



River and environmental processes in the wetland restoration of the Morava river

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Abstract

River engineering works and other man-induced changes may adversely affect natural character of the river system. In many cases they have caused major morphological and ecological instability problems which can seriously impair the conservation and amenity value of the riverine environment. The results of two projects focused at the restoration of the Morava wetland ecosystem are presented in this paper. Impact of the river regulation is analysed on the basis of defined river processes and ecology evaluation. Monitoring of biotic and abiotic changes provided background information for evaluation of efficiency of the former meander's restoration. As implemented restoration measures were not so effective as it was expected some alternatives of improvements are discussed with regard to the results of field observations, numerical and physical modeling. An optimal solution to protect the oxbow system against successive degradation and restore some extinct river functions is presented.

1 Introduction

The Morava river is one of the largest Danube tributaries. The lower part of the Morava basin creates a natural wetland ecosystem with valuable floodplain landscape, which is unique in Central Europe. This part of the river floodplain is bordered by the Dyje river, which is the main tributary of the Morava river and by confluence with the Danube river. For over 70 km, the Morava river creates the international border between Slovakia and Austria and it is situated in the western part of Slovakia along the former "Iron Curtain", that removed since 1989. The border river reach covers an area of 2470 km² that creates about 9 % of the total basin area. The river bed slope is variable but in average it can be



defined by the value $i_b=0,18\%$. Characteristic discharges are as follows: $Q_a=114\text{ m}^3\cdot\text{s}^{-1}$, bankfull discharge $Q_b=260\text{ m}^3\cdot\text{s}^{-1}$ and flood discharge $Q_{100}=1500\text{ m}^3\cdot\text{s}^{-1}$.

In the 1950s the originally strongly meandered river channel was straightened in the frame of river regulation and many meanders were cut off (see Figure 1). The impact of training works and other human interventions on the river processes and riverine environment was identified in the frame of *REMORAVA* project (Holubova, et al., 1997, Lisicky et al., 1997). Natural character of the river has been influenced by channel straightening, deficit in sediment supply and commercial dredging. Joined effect of limited flow interaction between the oxbow system and the main river channel and intensive sedimentation in floodplain supported successive degradation of the meander's ecosystem. This situation has led to the effort to increase the flow dynamics in the oxbow system.

2 River and environmental processes

A thorough understanding of flow characteristics and their interaction with channel geometry and planform is essential for almost any engineering, ecological, economic or management study involving rivers (Bathurst, 1997). Changes in the natural channel processes that dominantly controls the lower Morava river environment were defined in the frame of *REMORAVA* project, thus the essential results are presented in the following parts of the paper.

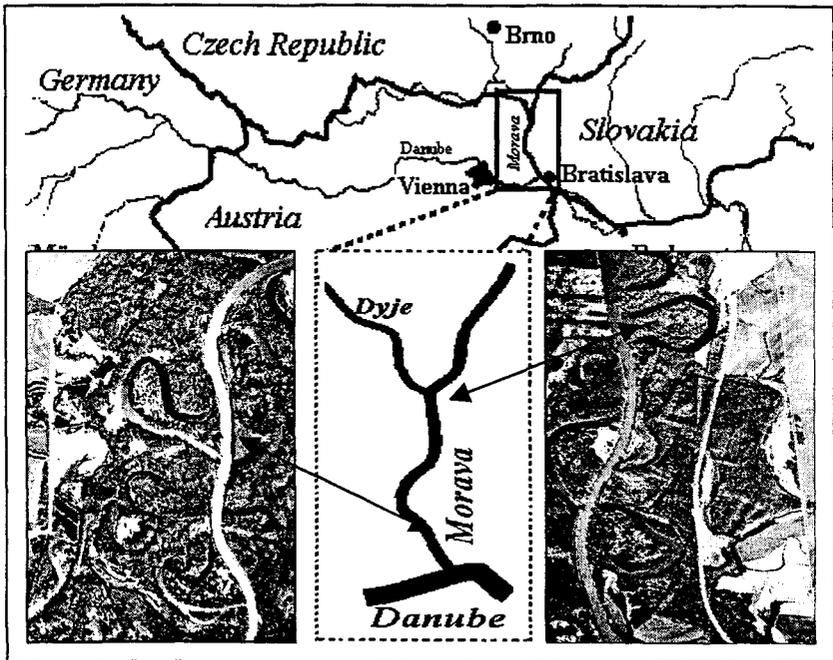


Figure 1: Layout of the lower Morava river and aerial photographs that illustrate the oxbow system in lower and upper part of the border river reach

