

AKADÉMIAI KIADÓ

# Local and catchment-scale effects of water retention measures at Lake Velence

Attila Kalman<sup>1,2\*</sup>  and Katalin Bene<sup>1,2</sup>

Pollack Periodica •  
An International Journal  
for Engineering and  
Information Sciences

19 (2024) 3, 74–80

DOI:

[10.1556/606.2024.00814](https://doi.org/10.1556/606.2024.00814)

© 2024 The Author(s)

<sup>1</sup> National Laboratory for Water Science and Water Security, Széchenyi István University of Győr, Hungary

<sup>2</sup> Department of Transport Infrastructure and Water Resources Engineering, Faculty of Architecture, Civil and Transportation Engineering, Széchenyi István University, Győr, Hungary

Received: December 31, 2022 • Revised manuscript received: February 1, 2024 • Accepted: March 7, 2024

Published online: May 9, 2024

ORIGINAL RESEARCH  
PAPER



## ABSTRACT

Climate change manifested its adverse impacts last year, with an extreme drought leading to a drastically low water level in Lake Velence, Hungary. Nature-based solutions have the potential to alleviate these impacts locally. While a few initiatives have been implemented in Hungary, widespread adoption of these solutions is expected to be a goal for the more distant future.

This research focuses on one catchment at Lake Velence to evaluate decision-maker's readiness and urban water management infrastructure for broadly implementing nature-based solutions. Methods include delineating the stormwater system and creating a numerical model to evaluate rainfall-runoff processes and the possible impacts of nature-based retentions. Surveys among local mayors were conducted to assess their perception of existing water infrastructures and implementations of nature-based solutions. Its widespread use may become significant, but its effect on the lake's water level remains negligible.

## KEYWORDS

nature-based solutions, sustainability, stakeholder involvement, climate change, irrigation, rainwater retention

## 1. INTRODUCTION

Extreme drought in 2022 illustrated the adverse effects of climate change in Europe and Hungary. The continent's climate is undergoing perceptible changes in the upcoming years, resulting in more extreme weather events. Trends include longer, more frequent heat waves, drought periods, and sudden, heavy rainfalls with higher peak intensities causing flash floods [1]. Therefore, traditional agriculture, natural ecosystems, wetlands, tourism, and living circumstances will face challenges in the drier summers.

With population growth, gray infrastructures spread [2], and the proportion of green space in the settlements decreased. These trends increase the risk of flash floods, runoff, and drought problems. Without intervention, living spaces, ecosystems, and social environments are degrading. While water management becomes more complex and integrated [3, 4], existing gray infrastructures are not suitable for managing the changing demands [5], but Nature-based Solutions (NbS) can do so [6]. They can reduce the negative effects of climate change and have sustainable, positive effects on biodiversity, water retention, irrigation, and well-being [7, 8].

Lake Velence, in Hungary, has become a heavily modified water body. In the 1960s–70s, extensive infrastructure developments (railway, highway) started in the region. Consequently, it has become a frequented tourist area, recreational destination, and livelihood and home for many. The increased human presence caused significant changes in the shoreline, landscape, and water resources. Gray infrastructures were implemented: beaches, campsites, holiday homes, constructed concrete walls, and ripraps replaced the natural shoreline. Gray urban developments replaced the green, natural land cover. Two reservoirs (Zámoly, Pátka) were

\*Corresponding author.

E-mail: [kalman.attila@sze.hu](mailto:kalman.attila@sze.hu)

 AKJournals

built in the upper catchment to regulate the water level in the lake, especially during the dry summer season.

In the 21st century, the region evolved into a suburban hub, attracting numerous residents from nearby major cities, like Budapest and Székesfehérvár to settle around the lake. The onset of the COVID-19 pandemic expedited this trend, resulting in a notable surge in population and consequential alterations to the landscape and land use. As a result, the runoff changed, exacerbating the problems caused by the current drought. Implementing, NbS is a fitting and effective response to address these emerging water management and resource-related issues. Two surveys were undertaken during the first and fourth quarters of 2022 to gauge the area's current state, evaluate water demand, and ascertain the willingness of local stakeholders to embrace NbS practices.

A stable water level in the lake is important in the region because of its deep integration into everyday life. Unfortunately, the water level has decreased dramatically in recent years, primarily attributed to the impact of climate change and land use alterations. The existing two reservoirs fail to compensate for the missing water [9]. The lake reached a negative low water level record (53 cm on 09.23.2022) since official measurements started [10]. The impact is significant. Besides the economic damages, it also causes severe ecological and social tensions and sustainability barriers for the local population and among stakeholders [11]. The current situation and the water management solutions often represent opposing interests. The paper investigates how stakeholder cooperation, and their more comprehensive knowledge may facilitate water-related developments. Secondly, it investigates the implementation effects of NbS locally and in the catchment.

