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NATURAL FLOOD PROTECTION MEASURES

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Abstract. The paper addresses nature based measures as an alternative and sustainable approach to flood protection. The aim is to analyse the catchment area of the selected location and propose measures that help reduce flood risk by increasing the retention capacity of the landscape and supporting natural processes in the landscape environment. The theoretical part presents the concept of nature-based solutions, their advantages over technical interventions, as well as examples from practice. The next chapter presents the realized measures in EU countries as urban parks, wetlands, river restoration, floodplain rehabilitation etc. Nature based measures increase biodiversity in the landscape as well as in the urban areas and contribute to climate change impacts mitigation as well as overall improving of the local microclimate.
Keywords: natural water retention measures, flood protection, flood risk

1 INTRODUCTION

Urbanization of built-up areas has increased significantly over the past century due to the increasing urban population. The physical expansion of urban areas is even faster than the expansion of urban populations due to the occupation of adjacent suburban areas, which are motivated by lower living costs than those experienced in city centers, easy access to transportation, and the demand for improved quality of life (Ferreira et al., 2019). The combined effects of more frequent extreme events and the development of urban settlements have resulted in an increasing incidence of urban flooding. Furthermore, the removal of vegetation and the expansion of impervious surfaces in built-up areas disrupt the hydrological cycle, i.e., reduce precipitation capture, evapotranspiration, and infiltration, thereby increasing surface water runoff (Shuster et al., 2005). Flooding is the most widespread natural disaster, accounting for 47% of all weather-related disasters, and one of the most costly in terms of socio-economic damage (UN DRR CRED, 2015). In Europe, floods account for up to 33% of natural events recorded between 1900 and 2019, ensuring a constant challenge in addressing flood events (CRED, 2019).

Floods are a natural phenomenon that significantly shapes the landscape and water regimes, but they also represent one of the most widespread and destructive natural disasters. As a result of climate change, more frequent extreme precipitation events, as well as inappropriate land management, their occurrence and intensity have been increasing in recent decades. Floods occur repeatedly in Slovakia, and their impacts affect not only natural ecosystems, but also the population, infrastructure and economy. Traditional technical solutions – such as the construction of dams, concrete dikes or flow regulation – have been used for flood protection for a long time, but they are increasingly proving to be insufficiently flexible and sustainable, especially in terms of long-term 6adaptation to changing climate conditions.

In recent years, alternative approaches that are based on natural processes in the landscape have therefore come to the fore. These so-called nature-based measures (Nature-Based Solutions – NBS) represent a comprehensive method of landscape management that uses greenery and water as tools to mitigate the consequences of extreme weather fluctuations. NBS include a wide range of measures, such as the restoration of floodplains, wetlands and floodplain forests, the revitalization of watercourses, slowing down runoff from the soil basin, the construction of dry polders, but also changes in agricultural and forestry management. In addition to the flood protection function, these solutions also have a positive impact on biodiversity, water quality, microclimate, soil structure and the overall resilience of the landscape.

The paper analyzes the significance and use of nature-based measures in flood protection, focusing on defining basic concepts, presenting individual types of nature-based measures and their benefits in landscape and water management, and examples of solutions abroad. It also studies a selected river basin, including its hydrological, geomorphological, and landscape characteristics, with the aim of proposing specific flood control measures using nature-based approaches. The aim is to highlight their effectiveness, ecological benefits, and possibilities for implementation in practice.

2 METHODS

Currently, around 12% of the European population lives in areas potentially prone to river flooding, although in many cases cities have flood barriers

Intensified precipitation events in the future may also lead to surface water (pluvial water) flooding. This phenomenon is particularly pronounced in highly impermeable urban areas where the drainage system cannot cope with the excess water.

An index of extreme precipitation days has been developed to monitor the development of precipitation events. This index is a relevant tool for agriculture, water management, transport and the urban sector. It is based on daily precipitation and indicates the number of days per year with daily precipitation totals exceeding the 95th percentile threshold of rainy days of the reference period.

Figure 1 shows the period from 1981 to 2010, where we can see the individual values for European countries. The index values in the Slovak Republic range from 6 to 8 extreme precipitation days. The highest value of 12 is achieved in Ireland and the lowest value of 3 in Spain.

