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Renewable Energy Based, Sustainable Multifunctional Ecosystem Service

[1] Balázs Kulcsár

[1] Faculty of Engineering, University of Debrecen, Debrecen, Hungary
Corresponding Author Email: [1] kulcsarb@eng.unideb.hu

***Abstract*— Adapting to the challenges of global climate change requires a new way of thinking in all areas of life. The use of renewable energy sources can provide an opportunity to reverse the negative spatial processes that have occurred in the past, often as a result of careless human interventions, and to create a healthy ecosystem service. There are many uses for a site, and coordinating them requires careful development and sustainable land use planning.**

The case study of the Rétköz lake in northeastern Hungary illustrates a habitat rehabilitation project where several human uses have been coordinated in the conservation and restoration of the natural environment. As a consequence of climate change, the good condition of the habitat can now only be maintained artificially, with the use of renewable energy sources playing a key role. The rehabilitation and sustainable management of the Rétköz lake is a model for resolving land use conflicts and providing a rich ecosystem service powered by renewables. The pilot project has produced positive results that were not expected, which could create an opportunity to reform the water management of the Tisza Valley for multiple purposes. The welcome increase in renewable energy-based energy production technologies could provide a good opportunity for sustainable management.

The hypothesis of the long-term research is that the water system of the Tisza Valley can be adapted to the expanded needs, partly by partial restoration of the former aquatic ecosystem and by modification of the existing infrastructure. The energy needs of the system can be met by locally available renewable energy sources, providing a sustainable multifunctional ecosystem service for the environment, economy and society. The aim of this research is to prove the above hypothesis.

***Keywords*—ecosystem service, landscape utilization, renewable energy, sustainability, water management.**

I. INTRODUCTION – RAISING A PROBLEM

As a consequence of global warming, the Carpathian Basin is affected by increasingly extreme precipitation patterns and heat waves, causing frequent droughts, not only in summer [1]. A large part of the basin is threatened by desertification, with unforeseeable consequences, but certainly with enormous environmental, economic and social damage [2]. There is therefore a need to increase the region's resilience and contribute to meeting global climate targets [3]-[5]. Long-term research is exploring the potential for creating a complex ecosystem service based on the use of renewable energy sources to address this problem, with sustainable results.

This large-scale research concerns the Tisza valley, which is a river that carries a significant amount of water, but due to the river regulation of the last two hundred years, most of this water flows through the Hungarian Great Plain without being used. Due to changing climatic conditions, this water is now much missed by the region's wildlife and economy. The question arises as to how the former water management system, which was designed to quickly drain away floodwaters, can be reformed to serve complex purposes, i.e. to protect against flooding, while at the same time providing water storage capacity for periods of drought, to serve as a near-natural habitat and to be sustainable. This paper presents the first phase of the research and its results. This first stage was the rehabilitation of the intertidal lake, which yielded unexpected results, validated the research hypothesis, generated further ideas and thus became a pilot project for comprehensive studies.

The case study, Lake Rétköz, fell victim to changing climatic conditions in 2014. Due to drastically reduced rainfall, the lake was left without water and dried up. Human intervention was needed to save the aquatic habitat, but sustainability could only be ensured artificially, which posed significant challenges. One of the key challenges was to provide the energy needed to replenish water.

In parallel to the above-mentioned problems, a process of energy transition is taking place worldwide, including the rapid expansion of weather-dependent renewable energy sources [6], whose rapidly increasing installed capacity is also taking a growing share of the Hungarian energy mix [7]. The energy surplus in favourable weather situations is simultaneously causing energy storage problems in the Hungarian energy system [8]. At the same time, the utilisation of 'surplus' electricity can offer a sustainable solution to the energy needs of water management. In this way, energy can be converted into a resource.

A. The aim of the pilot project

The objective of the long-term research is to determine the water retention capacity of the Tisza Valley based on the quantifiable results and empirical experience of the Rétköz Lake, by partial, multi-purpose restoration of the natural aquatic world and by assessing the potential other storage capacities [9]-[12]. To determine the locally available renewable energy potential, the energy demand for operation and the amount of available and to be integrated capacities for sustainable operation of the complex ecosystem service.

The research, as a model project and a pilot laboratory, is based on the rehabilitation of the Rétköz lake, which has based the potential for the development of a multi-purpose aquatic ecosystem service in the Tisza valley on locally produced renewable energy sources for its long-term sustainability.

