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Optimized Implementation of Nature-Based Solutions for Sustainable Economic Benefits in a Watershed with Water Deficit – a Case Study in Hilly Settlements of Lake Velence

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The adverse effects of climate change on water resources have been demonstrated recently. The shallow surface and groundwater levels throughout Europe in 2022 have not been restored, even during the winter-spring recharge period. Water scarcity causes economic damage and may lead to food supply shortages and social tension. For Lake Velence, extreme drought caused damage throughout the watershed. The record low water levels kept away tourists and reduced the revenues. Stakeholder cooperation on sustainable water-related developments is essential to overcome the water deficit in the area.
Surveys among local mayors confirmed that there is an affinity and possibility to sustainably utilize rainwater with the application of nature-based solutions. These infrastructures have low impacts on the lake's water level while noticeably improving plant and agricultural irrigation, though the benefits are mostly unknown among stakeholders. Consequently, profitability per area unit for agricultural and farming activities can be increased. The research quantifies the possible positive effects of economic incentives used to implement nature-based solutions in the hilly settlements of Lake Velence; they sustainably increase the yield of agricultural production and food security and economically beneficial tools for mayors to optimize placement of nature-based solutions within the catchment to achieve adequate soil quality and additional social benefits.

1. Introduction

Europe's climate has significantly transformed in the first decades of the 21st century. Along with global warming, the unpleasant effects of climate change are altering precipitation frequency and distribution. Last year provided numerous negative examples of these weather events resulting in extreme drought experienced across Europe. Similar heat waves and drought periods will become more common in the future, exacerbated by sudden, monsoon-like heavy rains. (EC, 2022). These unfavorable conditions will affect agriculture, food security the inhabitants of settlements, the natural ecosystems, wetlands (Weiskopf et al., 2020), tourism, and all sectors. Food loss due to inadequate water resources will have a negative impact on agricultural activity (Malahayati, 2022), which is of prime importance to the government and a notable contributor to GDP.
With economic development, the social and built environment also changes, and gray infrastructures gain more space, which decreases the green surface ratio. These changes significantly alter land use and landscape. If the development of the three pillars (environment-economic-social) is unbalanced, sustainability is not ensured (Rashid and Zakaria, 2021). With adverse climate conditions, the state of the natural and social environment significantly worsens (Bouman et al., 2020), partially in favor of economic benefits. Sustainable development affecting all three pillars can be indirectly enforced using financial incentives. Water management is becoming more complex and integrated within the settlements and beyond (Balatonyi et al., 2021). Gray infrastructures cannot adequately handle extreme rainfalls as excessive amounts cause overflow problems (EC, 2013). The broad implementation of nature-based solutions (NbS) is essential in water resource management (Voskamp et al., 2021) for sustainable development while increasing biodiversity and positively impacting well-being (NWRM, 2019).

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The catchment of Lake Velence, especially the lake's nearby surroundings and landscape, has been heavily modified since the 1960s. After extensive water, transport, and settlement infrastructure developments, the area became a popular tourist and weekend resort in the second half of the 20th century. The number of permanent residents around the lake has increased dramatically with the developed and modern infrastructures, the pleasant environment, and the nearby location of large cities. The lakeside settlements are currently functioning as suburbs of Budapest and Székesfehérvár, turning from temporary to permanent residential areas. As a result, social and environmental transformations and infiltration deteriorated due to diminishing green surfaces. Meanwhile, water demand increased with population growth at Lake Velence, increasing demand for farming and small gardening, and emerging desire for grape production.