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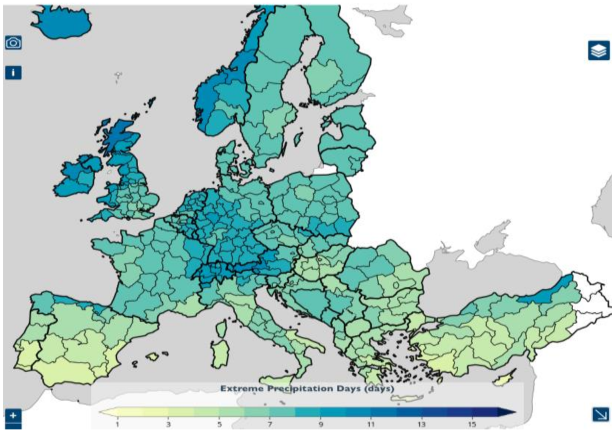

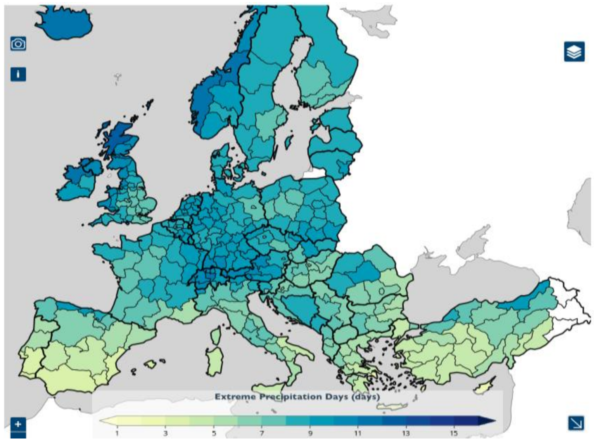

Figure 1. Extreme precipitation days (1981 - 2010)**Figure 2.** Extreme precipitation days (2011 - 2040)

For comparison, Figure 2 shows the period from 2011, which shows the expected development of extreme precipitation days until 2040. The values for the Slovak Republic have increased and range from 7 to 9.

Based on the information resulting from Figures 1 and 2, we can conclude that precipitation activity will increase over time, which may result in an increase in the number of floods in the Slovak Republic.

Figure 3 shows an analysis by the EEA agency, which shows the percentages of the population of individual European countries at risk of river flooding. In total, 12.1% of the population lives in areas with a high incidence of flooding. The most at-risk population is in the Netherlands, where it is as much as 23.4% of the total. The Slovak Republic is in second place with 21.7%, which, based on the latest population census from 2021, represents 1,182,491 at-risk residents.

