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Foundation of adaptive water management for areas affected by excess water inundation with landscape architecture tools

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CONTENT

1. BACKGROUND AND OBJECTIVES

Today, we are increasingly facing extreme weather events as a result of the direct and indirect impacts of **climate change**. Hectic and often extreme rainfall and precipitation patterns, strong temperature fluctuations, resulting in droughts, floods, flash floods or even **excess water** inundation in a given area. Hungary's basin-like natural geography and, at the same time, its relative abundance of water resources, creates specific challenges for surface water. In addition to rivers and lakes with permanent surface water, **intermittent water resources** are also important ecologically and functionally, but also from an aesthetic point of view, as they enhance the landscape and are a key element in efforts to counteract the negative effects of climate change. With their biologically active surfaces, they form part of the blue and green infrastructure, providing a complex ecosystem service.

A significant proportion of Hungary's lowland areas, almost 50% of arable land, is affected by excess water[1]. Although the extent of excess water inundation varies both spatially and temporally, they can be interpreted as intermittent water surfaces that contribute directly to increasing water efficiency as a potential means of water conservation. Excess water can be interpreted and analysed in a number of ways: landscape conservation, settlement morphology, landscape, ecology, hydrology, water management and economic aspects. This underlines the fact that excess water is a rather interdisciplinary research topic, relevant to many disciplines.

[1] Areas affected by excess water: "*mainly deeper, unimproved lowland areas not suitable for agricultural use, where a part of the local precipitation accumulates in the form of temporary excess water in large quantities and with high frequency"* (Dobó et. al. 2020)

Based on the above, the primary objective of my research is to analyse excess water with the tools of landscape architecture. This topic has not been the subject of any in-depth scientific research, especially with regard to their role in the system of areas of natural and landscape conservation importance, in order to provide a basis for adaptive water management and excess water reform. My thesis is divided into three main sections:

- Literature review and situation analysis (I),
- Landscape assessment of areas affected by excess water (II),
- Sample area analysis and assessment (III).

In **Unit I**, I focused on a detailed review and critical interpretation of the current approach and practice of excess water management, as well as of the existing national legislation and sectoral strategies, planning documents and previous research results, which contain the basic concepts (excess water, blue and green infrastructure, ecosystem services) relevant to the research topic. All of these analyses will contribute to changing the current theory and practice of excess water management and to informing its development.

In **Unit II** of my research, I conducted a complex national analysis of areas affected by excess water using spatial information tools, based on landscape conservation criteria. My aim was to explore and interpret the nature and landscape conservation significance, landscape shaping and landscape character, land use and landscape history of these areas under periodic flooding. By comparing the individual assessment results, scenarios for adaptive water management and land use in areas affected by excess water were developed.

Unit III contains sample area analyses, the aim of which was to supplement the national results from research Unit II with

data at local level and to confirm or even critically comment on the adaptability of the results.

The structure of the research is illustrated schematically in Figure 1.

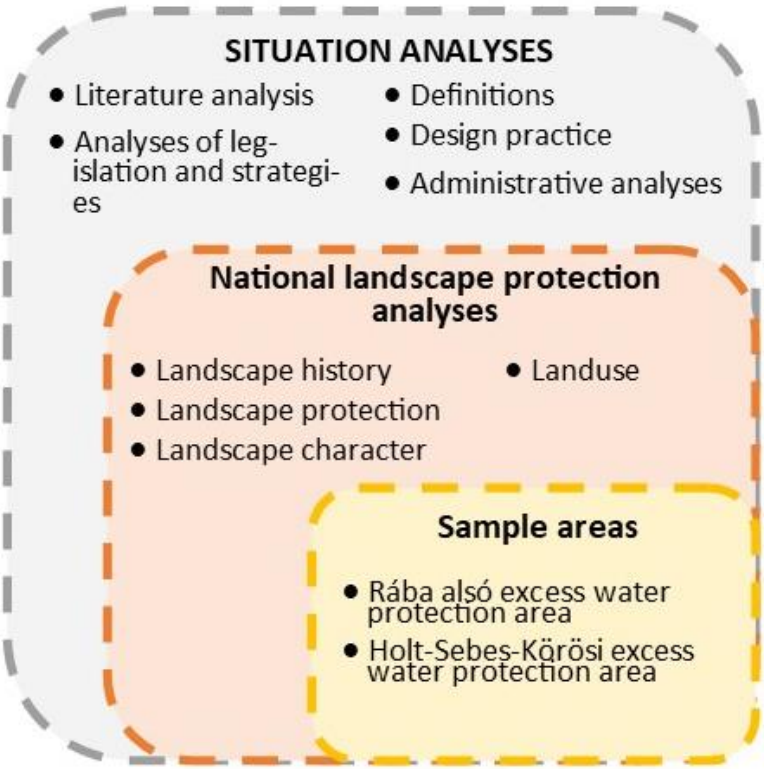

Figure 1: The structure of the research (own editing)

