NTNUs research and reflections from water conferences in 2025

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Sammendrag

NTNUs forskning og refleksjoner fra vannkonferanser i 2025. NTNU presenterer sin vitenskapelige formidling for 2025 innen vann- og avløpsteknikk på fire nasjonale og internasjonale konferanser. Dette omfatter et bredt spekter av temaer, fra forvaltning av grønn infrastruktur, tilpasning til klimaendringer, digitalisering og automatisering til det aktuelle temaet om det nye europeiske direktivet om avløpsrensing. Aktuell forskning blir kort presentert, satt i sammenheng og reflektert over.

Summary

NTNU showcases its scientific dissemination of 2025 in the field of water and wastewater engineering at four national and international conferences. This spans a wide area ranging from asset management of green infrastructure, adaptation to climate change, digitalization and automatization to the currently hot topic of the new European Urban Wastewater Treatment Directive. Current research is shortly introduced, put in context and reflected upon.

Introduction

NTNU was busy this year in disseminating its research at four international and national conferences in the water field - the *10th Leading Edge Conference for Strategic Asset Management* (LESAM - https://iwacyprus2025.com/), the *21st International Computing & Control in the Water Industry Conference* (CCWI - https://www.ccwi25.org.uk/), the *13th Urban Drainage Modelling Conference* (UDM - https://www.uibk.ac.at/en/congress/udm2025/) and of course the *Nordic Wastewater conference* (NORDIWA - https://nordiwa.no/). Four main topics arose this year during those conferences:

1. Asset management of green infrastructure (GI)
2. Climate change adaptation for urban water systems
3. Digitalisation and automatization in the water sector
4. Wastewater treatment discussion in Europe, triggered by the new European Urban Wastewater Treatment Directive (UWWTD)

Asset management of urban water infrastructure

Asset management is a mature topic, but the widening of its scope to **green infrastructure** is a novel development, and a necessary one. The current need for investment into the replacement and maintenance of our systems (Norsk Vann Rapport 259, 2021; Norsk Vann Rapport 294, 2025) is not including green infrastructure, as it is relatively recently built but this is going to change with expected life cycles of 30 years. These infrastructures are expected to be a no-regret cure for multiple urban challenges while contributing to sustainable and resilient urban water environments. Meanwhile, we are still lacking detailed and standardized assessment methods, reporting protocols and technical guidance for assessing and maintaining their effectiveness over their whole lifecycle. Research on this is necessary and done at NTNU contributing to this "growing field", as it was put in a keynote at *LESAM*.

Urban water systems are under the stress from different drivers emerging from anthropogenic activities. Among them **climate change** directly questions the paradigm we follow for designing systems, as well as the method we use for designing systems. It is deeply entangled with the other topics mentioned. Green Infrastructures being a solution for climate change adaptation in cities with aging legacy infrastructures. Change in climate may induce a change in maintenance procedure, for instance of green infrastructures. The revised UWWTD require the development of integrated urban wastewater management plans that require to consider climate change adaptation as a driver. The water sector community and the climate science community are, despite the links mentioned above two distinct communities with their own language. NTNU is working toward bridging the gap between the two community to untap the potential of better using climate information for water management, through workshops at *UDM* to identify the needs of the water community and research investigation to investigate the potential of state-of-the-art climate simulation.

Digitalisation and automatization

These are ongoing processes, and the topics are manyfold. Machine learning applications are still omnipresent but increasingly intermingled with the question of ethics and data quality and management. Better documenting our data is a key aspect for the implementation of the UWWTD which require to increase the level of digital maturity of utilities ad well as to enhance their potential for data interoperability Modelling and control of our systems requires better data to be able to optimally manage the limited resources we have available and increasingly robotics are looking to fill the gap for inspection and measurements within our pipes. NTNU is contributing to this field of research pushing for the standardization of data collection as well as exploring novel data collection methodologies using robotic technologies.

Implementation of the revised UWWTD

This topic has been under discussion for quite some time now in Norway. The directive has been adopted at European level and is now in the process of being adapted to Norwegian regulation. If implemented as written, it will require secondary, tertiary and quaternary treatment at many wastewater treatment plants. It aims at energy neutrality and requires cities to prepare integrated stormwater/runoff management plans. The directive, if complied with, will have a major contribution to preserve our water resources for future generations. Whether or not the Directive had been revised, many Norwegian treatment facilities already needed upgrading. The new legislation simply makes the timeline explicit and the targets binding. What matters now is how Norway responds.