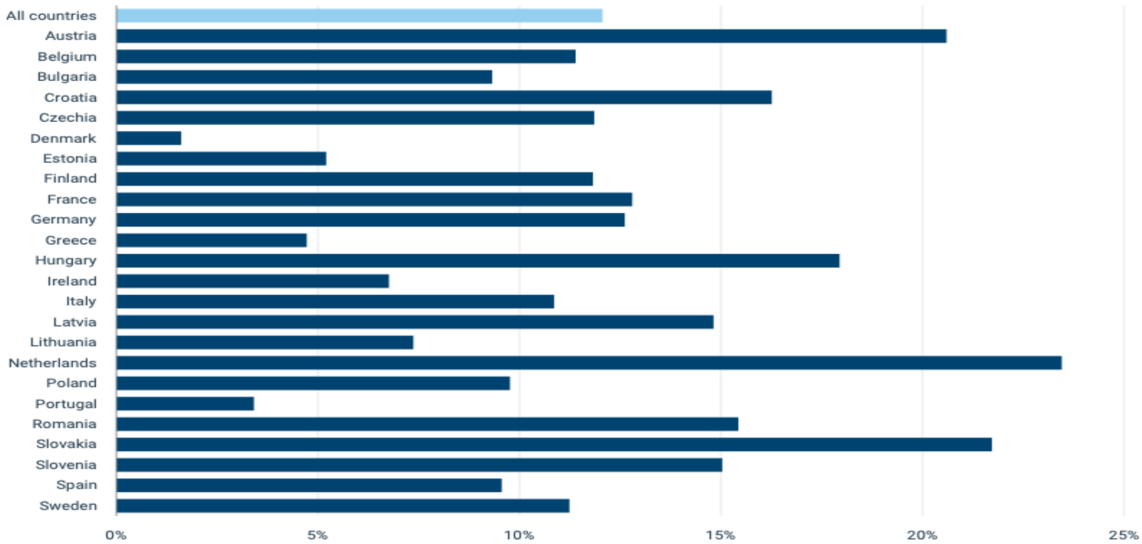

Figure 3. Percentage of the population at risk of floods

2.1 Causes of floods

Hydrological causes

Hydrological causes of floods include intense and prolonged rainfall that saturates the soil and increases surface runoff, as well as rapid melting of snow and ice during sudden warming or rain on snow cover. Insufficient water absorption by soil that is saturated or has low permeability also contributes to floods. Another factor is the rise in groundwater levels during prolonged rainfall. Obstructions in watercourses, such as silt or ice dams, can restrict the flow of water, causing it to overflow its channel. These factors often act together to increase the risk of floods.

Geographic and terrain factors

In higher elevations, the soil composition of mountainous areas is less permeable, which limits the natural drainage of rainwater and the loss of forest cover, resulting in increased water flow in stream and river beds during periods of intense rainfall.

Deforestation causes an increase in water flow by 4% to 5% during all periods monitored. Figure 4 shows the impact of deforestation on floods, which leads to a decrease in the soil's ability to absorb water and the river overflows its channel.

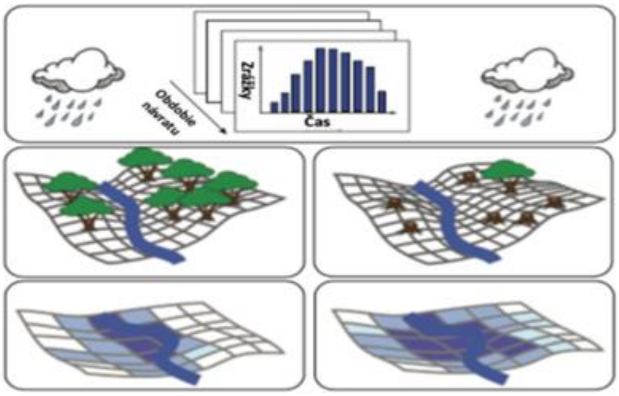

Figure 4. Modeling of floods caused by deforestation

Technical causes

Flood risk is significantly influenced by the current state of watercourses, their modifications and the capacity of floodplains. The distribution and technical condition of structures in the riverbeds also plays an important role, especially bridges, which can significantly affect the ability of the stream to drain water due to their construction and flow rate. The technical and maintenance condition of protective dikes is also important, as is the functionality of natural and artificial drainage elements, such as ditches and ditches. Another significant factor that can increase the risk of floods is the occurrence of unsecured washed-out material in the river basin, which can be carried away by water and cause blockage of profiles or a reduction in the flow capacity of the stream.

Climate factors

Climate change directly affects the water cycle by altering precipitation patterns, leading to floods, droughts and water shortages. The climate in Europe is changing rapidly and the extreme events that have occurred in recent years are a harbinger of what is to come with future global warming.

Urbanisation

Currently, urbanisation is one of the most significant factors influencing flood events. Deforestation and construction without taking into account natural drainage are intensifying this problem and result in limited permeability of rainwater during intense rainfall events. This increases the inflow of water into stream and river beds.

3 RESULTS

Traditional vs. Nature-based Flood Control Measures

The response to the exposure of communities to natural hazards has traditionally relied on engineering infrastructures. They are built, engineered, and physical structures, often made of concrete or other durable materials, that mediate between the human-built system and the variability of the weather and climate system. These include dams, sluices, seawalls, and breakwaters to protect rivers and coastlines from flooding, drainage systems for stormwater management such as storm drains, retention ponds, and air conditioning or cooling centers to manage extreme heat. Engineering approaches largely ignore or replace the functions of biophysical systems. Through the lens of SETs (Social – ecological – technological systems), these approaches tend to be entirely in the technological domain with little input from the ecological domain.

Traditional infrastructures provide an important means of adapting to biophysical challenges, including climate-induced hazards and extreme events, are often expensive to install and maintain, have long-term protective effects on ecosystems, tend to have low flexibility, and when they fail, can cause catastrophic impacts on the social and ecological domains of urban SETs. Nevertheless, in some cases, grey infrastructures may still be necessary. For example, Khazai et al. (2007) evaluated the role and effectiveness of coastal structures in reducing damage to coastal communities from tsunamis and storm surges caused by cyclones, hurricanes, and typhoons, finding that concrete seawalls are the most robust protection against various types of storm surges.