2. MATHERIALS AND METHODS

In line with the objectives, the research is structured in three main units. In the literature and situation analysis (I) section, the terms used in the thesis were defined: excess water and excess water-related concepts, blue and green infrastructure, ecosystem services. In Unit I, the primary objective was to interpret the relevant domestic legislation in force on the subject of the research, in order to answer the research questions concerning the definition, content and regulation of the concepts of excess water, blue and green infrastructure and ecosystem services. Since excess water management and blue and green infrastructure are planning tools and indicators that determine planning aspects and are therefore of paramount importance for sectoral plans (including settlement plans and strategies), I also reviewed and interpreted the existing sectoral strategies and concepts in practice. Thus, in the evaluation, I have specifically addressed the National Landscape Strategy, the National Water Strategy, the National Rural Strategy, the National Forest Strategy, the Second National Climate Change Strategy, the National Sustainable Development Framework Strategy, the 5th Environmental Programme.

Part I of the work focuses on exploring the links between spatial planning and excess water, identifying the links and identifying the gaps.

In the landscape-scale analyses that make up Unit II of the research

- excess water and land uses,
- the landscape history of areas related to excess water (the relationship between former floodplains prior to flood drainage), and

- excess water and areas of natural and landscape importance

I have explored the links between excess water and their history and the role of excess water in the landscape and in the conservation and protection of nature and landscape values. The assessments were carried out using ArcGis version 10.4 software on a national scale using the databases listed below.

1) Relationship between areas exposed to excess water and land use

I determined the land use characteristics of areas exposed to excess water inundation on a national scale by superimposing and intersecting the excess water frequency overlay[2] and the NÖSZTÉP[3] map database. A prerequisite for the development of scenarios based on the results of the research was the delineation of the overlap between arable land with excellent and good soil conditions and inland areas in order to establish adaptive inland water management. In the land-use unit I therefore interpreted and separated out the areas of arable land with excess water that are particularly suitable for farming, and then compared the areas that are less suitable for arable farming with the results of the rest of the research, based on their inverse.

2) Landscape history of areas exposed to excess water

This section of the work explores the landscape history of areas affected by excess water, in which the presence of landscape stability − affecting wetlands − is of particular

[2] OVF 2020

[3] Analyses carried out in the course of the research using the Ecosystem Atlas Map, Ministry of Agriculture, 2019 (KEHOP-430-VEKOP-15-2016-00001)

importance. The spatial methods used in the analysis consisted in digitising the map illustrating the hydrological situation prior to the flood relief works („*Map of the flooded and flood-prone areas of the Carpathian Basin before the start of the flood relief and drainage works*") and in extracting the spatial overlap with the areas currently affected by excess water. The national analyses were complemented by the sample area studies detailed in Section 3) of the research. I also used the results of the sample area landscape studies to validate the national analyses.

In the evaluation part, I have revealed for the first time the relative location of sites of nature and landscape importance and areas affected by excess water, the number of overlaps and the spatial distribution and concentration of sites, on a national scale, thus identifying areas exposed to excess water of particular value for landscape protection in Hungary.

3) Understanding the relationship between wetlands and sites of nature and landscape importance

In Unit III of the thesis, I carried out detailed natural geographic analyses on two sample sites („Rába alsó" and „Holt-Sebes-Körös" excess water protection section), primarily using geospatial methods, supplemented by field documentation as a result of repeated field visits. A detailed land use analysis was carried out for 6 historical time series (I., II., 1941 military survey, 1950-60, 1984-94 topographic map, NÖSZTÉP map illustrating the present situation), which resulted in the determination of the historical transformation of the watercourses and the green infrastructure network of the two sample areas. I also used the watery areas depicted in the Military Survey II to validate the stable watery areas delineated at the national scale in Unit 2) of research work by defining 10-10 points of comparison in the two sample areas.