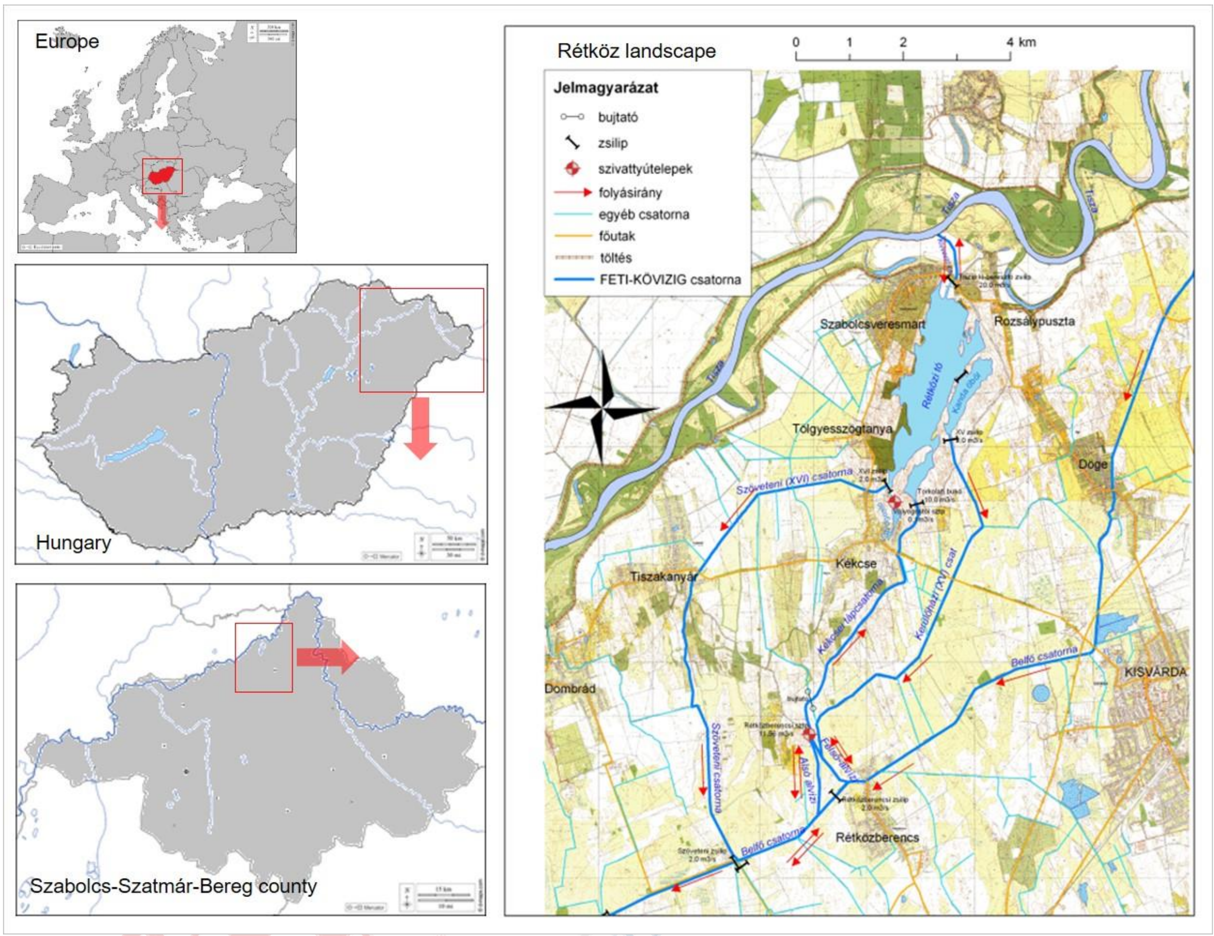

Figure 1. The examined geographical area and water management plan of the Rétköz [14]

II. BACKGROUND

A. The geographical area under study, determination of the territory

The area of the pilot project is located in the Great Plain, Upper Tisza, Rétköz, a small area of about 560 km2 [13] (Fig. 1). The area is a contiguous low-lying area, heavily dissected by water, which receives its water supply from the flood waters of the Tisza (Fig. 1).

The Danube and the Tisza, the two main rivers shaping the alluvial plain of the Carpathian Basin, transport significant amounts of water to the area [15]. Historically, the fluctuating rainfall distribution in the Tisza catchment area has resulted in frequent floods on the river, which have left large areas of the basin permanently or intermittently under water [16] (Fig. 2). Extensive river regulation works, which started in the 19th century, narrowed the previously large floodplains, especially on the Tisza, and aimed at rapid drainage of the floods and increased agricultural land [17]. This has affected the loss of both surface and groundwater resources. In the second half of the 20th century, a network of irrigation canals was built to supply water to the unwatered, drained flood plains, and groundwater was intensively exploited.

In the period before the current climate change, irrigation water was supplied through the sewer system. Over the last few decades, however, water levels have been falling, threatening the water supply, while the river carries a still significant amount of water through the basin. The water management system in the Tisza Valley is therefore based on past climatic characteristics and is no longer able to meet today's challenges.

III. HISTORICAL BACKGROUND

A. Regulation of the Tisza and its tributaries

Before the regulation of the Tisza, the floodplain of the river and its tributaries, fed by floods, formed a coherent system of marshes, swamps and meadows, an aquatic habitat rich in species. As the needs of the growing population increased, more and more land was brought under cultivation. From the 1700s onwards, damming, drainage and meander

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cutting to speed up the flow of water were therefore undertaken. By 1879, a total of 112 dams had been completed on the lowland stretch of the Tisza. The total length of the river was reduced from 1,419 km to 962 km, i.e. by 38%, and tens of thousands of square kilometers of cleared floodplain were made arable.