In the changing conditions, water retention decreases, as does precipitation during summer, resulting in local water shortages. The overall water cycle in the catchment changes significantly, resulting in disagreements among local stakeholders and challenges to water professionals. (Kabisch, 2016). They are unwilling to finance investments that they wrongly consider non-refundable (Pearson et al., 2010). Climate change and sustainability are not taken into account in their decision process because they are reasonably satisfied with the water resources provided by the drilled wells and water distribution networks, especially since these do not require any further investments on their side. NbS can adequately answer these emerging problems (EPA, 2023) and sustainably develop water resources. These infrastructures can bring additional economic benefits to the area (Jia and Zhang, 2021) and provide win-win economic solutions for all three pillars of sustainable development. With appropriate economic incentives (Santos and Shimada, 2021), increasing yield can be sustainably optimized while restoring the soil's good condition and chemical composition.

This paper introduces a sub-catchment of Lake Velence. It outlines an easy-to-use method for non-water professionals through an example of 3 settlements on calculating retainable rainwater and its achievable multiple benefits. The aim is to show that cooperating and well-informed stakeholders can create personal profits, national economic growth, and sustainable development using the positive benefits of nature-based solutions. The research develops an easy-to-apply methodology through a numerical example, showing that well-chosen state incentives can benefit local governments, farmers, society, and the environment.

2. Site description

The catchment area of Lake Velence is located in Central Hungary, part of a developed region. From an economic and social point of view, the center of the catchment is the lake and its nearby surroundings (Figure 1). The lake is approximately 30 km from Budapest and 10 km from Székesfehérvár, connected by modern highway and railway lines. The administrative areas of these two cities produce approximately 40 % of Hungary's total GDP, but their population is less than 19 % of the national population.

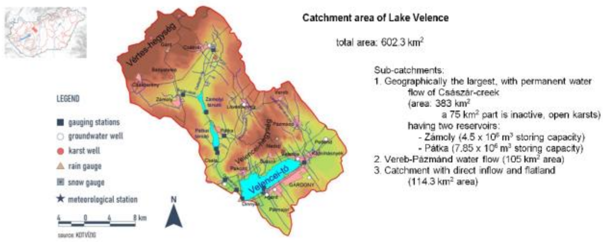

Figure 1: Catchment area and location of Lake Velence

2.1 The catchment and the lake – water management

The lake's surface area is approximately 24.2 km^2. The upper regulatory level is 170 cm, and the lower regulatory water level is 130 cm. The total water volume at an average depth (150 cm) is approximately 40x10^6 m^3. Although the water level in Lake Velence fluctuates throughout the year and over the years, the average has decreased in the past 35 y and has become even steeper in the recent decade (VIZUGY, 2023).

In the first half of the 20th century, the surroundings of Lake Velence were natural and undisturbed (Figure 2a), except for the sluice gate at Dinnyés on the southwestern side of the lake. The role of the gate was to reduce excessively high water levels. The popularity of the lake and the accompanying change in landscape and land use began in the 1960s with the development of the Budapest-Székesfehérvár railway lines and the construction of the M7 motorway. Comprehensive construction of seawalls and two water level regulating reservoirs were built – Zámoly in 1967 and Pátka in 1974 – to increase the water level of Lake Velence during the dry summer periods. (KDTVIZIG, 2009) About 25,000 m^3 equals 1mm of water level change in the lake.

The nearby location of the capital city, Budapest, made the lake popular; the number of visitors increased, and weekend houses and vacation homes multiplied. These brought further infrastructural developments: paved public roads, drinking water and sewage networks, shops, and restaurants. Meanwhile, the amount of garbage and sewage and the risk of contamination increased.

Figure 2: Landscape and land use change around Lake Velence (a,1930s, b, 2020s)