The individual assessment work packages themselves provide results on the nature and landscape conservation importance of excess water inundated areas, but the large amount of spatial data generated by the research provided a good basis for the identification of pilot sites for adaptive inundation management. To this end, eight different scenarios for land-use change in inland floodplain cropland were developed from a combinatorial analysis of the partial results of the research (spatial correlations between excess water inundated areas and excellent/good quality ploughland, landscape stability characteristics of areas exposed to excess water, landscape conservation importance of excess water areas).

3. SCIENTIFIC RESULTS AND THESIS

Excess water inundated areas have a high potential for water retention. My research results have supported the hypotheses that excess water greatly contributes to the ecological and aesthetic value of an area. Excess water inundated areas account for nearly 20% (19.26%) of the country's areas of nature and landscape conservation importance, while about 41.87% of excess water are protected. This demonstrates that they are valuable, intermittent areas that form an active part of the blue and green infrastructure network. The formation of excess water is the result of a complex interplay of static, but mostly dynamic, natural and anthropogenic processes, which justifies the need for extensive cross-disciplinary research in this field. The approach and tools of landscape architecture provide an opportunity to understand the complex processes taking place in the landscape and to identify appropriate adaptive management approaches, adapted to the landscape, which are essential for the sustainable functioning of the landscape, and to identify the target areas for their implementation.

In my thesis, I focused on the critical analysis and evaluation of the legislative environment and the relevant sectoral strategies, as well as the national spatial and urban planning instruments from the perspective of adaptive excess water management. The results show that excess water management, based on the empirical results of many decades, is currently undergoing a transformation due to the impacts of climate change, which is mainly reflected in the strategies summarising the definition of the long-term vision. Overall, however, excess water is still perceived by society and legislators as a negative, damaging water surplus from a farming perspective.

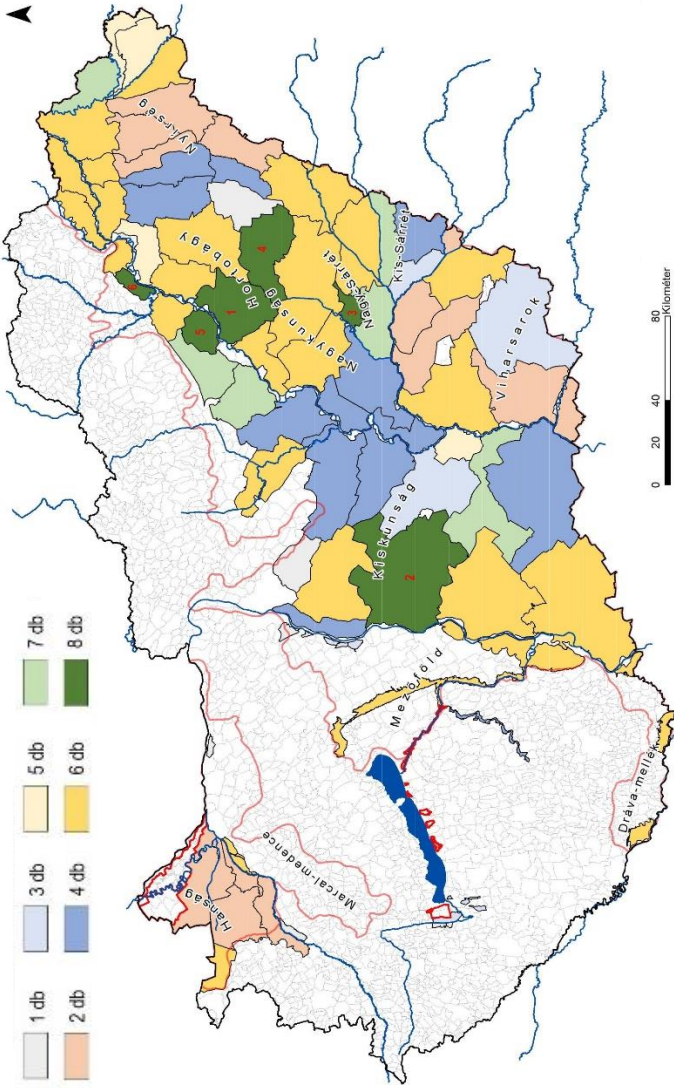

Figure 2: Cumulative result of land-use change scenarios for excess water inundated areas for each protection section (own editing)

<u>T1</u>: Concerning the approach of legal sources to excess water, I found that the legal regulatory environment views excess water as a damaging water surplus and that Hungarian legislation does not yet reflect and apply the adaptive water management approach that is essential for addressing climate change. In the existing sectoral strategies relevant to the research topic, the identification of excess water as one of the key tools for water retention is a step forward in the understanding of excess water.

