

THESES OF THE DOCTORAL (PhD) DISSERTATION

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**Determining ecological restoration potential in urban  
environment using the example of small rivers**

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## **1. BACKGROUND AND OBJECTIVES**

River restoration is one of the most important challenges of our time, as rivers and riverside landscapes have been and continue to be shaped by many natural processes and human activities. Urban river reaches are generally in worse ecological condition than rural reaches. Human impacts are reflected in changes in morphological structure, hydrological and water quality changes, as well as in changes in habitat structure and ecological processes, loss of biodiversity, disappearance of species sensitive to disturbance, among others. These effects are also referred to as "urban stream syndrome", which also shows that special attention needs to be paid to the restoration of urban river sections.

The main objective of my research was to methodologically analyse the determination of the restoration potential of urban river reaches, using the example of small domestic rivers. My aim was to develop an evaluation methodology that can be used to assess the need and potential for restoration of urban river reaches prior to planning the restoration of such sections, and to compare these spatially, covering hydromorphological, ecological, landscape, and recreational aspects. My research is related to the principles of the Water Framework Directive, however, from a methodological point of view, it does not follow it exclusively. In order to achieve my objectives, I carried out a research on the literature background and the domestic river restoration projects (Figure 1), on small domestic rivers; and then developed an evaluation method to determine the restoration potential of urban river reaches at study area scale, for which I tested the applicability at the national scale. On this basis, I have sought to answer the following research questions.

## **I. Literature background and analysis of river restoration projects:**

### **I.1. Literature on the determination of restoration potential**

1. How does the interpretation of the rehabilitation potential of rivers appear in the literature? What evaluation methods exist to determine this, and to what extent do they deal with inland river sections?

### **I.2. Study of river restoration projects in Hungary**

2. What is the status of river restoration projects in Hungary; where and for what purpose have restoration projects been implemented?
3. How and on the basis of which aspects can river restoration projects be typified, and what types can be separated?

## **II. Study of small rivers in Hungary:**

4. What is the trend in land use change along small rivers in Hungary, especially in the built-up areas of small riverside settlements?
5. How can the river sections of domestic small riverside towns be typified in terms of the structural relationship between the settlement and the river?
6. Is it sufficient to include the river reach delineated by the urban legal boundary in the river restoration, or could it be worth extending the restoration beyond the legal boundary?

## **III. Determination of restoration potential:**

### **III.1. Analyses on study area scale:**

7. What segmentation methods can be used to determine the restoration potential of urban river reaches?
8. What criteria system can be used to determine the restoration potential of rivers at the scale of the study area, and how can they be applied to different restoration sub-goals?
9. What is the restoration potential of the river reaches in the study area based on the developed evaluation method? Can the target areas of different restoration sub-goals be separated?

### **III.2. Analyses on a national scale:**

10. Is the methodology developed in the study areas applicable on a national scale? What criteria can be used for the national evaluation?
11. What is the restoration potential of the cities along small rivers according to the assessment method developed?

## 2. MATERIALS AND METHODS

The research was carried out in several steps. The first step was research on the topic of river restoration and small rivers in Hungary. I examined domestic river restoration projects in order to identify the status and types of restoration projects in Hungary. The methods used in this step of the research included analysis of domestic and foreign literature, and analysis of domestic projects according to location (urban or rural), the purpose of restoration, and the area of the measures implemented.

I examined land-use changes to explore the trends of built-up areas along the small domestic rivers. For this, I applied GIS analyses using the CORINE Land Cover (CLC) database from 1990, 2000, 2006, 2012, and 2018. Subsequently, I analysed the extent of river reaches that could be included in river restoration for small riverside cities with a population of over 5,000. To do this, I compared the location and length of river sections covered by the area delineated by actual land uses with the river segments covered by the legal urban boundary in the studied settlements. The land use delineation was based on the CORINE 2018 land cover database and Google Earth 2022 satellite maps.

Finally, I developed a scoring-based assessment method to determine the restoration potential of urban river reaches in three study areas. I assessed the restoration potential for seven restoration sub-goals by comparing the need and potential for restoration. My aim was to develop an assessment that takes into account the multifunctional role of urban rivers and therefore integrates hydromorphological, ecological, landscape, and recreational aspects. In developing the methodology, I took into account the results of the literature analysis. The assessment was carried out through field surveys, database analysis, and GIS analysis. I compared two different river segmentation methods on the study area scale in Szolnok. For the developed method, I tested its applicability on a national scale for three restoration goals. In this case, the data sources were national scale databases in order to make the evaluation results comparable. I carried out the assessment by analysing databases and GIS analysis, based on e.g. CORINE, OKIR, NÖSZTÉP, OpenStreetMap, TIR, VGT3.

