BALTIC RIM ECONOMIES
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Editor-in-Chief | Kari Liuhto
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Technical Editor |
Salla Mattila

Centrum Balticum
Vanha Suurtori 7
FI-20500 TURKU, Finland

www.centrumbalticum.org/en

centrumbalticum@centrumbalticum.org

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EXPERT ARTICLES

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AKI ARTIMO

Artificial infiltration of groundwater – drinking water on nature's term

Expert article • 3871

There are different terms to describe the intentional infiltration of available surface water into the aquifer. These are, for example: Groundwater recharge, Artificial infiltration of groundwater, and Managed Aquifer Recharge (MAR). The process is used to increase the natural yield of the aquifer, and to improve the quality of the infiltrated water.

There are just few basic requirements that are needed for successful implementation of groundwater recharge:

1. Source of raw water for infiltration
2. Suitable target aquifer
3. Application of suitable techniques for infiltration and recovery of water

In most European cases, especially in Northern and Central Europe, the artificial infiltration of groundwater is used for drinking water production. In some other cases, the method is applied to produce irrigation water for agriculture.

However, the successful implementation of aquifer recharge requires a lot of expertise and data from the raw water conditions and hydrogeological and geochemical conditions of the target aquifer. Knowledge of the aquifer properties is essential in the designing of suitable infiltration and recovery techniques, because this process harnesses the physical, chemical, and biological interactions that occur during the extended residence time of infiltrated water within the aquifer.

In addition, the requirements of the amount and quality of the data increase when the objectives and goals for artificial infiltration become more demanding.

Groundwater recharge can be utilized in different geological environments and climatic conditions. It is a globally applicable method as presented in the UNESCO publication Managing Aquifer Recharge (2021). Based on the case studies and applications around the world, artificial infiltration of groundwater can be described as a safe, sustainable and cost-efficient method to produce drinking water.

The technique is:

Cost-efficient technology for water supply

- It is a natural method with minor chemical use.
- It is easily automated and remotely controlled process.
- The method provides the water producer with a large sub-surface storage capacity, which also increases the resilience of the production system.

Sustainable way of managing water resources

- It provides adaptation tools for climate change in both increasing or decreasing precipitation.
- It can be used to restore and expand the existing aquifer capacity.

Safe solution for several common challenges

- Raising or stabilizing groundwater levels in the aquifer.
- Preventing saline intrusion or land subsidence caused by excessive groundwater pumping.
- It provides tools to manage stormwater runoff and floods.

The forementioned objectives and goals can be achieved with a highly sophisticated Managed Aquifer Recharge system. As one might assume, that level can't always be achieved. Shortcomings, for example, caused by the lack of raw water or wrong infiltration techniques can lead to issues with too low water production rates. Also, inadequate and insufficiently mapped geochemical conditions of the target aquifer or too short residence times of the infiltrated water can lead to water quality issues.

Therefore, more attention should be focused on mapping and modelling of the internal structures and properties of the aquifers. For example, 3D hydrogeological models can be applied to understand and depict the 3D hydrogeological structures of the aquifer. This architectural data of the aquifer can be further adopted to build more precise groundwater flow models to calculate and simulate the aquifer volumes, flow paths and residence times of the infiltrated water.

Failures to obtain water production goals might occur if they do not coincide with the natural capabilities and/or quality restraints of the aquifer to produce needed amounts of artificially infiltrated groundwater. Therefore, the mentioned modelling tools are vital both in planning and in the production phase of the Managed Aquifer Recharge project. An example of the project in which all these requirements have been met is the water production system built by Turku Region Water Ltd. The company built a MAR based system in the esker aquifer that meets the needs of the whole Turku region with more than 300,000 inhabitants and industry.

In the case of Turku Region Water Ltd., the application of MAR method has allowed more than 10 times bigger production rates as compared with naturally formed groundwater without any unwanted changes in groundwater quality. As a matter of fact, the company has restored the groundwater levels and spring discharge rates to a level that occurred in the aquifer prior to any groundwater intake.

Therefore, Turku Region Water's MAR system has gained excellent Sustainability Index ratings presented in the MAR publication by UNESCO in 2021.

Aki Artimo
CEO
Turku Region Water Ltd.
Finland

CHRISTOPHER CHESTERFIELD

Weaving water into urban planning for liveable cities

Expert article • 3872

Cities today face a range of challenges—climate change, urban growth, and environmental pressures—that require thoughtful and coordinated responses. Among these, the management of water and the planning of urban environments stand out as areas where greater integration can lead to more sustainable and liveable outcomes.

Water influences the physical form of cities, affects where and how development occurs, and plays a key role in community health and resilience. Despite this, water management and urban planning have often operated separately, resulting in inefficiencies and missed opportunities. Bridging this divide is essential for shaping cities that are both functional and future-ready.

The Case for Integration

Urban development and water systems are deeply intertwined. Impervious surfaces increase flood risk, land use decisions affect water quality, and infrastructure placement can either support or hinder sustainable water use. Yet, these connections are often overlooked due to fragmented governance and sectoral boundaries.

Integrated Urban Water Management (IUWM) offers a framework for addressing these challenges. It promotes a total water cycle approach—considering water supply, wastewater, stormwater, flood risk and waterway management together. But IUWM cannot succeed in isolation. It must be embedded within the broader urban planning system, which holds the tools, authority, and spatial vision to shape cities.

Urban planning, with its capacity to coordinate across sectors and scales, is uniquely positioned to facilitate integration. It can align infrastructure with land use, resolve competing interests, and implement policies that reflect shared goals. But to do so effectively, planning instruments must be designed with integration in mind.

Designing for Coherence

Achieving integration in urban and water planning requires more than aligning broad strategic goals—it demands coherence across the full hierarchy of planning instruments: from direction-setting, through plan-making, to implementation. Yet, integration becomes increasingly difficult as one moves down this hierarchy.

At the direction-setting level, strategic policies and frameworks are typically abstract and aspirational, allowing for alignment across sectors without the immediate pressure of operational constraints. These instruments can articulate shared visions and long-term goals, and are often developed with cross-sectoral input.

The plan-making level, however, presents more significant challenges. This is where strategic intentions must be translated into spatially explicit plans that guide land use and infrastructure delivery. Sector-based governance structures often reinforce sector-led planning approaches that do not always facilitate cross-sectoral, place-based outcomes Water is rarely a focal point for urban planning, with most water-related objectives or provisions reflecting a narrow or partial view of the total water cycle (e.g. focusing on water supply or stormwater management). Horizontal alignment is further complicated by spatial and temporal disparities between the planning activities of the two sectors. Water planning may focus on catchments and long-term infrastructure needs, while urban planning often centres on precincts and shorter development cycles. These mismatches make it difficult to coordinate planning efforts meaningfully.

At the implementation level, the challenge shifts to ensuring that plans are carried out as intended. Instruments like development approvals and codes often focus on compliance and procedural efficiency, which can dilute broader sustainability goals unless they are clearly embedded in earlier planning stages.

Ultimately, coherence is not just about the design of individual instruments, but about how they connect and reinforce each other across the planning hierarchy. Addressing the structural and procedural barriers at the plan-making level is key to unlocking the full potential of integrated urban and water planning.

Coordinating for Impact

Procedural integration focuses on how actors work together to implement planning instruments. It involves aligning tasks, sharing information, and building structures that support collaboration. But beyond formal mechanisms, the success of coordination depends heavily on the human dynamics that shape how integration is pursued and realised.

Effective coordination depends on:

- **Actor involvement:** Engaging the right stakeholders—planners, water authorities, developers—with shared motivations and the capacity to influence change.
- **Information sharing:** Creating a common understanding through data, tools, and joint assessments.
- **Governance structures:** From joint decision-making protocols to new agencies, structural reforms can embed integration into the fabric of institutions.

Practitioners and leaders who champion collaboration and see beyond sectoral boundaries can galvanise support and shift organisational priorities. Their influence helps build momentum and legitimacy for integrated approaches. This boundary spanning is enabled by organisational cultures and institutions share a common purpose and that value innovation and collaboration. Conversely, rigid hierarchies and risk-averse cultures can stifle it.

Leadership, trust, shared understanding, culture, and political will are essential for effective integration. While these factors are less tangible than formal policies or plans, they play a critical role in ensuring that planning systems work together in practice.

Conclusion: Building Water Sensitive Cities

To create cities that are sustainable, resilient, and liveable, we must transform how we plan and manage water. Integration offers a pathway to more sustainable and liveable cities. It requires coherent instruments, coordinated action, and a culture of collaboration. By weaving water into the urban fabric, we can shape places that not only survive but thrive in the face of future challenges.

Christopher Chesterfield
Professor of Practice
Monash Sustainable Development Institute
Australia

SARI MULTALA

Water resilience – the cornerstone of a sustainable future

Expert article • 3873

World water resources are under high pressure and pressures are increasing. The impacts of climate change are increasingly visible in our water systems and has effect in our everyday life. Extreme weather phenomena – floods, periods of drought and rising sea levels – challenge our infrastructure, ecosystem and the functioning of our society. Water resilience, or the ability to adapt to and recover from disturbances affecting water bodies, has become a key concept in climate and environmental policy.

In Finland, I see that water resilience means, among other things effective water supply in all circumstances, including in crisis situations. Natural water management, such as the utilisation of wetlands and flood meadows will balance the natural water circle. Investing in research and innovation so that we can develop new solutions for water management to adapt to the changing conditions.

Water resilience is not just a technical or ecological issue – it is also a social and economic challenge. The availability and quality of water have a direct impact on people's health, livelihoods and the vitality of regions. To achieve water resilient society means investments in green infrastructure, close cooperation with water sector actors and the development of legislation to support proactive and ensure sustainable, fair and inclusive water management.

The nature and especially waters, which have been under vast pressure from human activities during the past decades, do not recover that easily and fast that we have hoped. In addition, we have identified new substances and chemicals which causes risks to water quality and human health. Top of that there is more and more unbalance between water demand and supply. The efficient use of water is one of the key issues to protect water.

We are lucky in Finland, because we have plenty of clean water, which is sufficiently distributed and allocated, and we can take clean water for granted. The water management and protection are not an easy task and this I have noticed working in global, European and national level. I believe in strong cooperation. Water is bridging many different policies such as energy, agriculture, biodiversity. Finland has been a forerunner in water protection. I want to stress the importance of keeping the ambition to reach the objectives set in the EU -legislation for the status of waters. The achieve and maintain the water resilience means that we have to put effort to measures improving the quality of waters and water efficiency.

The commission has set a target to improve 10 % of the water efficiency in EU level by 2030. The improvement of water efficiency should be mainstreamed to all sectors, particularly to agricultural and industrial water use. I see that we still need to strengthen and address interdependences between food, energy and water. Better technologies based on closed cycles, improvement of resource and energy and improved wastewater treatment are some of the corner stones to achieve this target.

Efficient water use is important in the agricultural sector all parts of the Europe. Increasing agricultural production will increase water demand and therefore sustainable and integrated management of water use in agriculture needs special attention.

We need better water technologies based on closed water cycles and to improve the use of water resources and to look for new environmentally friendly energy technologies in order to support the green transition. Water efficiency in industrial production means improvement of energy and resource efficiency –closing the circles. I see that water reuse should be enlarged so that it also covers industrial use of treated wastewater as a resource for energy, heat and nutrients.

Also, improvement of the wastewater treatment processes in line with the new EU Urban Wastewater Treatment Directive will be our challenge. I would like to stress that innovative water efficiency and wastewater management solutions offer huge business potential to our technology development and to our industry.

We see the Council Conclusions on Water Resilience Strategy as a good solid base for the water protection in which the most important issue for the future work is highlighted. Finland understands the value of the water protection and we appreciate the added value of EU water legislation to support national water protection, and it has given a more solid base for our national environmental legislation.

We have a long history of integrated water management, and we have done long term work with water and marine protection on national and international forums already for many decades. Finland sees important that the strategy emphasises Source to sea -approach and contains a link to the joint mission to the OceanPact, which deals extensively with maritime policy and the state of the sea.

Finland sees important that the EU legislation is fully implemented and it´s application is streamlined throughout Europe. This is important especially for all investments and activities. The enterprises appreciate uniform and predictable legislation, and it safeguards healthy competitiveness.

I strongly see that the objectives set in the EU Water Resilience Strategy will need a change of policies towards more sustainable water management. This includes improving efficiency in water use, and reduction of water pollution in order to improve water quality and maintaining ecosystems. The water resilience will have impacts on human health, benefits to the economics, preparedness for risks to conflict and on increasing food security.

Climate change is also a security concern, which can disrupt infrastructure, and threaten food and water supply chains. To mitigate these risks, we have to promote climate adaptation measures, sustainable land use planning, and the protection of biodiversity. This can be done by developing resilient infrastructure that can withstand extreme weather events and long-term environmental shifts.

Water as a cross-cutting element is a part of the comprehensive security. In the concept for comprehensive security, the vital functions of society, such as the water and energy supply, are taken care of in collaboration between the authorities, business community, organizations and citizens at all levels of society. Broad cooperation with the stakeholders at the national and regional level, innovative water cycle management solutions and good governance in all levels to improve water efficiency and to reduce the water pollution.

Finland can lead the way in water resilience. We have strong water expertise, clean water resources and a desire to act towards water resilience in all sectors in society. Together we can build a society that not only survive the changes caused by the changing climate – but flourishes in the midst of them. Without clean water we cannot manage. We make all possible actions to meet the targets to pollution reduction in order to enjoy the wellbeing of waters.

I would like to finish by quoting the Water Framework Directive´s first preambular: *"Water is not a commercial product like any other but, rather, a heritage which must be protected, defended and treated as such."*

Sari Multala
Minister of the Environment and Climate Change
Finland

IQTIAR MD SIDDIQUE

Baltic cities face a water turning point

Expert article • 3874

The Baltic Sea region is facing a turning point in how cities manage water. Weather patterns are shifting. Long dry stretches are now followed by sudden downpours that flood streets and strain old drainage systems. Urban growth and industrial activity keep rising, while many networks are decades old and already stretched thin. Freshwater reserves are under pressure, and maintenance costs are climbing. Without coordinated action, cities from Helsinki to Gdańsk could face a future of both drought and contamination, putting health, local economies, and ecosystems at risk.

The Current Challenge

Many municipal water systems in the region were built for climate and demand profile that no longer exist. Large volumes of treated water are still lost through leakage and outdated distribution systems, wasting both energy and financial resources. Stormwater runoff continues to carry sediments and micropollutants into the Baltic Sea, undermining years of environmental restoration. Fragmented management between utilities, industry, and government institutions further complicates reform, slowing the adoption of integrated solutions.

The implications are far-reaching. Declining groundwater reserves and recurrent floods threaten residential areas, transportation systems, and industries. Rising sea levels and saltwater intrusion endanger coastal aquifers and drinking water sources. Each system failure increases the cost of treatment, carbon emissions, and operational risks, reducing the resilience of cities and their essential services.

Towards an Integrated and Circular Water Framework

A sustainable future for urban water depends on how well cities connect technology, design, and governance. The first step is digital transformation. Smart meters, leak sensors, and predictive models can help utilities spot losses early and plan maintenance instead of reacting to failures. When these systems are linked through digital twins, operators gain a real-time view of what is happening underground and where resources are being wasted.

The second step involves closing the loop. Treated greywater can be reused for irrigation, cooling, or street cleaning, which eases pressure on aquifers and reduces the volume of wastewater released back into the environment. In many dense city areas, systems that recover heat and nutrients from used water are already showing clear economic and environmental benefits. Together, these measures turn waste into a working resource and make every drop count before it leaves the system.

Building capacity at the local level is equally important. Utilities and municipalities need skilled personnel to design, operate, and maintain these technologies. Dedicated training programs, regional knowledge-sharing platforms, and financial instruments tailored for green infrastructure can make the transition more attainable for smaller cities. Public awareness campaigns that promote water-saving habits and acceptance of reuse technologies also contribute to success, turning citizens into active partners rather than passive consumers.

Governance remains the harder part. Regulations often lag behind technology, and responsibilities are divided across institutions. Transparent reporting, incentives for efficiency, and public involvement can help rebuild trust and make reforms practical. Policies that reward water reuse and pollution prevention will also help cities coordinate across borders and move toward shared regional goals.

Expanding cooperation between research institutions and municipal utilities will also play a significant role. Pilot projects that assess digital networks or circular reuse systems in medium-sized cities can generate valuable knowledge before wider adoption. Joint funding through European cohesion programs and cross-border initiatives can further support these efforts, ensuring that lessons learned in one location benefit others around the Baltic. Such collaboration helps cities progress collectively rather than through isolated experimentation.

The Contribution

Advancing sustainable water management in the Baltic region requires closer alignment between technical innovation and institutional decision-making. The integration of digital systems, circular resource recovery, and transparent governance can transform fragmented initiatives into a coherent regional effort. Collaboration through EU and HELCOM frameworks offers a practical platform to share experience, pool investments, and harmonize emerging technologies.

Cities that adopt such an integrated approach can move from reactive measures toward long-term resilience. Cleaner coastal waters, reduced operating costs, and greater public confidence are realistic outcomes when planning, technology, and policy work in concert. Strengthened cooperation across national and municipal levels will help define a Baltic model for water systems that are both resource-efficient and climate-ready.

Iqtiar Md Siddique
Ph.D., INCOSE Academic Equivalency
Research Consultant
Department of Industrial, Manufacturing and Systems Engineering, The University of Texas
El Paso, USA

ELENA TOTH

Reservoir management for water resilience and renewables generations

Expert article • 3875

We are faced with increasing water scarcity conditions and we anticipate a further intensification of the gap between water supply and demand in the coming years, resulting from a combination of climatic and anthropogenic factors. The European Water Resilience Strategy recently adopted by the European Commission foresees increased competition for freshwater supplies, which may also result in the exacerbation of regional conflicts between upstream and downstream stake-holders, including those with riparian non-EU partners. This requires additional efforts to foster the sustainable management of shared water resources, considering the novel challenges posed by changing climate and changing water uses.

The first step in mitigating the water scarcity risk is to reduce demand across all sectors of the economy through measures that increase water savings, efficiency, and reuse. But along with demand reduction, additional water resilience may be gained by increasing the amount of water we store and by optimising its management. In addition to increasing water retention on land, we may need to plan new reservoirs, small or large, and we certainly need to revise or rethink the operation of the existing ones, when they do not adequately meet all the recent societal needs and constraints - considering all relevant actors - and when the current management rules do not pay adequate attention to the protection of aquatic and terrestrial ecosystems.

Reservoirs use has undergone significant changes over the decades. In the past, they were originally often built by a single user for a single, specific purpose. Today, the same reservoir, to be truly sustainable from an economic, social, and environmental point of view, should be designed or, when already existing, managed as a multi-purpose and multi-user asset. Modern reservoirs are tasked with meeting not just one but a variety of purposes: drinking water supply, irrigation, industrial uses, hydroelectric power production, flood safety, transportation, and recreational uses. Some of such purposes were sometimes not even contemplated when many of the existing European reservoirs were designed, often decades ago, such as planning the releases for environmental protection and for the support of ecosystem services.

Recently, renewed interest has arisen for reservoirs management in relation to the water-energy nexus. At a time when all countries are making efforts to increase the share of renewable sources in their energy mix, the role of hydropower is more crucial than ever. Reservoir-based hydropower is particularly important because it is the only renewable source capable of storing energy, allowing it to play an essential balancing role in fully exploiting variable renewable sources, such as solar photovoltaics and wind power, whose output is intermittent and independent of consumer demand.