At NTNU, we are committed to supporting industries, governments and municipalities in this transition. This can be through joint research projects, pilot testing, and education. Our role is to build national competence in treatment process optimization, sewer network design, and risk assessment. The next decade will define the future of wastewater management in Norway. These upgrades will reduce pollution, balance investment costs through effective resource recovery, cut greenhouse gas emissions, and strengthen national competence for generations to come. We all share the same goal: to protect Norway's waters. With science, competence, and collaboration, we can achieve it – and some of it is already **the science of today**, shortly described below.

Maintenance planning of green infrastructure:

In recent decades, Green Infrastructure (GI) has been adapted across the world to mitigate the environmental impacts of urbanization. While GI systems such as bioswales, rain gardens, and green roofs are increasingly recognized for their role in flood mitigation and climate adaptation, municipalities continue to face challenges in ensuring their sustained performance (Bahrami et al., 2024). One of the themes discussed by NTNU at the *LESAM 2025* conference was the critical role of data in the proactive management of GI systems. Despite their importance, asset data on GI condition, performance, and failure modes remain scarce or inconsistent across municipalities, creating barriers to developing evidence-based maintenance strategies for GIs.

The research presented from NTNU at *LESAM* addressed this gap by introducing a methodology to identify external factors influencing GI performance and to define suitable proxies for spatial analysis. A proxy is a more simplified, more accessible representation of a complex process, that is used when direct, high-resolution data are not available (Ferretti and Montibeller, 2016)water and soil, increasing the acceptance of the projects, reducing implementation costs. The first step of the approach involved identifying key external stressors that can accelerate degradation of GI components. Stressors such as sedimentation from nearby unsealed surfaces, trash accumulation, leaf accumulation from nearby trees, pollution from road activities such as heavy metal and micropollutants from cars, and misuse of GI areas were identified and discussed. The second step evaluated the data requirements for modelling these stressors, investigating the sensitivity, availability, and suitability of different Norwegian datasets as proxies. This proxy-based approach aimed to bridge the lack of detailed inspection data by linking observable spatial and environmental factors to expected maintenance needs. The study demonstrated that, although direct data on maintenance frequency or failure events are lacking, a range of external indicators can be utilized to approximate maintenance needs. For example, population density, proximity to commercial sites, surface slope, surface cover, and proximity to high-traffic roads or industrial sites can serve as practical proxies for trash accumulation, sedimentation, or heavy metal accumulation.

Building upon these insights, results from the *LESAM* study were further applied and tested in a case study presented at *NORDIWA 2025* in Oslo. The Trondheim case focused on translating the identified proxies into spatial hotspot maps, illustrating zones of potentially high maintenance need across the city's network of planned GI systems. An example of the application of the methods was shown by overlaying two proxy indicators related to trash accumulation and leaf falling on a risk map (see Figure 1). The map visualizes where GIs are most exposed to those external stressors, making it possible for planning inspection efforts and maintenance needs according to the location of GI and the time of the season. The map revealed distinct patterns, with higher stress from trash accumu-

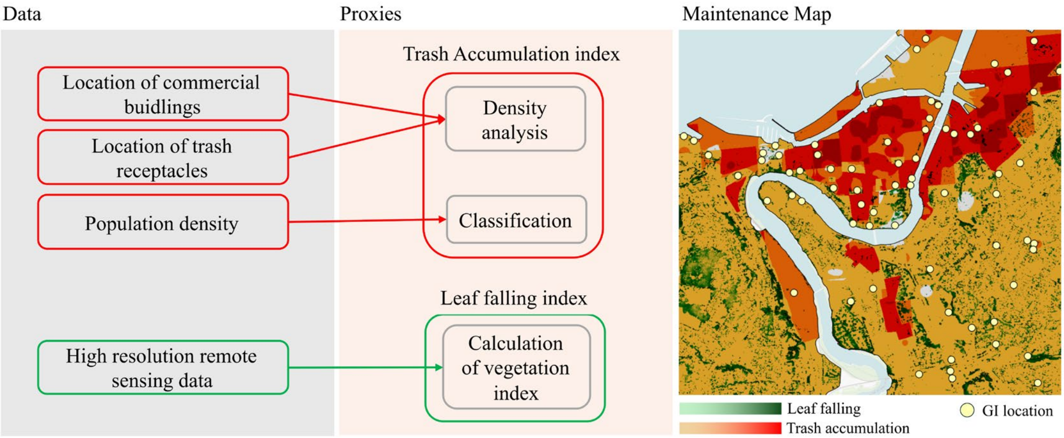

Figure 1. An example showing how different spatial data could be used as proxies that illustrate the intensity of external stressors on GIs (Case study: Trondheim).

lation concentrated around dense commercial areas, and a higher leaf falling index near residential zones.

