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Riparian vegetation on a riverbank of a restored side arm of the Danube near Neuburg, Bavaria. Photo: Veronika Ullmann 2025

CONTENT

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When Clear Water Lies: Filamentous Algae overgrow Macrophytes

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Abstract

As primary producers, submerged macrophytes depend on the availability of ambient light within the water column. This study evaluates underwater vertical PAR profiles measured in May 2025 at seven floodplain lakes and channels in the Danube Delta Biosphere Reserve, Romania, focusing on the *depth of optimum light exposure* rather than solely on minimal light requirements (euphotic depth). Alongside submerged macrophytes, dense accumulations of filamentous algae frequently develop in the water column, creating a 'false transparency' effect in which visually clear water overestimates the light available at the macrophyte canopy. Effective management and restoration of the Danube Delta therefore require supporting macrophyte communities capable of establishing and persisting under low-nutrient conditions. Only such resilient stands – free from filamentous algal overgrowth – can ensure that open-water transparency once again reflects true ecological quality.

Introduction

The Danube Delta Biosphere Reserve in Romania is characterized by interconnected small riverine channels and shallow floodplain lakes (Nichersu et al. 2022). The shallowness of these water bodies and their short residence times – often only a few days for the Danube Delta lakes (Los 1998) – generally provide suitable habitat for macrophytes. Underwater light – both as a resource and a signalling cue – often governs macrophyte recovery in degraded shallow lakes. Accordingly, the underwater light climate is quantified here using optical measurements to assess light availability in the water column.

Measuring Lake Depth of Optimal Light Requirements for Macrophyte Development

Assessing optimal light requirements for macrophyte development in the Danube Delta is essential for understanding ecosystem functions. Minimal light thresholds – 1% of surface irradiance for planktonic autotrophs and 2–4% for macrophytes – indicate only survival (Teubner et al. 2022). In shallow lakes, macrophytes flourish only under near-optimal light, around 12% of surface irradiance (Teubner et al. 2020), which ensures sustained growth, competitive strength against phytoplankton, and exposure of canopy leaves near the water surface. Observations from the oxbow lake 'Alte Donau' show that when large sediment areas receive this optimal light, macrophytes expand rapidly, forming dense, structurally complex stands that act as a major seasonal phosphorus sink and create a three-dimensional habitat. Mature submerged macrophyte stands are thus recognized not only for their biomass and nutrient retention but also as a distinct structural habitat formation, forming a third ecological component alongside benthic and pelagic zones (Teubner et al. 2022). These submerged 'underwater meadows' in freshwater are analogous to marine underwater forests, providing extensive habitat at the water surface and throughout the water column for fish, invertebrates, and other biota. Understanding the underwater light climate in the Danube Delta is therefore key to predicting macrophyte growth, habitat formation, and ecosystem stability, for example in common species such as *Trapa natans L., Ceratophyllum demersum L., Nuphar lutea (L.)SM,* and *Stratiotes aloides L.*

Figure 1. LI-COR underwater spherical PAR sensor (left; PAR plane air sensor not shown; Lacul Babina) and measurement of underwater light below filamentous algal mats and leaves of Nymphaea alba, respectively (right, Lacul Ligheanca).

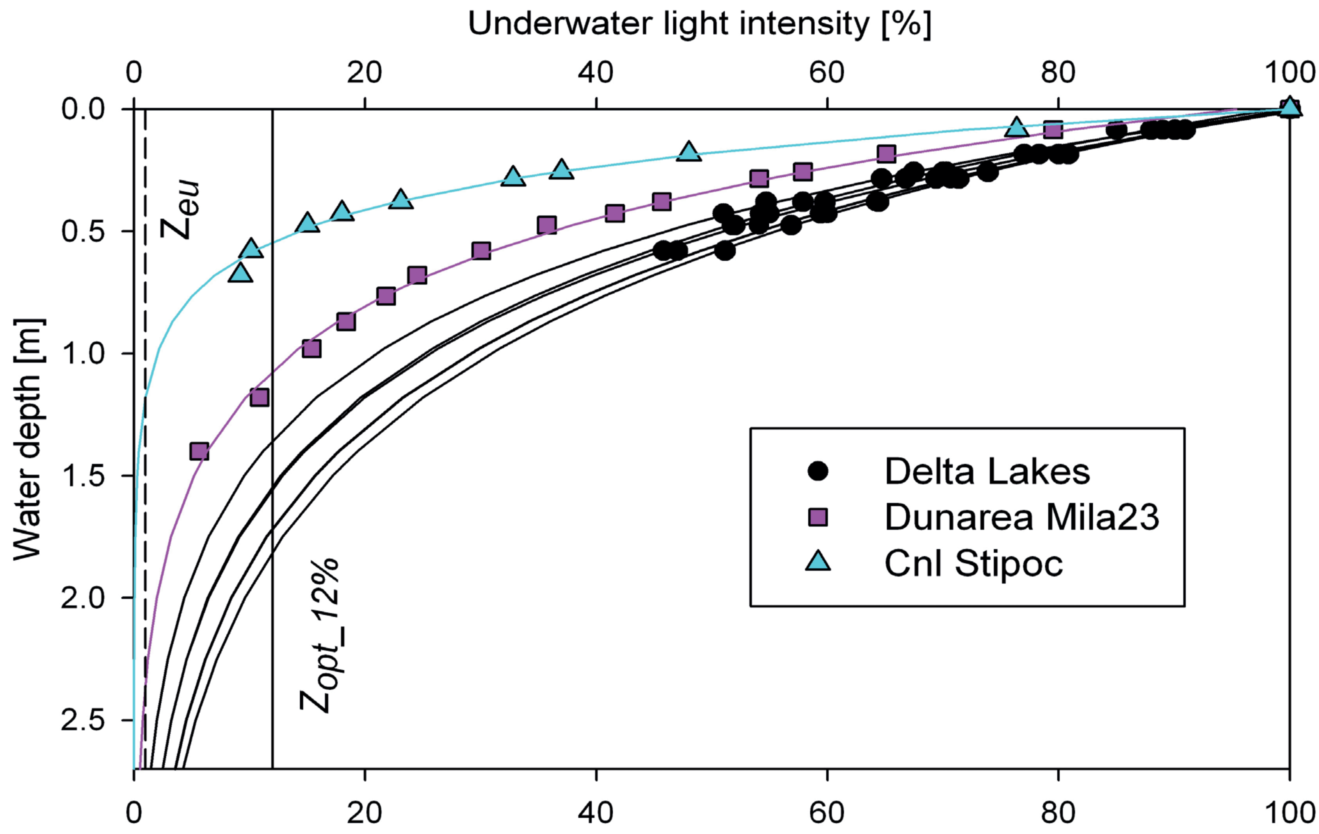

Figure 2. Underwater light profiles for Danube Delta Lakes (four floodplain lakes, Lacul Babina, L. Ligheanca, L. Vâcaru, L. Vâsins) and narrow natural watercourse connecting lakes of the Danube Delta, Gârla Lopatna), Danube oxbow waterbody at village Mila23 (Dunărea Veche at Mila23) and floodplain channel (Canal Stipoc). Data points indicate measurement depths, while the fitted curves extend beyond them to 2.70 m, corresponding to the maximum lake depth in the Danube Delta studied by Cristofor et al. (2003). Underwater light intensity of 1% (euphotic depth, z_{eu}) and of 12% surface ambient light (optimum light requirement for macrophyte growth, $z_{opt\_12\%}$) is indicated by dashed and solid line. Measurements from 8-11 May 2025.

Vertical Light Profiles Relevant to the Growth and Flourishing of Macrophytes

Measuring the underwater light climate in shallow lakes is challenging because Secchi disk readings are often inadequate. The Secchi disk has been used for over 200 years to estimate water clarity (Teubner et al. 2021), but it provides limited information in very shallow systems. Although widely applied, established first for marine and later freshwater observations, Secchi measurements are only meaningful where the Secchi depth is less than the actual water depth (Secchi depth survey for Danube Delta in Sarbu 2003). Entries such as 'Secchi disk visible at the bottom' cannot be used to calculate underwater light attenuation. In shallow floodplain lakes with soft, easily resuspended sediments, near-bottom Secchi readings are unreliable. Therefore, direct optical measurements using appropriate sensors are required to characterize the underwater light climate in these systems.

Underwater light profiles of Photosynthetically Active Radiation (PAR) were conducted with a 4π quantum sensor (LI-COR, at *fig. 1*). The light profiles in figure 2 were measured in open water adjacent to macrophyte stands, without shading effects from the aquatic plants, as macrophytes or filamentous algal mats. Curve fitting was extended to 2.70 m,

Parameter	Lacul Vârsina	Lacul Babina	Gârla Lopatna	Lacul Vâcaru	Lacul Ligheanca	Dunărea Mila23	Canal Stipoc
k_{PAR} [m^{-1}]	1.160	1.345	1.395	1.441	1.460	2.055	3.585
z_{eu} [m] $z_{macr\_4\%}$ [m]	**3.97** 2.78	**3.42** 2.39	**3.30** 2.31	**3.20** 2.23	**3.15** 2.20	**2.24** 1.57	**1.28** 0.90
$z_{opt\_12\%}$ [m]	**1.83**	**1.58**	**1.52**	**1.47**	**1.45**	**1.03**	**0.59**

Table1. Optical properties of water bodies in four Danube Delta lakes (lacul), a narrow natural watercourse (gârlă), an oxbow (Dunărea Veche at Mila23), and the Canal Stipoc, including mean vertical light attenuation coefficient (k_{PAR}), the euphotic depth at 1% surface ambient light (z_{eu}), the depth of minimum light requirement for macrophyte growth at 4% surface ambient light ($z_{macr\_4\%}$), and the depth of optimum light conditions for macrophyte growth at 12% surface ambient light ($z_{opt\_12\%}$, Teubner et al. 2020, 2022). All lakes and narrow natural watercourse are macrophyte dominated water bodies of low water flow velocity, different from the oxbow and channel.

Figure 3. Danube Delta floodplain lakes are characterized by dense submerged macrophyte meadows, typically formed by mixed species such as Potamogeton crispus and Elodea nuttallii. High water transparency, even in brownish waters coloured by dissolved humic acids, is perceived by humans as indicative of good water quality (Teubner at al. 2020) (top left, Lacul Ligheanca). Phytoplankton-induced turbidity reduces light availability in the water column and consequently suppresses the growth of submerged macrophytes (top right, oxbow Dunărea Veche Mila23). Filamentous algae can form veil-like, cottony structures in the water column or mats at the surface, and wave action can wash them ashore – making them easily visible (bottom left, Canal Catavaia). Small fishing boat navigating a narrow channel – Fishermen keep small channels open between lakes, supporting hydrological connectivity of the riverine lake system (Richardson 2021, Nichersu et al. 2022). In addition to trophic conditions, connectivity and flow velocity determine the survival of submerged macrophytes (bottom right, Canal Vârsina).

corresponding to the maximum lake depth reported for Danube Delta lakes by Cristofor et al. (2003), to cover the potential depth range in the system, even though most lakes measured here differ from those in the original study (except Lacul Babina). Because these Delta floodplain lakes are very shallow, seasonal water-level fluctuations strongly affect effective lake depth (Los 1998; Nichersu et al. 2022). During the five-day LI-COR survey May 2025, water levels were relatively high compared with typical seasonal conditions.