I have found that the concept of excess water is used within 556 Hungarian legal sources in force, in all of which the interpretation of excess water is approached from a water management perspective, emphasising its damaging nature and the need for and detailed rules of the mechanisms of protection against it. There is no legislation currently in force that incorporates the three definitions (excess water, blue and green infrastructure, ecosystem services) and approaches the concept of excess water from an ecological perspective.

In the strategies analysed (including the National Landscape Strategy, the National Water Strategy, the National Rural Strategy), the prominent role of excess water in mitigating the negative impacts of climate change is emphasised. In the vast majority of the long-term objectives set out in the strategies, excess water is identified as an ecologically positive phenomenon, but is not defined as an integral part of the blue and green infrastructure network, nor is its broad ecosystem services defined.

<u>T2</u>: I have created the concept of historically excess water inundated area, which refers to inundated areas that were inundated before the deflooding and draining activities.

The historically excess water inundated areas were defined by means of landscape-historical analyses on a national scale by processing the map " *Map of the flooded and flood-prone areas of the Carpathian Basin before the start of the flood relief and drainage works* " (Hydrographic Institute of the Ministry of Agriculture of the M. R., 1938). The results of a national landscape history analysis of flood-prone areas can contribute to a better understanding of landscape change processes in areas at risk of inundation and, in turn, to a better understanding of inundation processes and to the identification of the most appropriate adaptive inundation management methods in the area concerned. However, the local interpretability of historically excess water inundated areas identified through national geospatial analyses is of paramount importance, for which the spatial interpretation of sub-areas at a larger scale and more accurate historical sectional maps can be used to further refine the national results.

<u>T3</u>: Using spatial analysis, I have verified that 56.09% of the excess water inundated areas are formed in areas that were inundated before the flood alleviation and drainage, i.e. historically excess water inundated areas. At the same time, there is a significant proportion (43.91%) of excess water that have no historical history, i.e. they form in areas that were not regularly or intermittently covered by water prior to river regulation and flood management.

As the degree of vulnerability to excess water increases, the proportion of historically inundated areas increases in proportion. On a national scale, 77.27% of areas at high risk

of inundation, 66.24% of areas at medium risk of inundation, 59.51% of areas at low risk of inundation and 51.01% of areas at low risk of inundation are historically excess water inundated.

<u>T4</u>: Using spatial data analysis, I have demonstrated that the excess water inundated areas are of high conservation value, they are valuable wetlands and therefore a significant part of them is protected. On a national average, about 41.87% of them are protected as natural areas or under other categories of areas that contribute to the conservation of our landscape and natural heritage.

Areas exposed to exces water protected as protected areas and other areas of landscape and natural heritage conservation importance account for almost 20% of Hungary's areas of nature and landscape conservation importance. This is even more pronounced in the lowlands, where it is twice the national rate (almost 40%).

The protection of excess water inundated areas exceeds the national protection rates in almost all protection categories and in aggregate, both for protected areas and for areas protected under other categories of areas contributing to the conservation of landscape and natural heritage. The distribution of these areas in the lowlands is similar to the national one. The proportion of excess water wetlands protected is high in the categories of ex lege protected saline lakes and ex lege protected wetlands (twice the national average), both nationally and in the lowlands. For National Parks and Biosphere Reserves, the proportion of excess water in the Great Plain is well above the reference value. The distribution of areas under protection in the other categories of areas contributing to the conservation of landscape and natural heritage is higher in excess water inundated areas than

in the total proportion of protected natural areas. 41.76% of the excess water inundated areas are covered by other sites of landscape and natural heritage conservation, while 13.15% are protected natural areas.

Almost two thirds of the ex lege protected saline lakes are located in areas affected by excess water. Almost a third of the country's ex lege protected wetlands, Ramsar sites and Biosphere Reserves are also excess water. Nearly a quarter of national parks and Natura 2000 special bird protection areas are excess water inundated areas. In the vast majority of the protected categories analysed in the Great Plain (national parks, ex lege protected salt lakes, ex lege protected wetlands, National Ecological Network core area, Natura 2000 sites, Ramsar sites) almost 50% of the protected areas are excess water inundated areas.