Achieving stormwater quality management objectives through targeted bioretention cell design

As the role of GIs in urban stormwater management continues to expand, there is a growing emphasis on designing systems that not only mitigate flooding but also improve stormwater quality (Strømberg et al., 2025). Traditionally, Norwegian design guidelines have focused on hydrological objectives, such as peak flow and volume reduction. However, the recent revised European Urban Wastewater Treatment Directive (UWWTD) extends its scope to include stormwater and urban runoff, underscoring the need for systems that also address pollutant removal. In this context, NTNU presented at the *NORDIWA* conference a case study demonstrating targeted bioretention cells design can help meet stormwater quality objectives.

As part of EU Horizon StopUP project ("Stop Urban Pollution" www.stopup.eu), a full-scale vegetated bioretention cell installed on NTNU's campus in Trondheim was investigated. Eleven monitored events were analysed to assess inflow and outflow quality, alongside hydrological performance. The system achieved strong removal of particle-bound pollutants, including an average 70% removal of total suspended solids (TSS) and more than 90 % removal of measured polycyclic aromatic hydrocarbons (PAHs). Particle-bound heavy metals were removed at rates of 40-90%, where zinc had highest and arsenic had lowest removal. Dissolved metals showed limited or negative removal, especially for dissolved arsenic and copper. The bioretention cell also reduced runoff volume and peak flow by 70-90%, fulfilling its original hydrological design objectives.

Although the system was primarily built for flow reduction, these findings highlight both the strengths and limitations of conventional bioretention cell design. Particle-bound pollutants are efficiently removed through surface filtration, but dissolved contaminants require targeted measures. However, such modifications often conflict with hydraulic performance, particularly in cold climates where high infiltration capacity is needed to ensure infiltration during freezing conditions. Two key design aspects were emphasized during the conference. First, GI systems should be based on well-defined priorities, balancing water quantity and quality objectives, and focusing on the pollutants most relevant to the local recipients. Second, design storms should correspond to smaller, more frequent events to enhance pollutant removal efficiency,