Vertical Light Attenuation in Macrophyte-Covered Lakes Compared to Channels

Vertical light profiles were measured in a total of seven water bodies, as shown in figure 2. Light intensity, which decreases exponentially with increasing depth below the water surface, differed substantially across the studied sites. The lakes showed that even at 1.5 m depth, about 10–12% of surface light remained, thus providing a large vertical zone where macrophytes can develop and thrive. Based on underwater light attenuation, the depth of optimum ambient light for macrophytes in the five lakes and the natural watercourse averaged 1.57 m, ranging from 1.45 to 1.83 m ($Z_{opt\_12\%}$ in *Table 1*). This indicates that – under the light conditions measured in open water near macrophyte stands – there is considerable potential for macrophytes to flourish and to form surface carpets or underwater meadows.

As shown in figure 2, at all floodplain lake sites the depth of optimum light exceeds the measured depth profiles, due to the shallowness of the sampling locations. The depth of the minimum light requirement for macrophytes growth, $Z_{macr\_4\%}$, goes much deeper, averaging 2.38 m (2.20–2.78 m). The average of euphotic depth, Z_{eu}, is with 3.41 m remarkably deeper (3.15–3.97 m). The denser the macrophyte stands grow, the more self-shading comes into play. In this study, we found that directly beneath the leaves of *Nuphar lutea,* close to the leaf surface, strong shading occurs and reduces ambient surface light by 97–99% (with k_{PAR} values ranging from 44.39 to 59.30 m^{-1}, n = 5 measurements, Lacul Vâcaru, 8 May 2025). However, in less dense stands, light availability increases again with depth because natural light can

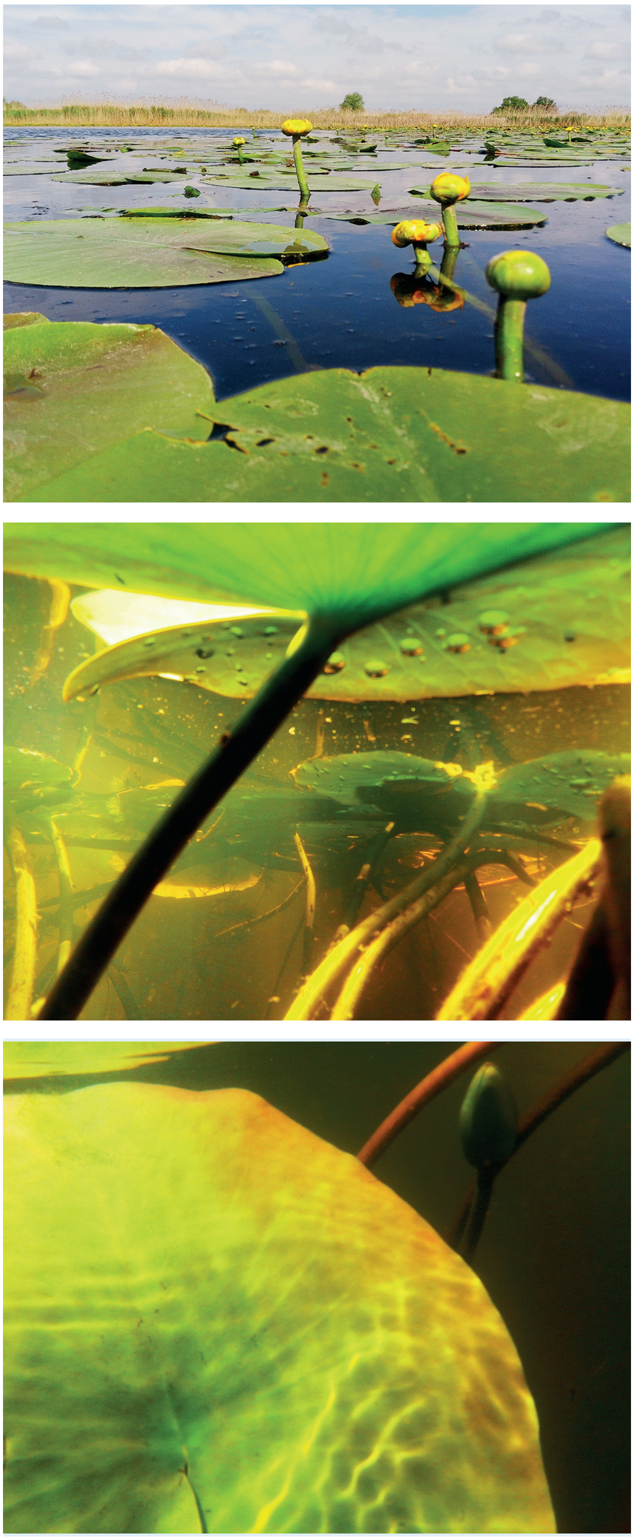

Figure 4. Nuphar lutea viewed from above (top) and below the water (middle). The underwater view shows that the leaves provide shade near the water surface, but in sparse stands sunlight can still penetrate the shallow littoral zone, ensuring good light availability near the sediment layer. Nymphaea alba showing sunlight reflected on leaves (bottom), Lacul Vâcaru, 9 May 2025.

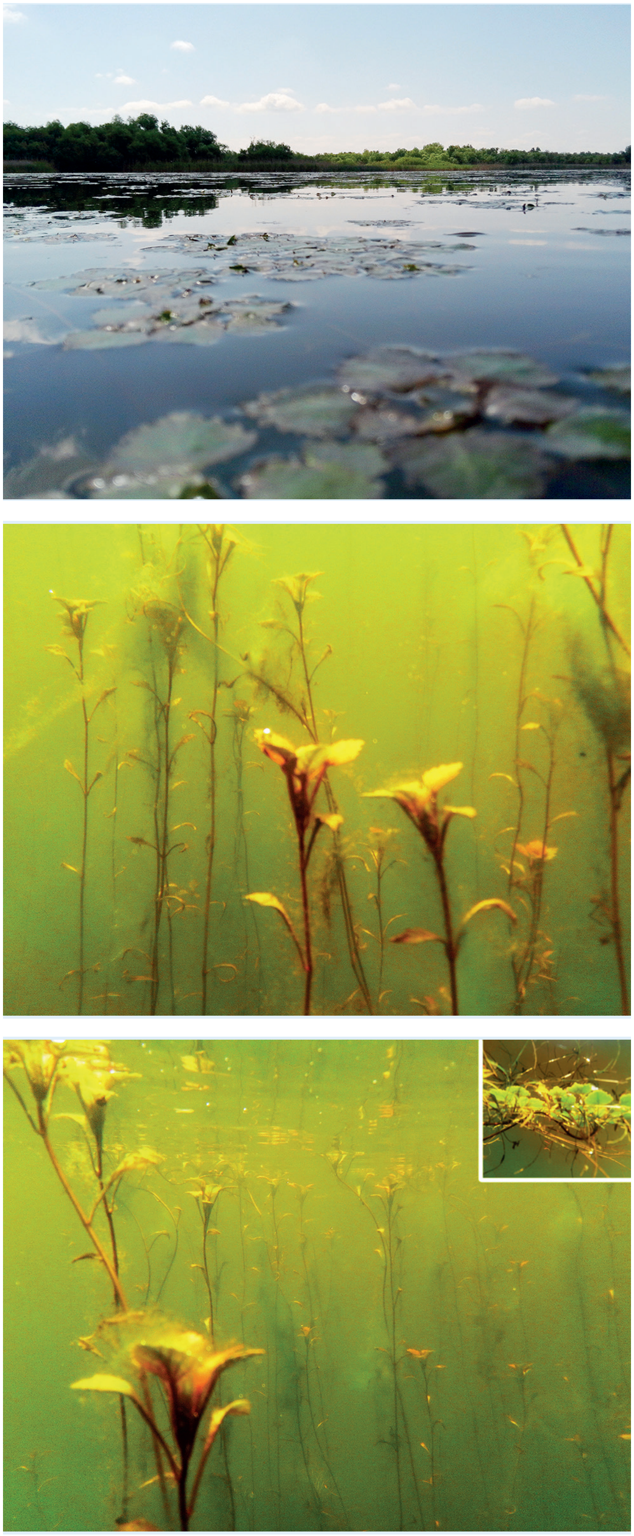

Figure 5. Trapa natans viewed from above (top) and below the water surface (middle, bottom). Dark leaf pigmentation results from photo-protective pigments adapted to high light exposure above water (top). Young spring shoots, still submerged, serve as attachment structures for filamentous algae, which form veil-like, cottony layers that persist in riverine floodplain lakes (middle). During the spring growth phase, Trapa competes with other submerged macrophytes and filamentous algae for light, ends once it reaches the water surface. After this bottleneck – when sufficient light is achieved despite turbidity caused by planktonic and attached filamentous algae in the water column – Trapa forms surface biomass carpets, providing habitat for other wetland organisms. Natural watercourse Gârla Lopatna, 7 May 2025, bottom; inset: view from below on a freshly established carpet.

pass through the loosely arranged leaves toward lake bottom (*fig. 4*, middle and bottom). This pattern differs from the usual vertical light decline in open water, as light attenuation increases with depth and light intensity decreases accordingly. It shows that single macrophyte plants – and even loose-leaf underwater canopies – do not cause substantial