Nature-based flood protection measures

Nature-based solutions (NBS) describe the development and use of nature and natural processes to address diverse socio-environmental challenges. These issues include climate change mitigation and adaptation, human security issues such as water and food security, and disaster risk reduction. The aim is for resilient ecosystems to provide solutions that benefit both society and biodiversity. The 2019 UN Climate Action Summit highlighted nature-based solutions as an effective method to combat climate change. For example, natural systems for adapting to climate change can include natural flood management, restoring natural coastal protection, and providing local cooling.

The concept of NBS is related to the concepts of ecological engineering and ecosystem adaptation. NBS is also conceptually related to the practice of ecological restoration. A sustainable management approach is a key aspect of the development and implementation of NBS. Rather than focusing on solutions "at the end of the pipe" or "at the point of the problem" as is the case with many traditional infrastructure solutions, sustainable urban drainage systems focus on slowing down and reducing the amount of surface water in an area to minimize the risk of flooding.

As a solution for NBS, the following measures are used to address flooding:

Intensive green roofs are composed of lush vegetation and are based on a nutrient-rich and deep substrate. They can withstand large plants and even conventional lawns, therefore intensive roofs generally require relatively high maintenance. Extensive green roofs (Fig. 5) are usually characterized by a shallow growing medium and are self-sufficient. They consist of low plantings that cover the entire roof area.

Urban parks (Fig. 6), forests and other green spaces in cities can cool temperatures by providing shade and increasing water evaporation. In addition, urban parks, forests and other green spaces provide a number of secondary benefits, such as mitigating surface runoff and thus reducing the risk of flooding, regulating air quality and providing recreational opportunities.

Figure 5. Example of a green roof solution

Figure 6. Example of a solution for urban parks and forests

Wetlands (Fig. 7) can be described as "transitional areas between terrestrial and open water systems". Wetlands are among the most productive environments in the world and are particularly important for providing water-related ecosystem services, including improving water quality, recharging groundwater, and regulating water flow and flooding. Although wetlands can provide countless benefits, wetlands and their quality are declining due to increasing urbanization.

Floodplains (Fig. 8) are low-lying areas adjacent to rivers that provide key ecosystem services including flood protection and rainwater retention. Many floodplain ecosystems in Europe have been significantly modified by agricultural development due to their fertile soil or have been separated from the river by dams and other hard engineering structures designed to control river flow.

Figure 7. Example of wetland maintenance

Figure 8. Example of a floodplain

In the past, riverbeds were modified by artificially reconstructing their bottom and banks by adding concrete or large stones to prevent floods, support agriculture and enable navigation. However, these modifications led to changes in the river flow and reduced water travel times. River restoration (Fig. 9) involves the removal of some inert and concrete structures and their replacement with vegetation. Such interventions could positively influence erosion processes, restore biodiversity and mitigate flood risk.

Seasonal streams (Fig. 10) are rivers in which water stops flowing at certain times in some places. Such streams provide flood protection and high levels of groundwater recharge and infiltration, but their abundance, distribution and flow regimes are altered by water abstraction, climate change and transfers between basins. Management should focus on restoring lateral connections and diversifying flows. This has a high potential to mitigate river floods and increase groundwater recharge.

Figure 9. Example of river restoration

Figure 10. Example of seasonal flow restoration

Re-meandering means restoring the "curved" course of a river by creating new meanders and reconnecting old severed branches. Severed meanders may have disappeared completely or may exist as dead-arm lakes, which are U-shaped lakes. In the former case, re-meandering should be based on old maps to reveal the original riverbed. In the case of dead-arms, the barriers between the beds should be broken into two water bodies, i.e. the dead-arm and the river. Meanders (Fig. 11) slow down the flow of water in a river and increase the volume of water that the river can carry.

Figure 11. Example of comparing the original riverbed with the current one

Figure 12. Example of a polder solution

Polders (Fig. 12) are reservoirs bounded by embankments (dykes) that form an artificial hydrological unit. They are most important in the lower reaches of larger rivers and coastal areas. Unlike retention areas, flooding can be controlled in polders.