2.1 Surface and ground water level regime

Flow dynamics in lower part of the Slovak-Austrian reach of the Morava river is influenced by the Danube discharge conditions. Backwater effect can reach maximally 23 km upstream, depending on the actual hydrological conditions on the Danube river. Irregular shape of the floodplain affects the flood flow dynamics particularly upstream of the narrowest part of the floodplain that is located in the central part of border reach (km 32). Non-uniform distribution of the mean velocity along the river is shown in Figure 2. It is evident that during the flood discharge rather low flow velocities prevail at the majority of the floodplain. These flow conditions create assumptions for intensive deposition. Various simulations with different discharge conditions have been analysed to identify crucial area of intensive sedimentation. Integrated influence of engineering works and other anthropogenic activities also induced essential changes in the groundwater level regime. Long-term development of the groundwater levels indicated significant decrease that occurred particularly in the central and upper part of the border reach. In this area groundwater levels dropped by about 0.90 m-1.20 m over the period 1958-1994. Localities of these changes correspond with the most significant incision of river bed.

2.2 River morphology, sediment transport, channel stability

Any modification to a river as a result of engineering works or its flow and sediment transport regime through land-use or river regulation can cause instability. Generally, bedload transport capacity of the river is proportional to the sediment supply and drag force, which fluctuates depending on flow dynamics and morphological characteristics of the river channel. As the bed material in the Morava river consists of fine gravel and sand, bedload transport take place at practically all flows. Depending on flow conditions the bed is covered by ripples and dunes.

The longitudinal profile of the river bed had practically not changed during a long period (1911-1952), except for the short river section influenced by the Danube. During this period free meandering of the river was successively limited by the dyke's construction. Relatively wide floodplain was reduced to a narrow strip varying in width from 300 m to 3000 m.

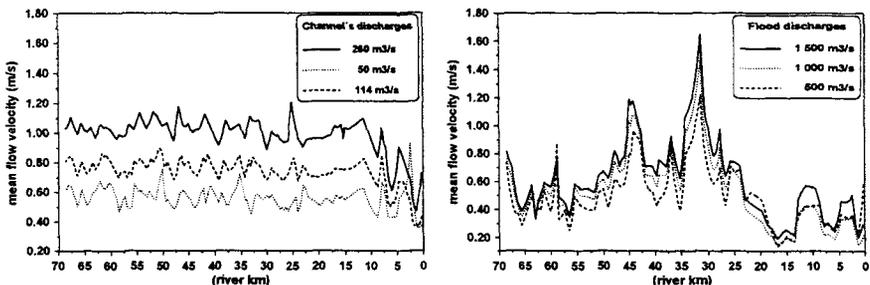


Figure 2: Distribution of the mean flow velocity in the Morava river

Since 1950s the present course of the main channel was fixed mainly for navigation purposes. Combination of trapping effect of the large reservoirs at the Dyje river and commercial dredging of the river bed affected dynamic equilibrium between sediment supply to the reach and sediment transport capacity through the reach. Analysis of the bedload regime in the lower Morava river was based on field measurements and numerical model HEC-6 (Holubova et al., 1997). The results indicated rather variable values of bedload transport capacity along the river channel but it may be characterised by the mean annual bedload transport, which is 45 000 m³. In the past, volumes of dredged material frequently exceeded this limit. In 1969 for example volume of 75 000 m³ was excavated. All these artificial interventions into the sediment transport resulted in the significant degradation of river bed that is evident especially in the central part of the border reach, where the river bed incised by about 2 m (Figure 3).