Coupling solar photovoltaics with reservoir-based hydropower is especially effective due to the positive seasonal complementarity of energy production and its synergy with existing power transmission infrastructure. In particular, floating solar photovoltaics is recently gaining attention as a novel technology for enhancing solar-hydro hybridisation. In such plants, photovoltaic panels are installed on a floating structure, which is anchored to the bottom and/or the sides of the water body. With respect to traditional ground-mounted photovoltaic plants, this allows to preserve forested or cultivated land, to increase the PV panels efficiency thanks to the water-cooling effect and to reduce evaporation losses. Unfortunately, most countries still lack dedicated regulations for floating photovoltaic systems, which present both technological and legal barriers that need to be addressed to facilitate their evolution toward large-scale adoption. The European Commission Joint Research Centre (JRC) has estimated the potential of installing FPV on existing hydropower reservoirs across EU countries, showing that such coupling would allow to produce significant additional energy. In the Baltic region, such potential is particularly high in Finland and Sweden, thanks to the large surface area of the reservoirs. On the other hand, it should be highlighted that in this region, the cold climate and ice formation present additional engineering challenges.

Another novel technological challenge that is potentially very interesting to address the water-energy nexus, is the integration between pumped-storage hydropower plants, intermittent renewable sources and desalination plants. The integration between these systems allows to exploit excess wind or solar energy, which would otherwise be lost or limited by grid congestion, using it either to store hydroelectric energy in the upper reservoir or to power the desalination process that is highly energy-intensive. In this way, it is possible to simultaneously harness energy and water resources, improving the flexibility of the electricity system based on clean and renewable energy, while also contributing to water security through the production of drinking water.

Many European reservoirs were built decades ago and designed years before their construction. Significant transformations are expected or already underway in the use of our reservoirs, due to changes in both societal and environmental needs (including the water-energy nexus) and in the forcing predicted by future climate simulations. It is necessary to anticipate the impact of these changes, in a fully multi-purpose and multi-user framework, adapting the reservoir management rules and optimising them according to the different possible future scenarios.

Elena Toth
Professor
University of Bologna, Department of Civil, Chemical, Environmental and Materials Engineering
Italy

President
Italian Hydrological Society (SII-IHS)
Italy

LEENA YLÄ-MONONEN

Water resilience in Europe and the Baltic Sea region

Expert article • 3876

Water under threat in Europe
Water is rapidly becoming a focus for policymakers across Europe and beyond. The triple planetary crisis of climate change, biodiversity loss and environmental pollution are having significant and cumulative effects on the quality and quantity of available water across our continent. Water scarcity is already an issue, with 34% of the European Union territory being affected during at least one season in 2022.

Levels of water scarcity have increased since 2010, and with climate change expected to further increase the frequency and intensity of drought events, it is unlikely that the situation will improve by 2030. This means that significant additional efforts are required to ensure sustainable water use. In June 2025, the European Commission published the European Water Resilience Strategy, which includes an EU-wide goal to enhance water efficiency by at least 10% by 2030.

In line with the 'water efficiency first' principle, reducing abstraction and enhancing efficiency should take priority over increasing supply. Diversifying water resources through reuse, desalination and rainwater harvesting can also enhance resilience, provided there is careful consideration of the impacts of these measures on energy use, climate mitigation, human health and ecosystems.

Pollution is an issue in Europe's waters, despite decades of pollution control legislation and measures. Waters continue to be impacted by chemicals, predominantly through atmospheric pollution from coal-powered energy generation and diffuse pollution from agriculture. The lack of improvement in chemical status can be partly attributed to long-lived pollutants, such as mercury and brominated flame retardants.

While political frameworks to address water quality are in place, targets are being missed with very real consequences. The Water Framework Directive (WFD) target for European rivers, lakes, transitional, coastal and groundwaters to meet good status by 2015 was not met, and indeed there has been little improvement since 2010.

Challenges in the Baltic Sea region
In the Baltic Sea region specifically, reporting of the third river basin management plans under the WFD showed high levels of failure in the chemical status of surface waters. Pollution, in particular by mercury and brominated flame retardants, causes widespread pollution, likely through deposition from the air. It should be noted that if these long-lived pollutants were not considered, then 75% of surface waters would achieve good chemical status rather than the current figure of just 3%.

For those countries bordering the Baltic Sea for which we have recent, data reported under the WFD (so excluding Finland and Russia), all coastal waters are failing on chemical status. There is also widespread failure of ecological status, with no transitional waters and only 15% of coastal waters registering good status.

The picture is similar when it comes to freshwater. Only 29% of freshwater bodies are in good or high ecological status, while 65% of reported rivers and lakes are failing on ecological status (data still pending for Finland).

Climate change is also affecting the Baltic Sea region. Hydro-climatic extremes in the region since the 1980s have caused over 100,000 deaths and losses of more than 2 billion Euro.

Improving water resilience in a changing climate
Urgent action is required to improve Europe's water resilience. Climate change is disrupting weather patterns and further increasing pressures on our water resources and ecosystems. Europe's water management practices are poorly adapted to cope with such rapid and large-scale change, which could compromise water security.

The potential for water savings varies greatly across Europe's regions and across sectors, but significant reductions in water abstraction are feasible. These could be achieved through technical and operational measures to reduce losses and leakages, as well as by improving water efficiency in electricity production, agriculture, public water supply and manufacturing.

Improving water efficiency by using water-efficient devices and processes, and increasing water reuse, is another key element in tackling water stress. Water pricing can be another important driver for reducing water use and improving efficiency, while at the same time providing a mechanism to fund water investments. Target setting, focused on saving water or reducing demand, can drive action and facilitate the monitoring of progress towards greater water resilience.

Knowledge is power
In addition to everything mentioned above, up-to-date and timely information on water quantity and quality is critical to Europe's ability to manage water and build resilience. A more robust knowledge base is needed to enable more equitable and sustainable water allocation between competing uses, while also keeping environmental considerations front and centre. Water resilience considerations, management practices and responsibilities at different governance levels vary considerably across Europe. A robust knowledge base also helps effective policy and decision-making, by identifying water resilience challenges and opportunities in specific areas of Europe, such as the Baltic Sea region.

Leena Ylä-Mononen
Executive Director
European Environment Agency
Denmark

FRANCESCO GRANATA

Pathways for hydrological resilience: strategies for adaptation in a changing climate

Expert article • 3877

Climate change is steadily transforming the global water cycle. Droughts are becoming longer and more intense, floods more frequent, and rainfall patterns increasingly unpredictable. Water systems that once operated within stable boundaries are now exposed to persistent variability and uncertainty. In this evolving context, the pursuit of hydrological resilience—the capacity of water systems to endure disturbances and recover while maintaining essential functions—has emerged as a defining challenge for sustainable development.

Resilience is not a fixed state but a continuous process of learning, adaptation, and transformation. It depends as much on governance and institutions as on infrastructure and technology. Traditional hydraulic works remain crucial, but they must now be complemented by flexible management frameworks, ecosystem-based approaches, and long-term foresight. The objective is no longer to restore past conditions after each shock, but to strengthen the ability to adapt to a new climatic normal.

Among the most promising drivers of this transformation is Artificial Intelligence (AI). Through the integration of vast and diverse data, from satellites, hydrological sensors, and climate projections, AI can identify trends and anomalies that escape conventional analysis. It enhances our ability to forecast droughts and floods, to monitor groundwater and water quality in real time, and to optimise allocation among competing uses. When embedded in decision-support systems, AI provides a foundation for anticipatory management, transforming data into actionable foresight. By combining physical understanding with data-driven learning, AI becomes a strategic ally for shaping water policies that are both adaptive and evidence-based.

Yet technological progress alone cannot safeguard water security. The effectiveness of AI and other digital tools depends on the quality, openness, and interoperability of data, as well as on the trust of the institutions and communities that use them. Investments in monitoring networks, capacity building, and cross-sectoral collaboration are therefore as essential as investments in infrastructure. Ethical and inclusive principles must guide digital transformation, ensuring that innovation serves as a bridge, not a barrier, between regions and generations.

Resilience is equally rooted in the natural environment. Rehabilitating wetlands, restoring floodplains, and enhancing groundwater recharge strengthen the buffering capacity of ecosystems while providing biodiversity and carbon sequestration benefits. In rural areas, nature-based solutions can stabilise yields, protect soils, and preserve livelihoods. In cities, green infrastructure can reduce flooding, mitigate heat, and improve the quality of life. The convergence of digital innovation and ecosystem restoration opens new pathways toward sustainable and adaptive water management, where technology and nature reinforce rather than replace one another.

At the global scale, hydrological resilience is becoming inseparable from economic and geopolitical stability. Water scarcity threatens energy production, food security, and regional peace. Shared aquifers and transboundary rivers require dialogue, trust, and cooperative management, not competition. Multilateral frameworks, supported by data transparency and common standards, can transform potential sources of tension into opportunities for collaboration. In this sense, investing in resilience is not only an environmental imperative but also a diplomatic and economic necessity.

Moving forward, achieving hydrological resilience requires a culture of cooperation across disciplines, sectors, and borders. It demands policies that embrace uncertainty rather than fear it, institutions that evolve with changing risks, and leadership that links innovation with equity. Artificial Intelligence can illuminate the path, but human judgment and shared responsibility must define the destination. The most effective strategies will be those that integrate scientific knowledge, digital intelligence, and ethical governance into a coherent and forward-looking vision.

In a changing climate, the resilience of water systems will define the resilience of nations. Strengthening hydrological resilience means safeguarding not only ecosystems, but economies and societies themselves. By coupling digital foresight with collective action and respect for natural processes, humanity can transform vulnerability into preparedness and ensure that water remains, today and for future generations, a source of stability, prosperity, and peace.

Francesco Granata
Associate Professor
University of Cassino and Southern Lazio
Italy

JOHANNA HERTTUAINEN

Adapting water services to climate change in Finland

Expert article • 3878

Water management is already on the road to adaptation, but more action is needed

Operational security of water management must be ensured under all circumstances. Finland has experienced significant disruptions in water supply and wastewater management due to storms, heavy rains, and droughts in the 21st century, prompting water utilities to enhance their preparedness. This has led to the development of local and regional water management strategies, with municipalities intensifying cooperation in areas such as water supply, emergency water supply, and wastewater treatment. Despite these efforts, many plants still lack a comprehensive climate risk assessment, and contingency plans often fail to incorporate climate change considerations.

Drought affects water availability

In response to climate change, droughts are becoming more frequent and prolonged, particularly in southern and central Finland. This poses significant challenges for water utilities reliant on groundwater, as well as those utilizing surface water and managing sewerage. Groundwater availability is decreasing, especially in small bodies or where intake approaches maximum yield. Additionally, groundwater level drops can alter water flow directions and increase bank infiltration, leading to water quality degradation. Surface water facilities are also at risk, as drought can cause oxygen depletion, fish deaths, and internal water body stress. During heatwaves, water consumption rises due to increased household use for irrigation, worsening water supply issues. Furthermore, prolonged droughts increase the risk of sewer network blockages and soil cracking, which can damage water and sewer pipes.

Heavy rains and floods hit the water services

The frequency of heavy rains and floods is escalating in Finland, with predictions indicating a tripling of flood risks by 2100. This rise in precipitation and flooding can significantly enhance groundwater and surface water quality, yet it also poses challenges to wastewater drainage and treatment systems. The influx of nutrients, solids, and contaminants into groundwater, especially in areas with thin soil cover, increases the risk of contaminating water intake wells. Surface water quality is also compromised by increased organic matter, pathogens, and nutrients due to heightened water currents. The deteriorating quality of surface waters necessitates enhanced water treatment at various facilities, including surface water, artificial groundwater, and bank infiltration plants. Sewage disposal systems may face increased strain, leading to overflows and bypasses. Furthermore, dilution or cooling of wastewater can disrupt biological treatment processes.

Temperature rises and storms affect water services directly or indirectly

Climate change introduces higher temperatures and more variable weather, including more frequent extreme events. These changes impact groundwater and surface water quality and the management of water supply. Storms and thunderstorms can introduce uncertainties, such as power outages, affecting water supply. In winter, while groundwater formation increases, the reduction in microbiological activity can lower water quality. The need for de-icing roads in winter can elevate chloride levels in groundwater. Warmer surface waters, reduced oxygen content, and algal blooms pose challenges to surface water plants, bank infiltration, and artificial groundwater facilities. Recreational water use and changes in agricultural practices, such as altered farming schedules and increased agrochemical use, further degrade surface water quality. Increased temperatures also affect drainage, leading to odor nuisances and hydrogen sulfide formation, which can damage sewer networks.

Main adaptation measures

Key adaptation strategies include relocating water intake wells and wastewater pumping stations to safer areas, enhancing water treatment capacities, exploring the yield of small groundwater formations, and ensuring backup water and power solutions. Effective planning, inter-facility cooperation, land use management, and the utilization of information systems and modeling are crucial for adapting to climate change. In 2025, an online tool named Vilso was introduced on the Vesi.fi webpage to assist Finnish water utilities in assessing their adaptation needs to climate change.

Johanna Herttuainen
Senior Coordinator
Finnish Environment Institute
Finland

ANTTON KETO

Integrated water resources management in Finland

Expert article • 3879

Introduction

Finland, often referred to as the "Land of a Thousand Lakes," has actually over 187,000 lakes and abundant groundwater reserves. In the minds of Finns, water is a central element of Finnish life and culture such as enjoying a Finnish sauna by the lake. However, despite this abundance, Finland faces growing challenges in managing its water resources sustainably. The main objective of Finland's water resources management is to ensure the sustainable use and protection of water bodies. This involves maintaining the ecological and chemical status of surface and groundwater, ensuring sufficient water supply for all sectors, and safeguarding aquatic ecosystems and human health.

Status and use of water resources

We have a good starting point. Finland has one of the highest per capita renewable freshwater resources in the EU. Water resources are approximately 110 billion m^3/year, which means per capita availability approximately 20 000 m^3/person/year – in other words multiple times more to most other EU countries like Poland (1600 m3/person/year) and Belgium (2100 m3/person/year). Industry accounts for about 80% of total freshwater use in Finland. This is primarily for cooling in energy production and manufacturing, meaning most of this water is returned to the source with low contamination. Municipal use (households and services) uses around 15% which includes domestic water supply, sanitation and public services. While the share of agriculture in terms of direct water withdrawal is small (around 5%), agriculture is a major contributor to nutrient loading in surface waters.

In this context, it is important to highlight that direct water use (e.g., household consumption) accounts for less than 5% of the average Finnish consumer's water footprint. Virtual water (embedded in imported goods and services) makes up the majority. It is estimated that even over half of Finland's total blue water footprint comes from imported products, including from countries with water scarcity problems.

The water status is moderately good, except for coastal waters. Almost 90% of the total lake surface area is classified as being in good or high ecological status and over 60% of river length is in good or high ecological condition. The majority of Finland's approximately 3,900 classified groundwater areas are in good condition, with only about 10% considered at risk. Coastal waters face the biggest challenges, as only 11% of their area is classified in good ecological status. Health risks from drinking water are low and all Finns have access to safe drinking water. However, local vulnerabilities, especially in small or private water systems, can lead to occasional outbreaks of waterborne diseases.

Water governance in Finland

Finland has already for decades promoted integrated approach for water governance, and the first basin-wide, multisectoral plans for 'comprehensive water resources management' were established already in early 1970s. Today, Finland's multi-level governance structure means that integrated water resources management combines centralized and decentralized approaches, with centralized approach providing strategic oversight and decentralized approach enhancing legitimacy and local responsiveness.

Finland's national water governance is based on EU policies. The key EU policies include the EU Water Framework Directive, aiming for all water bodies to achieve "good ecological status", EU Floods Directive that seeks to reduce flood risks, and EU Drinking Water Directive that aims to ensure safe and clean water for all citizens with focus on public health and environmental protection. These EU policies are complemented by national legislation such as Water Act, Act on Water Services, Land Use and Building Act and Dam Safety Act. There are also other, more voluntary governance processes such as catchment-based planning and water vision processes that bring different actors together to form a joint vision for future of a given waterbody. Such processes can at best help to enhance collaborative water governance that helps to strike a balance between conflicting interests around water.

Water governance implementation is a collaborative effort that involves multiple ministries and public sector agencies and is done in close collaboration with actors from other societal sectors. The Ministry of the Environment is responsible for water protection and environmental policies, while the Ministry of Agriculture and Forestry is responsible for use of water resources and water economy in general. The Ministry of Social Affairs and Health is responsible for water related health issues and health risks of chemicals, the ministry of Economic Affairs and Employment for industrial and energy policy and regional development, and the Ministry for Foreign Affairs for international water policy and cooperation.

Regional and local authorities have the main responsibility for the practical implementation of water governance. The regional ELY-Centres (Centres for Economic Development, Transport and the Environment) prepare and implement River Basin Management Plans, monitor water quality, and oversee flood risk management, while Regional State Administrative Agencies (AVI) admit water permits and enforce environmental regulations. Municipalities and Regional Councils manage local water services, land use planning, and environmental protection initiatives. While the regional administration reform that will come into effect at the beginning of 2026 will change these structures and roles, the main responsibility for practical implementation stays at regional and local levels.

Finland actively promotes water security and good water governance also internationally. International Water Strategy of Finland, prepared jointly by five water-related ministries, acknowledges water as a critical element for sustainable development and an essential resource for all human activities. It also recognizes water as critical for both sustainable development and security and its essential role in the implementation of development policy and trade policy. Finland is also active in transboundary water cooperation and water diplomacy, having initiated both UN framework conventions on transboundary waters and actively supporting the UNECE Water Convention i.e. Helsinki Convention. We also host the Baltic Marine Environment Protection Commission HELCOM.

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Future challenges

Despite its robust governance and abundant water resources, Finland faces several challenges in integrated water resources management. Tackling climate change, biodiversity loss and pollution together with aging water infrastructure, industrial green transition, bioeconomy developments and urbanization necessitate an integrated and adaptive approach to water governance. There is a also growing need for real-time monitoring, data integration, and digital tools to support planning and decision-making. Rising temperatures and changing precipitation patterns demand adaptive infrastructure and policies to manage floods, droughts, and water quality problems. Expanding urban areas and infrastructure development can disrupt natural water cycles and increase flood risks. Much of Finland's water and wastewater infrastructure is decades old. Upgrading these systems requires significant investment and innovation. In addition, new EU legislation on Urban Waste Water Treatment brings new requirements such as the Extended Producer Responsibility (EPR) to purify micropollutants which is a demanding task in terms of implementing legislation and practical operations

Industrial and mining activities that promote green transition pose risks of chemical pollution, and their impacts are not yet fully understood. Finland's critically important bioeconomy sector –including agriculture and forestry– impacts both quantity and quality of waters, while at the same time having great potential for re-considering water-land-climate linkages. All these challenges require active cross-sectoral coordination and stakeholder cooperation to prevent tensions and ensure sustainable use of water and related resources. At the moment, Finland stands as a global example of effective water governance, yet it cannot afford complacency. The country's commitment to sustainability, innovation, and international cooperation positions it well to tackle emerging water challenges. By continuing to foster cross-sectoral collaboration, invest in infrastructure, and embrace novel digital solutions and governance innovations, Finland can ensure that its water resources remain clean, abundant, and resilient for generations to come – as emphasized also in the new European Water Resilience Strategy.

