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SUSTAINABLE WATERS
City Blues

D1.2 SYNTHESIS REPORT FOR MULTI-RISK SCENARIOS AND SIMULATIONS

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AUTHORS

Ivar Annus, Nils Kändler, Kerta Kõiv, Murel Truu, *Tallinn University of Technology*

Ari Tarigan, Ana Alvarez, Cristian Tosa, Gopalakrishnan Kumar, *University of Stavanger*

Salla Leppänen, Anna Vilhula*, Tampere City Government*

Therése Ehrnstén, *Malmö City Government*

Maarja Täht, *Tartu City Government*

Kristiina Mardi, Mathias Joachim Skov Pristed, *Aarhus City Government*

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SUSTAINABLE WATERS City Blues

Summary

The report summarizes the modelling activities carried out in the City Blues project pilots to estimate and understand the potential impact of the nature-based interventions to storm water management. The report consist of three sections: in the first section the overall modelling process implemented in the project is described highlighting the similarities and differences in the scope and methodologies considered in different pilots; second section presents the results of the modelling exercise and gives an overview how the modelling results can be visualized and presented to the stakeholders including representatives from the municipalities and interested parties in general; third section highlights the potential impact of the developed solutions and provides model-based proof of the improvement that can be used in the decision making process. Each section includes pilot-based descriptions and results to stress the differences in the modelling and analyzing approaches.

The report has to be considered as a documentation of specific actions carried out in the City Blues project to support the efficient implementation of nature-based solutions to improve storm water management and increase resilience to climate change. The report is available for interested parties and can be used as a reference when implementing modelling-based approaches in the decision process. Based on the documented results it can be concluded that the modelling approaches have similarities in the overall process but the implemented methodologies can vary based on the pilot interventions, data availability and modelling capacity.

Contents

Models and methods used in the City Blues project

Hydraulic and hydrological models have been used for analyzing the performance and capacity of storm water systems for decades. Although it has been widely reckoned that all models are wrong to some extent, they have proven to be useful in analyzing the flow dynamics in complex systems (e.g. Pedersen et al., 2022). In City Blues project the partner cities have used different approaches to analyze the storm water system behavior in a catchment level prior and after the expected intervention. In Aarhus, Tampere and Malmö the hydraulic and hydrological models have been available to the cities for some time and prepared in cooperation with private consultation companies. Therefore, mostly commercial modelling software like Mike, Fluidit Storm, Scalgo and SUMBA have been used to model the flooding risks on the catchment scale.

Some of the cities (e.g. Malmö) have defined their own indicators (e.g. mobility to analyze how rescue service can reach buildings or the risk of economic damage to a building) to be able to get a deeper understanding of the consequences of standing water in cloudburst event. In addition, potential changes in stormwater quantity and quality under various climate change and urban development scenarios have been modelled to evaluate their impact on surrounding water bodies. In Tartu the hydraulic and hydrological models have been developed by the local water utility and improved by project partner TalTech to analyze the flow dynamics in the pilot catchment and to assess the impact of the intervention to the flood risk in the catchment.

Other type of climate risks that have been modelled in the partner cities are mostly related to water quality changes in the system and in the watershed to achieve the good chemical and ecological status. Potential heat islands have been identified in some of the cities using modelling to define the discomfort index for the citizens and to provide mitigative measures for most vulnerable social groups. In addition, the modelled risks have been related to noise propagation and shadow cast (e.g. Stavanger) to analyze the impact of city development to the existing urban environment. Thorough analysis of the climate risks in urban areas expect the availability of good quality data about the infrastructure, buildings, spatial distribution of citizens and services and long-time observations of multiple parameters critical for model calibration and validation. This has led the cities to start building digital databases and twins of the services and systems to improve the quality and reliability of the models.

The next chapters will give an overview of the modelling processes carried out in the City Blues project to analyze the potential impacts of the nature-based interventions in the catchment scale.

Description of the modelling process in the partner cities

This chapter outlines the general modelling process used in the partner cities with the focus on what was modelled, how it was done and why this approach was selected. The outcomes are presented separately for each pilot case.

Aarhus

Introduction

The process of modelling in Aarhus is dependent on several modelling steps, to ensure an informed step-by-step decision process. At the first step the water balance and functional requirements of the streams under investigation are analyzed. This is performed to achieve i) information of flow patterns, ii) hydrological limitations and iii) functional requirements of the streams. At the second step a flood analysis of cloudburst is provided along with estimated requirements for stormwater management through national guidelines and discharge requirements acquired from the stream analysis. Area and volume requirements of NBS solutions are estimated through national guidelines and programs with appropriate safety factors in relation to the requirements of the implemented measure. Finally, the whole cloudburst and stormwater management system is analyzed through MIKE urban to verify system requirements and support of initial modelling and to ensure that the planning have ensured no flood risks up to a 100-year return event.

In general, all modelling and planning of city structure and stormwater planning are coordinated through so called rainwater disposition plans, which acts as an overarching planning tool of all new larger city planning projects.

Catchment analysis

Capacity analyses for culverted stretches of the streams has been carried out by Aarhus Municipality and by consultant WSP. A hydraulic robustness analysis was carried out as an element in an assessment of whether a change in discharges from fortified areas affect the risk of erosion (and thereby the ecological quality) in a stream and whether the risk of flooding increases (exceeding hydraulic capacity of the stream). Thus, the robustness (how robust is the waterbody) analysis can help to qualify a discharge level that can be adapted to the conditions of the individual stream.

The hydraulic robustness analysis generally consists of two elements – erosion and flooding. The first one estimates the stream's erosion risk (Streampower) and the other estimates the flooding risk of a certain stream to the nearby areas. The robustness analysis is based on the discharge quantity at the discharge point. The topographically drained catchments, which are led to the storm water pipes, are therefore included in the discharge amount analysis.

Modelling Water Balance and Ecological Quality Ratio in Urban Watersheds

The Water Balance modelling and ecological quality ratio for Egå catchment (pilot area is tributary to Egå catchment) has been performed by consultant WSP using SUMBA - a box model developed by WSP in Denmark. This tool can estimate water balance based on a model that includes historic timeseries of flow and precipitation as well as new urban developments. Analyses were made to see what effect traditional sewer systems compared to sustainable urban drainage solutionshave on the water balance, which include estimation of flood prevention, evaporation, surface flow to the streams, infiltration to primary and secondary aquifer and temperature.

Flood analysis

Aarhus have performed a general city wide dynamic flooding analysis. The modelling is performed using MIKE 21 FM in a 80 cm resolution, for the following cloudburst events: 5, 10, 20, 50 and 100-year return events in 2020 and additionally 100-year return events in year 2100 in two different RCP-scenarios 4.5 and 8.5. In the project area, Nye, these models have been used to detect necessary flow paths, areal requirements of cloudburst basins and dimensional requirements to prevent flooding of the developing city. The resulting flow patterns and blue spots are incorporated into rainwater disposition planning in regard to flood risks.

