The French Dispatch: NTNU at Novatech 2023

By Mahdi Bahrami, Shamsuddin Daulat, Tone Merete Muthanna, Vincent Pons, Spyridon Pritsis, Bardia Roghani, Marius Møller Rokstad, Merethe Strømberg, Franz Tscheikner-Gratl

Mahdi Bahrami (M.Sc) is a Ph.D-student at NTNU.
Shamsuddin Daulat (M.Sc) is a Ph.D-student at NTNU, working currently at Klepp Kommune.
Tone Merete Muthanna (Ph.D) is a professor and teamleader at NTNU.
Vincent Pons (M.Sc) is a postdoctoral fellow at NTNU.
Spyridon Pritsis (M.Sc) is a Ph.D-student at NTNU.
Bardia Roghani (Ph.D) is a postdoctoral fellow at NTNU.
Marius Møller Rokstad (Ph.D) is an associated professor at NTNU.
Merethe Strømberg (M.Sc) is a Ph.D-student at NTNU.
Franz Tscheikner-Gratl (Ph.D) is an associate professor at NTNU.

All authors are affiliated at Norwegian University of Science and Technology (NTNU), Water and Wastewater group, Department of Civil and Environmental Engineering.

Sammendrag

Den franske utsendelsen; NTNU på NOVATECH 2023. Denne artikkelen presenterer forskning fra NTNU som omhandler håndtering av overvann og urbane overvannsystemer. Forskningen plasseres i en internasjonal kontekst med utgangspunkt i den siste internasjonale konferansen om temaet. Forskningsområdene spenner vidt, fra vurdering av eksisterende retningslinjer for naturbaserte løsninger, hvordan flomvurderinger påvirkes av å bruke hus som reservoar, til koordinert *asset management* av urban infrastruktur og studier av overvannskvalitet og forurensning i urban avrenning.

Summary

This article showcases the research done at NTNU regarding the management of stormwater and urban drainage systems and puts it into international context using the latest international conference on the topic as context. The topics range from assessment of existing guidelines on nature-based solutions, experimental testing of the impact of houses as reservoirs on flood estimation, coordinated asset management of urban infrastructure to urban runoff water quality and pollution.

Introduction

Novatech 2023 in Lyon was the latest iteration of the international IWA conference series which focuses on the field of urban drainage (https://www.novatech2023.org/en/). Urban drainage management is currently under transition, trying to create a more resilient hybrid urban drainage system, consisting of nature-based solutions (NBS) in combination with existing ageing pipe networks. NBS are associated with a strong paradigm shift at the urban scale, not only aiming to reduce pluvial flooding but also to preserve the environment, water resources (including groundwater aquifer) and biodiversity as well as to support human well-being and contribute to urban resilience. NBS and urban water management are central in the European Green Deal strategy regarding climate adaptation and mitigation, increasing of flooding resilience, zero pollution objective and biodiversity restoration, permitting an adaptive transition to tackle uncertainty. Pervasive digital transformation in all human activities may play a role in this transition, if all the barriers to the full usage of technologies in system monitoring and proactive maintenance are removed. In this context, management strategies to enable efficient functioning of this hybrid urban drainage system under transition are currently lacking. Above all, this transition phase and its hybrid steps are connected to the major societal challenges such as climate change impacts, urbanisation, new forms of governance (thinking about the upcoming new Urban wastewater directive and the discussion surrounding it), changes in people's lifestyle, needs and expectations, involving a manifold of different viewpoints, goals, and experiences. Most of these societal challenges are not new - large parts of Europe are (again) suffering from a major lack of rain and have (again) suffered another dry summer, endangering agriculture, provision of ecosystem services, and citizen's health. In other parts, the other extreme was observable (e.g., in Norway during "Hans"). While in rural areas adaptation to climate change leads to the strategy of strengthening the self-initiative of local stakeholders to implement small scale NBS within private compounds, urban areas are key territories to mitigate climate change, harvest rainwater and preserve/enhance biodiversity.