Antton Keto
Director, Water and Marine Protection Unit
Ministry of the Environment
Finland

ALEXANDRA MÜLLER

The solution to pollution is… prevention?

Expert article • 3880

Urban stormwater, comprising rain and snowmelt induced runoff in urban areas, is recognised as a major transport vector of a wide range of contaminants to receiving waters. The contaminants transported by urban stormwater may cause adverse effects on aquatic organisms, thus contributing to the urban stream syndrome, defined as the ecological degradation of streams draining urban areas. Such adverse effects may also impact raw water sources used for drinking water production as well as marine environments in case of stormwater discharges in coastal areas.

Although it is established that stormwater mobilises diffuse pollution from a multitude of sources, the main aim of urban water management systems has traditionally been to protect urban areas from flooding by the direct discharge of stormwater to the nearest water body without prior treatment. Current development of practices for stormwater management has shifted to embrace technologies which address both stormwater quantity (flooding) and quality (pollution control) as part of an integrated approach to stormwater management. However, while treatment may improve the quality of the water being discharged to receiving waters, it may lead to other challenges such as moving contaminants to another media that needs to be managed at a later stage.

The sources of stormwater pollution

A major source of stormwater pollution is traffic and traffic infrastructure, which include, e.g., exhaust emissions, road and vehicle wear and road management activities such as de-icing and inti-skid practices. Contaminant groups mobilised by road runoff range from solids to organic and inorganic contaminants. Building and structural surface materials also represent major sources of stormwater pollution and may, depending on material type, release various substances to runoff. For instance, metallic materials, such as copper and galvanized surfaces, may release high levels of dissolved copper and zinc, with the dissolved fraction being more mobile and bioavailable. Roofing membranes based on e.g., bitumen or PVC may release organic substances such as alkylphenols and phthalates, while outdoor paints and renders may contain and release biocides.

Other important sources contributing to stormwater pollution include countless anthropogenic activities in urban areas: e.g., construction and industrial work; washing of road tunnels or buildings; the use of fertilisers and pesticides; littering and accidental spills. Atmospheric deposition, transporting contaminants generated in urban areas with subsequent deposition on drainage surfaces in wet or dry weather, may also substantially contribute to the pollutant load transported with stormwater.

Source control as the solution to stormwater pollution

Deciding when mitigative actions are necessary can be rather subjective and depend on, e.g., the ecological sensitivity of the receiving waters, the level of dilution between the pollution source and the receiving waters, and the pollutant concentrations or loads in the actual runoff. It may often be both easier and more effective to limit the releases of contaminants instead of applying treatment to the runoff. Thus, source control is often the most effective mitigative tool. This can be achieved by phasing out important sources, as in the historically successful removal of lead from gasoline, which dramatically reduced lead levels in highway runoff and other environmental compartments. Similar phase-outs could be achieved for problematic substances in building and structure surface materials, as well as in vehicle parts such as brake pads and tires.

The way forward - Challenges and needs

Source identification is a central part of source control, but remains costly and technically demanding, further complicated by insufficient product transparency and fragmented responsibilities among stakeholders, as well as a constant introduction of new products and materials on the market. The legacy of existing material stocks embedded in buildings and infrastructure continue to release pollutants for decades, underscoring the long-term nature of this issue. Addressing these challenges requires a fundamental shift in strategy, including designing products and materials with minimal environmental impact, implementing stricter chemical regulations, and promoting circular economy principles to reduce hazardous substances entering urban systems. This is an issue that intersects construction, manufacturing, transportation, and consumer behaviour. Effective solutions demand coordinated efforts among regulators, industry actors, researchers, and municipalities, to share data, harmonize standards, and develop innovative approaches. Without such collaboration, preventive measures risk being fragmented and ineffective.

A holistic approach should integrate stormwater considerations into urban planning, product design, and procurement policies, while establishing clear accountability across the value chain. Embedding these principles into governance frameworks will ensure that stormwater management evolves from reactive treatment to proactive prevention. By prioritising upstream interventions, encouraging cross-sector partnerships, and implementing structural changes, cities can move toward resilient and sustainable water management, not only protecting aquatic ecosystems but also contributing to broader environmental and public health goals and ensuring that urban development aligns with long-term sustainability.

Alexandra Müller
Associate Senior Lecturer in Urban Water Engineering
Luleå University of Technology
Sweden

SUVI SOJAMO, LAURI AHOPELTO & MARKO KESKINEN

Enhancing Finland's water security through water governance

Expert article • 3881

Finland is often celebrated as a global leader in water management. With abundant freshwater resources, strong institutions, and high public trust, the country consistently ranks among the best in international water governance related indices. Yet beneath this reassuring image, Finland faces challenges that can threaten its water security. Climate change, diffuse pollution, aging infrastructure, and sectoral pressures from the bioeconomy and mining are testing the resilience of its governance system.

Water security is more than having enough clean water. It means ensuring sustainable access to safe water for people, ecosystems, and the economy, while protecting against hazards such as floods and droughts. Achieving this requires effective governance, including clear decision-making processes, accountability, and adaptive management approaches. Water security can be seen as both a goal and a governance challenge, as is particularly evident in three critical sectors: bioeconomy, mining, and water infrastructure.

Three Sectors, Shared Challenges

Bioeconomy
Forestry and agriculture form the backbone of Finland's bioeconomy, but they also contribute significantly to diffuse water pollution, which are harder to regulate than point-source emissions from e.g. factories. While industrial discharges are well-controlled, the cumulative impacts of land-use changes and climate variability remain under-addressed. Also institutions would require strengthening, as the Forest Act largely lacks strong environmental safeguards, and enforcement of Water Act provisions protecting small headwaters is weak. In agriculture, despite robust evidence linking nutrient runoff to eutrophication, the progress in tackling diffuse pollution has been relatively slow and would require new approaches.

Mining
Driven by global demand for critical minerals, Finland's mining sector is expanding—but its environmental impacts need careful consideration. The 2012 Talvivaara disaster, which released over a million cubic meters of toxic water, exposed serious gaps in oversight and preparedness. Today, economic incentives sometimes override conservation laws, and while some companies have improved transparency, others lack expertise or willingness to properly engage with local communities. Institutionally, the challenge is that cumulative impacts of several operations within one river catchment are not fully addressed in permit processes. Civil society groups have successfully challenged exploration permits in court, highlighting persistent governance tensions.

Water Infrastructure
Finland enjoys near-universal access to clean drinking water and sanitation, but its infrastructure is aging. Many utilities struggle to finance maintenance and upgrades, creating long-term risks for reliability and safety. Without renewed investment and long-term planning, this vulnerability can undermine parts of Finland's water security.

Systemic Governance Gaps
These sectoral issues reflect deeper systemic challenges. Shrinking public-sector capacity and budget cuts have impacted environmental permitting, supervising and governance. Environmental permits remain rigid, limiting adaptation to climate change and technological advances. Civil society participation is hampered by a lack of process transparency and resource constraints, leaving for example Indigenous Sámi communities feeling sidelined. Finally, the polluter-pays principle is inconsistently enforced: in both the bioeconomy and mining sectors, costs of environmental damage often fall on the public rather than the polluters.

Finland's governance approach, though generally strong, must also evolve to maintain a more systemic view that can drive change. Key priorities include:

- **Cross-sectoral collaboration** grounded in science-based decision-making, with more targeted use of environmental subsidies in e.g. agriculture and forestry.
- **Adaptive legislation** that is responsive to changing environmental conditions.
- **Enhanced public-sector capacity** for effective oversight.
- **Inclusive governance**, ensuring that marginalized voices—especially Indigenous and local communities—are heard.

Governing for Resilience: Lessons for Europe
As Europe faces intensifying droughts, floods, and pollution, the European Commission's Water Resilience Strategy signals a shift from reactive management to proactive resilience. Its objectives are: 1) restoring and protecting the water cycle, 2) building a water-smart economy, and 3) ensuring access to clean and affordable water for all. While ambitious and also partly contradictory, these objectives are important for guiding future water management.

Finland's experiences offer important lessons for water resilience. Strong institutions and stakeholder engagement are assets, but sectoral fragmentation and resource constraints can severely undermine coordination. The Water Resilience Strategy's main areas of action—governance; investments and infrastructure; digitalisation and artificial intelligence; research and innovation; and security and preparedness—are critical to bridging these gaps.

Resilience, however, is not just about system characteristics, but it is ultimately about people. Inclusive governance, education, and citizen empowerment must therefore complement and guide technical solutions. In Finland, traditionally expert-driven water governance must open to broader societal engagement, recognising local needs and addressing rural-urban divides.

The Road Ahead
Sustainable water management must bring together ecological integrity with economic vitality and institutional robustness with democratic legitimacy. Finland's experience shows both possibilities and challenges included in such an aim. We must establish adaptive water governance systems that consider the inbuilt tensions related to water while maintaining systemic and comprehensive view.

Expert article • 3881

Suvi Sojamo
Principal Researcher
Finnish Environment Institute Syke
Finland

Lauri Ahopelto
Leading Specialist
Finnish Environment Institute Syke
Finland

Marko Keskinen
Associate Professor
Aalto University
Finland

AKU SUOKNUUTI, INKERI KOLLMANN, TOMMI PEHO & TOPI HELLE

Finnish water expertise has growth potential

Expert article • 3882

In the global context, water is no longer just an environmental variable; it's a central economic, industrial, and strategic enabler. The entire Green Transition is fundamentally dependent on water: the hydrogen economy, battery manufacturing, industrial decarbonization, and tightening ESG requirements. The key challenge is no longer just scarcity, but efficiency, circularity, and resilience.

Why Finland? Finnish expertise was born not from abundance, but from a paradox: We host some of the world's most water-intensive industries (pulp & paper, mining, chemicals) while simultaneously adhering to Europe's strictest environmental legislation. We were forced to innovate.

This necessity drove the development of advanced solutions to treat complex industrial wastewater, including online monitoring and metals recovery. Concurrently, large investments in municipal treatment, such as the new HSY Blominmäki plant, created expertise that often exceeds EU regulations. This is complemented by high-tech leadership in digital smart water management. Reducing non-revenue water, for instance, is accomplished with digital modelling and GIS-based asset management. These smart solutions enhance energy efficiency, continuity management, and overall resilience.

The greatest growth potential for Finland's water sector is not in technology alone; the future of export lies in integrated service models and knowledge transfer. International clients no longer seek just a treatment plant; they demand a guaranteed outcome.

The Finnish Water Forum (FWF) is addressing this shift by embedding capacity building into its solutions. This includes developing continuous education modules with Finnish universities of applied sciences (successfully piloted in Egypt this year) and building an online learning platform to scale this training globally. These holistic elements, from operator training to operational support and good governance models, are crucial. Ultimately, Finland is not just exporting technology; we are exporting reliability and long-term partnership.

This concept extends far beyond training. In the EU-LIFE-SPRINGBOARD project, FWF is collecting European best practices across managerial, financial, and technical dimensions to support Ukraine in its reconstruction. This vital project was born from a cross-Baltic initiative to update wastewater treatment facilities on riverbanks running into the Baltic Sea.

The challenges facing the Baltic Sea, from impacts of climate change to the cumulative effects of industrial and agricultural runoff, are becoming increasingly complex. Tackling this requires a new level of predictive and analytic power. This is the goal of Finland's ambitious Digital Waters Flagship, which aims to secure water resources by creating digital twins of real-world water systems. These advanced models allow researchers and policymakers to simulate scenarios and test new management strategies in a virtual environment, enabling smarter, data-driven decisions to protect the Baltic ecosystem.

Within this high-tech context, the Finnish Water Forum (FWF) is an active partner in developing and applying practical R&D solutions. The Y-MAX project, for example, optimizes wastewater sludge treatment to maximize nutrient recovery and energy production while minimizing consumption. FWF also addresses the critical link between food production and environmental concerns. The Water Smart Food Systems project led by Invenire analyzed water treatment in food production facilities in Åland, identifying new technological solutions to improve water use and recycling.

Beyond these R&D projects, FWF facilitates vital cross-sectoral collaboration to solve emerging industrial challenges. The rapid rise in demand for European-produced battery materials and changing regulations has created pressure to develop new separation technologies. In the AKVE project, FWF acted as a key facilitator, kickstarting the dialogue between regulators, research institutes, and the private sector.

These solutions, tested and proven in the challenging Baltic environment, are directly scalable to tackle complex water challenges globally.

Aku Suoknuuti
Project Advisor
Finnish Water Forum
Finland

Inkeri Kollmann
Project Advisor
Finnish Water Forum
Finland

Tommi Peho
Project Advisor
Finnish Water Forum
Finland

Topi Helle
CEO
Finnish Water Forum
Finland

IRENA TUŠER

Civil resilience around the Baltic Sea

Expert article • 3883

The Baltic Sea region is one of Europe's most strategically important areas. It connects Northern and Central Europe through dense networks of maritime transport, energy routes and digital infrastructure. States around the Baltic Sea are closely integrated into EU and transatlantic structures, and their economies depend heavily on open trade, stable logistics and reliable critical infrastructures. In this context, civil resilience, understood as the ability of societies to withstand, adapt to and recover from shocks, has become a central element of both security and economic stability.

The security environment of the region has changed profoundly in recent years. Russia's aggression against Ukraine, increased military activity, cyber operations and pressure on information space have all contributed to a more contested strategic landscape. At the same time, countries around the Baltic Sea are deeply interconnected through energy systems, ports, shipping lanes and data networks. Disruptions in one part of the region can quickly translate into economic and social consequences elsewhere. Civil resilience is therefore not just a supporting function of defence, but a core condition for the continuity of everyday life, public services and business operations.

The risk landscape facing the Baltic Sea region is multifaceted. Geopolitical tensions and hybrid activities can target critical infrastructures directly or indirectly. Energy systems, including electricity grids and gas infrastructure, are exposed to physical incidents, technical failures and deliberate interference. Maritime transport and ports are vulnerable to accidents, extreme weather and intentional disruptions. Digital networks and data centres face cyber threats that can affect financial services, public administration or logistics chains. These risks do not exist in isolation: a failure in one system can cascade into others, amplifying the impact on societies and economies.

In response, states in the region have been reinforcing their frameworks for civil emergency preparedness and resilience. They draw on European and transatlantic approaches that emphasise the protection of critical infrastructure, continuity of government and essential services, and the ability to manage complex emergencies. National strategies increasingly frame resilience as a whole-of-society task, where central government, local authorities, private operators and citizens share responsibilities. Exercises and scenario-based planning are used to test coordination, communication and the ability to cope with simultaneous or prolonged disruptions.

Cross-border cooperation is a key feature of civil resilience around the Baltic Sea. Many infrastructures, from undersea cables to shipping routes, are inherently regional. As a result, information sharing, joint assessments and compatible procedures matter as much as national capabilities. Regional and subregional platforms provide opportunities to exchange lessons, compare approaches and coordinate responses. In practice, this can mean aligning contingency plans for ports and transport corridors, coordinating emergency support across borders, or sharing good practice on risk communication with the public.

At the operational level, several typical developments can be observed across the wider Baltic and Central European area. Public authorities and businesses are devoting more attention to business continuity planning, recognising that supply chains and service delivery must be able to function under stress. Emergency exercises increasingly include scenarios affecting energy systems, transport hubs or digital infrastructure, rather than focusing only on single-sector incidents. Cooperation between public and private actors is gradually becoming more structured, as governments depend on private operators for the functioning of many essential services, while companies rely on clear guidance and predictable regulatory environments.

Civil resilience in the Baltic Sea region also has a strong societal dimension. Populations need to be prepared for disruptions that may affect electricity, communications or mobility, sometimes for longer periods than people have been used to in recent decades. This includes basic household preparedness, trust in public institutions and a realistic understanding of what authorities can and cannot guarantee in a crisis. Risk and crisis communication therefore play a central role: they connect technical measures on critical infrastructure with the behaviour, expectations and support of citizens.

Looking ahead, several policy directions appear particularly important for strengthening civil resilience around the Baltic Sea. First, civil and military planning should be further aligned, so that defence efforts and resilience measures reinforce each other rather than operating in parallel. Shared situational awareness, compatible procedures and regular joint exercises can help bridge institutional boundaries. Second, states in the region would benefit from deepening their cooperation on risk scenarios, data and early warning. Common understandings of priority risks and potential cascading effects can make national measures more coherent and efficient.

Third, long-term investment in the resilience of critical infrastructure should remain a priority, even when short-term pressures compete for resources. This includes not only physical protection and redundancy, but also modernisation, maintenance and cybersecurity. Fourth, engaging the private sector as an active partner in resilience, instead of treating it as a purely regulated actor, can unlock expertise and innovation that public institutions alone may not possess. Finally, sustained efforts to inform and educate the public about preparedness can build a culture of resilience that supports authorities in times of stress and reduces the impact of disruptions on everyday life.

In a region where security, economy and environment are closely intertwined, civil resilience is not a separate agenda for emergency specialists. It is an essential framework for ensuring that societies around the Baltic Sea can continue to function, adapt and recover in an era of heightened uncertainty and interconnected risks.

Irena Tušer
Associate Professor, Head of the Centre for Security Research
AMBIS University
Prague, Czech Republic

irena.tuser@ambis.cz

RIKU VAHALA

Towards a resilient and modern water utility sector – Finland's national reform journey

Expert article • 3884

Finland's water services system is often praised for its high quality and reliability. Our water bodies are in good condition, drinking water meets strict quality requirements, and the services are fully financed through customer payments. In international comparisons, Finland is frequently placed at the forefront of sustainable and equitable water management. However, beneath these positive indicators lies a set of challenges that have prompted a strategic national reform effort.

The Finnish Water Utilities Association (FIWA) represents nearly all large and medium-sized utilities in Finland—around 300 in total, covering 90 percent of the country's water services. Our membership also includes some 200 companies and organizations operating in the sector. In addition to advocacy, FIWA coordinates the national water preparedness work under Finland's Emergency Supply Agency. While the institutional setting is robust, the operational environment is showing signs of strain that cannot be ignored.

Mounting Challenges Despite Strong Foundations

One of the most acute problems is the growing infrastructure renovation debt. Much of Finland's water infrastructure, especially pipelines, is approaching the end of its technical life. The pace of rehabilitation is far too slow. Estimates suggest that the current rate of investment must be multiplied two- or threefold to prevent further degradation. Over the next two decades, required investments in rehabilitation alone may exceed €10 billion. Small utilities are vulnerable, as they are responsible for wide networks but lack the customer base to support such financial burdens.

Another growing concern is emergency preparedness. Especially in smaller utilities, contingency planning has been insufficient. Some lack legally required emergency response plans, power backup systems, and even basic cybersecurity protocols. While many have made progress recently—helped by tools such as the VILSO climate adaptation platform—the level of preparedness still tends to correlate strongly with organizational size and professional capacity.

A third, and perhaps most systemic challenge, is fragmentation. Finland currently has over 1,100 registered water utilities. Only around 80 of these units employ more than ten people and manage their operations professionally. The rest include hundreds of cooperatives and municipally owned units with limited technical and financial capacity. This extreme decentralization weakens operational reliability, complicates regulatory oversight, and reduces resilience in the face of emerging risks such as climate change, cyber threats, or evolving EU directives.