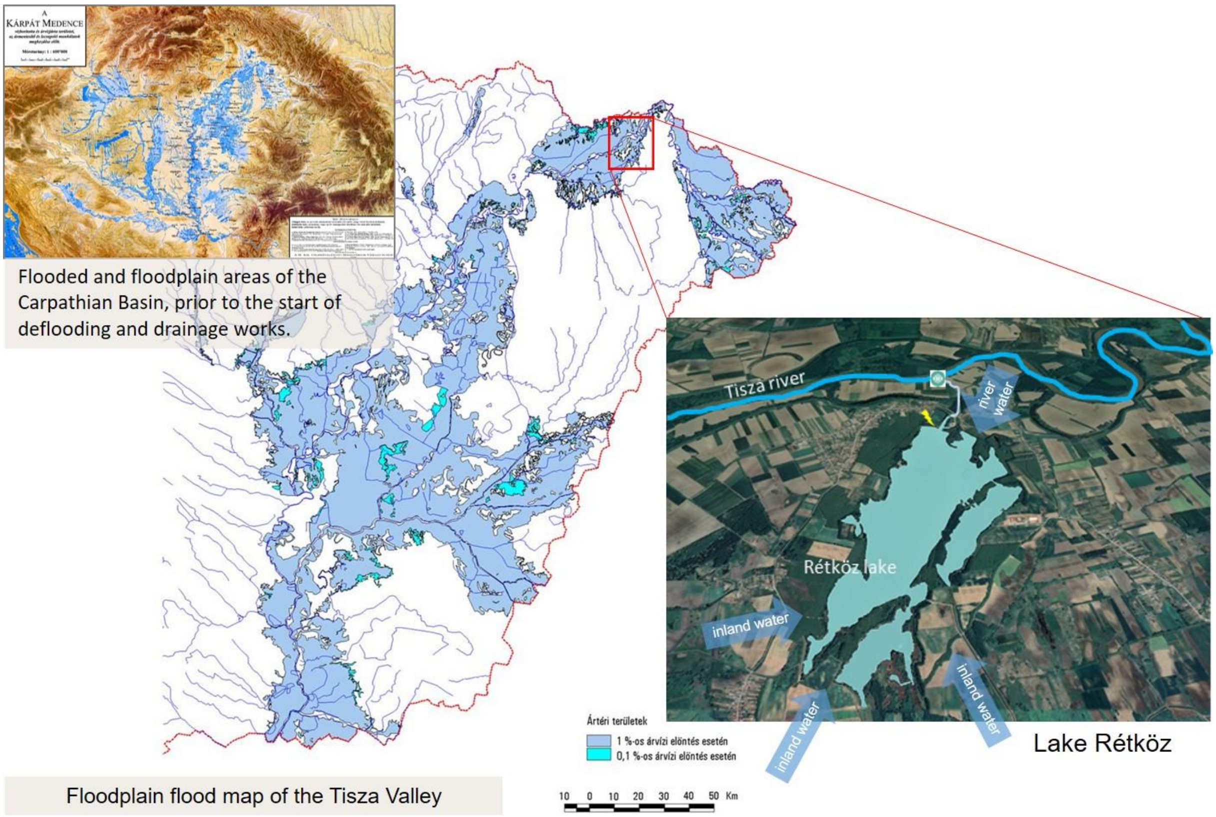

Figure 2. Water-covered and flood-prone areas of the Carpathian Basin, before the start of relief and drainage works [18].

In 1863, unlike the floods, there was a drought, which proved the need to build a network of irrigation canals. Another problem was inland flooding, as the embankments built, while protecting the area from flooding, prevented the inland waters that had accumulated behind the dams from flowing into the river. However, inland water damage was a problem until the 1970s. The area of the Rétköz lake was converted into a reservoir in 1990. Between 1998 and 2001, four consecutive record floods drained the Tisza, causing significant damage. This led to the development of the Vásárhelyi Plan, which aims to improve the water carrying capacity of the Tisza, revitalise the natural values of the floodplain and build six tidal reservoirs to break the peaks of flooding that can no longer be contained by dams by releasing water into less valuable areas. This last major plan for the Tisza represents the most complex thinking to date, with the objectives of rural development, nature and environment protection, ecotourism and recreation, in addition to flood protection and agricultural interests.

B. Regulation of the Rétköz

The watercourses and lakes of the Rétköz were drained in accordance with the regulation of the Tisza, and the Belfő Canal (the main drainage canal), built between 1860 and 1880, drained the water.

The inland drainage works undoubtedly resulted in a large amount of deflooded farmland. At the same time, the drainage systems of the late 19th and early 20th centuries sought to drain the lowest-lying areas and impose inhospitable farming practices on them. As a consequence, in many areas, inland water reoccupying the areas of old lakes and watercourses during the rainy season caused problems. In 1989, the decision was taken to create the Rétközi lake (also known as the Szabolcsveresmart reservoir) as an inland water reservoir to deal with the inland water situation in the settlements of Upper Szabolcs.

The conditions necessary for the protection of the wildlife of the Rétközi lake nature reserve are thus inseparable from the function of the Rétközi lake as a reservoir, since the formation and existence of this particular wildlife has been ensured for thousands of years by the presence of water in the area, i.e. inland waters.

