River Restoration as a Method Towards Harmonization of Natural Habitats in the Context of Ecological Corridors Preservation: A Case Study on the Hron River

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Abstract. Natural profile of the streams was conditional to the anthropological intervention, to channeling (canalization) of the watercourses due to the gradual settlement. The mentioned approach was involved because of the flood protection of residential areas, groundwater level adjustment, riverbed stabilization, etc. Corresponding anthropogenic interventions led to the devastation of several ecosystems and ecological corridors and their functions, occurring in the natural landscape environment. Consequently, rivers acquired new hydrological, hydraulic and biological parameters. The necessity of policy reaction led to the establishment of a framework for conservation areas, known as Natura 2000, in order to protect the threatened species and natural habitats. This article presents a case study based on a project aimed at the renewal of the flow-through of the blind river channel of the Hron river (in Slovakia) in its natural, historical channel's route with the length of 570 m and the width between 10-15 m. The aim of restoration of the river's arm included the recovery of aquatic habitats and stabilization of the floodplain area in the ecological corridor of the Hron river in the context of the efforts of the European Union (EU) towards strengthening harmonization of the interest of nature and human activities. Restoration of the blind river channel required an integrated approach and cooperation of key stakeholders, Slovak Water Management Enterprise, state owner enterprise and municipality of Rudno nad Hronom. As the areas of the old channels of riverbeds represent an important type of ecosystem, the process of their restoration needs to be planned properly. Planning the process consists of preparing detailed analyses of the current state of the bio-corridor with a focus on analysing the occurrence of vegetation and animal habitats, their combination and interaction. The connection between the ecological landscape and spatial planning leads to maximizing of benefits of the restoration, with the least possible interventions on the natural environment. Such an approach is fundamental regarding the harmonization and ecological connectivity between the natural and anthropogenic environment in the contexts of a sustainable strategy for the management and preservation of ecological corridors. The river's channels are important ecological corridors of the natural environment of each country not only because of the water supply for adjacent floodplain areas but also because of the slowing down of water outflow from the environment and conservation of the richness of aquatic and terrestrial habitats. Revitalization and maintenance of the river flows are essential for the preservation and reconnection of the existing bio-corridors in accordance
with the European Green Deal (2019) and help the natural environment in adaptation to occurring climate change.

1. Introduction

Rapid climate change, stressed ecosystems, and sharp declines in biodiversity are all indicators of the accelerating pace and global scale of human impacts on the environment. The global scale and rapidity of environmental change, recognition of the rate and magnitude of the global environmental crisis is challenging ecologists and urban planners.

Geographically circumscribed nature reserves are incapable of protecting all biodiversity and the precautionary principle applied to management interventions no longer ensures avoidance of ecological harm [1]. Urban expansion is significantly negatively impacting natural biodiversity, most directly in the form of habitat loss and fragmentation and landcover change due to the growth of urban areas, impact on freshwater biodiversity on a global scale and affects regulatory hydrological services either [2].

Ecologists and urban planners must promote opportunities to integrate ecosystem processes and biodiversity into landscape-scale interventions and encourage the nature harmonization. Therefore, this paper presents a case study aimed at the design of restoration of the blind river channel on the left bank of the Hron river in the village rural municipality of Rudno nad Hronom in the river km 98.08 to river km 8.27. The tendency of the case study is to point out the importance of restoration of the original natural river ecosystems for aquatic and other habitats and the access of such restored areas for wildlife in the context of the ecological corridor’s preservation.

2. Ecological restoration and nature harmonization

Intense human activities have broken the original ecological balance and affected structures and functions of the river ecosystem. Ecological restoration is a practice comprised of a range of intentional human actions that seek to assist with ‘the recovery of an ecosystem that has been degraded, damaged, or destroyed’ [3]. For example, we may positively value the assisted recovery of ecosystems or creation of ecological restoration of rivers, creation of ecoducts or the reclamation of brownfield sites to provide green space because it leads to an increase in biodiversity or aids with the recovery of endangered wildlife.

Freshwater species are already among the most threatened as a consequence of global consumption of water is increasing with growing populations. Freshwater ecosystems are particularly vulnerable to human impacts from activities in water catchments, fragmentation of rivers by infrastructure, and from water consumption that alters the quality, quantity, and timing of water flows [4]. All these effects are exacerbated by climate change. Many of the most serious impacts of climate change on people and biodiversity are felt via impacts on water, including floods, droughts, storms, and changes in rainfall distribution. To restore the damaged river ecosystem back to a healthy status, effective ecological restoration measures need to be implemented. River restoration planning process should be clarified, the restoration goal should be identified, and restoration actions be prioritized [1].

