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

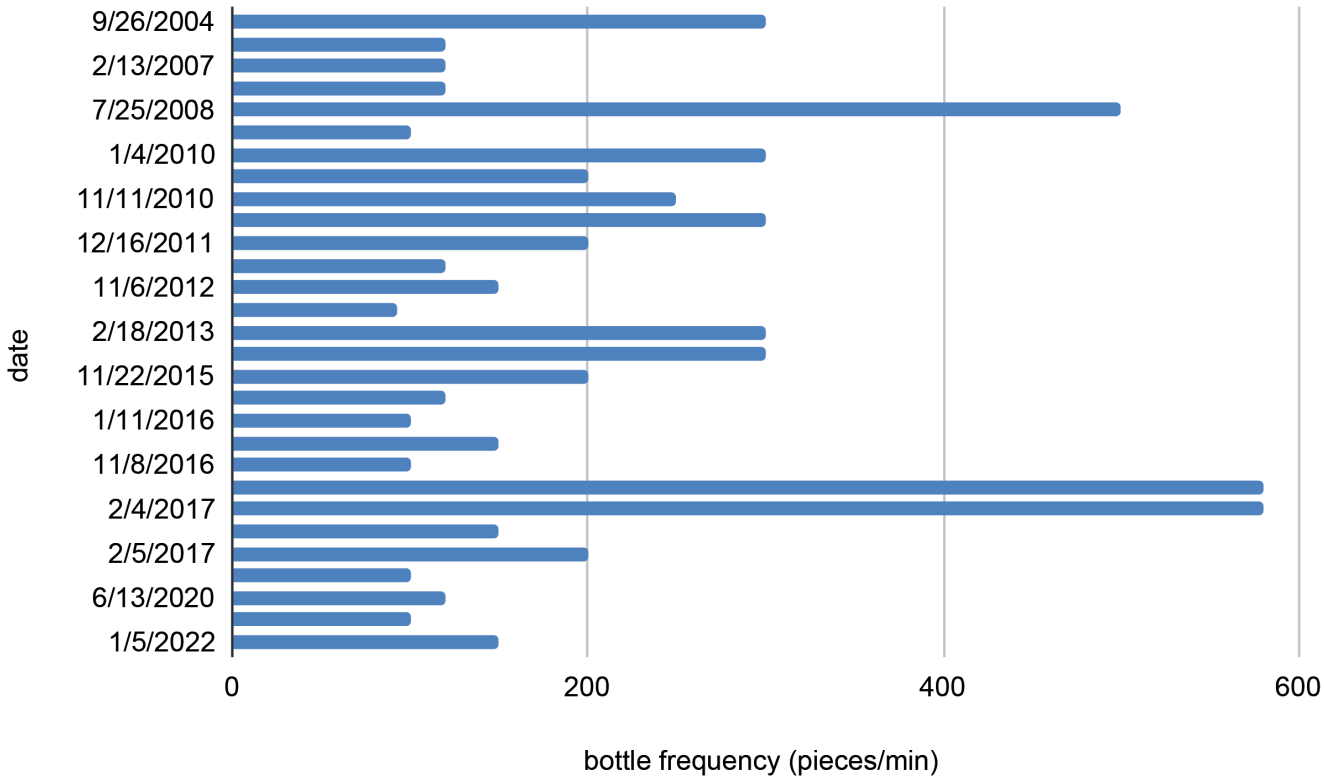

Figure 2. Plastic pollution waves with bottle frequencies exceeding the 90 items/minute threshold between 2004 and 2022 on the river Tisza based on personal field observations carried out by the Hungarian Water Authority Directorate FETIVIZIG. Credit: Zsuzsanna K.né Timkó Dr., Krisztián Szentirmai, József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