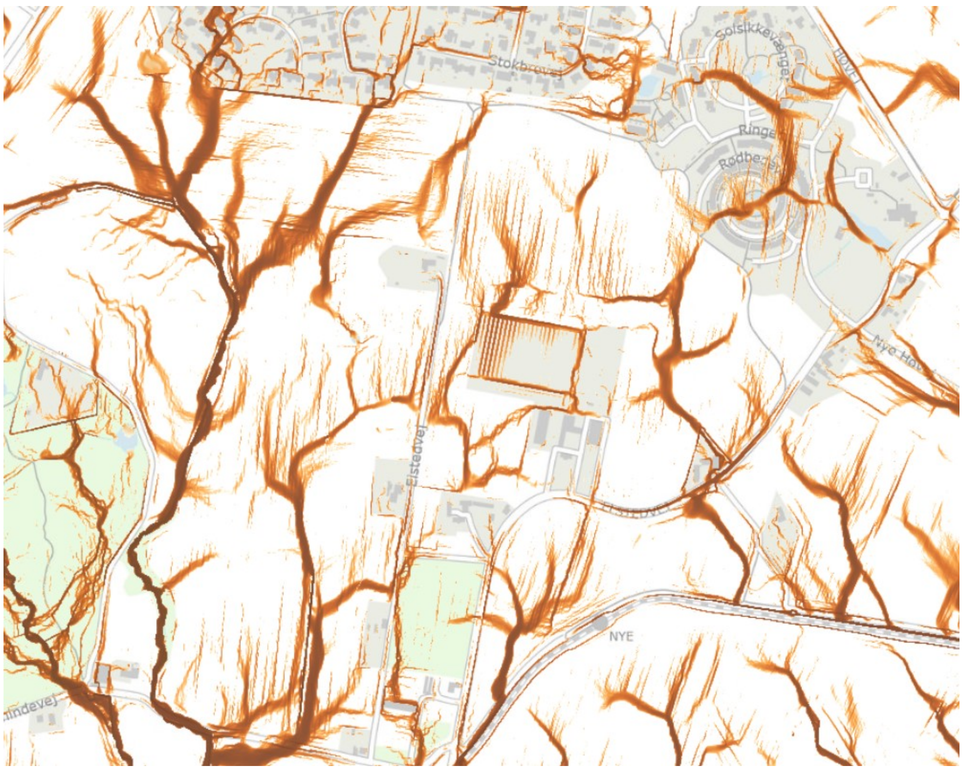

Figure 1 Example of flow path on terrain in Aarhus pilot area

Rainwater management

To ensure proper areal requirements throughout the planning processes, nationally developed tools are used to estimate necessary wet- and detention volumes of all NBS solutions. The estimations are stationary based on CDS rain but include both safety and climate factors along with effects of coupled rain events and return events. All NBS are hereafter placed in accordance with the flood analysis above, and volumes of traditional rainwater management and cloudburst are coordinated in conjunction, to ensure functional systems.

Model verification

As a final step before implementation all systems are verified through MIKE Urban modelling to ensure project planning has the correct framework. This is usually performed by either the utility company or private developer depending on responsibilities and wastewater planning.

Malmö

Modeling process in the City of Malmö

The city of Malmö has been modeling climate risks for a long time and has city wide models for the effects of flooding due to rainfall and cloudbursts, heatwaves and rising sea levels. For all city planning projects a more detailed modeling is done for flooding to ensure that the planning has no flood risks up to a 100-year return event including a climate factor. For coastal areas storm floods up to a 200-year return period is also modeled.
The Swedish Civil Contingencies Agency has a national guideline (Swedish Civil Contingencies Agency, 2023) for modeling cloudbursts that is very similar to the process used in the city of Malmö.
In Malmö mainly three tools are used for analyses:

- The City's own GIS-map where it's possible to see the city-wide model made in Mike+. It shows the highest level of water during the modeling period.
- Scalgo Live is a web-based tool where it's possible to see low points and flow paths. It's not adjusted for the capacity of the drainage system or infiltration which needs to be considered.
- Mike+ is a model that demonstrates flow, volume and levels of water during a selected analysis period. It includes the drainage and sewer system, and adjustments can be made regarding e.g. infiltration capacity.

Depending on the project, different tools and detail of modeling is needed. Scalgo is used e.g. for smaller developing areas or when streets are being rebuilt to make sure it's not negatively affecting the flood situation. Mike+ is used for bigger and more complex projects. A 3D model over the catchment area is then created to analyze the flow patterns in current situations and for future development when ground elevation, infiltration capacity and new measures have been implemented.

Modeling of the pilot area

The catchment area of the Riseberga stream, which is the City Blues pilot area in Malmö, is included in the city-wide models that already exist. There are also more detailed models for stormwater and cloudbursts in some areas e.g. Jägersro, which is a relatively big urban development project undergoing in the catchment area. Analyses of ecosystem services and an inventory of nature values have also been conducted there. In the City Blues pilot all of these different models and analyses, together with elevation data, knowledge about existing flooding problems etc., are considered to be able to come up with ideas and proposals for NBS that can improve both water quality and quantity and enhance biodiversity and recreational values. These suggestions can then be integrated into the land use planning so enough room for water is reserved for future implementation. Examples of modelling results of flooding due to cloudbursts are exemplified in the figures below.

The city of Malmö is missing a hydraulic model of the stream which makes it difficult to evaluate solutions affecting the stream in more detail. Such a model is needed to assess their effect on capacity, discharge and flow to be able to proceed with detailed design criteria for the suggested ideas for NBS. A hydraulic model is also needed for the process with a new permit pursuant to the Swedish environmental code to change the requirements in the current agriculture drainage organization that regulates the hydro-morphology of the stream.