A renewal ecology approach and harmonization of natural habitats aim to meet human needs while sustaining aquatic biodiversity. There are a number of existing examples of interventions consistent, such as environmental water releases that mimic pre-development river flows so as to conserve selected biodiversity; reserving aquatic refugia that also offer recreational opportunities; adding fish ladders to reservoirs to assist migration; systematically restoring riparian vegetation to cool rivers, reduce erosion and provide habitat and opportunities for recreation; the removal of redundant dams; and the renewal of flow-through of blind river channel. Integrated implementation of these established practices can enhance the catchment-scale functioning of aquatic systems and link urban, agricultural,
and natural areas [1]. This paper mostly focuses on the renewal of flow-through of blind river channel as an intervention of the nature harmonization.

2.1. Ecological restoration of the river channel
Renewal of the hydrological interactions between the main channel, backwaters and floodplains is central to rehabilitation and harmonization of natural diverse habitats. According to Addy et al. (2016) [5], river restoration can be defined as “the re-establishment of natural physical processes (e.g. variation of flow and sediment movement), features (e.g. sediment sizes and river shape) and physical habitats of a river system (including submerged, bank and floodplain areas),” with main aim at recovery of distinctive river habitat and biodiversity.

Blind river channels have lost their lateral hydrological connectivity with the mainstreams. The renewal of flow-through of the blind river channel would increase the biodiversity, standing crops, and production of aquatic biota, the quality and quantity of habitats, furthermore, they may provide suitable habitats for different kinds of a biome. Increasing meandering of a river can also lower the gradient, thereby reducing the flow velocity and sediment transport capability [6].

River mainstreams have lost their lateral hydrological connectivity with their meandering channels due to the anthropogenic degradation of their natural character, resulting in a habitat loss, harm on biodiversity, and the decrease of several benefits entire natural ecosystem is addicted on. This case study, therefore, provides an example of the approach of riverbed restoration aimed at the renewal of flow-through of blind river channel of the Hron river in its natural, historical channel's route, from a perspective that sees urban and landscape design as a mechanism for the realization of particular values across the landscape. The aim of restoration of the river's arm included the recovery of aquatic habitats and stabilization of the floodplain area in the ecological corridor of the Hron river in the context of the efforts of the EU towards strengthening harmonization. The project restored the river's arm to a more ‘natural’ state through the design and implementation of a series of in-river and landscape restoration techniques and methods [7].

3. Materials and Methods

3.1. Methodological process of riverbed restoration
The main aim of the revitalization of watercourses is to approach the natural appearance of the river basin as naturally as possible in the context of recovery and conservation of broader ecosystems. Within the process of riverbeds restoration, it is appropriate to follow a certain methodical procedure which can be divided into the processes before the beginning of restoration and the processes during the on-site modification. Beside each method, it is necessary to bear in mind that revitalization brings several changes in the natural structures of the landscape, therefore, already the first steps of restoration (meaning project proposal, analyses, etc.) should be in accordance with landscape-ecological aspects.

Before the beginning of on-site restoration process following stages were taken:
- analysis of the territory,
- recognition of the current flow status,
- the winding of the riverbed in corresponding terrain stages,
- the flow of smaller side river channels into the mainstream,
- determination of flow in the main riverbed,
- geometrical parameters (depth, width, riverbed ground, bank slope, etc.),
- the existence of hydro-objects on the river and their impact on flow,
- natural surrounding floras character (riparian vegetation, floodplain vegetation, etc.),
- recreational and fishing significance of the river.
Stages during the on-site modification process:
- analysis of the case study site,
- analysis of the characteristic structures of the territory,
- monitoring of interventions in the river surrounding ecosystem during the implementation phase of the restoration,
- control of the reaction and adaptation of biota of the river to the modifications made to the river ecosystem.

Within the analysis phase of the territory, we focus on its characteristics, the elements that it consists of, and indicators of landscape characteristics. Depending on the structure of the territory, analyzes are divided into analyzes of abiotic components, which include geomorphological and geological components (e.g. soil, water, climate) and a summary of the processes caused by these components, and analyzes of biotic components focused on living organisms in the territory with an emphasis on factors such as species composition and ecological, populational and bio-structural characteristics.