Against this background four main themes emerged and were discussed in the conference:

A) **Stormwater & technical solutions** focussing on the generalization of NBS, low-tech / soft-tech, design, effectiveness of source control and co-benefits (biodiversity, climate...).
B) **Stormwater & urban planning**, including public and large-scale development (industrial, commercial and housing), new urban forms, integration of water in the urban landscape, resilient and waterwise cities.
C) **Stormwater & Impacts,** discussing water pollution and quality (monitoring of rainwater and urban discharges), impacts on waterways, impact of climate change.
D) **Stormwater & Society** about the involvement of stakeholders, adaptation of organisations, regulatory issues, consideration of climate change, brakes and levers.

To address those themes and the accomplishing challenges, different approaches were pointed out as of interest:

1. Strategy, planning and governance.
2. Decision tools, data acquisition and management, modelling and artificial intelligence.
3. NBS (design, construction, performance).
4. Training, pedagogy, and teaching.

NTNU was involved in the scientific committee as well as in several workshops, giving presentations on the state of research in Norway crossing the boundaries of the main themes, applying a variety of different approaches. The topics range from the multiple benefits of NBS in the existing guidelines, over asset management of multiple infrastructures in an urban setting and the impact of houses as reservoirs in flood situations to diffuse urban pollution modelling and risk assessment.

Multiple benefits of nature-based solutions and their performance in international guidelines

This work was done in collaboration with INSA Lyon and addresses the main themes B, C and D using the approaches 1 and 3. The ecological burdens imposed by urbanization and population growth during the last decades have interrupted the natural water cycle and led to biodiversity loss, the formation of urban heat islands, higher greenhouse gas emissions, and the degradation of ecosystems. In this regard, the adoption of NBS or Green Infrastructure (GI), which offer numerous ecosystem services, is becoming increasingly popular. GIs are a network of natural and semi-natural elements, such as bioswales, green roofs, and vegetated

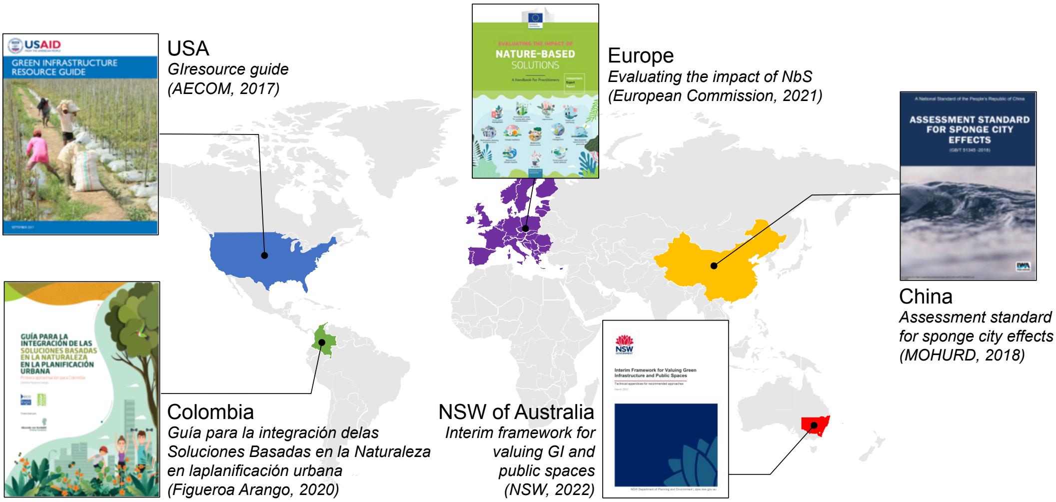

Figure 1. Examined international guidelines on performance assessment indicators for Green Infrastructure