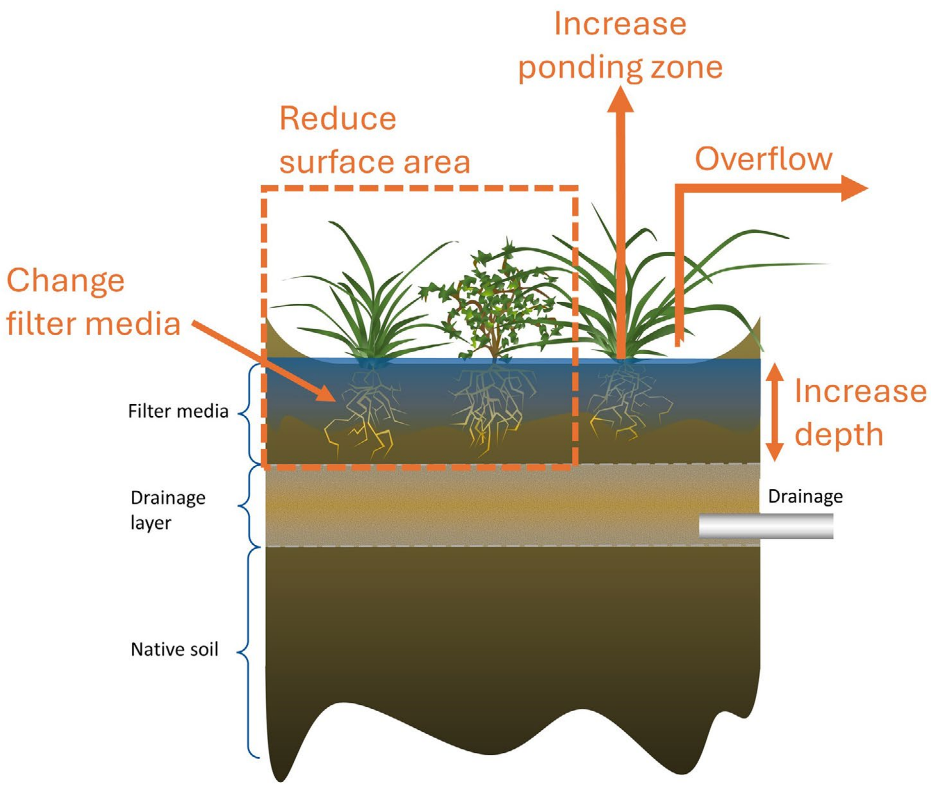

Figure 2. Proposed design modifications to the bioretention cell in Trondheim, where the system was evaluated based on water quality and quantity control.

while larger events are managed through overflow or bypass systems. Example of targeted design for water quality was proposed using the case study in Trondheim, where some of the proposed improvements can be seen in Figure 2. Integrating targeted design criteria for stormwater quality objectives will be important for Norwegian municipalities to meet the future UWWTD requirements.

The impact of choice on urban drainage design

Traditional urban drainage system design often relies on a single design storm, which is not guaranteed to represent the different types of storms that are expected to stress the system (Pritsis et al., 2024). Following up on our previous work, in this year's *UDM* we presented the results of a study based on different system designs created by students as part of an NTNU MSc level course. The students were provided with a model of an urban drainage system and a set of three design storms which the system had to handle. Comparing the resulting designs to those created using a single design storm we saw a slight improvement in system robustness, but stressing the systems with an ensemble of 1000 storms still exposes weaknesses. This strengthens the main conclusion of our study, that system response must be assessed under a variety of rainfall conditions to correctly evaluate its performance.

During the last months we have conducted a literature review of different methodologies for selecting monitoring sites in urban drainage monitoring campaigns. Although this has been an active field of research in the last decades, we noticed a lack of implementation of these methods in real-world projects. To investigate the reason for this lack of connection/imple-

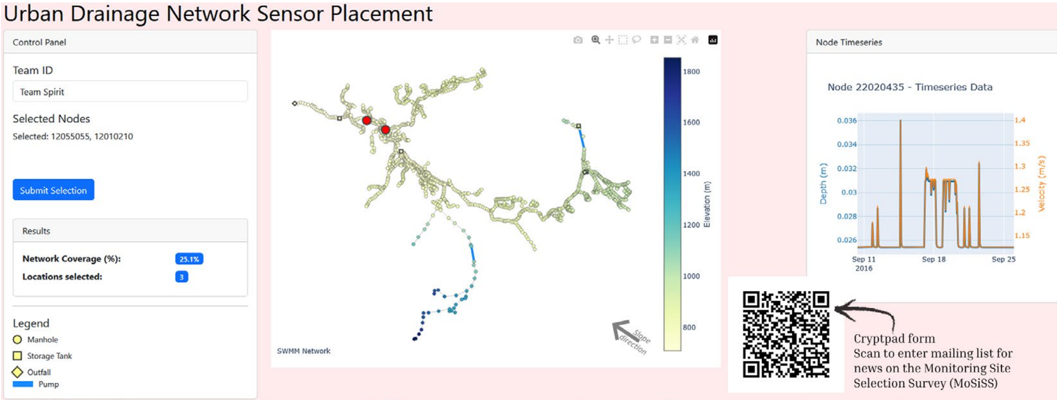

Figure 3. Monitoring site selection interactive survey (interested parties can follow the QR code to our mailing list for possible participants).

mentation and identify what methods are actually being used in practice, we have been developing an interactive survey to investigate how researchers and practitioners in the field of urban drainage systems approach the task of monitoring site selection when planning a data collection campaign. We conducted this survey for the first time as part of Dag&Nät, a workshop organized in Sweden by Luleå University of Technology (LTU). We presented the participants (a mix of researchers and practitioners) with a model of an urban drainage system and asked them to assume the role of an engineer planning a monitoring campaign where seven flowmeters can be installed in the system to collect data to calibrate a hydraulic model. They were given half an hour to navigate the system, use any information they deem important (pipe diameters, catchment topography, etc.) and pick the locations. Afterwards they were asked to fill out a questionnaire describing the process they followed and the limitations they experienced. The preliminary results of this workshop were presented at *NORDIWA*. The next step is to expand the survey into an online accessible tool to try for a wider range of stakeholders.