## 2. SITE DESCRIPTION

Lake Velence is located in Hungary (Fig. 1), between 2 major cities: Budapest and Székesfehérvár.

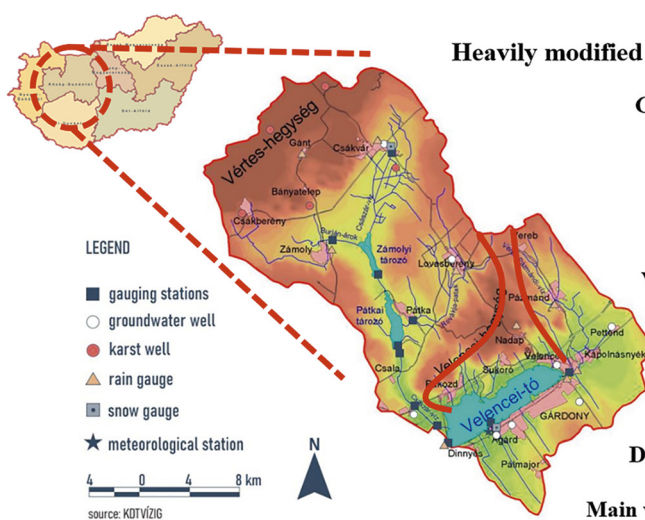


Fig. 1. Catchment of Lake Velence and the investigated sub-catchment (Source: on the basis of [12])

The lake has two regulating water levels: the upper is 170 cm, and the lower is 130 cm (Fig. 2 short and long dashed lines). With an average water depth (140 cm), the total water volume is approx.  $40 \times 10^6 \text{ m}^3$ . The rule of thumb is that one million  $\text{m}^3$  of water volume equals 4 cm of lake water level [13].

Though water levels fluctuate annually and throughout the year - and the lake even dries out with a frequency of centuries for some years - the 35-year trend is decreasing (dotted line in Fig. 2), especially in the last decade. It has been below the lower regulating level for over three years.

Precipitation plays a substantial role in influencing the water level of Lake Velence. Climate change forecasts suggest that the overall annual precipitation will not decrease; instead, there will be shifts in its distribution patterns. The annual average precipitation in the past 20 years was 537.5 mm (lowest in 2011 with 273.7 mm and highest in 2010 with 888.6 mm) with total of 319.6 mm average in 2nd (Q<sub>2</sub>) and 3rd (Q<sub>3</sub>) quarters [15]. The rising average annual

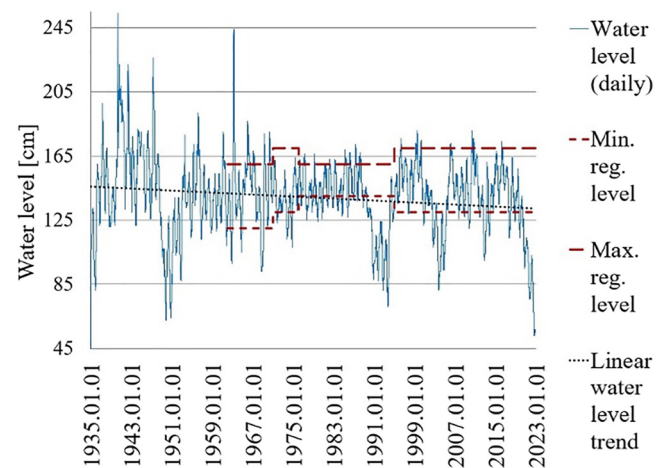


Fig. 2. Change of water level between 1935 and 2022 (Source of data: [14])

### Heavily modified catchment (size: 602.3 km<sup>2</sup>) with 3 main sub-catchments

**Császár-víz (Császár-creek)** – Northern and Western areas with constant water flow, 383 km<sup>2</sup> including 75 km<sup>2</sup> inactive, open karst area and two large reservoirs:

- Zámoly with 4.5 million m<sup>3</sup> storage capacity
- Pátka with 7.85 million m<sup>3</sup> storage capacity

**Vereb-Pázmándi-vízfolyás (Vereb-Pázmánd water flow)** – North-East nearby hilly area, 105 km<sup>2</sup> with 2 sub-catchments

- North-East hilly area, constant water flow (~62 km<sup>2</sup>)
- neighboring Northern area with direct rainfall runoff (~43 km<sup>2</sup> – marked and investigated area near the lake)

**Direct catchment area** – S & S-Eastern flatland (114.3 km<sup>2</sup>)

**Main water body: Lake Velence** (~24.1 km<sup>2</sup> & ~40M m<sup>3</sup>/@140cm)

temperature is leading to increased evaporation from the lake, presenting a negative impact. According to climate models, there is a forecasted 8% rise in evaporation by the mid-21st century compared to the period between 2000 and 2020. The increase in evaporation results in an annual decrease of 7 cm in water level. Consequently, a comprehensive, integrated water management approach at the catchment scale becomes critically important.