<b>I. Literature background and analysis of river restoration projects</b>			
<b>I.1. Literature research</b>			<b>Subject of research: small rivers</b>
<b>Use of terms</b>		<b>Restoration potential</b>	
Restoration and related terms	River, river bank, floodplain	Evaluation methods for rivers Methods for determining restoration potential	
		<b>RESULT:</b> 1. Characteristics of existing methods	
<b>I.2. Examination of projects</b>			
<i>Database creation, analysis</i>			
Overview of Hungarian river restoration projects: area covered, objective, measures			
<b>RESULT:</b> 2. Status of Hungarian river restoration projects 3. Definition of types of river restorations			
<b>II. Study of small rivers in Hungary</b>			
<i>Geospatial analyses</i>			
Analysis of land cover changes in built-up areas and the rivers in the settlement structure			
<b>RESULT:</b> 4. Changes in built-up areas along small rivers 5. Settlement structure types of river reaches 6. Identification of river reaches suitable for urban river restoration			
<b>III. Determination of restoration potential</b>			
<b>III.1. Study area scale</b>		<b>III.2. National scale</b>	
<i>Field surveys</i> <i>Database analysis</i> <i>Geospatial analyses</i>		<i>Database analysis</i> <i>Geospatial analyses</i>	
Developing a study area evaluation method Evaluations carried out in three study areas		Extension of the study area method based on national data	
<b>RESULT:</b> 7. Comparison of segmentation methods 8. Developing a method for assessing restoration potential by sub-goals in study areas 9. Results of the study area assessment of restoration potential		<b>RESULT:</b> 10. Developing a method for assessing restoration potential goals at national level 11. Results of the national assessment of restoration potential	

Figure 1: Overview of research



### 3. THESES, NEW SCIENTIFIC RESULTS

The new scientific results were based on the literature review of restoration potential (thesis 1), the analysis of river restoration projects in Hungary (thesis 2-3), the analysis of small rivers in Hungary (theses 4-6), and in relation to the determination of restoration potential based on the study area analyses (theses 7-9) and the national scale analyses (theses 10-11).

**Thesis 1. Based on a review of national and international methodologies related to restoration potential, I found that the most important characteristic of restoration potential is the joint assessment of the condition of rivers (need for restoration) and the possibility of restoration (limiting factors). By analysing the research, I proved that existing methodologies focus mainly on the assessment of rural river reaches, less research is done on the urban sections to determine restoration potential.**

Among the evaluation criteria of the reviewed methods, geomorphological, ecological, or hydromorphological aspects were the most common, related to the condition of the rivers. The most common evaluation criteria, related to landscape architecture, were land cover and land use (evaluated by more than 60% of the methods). In the case of the possibility of restoration, the natural features influencing the suitability of the area for restoration were most frequently examined, but several studies examined the proportion of urban areas and the existing infrastructure network along the river. Only about 10% of the methods were specifically designed to determine the restoration potential of an urban river reach, and a further 7% were considered suitable or partially suitable for assessing such areas based on their scale and criteria. Most often, the methods aim to achieve a specific sectoral (mainly ecological) restoration goal or provide an overall assessment of the condition of the river section.

**Thesis 2. I have found that three-quarters of the river restoration projects implemented in Hungary in recent decades have not or only partially involved urban areas. In terms of restoration goals, although the proportion of social and climate protection goals has increased slightly alongside ecological and flood protection goals, the proportion of projects with complex goals remains small.**

During my research, I analysed domestic river restoration projects from 2007 to 2020. 25% of the projects partially or fully involved urban areas, 20% of the projects in the case of small rivers. The majority of domestic projects had ecological and flood protection goals, but urban projects often failed to meet ecological and water quality goals. Ecological goals were present in 63% of all projects studied, compared to only 33% of urban projects. Social goals were slightly more frequent from 2014 to 2020, and the goal of adaptation to climate change also appeared, in line with the trend of recent years. For small rivers, a higher proportion of goals were related to restoring ecological status and adapting to climate change; a lower proportion were related to social objectives and improving water quality.

**Thesis 3. Based on the analysis of Hungarian projects, I identified the types of restoration projects based on the involvement of urban area, the purpose of the restoration and the location of the measures implemented during the project. Based on the results of the typification, I classified the projects into 15 types.**

The determination of the types of restoration projects was based on the type of area involved, on the basis of which I separated the urban, partially urban and rural restorations. For the typification, I further identified the purpose of the restoration (single purpose, multiple purposes, consideration of social purposes) and the location of the measures (riverbed, floodplain). Out of the 15 types, I have identified the following as urban restoration types:

1. urban restoration with one main goal, focusing mainly on the riverbed
2. urban, single-goal restoration, including the floodplain
3. urban, multi-goal restoration, focusing mainly on the river bed
4. urban, multi-goal restoration, including the floodplain
5. urban, multi-goal restoration, including social objectives, including the floodplain

Among the restoration types, my research focused on type 5: urban, multi-goal restoration, including social objectives, including the floodplain.

