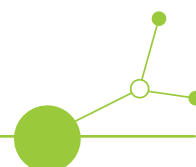


# Solution on improving urban bathing sites - Szentendre, Hungary



Final version  
01.2026





## Disclaimer

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# 1. Introduction

Due to warmer summers, more frequent heatwaves and increasing urbanisation, bathing sites are becoming increasingly popular. In addition to their recreational value, blue spaces contribute to improving the local microclimate and supporting aquatic ecosystems in urban environments. In Hungary, the number of designated bathing sites in the capital and its agglomeration is increasing, especially along the Danube River. Beyond high spatial and temporal variability in water quality, pollution in rivers may be transported over large distances, depending on the hydrological conditions. Influx from natural tributaries, treated or untreated sewage input, climate change-associated extreme weather events, increasing water temperatures and decreasing water levels may all negatively impact the water quality of riverine bathing sites.

The Hungarian Bathing Water Group identified climate change-related changes in water quality and quantity as primary stressors affecting bathing water safety. At the same time, treated wastewater discharges and accidental pollution events, such as combined sewer overflows (CSOs), were identified as additional sources of concern. Current regulatory monitoring requirements are considered insufficient to adequately characterise risks and prevent exposure to episodic water pollution events. Strengthening early warning capacities was therefore proposed to provide (near) real-time information on water quality conditions. Such information could support timely alerts to bathers in case of incidents, and could serve as a basis for more effective, risk-based management. Besides, limited public awareness regarding safe bathing practices and insufficient communication among stakeholders and partners (authorities, experts, operators and the public) were identified as key challenges.

The Hungarian Solution (D.3.1.1) forms part of the Hungarian Action Plan (O.2.1 / D.2.1.2) and translates the experiences gained during the pre-pilot and pilot phases into practical risk management and mitigation measures. During the pre-pilot phase (2024), the feasibility and applicability of the proposed monitoring design, and methods were tested and refined to support implementation during the pilot phase. Pilot activities (O.2.2 / D.2.2.1) implemented by the National Centre for Public Health and Pharmacy (NCPHP, LP) in cooperation with the bathing site operator Aquapalace Ltd. (PP2), included a comprehensive monitoring programme between March and November 2025, aimed at characterising pollution sources and assessing the influence of hydrological and meteorological conditions on bathing water safety. Monitoring locations were established along the Danube at Szentendre Island and the adjacent stream to assess potential contamination pathways under varying environmental conditions. Physicochemical parameters (e.g. temperature, pH, conductivity, and nitrogen forms) and microbiological indicators (faecal indicator bacteria) were assessed, while ecotoxicological tests (algal and *Daphnia* bioassays) were



conducted to evaluate potential biological effects of contamination. Emerging hazards, including *Vibrio sp.* and antimicrobial-resistant bacteria, were also included within the scope of the pilot phase, applying both culture-based and molecular identification methods.

The actions were listed in the action plan address the site-specific challenges and stressors identified at the designated bathing site, Postás Beach, including:

- Short-term pollution events associated with combined sewer overflows, which may require rapid response measures;
- Pollution pathways linked to the Bükkös-stream, identified during the pilot phase as a potentially important source of contamination;
- Climate change-related hydrological variability, including increasingly unpredictable flow conditions and extreme precipitation events;
- Limitations in conventional monitoring approaches to capture the high temporal variability of riverine bathing water quality;
- Gaps in stakeholder communication and preparedness, highlighting the need for clearer institutional coordination;
- Limited public awareness and access to timely information, emphasising the importance of transparent communication regarding bathing water quality, health risks, and precautionary measures.

The Hungarian Solution Report presents an integrated set of measures that supports safe bathing conditions through improved water quality, strengthened preparedness, enhanced communication, long-term resilience and transferability to similar settings.

## 2. Solutions implemented at Postás Beach, Szentendre

### 2.1. Characteristics of Postás Beach

Postás Beach is an easily accessible and popular recreational area located on a side branch of the Danube River in Szentendre, attracting a high number of visitors during the bathing season. The proximity of the river contributes to moderating local heat stress; however, climate change is expected to increase the frequency and intensity of heatwave exposures, likely resulting in even greater residential use of the beach in the coming years. While flooding has traditionally occurred during early spring or early summer, climate-driven hydrological variability has made water levels and flow patterns less predictable.



The site is also exposed to short-term pollution events. Heavy precipitation can wash pollutants from urban surfaces into the river, increase run-off through the adjacent Bükkös-stream or lead to CSOs at the nearby wastewater treatment plant (WWTP). Although dogs are prohibited at the bathing site, the area is not fenced, allowing animals to access the area and water body, potentially contributing to microbiological contamination.