A National Reform with Ambitious Goals

In response to these interlinked challenges, Finland launched a national water services reform in 2021. Led by the Ministry of Agriculture and Forestry, the reform aims to modernize the sector by 2030 in collaboration with municipalities, utilities, public agencies, and stakeholder organizations. The overarching goal is to ensure that the sector remains secure, sustainable, and fit for the future.

At the heart of the reform lies the pursuit of operational reliability, financial sustainability, digital maturity, and resilience. Ensuring public ownership and democratic accountability is also central, particularly as water services are increasingly recognized as critical infrastructure. The reform also seeks to make the sector more attractive to new professionals by strengthening training pathways and promoting innovation.

Significant progress has already been made. A revised Water Services Act was submitted to Parliament in spring 2025. Among its provisions are measures to prevent privatization of core infrastructure, reinforce planning obligations, and require more transparent asset management. The reform also encourages voluntary cooperation and mergers, supports the development of digital tools, and lays the groundwork for carbon-neutral water services. However, regional cooperation and structural consolidation have progressed more slowly than hoped.

Navigating Resistance and Building Momentum

One of the key bottlenecks has been the reluctance to merge small utilities into larger, more resilient units. Despite clear technical and economic arguments, political resistance and local identity concerns remain strong. Discussions are underway on whether stronger steering mechanisms—such as an operational licensing model—might be necessary to accelerate progress. Croatia's recent reform experience, where licensing requirements triggered structural consolidation, has been discussed as a potential model of last resort, in case voluntary incentives do not yield the desired outcomes.

Other policy priorities include strengthening digital infrastructure, integrating circular economy practices—particularly in sludge management—and aligning national regulation with new EU directives on drinking water and wastewater. The reform also continues to support export-oriented innovation and international collaboration.

A mid-term evaluation is scheduled for 2026. By then, it should become clearer whether the reform's current soft tools—such as financial incentives and voluntary guidelines—are sufficient, or whether more binding measures will be needed. Many in the sector believe that a combination of carrot and stick will be necessary to ensure real transformation.

Conclusion: Reforming to Strengthen Societal Resilience

Finland's experience illustrates a paradox familiar to many advanced water systems: high performance today can mask growing risks beneath the surface. Without deliberate and forward-looking reform, even the most successful systems can become vulnerable. The national reform is an attempt to act before crisis forces change.

By aligning technical, regulatory, and organizational developments, Finland seeks to secure water services not just as infrastructure, but as a foundational pillar of public trust and national resilience. The reform is not merely a sectoral update—it is a societal investment in continuity, competence, and collective preparedness.

Riku Vahala
CEO
Finnish Water Utilities Association (FIWA)
Finland

GARI VILLA-LANDA SOKOLOVA

Polluter-pays principle: cornerstone for sustainable water management

Expert article • 3885

Across Europe, citizens rightly expect clean water, healthy rivers, and affordable water services. Yet, every day, micropollutants flow from our homes into wastewater systems. These substances are biologically active, persistent, and costly to remove. The EU recast Urban Wastewater Treatment Directive (rUWWTD – (EU) 2024/3019) confronts this challenge with a forward-looking solution: Extended Producer Responsibility (EPR). EPR is a tool to implement the Polluter-Pays Principle (PPP), one of the founding pillars of EU environmental law, enshrined in Article 191(2) of the Treaty on the Functioning of the EU and reaffirmed by the European Court of Auditors. Together, these mechanisms ensure that those who cause pollution bear the costs of remedying it, safeguarding the environment, Europe's most vital resource - water, and the affordability of essential water services.

Why EPR is needed

Access to safe, affordable water and sanitation are human rights and a foundation of Europe's prosperity. Urban wastewater treatment plants (UWWTPs) have long been central to this mission, protecting public health and the environment. Yet, today's challenge goes beyond bacteria and nutrients: it is about removing micropollutants.

The rUWWTD sets targets for quaternary treatment — advanced processes to remove micropollutants, essential to protect aquatic ecosystems and drinking water resources, but it comes with significant costs. The Directive requires producers of pharmaceuticals and cosmetics to finance at least 80% of the costs for such treatment, reflecting their contribution to the pollution load.

This is not punitive; it is corrective. For decades, water operators have borne the growing costs of removing substances they did not produce. Most utilities are small or medium-sized public entities, serving communities that depend on them for affordable water and sanitation. Without EPR, these operators would bear the financial burden for removal of pollution created upstream.

EPR shifts the responsibility back to the source of the problem and creates a level playing field. Every producer placing pharmaceuticals or cosmetics on the EU market, whether manufactured in Europe or abroad, contributes their share.

The risks of going without EPR

Failing to implement EPR would have serious environmental, economic, and social consequences.

1. **Higher water tariffs and social unfairness.** If producers are exempt from covering micropollutant removal costs, wastewater utilities will have to pass these expenses onto user: households, small businesses, and farmers — who do not profit from these substances — would pay more for essential water services. The impact would be regressive, disproportionately affecting low-income families and small enterprises.
2. **Reduced investment capacity of water operators.** The Water Resilience Strategy identifies an investment gap of EUR 23 billion per year to implement existing water legislation (not including the recast Drinking Water Directive nor the rUWWTD). Without EPR funding, investments in innovation, digitalisation, climate mitigation and adaptation, and circular economy could be delayed or cancelled, resulting in weaker resilience of Europe's critical water infrastructure and slower progress towards a competitive circular economy.
3. **Threats to SMEs and local competitiveness.** Water-dependent small and medium-sized enterprises (SME) — including food producers, beverage manufacturers, and farmers — would face higher operating costs if water tariffs increase, eroding their competitiveness compared to sectors responsible for micropollutant emissions.
4. **Slower innovation and persistent pollution.** EPR should incentivise cleaner design: producers have a financial reason to develop substances that are less polluting. Without it, there is no economic driver to change. This will result in a continued flow of persistent pollutants into water bodies, forcing operators to install costly treatments indefinitely while pollution at the source remains unchecked.

A proportionate and forward-looking approach to ensure sustainable financing

EPR ensures:

- **Sustainable financing model and financial predictability:** producers' contributions — based on the quantity and hazardousness of their substances — will guarantee cost recovery and provide long-term planning security for the water sector
- **Fair cost allocation:** those responsible for pollution bear its clean-up costs.
- **Innovation incentives:** the more producers innovate to reduce toxicity and emissions, the lower their future financial contribution will be; EPR aligns economic incentives with environmental performance.
- **Shared responsibility:** costs are distributed across all entities placing products on the EU market, including non-EU manufacturers.

Moreover, the system is flexible. Member States can expand EPR to additional sectors, and smaller UWWTPs will only be required to implement micropollutant removal where risk assessments justify it.

Safeguarding a sustainable water future for Europe

Europe's water operators are committed to delivering the ambition of the rUWWTD: cleaner waters, resilient infrastructure, and a sustainable future. This requires adequate, fair financing. EPR provides precisely that — aligning environmental responsibility with economic logic.

Without EPR, the financial and environmental burden would shift from polluters to public services and, ultimately, to all water consumers. Water utilities would divert resources from innovation and climate resilience toward micropollutant removal, slowing Europe's transition to a sustainable and circular water economy. Small businesses would lose competitiveness. Pollution at the source would continue unchecked, and the PPP would be violated.

With EPR, Europe establishes a virtuous cycle: producers innovate to reduce pollution, wastewater operators receive the means to protect water bodies, and citizens enjoy affordable, safe, and sustainable water services.

Clean water is everyone's right, but it also must be everyone's responsibility.

Gari Villa-Landa Sokolova
Senior Policy Advisor
EurEau (European Federation of Water Services)
Belgium

gari.villa-landa@eureau.org

VÍTOR VINAGRE

Rethinking collaboration: water & planning

Expert article • 3886

Climate Change, Population Growth and Urbanisation: Challenges for Urban Water Management

Climate change, population growth and urbanisation present critical challenges for water management in urban areas. The intensification of extreme hydrological phenomena, such as prolonged droughts and floods, has made water security increasingly uncertain. These challenges require integrated solutions that take into account not only the technical aspects of water management but also urban planning, with the aim of mitigating the impacts of extreme events and promoting water circularity.

Indeed, the adaptation of cities to climate change in the urban water sector depends mainly on factors related to institutional collaboration and urban planning, being less influenced by the "state of the art" of the technologies involved.

Key Challenges

From the perspective of urban water management entities, the main challenges include infrastructure sizing, identifying new water sources, managing supply and demand, and locating treatment facilities, which, in the case of wastewater treatment, can become new sources of water "fit for purpose". On the other hand, for the entities responsible for spatial (and building) planning, challenges arise in the allocation of economic activities, the definition of construction guidelines (such as the implementation of dual plumbing systems, water retention in green elements, and ensuring permeable soils) and the development of "blue" and "green" infrastructure. These latter should combine water retention and infiltration with climate regulation, while simultaneously creating leisure and recreational spaces. It is thus evident that there is a symbiotic, almost mutualistic, relationship between these two sectors, with each contributing to the adaptation of cities to climate change.

To minimise risks, increase resilience, reduce costs and generate positive externalities, it is clear that climate adaptation in urban areas requires close collaboration between management entities and those responsible for urban planning. This integration is essential to address challenges such as the need for infrastructure rehabilitation/conversion, the growing demand for water and vulnerabilities related to changing climatic conditions.

Barriers and Drivers of Collaboration

Despite its importance, collaboration between the water and planning sectors faces significant barriers, such as a lack of institutional coordination, the perception of longer decision-making times, discrepancies in timelines between sectors, and legal limitations. Conversely, the implementation of national adaptation strategies and the strengthening of legal frameworks have been identified as key drivers for promoting collaboration.

Recommended Collaborative Practices

According to recent studies, effective collaborative practices between the water and urban planning sectors should include:

- Promotion of intersectoral collaboration: Integrate and operationalise this collaboration through coherent policies and regulations;
- Harmonisation of strategic plans: Align master plans (water and land) and construction guidelines with national and municipal resilience strategies;
- Definition of accessible technical solutions: Propose practical solutions that different actors can easily implement;
- Incorporation of scientific advances: Promote partnerships with academic institutions to integrate technical developments and foster training;
- Citizen engagement: Inform and mobilise the population regarding the necessary changes for climate adaptation.

Collaborative Model for Climate Adaptation

The materialisation of these practices requires the implementation of a collaborative model that organically and continuously links the technical, institutional and social dimensions at the municipal level. This model should bring together technical and institutional solutions that promote the inclusion of all relevant stakeholders.

To achieve this, it may be appropriate to foster the creation of independent organisational structures designed as "facilitators of change". These structures, whether temporary or permanent, would be responsible for leading transition processes, promoting the implementation of collaborative measures, and ensuring effective interaction between institutions and communities.

Conclusion

Regardless of the main climatic trends affecting a city – whether water scarcity or excess – climate adaptation in the urban water sector depends on a close relationship between management entities and those responsible for spatial planning. This relationship is essential to identify and implement effective measures that respond to the challenges associated with urban water under any circumstances, ensuring the sustainability and resilience of cities in the face of climate change.

Vítor Vinagre
PhD in Energetic Systems and Climate Change, Asset Management Coordinator
Águas do Centro Litoral, S.A.
Portugal

vcvinagre@ua.pt

VIRPI VORNE, ANU REINIKAINEN & KSAWERY KULIGOWSKI

Data gaps in Baltic coastal small-scale WWTPs

Expert article • 3887

Governing small-scale wastewater treatment plants (WWTPs) in coastal tourist areas of the Baltic Sea Region (BSR) is challenging. Seasonal population fluctuations, fragmented legislation, and limited data availability create a complex regulatory landscape. The NURSECOAST-II project, with 17 partners from eight countries, addresses these issues by mapping WWTPs under 2,000 Population Equivalent (PE) and analysing their operational and environmental characteristics. However, the project revealed significant gaps in data availability and regulatory coverage.

A key finding is the widespread lack of comprehensive data on WWTPs below 2,000 PE — including their number, performance, and treatment efficiency. This lack of data severely limits the ability to assess their environmental impact, particularly in sensitive coastal zones where tourism intensifies wastewater generation. The situation is further complicated by the absence of monthly or quarterly monitoring data, which makes it nearly impossible to evaluate seasonal variations in treatment efficiency. Designed primarily for permanent residents, these systems often struggle to cope with peak-season loads.

Before the start of 2025, regulation of small-scale wastewater treatment varied across EU Member States, since the previous Urban Wastewater Treatment Directive (UWWTD, Council Directive 91/271/EEC) excluded plants below 2,000 PE. This left smaller systems outside the scope of harmonized regulation, resulting in inconsistencies in monitoring practices, effluent standards, and enforcement. Small wastewater treatment plants are often regulated on a site-specific, permit-by-permit basis, a practice that further contributes to regulatory fragmentation across Member States.

The situation is partially changing. The revised Urban Wastewater Treatment Directive (EU) 2024/3019 lowers the threshold for mandatory centralized wastewater treatment to 1,000 PE. This means that all agglomerations above 1,000 PE must be equipped with collection systems and secondary treatment by 2035. The directive does not extend monitoring obligations to WWTPs below 1,000 PE. If such plants are subject to monitoring, it is due to national legislation, not EU-level requirements. In Finland, WWTPs above 100 PE require an environmental permit with monitoring; systems below 100 PE, typically household-scale, remain largely unmonitored.

The inclusion of WWTPs in the 1,000–2,000 PE range under the revised directive is expected to improve environmental protection in coastal areas, especially those under tourism pressure. While tertiary and quaternary treatments are reserved for larger plants, the directive promotes water reuse, resource recovery, and stricter monitoring of pollutants such as PFAS, microplastics, and pharmaceutical residues. Nevertheless, the environmental load from small WWTPs remains largely unknown. Their potential contribution to nutrient pollution, particularly nitrogen and phosphorus, may be substantial. In some cases, these plants may discharge insufficiently treated wastewater directly into surface water bodies. Their coastal proximity and seasonal use spikes can affect water quality and ecosystem health. The lack of sufficient data prevents accurate modelling of their cumulative impact, which is essential for informed policy-making and sustainable tourism development.

Small municipal WWTPs (< 2,000 PE) remain an important part of the overall water protection framework. The regulatory landscape is heterogeneous, and while some countries publish clear numeric values and monitoring schedules, in many cases the permit is the key legal instrument. Monitoring frequency of 2–4 effluent analyses per year is typical but may be more frequent depending on risk. Operators must focus on permit compliance, good process management, and staying informed of evolving regulatory expectations, especially around nutrients and sludge reuse.

The spatial, analytical, and legal analysis conducted by the NURSECOAST-II project uncovered numerous discrepancies in data accessibility, WWTP distribution, effluent standards, and technological solutions across the BSR. These inconsistencies highlight the urgent need for harmonized regulations and standardized data collection protocols. Establishing a common EU-wide database would greatly facilitate scientific research and policy evaluation. Such a database should be accessible to both specialists and the general public, promoting transparency and enabling local authorities to make evidence-based decisions.

In conclusion, the study underscores the importance of improving governance and data infrastructure for small WWTPs in touristic coastal regions. Although the revised EU directive expands regulatory coverage to agglomerations over 1,000 PE, monitoring obligations for smaller systems remain dependent on national legislation. Expanding the scope of EU directives, investing in unified data systems, and ensuring the effective implementation of EU directives in national level are key to enhancing the resilience of wastewater infrastructure and protecting the ecological integrity of the Baltic Sea.

Virpi Vorne
Research Scientist
Natural Resources Institute Finland (Luke)
Finland

virpi.vorne@luke.fi

Anu Reinikainen
Research Scientist
Natural Resources Institute Finland (Luke)
Finland

anu.reinikainen@luke.fi

Ksawery Kuligowski
Project Leader, Assistant Professor
Institute of Fluid-Flow Machinery Polish
Academy of Sciences
Poland

kkuligowski@imp.gda.pl

SABINA BEC

Circular use of drinking water sludge

Expert article • 3888

When we open the tap, we rarely think about the complex chain of processes behind the delivery of safe drinking water. Although the European Union sets common quality standards, the treatment steps required to meet them differ. Depending on local conditions, groundwater or surface water may undergo several stages of clarification and purification before distribution. These processes generate a by-product known as drinking water sludge (DWS) – a watery mixture of inorganic minerals, organic matter, and residues of coagulants (most commonly aluminium or iron salts) used to remove impurities from raw water.

Bottlenecks in recycling and reutilisation

Efforts to recover and reuse coagulants from DWS date back more than a century, with the first related patent issued in the early 1900s in the United States. However, despite decades of research, recovery technologies proved too costly and produced impure coagulants that could not compete with virgin materials. Moreover, recovery processes generated additional waste streams that were more difficult to manage than the original sludge.

In recent decades, the focus has shifted towards using DWS as a whole. Its high mineral content makes it promising for use in construction materials, as a soil amendment, or as an adsorbent for pollutants. However, local and seasonal variability in composition, impurities, and occasionally volume, limit its predictability as a product. Hence, for industrial applications, raw materials with well-defined composition and performance characteristics are generally preferred over DWS-derived materials.

Towards a circular approach

Can DWS still contribute to sustainable water management – and how? In the Baltic Sea region, DWS is typically iron-rich, reflecting both the natural occurrence of iron in raw water and the widespread use of iron-based coagulants. Iron exhibits a high affinity for phosphorus – an element of particular importance due to its dual role as an essential nutrient and a major driver of eutrophication. The limited water exchange in the Baltic Sea makes it highly susceptible to nutrient accumulation and eutrophication. Iron is also used in wastewater treatment and can be dosed into anaerobic digesters for sulphur binding. Recent advances in understanding iron–phosphorus interactions have revealed that exposing iron-rich sewage sludge to anaerobic conditions leads to the formation of vivianite – a paramagnetic iron phosphate mineral – providing a new route for phosphorus recycling.

Integrating these applications could create a more circular resource chain across the water sector. Given that most European wastewater treatment plants stabilise sewage sludge through anaerobic digestion, utilising DWS in a preceding step could add value and enhance resource recovery. This was the aim of the recently completed SETTLE project, funded by the European Regional Development Fund (ERDF) and carried out in Mikkeli, Finland. The laboratory results, currently in preparation for publication, showed that acidified DWS can remove phosphorus from wastewater in chemically enhanced primary treatment comparably to commercial coagulants. Nonetheless, a major challenge in achieving independence from commercial coagulants was identified as the mismatch between DWS supply and demand – the studied wastewater treatment plant would require up to ten times more sludge than the nearby drinking water plant could provide.

Therefore, DWS was also tested as an additive in the anaerobic digestion of mixed organic waste. In this application, the available DWS quantities could meet the needs of a regional biogas facility, and no negative effects on biogas production or process stability were observed. This supports practices from the Netherlands, where iron-rich DWS is already utilised in anaerobic digesters to reduce hydrogen sulphide formation.

Outlook

Drinking water sludge has long been viewed as an inconvenient by-product, but new insights into its chemistry and role in nutrient cycling – particularly for iron-rich DWS – are reshaping that perception. By connecting drinking and wastewater treatment through DWS reuse and coupling it with anaerobic processes, it is possible to move toward a more integrated and resource-efficient water sector, where materials are not discarded after a single use but reintroduced as valuable resources. Such approaches also align with the EU's Circular Economy Action Plan and its objectives for nutrient recycling. For broader implementation, however, technical feasibility must be demonstrated under varying DWS compositions, and regulatory harmonisation across EU countries is needed to enable its recognition as a reliable secondary raw material. Strengthening regional cooperation in the Baltic Sea area could accelerate these developments by fostering knowledge exchange, pilot-scale trials, and shared investment in circular resource technologies.