Autonomous robots for sewer maintenance

Sewer assets represent a significant resource in terms of functionality and economic value (Tscheikner-Gratl et al., 2019). Therefore, asset management is a key factor in ensuring the ongoing performance and structural integrity of all sewer systems. However, the extent of the system, often poor accessibility, and the harsh environment pose a challenge to further development in assessing the current condition of the sewer network. Although CCTV (closed-circuit television) is currently the most widely used method for sewer inspections, it can only offer limited data, plagued by uncertainties, with a limited spatial coverage and temporal resolution. Multiple sensor autonomous robots developed with efficient artificial intelligence (AI) sensing methods, incorporating mapping algorithms for sewers, allow for a step forward, providing more frequent updates, as well as temporal and spatial coverage regarding pipe features and defects. This improvement will allow the different stakeholders to have more complete information about the state of the network and facilitate sewer asset management.

The European Union-funded PIPEON (https://pipeon.eu/) project, which involves 12 partners from 8 different countries, aims to optimise sewer inspection and maintenance using AI-driven autonomous robotics (Autonomous inspection and monitoring robots working in sewer environments may change the way information about our systems is collected, both in spatial and temporal resolution, and could start a new information paradigm. This will lead to change into how we envision models could be used by utilities to manage their urban drainage systems, ranging from deterioration models for contemporaneous sewer condition, to better calibrated hydrodynamic performance models for sewer systems. These changes can be three-fold:

- The first is one of mainly accuracy, as more accurate geometrical data (collected by robots with better mapping capabilities and more appropriate sensors) will reduce network model uncertainty considerably.
- The second is the ability to pick up intermittent or unexpected changes, for example blockages, damages, or other physio-chemical changes that can be registered by sensors equipped on robots.
- The third is that a moving robot can be the sensor collecting hydraulic data as it moves within a changing system (e.g., registering flows) resulting in a Lagrangian rather than a Eulerian calibration data set.

Investigating all these aspects of this emerging area of monitoring and inspection technology, and how it could interact with current and emerging modelling capabilities, is important if the urban drainage community is to benefit from both new monitoring and modelling advances.

A workshop was organised to collect a wide range of expertise from different specialists in the field in an international setting as part of the strategies that arose during the discussion with the partners. *UDM* was the ideal event to hold such a workshop. Therefore, last September, NTNU hosted the workshop titled "Autonomous robotic inspection and monitoring and the implications for the urban drainage modelling community", in Innsbruck, Austria.

The workshop assessed and discussed the expectations of the urban drainage community on the autonomous robots as information source. Three main discussion topics were presented, involving hydrodynamic and deterioration models, as interactions between them are expected. The first topic addressed what data the existing models demand from autonomous robots. The second topic focused on the anticipated shift in modelling considering the new asset and monitoring data opportunities provided by the robots and sensing. The final discussion point centred on the feedback loop from modelling back to the robots. Ten countries from nearly every continent (Europe, America, Africa and Asia) were represented among the workshop attendees. Such a diverse environment provided valuable insights into the discussion topics. The workshop's documentation was retrieved and is currently under revision to extract the most significant outlooks, as the aim is to publish an opinion paper next year.

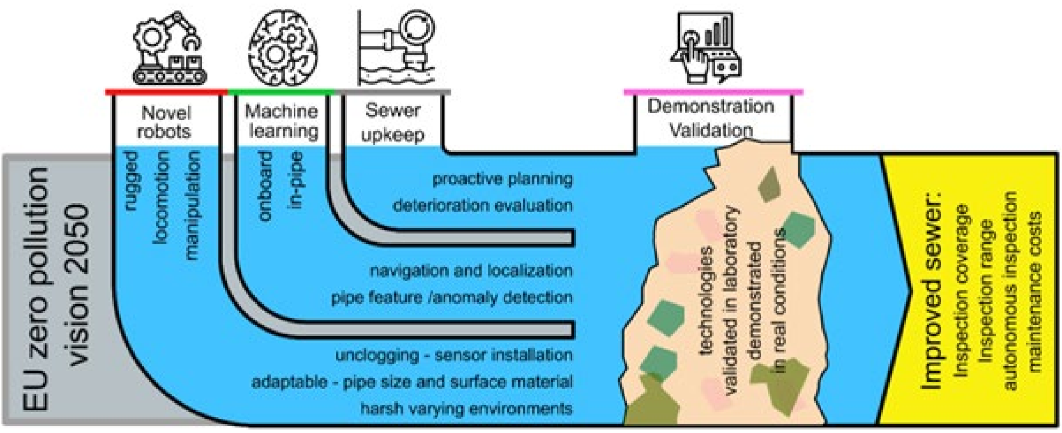

Figure 4. The PIPEON- Robotics and AI for Sewer Inspection and Maintenance concept (www.pipeon.eu)