2.2 Demography, hydrology, economy

Around 2000, as Budapest became overcrowded, a strong migration began to the lakeside settlements, which noticeably expanded around Lake Velence (Figure 2b). New real estate developments have increased the population by 60 % since 2000 in the six surrounding settlements, while nationwide it decreased by 3.5 %. The proportion of green surfaces decreased with growing population density and expanding tourist needs. Climate change has adverse effects: temperature and rainfall changes will significantly influence the water level of Lake Velence. Climate forecasts predict a similar amount of rain annually but with drier summers. With the rising annual temperature, evaporation will increase by about 8 % until 2050, causing an additional 7 cm (~ 1.7 Mm^3) loss from the lake's water level (Kékbolygó Alapítvány, 2022).
The research investigates the hilly sub-catchment on the northern side of Lake Velence. The area has three settlements: Pákozd, Sukoró, Nadap. Their population almost doubled in size during the last 30 y. New inhabitants want to create backyard gardens and viticulture partly as a hobby and partly in the hope of extra revenue. This demand requires comprehensive water management. Adequate water use and retention pose challenges as the depth of the aquitard is less than 10 m from the surface. The existing grey infrastructures are inadequate to manage flash floods and droughts. Cooperation with stakeholders and integrated water management is needed to overcome these problems. Several ecological and economic benefits are gained by optimal allocation and implementation of nature-based solutions beyond providing sufficient water supply. A major barrier to implementing NbS is the fear of the unknown and the lack of motivation. Last year, a series of questionnaire surveys among local mayors demonstrated that willingness to implement and use nature-based solutions rises with increased personal knowledge and worsening climatic conditions.

3. Methods

Due to the changes in land use and the negative effects of climate change, water resources management needs a catchment scale and integrated approach. Investigating the effects of implementing nature-based solutions within the settlements locally and at the catchment level is essential. The impacts of implementation on water volume and their economic effects are examined in the following steps:

- Determining the amount of rainwater that can be collected from impervious areas in the three settlements. Comparing the amount of retainable rainwater with the irrigation capabilities of NbS. Evaluate the impact on the water balance of Lake Velence.
- Quantifying the economic benefits of nature-based solutions. Determine the possible effect of economic incentives – payment subsidies versus penalty fees – with the use of NbS.

3.1 Retainable water volume

A sufficient amount of rainwater is required for adequate operation of water retention infrastructures, such as retention ponds. The available rainwater in the settlements was calculated. For the area calculation, only impervious surfaces (streets, sidewalks, road networks, roof surfaces of buildings and structures) were taken into account. The collection of water from these surfaces can be used for water-retaining structures. The calculation underestimates the water volume, but the error is small for the three settlements. It can be used as a preliminary approximation in the pre-planning phase. Municipalities have limited financial resources and personnel with specialty knowledge; therefore with this quick and practical calculation could overcome these barriers. The roads, road network surfaces, and roof surfaces of the buildings were estimated using open digital databases and maps (QGIS, Google Earth, e-kozmu). Necessary corrections were made during on-site visits. The flow coefficients were classified into three groups, as shown in Table 1.

Table 1: Surface runoff calculation basic parameters

	Name of catchment area (S)	Runoff coefficient (c)	Catchment area (A)
1	Surface of main roads and their sidewalks	$c_{road} = 0.9$	54,596 m^2
2	Surface of secondary roads, streets, sidewalks	$c_{build} = 0.85$	265,599 m^2
3	Roof surfaces of houses, properties, buildings	$c_{build} = 0.8$	327,591 m^2

The annual descriptive statistics were determined from the precipitation time series of the last 20 years: annual average Prec = 537.5 mm; annual median Prec(m) = 511.7 mm – lowest in 2011 with 273.7 mm and highest in 2010 with 888.6 mm. Retainable water volume (RWV) can be calculated for different rainfall scenarios from the surfaces listed in Table 1 using Eq(1);

$$RWV_{\#1} = k \cdot \sum_{i=1}^{3} A_i \cdot c_i \cdot Prec \qquad (1)$$

where A_i – surface area of the subcatchment [m^2], c_i = runoff coefficient of subcatchment [-]
k – climate coefficient [k = 1], Prec – annual amount of rainfall [m]