Sabina Bec
PhD Candidate
LUT University
Finland

GRAHAM A. GAGNON, AMINA K. STODDART, EMALIE K. HAYES & MEGAN FULLER

Beyond Mercury: UV LEDs for clean water

Expert article • 3889

Why UV LEDs are Important

According to the European Environment Agency Europe's State of Water 2024 report, "water stress is already occurring in Europe. It affects 20% of Europe's territory and 30% of the population every year." The Agency warns that "Europe's water is under significant pressure, presenting serious challenges to water security, now and in the future." These pressures underline the urgency for effective technologies that deliver safe water and wastewater treatment with minimal environmental burden.

Across the Baltic region, utilities are searching for practical solutions to maintain effective microbial drinking water and wastewater treatment technologies as global restrictions phase out mercury mining, a key component in traditional ultraviolet (UV) disinfection. The Minamata Convention on Mercury and recent EU regulations will soon eliminate its use in industry, but most UV disinfection systems still depend on mercury-vapor lamps. Mercury metal is a potent neurotoxin that demands complex disposal and storage. For utilities, compliance has become both an environmental and financial burden. Countries across the Baltic region stand at a critical inflection point on how to achieve disinfection in the absence of traditional mercury UV systems.

Utilities across the Baltic region have long depended on mercury lamps because alternatives were unavailable. However, that is no longer the case, with the advances in solid-state light technology enabling UV LEDs to deliver the same level of disinfection without mercury, with the added potential to reduce energy consumption and greenhouse gas emissions. Our research team at Dalhousie University in Nova Scotia, Canada, in partnership with AquiSense Technologies, Halifax Water, and other North American Utility and industry partners, funded through a Water Research Foundation grant, recently demonstrated the world's first municipal-scale UV LED reactor for wastewater treatment. The full-scale reactor, operating at 545 to 817 m3/day, achieved an average 3.2-log reduction of E. coli at a UV fluence of at least 30 mJ/cm2 and greater than a 3-log reduction in total coliforms, with delivered fluences between 28 and 148 mJ/cm2.

Conventional UV mercury lamps emit light and heat in all directions. In wastewater applications, heat can increase the rate of material buildup and fouling, leading to significant operational downtime and cleaning expenses. UV LEDs generate unidirectional light while dispersing heat backward, which results in minimal fouling, clear optics, and consistent delivery of UV light to the water column. This precision design produces targeted UV radiation that efficiently inactivates microorganisms while avoiding the high temperatures that promote fouling. Because LEDs emit photons in narrow wavelength bands, their disinfection performance can be optimized to match the DNA or RNA absorbance peaks of target microorganisms, enabling wavelength-specific inactivation and improved fluence efficiency.

Our recent research has shown that this precision application of UV also has the ability to degrade contaminants of concern. In tests with six trace organic pollutants, UV LEDs tuned to 275 nm degraded estrogenic and aromatic compounds up to ten times more efficiently than medium-pressure mercury systems by aligning emission wavelengths with molecular absorbance profiles. This ability to tailor wavelength emission opens new possibilities for chemical-free treatment of pharmaceuticals, hormones, and other micropollutants. As LED technology continues to advance, these insights suggest a new era of cleaner, smarter water and wastewater treatment.

Alignment with Baltic Sustainability Goals

For the Baltic region, where water protection and renewable energy integration are shared policy goals, UV LEDs present a unique opportunity. They could operate at low voltage and can be directly powered by wind or solar energy without conversion losses. Because their intensity can be modulated electronically, these systems can align power consumption with renewable energy availability and treatment capacity requirements. This design also supports the HELCOM Baltic Sea Action Plan by reducing the need for chemical transport, storage, and emissions associated with traditional treatment. Each installation represents a step toward decarbonized infrastructure that connects energy efficiency with ecosystem protection.

The European Commission's Water Resilience Strategy (2025) emphasizes that "reducing water abstraction and enhancing water efficiency should take priority over increasing supply". Integrating low-energy UV LED systems directly supports this directive while advancing the EU's target "to enhance water efficiency by at least 10% by 2030." The EEA also highlights that "Europe is the world's fastest-warming continent," and about "30% of the EU's land area experiences seasonal water scarcity annually." For northern regions like the Baltic basin, where climate impacts are intensifying, water-smart technologies that reduce operational energy and leakage are vital.

Expert article • 3889

The Future of Safe Water

The State of Water 2024 report calls for "up-to-date and timely information on water quantity and quality" to enable more equitable and sustainable water allocation.

The shift to UV LEDs is part of a broader modernization of how water quality is managed. As new treatment technologies are adopted, the way we design, monitor and evaluate treatment systems must evolve. Conventional microbial assays cannot capture wavelength-specific fluence or molecular-level impacts. Molecular tools such as quantitative PCR and next-generation sequencing now provide direct measures of viral and bacterial gene damage. As advancement progresses in treatment technologies (e.g., UV LEDs) and molecular detection methods (e.g., next-generation sequencing), it is essential that sampling frameworks and associated decision making evolves in parallel. Together these innovations can transform how utilities assess performance and risk in real time.

As LED technologies continue to improve, researchers are already looking toward the next step, where light sources are derived from heavy-metal free quantum dots to minimize toxic metal inputs and maximize light duration to improve sustainability. In practical terms, UV LED systems are already more sustainable than traditional mercury lamps and quantum LED (QLED) systems will advance treatment efficacy and sustainability. This next generation of UV technology builds directly on the success of today's UV LEDs and shows how light-based treatment can continue to evolve toward cleaner and smarter water systems.

Graham A. Gagnon
Vice President Research & Innovation (Acting), Professor & Director
Centre for Water Resources Studies,
Department of Civil & Resource Engineering,
Dalhousie University
Canada

Amina K. Stoddart
Associate Professor
Centre for Water Resources Studies,
Department of Civil & Resource Engineering,
Dalhousie University
Canada

Emalie K. Hayes
Post-Doctoral Researcher
Centre for Water Resources Studies,
Department of Civil & Resource Engineering,
Dalhousie University
Canada

Megan Fuller
Director of Indigenous Research
Centre for Water Resources Studies,
Department of Civil & Resource Engineering,
Dalhousie University
Canada

ANNA LUNDE HERMANSSON

Ship scrubbers continue to pollute the Baltic Sea

Expert article • 3890

Exhaust gas cleaning systems, also known as scrubbers, are installed on ships to enable a continued use of cheap residual high sulphur fuel oil while still being compliant with the International Maritime Organization's (IMO's) stricter limit in sulphur emissions to air. The most common scrubber, the open loop system, continuously pump onboard ambient seawater, which is sprayed over the exhaust where sulphur oxides and several other contaminants are being scavenged. The scrubber effluent, now highly acidic and containing high concentrations of heavy metals and organic combustion products, is then discharged directly back into the marine environment. While ready-to-use alternatives (e.g. low sulphur fuels) exists, these are generally substantially more expensive which is why an increasing number of shipowners are opting for the use of scrubbers on their vessels. Today, over 6000 vessels, consuming a substantial share (~25%) of the total bunker fuel demand globally, are operating with scrubbers, thus using high sulphur heavy fuel oil (HFO) as their main fuel. In the Baltic Sea, the number of ships operating with a scrubber have multiplied since 2015 since the implementation of the Baltic Sea as a Sulphur Emission Control Area (SECA), with the goal of reducing pollution. Research show that the growing scrubber fleet has resulted in an increased HFO consumption in this designated SECA, and since 2015, almost 10 million tonnes of HFO have been used and over 3 billion cubic meters of open loop scrubber effluents have been discharged within the Baltic Sea area.

Ecotoxicological studies, where marine organisms at different life stages are exposed to different dilution ratios of whole scrubber effluents, reveal adverse effects at extremely low concentrations. Larval development is among the most sensitive life-stages, meaning that the discharge of scrubber effluent can seriously threaten the recruitment at several trophic levels. When attempting to predict the toxicity of scrubber effluents, by summing up the predicted effects of known scrubber effluent constituents, it is evident that the toxicity is always underestimated. Even when more substances are added to the prediction, by applying computational methods to estimate adverse effects on substances where we do not have ecotoxicological data, the measured effects are observed at much lower concentrations. This suggest that there are other substances in scrubber effluents, currently not monitored and/or measured, that result in adverse effects and, additionally, this shows that the complex mixture may be more potent than the sum of its constituents due to synergistic effects.

When the societal damage cost from scrubber water discharges was estimated for the Baltic Sea, the cumulative damage cost amounted to €680 million between 2014-2022. The damage cost was calculated based on cost estimates from a willingness-to-pay study in combination with toxicity potentials and characterization factors calculated from a life cycle impact assessment model, yielding a price per cubic meter of discharged open loop scrubber effluent. The damage cost estimate is however an underestimate, only including a limited number of substances detected in scrubber effluents. Also, a review of the willingness-to-pay study and the toxicity potential show that damage cost of the currently included substances is likely to be higher.

A growing number of scientific publications show that the use of scrubbers will never be a sustainable solution but merely an economically motivated strategy to enable a continued use of the cheapest, and also the dirtiest fuel that exist on the market. Finland, Sweden and Denmark are taking action to ban the discharge of (open loop) scrubber effluents within their territorial waters and more countries within the Baltic Sea have limited the discharge of scrubber effluents at different spatially defined levels. HELCOM and its Member States should continue their strong collaboration to cease discharge of all scrubber effluents and the combustion of HFO within the Baltic Sea. Given the long-term strategic goals and resources invested in reducing the pressures from human activities within the Baltic Sea area, restricting the use of scrubbers and HFO, where readily available alternatives exist, is one measure that will have huge impact, both for the marine environment and from a socioeconomic perspective.

Anna Lunde Hermansson
Dr., Postdoctoral Researcher
Chalmers University of Technology
Sweden

RWTH-Aachen University
Germany
anna.lunde.hermansson@rwth-aachen.de

KRISTINA KOKINA & JĀNIS ZVIEDRIS

Smart water for a sustainable well-being

Expert article • 3891

Sustainable management of water resources is vital to ensure safe drinking water for present and future generations while protecting freshwater ecosystems. In Jurmala, Latvia, the municipal utility Jurmala Water demonstrates how integrated water abstraction, treatment, and treated wastewater discharge practices can achieve environmental protection and resource sustainability. Serving around 50,000 residents, the company manages the entire water cycle — from groundwater extraction to wastewater treatment and controlled discharge into the Lielupe River, which flows into the Gulf of Riga.

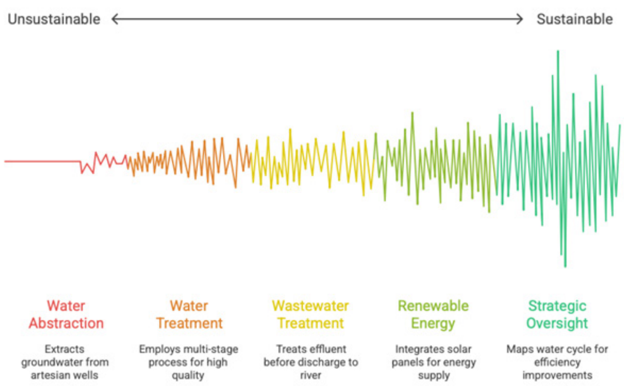
Water abstraction occurs from 20 artesian wells in Dzintari, Jaundubulti, Kauguri, and Kemeri, with depths from 145 to 255 meters. Jurmala Water employs a multi-stage treatment process to ensure high-quality drinking water. Aeration promotes iron oxidation, followed by filtration through quartz sand to remove iron and manganese. Nanofiltration membranes eliminate divalent ions and enhance water quality. Continuous monitoring using laboratory analyses and SCADA systems ensures compliance with WHO and EU drinking-water standards.

Equally important is wastewater management. Sewage from the serviced areas is treated at the Sloka wastewater treatment plant, where physical and biological processes remove pollutants before the effluent is released into the Lielupe River. This controlled discharge preserves aquatic ecosystems and protects the water source areas, effectively closing the loop of sustainable water management.

Innovation plays a central role in Jurmala Water's operations. The company has introduced floating solar panels to supply renewable energy for wastewater treatment[1] and has launched nutrient-recovery projects[2,3,4] demonstrating the application of circular water management principles. These initiatives reduce environmental impact, improve efficiency, and provide replicable models for other municipalities.

Releasing clean water back into the environment is essential. Proper effluent treatment maintains river ecosystem health, supports aquifer recharge, and ensures long-term water availability. It prevents the accumulation of hazardous substances, safeguards public health, and fosters community trust in municipal services. Achieving these results requires robust operational practices, continuous monitoring, and skilled staff capable of maintaining complex treatment systems and responding effectively to disruptions.

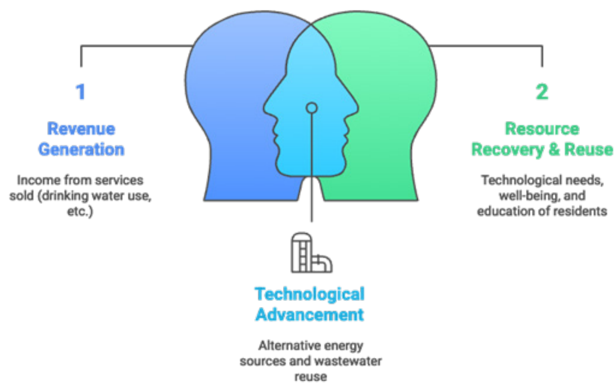
Figure 1. Water management practices range



Jurmala Water shows sustainable water management is built on technological excellence, strategic oversight, and environmental responsibility (Figure 1). By mapping critical points in the water cycle — from groundwater abstraction to effluent discharge — the utility identifies opportunities to improve efficiency, mitigate risks, and strengthen sustainability. Every stage, from treatment optimization to resource recovery, protects water resources for future generations.

Although Jurmala Water's revenues depend primarily on services sold, such as drinking-water supply, the company actively explores resource recovery and reuse for technological benefits, public well-being, and education. Developing alternative energy sources and reusing treated wastewater allows residents and visitors to benefit from sustainable practices — for example, by irrigating green spaces and, in the future, cleaning streets. The company views sustainability as a business objective and a balance between economic viability, environmental protection, and community education (Figure 2).

Figure 2. Jurmala Water's sustainability vision



This case highlights the importance of municipal utilities as stewards of the water cycle. Jurmala Water successfully combines operational efficiency with environmental care through integrated management, innovation, and adherence to international standards. Continuous improvement and proactive strategies ensure that clean water remains available for its community while setting an example of sustainable urban water management for towns and cities worldwide.

Jurmala Water exemplifies how municipalities can transform water services into a sustainable, resilient, and responsible system through high-quality treatment, responsible effluent discharge, and forward-looking innovation. Protecting rivers and aquifers is not just a regulatory duty but a lasting commitment to ecological stewardship and societal well-being.

Note
The language of this text was reviewed and improved using Grammarly AI tools.

[1] https://derex.lv/news/derex-built-the-first-floating-solar-station-in-baltic-region
[2] https://johnnurmisensaatio.fi/en/our-work/projects/the-pure-project/
[3] https://www.iwama.eu/tags/jurmala
[4] https://interreg-baltic.eu/project/renutriwater/

Kristina Kokina
Dr.Sc.Ing., Head of Water Treatment Technologies Department
Jurmala Water
Jurmala, Latvia

Associate Professor and Senior Researcher
Riga Technical University
Riga, Latvia

kristina.kokina@jurmalasudens.lv; kristina.kokina_1@rtu.lv

Jānis Zviedris
M.Sc.Ing., Head of Wastewater Treatment Department
Jurmala Water
Jurmala, Latvia

Lead Expert
Riga Technical University
Riga, Latvia

janis.zviedris@jurmalasudens.lv; janis.zviedris_1@rtu.lv

HANNA KYLLÖNEN

Industrial wastewaters in nutrient recycling

Expert article • 3892

Introduction

Large amounts of mineral nutrients are being released into the environment through various waste streams, leading to pollution of soil, water, and air. However, increasingly stringent legislation is driving the reduction of wastewater pollutants, particularly nitrogen (N) and phosphorus (P), while also promoting circular economy initiatives. At the same time, resource depletion and growing global demand for mineral nutrients have led to price pressures and a search for alternative nutrient sources, such as industrial wastewaters. Recovering nutrients from wastewater offers dual benefits: it removes impurities from water, making it reusable, and concentrates these impurities into forms that can be used as recycled nutrients.

Industrial wastewaters pose challenges for nutrient recovery due to their typically low nutrient concentrations, complex compositions, and the presence of contaminants such as heavy metals and organic pollutants. Low nutrient concentrations reduce the economic feasibility of recovery, while the complexity of wastewater makes selective extraction of desired nutrients difficult. Contaminants may accumulate in recycled nutrient products, potentially rendering them unsuitable for agricultural use. Furthermore, strict regulations govern the use of recycled materials in agriculture. Addressing these challenges often increases the cost and complexity of nutrient recycling processes.

Nutrient-Rich Industrial Wastewaters

Unlike municipal wastewater, industrial effluents vary significantly depending on the industry type and production cycles. Seasonal fluctuations in wastewater quality and quantity further complicate the design of standardized nutrient recovery processes. Findings from the TYPKI project, funded by Business Finland, VTT, the University of Oulu, and industry partners, revealed that industrial wastewater typically contains low nutrient concentrations, which are nonetheless too high to be discharged into the environment without treatment. Nutrient recovery was found to be most feasible when integrated into water purification processes. Since all generated streams must be managed during purification, utilizing concentrates for nutrient recovery becomes advantageous.

Mine waters generally contain low levels of organic nutrients, but some mineral nutrients can still be recovered. For example, wastewater from chemical leaching of concentrates can contain ammonium salts, albeit at low concentrations, necessitating additional concentration and purification steps. Tailings pond waters can be rich in sodium sulphate (Na_2SO_4) and can also contain potassium (K) and magnesium (Mg). Open pit water from mines may contain residual explosives, such as ammonium nitrate (NH_4NO_3). Although the concentrations are low, they often still are too high for direct discharge, making recovery from water purification concentrates a viable option. While phosphorus is typically not a major concern in mining, its use in metal refining and metal processing applications such as metal surface treatment, particularly involving phosphoric acid, can lead to elevated phosphorus levels in wastewater.

In the pulp and paper industry, N and P are present in wastewater, but often not in sufficient quantities to support biological treatment without supplementation. However, scrubber water from flue gas cleaning can contain valuable nitrogen compounds, especially nitrite (NO_2^-) and nitrate (NO_3^-) salts, which offer significant potential for nutrient recovery at the source.

The food industry generates some of the most nutrient-rich wastewaters due to the presence of organic nutrients and biological residues. In the European Commission funded Afterlife project, VTT studied wastewaters from dairy, beverage, and confectionery factories for the recovery of valuable compounds. These wastewaters, rich in organic content, were found suitable for microbial processes and nutrient recovery for fertilizer production. Dairy and meat processing wastewaters contain proteins, fats, and phosphorus, while beverage and confectionery wastewaters are rich in sugars, polyphenols, and nitrogenous compounds.

Biogas production processes, often integrated into industrial wastewater treatment, generate a liquid by-product known as digestate. This digestate is rich in ammonium, phosphorus, potassium, and organic carbon. It can be used directly as fertilizer or further processed to recover nutrients, such as struvite, through precipitation.