Modelling of inhouse plumbing systems

Water quality in premise plumbing systems (PPS) is a complex phenomenon, wherein the initial quality can change dramatically due to varying periods of stagnation and flow (Lee et al., 2023). Of particular concern is the growth of pathogenic Legionella—the cause of Legionnaires' disease—which grows optimally at 25 to 45°C (Bartram, 2007). Predicting Legionella concentrations in buildings requires comprehensive modelling, considering nutrients, water temperature, and water-biofilm interactions. Notably, PPS models have been developed in recent years to better understand water temperature (Hillebrand and Blokker, 2021). To estimate temperature changes over time, these models have used net water flow and heat transfer driven by temperature differences between system water and the room air. However, when net flow and temperature differences are small, existing models predict little to no temperature change. Still, considerable heat transfer and flow exchange can occur in some locations, such as near hot-water tanks or mixing valves. For instance, cold water in pipes upstream of hot-water heaters can significantly heat up overnight when the net flow is nearly zero. Because cold water should remain below 25°C–and ideally below 20°C–to prevent Legionella (Bartram, 2007), deviations above 25°C due to heat transfer can be considered thermal contamination.

During long periods of stagnation or low flow in PPS, water temperature inside the system approximates room temperature, reducing heat transfer between the system and its exterior as time passes. Similarly, when connected elements have similar temperatures, heat transfer between them is negligible. However, in some parts of a PPS, heat transfer between connected elements can be more significant than with the surroundings. In such cases, temperature changes between connected elements result from two mechanisms: heat conduction (diffusion) and heat convection.

A heat convection model was calibrated (Vargas et al., 2025) and used to reproduce tem-

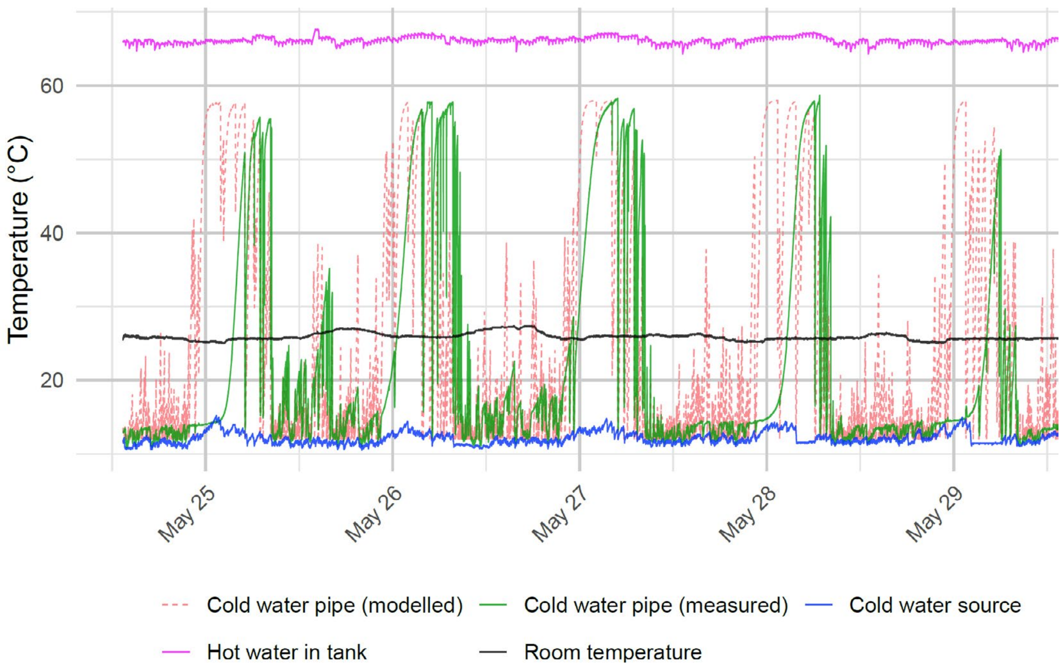

Figure 5. Case study measurements (solid lines) and model results (dashed lines) for water temperatures in the cold-water pipe upstream of the hot water heater. Data provided by Karolina Stråby (SINTEF Community, Oslo).

perature fluctuations observed in a real case study at a nursing home in Moss, Norway, as part of the SESSILE project. This case included water temperature and flow measurements in a cold-water pipe located upstream of a hot-water heater. Temperature measurements from the nursing home, showed notable increases in the cold-water pipe during periods of low hot-water demand and highwater age, especially overnight. The modelling results demonstrate that even with limited system information, temperature fluctuations can be predicted to some extent (see Figure 5).