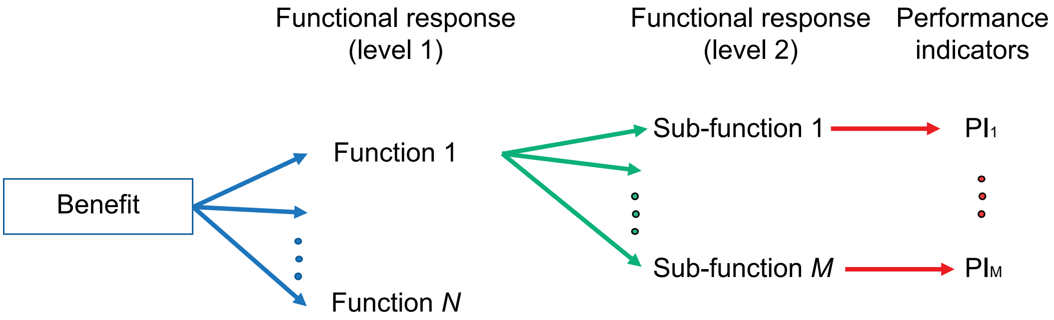

Figure 2. The hierarchical structure was adopted to classify the PIs according to the benefits and service functions of the GIs.

retention basins mainly designed to manage stormwater and provide numerous environmental and social benefits.

While the rationale supporting GI adaptation in urban planning emphasizes multifunctionality, the main criteria for their planning are still stormwater management and available space. This is in part due to a lack of comprehensive monitoring and performance assessment frameworks that cover the range of said benefits. Moreover, evaluating the performance of GIs based on measurable criteria across different temporal and spatial scales is crucial for their long-term operation. In recent years, several guidelines have been developed around the world to help with GI adaptation and performance assessment. In this regard, we critically examined GI performance assessment guidelines from China, state of New South Wales in Australia, Europe, USA and Colombia (see Figure 1).

The study was conducted in two distinct steps. In the first step, a thorough literature review was conducted to extract the most commonly repeated GI Performance Indicators (PIs) and classify them according to the hierarchical structure depicted in Figure 2. For example, the volume of stormwater runoff reduced (m^3) after GI's adaption is a PI to measure GIs' functional response toward runoff interception (level 2), which is a sub-category of functions related to stormwater runoff management (level 1), all of which could be considered as GIs role toward catchment sustainability (benefit). A total of 39 PIs in relation to GI benefits were extracted and classified.

In the following step, the previously mentioned GI guidelines were reviewed to assess their comprehensiveness regarding the extracted PIs across four groups of GIs benefits, namely catchment sustainability, environmental, economic, and social benefits.

In general, the results suggest a need for improvement in available guidelines regarding the inclusion of more PIs. Currently, the reviewed guidelines have overlooked the assessment of a wide array of performances that GIs could offer, particularly PIs related to social and environmental benefits. Although it should be acknowledged that the scope and perspective behind development of each guideline may vary depending on its intended purpose, a more comprehensive guideline could provide end users with support for a more informed and effective decision-making process regarding GI design, operation, and maintenance. Additionally, the reviewed guidelines lacked evaluation methods to assess the desirability level of the calculated/measured PIs. This highlights the necessity for further research to define the desirability levels for different PIs.

Hotspot analysis of integrated multi-utility asset management

Asset management has to be seen as a driver of change in our urban drainage infrastructure, and this study, in collaboration with TU Delft, the possibilities of combining information from different urban infrastructures into a combined approach are explored. In doing so, it addresses main theme B using approaches 1 and 2.

Several challenges confront asset managers when it comes to inspecting, maintaining, repairing, and replacing existing infrastructure assets in a cost-effective manner: ranging from ageing assets, lack of maintenance budget, rising facility usage, and high expectations of the society for better service quality. Many infrastructure systems and their constituent components can be thought of as interdependent, complex, adaptive systems, where "what happens to one infrastructure can have an effect on others". In practice, however, infrastructure systems and their components are generally managed separately, and the data is stored and managed in separate and often incompatible dashboards. In this regard, and to reduce service disruptions, repair costs, and downtime, an integrated multi-infrastructure asset management system can be adopted. Moreover, this approach facilitates the flow of information across different disciplines and activities, improving reliability, consistency, and efficiency of decisions.

The approach presented, addresses the problems of scale (stemming from the fact that size and lifetime of asset types differ largely) and the problems of interplay (the interaction problems that exist among different stakeholders. It aims to develop a framework based on the efficient expense utilization among the interdependent assets throughout the planning horizon while maintaining an acceptable level of service.