T5: As the frequency of excess water inundation increases, the proportion of areas exposed to excess water protected increases.

On a national scale, approximately 62.28% of the areas classified as high excess water inundation, 50.63% of the areas classified as medium excess water inundation, 45.06% of the areas classified as semi-low excess water inundation and 37.28% of the areas classified as low excess water inundation are protected or in other categories of areas that contribute to the conservation of landscape and natural heritage.

T6: The majority of the excess water inundated areas covered by sites of nature and landscape importance are historically excess water inundated areas.

As the frequency of excess water inundation increases, the proportion of historically inundated areas protected increases

also. Nationally, 63.57% of historically inundated areas with high excess water inundation frequency, 51.69% of areas with medium excess water inundation frequency, 47.54% of areas with semi-low excess water inundation frequency and 44.10% of areas with low excess water inundation frequency are areas of nature and landscape conservation importance.

T7: Excess water inundated areas are of major landscape importance in the lowland areas of the country as areas under intermittent water cover. Their role in shaping landscape character is primarily local, where their periodic presence has aesthetic value-enhancing ("landscape enrichment") and development-limiting effects.

The national share of excess water inundated areas covered by the landscape protection zone is 38.37% (slightly below the national average). The share of excess water inundated areas covered by the lowland landscape protection zone (38.33%) exceeds the share of landscape protection areas in the whole of the lowland (30.16%). Likewise, the proportion of excess water flood-prone areas (41.02%) in the Little Plain landscape protection zone is significantly higher than the proportion of landscape protection zones in the whole of the Little Plain (30.58%). As the degree of vulnerability to excess water inundation increases, the proportion of excess water inundated areas in the landscape protection zone increases. Areas exposed to excess water are typically (38.8%) found in field-dominated, homogeneous lowland landscape character types. Only 9.39% of the excess water inundated areas affect areas classified as water-dominated or water-influenced landscape character types. By restricting or influencing development, they also have a local impact on landscape character and thus contribute to the preservation of the character of the landscape.

<u>T8</u>: Based on a national and sample area spatial analysis of land use, I found that a significant proportion (more than 80%) of the excess water inundated areas are poor or medium quality arable land, which are cultivated as arable land despite the periodic surplus of water, and therefore a revision of the land use class of these areas is justified.

In Hungary, 58.52% of the exces water inundated areas are used as arable land and 18.80% as grassland. Only 9.79% of these areas are arable land with good or excellent soil quality, typically with low or low flood risk. Arable land with excellent soil quality accounts for 5.87% of the excess water meadow area and arable land with good soil quality for 3.92% of the excess water meadow area.

<u>T9</u>: I have developed a complex landscape-scale indicator system and assessment procedure to identify target areas for adaptive excess water management. The results of my research suggest that a combined database of historically excess water inundated areas with sites of nature conservation and landscape importance, and arable land with poor or moderate soil conditions can be used as a basis for identifying suitable areas for land-use change. Using these indicators, the eight scenarios I have developed provide a basis for land-use change or wetland conversion of at least 157 km^2 and up to 7638 km^2 of poor to medium quality excess water inundated areas.

4. CONCLUSIONS AND RECOMMENDATIONS

Due to its specific natural geography, Hungary is characterised by the presence of surface and groundwater, which has been of great ecological, strategic and economic importance throughout the country's millennial history. Prior to the de-flooding and water management works of the 18th and 19th centuries, a significant part of the country was periodically or regularly covered by water. These waterways made the Carpathian Basin fertile and thus particularly well suited to agricultural cultivation. As a result of socio-economic development and water management, the former landscape structure has changed over time and the extent of water-covered areas has now been reduced by approximately half. Water-related research, both surface and underground, has always been a dominant theme in Hungary, but thanks to our large rivers, the focus has been and still is on flood management and protection. Not surprisingly, given that the safety of life and property has become a high priority at national, societal and individual levels. As excess water as a phenomenon only emerged after the water regulations, research on it and the concept of excess water was not seen until the early 1900s. Many studies consider excess water as a new, intermittent water resource created as a consequence of water regulation works. The diversity in the definition of excess water demonstrates that it is a very complex, interdisciplinary subject. Its development is also the result of a complex process in which natural conditions and anthropogenic influences are combined. Although there is (are) an existing, formal definition(s) of excess water, accepted by the water profession, none of them can be considered as complete. Today's climate change trends and increasing weather extremes are significantly modifying the

results of models based on decades of experience, and hence the interpretation of excess water.