However, the creation of the Rétközi lake in 1989 was not for the purpose of wildlife restoration, but specifically for inland water protection. As a reservoir, the lake was integrated into the Upper Szabolcs inland water protection system, so the inland water protection function could not be ignored in the design and implementation of the habitat protection project. One of the specificities of the project was that the inland water protection regime was not an obstacle to the implementation of the project, but rather a facilitator, provided that the water protection aspects were taken into account. The technical solutions of the project were therefore designed with this aspect in mind (Fig. 1).

IV. DATA AND METHODS

The research uses interdisciplinary knowledge, empirical methods, empirical and estimation methods for renewable energy production, and geospatial methods.

A. Technical parameters

Lake Rétköz is the most important reservoir in the Upper Tisza region, built in 1990. The lake has a volume of 10.2 million m3 at the working water level and a surface area of 4 km2. The lake and its surroundings are a nature reserve, which is important for the wildlife of the whole Upper-Sabolsk region.

The lake is almost entirely supplied by the Tisza river, by gravity. However, the low water level of the Tisza over the last few years has made it no longer possible to draw water from the Tisza. The less important water recharge option is the discharge of inland water from the agricultural areas in the southern foreshore of the lake into the lake. However, this option was also not available during periods of low rainfall. By 2014, the water level in the lake had steadily decreased and then dried up completely. Due to the lack of water for many years, the original aquatic and riparian vegetation was degraded, invasive and ruderal species overpopulated, gradation processes took place and the original aquatic fauna was destroyed.

B. External technical installations on the Rétköz lake

The drainage of the inland waters of the Upper-Sabolac area into the Tisza is achieved through the main channel Belfő and the Rétközi lake (Fig. 3). The Rétközi lake reservoir is located in the upper inland water catchment area of the Upper-Sabolac inland water system, behind the left bank of the Tisza, in the area bordered by the villages of Szabolcsveresmart, Kékcse and Döge. It is bordered by natural landforms and hills, except in three sections where artificial barriers have been built. An inlet sluice is built into the Tisza flood protection embankment near Szabolcsveresmart to allow the inland water from the reservoir to be gravity fed into the Tisza, and to allow the lake bed to be filled or refreshed from the Tisza.

C. Tisza out- and inlet water lock

The lock is located at the 47+050 fkm section of the Tisza embankment. The sluice is designed for two-way water transfer under suitable water level conditions in the Tisza and its reservoir. The water transfer capacity is 20 m3/s in both directions.

Its function is to discharge incoming inland waters by gravity into the Tisza River when the water level of the Tisza allows it; to exclude flooding of the Tisza River, to provide living water in the Rétköz Lake by means of a suitable opening; and to drain the reservoir to the Tisza River. The average water depth of the reservoir at operating water level is 215 cm. The ideal operating water level is between 250 and 300 cm, depending on the prevailing tidal and inland water conditions (Table 1).

Table 1. Basic data on Lake Rétköz as a reservoir

	altitude above sea level (mBf[1])	**water level** (cm)	**water mass** (millió m^3)	**water surface** (ha)
Maximum water level	100.30	350	10.26	400.21
Operating water level	99.80	300	8.31	378.18

D. Definition of the problem – Critical water shortage along the Rétköz lake

The threshold level of the Szabolcsveresmart inlet canal was higher than the current water level of the Tisza, so that the problem of ensuring a constant supply of water to the lake had already been identified (Fig 3).

When the Rétköz lake bed as a reservoir was flooded in 1990, there was no Tisza tidal surge to fill the lake throughout the year, so the lake was fed by portable pumps through the outlet canal. The first full filling took place in early 1991.

Experience from the 1990s shows that, in the event of a tidal surge on the Tisza River reaching stage I readiness, the empty reservoir can be filled to operating water level in 4-5 days. The amount of water pumped into the lake depends on the hydrological situation. Between 1990 and 1996, the period was characterized by drought, so there were several years when it was not possible to release water into the lake. In the year 1997, which was richer in inland water, 5.9 million m3 , in 1998 13.0 million m3 , in 1999 25.0 million m3 and in 2000 6.0 million m3 of inland water were released into the lake.

The first critical situation occurred in 2003, when low water levels in the Tisza River prevented water from entering the lake after it was filled in early January, and the water level dropped from 250 cm to 36 cm by autumn.

From 2010 onwards, the higher water levels of the Tisza were regularly absent, so that during the period of generally low precipitation, the lake was not replenished either from the Tisza or from inland water. Water experts have been working to create fish beds by deepening the canal network. However, by June 2014, mass mortality had already begun in the channels in the lake bed. By July 2014, the lake bed had dried up completely and the water cover in the inner channel network had disappeared.

[1] height above Baltic Sea level

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Figure 3. Processes and causes of the drying up of the Lake Rétköz

E. Conditions for restoring the lake and its wildlife

In order to meet the needs of the flora and fauna in the pond, it is essential to maintain a constant water level close to the operating water level. During low water periods, there is no possibility of gravity recharge either from the Tisza or from the surrounding agricultural land. Only the Tisza river can be considered for pumping.