The methodology is based on the combination of three modules: I. Risk models of individual assets, II. Cost-benefit models, and III. Decision support models (see Figure 3). The risk model determines which asset(s) need intervention. It combines the failure (or survival) probability of an asset (which can be obtained via deterioration modelling), with the asset importance (the relative importance of assets to each other). Depending on the importance given to a pipe, higher or lower failure probabilities are tolerated and can be translated into different intervention thresholds.

The cost-benefit model compares the cost savings of integrated multi-infrastructure intervention (which can be obtained by calculating the shared work between the utilities i.e., the shared trench volume) with the costs of premature replacement (i.e., the remaining value of an asset at the time of replacement). From the comparison, the model calculates the net benefit for an integrated intervention. The benefit varies

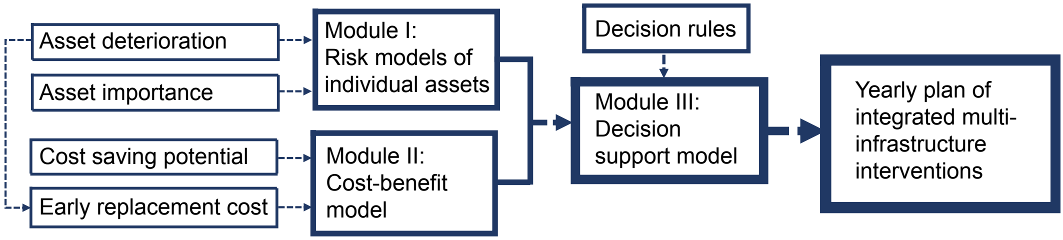

Figure 3. Flow chart for decision support framework of integrated multi-infrastructure interventions

Table 1. A selected project in the yearly plan 2025 to examine the possibility of joint intervention

	IT[*]	Age [y[**]]	Remaining use [y]	Remaining value	Shared trench volume	Cost sharing potential	% of saving (Joins intervention?)
⬛ Road	-	12	3	20%	18% (with water 1 19% (with sewer)	18%/2 =9% 19%/2 =10%	9%+10%-20%= -1% (no)
🟩 Water1	0.7	58	0	0%	38% (with road)	38%/2=19 %	19 % (Triggers action)
🟩 Water2	0.6	31	16	34%	38% (with road)	38%/2=19 %	19%-34%=-15% (no)
🟧 Sewer	0.8	31	1	3%	25% (with road)	25%/2=13%	13%-3%=10% (yes, if road joins)

[*] *Intervention threshold,* [**] *years*

depending on joining of the other co-located assets and their degree of co-location. The decision support model then suggests if joint intervention to be carried out based on a decision rule. There is only one decision rule: integrated intervention to be carried out only if the net benefit is positive.

The intervention thresholds are subject to change based on available budgets and level of service of the utilities. For roads, the intervention times are predicted by the road authority and the data is provided. Cost saving potential is obtained by calculating the amount of common work among the utilities. The amount of common work is defined by the shared trench volume among the co-located assets. The trench volume for an asset is the volume that is needed to be excavated to replace the asset. The shared trench volume among the assets is calculated using Python libraries, and Buffer and Intersect functions in GIS. The share of cost by a utility is then determined by dividing the shared volume by the number of assets sharing this volume.

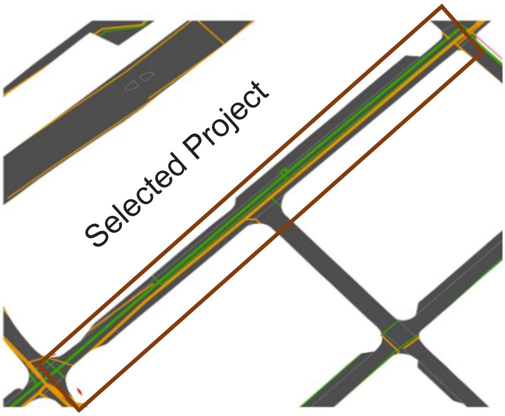

Figure 4. A selected project

The cost of early replacement is obtained by assuming a linear decrease between the initial state of an asset (time = 0, value = 100 %) and at the time when the pipe needs intervention (time = intervention time, value = 0%). To enable the full potential of using an interactive map with hotspots, possibilities for using external information should be made available to add (e.g., flood risk maps, maps of traffic, other external projects, urban development plans), something that is of course dependent on legislation and governance practices. Also, the information underlying the used models need to be included, along with a measure of their quality. As an example, one project is selected for the intervention plan in 2025 to showcase the results (Figure 4 and Table 1).