The catchment can be divided into three sub-catchments [16]. This paper focuses on the sub-catchment of the Vereb-Pázmánd water flow shown in Fig. 1. This area is 43 km<sup>2</sup>, located near the lake with a direct shore connection. It includes three settlements (Pákozd, Sukoró, Nadap) on the northern hilly shoreside of Lake Velence. Contrary to the declining national population trends (−7% since 1990), the population has grown rapidly in all three settlements and has almost doubled (+88.25%) in the past 30 years [17].

The shifting population dynamics and evolving land use patterns introduce new water-related tasks and challenges. In a small catchment like Lake Velence and in an even smaller sub-catchment like Vereb-Pázmánd, where water deficit is a concern, it is crucial to scrutinize the interaction of water interventions and retention effects at the local, settlement, and catchment scales. Moreover, the impact of climate change renders existing gray infrastructures inadequate for their intended purposes, for example the flash floods and the heat island effect. Addressing these challenges necessitates collaborative efforts across various sectors and stakeholders, including agriculture, tourism, small businesses, forestry, and fishing [18, 19].

### 3. METHODS

This study intends to investigate the possible willingness and effects of implementing NbS in the sub-catchment of Lake Velence. NbS methods – e.g., retention tank, wet pond, retention pond – are sustainable and can provide appropriate, resilient responses [20] by increasing retention capacities and reducing surface runoff [21] in changing circumstances and demands [22].

#### 3.1. Social awareness

Water management problems typically involve diverse stakeholders, many of whom may have limited awareness of global progress [23] and water retention measures. Extensive education and intense social participation [24] are necessary to reduce knowledge gaps and conflicts among stakeholders from the highest decision-making levels to the lowest [25, 26]. Using NbS to mitigate climate change effects will not be effective and sustainable without local stakeholders' collaboration and local government coordination [27, 28].

This research focuses on tracking the evolving willingness to implement NbS in response to increasing awareness. Additionally, it examines the potential water retention effects that their future implementation might have on the lake's water level. The method applied in the study is shown in Fig. 3.

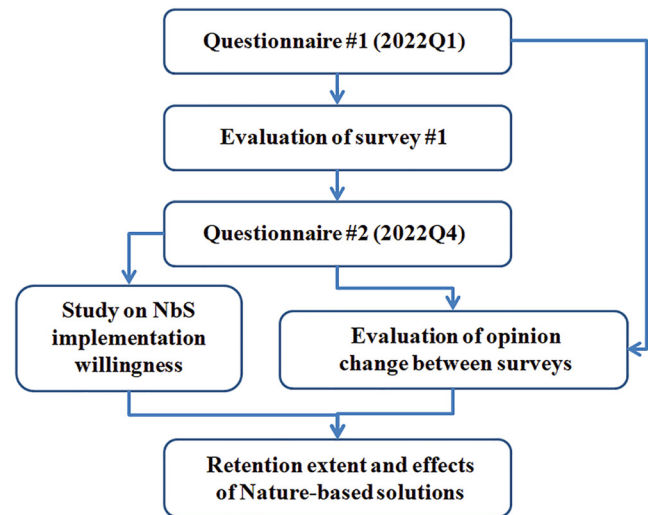


Fig. 3. Method to evaluate social impact in the study

Two questionnaires investigate the support and spread of NbS in three settlements of a sub-catchment with direct runoff (Fig. 1). The surveys were conducted among municipal majors in February 2022 and September-October 2022. Both surveys contained multiple-choice and explanatory questions, details are summarized in Table 1.

The surveys focused on water-related issues. Questions can be grouped into 7 main topics, as it is shown in Fig. 4. The primary topics were similar within the two surveys, but the questions were more detailed in the latter one. A new topic was added to the second questionnaire: public and stakeholder involvement.