In the driest years, 6.0-8.0 million m3/year of Tisza water could be needed. The maximum daily evaporation and seepage losses during the critical periods, including the years 2006-2014, are 2.0-2.5 cm/day, corresponding to 87,500 m3 of water (≈1000 l/s in continuous flow).

F. Methods of physical implementation – Restoration and recharge of the Rétköz lake for habitat protection

The title of the project is "Restoration and rewatering of the Rétköz lake for habitat protection". The project was implemented by the Municipality of Döge with its consortium partners, the municipalities of Kisvárda, Kékcse, Szabolcsveresmart, the Upper Tisza Water Management Directorate (FETIVIZIG) and the Faculty of Technology of the University of Debrecen. The aim of the project is to build a water intake and a water level control structure to ensure continuous water supply, and to stabilise the service and damage control roads leading to the structures. Rehabilitation of the facilities related to the maintenance of the lake bed, removal of harmful silt by dredging the lake bed, restoration of embankments, embankments and protection works, and rehabilitation of the water level control structure. The project started in autumn 2015 with a budget of approximately €2.7 million.

During the project, the participating municipalities carried out their general administrative tasks [19], including local environmental and nature protection, water management, water damage prevention, disaster management, economic organisation and tourism.

During the planning and implementation of the project, the areas surrounding the lake and its surroundings were managed on the basis of their environmental and economic use classification, and then adapted to this in the future to implement the ecotourism-related improvements that are essential for the presentation of the natural values of the lake and for scientific research.

G. Planned costs of operation

The largest share of the operating costs is the cost of water replacement. The cost used as the basis for the calculation of the operating costs for water replenishment, the cost of transferring 1 m3 of water to fill the interstitial lake, is 7 euro cents/m3. The cost includes the loss of pumps and maintenance costs, but excludes other losses such as leakage and evaporation. The data were used to calculate the cost of transferring water to fill the interluve of the Rétköz lake.

Daily, monthly and annual data were examined for the calculations (Fig. 4). The table is based on the hydrological analysis of the FETIVIZIG Hydrological and Data Analysis Department, taking into account the average and maximum water levels and water mass variations measured over the period 1991-2014.

Daily, monthly and annual water pumping costs for the Lake Rétköz

Month	The mass of water pumped into the lake – water mass reduction (m^3)	$1m^3$ water pumping cost (euro/m^3)	Water pumping cost in July (euro)	Water pumping cost / month (euro)	Water pumping cost / summer months (euro)	Total cost of annual water pumping (euro)
July	860 000	0.007	6,254	202		
Juni August (3 months)	2 277 611	0.007		180	16,564	
January-December (12 months)	6 254 265	0.007		1,353		45,486

Figure 4. Dredging of the lake bed and the installation of a pumping station at the mouth of the inlet channel to the lake. The costs of maintaining the permanent water security of Lake Rétköz.

H. Ensuring sustainable operation through renewable electricity generation

To ensure the multi-purpose use of the reservoir, it is essential to maintain a near-constant level of operating water throughout the year, which can only be achieved by the construction of a permanent pumping station. The project included the construction of a pumping station on the left bank of the Tisza river, consisting of three pumping units with a total capacity of 206 kWp, which can ensure a continuous water supply to the lake even during dry periods (Fig. 4). The project was completed by the end of 2015. In 2016, after the operational tests of the completed pumping station, the lake was filled to its operating water level in a trial run that started in mid-August.

The pumping station is operated by electricity, and its continuous operation imposes a significant financial burden on the operating water management board (Fig. 4). In order to minimise the operating costs, the possibility of providing the electricity demand of the pumping station by means of a photovoltaic system was considered. The idea proved to be a good one after careful calculations and software calculations [20]. The calculations showed that a solar PV system installed next to the lake could generate a significant part of the electricity needed to run the pumps. Since the park would also operate when the pumps are at rest, the electricity generated could be fed back into the national electricity system and sold to the universal electricity supplier.

The approach towards economic and environmental sustainability has been supported by the Hungarian government [21]. The preparation of the project started in August 2016 and in June 2017 a 200.2 kWp grid-connected solar PV system with installed capacity was installed near the Rétköz lake (Fig. 4). Based on the operational experience of the past 6 years, the PV system has delivered positive results. The plant has been able to supply the electricity demand of the pumps every year and the amount of electricity overproduced and fed into the grid has generated an additional annual average income of 10,000 euro for the operator FETIVIZIG.