In the selected project, for example, road will not join the intervention because it does not benefit with the current decision rule. However, if water pipe 1 accepts to incur a bit more than half of the shared trench cost (e.g., 70% by water pipe 1 and 30% by road) for the road to gain benefit, the road will join the intervention. As a secondary effect, sewer will also join the intervention. However, water pipe 2 is far from gaining a net benefit, thus it does not join the intervention. As compared to a conventional intervention approach, the proposed framework is more efficient from the standpoint of municipal expenditures on the same corridor.

Houses as reservoirs

We also got the chance to present results from a CoUDlabs (https://co-udlabs.eu/) project carried out in collaboration with Democritus University of Thrace (DUTH), National Technical University of Athens (NTUA), Universidad de Granada (UGR) and Universidad da Coruña (UDC), which is situated in the main theme C and the approach 2. The aim of this project is to investigate how the characteristics of a pluvial urban flood are affected by buildings retaining part of the flood volume. Studying urban floods, especially in the context of climate change, is very important. It is projected that the frequency and intensity of extreme weather events, including heavy rainfall, will be on the rise. Understanding and mitigating the impact of urban flooding is crucial to protect lives, property, and infrastructure in our rapidly urbanizing world, while also contributing to the resilience and sustainability of our cities in the face of these climatic challenges. More concretely, our goal was to provide an experimental dataset