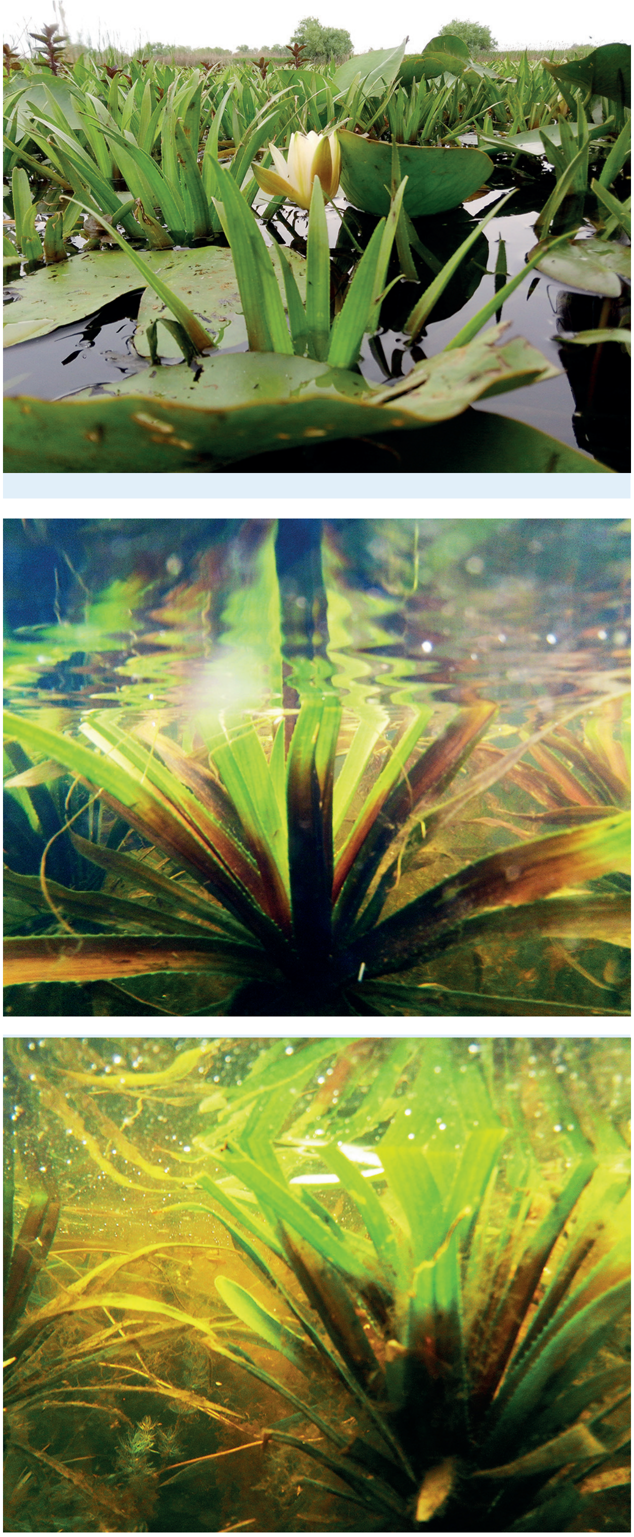

Figure 6. Stratiotes aloides seen from above (top) and underwater (middle and bottom). The stand in the middle photo is almost free of filamentous algae, unlike the bottom photo, which further shows a few shoots of Ceratophyllum demersum among dense stands of S. aloides, Lacul Vârsina, 10 May 2025.

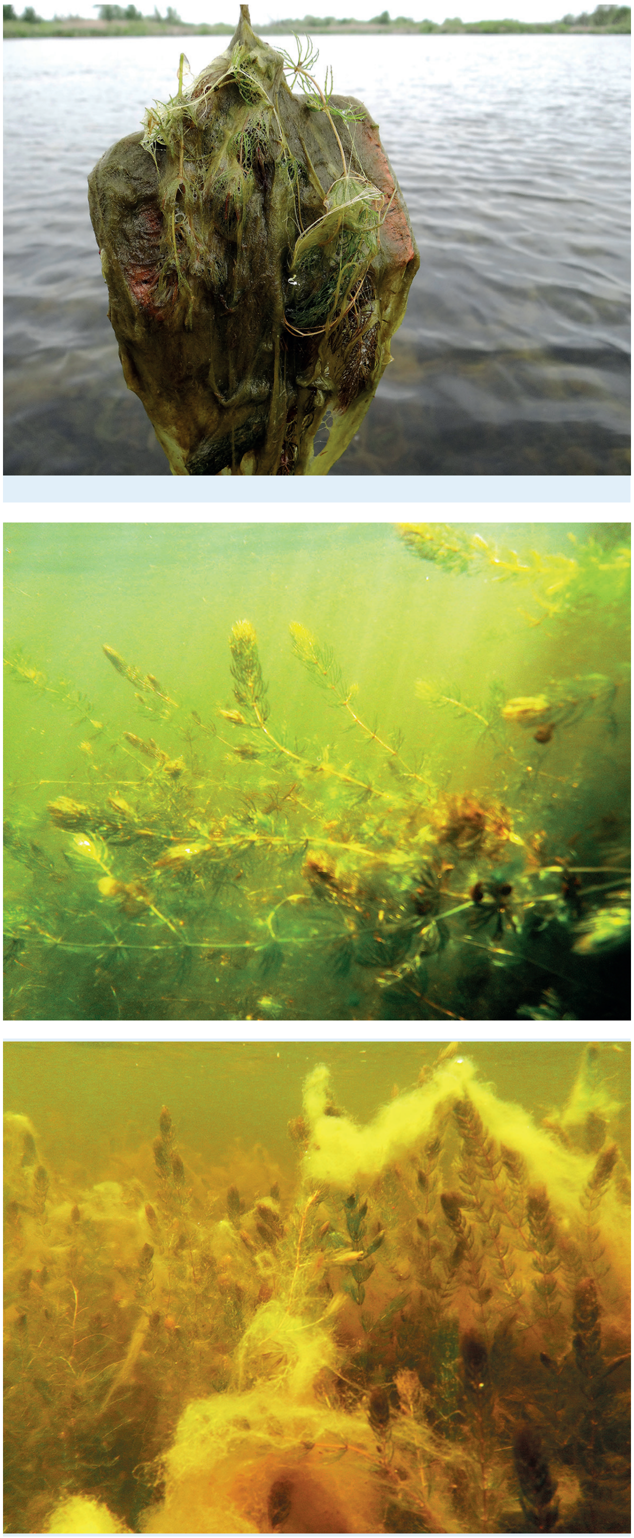

Figure 7. Ceratophyllum demersum sampled together with filamentous algae (top) and underwater stands viewed from a 'fish perspective' (middle and bottom). At first glance, the lake appears healthy due to its clear water, but extensive macrophyte stands are compromised, overgrown by filamentous algae. The middle photo shows a Ceratophyllum stand nearly free of filamentous algae, while the bottom photo depicts the common situation: the Ceratophyllum is covered by a dense, cotton-like layer of filamentous algae (10 May 2025, Lacul Babina).

shading below the water surface. It further implies that the scarcer the carpet of floating-leaved macrophytes, such as *Nuphar or Trapa*, the greater the light exposure reaching the sediment in shallow littoral zones, triggering the excessive growth of filamentous algae (Kemp et al. 2025).

The macrophytes observed at the measurement sites of these lakes included *Elodea nuttallii* (Planch.) H. St. in Lacul Ligheanca (*fig. 3*, top left), *Nuphar lutea* (L.)SM. and *Nymphaea alba* L. in Lacul Vâcaru (*fig. 4*), *Trapa natans* L. in the natural watercourse Gârla Lopatna (*fig. 5*), *Stratiotes* *aloides* L. in Lacul Vârsina (*fig. 6*), and *Ceratophyllum demersum* L. in Lacul Babina (*fig. 7*). It is worth noting that macrophytes often do not cover more than 40% of the lake area; a patchy mosaic of different species was common, and from other studies it is known that these patterns can vary seasonally and from year to year (Gaştecu 1993, 2021; Coops et al. 1999; Cristofor et al. 2003; Covaliov et al. 2003; Sârbu 2003; Schneider-Binder 2021; Janauer et al. 2021).

In contrast, in Canal Stipoc, light declined very rapidly, reaching only about 1% of surface intensity at roughly 1.5 m (*fig. 2*; Z_{eu} 1.28 m in *Table 1*). Such steep attenuation severely limits the depth zone in which macrophytes can grow under adequate light, as the minimum light requirement for macrophyte growth, $Z_{macr\_4\%}$, is met only down to 0.90 m, and the well-illuminated zone for optimal growth, $Z_{opt\_12\%}$, is even shallower at 0.59 m. Here, the $Z_{opt\_12\%}$ exceeds the measurement depth. Light attenuation at Dunărea Veche Mila23 fell between these extremes – between the lakes and Canal Stipoc – with moderate light attenuation, but as in Canal Stipoc, the $Z_{opt\_12\%}$ is shallower than the depth reached by the measured underwater light profile. It indicates that macrophyte growth cannot benefit from optimal light exposure at the canal bottom.

In the Canal Stipoc, surface-floating mats of filamentous algae were common along the channel banks. Measurements of shading beneath these mats showed a much wider range of attenuation compared with shading beneath *Nuphar leaves*, as both the thickness and areal extent of algal mats vary far more than those of individual leaves. The mean percentage of surface ambient light transmitted below the mats was 60.2%, with a median of 55.4%, ranging from 25.6% to 85.3% (Lacul Vâcaru, 8 May 2025, n = 5 measurements, *fig. 1*, right). Accordingly, light attenuation also varied widely, with k_{PAR} showing a mean of 9.3 m^{-1}, a median of 8.8 m^{-1}, and a range from 3.5 to 20.2 m^{-1}.

These patterns indicate that shallow Danube Delta lakes generally provide favourable light conditions for macrophyte expansion, if inferred from light attenuation in open water. In contrast, turbid channels such as Canal Stipoc, surrounded by degraded floodplains, restrict macrophyte growth to very shallow areas. This result aligns with the Secchi depth survey conducted in the Danube Delta by Sarbu (2003). Planktonic algal turbidity (*fig. 3,* top right), a major threat to submerged macrophytes caused by nutrient enrichment, is a common symptom of ecosystem deterioration, whereas sustainable restoration aims to re-establish submerged macrophytes and shift the system back toward a macrophyte-dominated, clear-water state (Teubner et al. 2018, 2020, 2021, Pall 2018).