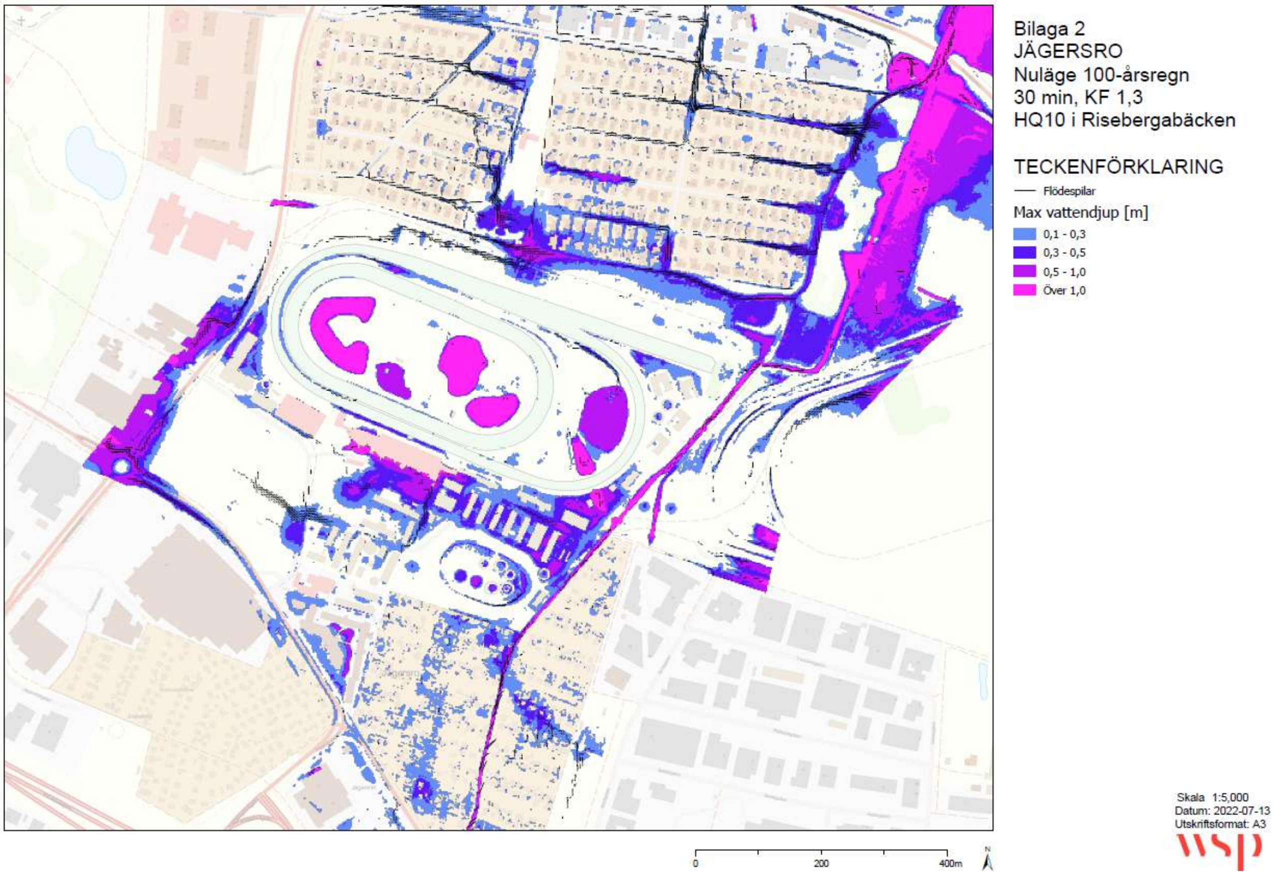

Figure 2 Current situation in Jägerso in the event of a cloudburst with a 100-year return period.

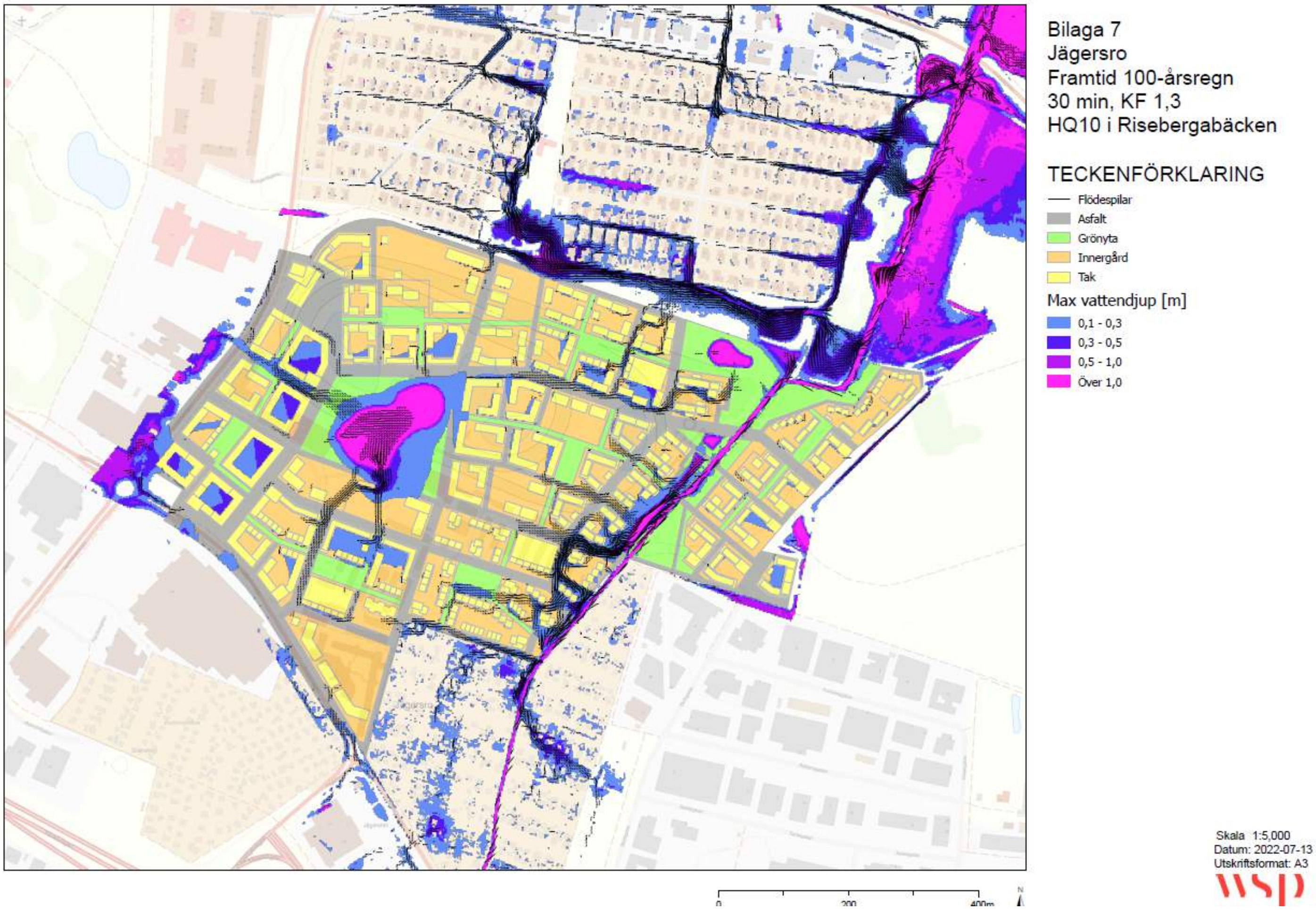

Figure 3 Future situation in Jägersro in the event of a cloudburst with a 100-year return period when the urban development is completed. Nature-based solutions in and along the stream can help the flood situation as well as increasing biological and recreational values for the whole area.

Stavanger

Introduction

The Stavanger modeling process is fundamentally rooted in the priorities of the Rogaland and Stavanger municipality to foster a sustainable and climate-resilient urban environment (Rogaland fylkeskommune, 2020; Stavanger commune, 2023). The strategic plans highlight the pressing challenges of increased rainfall, rising sea levels, and the urban heat island effect, which threaten the city's infrastructure and quality of life (Stavanger commune, 2024). In response, the municipality aims to integrate NBS into urban planning and development, emphasizing its role in stormwater management, flood mitigation, biodiversity enhancement, and climate adaptation.

The rising risks of intensified rainfall, exacerbated by the threat of sea-level rise, pose a significant challenge to the city's resilience. The strategic plan, *Vann i Stavanger 2024-2035* (Stavanger commune, 2024) underscores the urgency of this situation, highlighting the potential for overwhelmed stormwater systems and the contamination of freshwater reserves due to saltwater intrusion. In addition to the threats to safety and security, these threats jeopardize the region's delicate ecosystems and biodiversity.

Piloting locations for modelling exercise

Stavanger is presenting and testing several NBS examples across diverse locations, enhancing the comprehensiveness of the case studies. This approach allows for a more nuanced understanding of the effectiveness and adaptability of NBS in various urban contexts.

There are several lakes in Stavanger, such as Mosvatnet, Breiavatnet, and Stokkavatnet. These are highlighted as a key recreational areas and important parts of the city's green infrastructure, and it is emphasized the importance of preserving and restoring wetlands and water bodies in the region (Figure 4). Their recognition as key components of the city's green infrastructure and the emphasis on preserving their ecological functions suggest their inherent value in regulating water flow and mitigating flood risks. Therefore, these lakes can act as natural retention basins, temporarily storing excess stormwater runoff during heavy rainfall events, reducing the risk of flooding in downstream areas.