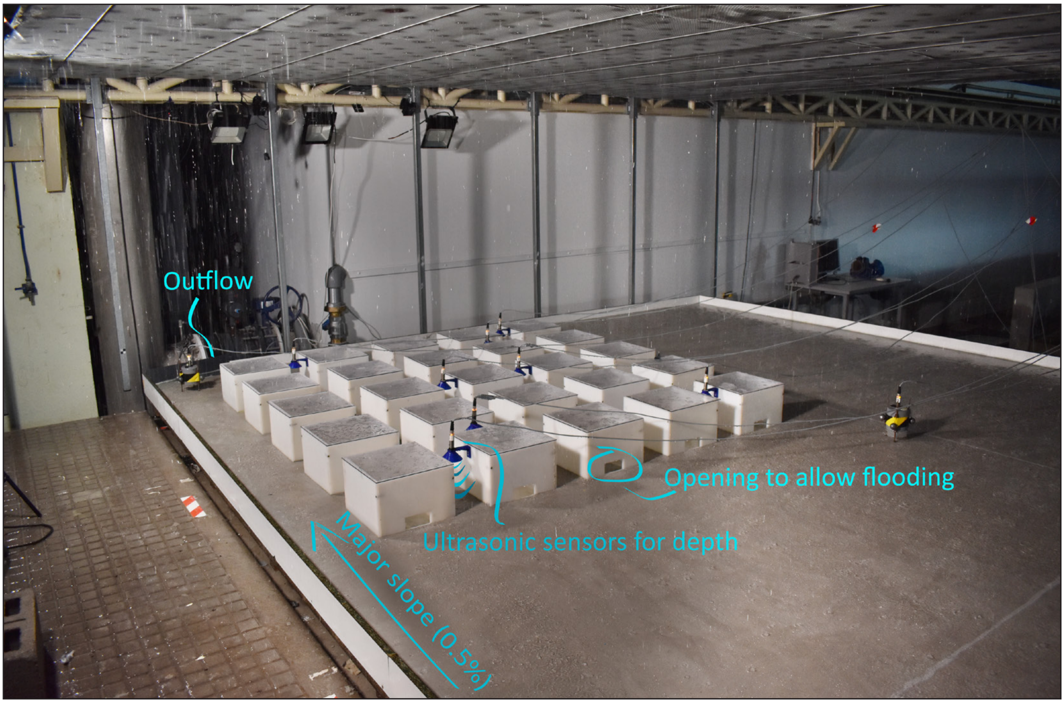

Figure 5. The experimental set-up at Universidade da Coruña

that can be used to quantify the storage effect of buildings. The STREET lab facility of UDC was used for the experimental set-up. The host university, UDC, provided a 26 m^2 rainfall simulator where, with the help of the lab technicians, we built a physical model of an idealized neighbourhood (Figure 5). All of the buildings had removable doors, allowing us to create different sets of flood-vulnerable buildings to collect data for different flooding scenarios. To measure the water in the flooded buildings, pressure sensors were installed in 11 out of the 25 buildings. Additionally, 10 ultrasonic depth sensors were installed outside the buildings to measure water depth. All the experiments were recorded using digital cameras; footage from some scenarios was used to derive velocity estimates using PIV (particle image velocimetry) methods.

The findings were presented at a workshop held on the opening day of Novatech, as well as in the poster session of the third day, where our poster was voted the best poster of that day. One of the main findings we presented is shown in Figure 6. We can see that the discharge at the outflow of the experimental catchment is clearly affected by the number of buildings that flood. In the case where all the buildings are vulnerable to flooding the flood onset is dampened on the outflow and the peak discharge is reduced to less than half of the peak value if no buildings flood. This points towards the need for more research on the topic of storage effect of buildings in pluvial floods.

The dataset will be made openly available under the FAIR data principles, as part of the broader Co-UDlabs community. This way it can enable more collaborative research on the topic. One of the outcomes we are expecting from this work is the use of this dataset to calibrate numerical models.

Stop Urban pollution (StopUp)

Urban pollution poses a significant threat to water quality in receiving waterbodies, such as rivers, lakes and coastal waters, which has dramatic consequences on the environment. Combined sewer overflows (CSOs) are a common part of the combined sewer network in

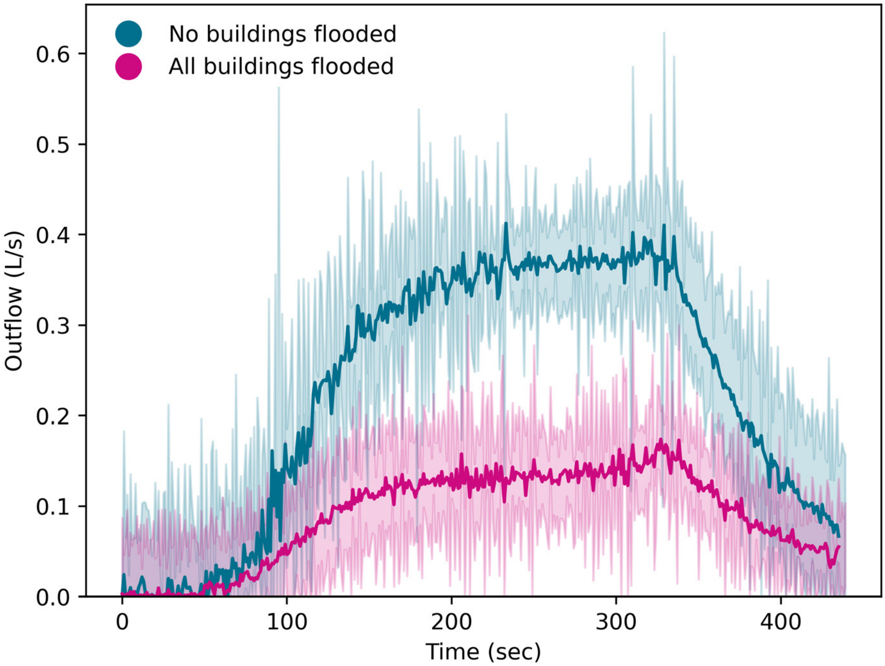

Figure 6. Comparison of outflow hydrographs for two different flood vulnerability scenarios

urban catchments and pose a serious risk of discharge of pollutants to recipients. This is in line with the main themes A, C and D and transverses all named approaches 1-4. To develop strategies to reduce urban pollution conveyed through sewer network, NTNU is involved in the Horizon Europe project StopUp (https://stopup.eu/), led by RWTH Aachen. This project aims at investigating the stormwater pollution pathways in the urban environment both in terms of monitoring, sampling, and risk reduction.

