River restoration as an element in sustainable urban development

Andrej Skrinar¹, Martin Misik², Matus Janota³

¹Slovak University of Technology, Faculty of Civil Engineering, Radlinského 11, 810 05 Bratislava, Slovakia  
²DHI Slovakia, s r.o., Hattalova 12, 831 03 Bratislava, Slovakia  
³Architect Matúš Janota, Hlavatého 2, 811 03 Bratislava, Slovakia

andrej.skrinar@stuba.sk

Abstract. In Bratislava (Slovakia), alongside the Danube River, there is a continuous green area of diverse character with enormous potential for quality of life in the city. A group of experts, enthusiasts and specialists for the Danube, architects and urban planners, natural scientists, water managers and conservationists formulated a vision of Bratislava's Danube Park (BDP). The vision is to create and protect a unique and extensive territory along the river with aesthetic natural and natural-close riverbanks in places of suitable morphological and hydraulic conditions along with connection of several branches back to the main Danube channel. Many spots of urban greenery are directly connected to this area, which could thus become its backbone, providing recreation and a resting place not only on the original bank of the Danube. The river in all its forms is the most important landscape element unifying this vast and varied territory. Besides the well-designed urbanized embankments, the character of the Danube River along with its hydromorphological and hydraulic parameters make it possible for Bratislava to have extensive riverbanks and inundation areas of natural character suitable for recreation, stay and movement of people near the river.

1. Introduction
Possibilities of using the natural conditions of the Danube River in Bratislava (capital of Slovakia) are unique and the appropriate restoration measures necessary to fulfil their potential, in line with modern trends, will be relatively simple and cheap. In Bratislava, alongside the Danube River, there is a continuous green area of diverse character with enormous potential for quality of life in the city. The river in all its forms is the most important landscape element unifying this vast and varied territory. Besides the well-designed urbanized embankments, the character of the Danube River along with its hydro-morphological and hydraulic parameters [1] make it possible for Bratislava to have extensive riverbanks and inundation areas of natural character suitable for recreation, stay and movement of people near the river.
A group of experts, enthusiasts and specialists for the Danube, architects and urban planners, natural scientists, water managers and conservationists formulated a vision of Bratislava's Danube Park (BDP). The vision we present is complex and unique - such an interdisciplinary team of experts has been put together for the first time. It is a great chance for Bratislava and inspiration for other cities. Unquestionable benefits of integrated approach to landscape planning are discussed in [2] or [3].

The BDP does not have the ambition to bring about major changes in the landscape character, as it rather wants to focus mainly on protecting the existing qualities of the area and gradually restoring its selected parts. The vision is to create a unique and vast area by a river with natural and close-natural riverbanks in places where morphological and hydraulic conditions and several branches linked to the main stem of Danube make it possible. The access of people in the area will be possible by walking and hiking trails, cycling routes as well as water routes in the river itself along with branches for recreational water sports.

The unifying element, connecting the diverse localities, will be the river itself, river banks, branches and floodplain forests that are located throughout the whole BDP area. It is these territories that need the greatest intervention - restoration. These are the most valuable elements of the area, either by attraction for visitors, beautiful views or by the natural quality.

2. Materials and methods
The BDP area spreads from the Austrian border through the Bratislava’s city centre to the Hungarian border (Figure 1) and includes mainly floodplains that are difficult to use economically and therefore remain non-urbanized to this day. Within the area, there are remnants of the river branch system, nature reserves and protected areas (NATURA 2000 and Ramsar sites), natural floodplain forests, open meadow areas, exposed gravel beaches, as well as production plantations of non-native Canadian poplar (Populus × canadensis).

In the city centre, the intended Danube Park touches the Janko Kráľ Park, the oldest public park in Central Europe, and down the stream, it continuously extends into the forest park in Rusovce and further into the park around the Rusovce Neo-Gothic manor house (Figure 1). There are well-preserved buildings of the fortification of the Bratislava bridgehead from 1938 at the Austrian border and also on the river kilometre 1862.

The area provides opportunities for sports - such as the boathouses, paddling and rowing centre, swimming lakes. Along the edge, very popular Bratislava's sports field, "the dike" is located, sought after by many cyclists, skaters and runners. Directly in the floodplain, there are localities appointed for recreational function in the natural environment by the Territorial Plan of the City of Bratislava. There are other sports facilities such as the horse racing area in close vicinity of the BDP area.