The creation or maintenance of floodplain and riparian forests (Fig. 13) can provide significant water quality and flood protection benefits. Trees use more water than shorter vegetation types, mainly because their thicker roots capture rainwater. Forest soils can retain and delay rainwater that flows into streams and rivers because of their more open structures, which lead to higher infiltration rates. The greatest potential of floodplain and riparian forests to delay the advance of flood flows comes from the hydraulic roughness created by trees, shrubs, and deadwood in the river and on the floodplain.

Figure 13. Example of maintaining floodplain/riparian forests

4 CONLUSIONS

The use and implementation of NBS as a means of flood risk management needs to be addressed individually based on local socio-economic and environmental factors. The type of NBS used is also determined by the ecosystem in which it is implemented. However, NBS often restrict human activity or require a change in land use, e.g. from agricultural land to forest. They may also require more space than traditional (grey) infrastructure. Land is undeniably important for nature-based measures. The additional need for land may include addressing the protection of private property.

Private property is protected by international human rights instruments, in particular Article 1 of Protocol No. 1 to the European Convention on Human Rights and Fundamental Freedoms. As a result, any involvement of a state authority in private property should comply with the standards set out in the case law of the ECHR (European court of human rights).

The European Union actively supports the NBS in its research agenda and policies. Reference to the NBS can be found in several important EU strategies, such as the EU Biodiversity Strategy to 2030, the EU Adaptation Strategy, the EU Green Infrastructure Strategy or the EU Action Plan on the Sendai Framework.

Scenarios for nature-based measures

The effectiveness of small-scale nature-based measures (NBS) is often evaluated in relation to reducing runoff volume and peak flow during flood events. Model results show that small-scale NBS are particularly effective for low-intensity events, where they can significantly reduce runoff volume and peak flow. However, their effectiveness decreases with increasing return period and flood intensity.

The analysis of large-scale nature-based measures (NBS) for flood mitigation often uses combined modelling to capture the dynamics of watercourses and floodplains. These approaches typically work with detailed terrain topography and hydrological parameters, which allow for accurate flood risk assessment. The models combine different simulation dimensions to account for the behaviour of water in both rivers and floodplains.

These simulations show that large-scale NBS can significantly reduce floodwater volumes during extreme flood events. However, reducing river flows is often not enough to solve the problems of local flash floods, which can continue to cause damage, especially in urban areas. These findings highlight the need to combine large-scale NBS with improvements to local drainage systems or other measures, such as small-scale nature-based solutions, to ensure comprehensive flood protection.

The evaluation of the effectiveness of flood protection measures uses a combination of different models that allow the analysis of the impacts of large-scale and small-scale nature-based measures (NBS) in conjunction with traditional technical measures (so-called grey infrastructure). Regional models focus on the assessment of the effects of large-scale NBS and provide boundary conditions for local models that are designed to analyze small-scale NBS and grey infrastructure. This approach allows the evaluation of combined solutions (so-called hybrid measures) for specific flood events.

The results show that hybrid solutions represent the most effective strategy for flood mitigation. Large-scale NBS can reduce high flows in large watercourses, while local measures, such as small-scale NBS and improvements in drainage systems, effectively address local flash floods. These systems can help to retain excess water in drainage channels and redirect it to multifunctional retention areas.

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REFERENCES

Ferreira, C.S.S, Kalantari, Z., Salvati, L., Canfora, L., Zambon, I., Walsh, R.P.D: Urban areas. In: Pereira P (ed) Advances in chemical pollution, environmental management and protection, vol. 4, Kapitola 6, 2019, ISBN: 9780128164150, Elsevier, Amsterdam, s 207–249