**Thesis 4. Based on the analysis of land cover changes in the landscape corridors along small rivers in Hungary, I have shown that the built-up areas along the rivers show a similar but smaller increase than the national trends. I found that, although the increase in urban green areas within built-up areas appears to be a positive trend, it shows little significant change along rivers when examined spatially.**

The growth of built-up areas is 10% along small rivers, compared to 14% nationally. Spatially, the increase in built-up areas is mainly in areas with former agricultural use. The increase in urban green areas is large in proportion (more than doubling in the 50 and 100 m landscape corridors), but spatially it represents a real change of character in the case of only a few settlements along the rivers. Urban green areas are proportionally larger in the narrower 50 and 100 m landscape corridors along rivers than further away from rivers, confirming the importance and potential of rivers in the green infrastructure system of the cities.

**Thesis 5. Based on the relationship between the river and the settlement's legal urban boundary, I defined the settlement structure types of river reaches. I have distinguished three main types: urban, peri-urban and rural river reaches. Three sub-types were identified for urban river reaches and two for peri-urban river reaches.**

Along small rivers in Hungary, I examined the relationship between the river and the urban boundary for towns with a population of over 5,000. Based on the results of the typification, I found that 26% of the river reaches in the 39 cities studied are of urban type, 30% are of peri-urban type, and 44% are rural river reaches. I have also separated subtypes for both urban and peri-urban river reaches. For urban river sections, these are the following: central element of urban area, as a single river; central element of urban area, not as a single river; on the edge of urban area, with one or more overhangs. For peri-urban river sections: on the edge of urban area, as an "external" boundary; separating several urban units, as an "internal" boundary. The majority of inland river sections are river sections that form the central element of the urban area, which may be present as a single river or flowing into a larger river in the settlement.

**Thesis 6. In the analysis of urban river reaches, I found that there is a difference between the length of the urban river section with a legal boundary and the length of river section with urban or recreational function along the floodplain. When examined on the basis of actual functions, the river section that can be included in the restoration is typically longer.**

In the 11 settlements with an urban river section, the average length of the river section is 24% longer if it is not considered as the urban legal boundary, but as the length of the river section on or along the floodplain with urban or recreational land uses. In this way I have proved that for urban river restoration, it is worth considering the real functions, since based on these, restoration that takes into account social goals will involve a longer river segment than the river reach based on the urban legal boundary.

**Thesis 7. During the study area research, based on the comparison of the evaluation results of sections with similar characteristics and sections of same length, I found that the choice of the segmentation method for the evaluation depends on the number and range of aspects to be evaluated, the spatial scale of the evaluation, the accessibility of the river section, and the purpose of the evaluation.**

I found that the delineation of preliminary section boundaries can be applied well if it is possible to delineate sections with similar characteristics from most evaluation aspects. In cases where the goal is to apply several different evaluation criteria, the delineation of shorter sections of the same length can also give good results. In addition, I established the spatial scale as an important aspect. In small areas, on shorter river sections (e.g. in urban areas), the method of short sections of the same length can be used; while on a large scale or if the river section cannot be easily accessed, which means that surveys cannot be carried out along the entire length of the river reach, it is better to delineate sections with similar characteristics. Pre-delineated sections with similar characteristics can therefore play a role in the conceptual delineation of the most important restoration goals and their main target areas in a given river section, while shorter sections of the same length can help in establishing a more detailed concept.

**Thesis 8. I have developed a method for determining the restoration potential of urban river reaches in relation to restoration sub-goals at the study area scale. In this way, the results can be further differentiated in comparison to previous research to determine restoration priorities. In the developed scoring methodology, I have included a total of 31 criteria for the assessment of the need for restoration and a further 11 criteria for the assessment of the possibility of restoration, expanding the range of criteria that can be used in the assessment, especially in the areas of recreational and landscape features.**

I have identified the most common restoration sub-goals in urban river reaches and assessed the restoration potential for seven of them based on a separate set of criteria: (1) improving the longitudinal connectivity, (2) improving the ecological and hydromorphological condition of the active channel, (3) achieving a more natural channel planform, (4) improving the naturalness of floodplain vegetation, (5) improving water quality, (6) improving recreational opportunities, (7) improving urban landscape aesthetic value. For each aspect I have provided a detailed description of the given aspect and its evaluation. On the basis of the methodology developed, I determined the restoration potential for each section by assessing the need for restoration (river condition, characteristics) and the possibility (limiting factors) of restoration, and comparing the results.