Considerable decrease of the river bed has induced instability of the river banks. Relatively high and steep river banks mostly consisting of silt, sand and clay with layers of fine gravel are susceptible to bank erosion. Rather high variability of the water level regime induces bank suffusion, which produces various types of failures. Blocks of bank material slide or fall towards the toe of the bank contributing to the higher volume of finer sediments in the channel. During the floods this material increases suspended sediment concentration in the stream supporting intensity of the floodplain deposition. Suspended sediment balance based on evaluation of field measurements in two gauging stations (km 32-km 60) indicated intensive sedimentation in this area. Rather high amount of sediments - 1 686 910 tons deposited in the floodplain between gauging stations over the period of 12 years (1985-1997). Major part (up to 62 %) was deposited in the floodplain during the flood events in 1996 and 1997. Intensive sedimentation of the river floodplain adversely affects situation in the cut off meanders and also contributes to the gradual raising of the floodplain. Reducing of the floodplain capacity has created additional flood hazard.

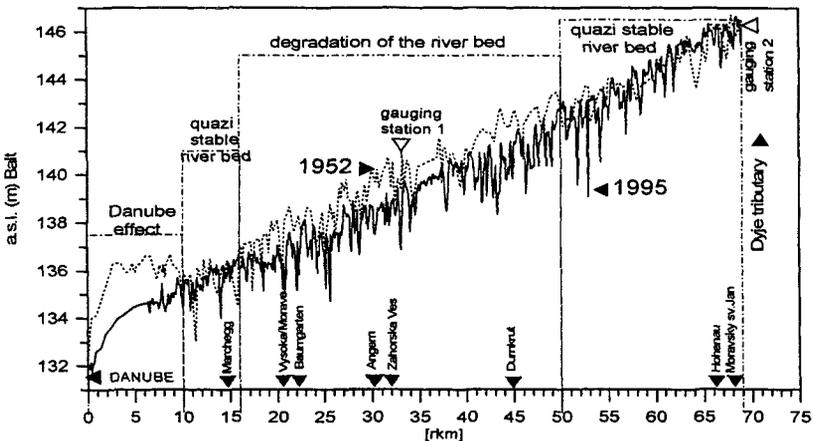


Figure 3: Morphological development of the Morava river bed (1952 -1995)

2.3 River and floodplain environment

There was a specific feature connected with development of this riverine ecosystem. As the whole floodplain had been for 50 years a closed boundary area its economical use was very loose and therefore the pressure on ecosystem very low. Further, the floods within the floodplain area occurred naturally every year and the forest species composition had been, unlike in the Danube floodplains, close to natural. So there was an opportunity to evaluate the influence of river regulation on different habitats without significant interference and to set up after the partial restoration a well defined biomonitoring system. The only inconvenience was, that due to the same circumstances almost no scientific information on the ecosystem parameters and species diversity was available and the inventory period was limited by 2 years. As the project represented a unique opportunity to establish up to now missing complex biomonitoring system, the range of surveyed biotic parameters was rather high. Following groups were studied: algae, water macrophytes, swamp and meadow vegetation, forest vegetation, Porifera, Turbellaria, Hirudinea, Bryozoa, Acarina, Collembola, Oligochaeta, zooplankton, Mollusca, Isopoda, Amphipoda, Mysidacea, Chaoboridae, Aranea, Ephemeroptera, Megaloptera, Odonata, Heteroptera, Trichoptera, Culicidae, Chironomidae, fish, amphibians, birds and small mammals (Lisicky et al., 1997, hidden bibliography).

3 Wetland restoration or degradation?

Many of restoration schemes are being implemented without required knowledge of river morphology and flow dynamics. This approach mostly based only on visual and aesthetic values is a frequent reason for ineffective implementation of restoration measures. In order to protect the oxbow system in the Morava river floodplain meander's reconnection was designed and implemented at the Slovak river side (*GEF-Biodiversity Project*). Except for a preliminary biological survey no relevant hydraulic and morphology studies preceded implementation phase. As the main effects were not achieved Phare Project was focused at analyses of the former restoration measures (morphology and flow dynamics) including biotic monitoring. The results of these analyses created background for optimal design of the oxbow system restoration (Holubova et al., 1999).