A shift in an approach has already begun across the board, including in water management, and is summarised in the short and long-term objectives of sectoral strategies. Emphasis on a landscape-scale and value-based approach, ensuring sustainable use of landscapes for both climate resilience and water resource management, and ensuring functional-ecological and aesthetic benefits, is of particular importance. Adaptation is one of the tools to achieve this.

Areas affected by excess water are an active part of the blue and green infrastructure network through intermittent water surfaces, but have not yet been explicitly assessed on a value-based basis. Strategies, higher-level plans and regulations address the role of excess water in water retention in principle, but do not provide a methodology for the designation of intervention areas and there are only a few examples of implementation in Hungary (e.g. the excess water reservoir in Rákócziújfalu under the LIFE-MICACC project).

P1. A joint understanding of excess water and blue-green infrastructure needs to be introduced in sectoral strategies and, in the long term, in the legislative system.

In the existing strategies reviewed in the research, excess water is partly described as a threat and partly as an opportunity (landscape potential). Blue and green infrastructure, with a clearly positive, ecological approach, is currently still negligible in strategies that set out a vision for the future at landscape level. There are as yet no examples of the two concepts (excess water and blue-green infrastructure) being understood together and linked, with areas affected by

excess water forming an active part of blue and green infrastructure, either in strategies or in the domestic legal system. The ecologically positive nature of excess water is not identified in legislation, and therefore a combined understanding of excess water and blue-green infrastructure needs to be introduced in sectoral strategies and, in the longer term, in the legal system. Although the strategies summarise the development objectives and identify planning aspects and directions, the implementation and regulatory regime is represented by the legal acts (laws, implementing regulations, etc.). It is therefore appropriate that the definition of excess water in legislation (and in technical material) and the approach to excess water should change towards new, adaptive approaches that are being reinforced by the impacts of climate change.

P2. I propose to include the designation of areas suitable for water retention in land-use and town-planning plans.

The spatial plans, and in particular the town and country plans which regulate the development of a given area or municipality, currently provide little guidance on the designation of areas suitable for water retention or the management of areas at risk of excess water. Areas regularly subject to excess water inundation are included in almost all but a few county plans. At the municipal scale, these areas are mostly defined by adapting the higher level plans, which are basically relevant for the directions of expansion of grey infrastructure (land-use constraints). At the local level, one of the most effective theoretical and planning guidelines with practical utility could be the zoning of areas suitable for periodic water retention, based on the areas affected by

excess water and the indicators or scenarios developed in the research. In this way, it is proposed to establish, as an element of the planning toolbox, a zone at municipal level that best takes into account local conditions and effectively reflects the need to mitigate the negative effects of climate change.

P3. I propose to integrate the nature and landscape conservation significance of areas affected by excess water into the specialised curricula of excess water-related subjects, and thereby renew the definition of excess water.

The definitions of excess water currently in force and adopted are mainly definitions of its formation, which need to be supplemented by integrating the ecological aspects also reflected in the policy strategies. Most of the research on excess water in recent decades has focused mainly on its damaging role, but its value and seasonal water resources are now being increasingly appreciated. My research has demonstrated the landscape value of areas affected by excess water, which can be integrated into the scientific and awareness-raising curricula of the various disciplines, in particular the water sector and agriculture, which are most relevant to the topic, in order to change the negative perception of excess water.

P4. Local level analysis of sites suitable for land use change in areas affected by excess water, additional assessments from ecological and economical point of view.

The sites suitable for land-use change in areas affected by excess water were identified and defined on a national scale by means of spatial data analysis of the databases at my

disposal. However, the delimitation and local adaptation of all these areas at the export level is possible locally by integrating further analyses. There are a number of natural (e.g. micro relief), anthropogenic (e.g. existing sewer network, established production structure) and regulatory factors (e.g. land structure, ownership) that influence the suitability of a given area for land use change, which cannot be determined within the scope of this research or on a national scale, and therefore require spatial interpretation of local knowledge for the implementation of adaptive inland water management.