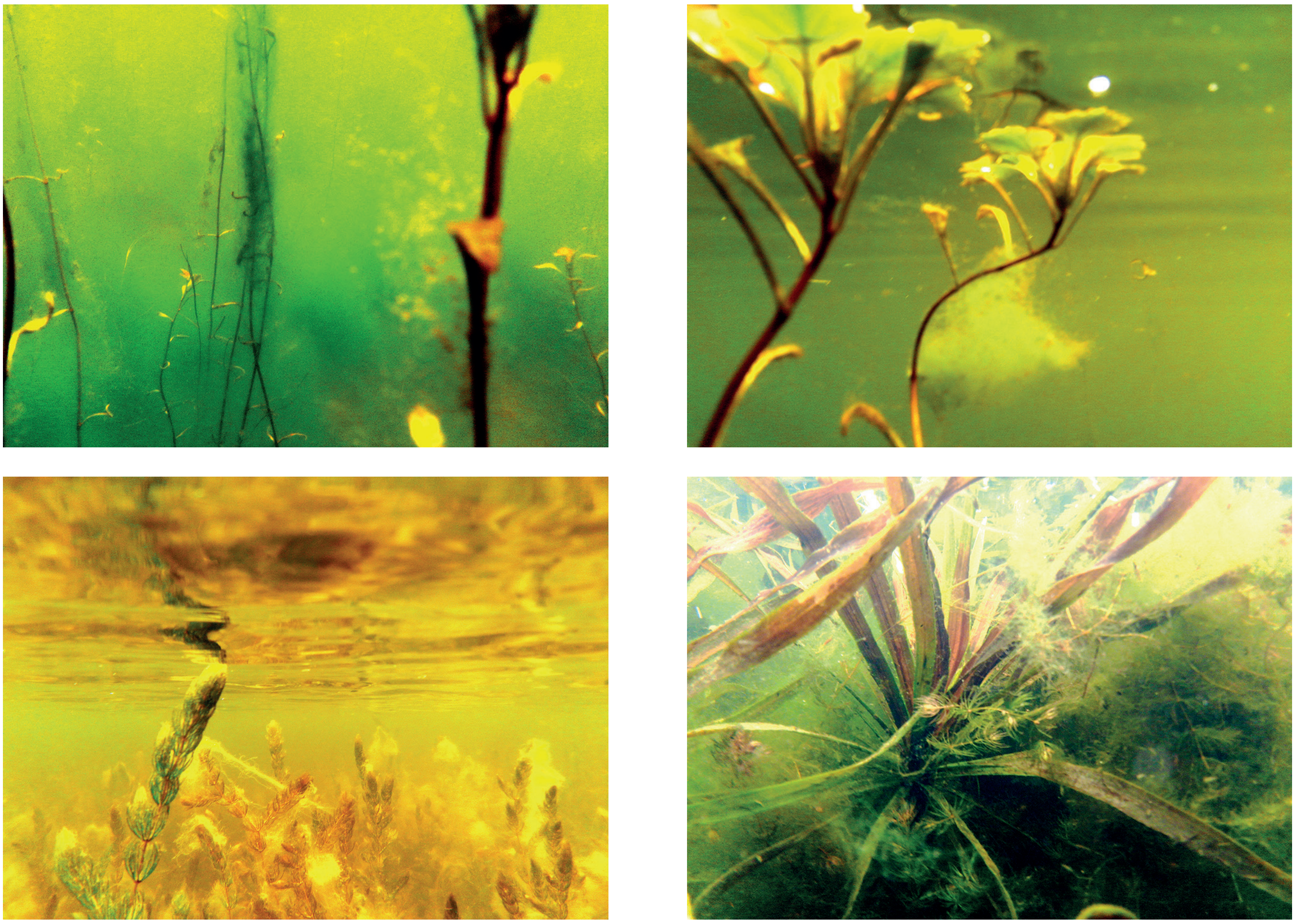

Figure 8. Summary of the concept of 'false water transparency': Apparent water clarity of water body can overestimate actual underwater light availability for stands of submerged macrophytes. Filamentous algal mats create patchy shading patterns when attached to macrophyte leaves or shoots. Shown here: Trapa natans (top left and right), Ceratophyllum demersum (bottom left), and Stratiotes aloides (bottom right).

'False transparency' can Mask early Signs of Macrophyte Decline.

Depth estimates for optimal macrophyte light requirements ($Z_{opt\_12\%}$), as well as for minimum requirements ($Z_{macr\_4\%}$, Z_{eu}), show that Danube Delta lakes offer favorable light conditions for macrophyte growth compared with other systems. Nonetheless, even ongoing recent reductions in nitrogen and phosphorus loads (Zaharia et al. 2022) have not resulted in corresponding increases in macrophyte abundance. The opposite trend was noted by Schneider-Binder (2021), who reported for example a clear decline in water chestnut despite remaining notable populations. Filamentous algae, however, appear to have proliferated in recent years, as observed by local fishermen, consistent with Covaliov et al. (2003), who noted low-abundance mats among macrophytes in June 2001, reflecting a trend reported globally. Conventional light assessments in the open water site of a lake – Secchi depth and open-water PAR profiles – however, do not account for shading generated by epiphytic filamentous algal mats, attached to macrophytes or floating at the lake water surface (*fig. 1*, right, *fig. 3*, bottom right). These algal species including *Cladophora glomerata, Hydrodictyon reticulatum*, and *Spirogyra* sp. in the Danube Delta (Covaliov et al. 2003) can even outcompete macrophytes under moderately eutrophic, warm, and clear-water conditions (Ozimek et al. 1991; Kemp et al. 2025). Droughts in the delta lead to a progressive loss of aquatic habitats (Jitariu et al. 2022), which at first glance compromises further stands of many submerged macrophyte species. In contrast, filamentous algae seem to gain a short-term advantage from increasingly shallow, warmer, and more transparent water bodies before these areas ultimately dry out due to prolonged aridity, driven by climate change and insufficient management to mitigate these global impacts.

The current Danube ecosystem status of a flourishing underwater, cotton-like layer of filamentous algae results in 'false transparency', where visually clear water overestimates actual light availability in the submerged macrophyte zone. Observations reveal that macrophytes such as *Trapa natans, Ceratophyllum demersum, Stratiotes aloides* (*fig. 8*), and even invasive species such as *Elodea nuttallii* (Lupu et al. 2025) are frequently covered by epiphytic filamentous algae during this May survey. The widespread occurrence of dense, veil-like algal structures and floating mats in the Delta indicates an increasing risk of macrophyte suppression. Restoration efforts mitigating further ecosystem degradation must therefore prioritise promoting macrophyte communities capable of thriving under low-nutrient conditions. Only then can open-water transparency return as a reliable indicator of ecological quality.

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Coordinated water resources allocation in the Hungarian part of the Tisza River Basin

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Abstract

The Tisza–Körös Valley Integrated Water Management System (TIKEVIR) represents one of Hungary's most complex hydraulic networks, designed to balance the spatial and temporal distribution of water resources across the Great Hungarian Plain. This study analyzes the coordinated operation of the system during the 2025 water scarcity period, focusing on the implementation of the Water Restriction Action Plan and the introduction of system-wide operational scheduling. Based on daily hydrological monitoring and the application of reduction factors (r_t), water allocations were dynamically adjusted to match available discharges and user demands. Despite critical low-flow conditions comparable to the 2022 drought, adaptive management enabled the retention of approximately 15 million m³ of surplus water in Lake Tisza and the transfer of more water to the Körös Valley. The results demonstrate that coordinated scheduling significantly improved the efficiency and equity of water resource distribution under constrained conditions. The applied methodology provides a replicable framework for enhancing drought resilience and sustainable water governance in large-scale lowland hydrosystems.

Introduction

The Tisza Valley is one of Hungary's most significant hydrological and economic regions, covering about 45% of the country's territory. The Tisza River and its tributaries – such as the Bodrog, Sajó, Zagyva, Körös and Maros – shape the natural landscape, agricultural potential, and settlement structure of the Great Hungarian Plain (ICPDR, 2019). Water management in this region is particularly complex, as it must simultaneously address flooding, inland waterlogging, and drought, while ensuring the sustainable use of water resources.

Due to the flat terrain and poor drainage, inland waterlogging is another major issue in the Tisza region, especially during wet winters and springs (Somlyódy, 2011). The total length of inland drainage canals exceeds 30,000 km. However, with the growing impacts of climate change, water retention has become increasingly important. The goal is not only to reduce damage but also to stabilize groundwater levels and support the water needs of natural ecosystems and for irrigation purposes.

The Tisza Valley is among the driest regions of Hungary, and drought has become an increasingly severe economic problem, particularly for agriculture, which depends heavily on irrigation. In recent years, there has been a strong emphasis on irrigation development and efficient water use. The Kisköre Reservoir (also known as Lake Tisza) plays a key role in this system: it regulates water flow, supplies irrigation water, and also serves recreational, fisheries, and environmental protection purposes.

The northeastern region experiences the harshest winters, the central area is the driest, while the southeastern part has the warmest summers. In the southern Great Plain, the mean annual temperature exceeds 11 °C, whereas in the northeast it remains slightly below 10 °C. Summers are the hottest (with a mean July temperature of around 21 °C) and winters the coldest in this area. The annual total of sunshine hours exceeds 2,000 over most of the Great Plain. The lower cloud cover, reduced relative humidity, and limited, highly variable precipitation contribute to the frequent occurrence of summer droughts.

An analysis of the temporal and spatial characteristics of drought events indicates that all major droughts occurring in Europe have historically affected Hungary as well. Projections suggest that approximately 90% of the national territory is likely to be exposed to drought conditions, with the lowland areas exhibiting the highest degree of vulnerability. Nevertheless, the detrimental effects of droughts can be alleviated through the adoption of integrated water management approaches and the application of efficient irrigation technologies (Tamás, 2016).

In Hungary, the regional Water Directorates are responsible for ensuring the provision of water at the appropriate locations and times. To enhance resilience against extreme hydrometeorological phenomena, the Hungarian 'National Water Strategy' prescribes both short- and long-term measures. Achieving these objectives, particularly the adequate water supply for lowland areas even during exceptionally dry years such as 2022, requires a high level of preparedness. The foundation for such efforts lies in the Tisza–Körös Valley Integrated Water Management System (TIKEVIR), which provides the technical and engineering framework for water distribution in the Great Hungarian Plain. The primary purpose of establishing TIKEVIR was to secure water resources, implement regulated water governance, and mitigate the impacts of hydrometeorological extremes across the region (Vizi et al., 2018).

Tisza–Körös Valley Integrated Water Management System (TIKEVIR)

The Tisza–Körös Valley Integrated Water Management System (TIKEVIR) is one of Hungary's most complex and extensive lowland water management systems. Covering an area of approximately 12,000 km² between the Tisza and

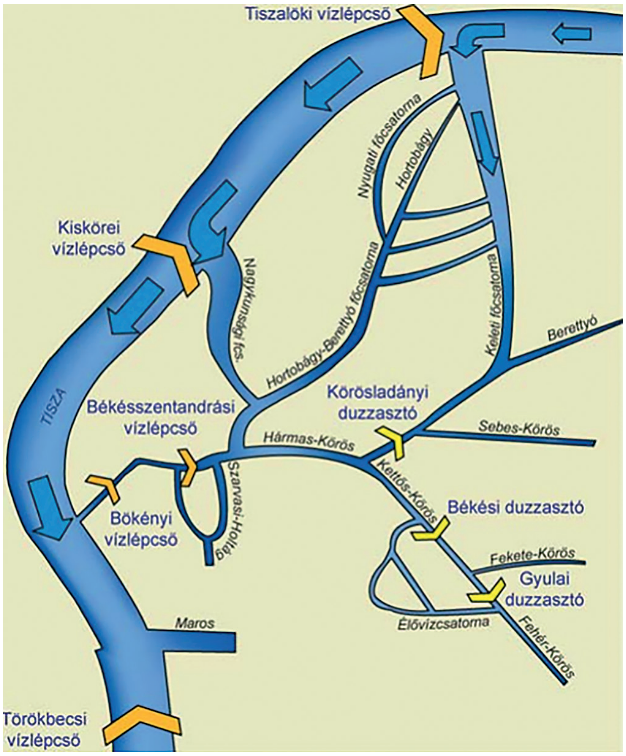

Figure 1. Schematic layout of the Tisza–Körös Valley Integrated Water Management System (TIKEVIR) (source: General Directorate of Water Management).