## 2.2. Multiparameter sonde as an early warning method

Early warning systems can support the detection of pollution events and provide timely information to relevant stakeholders, enabling the issuance of health advisories or temporary bathing restrictions when necessary. Such systems also facilitate transparent communication with the public regarding bathing water quality and associated health risks. Within the UrbanBlueHealth project, several early warning approaches were evaluated across pilot sites. These methods are adaptable to bathing sites with similar hydrological and pollution characteristics, contributing to more coordinated and risk-based management.

A review of historical datasets, including regulatory monitoring results and measurements collected during the pre-pilot (2024) and pilot (2025) phases, demonstrated that monthly or biweekly sampling is insufficient to capture the high temporal variability of riverine water quality. This limitation substantially constrains the ability to identify, prevent, or mitigate exposure to short-term pollution events. Building on these experiences and best practices from project partners, sensor-based automated data collection is implemented at Postás Beach from the beginning of the 2026 bathing season.

### 2.2.1. Sensor-based monitoring at Postás Beach

The selected device, a YSI EXO3 multiparameter water quality sonde, includes five universal sensor ports, enabling a modular configuration tailored to site-specific monitoring objectives and local environmental conditions.

#### 2.2.1.1. Sonde configuration

The sonde is equipped with sensors measuring key physicochemical parameters and records data at 15-minute intervals, thereby providing high-resolution insight into short-term water quality dynamics. The selected measurement frequency and sensor configuration are consistent with the monitoring approach applied at the Croatian case study site, supporting methodological comparability between pilot locations.



The sonde includes the following sensors:

- Oxidation-Reduction Potential (ORP) and pH sensor: ORP reflects the oxidative state of the water, which may shift rapidly during pollution events, while changes in pH may indicate chemical inputs, wastewater influence or stormwater inflow;
- Temperature and conductivity sensor: water temperature influences microbial growth and activity, while conductivity measurements can help the detection of sudden inflows of different water masses, including runoff or wastewater discharges;
- Optical dissolved oxygen sensor: dissolved oxygen concentrations respond rapidly to changes in water quality and may decrease due to organic pollution, microbial decomposition, or altered hydrological conditions. While algal activity can also affect dissolved oxygen concentrations, this is considered less relevant at the pilot site due to relatively low water temperatures and fast flow.
- Turbidity sensor: elevated turbidity often accompanies stormwater runoff, sediment resuspension or wastewater inputs;
- Central wiper: a self-cleaning module that occupies the central port, designed to maintain sensor surface cleanliness, reduce biofouling, and improve data reliability during longer deployment periods.

#### 2.2.1.2. Installation and placement

The installation is carried out jointly by the NCPHP (LP), the operator of Postás Beach (PP2), and the distributor company (Velinor Ltd.). The sonde is mounted on a dedicated buoy, positioned at a safe distance from the designated bathing area. The position considers the main flow pathway, where pollution is most likely to be transported, accessibility for routine maintenance, and minimal interference with recreational activities. This strategic positioning maximizes the system's ability to detect pollution events affecting the bathing site.

#### 2.2.1.3. Data transmission and use

Sensor data is downloaded manually at regular intervals (approximately monthly), to establish baseline conditions for the monitored parameters and identify “out-of-range” events. Rather than focusing on absolute values alone, emphasis is placed on identifying normal ranges, temporal variability, and characteristic trends associated with undisturbed conditions. These baseline patterns help to distinguish between natural fluctuations and pollution-related anomalies. In the



longer term, upscaling of the system for automated data transmission and management may be possible, supporting further development of an early warning system.

Although bathing water quality classification is primarily based on microbiological indicators, continuous physicochemical monitoring can provide proxy information on changing environmental conditions and potential contamination events. Sudden deviations in monitored parameters serve as early indications of pollution incidents, enabling precautionary management actions prior to the availability of laboratory-based microbiological results.

In the medium- and long-term, this solution will enable the assessment of seasonal variability in the selected parameters. Understanding seasonal patterns is essential for defining provisional site-specific risk thresholds, supporting risk assessment and early warning. Intervention thresholds are based on observed baseline variability and expert interpretation, with refinement expected as additional data become available.

Real-time data obtained from the sonde:

- Supports rapid identification of unusual trends or threshold exceedances;
- May triggers targeted confirmatory sampling;
- Supports timely communication among stakeholders and with the public through different communication channels.