3.2 Economy benefits and incentives of rainwater retention

The implementation costs of a retention pond are evaluated by determining its whole life cycle costs. They include the implementation costs, the maintenance and repair costs throughout the lifetime, and the restoration costs of the area. NbS have long lifespans, well over 50 years. It is necessary to include inflation rates, economic growth, and interest rates for different periods. A retention pond can create income and revenues. Within the scope of this study, the quantification of the indirect effects and subjective positive externalities (better air, richer wildlife, a more pleasant living environment, recreation, tourism, amateur fishing, etc.) are not examined. Only the additional benefits achieved by irrigation are taken into account. Eq(2) shows the possible available profit of the retention pond for its lifetime:

$$Profit = \frac{Y_f \cdot \sum_1^n R \cdot \frac{(1+p)^n}{(1+i)^n} - I + \sum_1^n M \cdot \frac{(1+g)^n}{(1+i)^n} - C}{n+1} \pm INC_k \qquad (2)$$

where
I – investment costs; M – maintenance and repair cost
C – end-of-life recovery cost; R – annual revenue
Y – yield factor; p – price increase, rate of inflation (3.50 %)
i – interest rate for refinancing (3.90 %); g – economic growth (4.00 %)
n – lifespan, number of years (50 y); INC_k – state incentive (+ is grant; - is tax)

As a result of irrigation, the average annual yield and crop harvest will increase the income. With the implementation of nature-based solutions, higher revenue and food security are realized throughout the lifetime. It may happen that due to increased water resources, the farmer's choice of vegetation has harmful effects on the environment and on the composition of the soil. The legislator can wisely influence the farmer's choice of crops and displace alien species by well-chosen incentives and production-influencing taxes.

4. Results

In recent years, Lake Velence has received special media attention, primarily due to its extremely low water level. According to the new guidelines, all rainwater falling on the watershed must be collected, transported, and stored in the lake. Despite various efforts, the water resources in the watershed are insufficient to raise the lake's water level significantly, and the water level has not even reached the lower regulatory level for over three years. Therefore, it is particularly important that the impact assessments of newly implemented water retention measures in the settlements and in the entire watershed.

4.1 Determining runoff and water balance effect

The retainable water volume (Eq(1) for the three settlements and three different rainfall scenarios are summarized in Table 2. To include losses, rainfall events with less than 5 mm were removed. The annual rainfall was recalculated; the average rainfall was 409.8 mm, the lowest (in 2011) 171.8 mm and the highest (in 2010) 738.2 mm. The settlement requested three retention ponds with a required 3-4 x 10^4 m^3 water volume. There is more than enough water for retention ponds, based on comparing retainable water to the required water volume. Even with the lowest annual precipitation, the available rainwater is tenfold.If the total available amount of retainable rainwater is withheld, it would reduce the lake water level per quarter by 2 mm, which is negligible compared to the depth of the entire lake. The implementation of NbS in the three settlements has no significant effect on Lake Velence's water level since the desired water volume is negligible. This method for municipal pre-assessing a water retention measure calculation is fast and suitable.

Table 2: Annual retainable rainwater volume from impervious surface runoffs with three rainfall scenarios

	Name of catchment area (S)	Lowest rainfall [273.7 mm]	Lowest rainfall modified [171.8 mm]	Average rainfall [537.5 mm]
1	Settlement 1 – Pákozd	75,749 m^3	47,547 m^3	148,759 m^3
2	Settlement 2 – Sukoró	50,384 m^3	31,626 m^3	98,946 m^3
3	Settlement 3 – Nadap	20,835 m^3	13,078 m^3	40,916 m^3
	Total:	146,968 m^3	92,251 m^3	288,621 m^3

4.2 Economy benefits and incentives of retention

Economic actors seek their utilities and prioritize their decisions to maximize revenues and achievable profit. When economic benefits are examined, projected revenues and costs are evaluated over the entire lifetime. This research focuses on direct costs and revenues arising during the operation of wet retention ponds. It leaves out indirect or secondary benefits such as extensive ecosystem benefits and positive externalities. Maintenance costs make up a significant part of the lifetime costs. However, it is often the case that NbS are maintained in social cooperation in exchange for the available benefits. The present calculation does not count on positive, secondary benefits. Retention ponds can store a portion of runoff volume and can act as irrigation reservoirs to increase yield and revenues. Figure 3 shows how crop yield changes with different climate scenarios and varying degrees of use of nature-based solutions.