Körös rivers, its primary objective is to balance the effects of water scarcity and water abundance by enabling the spatial and temporal redistribution of water resources. This regulation serves agricultural production, municipal water supply, as well as ecological and recreational needs in the region.

The central element of TIKEVIR is the Kisköre Dam (Lake Tisza), which regulates the flow of the Tisza River and allows controlled water transfer towards the Körös Valley, the Nagykunság, and the Hortobágy regions. Its main conveyance channels – such as the Nagykunság Main Canal, the Jászság Main Canal, and the Hármas–Körös–Berettyó connection – form an interconnected network that enables multi-directional water movement (*fig. 1*). The operation of the system is supported by automated hydraulic structures, sluices, and pumping stations that ensure precise quantitative and qualitative water regulation.

Beyond irrigation, TIKEVIR performs complex water management functions, including inland drainage, flood control, and ecological water supply to the Körös Valley. In recent years, system development has focused on climate-adaptive water retention, digitalized operational control, and sustainable water resource management. TIKEVIR plays a key role in maintaining water security in the Tisza Valley and preserving the overall hydrological balance of the Great Hungarian Plain.

Hydrology

In certain parts of the TIKEVIR system, the satisfaction of water demands had already become limited by the end of June. In some sections of the Hármas–Körös and Kettős–Körös rivers, the discharge values turned negative, and the rate of evaporation also increased. An important consideration was the establishment of a unified priority ranking, taking into account both licensed and extraordinary water demands. According to the 'Hungarian Act LVII of 1995 on Water Management', ecological water replenishment has priority over agricultural water use, and it was not clearly clarified which water supply belongs to which category.

On the day when the water resources allocation was ordered according to the Water Restriction Action Plan (1 July 2025), the discharge of the Hungarian section of the River Tisza was comparable to the lowest flow conditions observed during the severe water scarcity period of 2022 (Vizi, 2023) (*fig. 1*). On the free-flowing section downstream of the Kisköre Dam, due to the recent developments of the surface water intake facility at Szolnok, maintaining a minimum discharge of 58–61 m^3/s was sufficient at Kisköre, instead of the former minimum requirement of 65 m^3/s. As a result, approximately 15 million m^3 of additional water could be retained in Lake Tisza during the summer period.

Operation under reduced downstream water levels resulted in the establishment of new Low Water Reference (LWR) levels at Kisköre-alsó (-342 cm), Tiszaroff (-383 cm), and Szolnok (-301 cm). To maintain the operational safety of the Szolnok surface water intake facility, a provisional structure was once again constructed during the 2025 water scarcity management period.

At Tiszalök, during the mitigation operations, the diverted discharge temporarily fell below 60 m^3/s on two occasions: between 18–20 August (minimum 51 m^3/s) and between 9–10 September (minimum 57 m^3/s).

Throughout the year, water replenishment of the Körös Valley via the Nagykunság Main Canal exceeded the prescribed discharge of 16 m^3/s during several intervals. Between 12–18 July and 21 July–8 August, the combined discharge through the eastern and western branches reached 20–24 m^3/s. Conversely, during the period of 18–26 August, reduced transfer rates had to be maintained, with the eastern branch flow decreasing first to 12 m^3/s and subsequently to 10 m^3/s.

During the flow regulation period (1 July–15 September), approximately 65 million m^3 more water was transferred to the Körös Valley compared to the same period in 2022. Throughout the summer, water transfer through the Keleti Main Canal was continuously maintained at the maximum level permitted by technical constraints. Nevertheless, it should be emphasized that increasing the discharge capacity through the Bakonszeg structure would be desirable to enhance future operational efficiency.

To facilitate the most effective execution of water distribution, discharge measurements were carried out across the extended impact area of the TIKEVIR system. The results of these discharge measurements provided essential input data for the daily water balance calculations.

Water resource sharing based on the TIKEVIR Water Restriction Action Plan

The water use restrictions were necessitated by the natural decline in available water resources and the concurrent increase in water demand. The resulting constraints must be borne equitably by all water users within the TIKEVIR system. The degree of restriction applied within the irrigation systems (denoted as rt, the reduction factor) is determined for each subsystem by the ratio between the daily transferable water volume and the total daily water demand.

The efficient allocation of available water resources was greatly facilitated by several moderate increases in discharge that occurred on four occasions during the summer, due to rainfall events in the upper Tisza catchment area. Each of these episodes provided an opportunity to replenish stored water reserves – such as those in Lake Tisza and the irrigation canals. In contrast, no significant runoff-generating precipitation occurred in the Körös catchment area; however, under more favorable hydrological conditions, the water replenishment to the Körös Valley via the Nagykunság Main Canal was temporarily increased by 5–6 m³/s.

Considering the TIKEVIR system as a whole, the highest recorded daily water demand occurred on 24 July 2025, reaching 96.8 m³/s, while the lowest reported demand (39.6 m³/s) was observed on 15 September.

During the 77 days of coordinated water resources allocation, temporary increases in river discharge allowed for 15 days when it was not necessary to reduce the reported water demands through scheduling adjustments. However, during the remaining 62 days of the two-and-a-half-month period, varying levels of demand reduction were required.

The lowest reduction factor was recorded on 30 August, when only 31.2% of the reported water demand could be met within the Tiszalök subsystem, and merely 28.4% within the Kisköre subsystem. By that time, however, the overall reported demand across the TIKEVIR system had already decreased to approximately two-thirds (60.4 m³/s) of the seasonal maximum of 96.8 m³/s.

Water allocation scheduling in the extended TIKEVIR System

The extended TIKEVIR system integrates multiple hydraulic subsystems and irrigation networks across the Tisza River Basin, requiring coordinated operational management during periods of limited water availability. Water allocation scheduling serves as a key component of this management framework, ensuring the equitable and efficient distribution of available water resources among users while maintaining ecological flow requirements. This process relies on continuous hydrological monitoring, dynamic assessment of inflow and demand patterns, and the application of reduction factors (r_t) to balance system-level water use with daily transferable capacities. The methodology applied during the 2025 water scarcity period aimed to optimize the use of constrained water resources

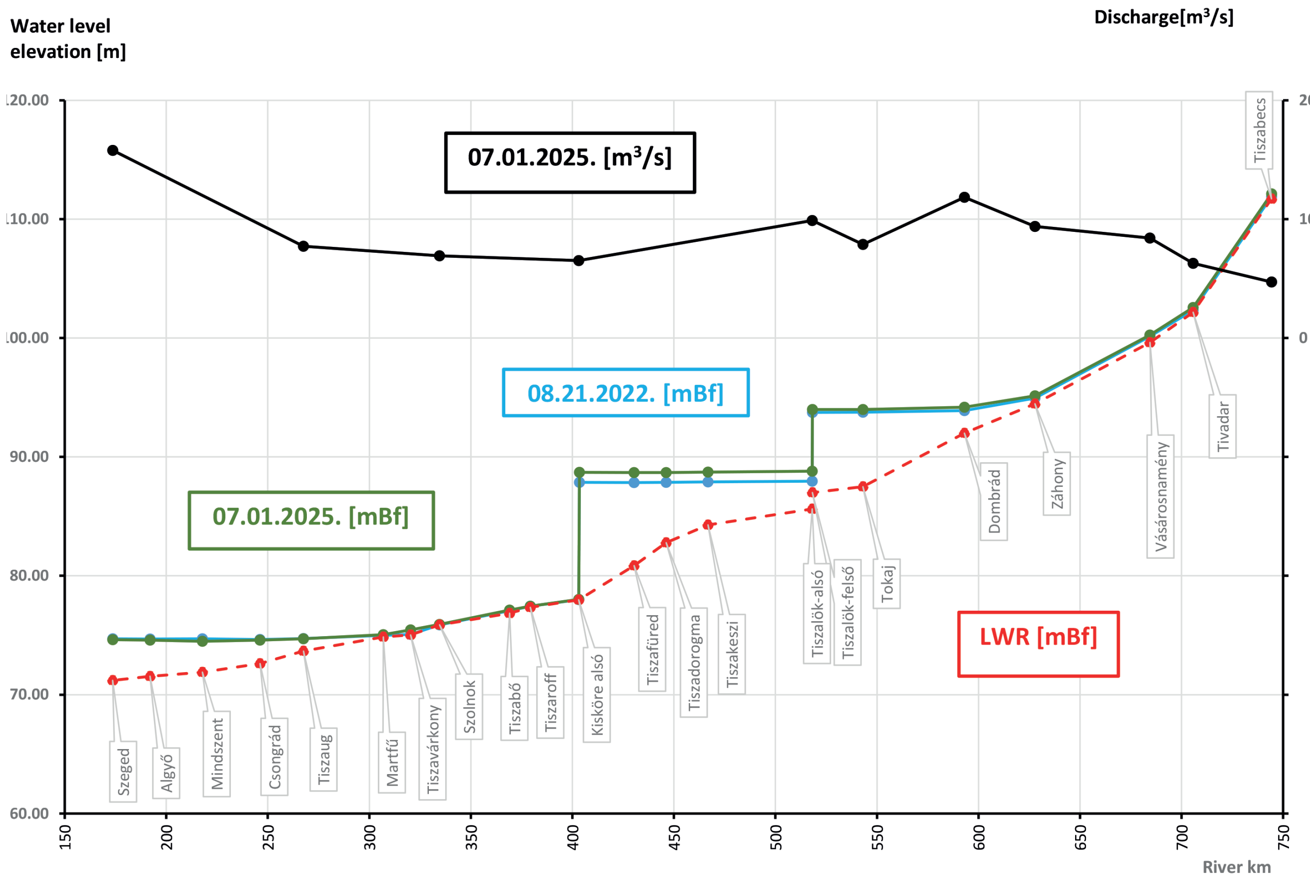

Figure 2. Hydrological situation along the Tisza River compared to the minimum level of 2022. Copyright: Dávid Béla Vizi

while minimizing the adverse impacts on agricultural production and ecosystem services.

In order to ensure the most efficient and economical distribution of available water resources, the regional Water Directorates introduced subsystem-level operational scheduling within their operational area. This approach aimed to reduce the magnitude of simultaneous water withdrawals across the system.

The implementation of scheduling allowed for the limistation of concurrent abstractions, and, when necessary, for the reduction of the maximum withdrawal rate at individual intake points. The scheduling process covering the extended TIKEVIR system required careful coordination and close monitoring. The target discharge values were calculated daily as the product of the reduction factor and the total requested discharge. These values were determined based on the available water resources and the concurrently reported water demands, according to the TIKEVIR Water Restriction Action Plan.

KÖTIVIZIG evaluated the effectiveness of the scheduling each day by comparing the allocated discharges with the quantities of water that could be distributed according to the reduction factor within the extended TIKEVIR system.