The authors developed a method to quantify the REtention Readiness (*RER*) of NbS. *RER* can estimate possible NbS projects and their sizes for the upcoming years in a region and quantify the subjective and objective background of the investigated settlements using the questionnaire result. Eq. (1) uses the results of the surveys to calculate *RER*,

$$RER = \sum_{i=1}^3 IW_i \cdot FIO_i, \quad (1)$$

Implementation Willingness (*IW*) is determined based on the surveys' normalized weighted average (1-5 scale) responses among mayors. The Financial-Infrastructural Opportunity (*FIO*) ratio is between 0 and 100% and is calculated from the available financial resources and present infrastructural status and opportunities. *RER* is a ratio between 0 and 100%, depending on the *IW* of the private and public sectors.

#### 3.2. Water retention

Besides retention readiness, another influencing factor of NbS implementation is the available rainwater for retention. Due to steep hills near the lake's shore, water directly runs off into the lake from this area. Utilizing NbS decreases catchment's runoff and inflow to the lake, which could influence the lake's water level. Despite not implementing NbS for water retention, the lake's water level became exceptionally low in 2022.



Table 1. Summary of conducted surveys among mayors in the sub-catchment

Time of survey	Questions in the survey.	Request method and repetition.	Approached settlements.
February 2022	8 explanatory & 12 multiple-choice questions (true-false or with max. 5 answers).	First invitation and request sent by e-mail. A repeated e-mail request was sent after 2 weeks.	11 settlements in the catchment close to the boundary or physically close to the lake.
September-October 2022	16 explanatory & 43 multiple-choice questions (true-false or with given answers).	First invitation and request sent by e-mail. A repeated request during a personal inquiry and visits.	14 settlements in the catchment, only the northern “karts” region was left out.

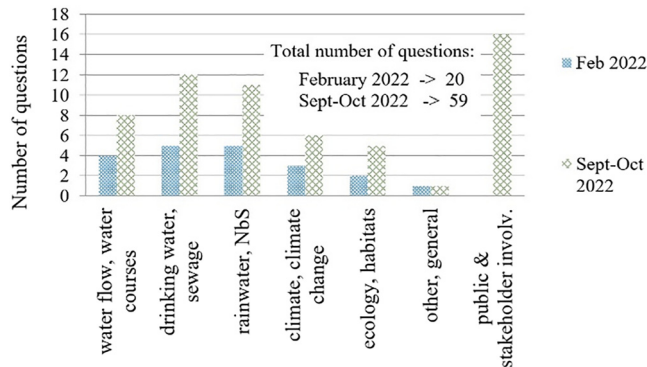


Fig. 4. Main topics of the questionnaires and the number of related questions (Source: Author)

Landscape and land use have undergone severe transformation in the past decades because of rapid population growth and infrastructure developments financed by the Hungarian Settlement Development Operative programs [29]. Many of these new infrastructures are not updated on the maps yet. Therefore, the available rainwater harvesting surface areas were estimated by a combined methodology. The road and sidewalk network surfaces and the buildings' roof surfaces were estimated in the three settlements of the highlighted sub-catchment using digital maps and local measurements. The surfaces were categorized into four groups:

1. Public streets, main roads, and sidewalks;
2. Private sidewalks and parking lots;
3. Houses' and public buildings' roofs;
4. Vineyard, backyard farming, small gardens.

For public surfaces, Quantum Geographic Information System (QGIS)-3.28.2-Firenze [30], Google Earth-9.177.0 [31] and e-kozmu [32] were used to measure street and road lengths and roof areas. The surface and pavement areas and the width measurements of roads and sidewalks were revised during the on-site visits.

The roof areas of buildings were also verified during on-site visits, and the necessary modifications were performed accordingly. Due to inaccurate databases, a safety Error Factor ( $ER$ ) was implemented for roads, streets, and road-drainage surfaces. Based on random measurements, road drainage surfaces were modified by 10%, while roof surfaces were modified by 15%.

The Estimated Retention Volume ( $ERV$ ) calculation was developed during the research to consider two pillars of the sustainable development goals: environmental and social. The environmental pillar is based on the rational method, and  $RER$  is based Eq. (1).  $ERV$  can be calculated:

$$ERV = \sum_{i=1}^3 A_i \cdot C_i \cdot p_{est,x} \cdot ER_i \cdot RER, \quad (2)$$

where  $C_i$  is the runoff coefficients;  $A_i$  is the surface areas;  $p_{est}$  is the annual average precipitation. For public and private roads and sidewalks  $C_{r,s}$  was set uniformly to 0.9, while for roof surfaces  $C_{roof}$  was set to 0.8. For gardening and vineyard surfaces  $C_{agr}$  was 0.2. The  $ER$  was determined by half a dozen random measurements in each settlement and the value was rounded up to 5.