Sonde signals are integrated into the existing preparedness plan for the bathing site. As part of this process, a risk management framework addressing climate change-related scenarios is developed, thereby enhancing the long-term resilience of the bathing site.

## 2.3. Communication

### 2.3.1. On-site public information

A key component of the sustainable management of Postás Beach is enhancing public awareness, particularly by promoting safe bathing practices through clear and accessible communication. To ensure bather safety and improve local environmental conditions, guidance on the available infrastructure (hygiene facilities, changing cabins and drinking water points) and site-specific rules is disseminated on site. As part of the modernisation process, a solar-powered electronic information board is installed on the riverbank at the beginning of the 2026 season. The display provides near real-time information on water quality status, weather conditions, public health advisories, and operational status of the beach (e.g. temporary closures and reopenings). This



measure supports reducing exposure of the bathers to contaminated water in case of pollution events.

### 2.3.2. Digital transparency and early warning communication

On-site communication is complemented by digital tools, including the development of a dedicated website for Postás Beach. The website functions as a central platform, providing access to project-related data, bathing water status updates, early warning notifications, and general information. To maximise the dissemination of time-sensitive information, key notifications, such as public health warnings and official announcements are also integrated into the Szentendre city mobile application. This ensures rapid and direct access to up-to-date information for both residents and visitors. These communication channels form an essential component of the early warning framework developed within the project.

### 2.3.3. Stakeholder and institutional communication

In addition to public communication measures, the strategy establishes predefined communication channels and response protocols among key stakeholders, including the municipality, public health authorities, the bathing site operator and relevant utility and technical service providers. These pathways are intended to facilitate the timely exchange of critical information and support a rapid, coordinated response during short-term pollution events or other incidents affecting bathing water safety.

To ensure the practical effectiveness of the established procedures, a simulation exercise is conducted prior to the start of each bathing season. The exercise tests information flow, coordination mechanisms, and institutional responsibilities under different risk scenarios, ranging from severe weather warnings issued by the meteorological service to technical alerts communicated by the waterworks operator. The simulation process also supports the identification of procedural gaps and opportunities for further refinement of the communication framework.

## 2.4. Other risk mitigation measures

A further key objective is the long-term improvement of bathing water quality through pollution sources control and preventive risk mitigation measures. CSO events at the nearby WWTP represent a significant risk, as discharges enter the Danube in close proximity to the bathing site and have resulted in several temporary beach closures in previous seasons.



In 2024, a stormwater retention reservoir was constructed at the WWTP, to temporarily store combined sewage during heavy rainfall. This measure has significantly reduced the frequency of pollution incidents; no incident was observed in 2025. In the longer term, further evaluation will be required to assess whether the reservoir's current storage capacity remains sufficient under changing climate conditions, particularly considering the increasing frequency and intensity of extreme precipitation events. An additional long-term measure will involve assessing the feasibility of extending the WWTP outfall pipe to discharge further into the midstream section of the Danube. These assessments will be carried out by relevant local stakeholders, including the beach operator, the Municipality of Szentendre and the WWTP operator).

The Bükkös-stream was also identified as a potential pollution pathway during the pilot phase. In response, this aspect will be integrated into a stream revitalization project, initiated under the coordination of the Municipality of Szentendre and supported through national funding. The intervention framework will include the identification and control of upstream pollution sources. To support pollution source tracking and improve understanding of contamination pathways, additional upstream locations are sampled along the stream during the 2026 bathing season.

### 3. Transferability

The solution developed at Postás Beach has been designed to be transferable to other bathing sites facing similar environmental and operational challenges. In particular, the modular configuration of the multiparameter sonde enables adaptation to site-specific monitoring needs, while the scalable communication model can support improved preparedness and public awareness. The proposed approach combines continuous monitoring, early warning capacities, stakeholder communication, and source-oriented mitigation measures within an integrated risk management framework. However, implementation should take into account local environmental conditions, governance structures, technical capacity, and data availability.

### 4. Summary

The pilot activities implemented at Postás Beach demonstrate how sensor-based monitoring, strengthened stakeholder coordination, and improved communication mechanisms can support enhanced preparedness and public health protection at riverine bathing sites. Through the establishment of baseline monitoring, strengthened institutional preparedness, and improved communication pathways, the implemented measures aim to support safer bathing conditions and increased operational resilience.



The experiences gained at Postás Beach provide a practical foundation for adaptation at other bathing sites facing similar environmental and governance challenges, thereby contributing to the broader development of climate-resilient bathing water management approaches.