Technologies for Nutrient Recovery

The choice of nutrient recovery technology depends on the quality and quantity of the wastewater, as well as the desired quality of the final nutrient product. While the goal is to develop simple recovery concepts, these often involve multiple technologies in sequence. Since no universal solution exists for nutrient recovery from industrial wastewater, two examples from the TYPKI project are presented below.

In one case, nanofiltration (NF) and reverse osmosis (RO) were used to treat concentrate leaching wastewater, producing reusable water as permeate with low concentrations of impurities. A calcium (Ca) concentration below 30 mg/L is preferred to achieve high water recovery in NF and RO processes. This can be achieved through precipitation using oxalic acid or sodium carbonate. The purified water can constitute up to 95% of the effluent volume, which results in a 20-fold reduction in the volume of nitrogen-containing water, effectively concentrating the nutrients. For nitrogen recovery, a membrane contactor (MC) can be used to extract ammonia from the concentrate, producing a pure 30% ammonium sulphate ($(NH_4)_2SO_4$) solution.

In another example, nutrients from open pit water were recovered using NF as a pretreatment step before RO concentration. The optimal NF membrane exhibited high sulphate rejection and low nitrate rejection. This process increased the nitrate concentration in pit water from 110 mg/L to 3,900 mg/L. However, further concentration and purification of nitrate compounds, such as potassium nitrate (KNO_3), require additional technologies, such as crystallization. The additional step increases production costs. The estimated operating cost for NF and RO is as low as 0.5 €/m^3 (assuming 0.1 €/kWh), whereas cooling crystallization costs exceed 4 €/kg of KNO_3.

Market and Products

The market and application of recycled nutrients are governed by a combination of EU-wide and national regulations. Strict requirements for purity and concentration, driven by safety, performance, and market acceptance, make nutrient recycling a challenging business. Moreover, the presence of well-established nutrient sources and end-users further raises the entry barrier.

However, upcoming policy developments are expected to promote circular economy initiatives. Wastewater treatment plants may be required to recover a portion of nutrients, while chemical companies could be encouraged, or even mandated, to incorporate recycled nutrients into their products.

Current separation technologies already enable the simultaneous production of purified water and the recovery of concentrated, high-purity nutrient products. The key question remains: when will this become broadly profitable?

Hanna Kyllönen
Senior Scientist
VTT Technical Research Centre of Finland Ltd
Finland

hanna.kyllonen@vtt.fi

LOTTA LEHTI

Towards a toxic-free water cycle

Expert article • 3893

Background

There is growing concern about pollution from toxic chemicals in the water cycle. While the water protection work in the Baltic Sea Region has traditionally concentrated on eutrophication and nutrient removal, there is now a consensus that hazardous substances are one of the main threats to the aquatic environment. Further, the many chemicals, extremely persistent and mobile in the environment, pose a threat to human health.

The EU is addressing this problem mainly through legislation. The revised Urban Wastewater Treatment Directive (UWWTD 2024/3019) came into force on 1 January 2025. The directive marks an important milestone for public health and the protection of water resources, introducing ambitious new requirements to remove micropollutants from wastewater. According to the revised directive, member states will have to ensure the application of the treatment steps meeting new thresholds for quaternary treatment in larger plants of 150 000 PE and above by 2045.

Mobile pilot plant concept

One of the main aims of the EMPEREST project (2023–2025), co-funded by the Interreg Baltic Sea Region Programme, was to support the implementation of the revised UWWTD. The implementation will require extensive investments in quaternary treatment. The results of the EMPEREST piloting will support wastewater treatment plants and local authorities in making informed decisions about cost-effective technologies for micropollutant removal to unlock the investments.

Two pilot plants were locally constructed, respectively, by Gdansk Water Utilities Ltd. and Tartu Waterworks Ltd., to test the selected proven technologies at the wastewater treatment plants in different combinations with varying process parameters. After the first round of testing, the mobile containers continued their journeys to four more cities: Szczecin, Kaunas, Tallinn and Turku. During the testing periods in six sites, regular analysis of water samples allowed to assess the effectiveness of the technologies in the removal of organic micropollutants and thus support the piloting WWTPs in their decision-making regarding most suitable trains of technologies for their conditions.

Results on micropollutant removal from wastewater

The results of the EMPEREST technology pilots can be found in the project report, Strategies and technological means for minimising organic micropollutant emissions from WWTPs and its six annexes featuring the results of each piloting plant (all reports are available on EMPEREST project website). The results focus on the efficiency of advanced treatment technologies for removing organic micropollutants listed as indicator substances in the revised UWWTD.

While factors affecting the choice of micropollutant removal technology vary between different plants, activated carbon adsorption and ozonation proved to be feasible techniques for removing the micropollutants currently listed in the revised UWWTD.

Regarding per- and polyfluoroalkyl substances (PFAS) in particular, the results are complex and further testing is needed. The EMPEREST results on PFAS removal indicate the following:

- Conventional use of ozone alone is not efficient in PFAS removal. Ozone can reduce the length of the PFAS chain, while the resulting shorter-chain PFAS or other intermediates are persistent and potentially harmful as well.
- Granular activated carbon (GAC) filtration can be effective at removing specific long-chain PFAS.
- Ion exchange (IE) is an effective method for both long-chain and short-chain PFAS, however, the operational costs of IE filters are high.
- Nanofiltration has proven to be effective in removing PFAS, but results in a large volume of concentrate, which needs its own treatment or destruction process.

The EMPEREST mobile pilot plants showed that the mobile pilot concept is a cost-effective tool for supporting the upgrade and development of numerous WWTPs, without the need of constructing individual pilot installations.

Conclusions

The EMPEREST project was built on the shared understanding that removing organic micropollutants, including PFAS, is necessary for safe circularity of water and sludge. The project showed that despite advanced technologies, preventing the hazardous substances pollution is a more effective and cost-efficient approach. Upstream prevention measures include increasing the selection of PFAS-free products on the market, strengthening the consumer responsibility to make PFAS-free choices and supporting a general PFAS ban in industry. The EMPEREST project worked also on prevention through building a risk-assessment tool for local authorities for identifying the PFAS pollution hotspots in their city and for starting to mitigate the risks. Further, EMPEREST project undertook an extensive training programme for building capacities of different stakeholders on the topic of PFAS, other organic micropollutants, their removal from the water cycle, prevention measures, etc. Finally, EMPEREST produced, with the support of Baltic Marine Environment Protection Commission HELCOM, guidelines for monitoring and assessing the PFAS pollution in the aquatic environment of the Baltic Sea and catchment area. Continued monitoring and assessment of pollution is vital: reliable data is key in the building of a toxic-free future.

Lotta Lehti
Project Coordinator
Union of the Baltic Cities Sustainable Cities
Commission c/o City of Turku
Finland

lotta.lehti@turku.fi

PETER R. NKHOMA

Scaling water reuse for global sustainability

Expert article • 3894

Water is a foundational natural resource essential to global sustainability; it underlies all human activities and the functioning of natural systems. Yet globally the strain on freshwater resources has intensified to critical levels as global population increases and economic activity accelerates, albeit unevenly across geographic space. The United Nations projects that by 2030 global water demand may exceed available supply by as much as 40%. It is likely that without significant reforms to global water management and governance, in the context of climate change, demand will intensify competition for water resources, potentially elevating water scarcity as a source of geopolitical tension and conflict. To avert a widespread crisis, nations must look beyond conventional freshwater sources toward sustainable alternatives capable of supporting both domestic and industrial consumption. Among these, water reuse, particularly potable reuse, has emerged as one of the most promising solutions.

Addressing the global water challenge necessitates a paradigm shift in how societies conceptualize and manage water, moving from a linear model of extraction and disposal to a circular framework centered on recovery and reuse. This transition also requires a structural reimagining of the human–water relationship and reevaluating the systems that govern water use and management. Importantly, recent technological advances now permit the production of recycled water that satisfies or exceeds international drinking standards.

Successful large-scale implementations in countries such as Singapore, Australia, Namibia, and the United States have demonstrated the technical feasibility, cost-effectiveness, and long-term sustainability of recycled water systems, showing that water reuse can safely augment or even replace conventional sources, thereby strengthening both water security and ecological balance. These schemes illustrate that the obstacles to widespread adoption of water reuse are socio-institutional rather than technical: they are rooted in how societies understand, communicate about, and ultimately trust recycled water as a safe and legitimate resource. Global adoption of water reuse, particularly forms that involve close personal contact, such as direct potable reuse remains limited, with public perception representing the primary obstacle to scaling water reuse worldwide.

Public resistance to water reuse persists despite rigorous empirical evidence supporting the safety of purified recycled water. Many communities remain opposed, driven both by psychological and cultural aversion, often referred to as the "yuck factor," which stems from deep-seated feelings of disgust and limited understanding of advanced treatment processes, as well as by ongoing concerns about potential health risks from pathogens and pollutants of emerging concern. Compounding this challenge is the erosion of public trust in institutions responsible for water governance. In many cases, communication from authorities has been highly technical, top-down, and detached from community realities, reinforcing skepticism rather than alleviating it. Consequently, even scientifically sound water reuse projects have faced resistance, delays, or outright rejection.

Conversely, where water reuse has been embraced, the success has been grounded in robust communication, education, and trust-building. Long-term public awareness campaigns that demystify treatment processes, community participation in decision-making, and transparent information-sharing have all proven effective in fostering legitimacy. Singapore's NEWater program exemplifies this approach: decades of consistent education, open tours of treatment facilities, and the strategic framing of water reuse as a symbol of national resilience transformed public attitudes.

Replicating success across diverse global contexts requires sensitivity to local conditions and recognition that public acceptance of water reuse is shaped by distinct cultural, social, and environmental factors. This calls for a paradigm shift from prescriptive, one-size-fits-all policy frameworks toward adaptive, participatory models of governance that are responsive to local realities.

Potable reuse is no longer experimental, it is a proven, safe, and cost-effective solution when technology, governance, finance, and social legitimacy align. From Singapore's NEWater and Orange County, California, indirect potable reuse systems, which laid the groundwork for public acceptance and technological confidence, to Windhoek, Namibia, and pioneering direct potable reuse programs in Big Spring and El Paso, Texas, the evidence shows that potable reuse can be scaled as a core pillar of twenty-first century water security.

The move toward widespread water reuse must therefore be understood as a transformative pathway, not a marginal adaptation, aligning with the broader transition toward circular resource economies in which waste streams are reconceptualized as sources of renewal. Clearly, technology is no longer the principal constraint; the real challenge lies in building social legitimacy and establishing supportive governance structures through transparent communication, trust-building, and cultural responsiveness.

This trajectory reflects a shift in environmental governance, from a narrow focus on technological fixes to a systems-based approach that integrates science, society, and policy. The future of global water security will depend not only on technological capability but also on our collective capacity to build trust, foster collaboration, and communicate effectively across scales.

Ultimately, scaling water reuse for global sustainability requires nations to move beyond reactive crisis management toward proactive stewardship of water resources. By embedding water reuse into the mainstream of policy, infrastructure, and culture, societies can transform it from a niche innovation into a bedrock of global water resilience, reducing vulnerability to scarcity and mitigating climate risks.

Peter R. Nkhoma
PhD, Geography Instructor
Delta College
Michigan, USA

peternkhoma@delta.edu

OSKARS PURMALIS, JANIS KRUMINS & MARIS KLAVINS

Reclaimed wastewater reuse topicality in Baltic Sea area

Expert article • 3895

Baltic Sea region is centring around Baltic Sea and its waters have connecting function for countries and is a resource for development and major value for countries of the region. It seems Seas are inexhaustible resource, however in reality situation is far from ideal. Urban growth, industrialisation, development of agricultural production puts major stress on water resources as indicated by water exploitation index. Countries around Baltic Sea are very aggressively disturbing natural water cycle and in coming future human impacts will only increase aggravated by climate change impacts.

As most significant threat for Baltic Sea can be considered eutrophication leading to algal growth, destruction of biological diversity, causing oxygen depletion in deeper layers of the Baltic Sea. Source of eutrophication are nutrients (nitrogen and phosphorous compounds) coming from agriculture, and all kinds of wastewaters.

Both EU regulations, both regional authorities (Helsinki Commission – HELCOM) decisions requires significant reduction of nutrient loading. A new challenge to water resource management system is recently adopted water resilience strategy, putting water pollution reduction tasks in the centre of attention urging search for new solutions.

A significant source of Baltic Sea pollution are discharges from wastewater treatment facilities and recent analysis characterise flows of nutrients as significant problem. At the same time there exist approach to reduce both water consumption and simultaneously nutrient loads to receiving water bodies and seas – reclaimed water use. Reclaimed water can be used for recreational applications, in construction industry and other areas, but most widely it is used for irrigation. Use of reclaimed water for irrigation is a tool to recover nutrients, present in wastewaters and use nutrients still present as fertilisers to support plant growth. Reclaimed water use in agriculture is a common praxis in dry and hot region countries, however, in the Baltic Sea area, exist falsely believes in endless of water resource availability and reclaimed wastewater reuse is rare – only few demonstration cases. Such approach is wrong! Reclaimed water use can be considered as an efficient tool to achieve both water resource saving aims, both Baltic Sea pollution reduction with nutrients.

The reuse of reclaimed water is gaining attention across the Baltic Sea region as countries contend with growing pressure on freshwater availability, nutrient management, and climate resilience. While the Baltic Sea region is perceived as a water-abundant area, several underlying drivers are continuously elevating the relevance of water reuse. These drivers include increasing urbanization, seasonal drought risks, over-extraction of groundwater in coastal zones, and targets for nutrient reduction becoming stricter the under EU and HELCOM obligations.

BSR Interreg project "ReNutriwater" aim is to demonstrate feasibility of reclaimed water reuse in the Baltic Sea area, not only demonstrating performance of this approach, but also providing analysis of factors, promoting of this approach and identifying barriers. "ReNutriwater" involves stakeholders (wastewater treatment facility operators, NGO, professional organisations, universities from 5 BSR countries (Denmark, Poland, Latvia, Lithuania, Finland) with an aim in piloting cases to demonstrate to professionals in water management sector and politicians the reclaimed water use is feasible and gain-gain approach. Additionally in project innovative approach has been elaborated proposing to use reclaimed water for cultivation of algae biomass, prospective for use of biofuel as well as algal biomass with diverse applications. Project is resulting with a hand book supporting implementation of reclaimed water reuse available for any wastewater treatment operator.

Water reuse offers an opportunity to reduce pressure on freshwater resources, improve resource circularity, and support the Baltic Sea region's transition toward a more climate-adaptive and sustainable water economy. For instance, in urban contexts, treated wastewater can be repurposed for industrial cooling, street cleaning, and groundwater recharge, thereby reducing abstraction stress on lakes and aquifers. Meanwhile, in agriculture, reclaimed water can help bridge seasonal irrigation gaps as precipitation patterns over time become more unpredictable.

However, reclaimed water reuse is still at an emerging stage and presents numerous technical and governance-related risks. For instance, concerns remain about the introduction of micropollutants, pharmaceuticals, pathogens into soils or groundwater if reclaimed water is used. These risks are intensified by the lack of harmonized standards across the EU and the slow uptake of the EU regulation on minimum requirements of water reuse, which remains voluntary. Public acceptance is also a critical barrier because of the stigma associated with reclaimed water. Furthermore, economically, the upfront investment in the reclamation technologies is also prohibitive, while, politically, everything wastewater related lies with different ministries and agencies, making integrated policy implementation difficult.

Despite these challenges, the Baltic Sea region is well positioned to lead in water reuse innovation. Many countries already possess high standards for wastewater treatment, and growing interest in nutrient recovery and circular economy strategies aligns closely with water reuse initiatives. Pilot projects already have demonstrated technical feasibility and social acceptability under well-regulated conditions. Thus, reclaimed water reuse deserves greater political prioritization, cross-border coordination, and investment due to growing geopolitical uncertainties and resource dependencies.

Oskars Purmalis
Dr. geogr., Associate Professor
Department of Environmental Science,
University of Latvia
Latvia

Janis Krumins
Dr. geogr.
Department of Environmental Science,
University of Latvia
Latvia

Maris Klavins
Dr. habil. chem., Professor
Department of Environmental Science,
University of Latvia
Latvia

KLARA RAMM

Water renewal as a joint activity of the Baltic community

Expert article • 3896

Fresh water is a resource without which human civilization, agriculture, industry, and cities cannot exist. Public well-being, health, and the natural environment all depend on it. Yet, water is still too often viewed solely as a component of municipal infrastructure or the exclusive domain of hydrologists or engineers. This narrow perspective leads to fragmented management and the loss of synergies that could strengthen local and regional actions.

Climate change and the growing pressures of civilization, which lead to the degradation of ecosystems, also force us to break free from conventional thinking. Water is not a problem, but a shared resource of politicians, urban planners, farmers, doctors, economists, sociologists, and engineers. Integrating multiple perspectives is a necessary condition for ensuring long-term social and economic security in the context of access to sufficient and clean water resources.

The traditional urban wastewater management model, derived from a 1991 EU Urban Wastewater Treatment Directive, was based on a simple triad: collect-treat-discharge. This approach was one of Europe's greatest achievements in the 20th century, ensuring sanitary safety and reducing water pollution.

However, the 21st century requires a new paradigm. Today, wastewater is increasingly seen as a source of recoverable resources: clean water, nutrients, biomass, energy, cellulose, etc. This is the essence of a circular economy, where water is given a second life. The adoption of the recast EU Urban Wastewater Treatment Directive (2024/3019) legitimized this shift, emphasizing recovery and reuse as key objectives of European water policy.

Wastewater treatment plants can now evolve into bio factories - urban symbiosis hubs where reclaimed water is used for irrigation, street cleaning, or industrial cooling, where nutrients replace synthetic fertilizers, and wastewater heat supplies district heating systems.

The Baltic Sea Region is particularly vulnerable to climate change, eutrophication, and water scarcity. No country can face these challenges alone. International cooperation and exchange of experience are essential. Local governments can implement integrated approaches to water management that go far beyond drinking water supply and wastewater services. Water must not be treated as an isolated policy issue.

The ReNutriWater project, funded by Interreg Baltic Sea, provides practical guidance on scaling up water and nutrient recovery. It focused on the safe water reuse for irrigation and landscaping, reducing pressure on freshwater resources. It also addresses the recovery of nutrients (particularly nitrogen and phosphorus) to replace chemical fertilizers. Stakeholder engagement and education are crucial to ensure that local authorities, farmers, businesses, and citizens understand that reclaimed water is safe, beneficial, and aligned with the objectives of the Water Resilience Strategy and the European Green Deal. The solutions developed in the project offer municipalities guidance on adapting to local realities and building trust in circular water management practices. Pilot initiatives under ReNutriWater, such as small-scale nutrient recovery systems and demonstration sites for water reclamation, show that a circular water economy can be both cost-effective and socially acceptable when supported by knowledge-sharing platforms and strong networks.

Organizing urban and regional water symbioses requires cooperation between water utilities, energy producers, industries, farmers, and municipal authorities. It also presents an educational challenge: both officials and residents must be convinced that closed-loop water is an opportunity, not a threat. Local governments can act as integrators, working with schools, universities, NGOs, and community groups to foster innovation. Successful water projects in Europe prove that when various sectors join forces, solutions become more resilient, sustainable, and socially accepted. In BSR, we already have many interesting industrial symbioses, such as Kalundborg, Rotterdam, or Katowice (cooling water). But thanks to the ReNutriWarter project, urban solutions are also emerging, for example, in Kuopio, Jūrmala, Warsaw, Samsø, and Polańczyk.