During the process of river-basin restoration in a natural way, was also important to analyze the issues arising in the locality resulting from river flow regulation. The analysis was focused on identifying ecological hazards caused by various factors such as water flow decline due to the construction of hydroelectric power stations on the river, or industrial activities connected with the use of the water from the river basin. Riverbed was also analyzed from a hydrological point of view, focusing on fluctuations in flow rates and the state of flood protection on the stream.

3.2. Analysis of study area
The area where the case study was carried out is located in the territory of the Slovak Republic (SR) near the municipality Rudno nad Hronom. A territory of the blind river channel is situated in the floodplain area, on the left side of the Hron river between the main riverbed and the road connecting the village with the neighbouring village. Hron is the second-longest river in Slovakia, with many important side stream flows. The river basin occupies up to 11 % of the total area of SR, therefore, it is an important water and natural wealth, and site of various types of habitats. The riverbed is naturally meandering, however, it has been a subject to regulatory adjustments on several locations due to the flood protection of the adjacent municipalities. Moreover, four small hydroelectric power stations are built on the river, which significantly disturbs the flow of the river, negatively affects the river's ecosystem, habitats and near-living wildlife.

3.2.1. History of the river channel. In the historical maps of the territory, from the second half of the 19th century, the river channel starts to be figured on the lower edge of the village in the valley of the river basin. This river channel was created by a natural process - by grinding during high water levels in the mainstream. The inundation area of the channel was covered with riparian forests and appropriate habitats. Vegetation was noticeably disturbed by anthropogenic interventions due to economic use of the surrounding land, while only a minor part of the original plant species was preserved and persists in the area until today.

3.2.2. State of the river channel and surrounding territory before the restoration process. Flood and regulatory modifications of the river Hron and the influence of time, water erosion, sedimentation activity, and insufficient maintenance of the channel, contributed to clogging and thus the complete destruction of the historical river channel. This process resulted in the separation of the channel from the mainstream and led to the change of status from the flow channel to the dead one, meaning the
channel of the river both ends of which are clogged, impermeable and the connection with the mainstream is almost completely interrupted.

Before the restoration process in 2017, water in channel bed was only presented during the increased water levels when the channel was filled with seepage from groundwater level, or with water from the mainstream during the flooding states (Figure 1). Because of the clogging of the input and output of the channel and disappearance of steady water level, the overall groundwater level deteriorated, and river ecosystem has lost several significant aquatic habitats and option for spawning of phytophilic fish species that had previously been found in this river channel.

The area is overgrown with various types of invasive woody plants and grasslands, that due to their good reproductive ability spread very quickly and are not significantly anthropogenically treated. In the territory, there is vegetation with coastal stands of European importance, namely lowland floodplain with a remnant of biotopes from the willow-poplar forests, which were spread in this area in the past. However, the loss of a continuous water level had an adverse effect on the floodplain forest area, which is characterized by the extraction of nutrients from permanently waterlogging by groundwater or surface floods. The root systems of vegetation on the banks of the stream are bound to the water regime, thus contribute to the overall stability of the riverbed. Such greenery forms important landscape-ecological elements for the surrounding ecosystems and can perform an important function as a bio-corridor.

![Figure 1. Blind channel before the restoration process (2017) fulfilled with water from seepage/floods](image)

Because of the importance of ecological corridors preservation and significance of habitat diversity, the main stakeholders - the municipality Rudno nad Hronom and Slovak Water Management Enterprise, state owner enterprise (SWME), have decided to renew the blind channel and restore the adjacent area.

3.3. Input data
The study was prepared on the basis of background materials obtained from the municipal office, and the documentation obtained from state and private enterprise. The fundamental input data was a detailed aerial picture and a network of elevation points and fracture edges of the current state of the terrain. These materials were prepared and provided by private enterprise EUROSENSE.

Another background material was project documentation provided by the state enterprise SWME, that is managing enterprise responsible for the studied section of the watercourse, and which, together with the municipality, was the main initiator and investor of the channel restoration project. Provided documentation contained the proposed situation of the end section of the channel (193 m) with the
outflow into the mainstream in river km 98.08 at a scale of 1:200, and the longitudinal profile of the channel at a scale of 1:500/100. Another received input data was the drawing of the channel's cross-section at a scale of 1:100.