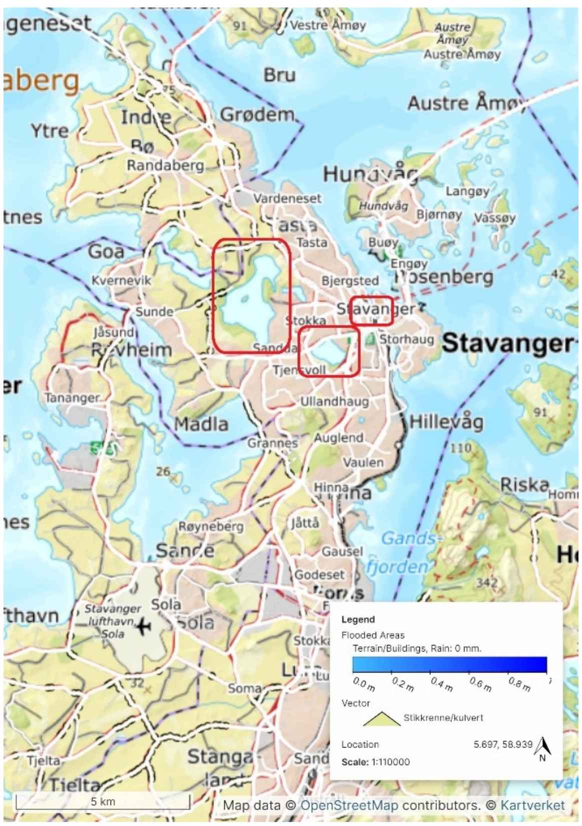

Figure 4 – Location of Stavanger pilot sites

In addition to the lakes and their surrounding areas, the Nytorget project presents a valuable opportunity to analyze and model the impact of NBS on stormwater management in a newly developed urban park. Nytorget is an area undergoing significant development in central Stavanger, including the construction of a new park. The work involves updating the water and sewage networks. The park will feature nature-based stormwater management, integrating water as a resource and design element.

Underlying Assumptions for the Modelling Process

Based on the rainfall intensity–duration–frequency (IDF) data from the Norwegian Centre for Climate Services, the requirements for the modelling foresee a usage of a baseline rainfall intensity of 26.8 mm for a 60-minute duration and a 100-year recurrence interval. This value will be adjusted with a 30% climate surcharge, resulting in an estimated rainfall intensity of 34.84 mm for future 100-year events. The selection of the 30% surcharge is based on recommendations for precipitation-rich areas, such as Stavanger, considering the anticipated increase in heavy rainfall due to climate change.

In addition to IDF data, sea-level rise poses significant challenges for the Stavanger coastline. According to the Norwegian Mapping Authority, the ocean surface continues to rise along the Norwegian coast. Projections based on IPCC show that Norway's coastal average relative sea-level change for 2100, relative to 1995-2014, varies depending on the greenhouse gas emission scenario. For example, under SSP3-7.0 (intermediate emissions) scenario, there is an average rise of 0.55 m, with a confidence interval or 0.30 to 0.85 m. Even small increases in sea level can significantly increase flooding frequency. For example, a 0.1 m sea-level rise could triple the flood risk in many locations. Western and Southern Norway, where Stavanger is located, will likely experience these increases in flooding frequency sooner than other regions.

Tampere

Introduction

In Tampere modelling was used to analyze the capacity and functionality of the planned NBS in the pilot area in Takahuhti. The pilot area is part of a large catchment and the plan was to find out can the predefined efforts solve flooding problems in the catchment area at least a little. The objective was related to the rapid growth of the city and the effects it has on stormwater. In the upstream catchment area, there will be new construction in the coming years, which will increase the volume of stormwater runoff. Therefore, it was also considered whether the effects of the new construction could be modelled to understand what form the solution should take to be useful also in the future.

Modelling was done by the consultant AFRY Finland Oy and Fluidit Storm (version 2.5) software was used for modelling. Tampere's stormwater model (SWMM) was used. It includes almost all Tampere's stormwater pipes and key ditches. The stormwater model of Tampere was calibrated as regards the upper catchment area of Varsanpuisto-Huhmarpelto area by using the available flow rate and rainfall data.

Calibration of the model

Data from the bus station's rain gauge and Ruotulanpuisto park's flow meter covering years 2023 and 2024 were used for the calibration of the model. Among the rain and flow events, such rain falls were selected where the flow meters seemed to react according to the rain. This resulted in, for example, the omission of the most extreme rainfalls, because the flow meter reacted only a little due to a local rain.

For calibration, two about 6-hour rain events were chosen (Figure 5 and Figure 6) and for validation, one rain event with a slightly weaker reaction was used (Figure 7). The setting values of the model were adjusted so that the runoff from catchment areas without stormwater drainage is less and slower. In addition, the roughness coefficient of all the channels was increased.

The graphs indicate that the model gives slightly higher flows than what has been measured. This is acceptable, because with less frequent rains (design storms) the runoff coefficient of the catchment area actually increases and the peak flow also becomes proportionally higher. In addition, the measured and modelled flow data of Ritaoja ditch was examined. Ritaoja's modelled flow peaks corresponded well to the measured flows.