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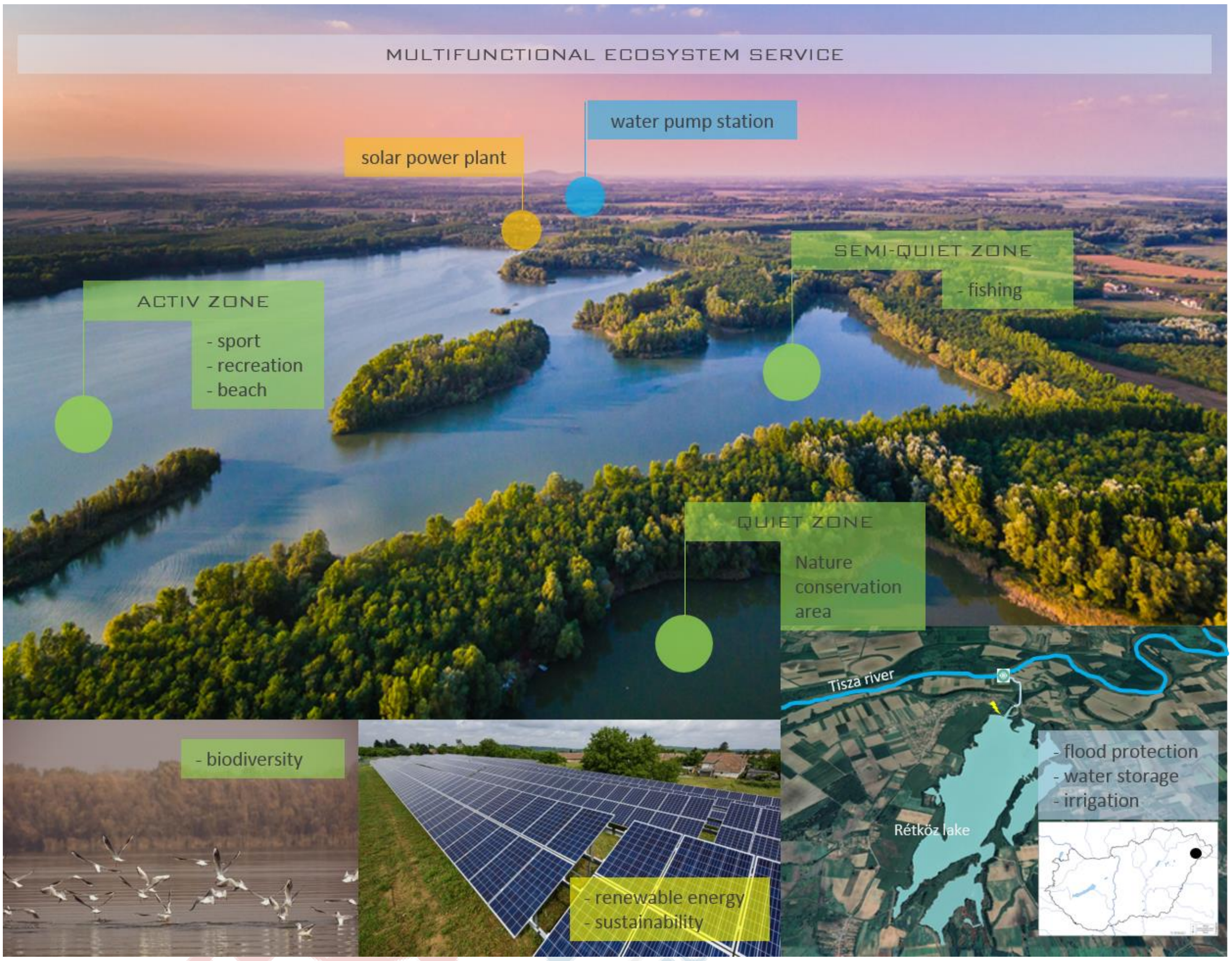


Figure 5. The Lake Rétköz pilot project. Allocation of land according to use.

I. Complex recovery without land use conflicts

To achieve multifunctional use of the aquatic ecosystem, several, often difficult to reconcile, needs had to be met in one geographical location and at one time. In order to avoid conflicts, three zones were created to take advantage of the natural divisions of the lake basin (Fig. 5):

1. The largest basin of the lake hosts the so-called active zone, where active human activity is present. These activities include water sports, beach, bicycle tourism, fishing and other recreational tourism activities.
2. the semi-western zone, the middle basin of the lake, also known as Kanda Bay, where nature is present and fishing is the only activity.
3. The third basin of the lake is the resting zone, where all human activity is prohibited, and this part of the lake is a nature reserve with a high degree of protection, closed to visitors.

V. REULTS

Having met its basic objective, the rehabilitation of the Rétköz lake has delivered results beyond expectations, in terms of water management, nature conservation and sustainability. In addition to the above, the multifunctional ecosystem service created has also generated a wide range of social, economic and cultural benefits:

A. Water management results

The water management rehabilitation of the Rétköz Lake has been completed as intended, with the installed pumps and sluices maintaining a constant operating water level. The water body of the lake, with its controllable water level control, serves regional water management purposes: flood protection, irrigation water storage, inland water drainage, nature conservation, tourism, municipal and other economic water supply.

B. Natural protection results

Thanks to successful rehabilitation, the Intertidal Lake will ensure the ecological water needs of aquatic habitats are met, the extent and integrity of the lake is maintained, habitat mosaicism is maintained, open water areas are preserved, degraded habitats are restored, and bird migration and feeding sites are restored. The project has made it possible to provide visitors to the area and the population of the surrounding municipalities with an appropriate level of information, to promote a conservation approach and to develop and implement educational and ecotourism programs. To this end, facilities have been built to promote the lake as a place to learn about nature, such as a visitor center, a nature trail, a boat landing stage, a boathouse, accommodation and a forest school.