3.1 Implementation of former restoration measures

Four meanders in three localities on the Slovak side of lower Morava floodplain were selected for implementation of the restoration measures. Rockfill weirs were constructed at the entrance part (inflow) of these meanders. The altitude of the weir crest was not uniform; the lowest one matched with the mean water level. Thus, flow overspilled the weirs when discharges exceeded the mean annual discharge. Even if entrance part was not adjusted to an original meander width, its capacity is considerably higher compared with outflow part, which was created by the narrow and deepened channel. As a result meanders operate like

reservoir - the inflow discharges (Q_{in}) considerably exceed outflow discharges (Q_{out}) - with similar negative impacts on sediment transport.

Having no previous experiences with limitations imposed on restoration by changes in climate and discharge of the river, the expectations were rather high. It is evident that diversion of the main flow into the meanders will not be easy to achieve due to state borderline in the present main river channel. The development of the water biota through almost one-century has been shifted from the originally coexisting meandering eupotamal and lenitic plesiopotamal (isolated and mingling only during the floods) to prevailingly canalised eupotamal (with higher flow velocity) and its parapotamal. Under natural conditions the fish fauna of the isolated meanders is poorer (13 – 18 species) compared to the main channel and interconnected side waterbodies (23 species). There is also significant difference between parapotamal and plesiopotamal in plankton development and abundance. It is obvious that within the next decades without technical maintenance the connection between the cut-off meanders and the main channel would become less frequent, so that they would transform into plesiopotamal and then into shallow pools bearing water only during several weeks in the post-flood period. The next stage would be a homogenised floodplain and disconnected channel with incised river bed. So most of the ecologist's expectations were focused on reintroducing of disappeared slowly flowing and meandering lowland river. This would mean improving the river health and restoration of the original diversity by increasing the habitat diversity, but not necessarily the species diversity. On the contrary, the restoration could contribute to getting rid of some allochthonous and invasive species.

3.2 Abiotic impacts of the meander's reconnection

Present situation in all reconnected meanders is very similar. Except for short sections in the area of inflow and outflow parts flow velocity, even at bankfull discharges drop below 0,1 m/s, creating conditions for intensive sedimentation. With higher discharges, relatively large volumes of sediment (bedload and suspended load) are transported into meanders. Due to low flow velocity an extensive deposits have been formed particularly in the area close to the entrance part. For example after two years the total volume of deposits in one of the meanders was 43 000 m³. Composition of the deposits varies depending on flow

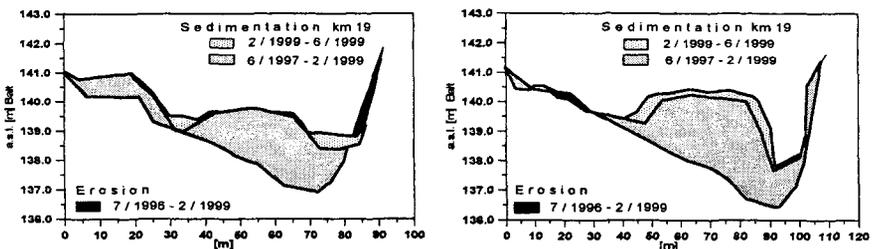


Figure 4: Morphological changes in the reconnected meander (1997-1999)



conditions and bed material composition. High sedimentation rate in the meanders accelerates their degradation. Morphological changes can be seen in Figure 4. Many aspects indicate that present situation is worse as it was prior to meander's reconnection and emphasise the need for improvement of the restoration measures. The main objective is to provide required flow dynamics that would enable continuous sediment transport through the meander.