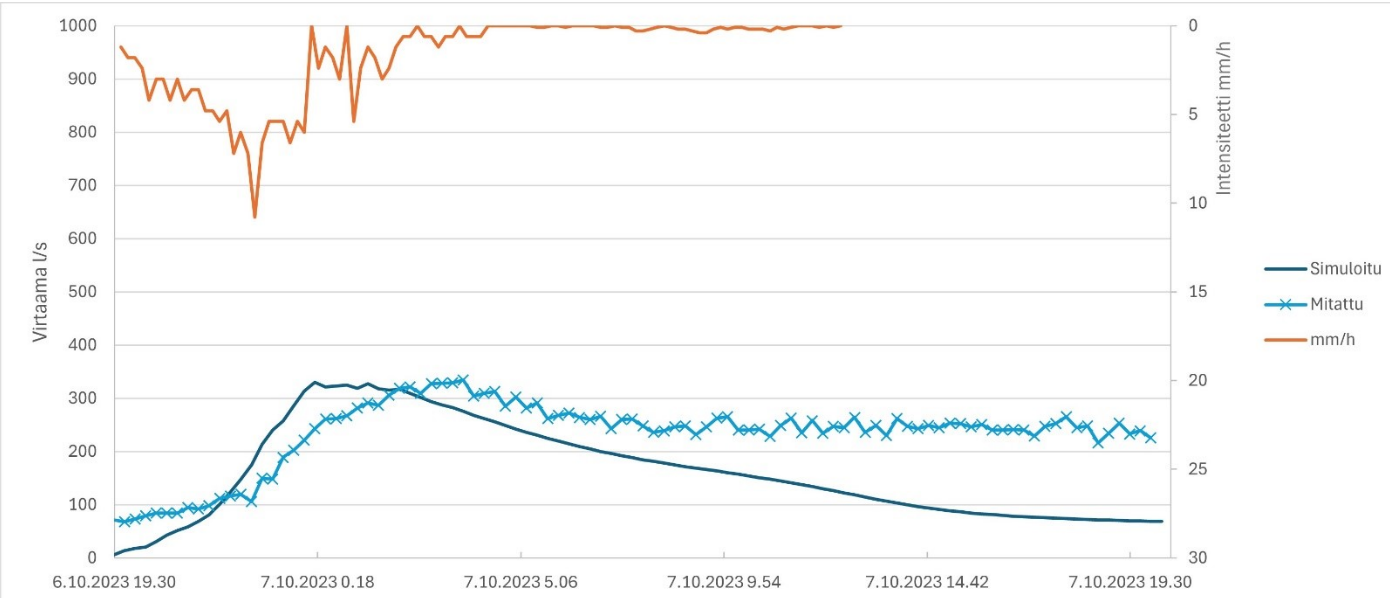

Figure 5 – Comparison of the measured and modelled flow rates, rain fall event 1

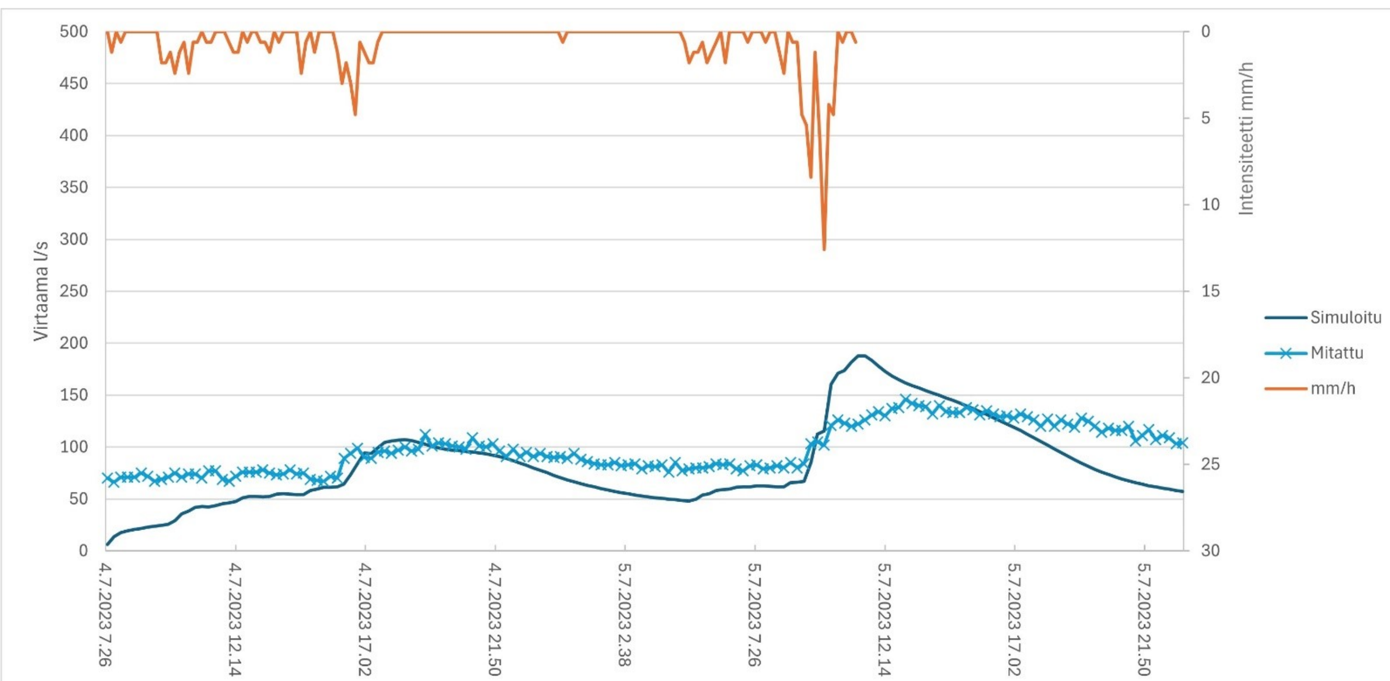

Figure 6 – Comparison of the measured and modelled flow rates, rain fall event 2

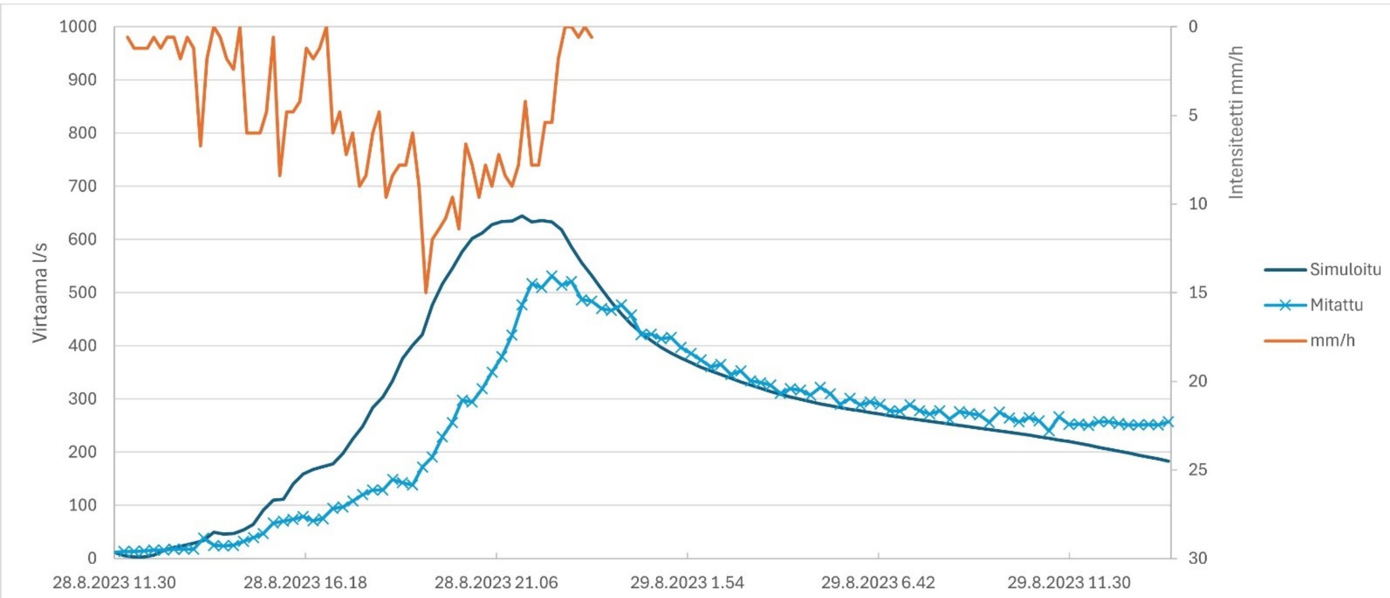

Figure 7 - Comparison of the measured and modelled flow rates, rain fall event 3

Dimensioning of culverts

One new culvert is planned for the area. With the help of modeling inspections, the new culvert was dimensioned for the park area, and the dimensioning of the existing Kuusimäenkatu culvert was checked.

Dimensioning of the culverts was based on rain that occurs once in 50 years and the subsequent flow, which according to the simulation is about 1 m^3/s. The flow rate causes a water depth of approximately 1.1 m in the channel in the dimensioning situation.

Dimensioning of dam structure

The dimensioning of the dam structure, which dams up water to alluvial meadows, was also examined.

Three requirements for the dimensioning of the dam structure were set:

- Water already rises to the planned alluvial meadows by flow repeated once a year
- Flood water level of the channel must be below the ground level of the plots, in order to take sufficient safety into account.
- The dam must not prevent the movement of fish.

Impact of alluvial meadows now and in densifying land use situation

The model was used to study how much the alluvial meadows affect the water level of the downstream ditch section up to the Takahuhtitie road. In addition, flood maps were prepared for the Varsanpuisto and Huhmarpelto planning areas for various situations under consideration.