C. Economic results

The water management and conservation achievements are outstanding in themselves, but the restored aquatic ecosystem provides additional economic services. Inland water and the reservoir of the Tisza provide a balanced agricultural water supply, an aesthetic and high quality landscape environment for a wide range of tourism activities such as water sports, recreation, ecotourism, fishing and cycling.

D. Realizing climate targets

Water security and a renewed and preserved natural environment provide invaluable climate services. It has a significant CO2 sequestration and oxygen production capacity, tempering the local microclimate and stabilising groundwater levels.

E. Sustainability

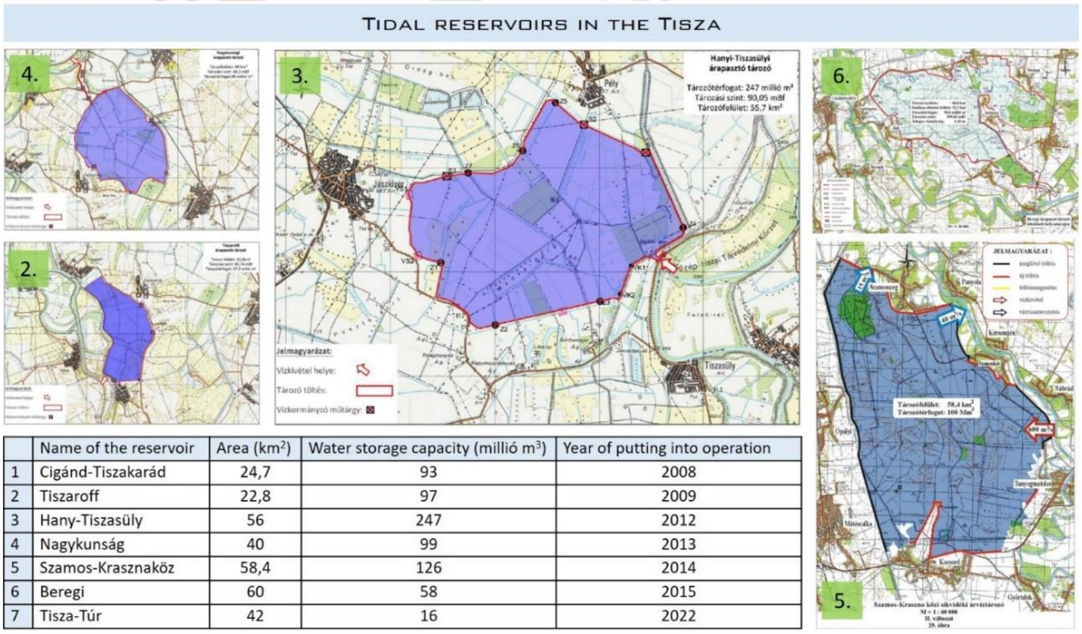
The achievements listed above already contribute to environmental sustainability. However, in order for all elements of the project to operate in a sustainable manner and to provide a healthy, multi-purpose ecosystem for continued service, two essential conditions had to be met. One is to ensure a constant water level in the lake and to provide the necessary energy from renewable sources. Thus, Lake Rétköz can be considered as an economically, ecologically and energetically sustainable pilot project with a high level of success.

VI. CONCLUSIONS

Geography is characterised by complex thinking, a broad vision and a systemic approach to problems. The new perspective is a synthesis of the results of different disciplines, an extension of a concentrated disciplinary vision. Geography, with its comprehensive knowledge, contributes with its "Earth-system managerial" thinking to the development of a well-functioning system with broad benefits. It aims at a beneficial, healthy and sustainable functioning of the whole system, while providing an effective response to regional and local issues of adaptation to the adverse effects of climate change.

The solution to the local problem and its unexpected positive experience could create opportunities for regional application and a rethink of water management in the whole Tisza Valley and the Carpathian Basin.

Based on the positive results of the pilot project, further studies will be launched to determine how much water can be retained, how much energy is required to manage the water and how this can be achieved using only locally available renewable energy sources.



	Name of the reservoir	Area (km²)	Water storage capacity (millió m³)	Year of putting into operation
1	Cigánd-Tiszakarád	24,7	93	2008
2	Tiszaroff	22,8	97	2009
3	Hany-Tiszasüly	56	247	2012
4	Nagykunság	40	99	2013
5	Szamos-Krasznaköz	58,4	126	2014
6	Beregi	60	58	2015
7	Tisza-Túr	42	16	2022

Figure 6. Data on the tidal reservoirs constructed under the Further Development of the Tarns Plan programme.

A. Water storage options

The Tisza valley offers a number of opportunities for the retention and strategic storage of water carried by the river.