As illustrated in figure 3, throughout the period between 1 July and 15 September, the total discharge released for water replenishment under the scheduling regime only persistently exceeded the reduction-factor-adjusted target between 13 and 21 August. This corresponded to the period when the required water quantities could only be supplied by utilizing the surplus water stored in Lake Tisza, resulting in a notable decrease in upstream water level – up to 3–4 cm per day. During the entire mitigation period, the total actual discharge released through the scheduling process remained significantly lower than the total reported demand (blue columns in *fig. 3*) on a system-wide scale.

There were certain periods during which individual Water Directorates exceeded the water volumes calculated for them based on the respective reduction factors. However, apart from the previously mentioned interval, these deviations did not result in sustained overuse at the overall TIKEVIR system level, as other Directorates simultaneously utilized considerably less water than their allocated quotas.

At the TIKEVIR system scale, the highest recorded discharge occurred on 25 July 2025, amounting to 56.0 m³/s, which represented 58.3% of the total reported demand on that day (96.1 m³/s).

It can be concluded that the coordinated and system-wide implementation of operational scheduling enabled a substantially more efficient and balanced distribution of available water resources.

Conclusions

Water management in the Tisza Valley is one of Hungary's most complex and vital environmental, economic, and social issues. The 19th-century river regulations created safer living

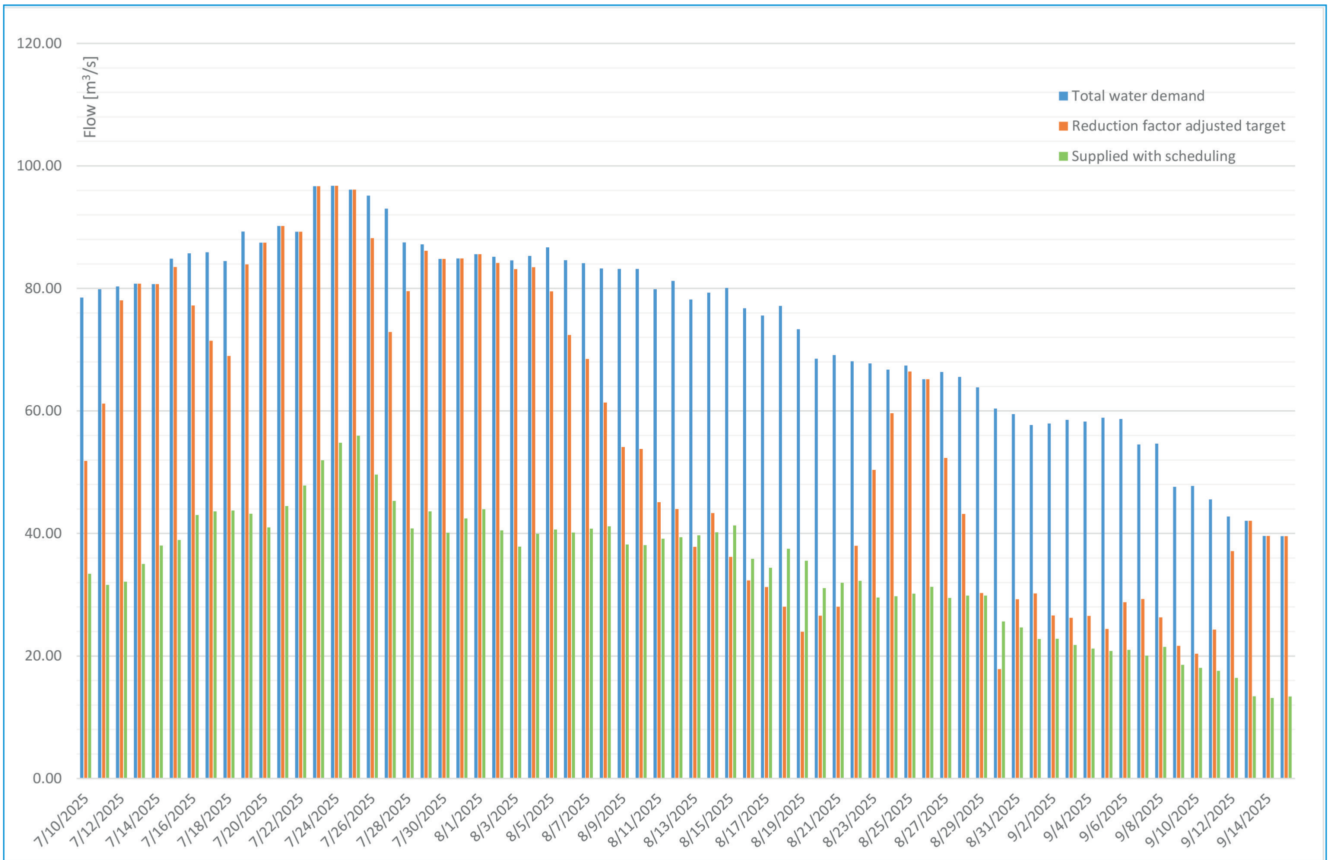

Figure 3. Total water demand and the reduced value by the reduction factor compared to the water volumes delivered by scheduling. Copyright: Dávid Béla Vizi

conditions, but the modern challenges of climate change, drought, and water quality require new, flexible, adaptive solutions. The future of water management in the region lies in water retention, maintaining ecological balance, and strengthening cooperation between regions and countries.

The research analyzes the implementation of the Water Restriction Action Plan, which established a regulated framework for equitable water distribution among irrigation, municipal, and ecological users. The study emphasizes the introduction of operational scheduling within the extended TIKEVIR system, designed to harmonize subsystem-level water abstractions and to optimize the utilization of limited water resources through the application of reduction factors (r_t). Daily discharge targets were dynamically adjusted in accordance with the available water stocks and concurrent demands, enabling responsive and data-driven system management.

Hydrological observations revealed that, by late June, several sections of the system experienced restricted water availability, with minimum discharges comparable to those recorded during the 2022 drought. Despite this, effective coordination allowed the maintenance of critical ecological flows and the retention of approximately 15 million m³ of additional water in Lake Tisza. During the 77-day allocation period, 65 million m³ more water was transferred to the Körös Valley compared to 2022, while demand reductions were necessary on most days to ensure sustainability.

Overall, the study demonstrates that coordinated, system-wide scheduling significantly enhanced the efficiency and fairness of water allocation within the TIKEVIR network. The adaptive management framework applied in 2025 provides a model for future drought resilience and sustainable water governance in large-scale lowland hydrosystems such as the Tisza Basin.

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The Tisza Basin – Source of Innovative Solutions to Plastic Pollution in Rivers

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Plastic pollution in the Tisza River Basin

The Tisza (Тіша/Tisa/тиша/Theiss) is the Danube's longest tributary, stretching over 960 kilometers. Like the Danube, it is an international river, collecting water from five countries (Ukraine, Romania, Hungary, Slovakia, and Serbia) before joining the Danube. It drains the largest sub-basin of the Danube River Basin, covering a catchment area of more than 157,000 km². The Tisza River Basin lies within the Mid-Danube or Pannonian Basin – an area of almost 300,000 km² where four of the Danube's largest tributaries meet: the Morava, Drava, Sava, and Tisza. Historically, about 10% of the basin was covered by rivers, lakes, and wetlands, a landscape comparable to present-day Finland (Bódi, 2014; Jurvelius, 1983). During flood periods, the water-covered area could double or even triple, the extent and structure of surface waters in the medieval Pannonian Basin were visualised with the help of artificial intelligence (Jakab et al., 2025). By the mid-19th century, however, extensive river regulation and drainage works radically transformed the basin. Approximately 85–90% of surface freshwater has been lost since then (Werners et al., 2010), making it the second-largest loss of surface waters in the world after Ireland (Fluet-Chouinard et al., 2023). River meanders were cut off, and almost all natural watercourses were confined between levees. The Tisza alone lost 112 of its meanders, shortening its length from 1,419 to 962 km, while its floodplain shrank to less than 10% of its original size (Lászlóffy, 1982). This transformation disrupted local water cycles, intensified droughts, and increased the impacts of climate change – including extreme floods, water scarcity, and desertification. It also unintentionally worsened plastic pollution. The faster flood waves and higher flow velocities of regulated rivers now transport massive amounts of floating waste. In effect, during every flood, the river flushes out its accumulated pollution, sweeping plastic from floodplains downstream. Although the EU Water Framework Directive and the EU Mission Restore Our Ocean and Waters have improved water quality in EU countries, transboundary rivers such as the Tisza, with its source lying outside the EU, remain difficult to manage.

Today, the Tisza is among the most plastic-polluted tributaries of the Danube, the abundance of passing PET bottles often exceeding the 50 items/minute threshold (*fig. 1 & 2*).

Floating riverine litter accumulations – the riverine counterparts of marine garbage patches – can reach considerable sizes. In front of the Kisköre Hydropower Plant, the riverine litter accumulation sometimes covers more than 1.5 hectares, large enough to be visible from space (Magyar et al. 2023). The scale of plastic pollution has attracted growing scientific attention. Thanks to years of dedicated research, the Tisza River Basin is now one of the most extensively studied freshwater systems in the world in relation to plastic pollution. Research ranges from microplastic analyses, long-term citizen science monitoring and remote sensing surveys (Mohnsen, A. et al, 2023), to particle-tracking models and GPS-based litter tracking (Tikász G. et al., 2025). These studies have made it possible to understand the dynamics of plastic transport in the river and to estimate the amount of pollution with increasing accuracy. According to citizen science data, more than 3,500 plastic-polluted sites have been identified along Tisza's floodplain, with the tributaries also affected: along the Bodrog River, for example, around 0.65 tons of plastic waste per river kilometer have been documented in floodplain deposits (Molnár et al. 2024). Since these deposits mostly contain only the most buoyant plastics, the real plastic accumulation rates are likely much higher. Field reports indicate that stranded riverside plastic pollution harms wildlife – from abandoned white-tailed eagle nests to storks suffocating on swallowed rubber straps (Milvus foundation, 2023). But the environmental problem of riverine plastic pollution has also inspired innovation and community action.