3.4. Design of the channel restoration
When designing a blind channel restoration, the proposed routing followed the original channel's route of the old channel as closely as possible, both, because of the ecological and economic point of view. Such a design ensured similarity to the natural river channel bed, consequently, the impact of recovery on current biota was limited, and the cost of earthworks was less costly.

Parameters of the designed renewed river channel were following. The total length of the channel was approximately 570 m. A simple trapezoid with a total width of up to 15 m was designed as a cross-section, the bed of the channel was designed with a width of 3 m and slopes of the channel's banks with a ratio of 1:2. Firstly, it was necessary to create the proposed channel route and surrounding terrain. Based on the provided data, the design route of the arm was created in software AutoCAD Civil 3D. This provided the drawing of the longitudinal profile of the channel at a scale of 1:1000/100 with the proposed channel bed and the terrain of the original channel route. From the topography of the designed channel, twenty-seven cross-sectional profiles of the riverbed were delineated, and the total volume of excavations and embankments earthworks were determined.

The next step was the creation of the one-dimensional mathematical model of steady flow with the mixed-flow character in the HYDROCHECK software, where the values of average daily and annual flow rates measured in river mainstream profile from 2005 in Bzenica, a village located less than 13 km north of Rudno nad Hronom, were entered as boundary conditions. Flow rates of \( Q_{180d} \), \( Q_{90d} \), \( Q_{30d} \), \( Q_1 \) and \( Q_{100} \) were entered the software. The result from the 1D mathematical model was to determine the heights of the water level in the channel at various flow rates, which were further used as boundary conditions entered in the 2D hydrodynamic model created in the MIKE 21 FM program. The channel design created in the 2D hydrodynamic program was using the data from Hydrocheck, AutoCAD Civil 3D and Esri ArcMap. In the Esri ArcMap environment, was combined the design of the riverbed route with the morphology of the existing terrain.

The final morphology of the area of interest was exported to the hydrodynamic modelling program created by DHI enterprise, MIKE 21 FM. The software developed a flexible triangular and rectangular computational grid, where the triangular grid formed the inundation area and the rectangular grid was used in the Hron riverbed and in the designed channel, to better reflect the channel profile and minimizing computational steps and thus speeding up the hydraulic model process. Program MIKE 21 FM was launched for flow rate \( Q_{90d} \). The result of the launch of the model is a displayed of the bathymetry in detail, and a map of vector velocities of water flow in the designed channel, as well as the flow achieved in the channel under these conditions. Model of the designed channel reflecting depths is shown in figure 2, whereas velocities in the designed channel are shown in figure 3.
4. Results and discussions

By designing the channel model for flow $Q_{90d}$ in the software Mike 21 FM, we found the water continuing flow in the restored channel of 0.76 m$^3$.s$^{-1}$, and the depths will be in the range between 30 - 40 cm with a water flow rate of 0.2 – 0.5 m/s. These parameters are sufficient for the continuous flow and oxygenation of the river habitats. Such flow with water level stability could ensure the conservation of many currently endangered habitat species or their restoration in the area of interest, as well as allow a smooth transition for fish migration and other aquatic animals.

Model of the design of blind channel was provided to main stakeholders in order to support the study area restoration. Excavation work began in the lower part of the channel in its effluent into the mainstream in autumn 2017. The excavation works were provided by the division of enterprise SWME, a Central Hron River Basin Administration Zvolen, and the initiator of the project, municipality Rudno nad Hronom. The main background material for the commencement of excavation work and the channel restoration was the project documentation prepared by SWME, which included a detailed situation of this channel's site at a scale of 1:200, drawing of initial 200 m of the channel and longitudinal profile at a scale of 1:500/100. During the excavation works were excavated approximately the first 60 meters of the total length of the channel, started to be filled with water from the main riverbed (Figure 4). The transverse profile of the channel has the shape of a simple trapezoid.
with slopes ratio 1:2. The width of the effluent site of the channel is 3 m. The newly designed channel route meets the normative criteria and technical, operational, economic, environmental and esthetical requirements. There was an emphasis placed on minimizing the impact of adjustments on the overall river's ecosystem and the surrounding area, adjacent settlements, roads and other infrastructure.