Environmental response to meander reconnection

After the reconnection of the two meanders, a significant change in biocoenoses composition occurred. The abundance of limnophilous fish species lowered (*Tinca tinca* disappeared totally) in favour of both rheophilous (*Abramis ballerus*, *Abramis sapa*, *Gobio albipinnatus*, *Leuciscus idus*) and eurytopic species (*Aspius aspius*, *Alburnus alburnus*, *Gymnocephalus cernuus*), but the number of species did not change as the meanders were in the past communicating at higher discharges with the primary channel. The species diversity of water macrophytes decreased from 13 to 5. The changes were not that conspicuous that they would cause the simulation of the main channel conditions (e.g. *Lemna minor*, *Spirodela polyrhiza*, *Polygonum amphibium* f. *natans* and *Myriophyllum spicatum* remained), but still 3 species of *Potamogeton* (*crispus*, *nodosus* and *pectinatus*) as well as of course *Nuphar lutea* and *Trapa natans* disappeared. The changes in invertebrates (mainly benthic organisms) showed a shift from stagnicolous to semireophilous species composition. This goes mainly for insects, where the changes occurred not only due to different flow conditions, but also because of the new sapropel sediments in the reconnected meanders. In mayflies *Limnephilus* and *Athripsodes* decreased in number, while new rheophilous species appeared (*Baetis pentaplebedes*, *Heptagenia flava*, *Caenis macrura*). The decrease of some other benthic stagnicolous groups (sponges, flatworms and leeches) was not so important, many of them remained, and their local fauna was enriched by really rheophilic species like *Dugesia polychroa*, *Erpobdella nigricollis* and the bryozoan *Plumatella emarginata*. Also the abundance of Oligochaeta species preferring lotic conditions increased (*Nais elinguis*, *Psammoryctides barbatus*, *Potamothrix moldaviensis* and *Psammoryctides moravicus*). As far as for the planktonic organisms, the river itself does not have any autochthonic zooplankton community and those species, which do occur originate from some of the pools or reservoirs communicating with the river. Therefore, as expected, after the reconnection a strong decrease both in abundance as in species diversity happened. Some of the allochthonous cladoceran species drifting in the primary channel enriched the fauna of the meanders (*Bosmina coregoni*, *Daphnia galeata*, *Moina weismanni*, *Disparalona rostrata*). The cut-off meanders were during seasons with low discharge disconnected from the river and suffering because of oxygen depletion. Under such conditions they behave like plesiopotamal and in dry years a massive fish kill may occur and only undemanding species of invertebrates survive. One of them is *Chaoborus flavicans*, a dominant vertically migrating larva in the reference meander (comparative area). Its small populations in the meanders



under restoration disappeared completely very soon after the reopening. The unexpected creation of a mighty gravel-sand bank in the inlet part of the meanders created a new habitat used in the first year by terrestrial annual plants, mainly of *Chenopodium* and *Amaranthus*, but also *Echinochloa crus-galli*, *Polygonum persicaria* and *Xanthium albinum*. Hence the further existence of such biotopes important otherwise also from point of view of some birds and other animals, would require a targeted management.

4 Improvement of the meander's restoration

The basic requirement of any restoration works is to increase local morphological, hydraulic and sedimentological variability given the natural constraints of the river (Hey, 1992). The main objective of improvement measures was to increase the flow dynamic that enables continuous sediment transport through the meander and higher habitat diversity. In order to achieve required flow conditions many of structural and non-structural measures were tested using numerical and physical models under the various flow conditions.

4.1 Alternatives of restoration measures

The main scenarios for improvement of the former restoration are as follows:

- Scenario 1– adjustment of the inflow/outflow parts to their original size combined with deposits removal,
- Scenario 2– presents weir in the main river channel combined with adjustment of the inflow /outflow parts to an original size, deposits removal,
- Scenario 3– total blocking of the main river channel combined with adjustment of the inflow part to an original size and deposits removal.

The results of numerical modelling of flow dynamics for various combination of restoration measures indicated that better flow conditions in the re-opened meanders may be achieved by structural (weirs, deflectors) as well as by non-structural restoration (total diversion of the river flow into the meanders). Solution presented by scenario 1 is not sufficient to provide required flow conditions. Several authors argued that structural restoration represented namely by weirs are really only beneficial in upland rivers, which have steep gradients and where tranquil, ponded reaches are rare since lowland rivers are already ponded over considerable distances (Hey, 1992). The results obtained by numerical modelling matched with these arguments (Holubova & Lukac, 2000).