Design storms occurring once every 1, 3, and 50 years on average were used in the measurements and studies. A situation that repeats on average once every 100 years was also studied, where the densifying land use was taken into account by adding 10% of impermeable surface to the catchment area above the study area.

Simulations were made with four return period rains: 1, 3, 50 and 100 year. The 1 and 3 year return periods were chosen to show that the designed system works with more often happening rain events. The 50 and 100 year return periods were chosen to simulate how the designed system would work in rare rain events. The duration of the design rain was chosen to be three hours as this caused the highest flows.

Tartu

Modelling was used for selecting the location of the pilot site, preliminary dimensioning of the structures, preliminary functionality analysis and providing input for the technical description for detail designing. For that 1D drainage model was provided by City Blues associated partner Tartu Waterworks. The model contains both existing pipelines and future investments which made it a suitable tool to analyze the impact of City Blues pilot solution also in longer timescale. The size of the catchment is ca 350 ha with relatively high imperviousness, causing rapid runoff with high peak volumes. Therefore, pluvial floods are occurring in the catchment in many times a year. The main objective of City Blues pilot is to create areas in the catchment to retain excess stormwater during cloudburst and thus reduce the risk of flood. The catchment does not have stormwater treatment at the outlets. Therefore, the second objective of the pilot is to improve water quality utilizing nature-based stormwater solutions.

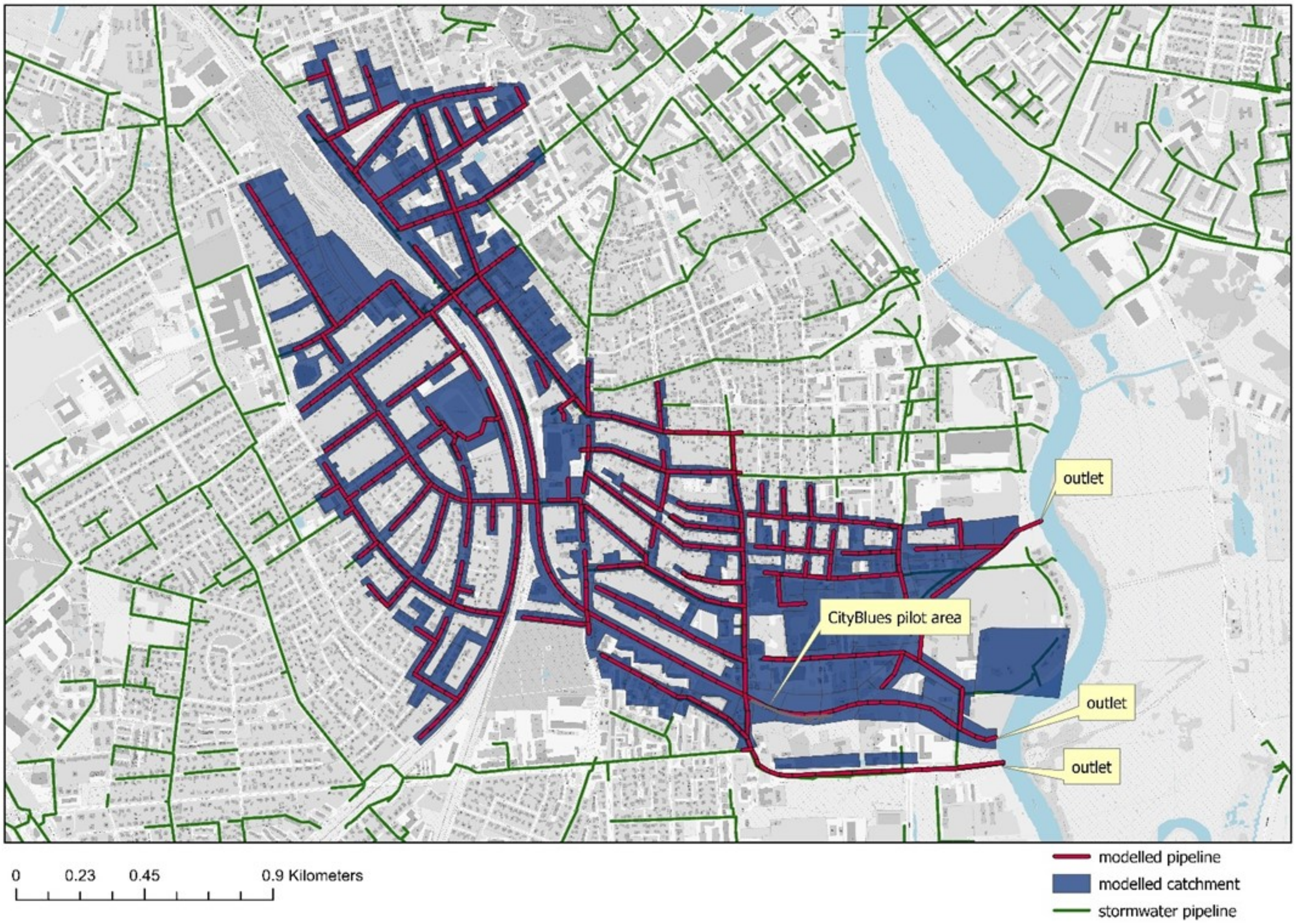

Figure 8 – Layout of the Tartu catchment and pilot area

Modelling was performed with EPASWMM software capable to model both pipelines, retention solutions and green infrastructure. Different scenarios were analyzed to select the most suitable solution for the pilot site, modelling also the limits and considering various risks. The results of the modelling were used as an input in the technical description for detailed design.

Results of the modelling of NBS implementation

Aarhus

Based on catchment analyses and modelling as well as screening of use of harvested rainwater as secondary water resource to reduce the use of drinking water for toilet flush and washing machine and water balance calculations the stormwater management plans have been prepared for development of Nye– Aarhus Pilot.

The catchment analyses and capacity analyses point out some critical risks that Aarhus will try to solve during this project period via some strategies that will be prepared in collaboration with developer, stakeholders and utilization company. The analysis will be used as a basis for decision-making in land-use planning and investments for both the city and the water utility.

In City Blues Aarhus will implement diverse NBS's. The Aarhus pilot will focus on two streams within the boundaries of a planned city development on the outskirts of Aarhus: Ravnbakke Stream and Bueris stream. The city Nye is planned for development over the coming 20-30 years with an expected population of 15 000-20 000 citizens. Ravnbakke stream is a 1.2 km long stream on the eastern edge of the development, whereas the approximately 2.5 km long Bueris stream runs through the more central part of the development in an area currently used for agriculture. Both streams were channelized, partly piped and deepened in the late 19th-century to gain agriculture land. Both streams run out in the Egå Engsø – a manmade lake on the river Egå that is approximately 1.1 km from Aarhus Bay. The topographical catchment of Ravnbakke stream is 1.5 km^2 and Bueris stream have topographical catchment of 1.6 km^2 .

A minor part of the eastern catchment is owned by Aarhus Municipality whereas the rest is privately owned by the developer. It will be a future residential area in the city. Nature, biodiversity and water are drivers for urban development and the community at the heart of the resilient district. The nature-based development is a result of the strong collaboration and a common vision. Together with the consultant and utility company different solutions will be established.

Flooding modeled in Scalgo Live is based on the Danish Elevation Model from 2015. In relation to an assessment of depressions, as potential future basin location, it is taken as a starting point from the assumption about flow on the ground. Different low areas appear where water gathers on terrain, and it is considered suitable areas to establish water harvesting ponds.