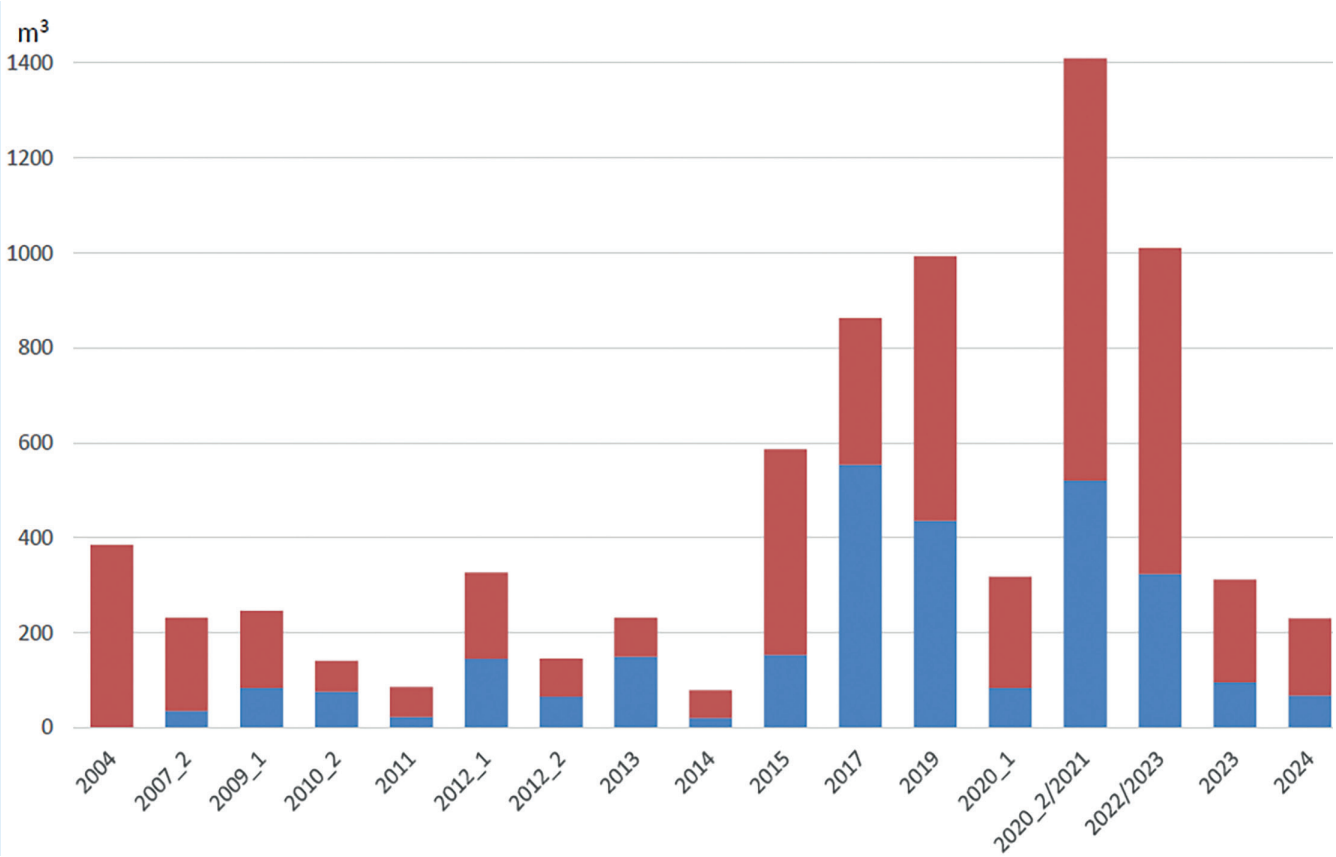

Figure 3. Temporal overview of extracted amounts of riverine litter as per data provided by Hungarian Water Authority Directorate KÖTIVIZIG between years 2004 and 2025. Garbage (KÖTIVIZIG's term for anthropogenic riverine litter) highlighted with BLUE color, Usable Wood (KÖTIVIZIG's term for driftwood)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