Figure 1. Plastic flood event on the upper section of the Hungarian Tisza, close to the settlement of Vásárosnamény. The pollution is halted by the steel barges of the Upper Tisza Water Authority Directorate. Credit: FETIVIZIG

River Cleanup methodologies for experts and communities alike

Across the Tisza River basin, several water management authorities are actively involved in collecting and managing floating river waste (*fig. 1*). Among them, two Hungarian regional directorates stand out: the Upper Tisza District Water Directorate (FETIVIZIG) and the Middle Tisza District Water Directorate (KÖTIVIZIG). Both have decades of experience in river cleanup operations, using workboats and heavy machinery to remove floating solid waste from the

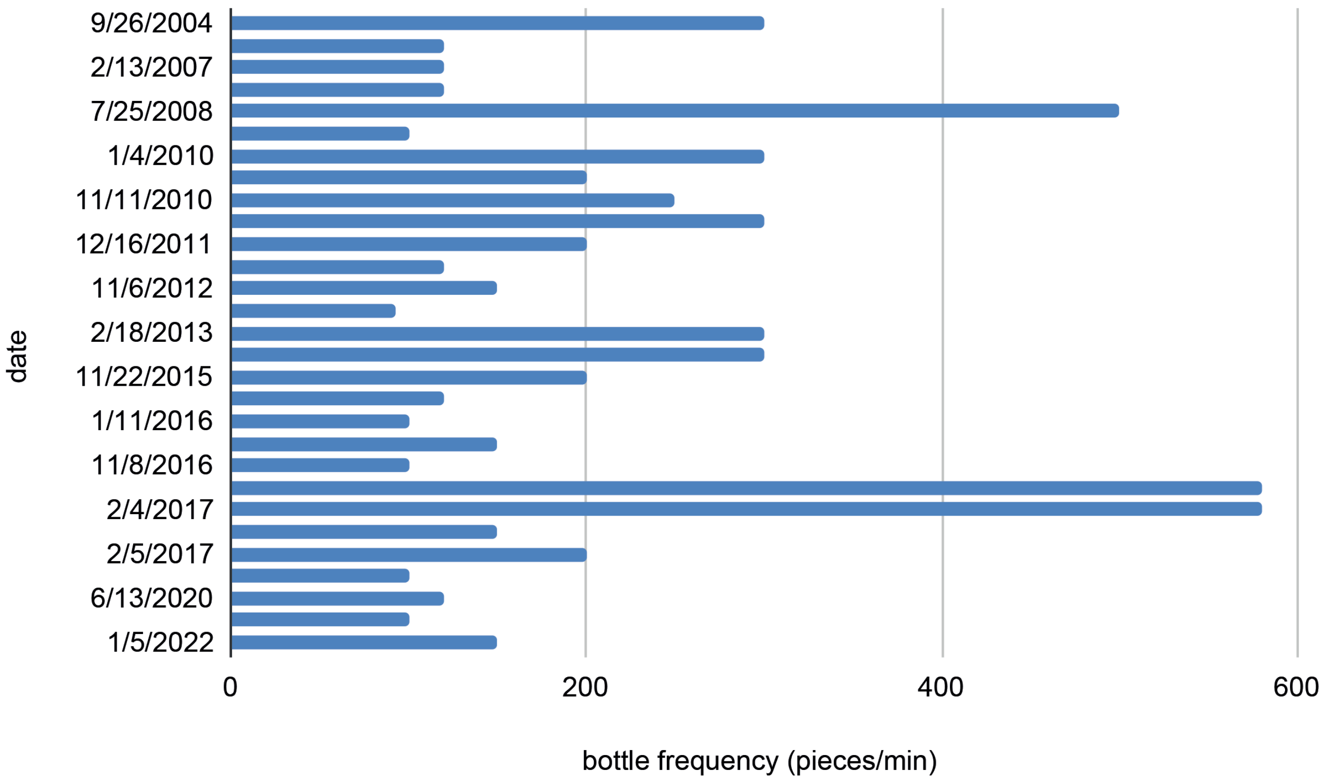

Figure 2. Plastic pollution waves with bottle frequencies exceeding the 90 items/minute threshold between 2004 and 2022 on the river Tisza based on personal field observations carried out by the Hungarian Water Authority Directorate FETIVIZIG. Credit: Zsuzsanna K.né Timkó Dr., Krisztián Szentirmai, József Veres, Gábor Molnár

water (*fig. 3*). In recent years, Romanian water authorities have also joined these efforts, particularly along the Someș and Criș rivers, where regular cleanup operations now take place. Most of the recovered waste is still sent to landfills or incinerated. Hungary offers an encouraging exception: through collaboration between its water management agencies and the civil initiative Plastic Cup, the more sustainable circular economy approach is applied.

The Plastic Cup (PET Kupa in Hungarian) initiative, an active partner of EU-funded projects such as DALIA (https://www.dalia-danube.eu/) and Aquatic Plastic (https://interreg-danube.eu/projects/aquatic-plastic/news), has been developing sustainable river cleanup methods for more than a decade. During this time, the initiative has removed over 440 tonnes of riverine litter from the Tisza – and successfully recycled about 60% of it (*fig. 4*). Even more remarkable are the results in prevention: through small-scale investments in upstream source areas such as Ukraine, more than 1,200 tonnes of household waste were prevented from entering the river system in just two years (Bitter & Hankó, 2023). These preventive actions combine local capacity building, equipment provision, and awareness raising – especially in vulnerable regions such as war-affected Transcarpathia. Through Erasmus+ educational projects, Plastic Cup has introduced environmental programs where teachers and students learn about plastic pollution, adopt river sections, monitor litter, and take part in cleanup actions. At the start, the program relied on the Ocean Literacy educational framework, endorsed by the United Nations and the European Union (McRuer et al., 2024). However, it soon became clear that while ocean literacy provided a strong foundation, it was not fully suitable for riverside communities. Educators found that the connection between local people and their rivers had weakened so much that teaching about rivers required a new approach – one that could rebuild this relationship and help people appreciate rivers as living and life-supporting systems.

The adaptation of Ocean Literacy into River Literacy

The ongoing pollution of rivers in Central and Eastern Europe has changed how communities perceive their waterways. To help reconnect them with water, the Riversaver platform was launched in 2025. Available under riversaver.eu, the open-access platform is built on open-science principles, collecting and sharing practical, field-tested solutions to tackle plastic pollution in rivers across the Danube Basin and beyond. A strong emphasis is placed on education. In cooperation with the Erasmus+ Programme, experts and educators from five Danube countries developed an adapted educational framework called River Literacy, working with 40 schools, more than 75 teachers, and over 1,000 students (Molnár et al., 2025). Educational materials were published in four Danube languages and English, focusing on involving students and communities in hands-on activities such as river monitoring, cleanup actions, and river section adoption. The River Literacy Frame-

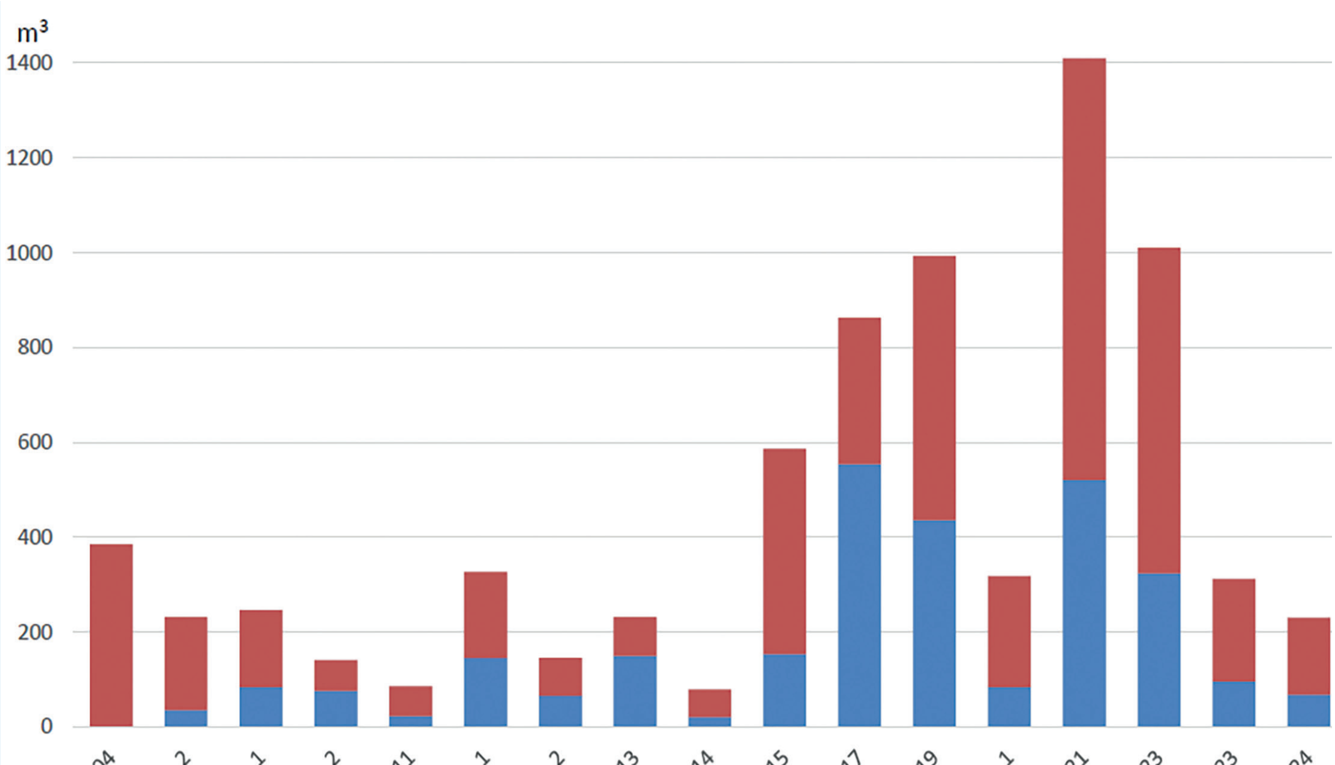

Figure 3. Temporal overview of extracted amounts of riverine litter as per data provided by Hungarian Water Authority Directorate KÖTIVIZIG between years 2004 and 2025. Garbage (KÖTIVIZIG's term for anthropogenic riverine litter) highlighted with BLUE color, Usable Wood (KÖTIVIZIG's term for driftwood) highlighted with RED color. Credit: Attila Lovas, Melinda Váczi, Tisza Office

work builds on and complements Ocean Literacy, transforming complex hydrological and ecological concepts into seven simple, memorable principles, published recently:

1. Everything that happens to the river affects the ocean.
2. The lives of rivers and people are closely connected.
3. Every river is vulnerable and deserves protection.
4. The river gives life, but it can also take it away.
5. The river is a shared heritage, not a commodity.
6. The river and its life shape the landscape, the weather, and the climate.
7. The river and its creatures are largely unexplored.

Figure 4. The recycled riverine litter can take surprising forms. Riversaver kayaks are made out of environmental plastics, mainly the polyethylene fraction of the plastic pollution collected on the river Tisza. Credit: Eniko Kubinyi

River Literacy is more than an educational concept – it is also a call to action. It encourages hands-on participation through citizen science, cleanup campaigns, and community stewardship. It helps people feel connected to their environment again, reducing eco-anxiety and fostering what many describe as 'blue therapy'. Recent studies have shown that cold water swimming and exposure to 'blue spaces' can enhance well-being and mood, while also reducing anxiety (Britton et al., 2020; Miller et al., 2024). Within the educational framework of River Literacy, blue therapy has a broader context: it refers to a wide variety of recreational and environmental educational activities (e.g., reading, co-working, meditation, yoga, and rowing) carried out by the riverside. This new dimension highlights the potential mental health benefits of human–river interactions. It aims to alleviate the anxiety associated with water-related environmental stressors, including pollution, droughts, and climate change. Although still evolving, River Literacy shows great promise. Once widely adopted, it could reconnect people to rivers and reshape how we understand and care for freshwater ecosystems – just as Ocean Literacy transformed our perception of the seas.