P5. I propose to implement land-use change in area affected by excess water in defined project area(s) and monitor the results in the short and long term.

My research has identified excess water protection sections where land use change is justified from a landscape conservation point of view. The additional analyses and design at the design level, as described in Proposal 4, have resulted in the identification of areas that can be effectively designated for land-use change and the interventions needed to implement them as a means of adaptive excess water management. After the land use change has been implemented, the area concerned should be monitored continuously from both a functional and an ecological point of view, so that the short- and long-term effects can provide additional information for adaptation on a national scale and so that any necessary adjustments or new indicators can be defined for other areas.

5. PUBLICATIONS CONNECTED TO THE TOPIC

Journal articles

1. Filepné Kovács Krisztina, Varga Dalma, Kukulska-Kozieł Anita, Cegielska Katarzyna, Noszczyk Tomasz, Husar Milan, Iváncsics Vera, Ondrejička Vladimir, Valánszki István (2024): Policy instruments as a trigger for urban sprawl deceleration: monitoring the stability and transformations of green areas. In: *Scientific Reports* 14, paper: 2666, 15 p.

2. Varga Dalma Erzsébet, Hubayné Horváth Nóra, Módosné Bugyi Ildikó (2020): Rába és Sebes-Körös menti belvízjárta területek szerepe a védett területek rendszerében. In: *4D Tájépítészeti és Kertművészeti Folyóirat*. 57. sz., Budapest. pp. 58-69.

3. Dalma Varga, Nóra Hubayné Horváth (2021): Methodological Issues for a Landscape-Changing Analysis in Adaptive Excess Water Management. In: *Journal of Agricultural Science and Technology*. pp. 65-74.

Conference publications

4. Varga Dalma Erzsébet, Hubayné Horváth Nóra (2022): Módszertan a belvíz, a zöldinfrastruktúra és az ökoszisztéma-szolgáltatás kifejezések előfordulási gyakoriságának elemzéséhez jogszabályokban, stratégiákban. In: Fodor Marietta, Bodor-Pesti Péter, Deák Tamás (szerk.): *A Lippay János – Ormos Imre – Vas Károly (LOV) Tudományos Ülésszak tanulmányai*. Magyar Agrár- és Élettudományi Egyetem, Budai Campus, Budapest. pp. 762-768.

5. Varga Dalma (2019): A belvíz fogalom értelmezései a hazai és nemzetközi szakirodalmakban. In: Fodor Marietta, Bodor Péter (szerk.): *SZIENtific meeting for young*

researchers - Ifjú Tehetségek Találkozója (ITT). Szent István Egyetem, Gödöllő. pp. 313-316.

6. Varga Dalma, Hubayné Horváth Nóra, Módosné Bugyi Ildikó (2019): A zöldinfrastruktúra hálózat történeti változásainak jellegzetességei belvízjárta területeken. In: Fazekas István, Lázár István (szerk.): *Tájak működése és arculata.* MTA DTB Földtudományi Szakbizottság, Debrecen. pp. 67-73.

7. Varga Dalma (2019): Tájtörténeti elemzések belvízzel érintett területeken. In: Módosné Bugyi Ildikó, Csima Péter, Hanyecz Katalin (szerk.): *A táj változásai a Kárpát-medencében: XII. tájtörténeti tudományos konferencia kiadványa: Füleky György emlékkonferencia*. Érd. pp. 184-188.

8. Varga Dalma (2019): Methodological issues of landscape-transforming analysis in adaptive inland water management. In: Ing. Monika Tóthová, doc., Ing. Judita Bystrická, Ing. Kristína Candráková, Mgr., Dominik Hollý (szerk.): Proceedings of Scientific Conference of PhD Students of FAFR, FBFS and FHLE SUA in Nitra with international participation. Slovak University of Agriculture in Nitra, Szlovákia pp. 52.

Book excerpt

9. Priváczki-Juhászné Hajdu Zsuzsanna, Varga Dalma, Bíró Tibor, Hubayné Horváth Nóra (2019): Tájhasználati változások hatása belvízvédelmi létesítményekre. In: Szlávik, Lajos (szerk.): Magyar Hidrológiai Társaság XXXVII. Országos Vándorgyűlés. Magyar Hidrológiai Társaság (MHT), Budapest. ISBN: 9789638172402. 20 p.

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