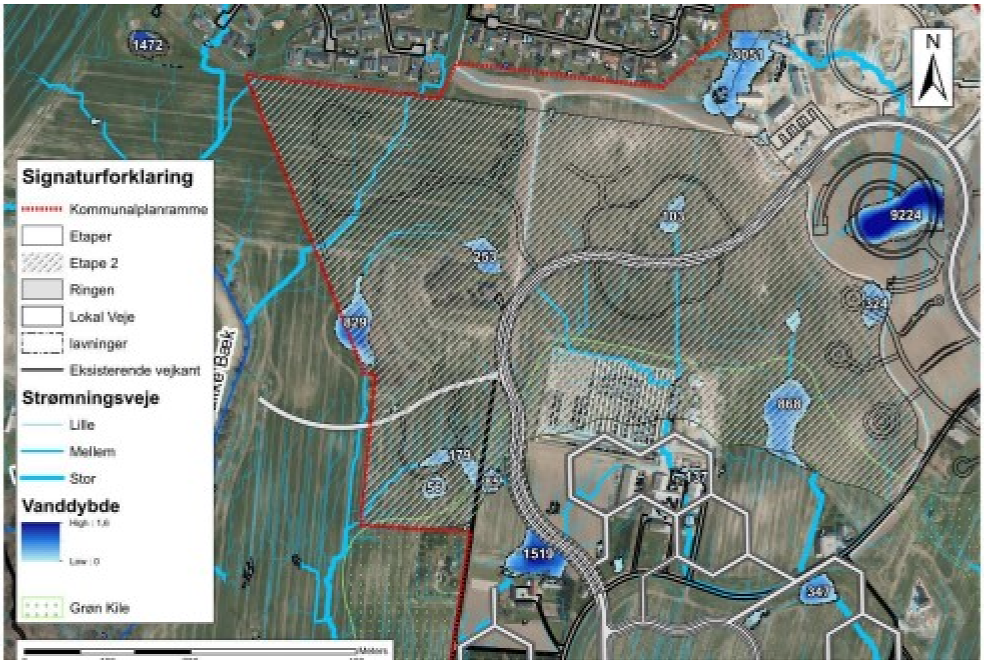

Figure 9 – Low point analysis in Scalgo for the Aarhus pilot site

In general, rainwater management is based on blue-green solutions close to the ground, which must be value-creating. Therefore ditches and gutters are favored with temporary detention in small depressions and water holes. However, pipelines are used where terrain solutions are not assessed to be feasible and add value.

The rainwater system generally has a flow direction from north to south, towards the Inner circle (Kulturring -main road in the city), where the large rainwater islands are located. The system is dimensioned according to applicable standards and regulations, for water quality and water quantities to be handled.

The rainwater system forms water corridors, and in case of cloudbursts, the primary function of these water corridors will be to transport water safely and without causing damage for the surroundings.

The rainwater system's is dimensioned for a projected climate 100-year event. This ensures that stormwater is retained within the plan's grazing area and throttled down as normal discharge, thereby protecting downstream areas, such as receiving water bodies, railways, motorways, etc.

The exact placement of swells connecting the rainwater ponds will be decided in detail project.

An area/point has been designated within stage 2 which could potentially be particularly vulnerable in a cloudburst situation, that is pointed out on figure below:

Figure 10 – example of vulnerability analysis performed in Aarhus pilot site

The capacity analyze is used to define the critical areas in streams that are vulnerable for flooding and erosion risk. The robustness analyzes have been carried out for Bueris stream. The natural runoff in relation to the erosion risk is calculated using the winter median maximum runoff and a winter Manning coefficient. For erosion risk the flow velocity is the most critical parameter. The highest speeds are usually achieved in winter, where there are fewer water and edge plants to create resistance in the stream at the same time when there is a larger flow velocity. Figures below show the stream power values (W/m2) for the studied stream section at different discharge levels, which for the sake of clarity is shown divided into four station intervals. Colored lines on the far left of the figures show the situation corresponding to the winter median maximum runoff (0.88 l/s/ha – reference, natural run off from the catchment area). Other lines reflect emission levels of up to 4.0 l/s/ha from future building developments. From the figures it is evident that an increased erosion risk (stream power values > 35 W/m2) is already introduced at a discharge of 1 l/s/ha. However, this only seems to be the case over longer distances at a discharge level of 2 l/s/ha. To quantify the overall effect of an increasing discharge level in terms of the erosion risk in Bueris Bæk, a graph has been set up with the number of meters of affected stream (stream power values > 35 W/m2) as a function of emission level. It appears from this that number of meters of stretch with increased erosion risk primarily increases up to a discharge level of 3.5 l/s/ha, after which the potential effect of increasing emissions decreases.

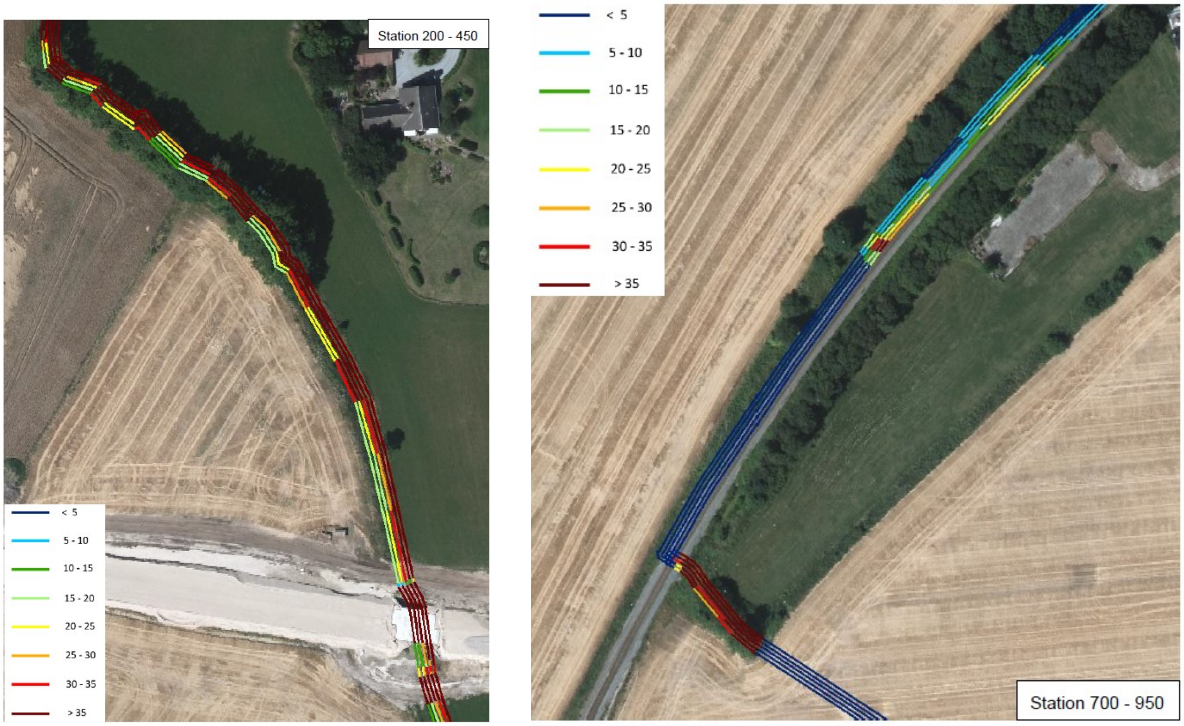

Figure 11 – examples of the streampower (erosion risk) calculations in Aarhus pilot site

For culverted sections the capacity was calculated by using the dimensions of the culverts, material, internal roughness of a culvert, slope of the land it's installed on.