**Thesis 9. Based on the developed methodology, I determined the restoration potential of the urban river reaches in three study areas along the Zagyva in the cities of Szolnok, Jászberény and Hatvan in terms of seven restoration sub-goals. I identified the main differences between the analysed settlements, and based on the results, I concluded that the developed method is suitable for the assessment of the need and possibility of restoration, and for the spatial comparison of these in the case of urban river sections, before the detailed planning of the restoration, mainly for the preparation of conceptual plans.**

In Szolnok, most of the evaluated sections have a high restoration potential for the sub-goals of improving water quality, improving recreational opportunities and improving urban landscape aesthetic value. In addition, half of the sections have high potential for the sub-goals of improving the ecological and hydromorphological condition of the active channel, achieving a more natural channel planform and improving the naturalness of floodplain vegetation. In the city of Jászberény, a significant proportion of the assessed river sections have a high restoration potential for the sub-goal of improving recreational potential, and almost half of the sections also have a high potential for the sub-goal of improving urban landscape aesthetic value. In Hatvan, the entire urban river reach has a high restoration potential for the sub-goals of improving the ecological and hydromorphological condition of the active channel and improving urban landscape aesthetic value. In addition, the sub-goal of improving recreational potential has a high potential for more than half of the sections.

**Thesis 10. During the examination of the applicability of the study area methodology on a national scale, I defined the range of aspects that can be included in the evaluation. I found that the study area methodology can be applied with modifications to several settlements, even on national scale.**

I have examined the applicability of the study area scale evaluation methodology to several settlements at the same time on a national scale. During the adaptation of the method, I identified three main restoration goals and assessed the restoration potential for these: (I) improving ecological and hydromorphological conditions; (II) improving water quality; (III) improving recreational and landscape aesthetic value. From the system of criteria in the study area, 16 criteria in the case of the need for restoration and three criteria in the case of the possibility of restoration were suitable for the national scale evaluation. Of the study area criteria, those with a national database and spatial data set can be used.

**Thesis 11. As a result of the national scale research, I have determined the restoration potential of the examined urban river reaches. Based on the results, I determined which settlements have the highest potential for achieving which restoration goals. I found that, although the level of detail of the evaluation results is below that of the study area evaluation, the main differences can be identified for the restoration goals and conclusions can be drawn about their importance and prioritisation.**

The subject of research on a national scale were urban river reaches on small rivers in Hungary. Based on the results of the assessment, settlements with high potential for restoration were identified. In the city of Nagyecsed all three restoration goals have high potential. In the case of Hatvan and Jászberény, the improvement of water quality and the improvement of recreational and landscape aesthetic value have high potential; in Szolnok, the improvement of ecological and hydromorphological conditions and the improvement of recreational and landscape aesthetic value. In addition to these, Kaposvár and Zalaegerszeg, as cities with a high potential for restoration in terms of improving ecological and hydromorphological conditions, and Győr and Mosonmagyaróvár, which have a high potential for improving recreational and landscape aesthetic value, were highlighted in the results.

#### **4. RESULTS, CONCLUSIONS AND RECOMMENDATIONS**

The methodology developed in my research can be applied to landscape architecture practice in whole or in part to several types of plans. It can be part of river basin management planning and landscape character research.

To improve the methodological preparation of urban river restoration, I developed an assessment method that can be used to identify the need and potential for restoration of small urban rivers, and thus to evaluate their restoration potential. The assessment by restoration sub-goals allows for the spatial prioritisation of individual goals along the river reach in the study area. On a national scale, the results can be used to identify which settlements have the greatest potential for achieving which restoration goals.

The evaluation methodology developed in this research can be applied in practical planning for the preparation of river restoration projects, especially for the preparation of conceptual planning. Tables presented in annexes, which provide a detailed description of the evaluation criteria and methodology, are helpful in this respect and can be used in part or in whole during the planning process. In addition to restoration plans, the assessment methodology can also be used in the preparation of green infrastructure development plans. Another application is the use of the assessment in river basin management planning to assess the floodplain of rivers. The national scale assessment has identified several data sources with national coverage, that can be used to compare urban river reaches. The landscape and esthetical assessment parts of the methodology can also be integrated into landscape character-focused research. The research methodology for identifying river sections that can be included in urban restoration can be applied to the development of urban planning tools.

As a continuation of the research, there is scope to expand the restoration sub-goals, for example the inclusion of connected flood-free areas outside the floodplain. It is possible to examine what and how could be incorporated into the WFD system from the evaluation I created. The assessment for landscape and recreational purposes is not included in the WFD. The associated condition assessment could be integrated into the WFD system, but this would require bridging the differences in scale and revising the assessment of the criteria.

## 5. THE AUTHOR'S PUBLICATIONS RELATED TO THE TOPIC

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