## 4. RESULTS

### 4.1. Survey

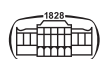
The increased attention and media coverage caused by the extreme summer drought in 2022 also showed how awareness could change the attitude of decision-makers. Despite a little over six months between the surveys conducted by the authors, there was a notable shift in the overall atmosphere. The majority of mayors - even under the burden of post-covid recovery and challenging energy bills - became supportive and interested in the topic. The responsiveness - the willingness to respond increased - even with a much longer questionnaire (Table 2).

Water and NbS-related awareness significantly increased resulting in more diverse project ideas and water related development suggestions (Fig. 5).

Basic infrastructure development demands (drinking water, sewage) hardly changed, but projects related to NbS, wetlands, and ecological developments have tripled in number from spring to fall (from 4 projects in Spring to 12 projects in Fall).

Table 2. Responsivity rate of the questionnaire surveys

Time of survey	Responsive settlements
February 2022	A total of 4 questionnaires were completed, which is a 36% response rate.
September-October 2022	A total of 7 questionnaires were completed, which is a 50% response rate.



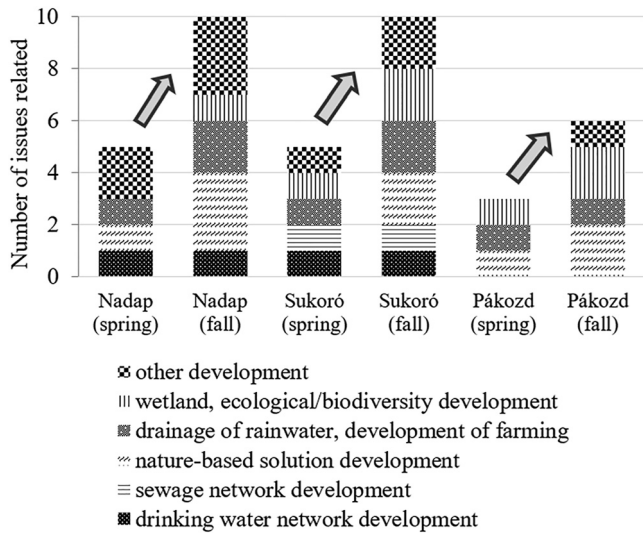


Fig. 5. Attitude change toward water-related issues among mayors from spring to fall in 2022 (Source: Author)

4.2. Assessment of the influence of NbS measures

The retention of rainwater for irrigation purposes in settlements is becoming more and more prominent with climate change. The maximum retainable water from the watershed was calculated, and the impact of different retention efficiencies on the lake’s water level was evaluated.

There are various ways to collect and retain rainwater; the most common surfaces: public roads, sidewalks, roofs of buildings, cultivated-uncultivated areas, and parking lots. Determine the retainable volume, *ERV*, Eq. (2) was used. The calculated surface areas in the settlements are shown in Table 3.

To determine *RER*, *IW* and *FIO* were uniformly set to 1 in Eq. (1), meaning all conditions are assured ideal (e.g., financial resources, orderly property relations); therefore, the *RER* value is 1.

The average annual rainfall of the past 20 years was used to determine rainfall volumes. It was assumed that no losses occur; all rainwater creates runoff. The calculated rainfall without the 5 mm daily threshold was  $p_{est,0} = 537.5$  mm. In a second scenario, only events with daily rainfall exceeding 5 mm were considered, resulting in a rainfall volume of  $p_{est,5} = 409.8$  mm. Using Eq. (2), rainwater volume (*ERV*) was calculated for the two rainfall scenarios (Table 4).

Depending on the local willingness and available financial and infrastructural background, the rainwater retention ratio may impact the lake’s water level through reduced inflow. *RER* was varied between 0 and 100% to investigate the effects and impacts of different water retention ratios in NbS on the lake water level. The possible retention with *RER* = 1 is approx.  $3 \times 10^5$  m<sup>3</sup>, equivalent to 1.2 cm lake water level (Fig. 6).

The concrete retention effect of NbS varies when *RER* changes. For example, 5% retention means less than a 1 mm annual lake water deficit. Based on the survey results, implementing the planned NbS in the future retains approx. 25% of retainable rainwater. This results in an approximate

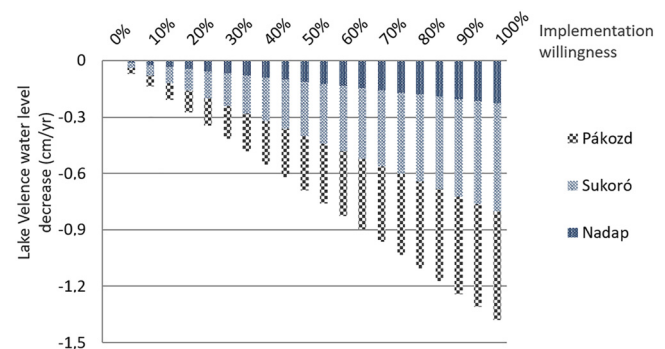


Fig. 6. The effects of different water retention rates on the lake’s water level (Source: Author)