Excavation works were later suspended due to landowner objections, however, during 2018, after the agreement with landowners, the project initiators decided to continue in digging, and to open and overflow the other side of the channel, its influent. The channel routing had to be partially modified, so it is distinct from the historical route or the proposed route from the model. The arm restoration process was completed in early 2019, with the arm completely overflowed and gradually filled with a constant water level (Figure 5). A restoration process is intended to keep the riverbed and its stability free to regain its natural flow character. Such restoration benefited mainly the aquatic ecosystem while supporting the occurrence of biodiversity in the territory and helped to restore the various species of habitats that occurred in the area before the clogging of the river channel. Observations of adjacent habitat responses to the restoration and revitalization of the channel are nowadays being observed at the restored territory.
Figure 5. Restored channel during summer 2019 (pictures on the left – influent/effluent) and winter 2019 (pictures on the right – influent/channel stream) [8]

5. Conclusion
The aforementioned literature review explores the effect of nature revitalization and harmonization interventions at the wider landscape. The case study describes a real project of the restoration of flow-through of a blind historical river channel in the Hron river in Slovakia. The main aim of the project was to restore the river's channel to a more 'natural' state through designing and implementation of a series landscape restoration techniques, methods and management operations, and thereby restore the river to its original natural state. The research has shown the importance of the recovery of original river's routing and stabilization of the floodplain areas in the ecological corridors not only because of the conservation of significant aquatic habitats but because of the natural functioning of the river's ecosystem and slowing down the water runoff from the landscape. The paper concludes with the key principles of the revitalization process in the context of river ecosystems conservation and strengthening of habitat diversity.

The focus of the paper is to study the resilience of water ecosystems and to meet the new challenges of nature harmonization in the restored environment. The paper summarizes the following key principles for the water system resilience and harmonization:

- Adaptive water harmonization and adaptive nature harmonization are the key tools to address water ecosystem resilience;
- Ecologists, urban planners and water engineers must promote opportunities to integrate nature harmonization into landscape-scale interventions and encourage the ecosystem and biodiversity resilience, thus conserving the existing ecological corridors;
- The increasing vulnerability of the water ecosystems calls for holistic strategies and diverse approaches to nature harmonization to be recognized and supported;
- It is necessary to improve management policies and practices by learning from the outcomes of implemented management strategies.

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References
[1] D. M. J. S. Bowman, S. T. Garnett, S. Barlow, S. A. Bekessy, S. M. Bellairs, M. J. Bishop, R. A. Bradstock, D. N. Jones, S. L. Maxwell, J. Pittock, M. V. Toral-Granda, J. E. M. Watson, T. Wilson, K. K. Zander, and L. Hughes, "Renewal ecology: conservation for the Anthropocene,"
Restoration Ecology, vol. 25, no. 5, pp. 674-680, 2017.

[2] T. Elmqvist, W. C. Zipperer, and B. Güneralp, "Urbanization, habitat loss, biodiversity decline: solution pathways to break the cycle," pp. 139-151, 2016.

[3] J. Prior, "Urban river design and aesthetics: a river restoration case study from the UK," Journal of Urban Design, pp. 512-529, 2016.

[4] J. Pittock, M. Finlayson, A. H. Arthington, D. Roux, J. H. Matthews, H. Biggs, R. Froend, I. Harrison, E. Blom, and R. Flitcroft, "Managing freshwater, river, wetland and estuarine protected areas," p. 569–608, 2015.

[5] S. Addy, S. Cooksley, N. Dodd, K. Waylen, J. Stockan, A. Byg, and K. Holstead, “River Restoration and Biodiversity: Nature-Based Solutions for Restoring the Rivers of the UK and Republic of Ireland,” p. 74, 2016.

[6] P. Baozhu, Y. Jianping, Z. Xinhua, W. Zhaoyin, C. Jiao, L. Jinyou, L. Zhiwei, Z. Na, and X. Mengzhen, "A review of ecological restoration techniques in fluvial rivers," International Journal of Sediment Research, vol. 31, no. 2, p. 110–119, 2016.

[7] Á. Agócssová, and A. Škrinár, “Restoration of the dead arm of the Hron River near Rudno nad Hronom,” 2018.

[8] M. Jančok, Za živé rieky, “Hron river channel near Rudno nad Hronom,” 2020. [Online]. Available: https://www.facebook.com/ziverieky/?epa=SEARCH_BOX (in Slovak).