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Young Danube Research Workshop: Beyond Spreadsheets

Figure 1. Peter Lieberzeit on navigating the line between responsible application and academic misconduct when using AI in academic research. Photo: Melissa Hiltl

Since the beginning of the year, PhD researchers in Vienna working on topics connected to the Danube have been meeting up to provide a forum for exchange and connection across disciplines and institutions, with support from the Austrian Committee for Danube Research. The 'Young Danube Research' events are organised voluntarily by researchers at BOKU University and University of Vienna and respond to needs identified by early career scientists, including social meet-ups, sharing experiences of methods and tools as well as the academic world more generally.

On Wednesday, 7 May 2025, the first workshop organized by the Young Danube Research Group took place at the Wilhelm Exner Haus of BOKU University. Under the title 'Beyond Spreadsheets', this half-day workshop offered an opportunity for PhDs to explore a variety of digital tools beyond traditional excel spreadsheets, focusing on how these tools can support us in conducting research, publication writing, and teaching.

Figure 2a and b. Impressions from the summer picnic on Danube island, Vienna. Photo: Daniela Hatzenbühler

Early-career scientists discussed with peers and senior researchers the potentials and challenges of applying digital methods, especially Large Language Models like ChatGPT.

Laura Ganglgruber and Peter Lieberzeit (University of Vienna) opened the floor with insightful talks on how AI tools can be integrated responsibly into the academic workflow – raising important questions about the ethical and legal boundaries, which led to a lively and thoughtful discussion.

Further contributions by Johannes Kowal, Martin Tschikof, Katharina Bauer, and Diana Hatzenbühler (all either current or recent PhD researchers at BOKU or University of Vienna) showcased a wide range of research tools, including ecological network analysis, fuzzy cognitive mapping, participatory GIS, and working with R. These talks inspired lively breakout sessions, being used by participants to discuss methods in more depth and for exchange on experiences.

A big thank you to everyone who joined us, shared their insights, and made this event such a great first workshop, and we're excited for what's next!

In summer 2025, a visit of the Simmering Waste Water Treatment Works was organized, as well as a workshop on academic publishing, and a summer picnic on the Danube island. More information and an opportunity to join the mailing list for updates on events can be found on the ÖK IAD website here https://oek-iad.boku.ac.at/young-danube-research/ or by emailing youngdanube@gmail.com – we welcome anyone interested in joining us.

Katharina Bauer, Diana Hatzenbühler, Melissa Hiltl, Christoph Novotny, Samuel Roudbar.

46th IAD conference will take place from August 10–14, 2026

A Danube oxbow in Gemenc. Photo: Katrin Teubner

Dear Colleagues,

We are pleased to announce that the 46th IAD conference will take place from **August 10–14, 2026** in **Baja, Hungary.** The conference's theme, which celebrates the IAD's 70th anniversary, is **'The Socio-Ecological Future of the Danube: Integrating Riverine and Terrestrial Systems for a Sustainable Danube.'** Welcome to Baja!

Conference schedule:

- Three days are devoted to conference sessions
- One-day excursion to the Danube-Drava National Park
- One day will be dedicated to EU projects, including a half-day section and a half-day workshop.

The conference website will be available in early 2026.

The Faculty of Water Sciences of the Ludovika University of Public Service will host the 70th IAD conference (https://en.uni-nke.hu/faculties/faculty-of-water-sciences/about). The Faculty of Water Sciences begun its operation in Baja 1 February 2017. Thanks to its predecessors, the Faculty has a heritage of over 60 years in water-related higher education. Water engineering education in Baja has nationwide significance and international appreciation. It currently offers three bachelor courses and a number of specialized courses, continuing the tradition of engineering-based water management. The long-term goal is to become a leading international research and education center in water management. In 2020, the faculty launched an international water policy and water diplomacy master program to prepare water specialists, diplomats, current and future government officials to address the challenges of international water co-operation. In 2024 a new master program was started under the title 'Water hazard management'. The aim of this program is to train professionals with state of the art technical, administrative, legal, and economic knowledge to be capable of performing complex damage prevention activities in the field of water management.

The faculty has six departments, one of which is the Department of Regional Water Management, which will host the conference.

Baja, a town of 35,000 inhabitants, is located on the left bank of the Danube River in Bács – Kiskun County. Situated 160 kilometers south of Budapest, it lies halfway along the river (flow kilometer 1479). It has been the most important southern crossing point on the Hungarian Danube for centuries. The National Public Port of Baja is the second most important port in Hungary on the Danube – Main – Rhine waterway system. For centuries, Baja played a leading role in regional trade, including crops, livestock, and wine. During the Ottoman Empire, Baja was the center of the 'nahiya' of the region, a significant fortress and port with hundreds of houses, mosques, and baths. However, by the end of the Turkish era, the settlement became abandonned. In the 17th century, Bosnians fleeing the Turks settled in the town, followed by Croatians (Bunyevac and Sokac) and Serbians. In the 18th century, Germans (Swabians) and Hungarians also settled there. Baja is a beautiful, charming, green and blue town.

Obituary for Thomas Tittizer

On July 7, 2025, Prof. Dr. Dr. h. c. Thomas Tittizer passed away in Boppart at the age of 87, after a longer period of illness and amidst his large family. Hence, a rich life has been fulfilled. The International Association for Danube Research (IAD) loses a highly esteemed person and respected colleague, as well as an honorary member.

Thomas Tittizer was born on January 29, 1938, in Pânkota, Romania. His family originated from the Black Forest and settled, as part of the German-speaking community, in the Banat during the 19th century. In Romania, he studied biology between 1959 and 1964 at the University of Timisoara and Bucharest, specializing in hydrobiology with a focus on zoology, completing his studies with a diploma. He then worked for two years as a high school teacher in biology and chemistry and another two years as a biologist at the State Water Authority of the Banat and Transylvania Regions, focusing on water quality monitoring.

In 1969, he came to Germany as a Max Planck Society fellow and earned his doctorate in 1973 in the field of ecological chemistry at the Georg-August University of Göttingen. In 1974, he was employed by the Federal Institute of Hydrology in Koblenz (BfG). From the mid-1980s, Thomas Tittizer increasingly engaged with the impacts of hydraulic engineering measures on aquatic communities, establishing – amongst others – a standard method to monitor the macrozoobenthos independent of the flow.

Thomas Tittizer taught at the Johann Wolfgang Goethe University in Frankfurt/Main, the Technical University of Darmstadt, the University of Bonn, and was an honorary professor at the State University of Pitesti/Romania. He supervised numerous diploma and doctoral theses. His main research areas were in applied limnology and the migration of neozoa, particularly in the Rhine-Main-Danube Canal. His great expertise in macrozoobenthos is reflected by his large publication record (see "thomas-tittizer.de") and by his cooperation with the ICPDR (EU-WFD).

Thomas Tittizer was a member of numerous national and international organizations and working groups. His activities in the IAD encompassed, amongst others, Country Representative of Germany (1988-2001), Expert Group Leader 'Zoobenthos/Zooplankton' (1994-2001), and Editor of 'Donau Aktuell / Danube News' (1999-2005). As a leader, he was demanding as well as promoting, open and always keen to try new things. He had an enormous knowledge of IAD-history (see, e.g., his articles in DN-40, 2019 and DN-13/14, 2006). The IAD will keep fond memories of him.

Bernd Cyffka & Jürg Bloesch

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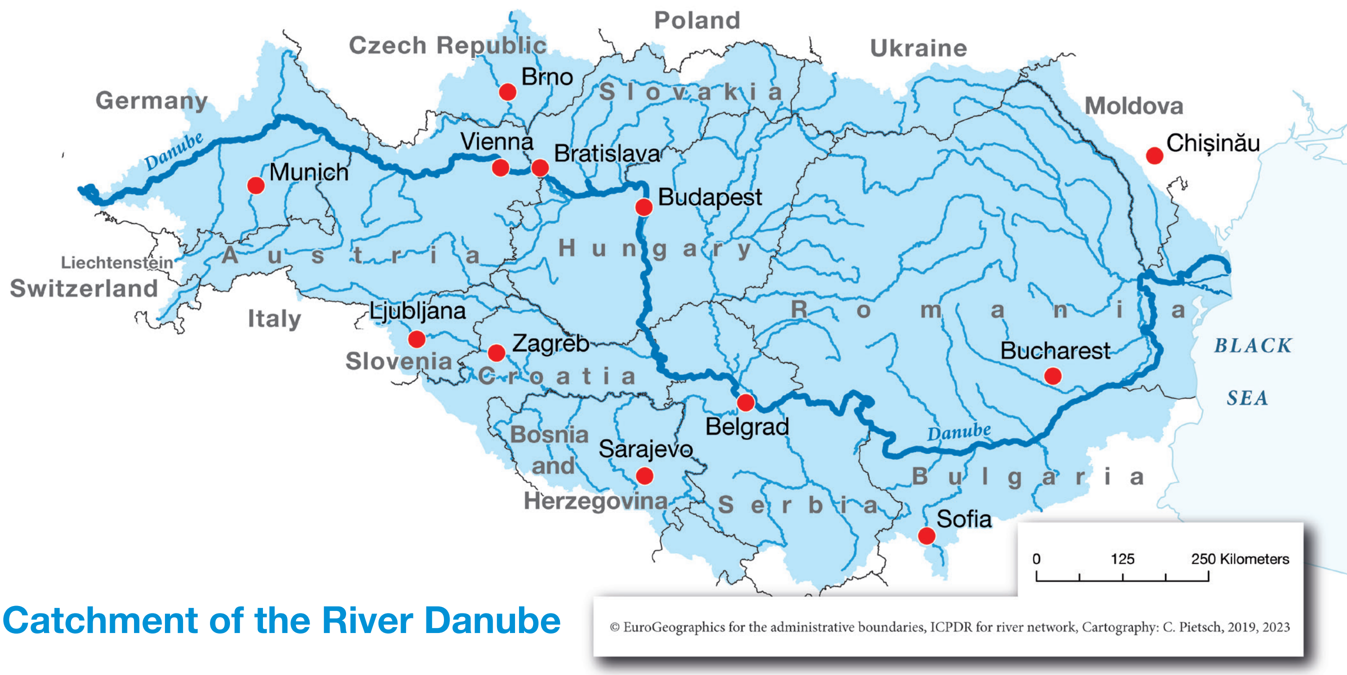

Catchment of the River Danube

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