Water knows no administrative boundaries, so neither can our policies or actions. It is time to break down institutional barriers, connect municipalities across the Baltic Sea Region, and develop common standards for reuse, recovery, and protection.

Local government officials and decision-makers face a choice today: either continue with fragmented actions and risk escalating water crises or boldly embrace cooperation that brings long-term benefits.

By adopting the principles demonstrated in projects like ReNutriWater, the Baltic community can transform water management into a driver of resilience, security, and innovation. Giving water a second life is not just an environmental necessity; it is a social and economic opportunity.

Klara Ramm
Expert
Chamber of Economy "Polish Waterworks",
Warsaw University of Technology
Poland

k.ramm@igwp.org.pl

ELISA ROSE

Water reuse across the Baltic Sea region

Expert article • 3897

Five years ago, a simple but ambitious idea began to grow near Braniewo, Poland through the Baltic Sea Region: what if every drop of water could be used more than once? That idea became **WaterMan** – a cross-border Interreg Baltic Sea Region project co-funded by the European Union uniting municipalities, research institutes, and water companies around one shared mission: to make water recycling a practical, local reality.

Now, the results are tangible. Across six partner countries, new water management systems, feasibility studies, and water reuse strategies are transforming how communities manage their most vital resource. The message is clear: the future of water resilience has already begun.

When WaterMan launched in 2023, its founding principle was both modest and powerful: *just get started.* Instead of waiting for perfect conditions, the partners committed to testing solutions on the ground—using existing technologies, tailored to local circumstances, and designed to be affordable and low-maintenance.

The goal was not just to innovate, but to demonstrate that water recycling works in practice. Whether tackling too much water during floods or too little water during droughts, each pilot project would show how even small local actions could make a measurable difference.

Pilot examples That Make a Difference

In **Kalmar, Sweden**, a team of municipal gardeners led one of WaterMan's earliest pilots: a mobile container-based wastewater recycling system used to irrigate young trees. Compact, efficient, and ready to replicate, it provides a model for any municipality wanting to green its spaces without draining its resources.

In **Gargždai, Lithuania**, a low-cost stormwater retention pond inspired by Swedish examples became a local milestone—the first of its kind in the country. What started as an experiment is now a functioning demonstration site showing how simple designs can yield major benefits for local water resilience.

In **Berlin, Germany**, researchers at the Center of Competence for Water took a data-driven approach, studying how treated wastewater could be reused as cooling water for industrial facilities. Their feasibility study provides the evidence policymakers need to move from theory to action.

And in **Braniewo, Poland**, the project introduced a dual pilot: a rain garden that captures and filters runoff from a parking area, and a swimming-pool recycling system designed to reuse treated pool water for non-drinking purposes. Together, these solutions turn everyday public sites into living examples of sustainable water use. They also help educate local communities—through signage and school visits—about the importance of smart water management in a changing climate.

Learning and Sharing Across Borders

One of WaterMan's biggest successes lies in how knowledge flows among its partners. Through continuous peer reviews, expert consultations, and cross-country exchanges, each team refined its work with input from others.

This spirit of collaboration made it possible for regions at very different stages of water management development to learn from each other. Swedish experience informed Lithuanian innovation; Polish pilots inspired educational initiatives; and German research offered scientific grounding for future regulations.

As one partner summed it up: *"In WaterMan, progress didn't come from working in isolation—it came from learning together."*

From "If" to "How"

By 2025, the project's focus had evolved from experimenting with technologies to shaping long-term strategies. Each region developed its own **model strategy for water recycling**, analysing how local geology, climate, and governance and formulated actions to promote water reuse.

The results point in one direction: the debate is no longer if water recycling should happen—it's how to make it standard practice.

Still, challenges remain. Many countries lack e.g. financial investments or clear legal quality standards of recycled water. To help fill these gaps, WaterMan partners have prepared a **policy paper** to share their insights with national and EU policymakers. The aim is to make regulatory systems as adaptive as the technologies they govern.

WaterMan's legacy is already spreading. Local authorities across the Baltic Sea Region are adopting its methods, adapting its pilots, and integrating water recycling into urban planning. The mindset is shifting—from emergency response to long-term resilience.

The work doesn't end here. WaterMan's open-access **Toolbox** gathers all project materials—technical blueprints, policy recommendations, and step-by-step guides—for anyone ready to take their own first steps toward water recycling. **Visit the WaterMan Toolbox!**

Want to stay informed about the latest results and success stories from the Baltic Sea Region? Sign up for IN THE LOOP, WaterMan's newsletter bringing you new insights and practical tools for water reuse management.

Elisa Rose
Water Expert
Berlin, Germany

e.rose@aquarose.de

JENNA SENECAL, PRITHVI SIMHA, EVELINA VINNERÅS, NICOLA PARFITT & BJÖRN VINNERÅS

Circular sanitation takes the football field

Expert article • 3898

When tens of thousands of football fans fill Studenternas arena in Uppsala, few realise that the stadium's sanitation system is quietly modelling the future of urban sustainability. Behind the scenes, the Swedish urine recycling company Sanitation360, together with the Swedish University of Agricultural Sciences (SLU) and the City of Uppsala, has installed one of Europe's first and largest urine collection and treatment systems.

Sanitation360's urine recycling installation, supported by the CiNURGi Project, demonstrates how cities can recycle urine at public venues and how urine-diverting toilets and urinals are becoming the new normal in the process of creating a more circular society. This initiative addresses two long-standing challenges of modern sanitation — managing hydraulic and nutrient peak loads during large events, and turning what is traditionally viewed as waste into a valuable agricultural resource.

Managing peaks

Large arenas experience extreme fluctuations in wastewater flow. During matches or concerts, thousands of toilet visits occur within short periods, creating significant hydraulic surges and nutrient shocks for municipal wastewater treatment plants. These peaks force utilities to maintain excess treatment capacity and operate with high energy demand, even though such high loads occur only occasionally. If a wastewater treatment plant does not have this extra capacity, then untreated wastewater is released into our waterways, exacerbating eutrophication and overall water pollution.

At Studenternas, urine is diverted and collected before it reaches the conventional sewer network. As urine is the most nutrient rich fraction we excrete, each visit to the urine-diverting toilets or urinals removes the most nutrient-dense fraction from the wastewater flow. With an average attendance of around 7,000 people at Studenternas, the installed system collects the equivalent of about 1,050 kg of fertiliser every year, enough to fertilise three football fields every year.

Controlling odours

The collected urine is stabilised with an eco-friendly, food grade stabiliser. On-site stabilisation of urine is crucial both for retaining its valuable nutrients and for controlling odours. Without the stabilisation, the most sought after nutrient in our urine, nitrogen, escapes as a gas, producing the unpleasant smells commonly associated with urinals and festival toilets. This source-separation approach captures a concentrated stream of nitrogen, phosphorus, and potassium — nutrients essential for food production yet often lost in conventional treatment systems.

Circular potential

The stabilised urine is concentrated on site to reduce the volumes, and subsequently transported to Gotland, where Sanitation360 processes it into a solid fertiliser product known as Granurin. The concentration process reduces the mass of the original urine by a factor of roughly 25 while retaining all its nitrogen, phosphorus, potassium and micronutrients.

Granurin is a clean, safe product that replaces synthetic fertilisers and offers a regional source of nutrients at a time when global supplies are becoming less predictable. Reducing the need for synthetic fertilizers helps shrink one of the world's most polluting industries, as synthetic fertilizer production generates more emissions than global aviation and shipping combined. The Studenternas installation demonstrates a local example of nutrient circularity where valuable nutrients are reintroduced into the food production cycle.

The Studenternas installation is a permanent, full-scale demonstration within a public facility. It provides valuable data that can not be collected in a laboratory or from a temporary pilot test. The data helps us understand how people behave when using urine-diverting toilets in a high-traffic setting, how the drying technology performs over time, and what the operating costs look like under real conditions.

This case illustrates that circular nutrient management can be integrated into existing infrastructure without compromising user comfort or hygiene. It also highlights the importance of collaboration between municipalities, academia, and private companies in turning conceptual sustainability goals into practical solutions.

Towards scalable circular sanitation

Urine-diverting sanitation systems alleviate pressure on urban wastewater systems while recovering nutrients that would otherwise be lost and released into the environment as pollutants. Scaling up such initiatives will help cities meet multiple policy targets simultaneously, such as, reducing nutrient emissions to waterways, lowering reliance on fossil fuel-based fertiliser production, and advancing a circular bioeconomy. Sanitation360 installation provides a tangible model for rethinking sanitation as a service that not only protects public health but also regenerates natural systems. At Studenternas, every matchday now contributes — quite literally — to growing the future.

Expert article • 3898

Jenna Senecal
CEO
Sanitation360
Sweden

jenna@sanitation360.se

Prithvi Simha
CTO
Sanitation360
Sweden

prithvi@sanitation360.se

Evelina Vinnerås
Project manager at Studenternas
Sanitation360
Sweden

evelina@sanitation360.se

Nicola Parfitt
Market Developer
Sanitation360
Sweden

nicola@sanitation360.se

Björn Vinnerås
Chair
Sanitation360
Sweden

bjorn@sanitation360.se

ESTHER DÍAZ-CANO & JULIO BERBEL

Water standards: gains, gaps, and justice

Expert article • 3899

Certifications in the agri-food sector initially concentrated on organic and conventional farming systems, as well as food processing standards. More recently, water stewardship certifications have emerged as voluntary mechanisms to structure and improve water management across agricultural and manufacturing operations. In essence, they set standards and audits that reward those who measure, reduce, and manage their water-related impacts at site and catchment scale. Their appeal is twofold: they facilitate dialogue with communities and authorities, and they generate market signals — reputational and, at times, monetary — for producers and brands.

The available evidence suggests environmental benefits when audited practices translate into concrete measures: controlling run-off, reducing erosion and nutrient losses, and measurable improvements in water quality and quantitative status of water bodies in projects with post-implementation monitoring. These results are most apparent when a catchment approach is adopted, performance is monitored, and interventions are tailored to local conditions. Nevertheless, the literature itself highlights methodological uncertainties (modelling, scales of analysis) and verification gaps that can dilute aggregate effects and open space for opportunistic behaviour. In governance terms, a recurring recommendation is to reinforce transparency and traceability of impacts if the goal is to move from "good practice" to verifiable environmental outcomes.

Beyond biophysical performance, the most intense debate concerns equity. Critical analyses note that many standards are defined and monitored by private actors with significant influence over global markets, which can reinforce power asymmetries along the chain. For smallholders, the fixed costs of certification, auditing, and technological adoption are barriers to entry. Added to this is a technocratic bias towards "efficiency" (for example, promoting drip irrigation) that does not always reduce consumption at catchment scale and can provoke undesirable distributional effects: concentration of water and land rights, or the unravelling of local allocation arrangements in traditional irrigation systems. These dynamics challenge the notion that certification, in and of itself, guarantees a fairer allocation of responsibilities along the chain.

The problem is not only distributive, but also analytical. In complex aquifers it is difficult to attribute impacts to individual users and, therefore, to verify robustly criteria that require "no negative impact" on the aquifer. When audits are sporadic or fail to capture operational variability, the system's credibility suffers. The consequence is familiar: certifications tend to accredit individual actors without addressing systemic determinants — consumption patterns, inadequate regulatory frameworks — and thus treat symptoms rather than causes.

What, then, motivates producers to seek certification? Empirical evidence points to a combination of market incentives (access and differentiation), reduced regulatory risk, and the search for technical support. In a choice experiment with 116 farmers in Italy, Croatia, and Greece, participants displayed a higher willingness to pay for a scheme that guaranteed efficient water use, with a preference for a public certifying body and for receiving technical assistance during adoption. In other words, demand for certification increases when the design incorporates complementary goods (training, accompaniment) and when scheme governance is perceived as more credible.

The literature on stewardship behaviours adds useful nuance: "know-how" to implement practices, risk perception, and the search for peace of mind are important triggers of action, whereas complacency, inconvenience, and costs hinder sustained adoption. Translated into certification design, this suggests that schemes which simplify compliance, reduce transactional burdens, and provide practical information are more likely to change behaviours durably.

Three lessons emerge for a fairer and more effective use of water stewardship certifications:

1. **From site to catchment.** Standards must clearly link on-farm actions to measurable catchment-level outcomes, supported by baselines, indicators, and post-intervention monitoring, with audit requirements calibrated to contextual risk. Without such traceability, certifications ultimately recognize effort rather than verified results. At the same time, when farmers implement best available practices and comply with authorized water abstraction limits, certification schemes should not hold them accountable for failures that stem from shortcomings in public water governance.
2. **Equity and costs.** Integrating support mechanisms for smallholders (technical assistance, progressive scaling of requirements, reduced fees, group certification) is necessary to avoid widening gaps. In addition, avoiding one-size-fits-all technological prescriptions (e.g., drip irrigation as a universal "best practice") and prioritising verifiable water outcomes helps to mitigate undesirable distributional effects.
3. **Distribution of responsibilities.** Water management along the chain requires shared, contractual obligations: buyers and brands should co-finance improvements at source and assume science-based water targets, and audits should examine both producers' practices and buyers' sourcing policies. Independent oversight and public reporting of impact metrics strengthen accountability.

Water stewardship certifications are valuable instruments for aligning private incentives with public objectives for water sustainability. Their benefits are tangible when combined with outcome metrics and a context-sensitive design. But they can also reproduce inequalities if they turn "efficiency" into dogma, shift costs onto those with least capacity, and fail to distribute responsibilities across the chain. The challenge is not to discard them, but to reform them so that they meet their promise: to contribute, with evidence in hand, to healthier catchments and socially just water transitions.

Esther Díaz-Cano
Research Fellow and Temporary Lecturer
WEARE Research Group, Universidad de Córdoba
Spain

Julio Berbel
Full Professor of Agricultural Economics
WEARE Research Group, Universidad de Córdoba
Spain

SAMARA LÓPEZ-RUIZ

Stormwater fees for sustainable cities

Expert article • 3900

Urban water systems have long treated stormwater as a residual burden hidden in general sewer charges or taxes. However, as urbanisation intensifies, rainfall grows more extreme and infrastructure ages, the runoff costs—flood risk, pollutant loads, repair and expansion—can no longer be ignored. A well-designed stormwater fee, tied to each parcel's impermeable area and responsive to on-site mitigation, offers more than revenue: it realigns incentives, secures funding and fosters resilient drainage. Its success, however, depends on careful design, legal legitimacy and social acceptance.

The distortion such fees address is clear: property owners rarely pay directly for the runoff they generate. Expanding roofs, driveways, and pavements convert natural infiltration into rapid flow, overloading sewers, causing overflows and raising maintenance costs. Without a differentiated charge, impermeability is underpriced and innovations like permeable paving or rain gardens remain unattractive. Authorities can recover costs and promote decentralised retention by charging per square meter of surface draining to the public system.

The first design task is selecting a metric that credibly reflects hydrologic impact. Most jurisdictions use parcel-level impervious surface, estimated through GIS or remote sensing, sometimes adjusted for partial infiltration or normalised via "equivalent residential units" (ERUs). In Germany, municipalities levy surface water charges, often between €0.50 and €2 per m^2 annually, with reductions when on-site retention is applied. Berlin's utility, for instance, charges about €1.80 per m^2 but exempts parcels that manage runoff locally.

Rate structure is equally important. Many systems apply hybrid models: households pay a fixed charge linked to an ERU, while larger or non-residential parcels are billed proportionately to impermeable area, sometimes with a minimum to ensure recovery. Philadelphia shifted from a meter-based to an area-based model precisely to align charges with runoff burdens and improve equity.

Crediting mechanisms further strengthen incentives. Parcels reducing discharge through infiltration, detention, green roofs or disconnection may earn discounts. Some jurisdictions allow tradable credits, as in Washington, D.C., where regulated properties unable to retrofit can purchase surplus retention credits from others. A municipal price floor helps stabilise this market and prevent volatility.

Nonetheless, risks remain. In Pennsylvania, courts questioned whether stormwater fees were genuine service charges or disguised taxes, threatening municipal finances. This highlights the need for ordinances that define the fee as a service, document costs, and link charges to measurable benefits. Public resistance is another hurdle. Citizens often resent new charges unless billing is transparent, roll-out is gradual, and revenues are visibly reinvested. Philadelphia's "Green City, Clean Waters" sought to address this by coupling fees with large-scale green infrastructure, though cost overruns and delays have raised doubts about its sustainability.

Equity concerns are also significant. A uniform per-m^2 rate may burden low-income households or small plots. To counter this, some cities introduce progressive tiers, discounts, annual increase caps, or retrofit subsidies. Administrative demands—verifying credits, auditing compliance, maintaining GIS datasets—add costs, so many schemes begin with simplified regimes and refine over time.

For Europe, stormwater fees are promising but require adaptation. Drainage is often embedded in general wastewater tariffs, so creating a separate component may need legal reform. A feasible pathway includes: mapping imperviousness; assessing full life-cycle costs; enacting clear ordinances; designing credit programs; piloting at the district scale; and publishing performance indicators such as managed area, retained volumes or overflow reductions. Shared methodologies at the European level could further support harmonisation and mutual learning.

Stormwater fees thus represent more than a financing tool: they make visible runoff costs, incentivise infiltration and retention, and shift burdens toward those who contribute most to hydrologic stress. The legal, political and administrative challenges are real, but international experience shows they can be overcome. With careful adaptation, such fees could become a cornerstone of sustainable urban water management in European cities.

Samara López-Ruiz
Post-Doctoral Researcher
Institute of Sustainable Processes,
University of Valladolid
Spain

samaralr@uva.es

IVAR ANNUS & MUREL TRUU

Urban water management needs joint operation

Expert article • 3901

Across Europe, cities have become increasingly vulnerable to pluvial flooding — from Copenhagen to Valencia, extreme rainfall events have revealed the limits of traditional, static, and monofunctional drainage systems. The infrastructures that were designed for predictable conditions now face accelerating climate variability, rapid urbanization and often struggle with legacy practices and rigid governance frameworks that lack flexibility and adaptation.

To increase the flexibility and functionality of the urban water assets, nature-based solutions (NBS) have become widely promoted in EU, national and regional climate adaption policies. They are expected to perform as one cure-for-all mitigation measures to reduce flood risks, droughts, improve water quality and citizen well-being. Yet in practice, NBS are often treated as isolated, plot-scale interventions — green roofs, rain gardens, ponds — rather than components of an interconnected urban watershed system. As a result, their full potential remains underused, and benefits such as water quality enhancement, ecosystem connectivity, equity, and health benefits are not achieved. This fragmented approach, coupled with a lack of a full life cycle perspective, limits their effectiveness.

Recent analysis on NBS failures have pointed out that cities do not have clear pathways and suitable frameworks to consider the multifunctionality, connectivity and social equity when planning the solutions to mitigate climate-caused risks and to ensure the other potential benefits like increasing the biodiversity and overall satisfaction of the citizens. The failures caused mainly by the lack of cooperation between different departments and community will result in an underperformance of the solutions compared to the desired impacts. The failures in the design and operation and maintenance phase on the other hand will cause critical failures of the solutions stressing the importance of collaboration and joint operation throughout the life cycle of the solutions. In summary, the existing NBS projects are often a) planned in isolation from larger watershed context; b) planning is fragmented across departments and throughout the planning process; c) long-term operation and maintenance and stakeholder engagement is undermined.