The main takeaways from this study were that:

- Axial heat transfer is significant under low/stagnant flow in the vicinity of water heaters and mixing valves.
- Location and positioning of system components can be used to control heat transfer from convection.
- Axial thermal contamination is predictable (i.e. can be modelled), even with limited input information.
- PPS modelling should include axial heat transfer to assess the possibility of thermal contamination of cold-water components.

A risk assessment framework to evaluate soil improvers derived from sewage digestates in Norway

Recovering valuable resources from sewage sludge offers significant potential to address resource scarcity and reach circular economy goals. However, land application of these resources also raises legitimate public health and environmental concerns due to potential contamination by pathogens and persistent chemicals.

This study (presented at *NORDIWA*), conducted under the EU WIDER UPTAKE Project (https://wider-uptake.eu/), implemented a thorough quality monitoring and risk assessment framework to evaluate soil improvers derived from sewage digestates in Norway (Ardiyanti et al., 2024). The framework assessed compliance with fertilizer regulations, microbial safety, and environmental risks from 168 chemicals. These include heavy metals, polycyclic aromatic hydrocarbons (PAHs), per- and polyfluoroalkyl substances (PFAS), and pharmaceuticals. The study found that organic contaminants such as PFAS and pharmaceuticals in the soil improver samples posed negligible risks due to their low concentrations (see Figure 6). Environmental risk characterization revealed a cumulative RQ of 3.4, driven primarily by heavy metals, contributing 57 % of the total risk. Long-term risk analysis showed that repeated application of the soil improver could gradually increase heavy metal accumulation in agricultural soils, with overall risks rising by 10% over 50-year simulation.

The results demonstrated that the soil improver met most fertilizer quality standards required by both the Norwegian fertilizer regulation and the revised European Fertilising Products Regulation, including nutrient and pathogen limits, except for elevated zinc levels in some samples.

Quantitative microbial risk assessment (QMRA) showed that infection risks from *E. coli* and *Salmonella* were consistently below the WHO benchmark of 10^{-6} disability-adjusted life years (DALYs), even under conservative assumptions. Quantitative chemical risk assessment (QCRA) indicated that heavy metal risks for human health were below the risk thresholds (Risk Quotients (RQ) < 1), with cumulative RQ values of 0.5 (median) and 0.9 (95^{th} percentile).

These results emphasize that the benefits of nutrient recovery and soil improver must be balanced against long-term contamination risks. They also demonstrate the value of an integrated risk framework that ensures product safety, regulatory compliance, and protection of both human health and the environment. These pillars are essential for the safe and wider uptake of wastewater resource recovery.

Reflections on the discussion on the UWWTD at NORDIWA

At *NORDIWA*, many presentations and workshops were naturally related to the revised UWWTD and its implementation. It was

