These indicators are therefore not able to describe significant differences in this particular case. However, the variations of these quantities between different water levels do show significant differences between Gemenc and Lobau. Generally, all three variational indicators used in this work are much higher for the case of Gemenc. This indicates a higher hydrological variability and consequentially a greater habitat diversity in this floodplain. However, the entire ecological situation can – of course – not be assessed by use of such indicators.

- It has been observed, that even in well-studied regions as the Gemenc floodplain, considerable data-gaps can occur. Inaccurate topographic information (crude geo-referencing of the Nyeki cross-sections) lead to inaccuracies in our investigation of the sedimentation process. However,

it was possible to estimate the correct order of magnitude of sediment deposited. Additionally, the present knowledge about nutrient dynamics in Gemenc is limited. Therefore new N and P measurements have been carried out. It must be stressed, that adequate topological information, water level time-series of the main stream as well as reliable nutrient (or pollutant) measurements are crucial for such hydrology-based ecological investigations.

Cooperations

This MOEL project carried out between August and November 2008 at the VITUKI in Budapest has lead to the following international links and present cooperations:

- As this research project has an inter-disciplinary character, the participation of researchers from three different disciplines lead to a fruitful cooperation: Mr. István Zsuffa from VITUKI in Budapest is hydrologist, Mr. Thomas Hein from the Wasserkluster Lunz is aquatic ecologist and Mr. Peter Winkler is physicist with experience in the modelling of natural systems.
- The applicant, Peter Winkler, has strongly profited from István Zsuffa's extraordinary expertise in hydrological simulations and GIS. During his stay in Budapest, he has extended his knowledge and experience in the modelling of ecological systems and has got detailed insight into the hydrology, ecology, history and topology of an important central European floodplain, the Gemenc. Ecological aspects have been intensively discussed with Thomas Hein. On the other hand, Peter Winkler has supported the VITUKI Budapest by expanding its computational and mathematical capacity.
- As all three involved researchers are currently working on the EU project WETwin, which has started in December 2008, further cooperation between Wasserkluster Lunz and the VITUKI Budapest is guaranteed. Several stays of Peter Winkler in Budapest are likely within the next years. (The project WETwin is a large international project with partner institutions from three continents. It's scope is to strengthen and develop ecologically sustainable management methods for wetlands while maintaining their community services, espesially in the southern hemisphere.)
- Another possible cooperation concerns the Eötvös Jozsef Föiskola in Baja, Hungary. As Mrs. Anna Tamás Enikö is working in this institution about sedimentation processes in the Gemenc floodplain, future cooperations are envisaged.

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Acknowledgements

The applicant, Peter Winkler, is highly thankful to István Zsuffa for the warm welcome in Budapest, his hospitality and the extraordinarily fruitful scientific cooperation. Thanks to Thomas Hein for his support during the application of this project and for many interesting discussions about ecology and related topics, to Severin Hohensinner for supplying important information about the Lobau and to Valentina di Giovanni for organising accommodation in Budapest. Thanks to the directorate of the Duna-Dráva Nemzeti Park for supplying a lot of useful information about the Gemenc floodplain and for carrying out the sediment measurements. Last but not least, Peter Winkler thanks the Österreichische Forschungsgemeinschaft (ÖFG) for funding this project and for carrying out the application in a friendly, quick and unbureaucratic way.