To overcome these barriers and respond to this complexity, municipalities and academic partners in the City Blues project funded by EU's Interreg Baltic Sea Region programme are co-developing a joint operational model for NBS (NBS model) to support cities of different sizes, development stages, and capacities. This model aims to make NBS planning, design, operation and maintenance more robust, replicable, and grounded to be suitable for applications in a real urban context. It provides a shared framework for how cities can govern, implement, and maintain NBS systems across the full lifecycle — from concept to retirement.

The NBS model stresses the importance of treating urban watersheds as functional planning units in cities. Every single intervention implemented on a plot or district scale will affect the stormwater management on the sub-catchment. Therefore, it is important to analyze the potential impact (both positive and negative) of the planned solution at a broader scale considering the changes in flow paths and volumes. Catchment scale approach helps to understand where to plan green areas so that they do not need additional watering during dry periods and which solutions and where have the largest effect to improve the climate proof at a single building, district or city.

A key element in reducing the probability of NBS failures is to root the lifecycle thinking approach in the city governance procedures. The NBS model supports the adoption of lifecycle-based thinking fostering cooperation between different departments, community, and stakeholders in all phases including planning, design, operation and maintenance. This ensures that the potential underperformance of the units caused by the fragmentation of the planning process will be mitigated as the key performance influencers at the operation and maintenance phase are considered and communicated with the stakeholders early on.

Recent studies on multi-system intervention planning frameworks for interdependent infrastructures like NBS have shown that effective implementation of such models can lead to up to 25 % cost savings when considering service unavailability costs for infrastructure on a regional scale.

We expect that implementing NBS model will increase the efficiency of single NBS units, ensure multiple benefits besides stormwater management and reduce the costs induced from the potential failures and uncoordinated operation and maintenance practices. Instead of piloting single high-performing NBS in isolation, the model promotes integrated solutions tailored to catchment-scale challenges. By drawing on the transition paths, and the lessons learned from both successes and setbacks of other cities, it supports municipalities in developing resilient and adaptive local models for mainstreaming NBS.

Ivar Annus
Professor in Urban Water Systems Tallinn University of Technology
Estonia

Murel Truu
Expert in Sustainable Urban Water Management
Tallinn University of Technology
Estonia

MATILDA GUNNARSSON & KARINA BARQUET

Nature-based solutions in Swedish stormwater management

Expert article • 3902

Expansion and densification of urban areas, in combination with the effects of climate change on precipitation patterns and intensity, make cities sensitive to flooding. This calls for stronger and earlier integration of climate adaptation measures in spatial planning and stormwater management.

In response, the Swedish government has set two key milestones within its environmental goals framework to enhance sustainable stormwater management:

1. By 2023, all municipalities must integrate sustainable stormwater management into the planning of new buildings or significant modifications to existing structures.
2. By 2025, municipalities at risk of significant stormwater impacts on soil, water and the built environment must complete a mapping process, develop action plans for sustainable stormwater management and begin implementation.

Sustainable stormwater management prevents stormwater runoff, treats polluted stormwater, supports urban ecosystem services and adapts to a changing climate. A common approach is to use Nature-based Solutions (NbS), described as multifunctional and cost-effective solutions addressing societal challenges by protecting or developing ecosystems while promoting biodiversity and well-being.

Although NbS are recognised solutions for sustainable stormwater management, challenges remain in planning, procurement and implementation. These challenges are often socio-institutional rather than technical. Uncertainties in responsibilities, financing, costs and knowledge contribute to delays in adoption. Moreover, evidence on how co-benefits and multifunctionality are perceived remains limited.

Based on this, within the HydroHazards project, we examined cost estimates for NbS, the extent to which co-benefits are included in Swedish municipal stormwater guidance, and their alignment with policy.

Availability of cost estimates

There is a general need for more context-specific cost data, along with descriptions of what these costs include. Costs of NbS vary depending on where and how they are implemented. Factors like size, design, context and the aim to deliver additional benefits influence costs for both implementation and operation and maintenance (O&M). Estimates of intervention costs are often uncertain, and detailed O&M costs are rare.

Inclusion of NbS in municipal steering documents for stormwater management

NbS are incorporated into stormwater management in Sweden. The specific term "nature-based solutions" is not however widely used in municipal stormwater documents. Instead, terms like "open", "local", "green and blue", "sustainable" and "multifunctional solutions", as well as examples of specific NbS are highlighted as preferred approaches for managing stormwater.

Generally, municipal stormwater documents address co-benefits, and most of these documents make reference to multifunctional stormwater solutions. However, the co-benefit coverage varies. Flood risk control, water quality, biodiversity, aesthetics and health are frequently mentioned; while heat island effect, carbon sequestration, air quality, energy consumption and noise reduction are only included to a limited extent.

Responsibilities in municipal stormwater management

Municipalities recognise the importance of clarifying responsibilities for stormwater management, but the level of detail and thoroughness varies. The division of responsibilities for stormwater management is complex, with no single actor holding full authority. Different actors, both within and outside municipal government, influence the overall stormwater management. Responsibility across the full life cycle of NbS should therefore be defined early, including O&M and associated costs, especially for shared solutions.

Alignment with policy

There is strong regulatory and policy support for the implementation of NbS and/or potential co-benefits. Despite the strong support, regulatory and policy frameworks often insufficiently recognise the multiple co-benefits of NbS. This can undermine the monetary and non-monetary value, and the business case. Regulatory and policy development that accounts for multifunctionality is needed to accelerate uptake.

Moving forward

A more mainstream and consistent approach to quantifying and tracking costs, especially for long-term operation and maintenance, would strengthen municipalities' ability to plan, budget, and procure NbS. Our study shows that cost data are scarce and rarely standardized, which limits learning and slows scale-up. Similarly, greater emphasis on the multifunctionality and broader benefits of NbS could strengthen the business case and enable co-financing across sectors. Finally, clearer life-cycle responsibilities and shared service models for multifunctional solutions are needed, particularly where public and private land overlap. Taken together, these findings point to a practical agenda for unlocking wider adoption: shared cost frameworks, consistent evaluation of co-benefits, and governance routines that support long-term delivery.

This text is based on the SEI report *"Nature-based solutions in municipal stormwater management in Sweden: costs, co-benefits, responsibilities and policies".*

Matilda Gunnarsson
Research Associate
Stockholm Environment Institute
Sweden

matilda.gunnarsson@sei.org

Karina Barquet
Team Leader: Water, Coasts and Ocean;
Senior Research Fellow
Stockholm Environment Institute
Sweden

karina.barquet@sei.org

EWA LEŚ, ANDREA CERVANTES & GUNNAR NORÈN

Source to see approach to ensure the GES of the Baltic Sea

Expert article • 3903

One of the major problems for surface water in the Baltic Sea Region countries is eutrophication caused by diffuse pollution of nitrogen and phosphorus from agriculture, because of constant on-going overfertilization when Economic Optimal Fertilization is applied. Much has been done to reduce the load of nutrients from agriculture, but still, the measures are voluntary. Among the measures proposed to fulfil the WFD and the Baltic Sea Action Plan (BSAP), are also various restoration methods in the landscape. To prevent eutrophication, land-based measures in agricultural areas, such as buffer strips, sedimentation ponds and re-wetted and constructed wetlands are essential, with priority in lower river basins with high nutrient water concentrations. More important, besides End-of-pipe solutions, are mandatory measures to minimize overfertilization via yearly calculation of nutrient surplus on each field. Restoration to counteract nutrient leakage from agricultural areas is not to be forgotten – not only to mitigate eutrophication, but also to act as a carbon sink and promote biodiversity.

Hydromorphology pressures, such as river barriers, enhance eutrophication processes by slowing down the natural free-flow of water and reducing self-purification abilities.

Under the Nature Restoration Regulation, EU Member States are required to implement restoration and habitat re-establishment measures gradually. These measures shall cover at least 20% of land and sea areas in the EU by 2030, and all ecosystems in need of restoration by 2050 (Art.1(2)). It also requires MS to assist in restoring at least 25 000 km of free-flowing rivers by 2030 (Art. 9).

In terms of NRR implementation, firm monitoring practices must be implemented to follow the state of both passive and active restoration areas, considering climate change, eutrophication, pollution, and other anthropogenic stressors. These practices strengthen climate adaptation and help in choosing the right restoration tools for the area of restoration.

Below, the crucial active measures related to the freshwater ecosystems are presented, including those related to eutrophication.

Exemplary active restoration measures:

- For longitudinal continuity, total dam removal should be a priority. Focus on constructed natural bypasses and install fishways only if dams cannot be removed.
- Establish a requirement of a minimum annual flow so all aquatic species can survive and a slope angle of 2 degrees so all kinds of river fauna can migrate up and down streams, in bypasses/fishways.
- Restore also lateral connectivity and improve the natural functions of the floodplains, i.e. remove artificial embankments, and restore floodplains.
- Ensure natural buffer zones along the entire river and tributary length and, for water bodies of at least 10-20 m, for 80% of the river length to reduce eutrophication pressure and to support biodiversity.
- Reduce input of nutrients from livestock and farming (e.g. by promoting organic farming, improving soil stability) and via mandatory measures for minimization of nutrient surplus with fertilization practices (which can be seen as a passive measure) which would reduce water column nutrient concentrations.

By the 1st September 2026, Member States shall submit Nature Restoration Plans (NRP) for their territories, including exclusive economic zones (EEZ), indicating how NRR targets will be implemented and achieved. Moreover, measures in place must deliver actual source-to-sea restoration of all riverine, coastal, and marine ecosystems in the Baltic Sea catchment area.

Conclusion

CCB has prepared guiding recommendations for the development of NRPs, the achievement of restoration targets and, ultimately, GES in the Baltic Sea catchment area. As well as elaborated a list of tailored ecosystem-specific recommendations for riverine, coastal, and marine restoration (active and passive), to contribute to the importance of the land-to- sea connection. To achieve the goals of the NRR in the Baltic Sea, it is essential to establish a common regional understanding and develop clear guidelines.

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Ewa Leś
Eutrophication Working Area Leader, River University Founder
Coalition Clean Baltic, River University
Sweden

ewa.les@ccb.se

Andrea Cervantes
Biodiversity Officer
Coalition Clean Baltic
Sweden

Gunnar Norèn
Senior Advisor
Coalition Clean Baltic
Sweden

JAIME NIVALA

Nature-based solutions for urban water management

Expert article • 3904

Challenges to treatment of urban water systems and the potential of enhanced natural treatment solutions

Urbanization is accelerating at an unprecedented rate across the globe, bringing with it numerous challenges related to water management. A significant issue is water scarcity and water insecurity, which threaten the sustainability of cities and rural areas alike. Urban water systems are under immense pressure from increasing population densities, pollution, climate change, and aging infrastructure. These challenges not only compromise human health and wellbeing but also have detrimental effects on ecosystems, which provide crucial services such as clean air, water, and soil health.

In Europe, over 70% of the population currently resides in urban areas, and projections indicate this figure will surpass 80% by 2050. As cities grow, the existing centralized infrastructure—pumping stations, treatment plants, sewer networks—becomes increasingly strained and less resilient against the impacts of climate change. Extreme weather events such as floods, storms, and droughts are becoming more frequent, threatening to overwhelm urban water systems and result in failures, environmental contamination, and economic losses.

One of the fundamental issues in urban water management is the pollution of surface and groundwater. Urban stormwater, wastewater, and runoff often contain a complex mixture of pollutants from point sources (such as industrial discharges and sewage outfalls) and non-point sources (such as vehicle emissions, urban runoff, and land use activities). These pollutants can compromise water quality, threaten human health, and damage ecosystems, ultimately impacting land value, urban aesthetics, and residents' quality of life.

Given these challenges, there is an urgent need to rethink traditional approaches to urban water treatment. Conventional centralized systems, while effective in many respects, often lack the flexibility, resilience, and sustainability needed to cope with the increasing demands and complexities of urban water cycles. As a response, constructed wetlands, green infrastructure, and other nature-based solutions are gaining recognition for their potential to offer sustainable, cost-effective, and multifunctional benefits.

Advantages of applying enhanced natural treatment solutions

Nature-based solutions for water management can significantly improve water treatment outcomes by harnessing natural processes such as wetland vegetation, soil filtration, microbial activity, and ecological functions. These systems can be integrated into urban landscapes to provide multiple benefits simultaneously. For example, they can improve water quality by removing chemical pollutants, sediments, and pathogens, while also reducing flood risks through increased stormwater retention and infiltration.

Beyond their primary treatment functions, these systems contribute to mitigating urban heat island effects by greening the cityscape and increasing green cover. They also offer aesthetic and recreational value, transforming neglected areas into attractive urban green spaces. This integration of ecological features supports the goals of creating more livable, healthy cities.

From an environmental perspective, nature-based solutions contribute to the circular economy by promoting water reuse and resource recovery. Treated water can be reused for irrigation, industrial processes, or even potable purposes, depending on its quality. Such reuse reduces dependency on external water sources and alleviates pressure on limited freshwater reserves. Additionally, these systems provide ecological habitats, enhance biodiversity, and improve social inclusion by involving local communities in their planning and management.

Socially, nature-based solutions promote greater equity and social cohesion, as community members are often engaged in the co-design, implementation, and maintenance of natural treatment systems. They foster environmental awareness and stewardship, which are crucial for the long-term sustainability of urban water management strategies.

However, the widespread adoption of nature-based solutions faces several challenges. Designing, planning, and implementing these systems at scale requires overcoming technical, financial, and institutional barriers. Ensuring long-term operational sustainability and addressing potential hazards, such as chemical or biological contaminants, necessitate validated risk assessment methodologies. Financing mechanisms must be innovative and adaptable to diverse socio-economic contexts to facilitate large-scale deployment.

The MULTISOURCE project

The MULTISOURCE project (ModULar Tools for Integrating enhanced natural treatment SOlutions in URban water CyclEs, EU Grant Agreement 101003527, 2021 – 2025) initiated the development of innovative, adaptable, and scalable nature-based solutions for urban water management. The core goal was to create a comprehensive process that promotes the adoption of nature-based solutions (NbS), reducing the discharge of untreated or inadequately treated polluted water into urban environments.

The project prioritized the development of modular, open-source tools that enable decision-makers to plan, design, and implement natural treatment systems effectively. These tools incorporate a holistic approach, considering environmental, economic, and societal factors, with a focus on life cycle analysis and circular economy principles.

To demonstrate the practical application of these concepts, the project piloted NbS for water management in seven countries: Belgium, Germany, France, Italy, Norway, Spain, and the United States. These pilot projects targeted various urban water streams, including raw wastewater, and pre-treated wasteawter, combined sewer overflow, stormwater, rainwater, and urban runoff. More information about the results of the project is available on the project website at www.multisource.eu, including pilot fact sheets, the NAT4WAT NbS technology selection tool, the MULTISOURCE Planning Platform, three policy briefs, and a multitude of open-access peer-reviewed journal articles. An open-access textbook on the fundamentals, process design, and implementation of treatment wetlands will be published and available for free download in early 2026 (Treatment Wetlands, Third Edition).

Jaime Nivala
PhD, Director of Research
INRAE — National Research Institute for Agriculture, Food, and the Environment
Research Unit Reversaal — Reduce, reuse and valorize wastewater resources
France

jaime.nivala@inrae.fr

RIINA LIIKANEN

Resilient Water Services in a Changing World

Expert article • 3905

Finland is famous for abundant water sources, which form the basis for a high-quality and reliable water supply. We consistently rank at or near the top in international comparisons for both drinking water quality and sanitation. However, the security of water services can't be taken for granted. The high security is a result of long term and continuous work and development at water utilities, different levels of governance and other stakeholders.

In Finland, municipalities are obliged to organise water services according to the needs of their population. Water services are delivered either by municipally owned water utilities or by water cooperatives owned by the water users themselves. Thus, water services are managed as a public good, which model will be further reinforced when the revised Water Services Act comes into force in 2026.

The foundation of continuous water services lies in proportionate risk management, which minimises the number of disturbances. Systematic risk assessment and management procedures are standard practice for ensuring both the quality and availability of drinking water. Nowadays, many water utilities also apply systematic risk management to areas such as cybersecurity, environmental impact, and economic viability.

In the context of risk management, the aim has always been to build redundant and flexible water supply systems. This includes, for example, utilising multiple water sources, relying on proven and secure processes, and duplicating functions and networks wherever feasible. Even robust infrastructure is put to the test during a crisis. That is why emergency preparedness and contingency management are essential for resilient water services. Water utilities have emergency plans covering a wide range of scenarios - from natural disasters, such as droughts and flooding, to technical or man-made failures like power outages, pipe bursts, and drinking water contamination.

Sound risk management, preparedness, and contingency measures are cornerstones for reliable water services, but the evolving threat landscape challenges us. Resilience requires continuous effort to ensure proportionate actions and sustained development. Challenges to water security include climate change and its effects on water quality and quantity, complex interdependencies, interruptions in the supply chains of critical materials and services, as well as digitalisation—both as a beneficial tool and as a target for cyber threats. In recent years, security authorities in Finland and across Europe have also noted an increased risk of intelligence activities and hybrid attacks targeting critical infrastructure, such as water services.

Threat awareness forms the basis for adapting to the current security landscape. This awareness is also crucial for motivating the adoption of more stringent physical, personnel, and cyber security measures, as well as enhanced data protection. In Finland, the Water Services Pool supports water utilities' threat awareness by maintaining sector's national situational awareness in broad co-operation with relevant stakeholders. Water utilities' experiences in organising water services in Ukraine are also evaluated to assess our preparedness to provide services under any circumstances.

One of the greatest long-term challenges to resilient, 24/7 water services is aging infrastructure and the sector's capacity to ensure sufficient resources for maintenance and renewal. To guarantee well-functioning infrastructure—from water abstraction and treatment to the distribution network and back to wastewater treatment and discharge—the ongoing reform of the Water Services Act aims to strengthen the financial stability and asset management of water utilities in Finland.

Similarly to the present Water Services Act reform, legislative requirements and best practices and operational procedures in Finland's water sector have consistently evolved proactively to address emerging threats and in response to lessons learned from experienced crises situations. An excellent example of the latter is Nokia water crisis, where more than 8 000 people fell ill from waterborne outbreak in 2007. In the aftermath, contingency planning and disinfection preparedness became mandatory for all water utilities. The Nokia case also led to the development of new guidelines and best practices in crisis communication, alternative drinking water distribution, and contingency planning.

In addition to the preparedness and contingency measures taken by water utilities to ensure continuous services, it is crucial that societies are also prepared to cope with temporary interruptions to water services. In Finland, the 72-hour household preparedness recommendation advises every household to be equipped to manage independently for at least three days during various types of disruptions, such as extended power or water outages. This recommendation includes storing some liters of bottled water, as well as having a clean container for collecting and storing drinking water. Public services and private businesses should also be prepared to receive or collect alternative delivery of drinking water, or to close their water-related operations in a controlled manner.

Water resilience is a shared responsibility. All levels of governance, legislation and water suppliers as well as water users must play their part to ensure water is available and safe for all purposes, now and in the long term.

Riina Liikanen
D.Sc. (Tech.), Chief of Preparedness
Finnish Water Utilities Association
Finland

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