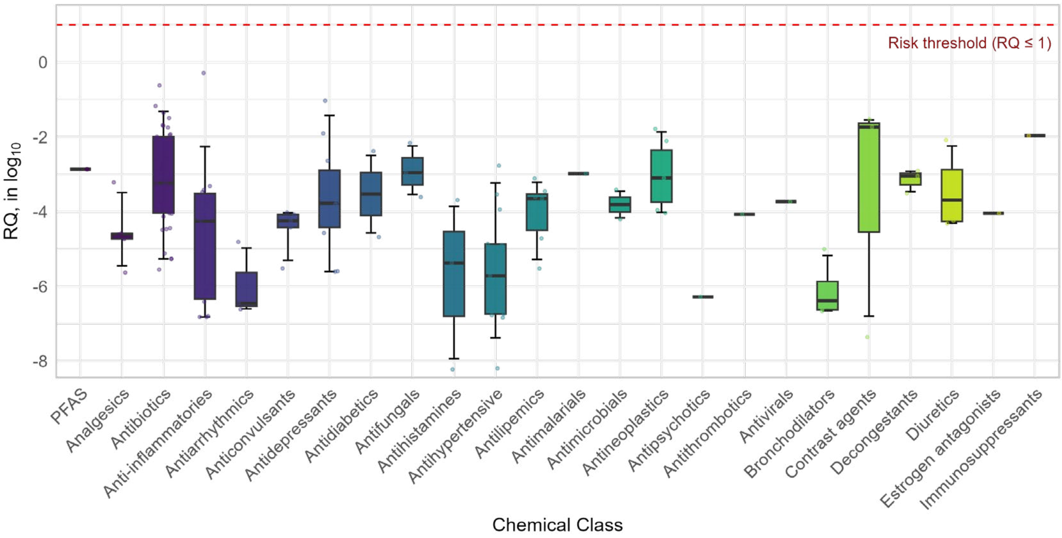

Figure 6. Distribution of soil risk quotients (RQ_{soil}) by chemical class. The red dashed line indicates the risk threshold (RQ ≤ 1).

encouraging to see that many municipalities have already begun planning, evaluating the directives' implications and considering how to meet its requirements. For example, Maria Barrio from the municipality of Trondheim and Solveig Alvik from Vann og avløpsetaten in Oslo presented details from the plans the two cities have for upgrading and extending their water and wastewater infrastructure, how to tackle economic challenges and how to include a larger organization in such an effort. Many presentations further focused on advanced wastewater treatment, removal nutrients and chemical pollutants like PFAS. For example, Nordre Follo municipality has carried out pilot studies for advanced nitrogen removal using Membrane Aerated Biofilm Reactors (MABR), that have the potential to efficiently remove nitrogen in an energy and cost-efficient way. Katrine Jansen from HIAS IKS presented results from pilot scale testing of a novel combined nitrogen and phosphorus removal configuration at HIAS WWTP, also using MABR technology, that requires less energy than conventional processes and can help Norway achieving the stricter requirements for energy neutrality and nutrient removal of the UWWTD.

In many presentations, the Nordic perspective on relevant challenges was compared, what happens currently in Denmark, Sweden, Finland or Norway. Interestingly, the Norwegian perspective was often absent, starting with the opening plenary session. After a strong message from Veronica Manfredi, the Director for Zero Pollution, Water Resilience and Green Cities, about the role of European wastewater services in safeguarding water resilience, representatives from national ministries/agencies in the Nordic countries presented and discussed the "Main challenges and solutions for the Implementation of the recast Urban Wastewater Treatment Directive in Denmark, Finland, Sweden and Norway." Representatives from Denmark, Sweden and Finland discussed their specific challenges, but Norway did not send a representative. Perhaps this says more about Norway's current stance towards the topic than a participation in the discussion could have.

Similar Aha! moments were observed in other sessions, for example then Jose Antonio Baz Lomba from the Norwegian Institute of Public Health talked about the Nordic perspective on challenges, opportunities, and best practices related to implementing of Article 17 of the UWWTD on Urban wastewater surveillance. The article requires states to set up a national system for cooperation and coordination between competent authorities responsible for both public health and urban wastewater treatment. Setting up of such national systems should aim to identify and monitor public health parameters in the inlet of urban wastewater, including pathogens such as SARS-CoV-2, antimicrobial resistance (AMR), poliovirus, influenza virus, emerging pathogens, and other relevant indicators. While Sweden, Denmark and Finland have established strategic sampling for this purpose and publish the data on public websites or repositories, no such things are happening in Norway right now. Another example for the lack of coordinated national activity in Norway was the absence in a workshop about the greenhouse gas nitrous oxide (lystgass) in wastewater treatment. Under the topic "Taming the Laughing Gas: Serious N2O Mitigation Approaches in WWTPs", representatives from Sweden, Denmark and Finland were invited to present the national perspective on the topic. Norway was missing again, in spite the fact that municipalities are working on this topic, for example HIAS IKS.

The discussions at NORDIWA highlight that this transition is more than a legal obligation; it has significant technical and environmental consequences. Higher contaminant removal efficiency in the effluent, required by the UWWTD, is expected to subsequently shift the contaminant profile in the sewage sludge. This will have direct implications, particularly given Norway's continued reliance on land application as the primary strategy for sewage sludge management. As wastewater technologies evolve, risk management practices must also adapt. Continuous evaluation is needed to ensure that reuse applications, once deemed safe, continue to meet health and environmental safety standards under changing treatment conditions.

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