Table 3. Calculated surface areas in the settlements for water collection for retention (the total for sub-catchment highlighted)

	Pákozd (m <sup>2</sup> )	Sukoró (m <sup>2</sup> )	Nadap (m <sup>2</sup> )	Total (m <sup>2</sup> )
Public streets, main roads, and sidewalks (surface)	152.753	131.378	36.074	<b>320.195</b>
Private sidewalks and parking lots (surface)	43.451	23.112	9.875	<b>76.438</b>
Houses and public buildings’ roofs (surface)	186.219	99.049	42.323	<b>327.591</b>
Vineyard, small gardens, backyard farming (surface)	18.000	8.000	22.000	<b>48.000</b>
Total				<b>772.224</b>

Table 4. Maximum retainable volume in case of ideal *RER* (*RER* = 1), theoretical maximum highlighted

	$A_i$ (m <sup>2</sup> )	$C_i$	$ER_i$	$ERV; p_{est,0}$ (m <sup>3</sup> )	$ERV; p_{est,5}$ (m <sup>3</sup> )
Public streets, main roads, and sidewalks	320.195	0.9	0.90	<b>139.405</b>	106.285
Private sidewalks and parking lots	76.438	0.9	0.90	<b>33.279</b>	25.373
Houses and public buildings’ roofs	327.591	0.8	0.85	<b>119.735</b>	91.288
Vineyard, backyard farming, small gardens	48.000	0.2	1.00	<b>5.160</b>	3.934
Total	772.224			<b>297.579</b>	226.880



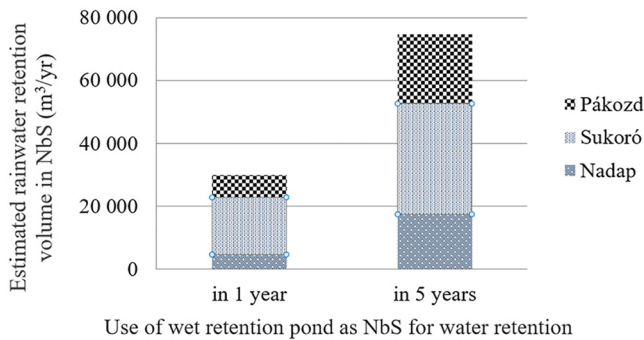


Fig. 7. Future effects of NbS' measures based on calculated *ERV* (Source: Author)

annual water level deficit of 3 mm in the lake, which can be considered negligible.

The water retention capacity of feasible NbS was initially estimated to be 30,000 m<sup>3</sup> per year during the first survey. This included swales, rain gardens, infiltration basins, and small private rainwater tanks. Following the extreme drought in 2022, the project ideas multiplied, leading to a revised planned *ERV* of 80,000 m<sup>3</sup> annually. Figure 7 illustrates this change over the period between the two surveys.

Compared to the initial survey, additional NbS measures introduced in settlements include retention ponds, rainwater harvesting, infiltration trenches, and peripheral solutions like detention and retention ponds. While concrete measures have been limited so far, the growing willingness and awareness and upcoming national and European Union grants are expected to drive these developments in the next decade.

Consequently, the retention ratio and stored rainwater volume for irrigation purposes are anticipated to increase in the hilly areas. This heightened retention may lead to a reduced inflow from the catchment to Lake Velence. However, it is expected to foster more diverse local ecosystems and enhance plantation yield. The long-term impact on Lake Velence's water level remains uncertain, but the positive effects of these local NbS initiatives in the hilly settlements are projected to outweigh the negative impact of the annual ~3 mm decrease in lake water level.

To effectively adapt to these changes, integrated water management and catchment-scale modeling will be essential. These approaches aim to ensure water resources' sustainability and mitigate climate change's adverse effects on stakeholders.

## 5. CONCLUSION

Catchment-scale integrated water management is increasingly crucial for mitigating the adverse effects of climate change on Lake Velence, which has been experiencing a water deficit for several years, leading to record low water levels due to extreme weather events. The widespread implementation of NbS for water retention may influence the lake's water

budget and level. While the annual 0.2–0.3 cm decrease might be imperceptible, the locally retained rainwater enhances living conditions, bolsters vegetation water supply in settlements, and fosters a more favorable microclimate.