Shuster, W.D., Bonta, J., Thurston, H., Warnemuende, E., Smith, D.R.: Impacts of impervious

surface on watershed hydrology, 2005: In: Urban Water, J 2(4): s 263–275
The United Nations Office for Disaster Risk Reduction and Centre for research on the Epidemiology of Disaster (UN DRR CRED): The human cost of weather related disasters 1995-2015, 22015, https://www.unisdr.org/2015/docs/climatechange/COP21_WeatherDisastersReport_2015_FINAL.pdf
Centre for Research on the Epidemiology of Disaster (CRED): Natural disasters 2019, 2020, https://www.cred.be/sites/default/files/adsr_2019.pdf
European Environment Agency: *Responding to climate change impacts on human health in Europe: focus on floods, droughts and water quality* [online]. Luxembursko: EEA, 2024. Dostupné na internete: https://www.eea.europa.eu/en/analysis/publications/responding-to-climate-change-impacts. ISBN 978-92-9480-635-2
Data collected on behalf of the Copernicus Climate Change Service (C3S), Available online: https://climate-adapt.eea.europa.eu/en/metadata/indicators/extreme-precipitation-days
Characteristics of floods, Available on the Internet: https://www.svp.sk/sk
Far, L.; Nikookar, M.; Rayegan, R.: The role of landscape planning in reducing damages caused by flood (case study: Nekaroud, Iran) International Journal of Disaster Risk Reduction [online]. Tehran: Shaid Beheshti University, 2024., Dostupné na internete: https://doi.org/10.1016/j.ijdrr.2024.104721. „Preložené nástrojom [CHAT GPT: https://chatgpt.com]
Lallemant, D. et al.: Nature-based solutions for flood risk reduction: A probabilistic modeling framework [online]. Singapore: Technologická univerzita Nanjang, 2021. Dostupné na internete: https://doi.org/10.1016/j.oneear.2021.08.010 „Preložené nástrojom [CHAT GPT: https://chatgpt.com]
Depietri, Y.; Mcphearson, T.: Integrating the Grey, Green, and Blue in Cities: Nature-Based Solutions for Climate Change Adaptation and Risk Reduction [online]. New York: The New School, 2017.
Debele, E. S. et al.: Nature-based solutions can help reduce the impact of natural hazards: A global analysis of NBS case studies [online]. Guildfort:University of Surrey
City parks. Available online: https://pereny.eu/preziji-mestske-parky/
Restoration and management of wetlands. Available online: https://sita.sk/nasvidiek/mokrade-su-domovom-pre-vyse-stotisic-druhov-organizmov-vyznamne-pomahaju-v-boji-proti-zmenam-klimy/
Restoration and management of floodplains. Available online: https://slovakia.panda.org/?6660916/Rieka-Morava-a-jej-zaplavove-luky-su-vynimocne-Chysta-sa-obnova-povodnych-brehov-a-meandrov#
Restoration of rivers. Available online: https://malacky.sk/do-rudavy-sa-vracia-zivot/
Restoration of seasonal flows. Available on the Internet: https://vedator.space/meandre-starych-riek/
Renaturalization of polders. Available on the Internet: https://www.voda-portal.sk/Dokument/suchy-polder-svp-protipovodnova-ochrana-102190.aspx
Creation of floodplain forests. Available on the Internet: https://bratislavskykraj.sk/tag/luzne-lesy/
Bogdzevič, K.: Floods and nature-based solutions. A call for a legal approach, Current Opinion in Environmental Science & Health [online]. Litva: Mykolas Romeris University, 2023. Dostupné na internete: https://doi.org/10.1016/j.coesh.2023.100521. „Preložené nástrojom [CHAT GPT: https://chatgpt.com]
Opperman, J.; Galloway, G.E.: Nature-based solutions for managing rising flood risk and delivering multiple benefits [online]. Washington DC, USA: Global Science, 2022. Dostupné na internete: https://doi.org/10.1016/j.oneear.2022.04.012. „Preložené nástrojom [CHAT GPT: https://chatgpt.com]
Výleta, R.; Kohnová, S.; Valent, P.: Solved problems in hydrology I. - River basin, precipitation, flow rates and hydrological balance [online]. Bratislava: STU, SvF, 2018. [cit. 2025-02-23].

Available on the Internet: https://www.kvhk.sk/dokumenty/predmety_katedry/ucebne_texty/hydrologia_-_riesene_ulohy_i.pdf . ISBN 978-80-227-4887-2
Kaletová, T.: *Forestry melioration* [online]. Nitra: SPU, FZKI, 2017. Available on the Internet: http://www.slpk.sk/eldo/2018/dl/9788055216942.pdf. ISBN 978-80-552-1694-2
Šutý, P.: *Building wetlands in forests – Technical and biotechnical measures* [online]. Oščadnica: 2023. Available on the Internet: https://www.zilinskazupa.sk/files/3-p-suty-ekostav-mokrade.pdf