The BDP vision is wide and includes a wealth of data, documentation and studies necessary to carry out the plan. To drive a more sustainable future for the Danube River in Bratislava, the vision has many levels, the basic of which are: (i) Urban design and planning, (ii) water management and restoration and (iii) nature protection. Therefore, the initiative brings together leading Slovak experts in these fields – architects and urban planners, natural scientists, water managers and conservationists. Authors of this study are as well the co-authors of the vision and members of the BDP initiative.
Figure 1. The design area of the Bratislava's Danube Park
2.1. Urban design and planning
The main intention of the BDP is to ensure people's access to the area, create longitudinal interconnections along the Danube, preferably directly near the riverbank (Figure 2) and transverse entries to the area at appropriate locations. The basic communications network is shown in Figure 1. In order to make the area more attractive, it is important to create more locations to stay by the water – the river entries and swimming places right on the riverbanks. Some examples are given in Figure 3, Figure 4 and Figure 5.

![Figure 2. Sightseeing path along the bench of the reinforced riverbank](image)

![Figure 3. Ground plan of the river bank restored to the form of a natural beach, with binding the existing bank reinforcements at the edges](image)
Figure 4. Cross-section of a restored bank to the form of a natural beach

Figure 5. Axonometric sketch of the river bank restored to the form of a natural beach, with binding the existing bank reinforcements at the edges
2.2. Water management restorative measures

To meet the objectives of the BDP, water management restoration measures were proposed, consisting of renaturalisation of the Danube banks and restoration of the Danube side branches.

2.2.1. Bank renaturalisation. The principle of the proposed river bank renaturalisation is the restoration of the natural and aesthetic form of the banks at selected locations (Figure 1), allowing people to enjoy the access to the water and restoring the river ecosystem and its functions. This will have a positive impact on people's quality of life, biodiversity and hydro-morphological and biological indicators of water quality as required by the European Water Framework Directive [4].

For the design of restoration of the banks, the hydraulic and hydro-morphological conditions of the Danube were respected. The reaches have been identified, on which it is possible and desirable to restore the natural bank without the need for bank reinforcement (Figure 3, Figure 4 and Figure 5). Mostly, these are located in the convex, i.e. the inner parts of the river curves where the water flow velocities are lower, thus the bank is not heavily attacked by erosion and there is no important infrastructure near the bank. In places where river bank renaturalisation is desirable, but due to the flow conditions, the bank reinforcement is necessary, a technical restoration is proposed, i.e. modification of the bank reinforcement into a close-nature form. Some examples are given in Figure 6, Figure 7 and Figure 8.

Figure 6. Local modification of the bank reinforcement into the close-nature form – axonometric sketch
2.2.2. Restoration of the Danube side branches. The principle of the proposed renewal of the Danube side branches is the restoration of lateral connectivity between the main stem of the Danube and the lateral branches, restoration and revitalization of existing and lost water areas and wetlands.
This will greatly contribute to restoring the river ecosystem and its functions and improving the ecosystem services. Lateral branches renewal will also have a beneficial effect on flood protection. Renewed branches will be able to contribute significantly to the large water flows transfer during the flood events and in the case of clogging the main river bed by ice.

Anthropogenic activities significantly reflected on the branches condition especially in the last 50 years (Figure 9). In particular, extensive gravel mining and backfilling by construction waste have changed them most.

The design of the branches reconnection (yellow dashed line in Figure 9) was assessed by hydrodynamic modelling at the mean long-term discharge of the Danube in Bratislava ($Q_a$) and at the $Q_{100}$ flood flow. The numerical two-dimensional hydrodynamic model DHI MIKE 21 FM was used to predict the water levels. The results of the calculations for the mean long-term discharge ($Q_a = 2061$ m$^3$.s$^{-1}$) declare favourable conditions for the navigation of recreational craft along the entire path resulting from the proposed linking of the branches and at the same time the simulated values of flow velocities suggest that there will probably not be any significant sedimentation with a decrease of flood discharge levels (Figure 10).
2.3. Nature protection

In terms of nature conservation, BDP aims to preserve and respect existing protected natural areas and to enhance them. The current framework of nature protection in this area appears to be sufficient and the expansion of protected areas is not an ambition of the BDP initiative.