4.2 Environmentally sensitive restoration scheme

The lowland river restoration is best achieved using non-structural procedures, as the natural character of the river can be reinstate. Scenario 3 that represents full diversion of the river flow into its original channel, would enable to reinstate the original meander pattern in some localities and full integration of some meanders into the river system. Partly free river meandering assumes removal of the bank

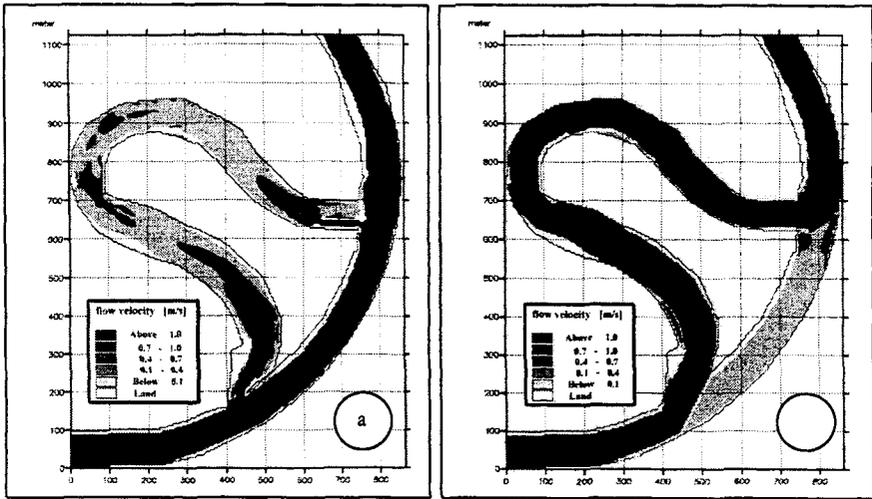


Figure 5: Flow velocity distribution for bankfull discharge, a) present state - reconnected meander, b) new proposal - full discharge diversion

reinforcement from selected river reach. Comparison of flow conditions for present state and full discharge diversion (MIKE-21) can be seen at Figure 5 (Holubova & Lukac, 2000). Through this type of meander restoration also the some problems identified in the main river channel and floodplain can be partly or as a whole eliminated. Lower sediment transport capacity would support process of the river bed and banks stabilisation, which would diminish intensity of bank erosion and floodplain sedimentation. Higher frequency of the mean floods would enable interaction of the channel and floodplain processes. Changes in the sediment transport regime would induce higher habitat diversity - successive reconstruction of gravel bars, riffle/pool sections within a restored river reach that had previously been dredged and straightened. Integration of some meanders into the river system would enable to restore natural dynamics of river processes creating beneficial conditions for diversification of aquatic biota.

It became obvious, that isolated and not sufficiently intensive restoration activities can not be recommended neither from hydrological nor ecological point of view. Shifting of minor part of the discharge into a former meander induces predictable changes in biocoenoses composition and in abundance of different ecological groups, but on a longer period without repeated maintenance, the ecosystem tends to return to the previous state. Even if there is no possibility of restoring the whole river basin, effective restoration designs can be realised using the whole discharge diversion for selected river reach. Under the changed conditions meanders integrated into the river system will not be identical compared with situation prior to their cut off. The decision should be taken upon the results of modelling of such a section. Sophisticated revetment measures can not be recommended, and if so, only as a temporary help for transforming of ecosystem, which will maintain itself.



5 Conclusions

Experiences with implementation of restoration measures in the Morava river floodplain proved that further restoration procedures should arise from all relevant knowledge of the river and environmental processes. Projects results indicate that restoration of the lowland river oxbow system is the best achieved by re-establishment of the original meander pattern in selected river reaches with regard to the present constrains (particularly dykes). This of course create only starting point for more complex restoration scheme that should be formulated in common Slovak and Austrian restoration and management strategy. Problems of the state borderline, which passes through the main channel could be eliminated by formulation of this strategy as both countries have similar restoration aims in the lower Morava river floodplain. Integrated effort of engineers, ecologists and public of both countries could provide assumptions for environmentally sensitive and effective restoration of the Morava wetland area and create intellectual and human bridges across the border.

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