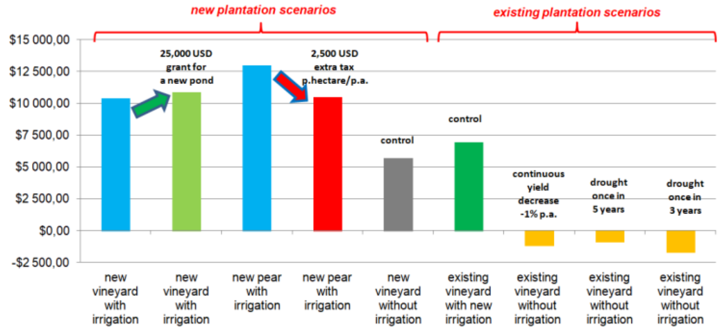

Figure 3: Nominal GDP growth per (ha×y) for different scenarios

The five left columns show newly cultivated areas, and the four right columns refer to existing land use. In the existing plantation, a new retention pond can increase an existing vineyard's income per hectare used for irrigation (green column). The orange columns (on the right) show three scenarios for an existing vineyard without irrigation. One case is with decreasing yield due to heat waves and decreasing precipitation. The other two cases show recurring droughts every 3–5 y. With more frequent droughts, annual revenues significantly decrease. Nature-based solutions for irrigation can increase yield and income if examined over their 50 y lifetime. Farmers and municipalities have aligned interests to be implemented by wise economic incentives.

A new retention pond brings secondary local benefits through social and environmental factors, enhanced well-being, better micro-climate, higher biodiversity, recreation area, and pleasant surroundings. They increase the attractiveness of the area and the value of the properties. Further implementation of NbS would preserve the attractiveness, competitiveness, and tax higher revenue from the higher farmer incomes. Municipal subsidies can bring additional advantages for both parties. The municipality can control the location and design of the retention pond with grants. They can maximize their secondary benefits while the farmer can reduce investments and increase the revenues. The impact of subsidies was demonstrated in the study area with a 25,000 USD grant. The green arrow shows the effect of the grant in the case of a newly cultivated area with rainwater irrigation from a retention pond. The other known economic incentive is the penal tax. The revenue is visibly high for a new pear orchard with irrigation (red column). The municipality can take advantage of this and collect taxes (set to 2,500 USD/ha/y for example) on usage of the retention pond. The red arrow shows the effect of this tax, and with the right amount, it does not demoralize the farmer. At the same time, this revenue contributes to the settlement budget in a more advantageous position.

Consequently, taxes open up further possibilities for the municipalities. A well-chosen tax rate or grant can drive farmers from one crop to another. Farmers can still make generous profits with the incentives, while these are advantageous for social and economic pillars of sustainable development, in terms of indigenous species, soil conservation and landscape character. The possibility of intervention by economic incentives is in the hands of the municipality. Regardless of the method, implementing NbS provides significant benefits.

5. Conclusions

Changing land-use and climate conditions are coupled with decreasing infiltration and increasing droughts, reducing agricultural opportunities. Nature-based solutions are good alternatives to sustainably manage challenges, even in water-deficit watersheds like Lake Velence. The case study showed that sustainable development can be enhanced through financial benefits and economic incentives. Retention ponds can generate 6-12,000 USD/ha/y additional GDP if stakeholders cooperate and know the realizable economic benefits. Additionally, farmers can be driven with incentives – payment subsidies or penalty taxes – to implement nature-based solutions that indirectly increase positive externalities, thus enhancing sustainable development's social and environmental pillars.

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