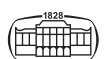
Extreme weather conditions caused by climate change may affect this negatively. The increased water volume on-site improves local water security and positively influences the water supply of small gardens and vineyards. Given the low probability of negative consequences from nature-based solutions, their impact appears more advantageous to the entire catchment than detrimental to the lake. Lower water levels, beneficial for the lake's ecology, prompt the need to investigate their extent and impact on tourism in waterfront settlements. To better understand the economic and non-economic effects of NbS methods and their correlation with water levels, a more precise estimation, increased stakeholder involvement, and heightened social awareness are essential.

## ACKNOWLEDGEMENT

Authors cordially thank the permissions to use the data of Central-Transdanubian Water Directorate [14] known as KDTVÍZIG. The research presented was carried out within the framework of the Széchenyi Plan Plus program with the support of the RRF 2.3.1 21 2022 00008 projects.

## REFERENCES

- [1] G. Ámon and K. Bene, "Rainfall duration and parameter sensitivity on flash-flood at a steep watershed," *Pollack Period.*, vol. 18, no. 2, pp. 54–59, 2023.
- [2] Google Earth Engine Data Catalog, Copernicus CORINE Land Cover dataset, 2023. [Online]. Available: <https://earthengine.google.com/>. Accessed: Apr. 28, 2023.
- [3] Green infrastructure, European Commission, Document 52013DC0249 - EN, Brussels, 2013. [Online]. Available: [http://ec.europa.eu/environment/nature/ecosystems/strategy/index\\_en.htm](http://ec.europa.eu/environment/nature/ecosystems/strategy/index_en.htm). Accessed: Dec. 28, 2022.
- [4] L. Balatonyi, G. Reich, B. Jancsó, Z. Nagy, K. Buzás and L. Tóth, "Sustainable urban water management, vision of the future for municipalities" (in Hungarian), *Belügyi Szemle*, vol. 69, no. 12, pp. 2189–2207, 2021.
- [5] I. M. Voskamp, C. de Luca, M. B. Polo-Ballinas, H. Hulsmann and R. Broelsma, "Nature-based solutions tools for planning urban climate adaptation: State of the art," *Sustainability*, vol. 13, no. 2, 2021, Art no. 6381.
- [6] H. Masliah-Gilkarov, "Shared waters – joint responsibilities," Annual Report 2021, International Commission for the Protection of the Danube River, 2022. [Online]. Available: <https://www.icpdr.org/main/publications/annual-reports>. Accessed: Dec. 20, 2022.
- [7] Floodplains: a natural system to preserve and restore," European Environment Agency, Report No 24/2019, 2020.
- [8] Natural Water Retention Measures, NWRM, Office International de l'Eau, 2019. [Online]. Available: <http://nwrme.eu/>. Accessed: Apr. 4, 2023.