The river bed

One of the most obvious options for storing large quantities of water is the Tisza riverbed itself. Three hydroelectric power plants were planned on the Tisza from the 1950s onwards, of which the Tiszalök and Kisköre power plants were built. Both power plants are capable of retaining a significant volume of water from the riverbed through the irrigation canal system in the lowlands to the former flood plains, thanks to their damming. However, the third power plant, in Csongrád, has not been completed. If built, the power plant could retain a significant amount of water in an additional 157 km of riverbed and in the reservoir areas bordering the river. However, at present, during periods of drought and low water levels, the Tisza acts as a drainage channel, causing water-logging and further reducing groundwater levels in the surrounding agricultural areas, exacerbating water supply problems. Below Kisköre, the next power plant is the Novi Bečej hydroelectric power plant in Serbia, which has a back-pressure effect as far as Csongrád. The Csongrad dam is therefore missing from the system and its construction is justified.

Mortlakes

The Tisza was regulated by 112 cut-throughs. The river meanders that were cut and the meanders that were naturally dammed in the pre-regulation period now form some 200 mortlakes along the Hungarian stretch of the Tisza, which could provide additional significant reservoir capacity.

Tidal reservoirs

Seven tidal reservoirs have been completed under the Further Development of the Vásárhely Plan (Fig. 6). These reservoirs are mainly used to break down flood peaks. Since their construction, only the Tiszaroff reservoir has required flood protection filling in June 2010. However, these reservoirs could also be used to store water from lower tides during drought periods. During floods, water flows gravitationally into the reservoir through the sluices. However, pumping stations are needed for small-scale recharge.

Soil

By periodically flooding floodplains and reservoirs (1-2 months), significant amounts of water can be stored in the soil. This method can be used to raise the ground water table and increase soil water reserves for summer drought periods.

Irrigation canal system.

The water of the Tisza is supplied to the exempted agricultural land by an extensive system of irrigation canals. The length of the system fed by the Tisza water reaches 1000 km, providing the potential for significant additional water storage capacity.

Danube - Tisza canal.

The Danube-Tisza canal is an artificial canal in the northern part of the Kiskunság region, which was planned several hundred years ago and of which only 22 km have been built. Its extension has been considered several times for both navigation and water replenishment purposes. The gradual drying out of the Kiskunság sandflats and the changing climate have led to a significant reduction in groundwater levels, threatening the landscape with desertification. Its construction is therefore justified on both environmental and economic grounds.

Aquifer sedimentary rocks.

During the accumulation of the Carpathian Basin, several kilometres of sediment have accumulated, which has a significant water storage capacity. A significant part of the aquifer water stored here can be considered as fossil, due to the rate of recharge measured in human time scales. At the same time, significant quantities of water are extracted from groundwater reservoirs. If future extraction continues at current levels, these water supplies will need to be replenished to ensure sustainability. This can also be done by injecting water from the Tisza after purification.

B. Renewable energy sources options

The mechanical movement of water required for reservoir capacity utilisation and water steering is a significant energy demand. The use of weather-dependent renewable energy sources, essentially wind and solar, can put the calculations of the return on high-cost water investments on a new footing. Based on the experience of Lake Rétköz, several options should be explored in the later stages of research:

Solar and/or wind power plants installed on the water movement site

The solar power version of this option is entirely similar to the one used at the Interlake Rétköz site, where the solar power plant was installed specifically to power the pumping station. In addition to the solar plant, a vertical axis wind turbine can be used, which does not pose a threat to birdlife. In order to avoid the adverse effects of the energy price movements in 2022 and 2023, it is appropriate to consider a combination of renewable energy sources. A solar/wind hybrid power plant could help to achieve more balanced production. The deployment of local energy storage capacity should also be considered to further strengthen off-grid and balanced generation.

Capturing energy surplus in the operation of the water management system

The share of weather-dependent renewable energy sources in the energy mix is increasing dramatically. However, they have the disadvantage of over-generation in favourable weather conditions, which poses a significant challenge for electricity system managers to capture, transmit or store. In 2023, there were several events on the Hungarian energy exchange where the energy price had a negative sign. In the water management system, especially for the transmission of water for storage, the energy demand is not "just in time". This can be an advantage when the green energy price on the energy exchange is zero or negative. This electricity can be put to good use to provide the energy needed to stockpile water reserves.

If the hypothesis of the research is confirmed, this comprehensive renewable energy-powered water management could serve as a model for many other regions of the world facing similar challenges.

VII. SUMMARY

One element of adapting to the challenges of climate change is to put water management in the Carpathian Basin, including the Tisza Valley, on a new footing. The new challenges require a multifunctional transformation of the water management system. This must be done with a complex vision that can be operated sustainably and have a positive impact on the environment, the economy and society. Locally available renewable energy sources have a key role to play in this.

The first element of the large-scale research presented in this study, the rehabilitation of the Rétköz lake, has produced results beyond expectations, becoming a starting point and a pilot laboratory for research at regional level. The pilot project has confirmed the hypothesis that the aquatic ecosystem can be managed as a near-natural landscape with sustainability considerations and with moderate and careful use. The complex ecosystem service created is also a positive response to the adverse effects of climate change.

VIII. ACKNOWLEDGEMENTS

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Nemzeti Kutatási, Fejlesztési és Innovációs Hivatal

AZ NKFI ALAPBÓL MEGVALÓSULÓ PROJEKT

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