The main current problem is insensitive environmental management of the area. Examples of real damage to the natural environment of the Danube from the recent past include the insensitive technocratic modification of the popular natural beach of Lido to the non-aesthetic and inaccessible riverbank in the 1980s and the destruction of the valuable and stable natural riverbank of the Owl Forest protected area and its replacement by the insensitive and inadequate quarrying in the first decade of the 21st century. At present, the threat continues with the insensitive reinforcement of the left Danube bank at Vlčie hrdlo near the Kopáč island (winter 2018). Hundreds of meters of natural riverbank, an important part of the river's ecosystem and a popular place for people to stay by the river, have been transformed into a devastated dead bank filled by stones, even though such a measure was not needed (inner curve, low flow velocities, the dike 400 m away), as well as the form of reinforcement is unsuitable. The devastating deforestation on the left bank of the Danube between Čunovo and Dobrohošť (winter and spring 2018) is also problematic. Deforestation on the Danube banks and its inundation area will have very negative ecological consequences for decades, it was
carried out in contradiction with the basic principles of ecological management, and furthermore it was inadequate and inappropriate from the viewpoint of flood protection. Moreover, these measures seriously increase the risk of introducing the invasive plant species, the most dangerous of which is *Fallopia japonica*. In recent years, this plant has been expanding in Slovakia at breath-taking speed, which represents a significant environmental risk [5]. Defining the entire area as a park can reverse this trend and unify the management to best meet the environmental principles and real needs of the BDP area.

Even today, the Danube in Bratislava stands out for its fish species richness (more than 50 species), but the state of many populations is critical, because they do not have suitable habitat to reproduce due to inappropriate riverbank regulations. Proposed restoration of the branch system and restoration of the riverbanks have the great potential to solve this problem.

3. Results and discussion
The Danube, its natural character and a healthy river ecosystem is important for Bratislava as the capital and the centre of the region with a border crossing for the environment, for people's quality of life and for sustainable economic development.

The public has eminent interest that the maintenance and environmental management of the Danube River and its banks is in accordance with the recent progressive expertise, knowledge and procedures to ensure that the natural environmental quality of the Danube and its banks will not deteriorate but improve. Representatives of the initiative are interested in working with the relevant institutions, in particular the local government and the river manager to take the restorative measures that preserve and restore the natural character of the stream as much as possible, restoring and preserving the river's branches, restoring the natural character of the banks, replacing insensitive bank reinforcements by an aesthetic and nature-friendly alternative, allowing a healthy river ecosystem life and a pleasant public approach to the river.

The authors of the initiative have learned a lot and have been inspired by the implemented completed projects of other urban rivers restoration, such as the Isar River in Munich, Germany (The Isar Plan) [6] and [7].

Because the success of river restoration efforts depend not only on a scientific understanding of form and process within urban river systems but also on the acceptance and support of urban communities and integration within urban design and planning [8], the first step will be to declare the city's and public's interest of vision-performing with the help of conceptual materials and studies. An important step will be to coordinate the city with the relevant state institutions, in particular with the river manager (Slovak Water-Management Enterprise), with the other actors in the area along with the public, so that the vision of the final outcome is widely accepted and supported.

4. Conclusions
The main concerns of the BDP are as follows: (i) to increase people's quality of life in accordance with the principle of coexistence with nature, (ii) to use the potential of the Danube in Bratislava for relax, recreation and sport in the natural environment and (iii) to create a continuous interconnected area along the Danube River integrating human activities and the natural environment.

The BDP does not have the ambition to bring about major changes in the landscape character, as it rather wants to focus mainly on protecting the existing qualities of the area and gradually restoring its selected parts.
The BDP vision is wide and includes a wealth of data, documentation and studies necessary to carry out the vision. The process of implementation will be gradual. The first step will be to declare the city's and public's interest of vision-performing with the help of conceptual materials and studies. An important step will be to coordinate the city with the relevant state institutions, in particular with the river manager (Slovak Water-Management Enterprise), with the other actors in the area along with the public, so that the vision of the final outcome is widely accepted and supported.

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