- [9] Proposal for the sustainable water replacement of Lake Velence (in Hungarian), *Kék Bolygó Klímavédelmi Alapítvány*, 2022. [Online]. Available: [https://kekboogyoalapitvany.hu/wp-content/uploads/2022/04/Velence-tavi-munkacsoport-jelentes\\_-2022-04-14-1.pdf](https://kekboogyoalapitvany.hu/wp-content/uploads/2022/04/Velence-tavi-munkacsoport-jelentes_-2022-04-14-1.pdf). Accessed: Oct. 22, 2022.
- [10] The natural geography of Lake Velence (in Hungarian), *Országos Vízügyi Főigazgatóság*, 2009. [Online]. Available: <https://www.vizugy.hu/index.php?module=content&programelemid=44>. Accessed: Nov. 2, 2022.
- [11] S. Tóth, “The catchment’s surface water system and its role in water replacement” (in Hungarian), in *Conference on the Impact of Climate Change in the Lake Velence Catchment Area*, Székesfehérvár, Hungary, September 23, 2022. [Online]. Available: <http://www.fmmk.hu/vizgazdalkodas/index.php/tovabbkepzes/>. Accessed: Sep. 23, 2022.
- [12] Domestic implementation of the water framework directive, Water collection management plan, 1-14, Catchment of Lake Velence (in Hungarian), *Vízügyi és Környezetvédelmi Központi Igazgatóság*, 2009. [Online]. Available: [http://www2.vizeink.hu/files/1\\_14\\_Velencei\\_to\\_VGT\\_terv.pdf](http://www2.vizeink.hu/files/1_14_Velencei_to_VGT_terv.pdf), Accessed: Mar. 25, 2023.
- [13] The water balance of Lake Velence in 2021 (in Hungarian), *Középdunántúli Vízügyi Igazgatóság*, Székesfehérvár, 2022. [Online]. Available: <http://www.kdtvizig.hu/hu/velencei-to-vizmerleg>. Accessed: Apr. 20, 2023.
- [14] Central-Transdanubian Water Directorate – KDTVÍZIG, Székesfehérvár, 2022. [Online]. Available: <http://www.kdtvizig.hu/>. Accessed: Mar. 20, 2023.
- [15] Meteorological Database (in Hungarian), Hungarian Meteorological Service, OMSZ, 2023. [Online]. Available: <https://odp.met.hu/climate/>. Accessed: Mar. 20, 2023.
- [16] F. Alsilibe and K. Bene, “Watershed subdivision and weather input effect on streamflow simulation using SWAT model,” *Pollack Period.*, vol. 17, no. 1, pp. 88–93, 2022.
- [17] Annual settlement statistical data (in Hungarian), *Központi Statisztikai Hivatal*, 2021. [Online]. Available: <https://statinfo.ksh.hu/Statinfo/haViewer.jsp>. Accessed: Apr. 24, 2023.
- [18] V. G. Mitchell, “Applying integrated urban water management concepts: A review of Australian experience,” *Environ. Manage.*, vol. 37, no. 5, pp. 589–605, 2006.
- [19] L. J. Pearson, A. Coggan, W. Proctor, and T. F. Smith, “A sustainable decision support framework for urban water management,” *Water Resource Manage.*, vol. 24, pp. 363–376, 2010.
- [20] Z. Ghofrani, V. Sposito, and R. Faggian, “Maximizing the value of natural capital in a changing climate through the integration of blue-green infrastructure,” *J. Sustain. Develop. Energ. Water Environ. Syst.*, vol. 8, no. 1, pp. 213–234, 2020.
- [21] H. Qingchang and A. Reith, “Using nature-based solutions to support urban regeneration: A conceptual study,” *Pollack Period.*, vol. 17, no. 2, pp. 139–144, 2022.
- [22] P. Galambos, “Municipal water management and the circular economy” (in Hungarian), *Hidrológiai Közöny*, vol. 101, no. 3, pp. 40–46, 2021.
- [23] J. Deely, S. Hynes, J. Barquín, D. Burgess, G. Finney, A. Silió, J. M. Álvarez-Martínez, D. Bailly, and J. Ballé-Béganton, “Barrier identification framework for the implementation of blue and green infrastructures,” *Land Use Policy*, vol. 99, 2020, Art no. 105108.
- [24] S. M. Miller and F. A. Montalto, “Stakeholder perceptions of the ecosystem services provided by green infrastructure in New York City,” *Ecosystem Serv.*, vol. 37, 2019, Art no. 100928.
- [25] J. Lamond and G. Everett, “Sustainable blue-green infrastructure: A social practice approach to understanding community preferences and stewardship,” *Landscape Urban Plann.*, vol. 191, 2019, Art no. 103639.
- [26] N. Kabisch, N. Frantzeskaki, S. Pauleit, S. Naumann, M. Davis, M. Artmann, D. Haase, S. Knapp, H. Korn, J. Stadler, K. Zaunberger, and A. Bonn, “Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action,” *Ecol. Soc.*, vol. 21, no. 2, 2016, Art no. 39.
- [27] Y. Wang, M. Sun, and B. Song, “Public perceptions of and willingness to pay for sponge city initiatives in China,” *Resour. Conserv. Recycl.*, vol. 122, pp. 11–20, 2017.
- [28] J. B. Williams, R. Jose, C. Moobela, D. J. Hutchinson, R. Wise, and M. Gaterell, “Residents’ perceptions of sustainable drainage systems as highly functional blue green infrastructure,” *Landscape Urban Plann.*, vol. 190, 2019, Art no. 103610.
- [29] Development Programs (in Hungarian), *Miniszterelnökség*, 2023. [Online]. Available: <https://www.palyazat.gov.hu/>. Accessed: Apr. 12, 2023.
- [30] Open-Source Desktop GIS software platform, QGIS, software version: QGIS-3.28.2-Firenze, 2022. [Online]. Available: <https://qgis.org/en/site/about/index.html>. Accessed: Oct. 31, 2022.
- [31] Open-Source online platform, Google Earth, release version: GoogleEarth-9.117.0, 2021. [Online]. Available: <https://earth.google.com/web>. Accessed: Oct. 31, 2022.
- [32] Unified Electronic Public Works Register (in Hungarian), 2020. [Online]. Available: <https://ekozmu.e-epites.hu/alkalmazas>. Accessed: Jan. 27, 2023.