In particular, it aims at investigating transport of diffuse pollution through advanced monitoring techniques and developing a framework for the implementation of pollutant-related risk reduction measures, targeting, for instance, intervention at the source. The project is organized through several work packages. The first one targets the characterization of pollution risks. The 2nd one consists in integration of modelling approaches to diffuse pollution. It includes the development of hydrological models for the different case studies, and the use of climate change data for long-term forecasting. The 3rd work package aims at the evaluation of technological solutions for risk mitigation. Finally, the 4th one, where NTNU is the lead, aims at putting the knowledge, tools, and information from the work packages together to develop an approach to limit the risk of stormwater-related diffuse pollution in the urban environment.

At NTNU Gløshaugen campus, in a collaboration between SINTEF and NTNU, a laboratory for zero emission buildings (ZEB) was built to investigate, develop, and test new and innovative materials and solutions. The laboratory consists of a full-scale office building, where facades and technical systems can be modified and replaced, with surrounding areas, including different urban surfaces, and a bioretention cell. The ZEB lab is fully equipped with sensors to monitor different variables of interest (indoor and outdoor climate, etc.). In particular, a detention tank was built nearby the main building to dampen stormwater discharge to the drainage network, and to investigate the potential of stormwater reuse. The ZEB lab is an ideal full-scale pilot for StopUp. The flow from each different surfaces (a bioretention cell, a parking lot, the roofs, etc.) is continuously monitored and discharged into the detention tank. It also offers the possibility to measure stormwater quality from individual surfaces through both online monitoring and grab sampling.

The result of the investigation at ZEB lab are planned to be used to investigate the potential of bioretention cells at catchment scale in an urban catchment in Lademoen, Trondheim. The effect of the implementation of bioretention cells is expected to combine both stormwater quality improvement and reduction in volume duration and frequency of overflows. Based on the study of the Lademoen catchment and the full-scale site fully instrumented at ZEB, an Urban Runoff Water Quality Management Plan (URWQMP) will be developed. The key challenges addressed in the URWQMP are the question of scale (spatial and temporal), level of information available, and the level of reliability of the information.

Indeed, the different case studies presented in StopUp involve different climates, different land-uses, and different spatial scales. It means that the URWQMP should account for the large disparities of challenges related to diffuse pollution. The scale considered (e.g., city scale or site scale), and the level of detail available may have an influence on the measures to mitigate the risk of pollution. Similarly, the pollutants likely to be found may depends on past industries implemented in the catchment, or on climate (e.g., use of salt in cold climates). It means that the URWQMP should offer flexibility to adapt to local conditions.

Lastly, one of the differences between the sites, is the level of information available and the information's reliability. It is perhaps the most crucial aspect to account for. Indeed, different municipalities in different countries have different level of resources available and different information they can rely on. Their possibility to use a reliable hydrological model to support the planning of risk mitigation measures may also differ. Consequently, the URWQMP should explicitly provide information on the level of uncertainty depending on the available information. It should also provide a decision tree to decide if the level of uncertainty may result in an increased risk, and if the appropriate risk reduction measure consists in data collection.

Conclusion

The briefly shown research, highlighted in this article and presented at the Novatech, showcases the current state of research regarding urban drainage at NTNUs water and wastewater group, that is well in line with the international topics in focus. NBS are getting more and more attention as state-of-the-art in urban stormwater management and guidelines must take into account the wide variety of functions they can provide. This is a first step towards a better management of those systems leading to an asset management extending on NBS. The coordination between existing infrastructures in general has potential to improve the rehabilitation planning. How and how often it can be done is still a topic for research, as well as the question of how and to which degree asset management can contribute towards adaption to climate change. One of these impacts is increased probability of extreme rainfall events in parts of the world. Flood modelling is a tool to estimate risks, plan countermeasures and increase resilience. To calibrate those models and provide insight in the processes, lab experiments are a key ingredient to be done. The same goes for the assessment of diffuse urban pollution and in consequence the management of urban runoff, closing the circle of interconnected topics.

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