Due to the steep slope in both terrain and stream, there is no significant risk of flooding along Bueris stream from the start of the stream section to the underpass under the Grenåbanen as well as in culverted sections installed along the Grenåbanen. The existing culvert under the motorway is increased in size, so the risk of flooding will be small on the stretch from Grenåbanen to the outlet in Egå Engsø. If existing culverted systems downstream of the Grenåbanen is maintained, there will, however, be a risk of back-up in wells and flooding of the areas of Grenåbanen, north of the motorway and potentially also of the motorway itself.

Modelling revealed that the existing stone chest under the Grenåbanen becomes limiting at a discharge of 5 l/s/ha in addition, two smaller areas with flood risk have been identified. The analyze indicated that the recommended discharges to Bueris stream should be under the 1 l/s/ha to respect the capacity in the waterbody.

Malmö

The City of Malmö is not implementing any NBS in the project City Blues and has therefore no results of detailed modeling of NBS implementation to present. There are more general results of modelling of flood situation (see the section above) and also of water quality. These are being used in the Malmö pilot to develop a strategy for future nature-based solutions in the catchment area. The strategy will suggest different solutions in different parts of the catchment area and present it with illustrations to be used in discussions with developers, city planners, politicians and citizens. The plan is also to create a hydrological model so that the effectiveness of suggested solutions can be evaluated.

Together with the water company the water quality is being modeled through a Stormtac analysis of the catchment area. This is a way of finding suitable areas for stormwater treatment ponds and wetlands. In some areas these solutions can combine water quality and quantity, but the first step of the analysis only considers water quality which is shown in the map below. The results are mainly presented with maps that visualize the possible locations and calculations of the amount of pollutants that can be treated and to what cost. The analysis will be used as a basis for decision-making in land-use planning and investments for both the city and the utilization company.

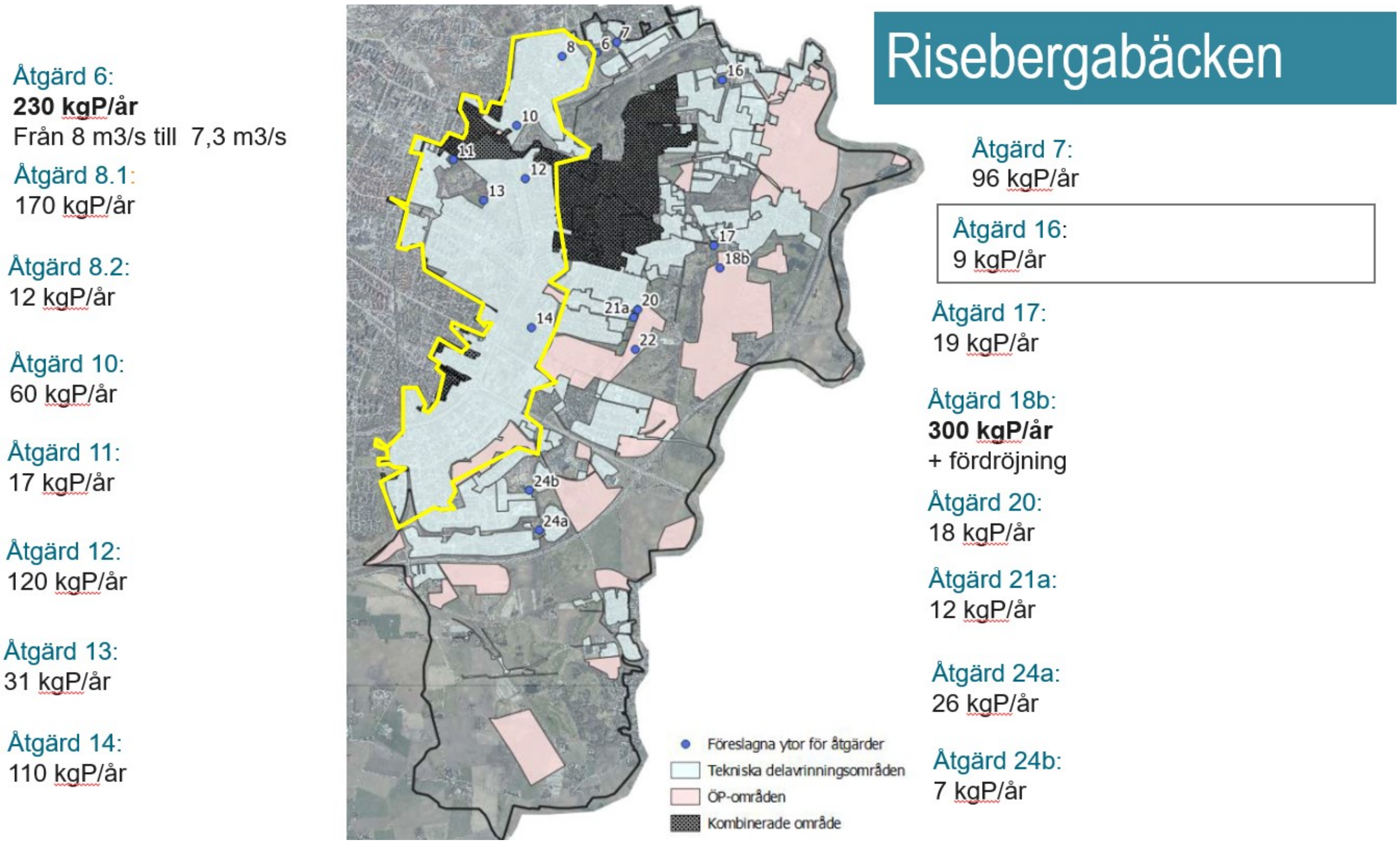

Figure 12 – Water quality analysis in the Malmö pilot area

Stavanger

State of practice in Stavanger

The modeling exercise leverages Scalgo Live to provide a comprehensive overview of the area's potential water accumulation points. Specifically, it presents the potential impacts of extreme rain events and the resulting water runoff on residential areas surrounding Mosvatnet, Breiavatnet, and Stokkavatnet in Stavanger. This enables to identify flood-prone areas and critical points in the runoff system.

The municipality has already addressed critical water accumulation in the residential areas. On the north-west side of Mosvatnet, there is an existing stormwater infrastructure, that is channeling stormwater through pipes to Mosvatnet from the Eiganes residential neighborhood. Similarly, the planned Texaslunden project aims to collect stormwater from residential areas, transport it under Madlaveien, and, through a natural filtration system, discharge it into Mosvatnet.

The Nytorget project, which involves transforming a grey, asphalt-dominated square into an attractive park area, also prioritizes NBS for stormwater management. The project includes the construction of rain beds and other green infrastructure elements to manage runoff and reduce the burden on the drainage system.

In this modelling exercise the potential flood risks in residential areas surrounding Mosvatnet is highlighted and mitigation strategies, particularly NBS showcased, to enhance the city's resilience to future cloudbursts. Figure below utilizes a baseline rainfall intensity of 26.8 mm for a 60-minute duration and a 100-year recurrence interval. This value was adjusted with a 30% climate surcharge, resulting in an estimated rainfall intensity of 34.84 mm for future 100-year events. The software doesn't account for certain hydrological and hydraulic parameters, such as infiltration, pipe network capacity, and water velocity. Additionally, resolution constraints can limit the level of detail in the analysis.

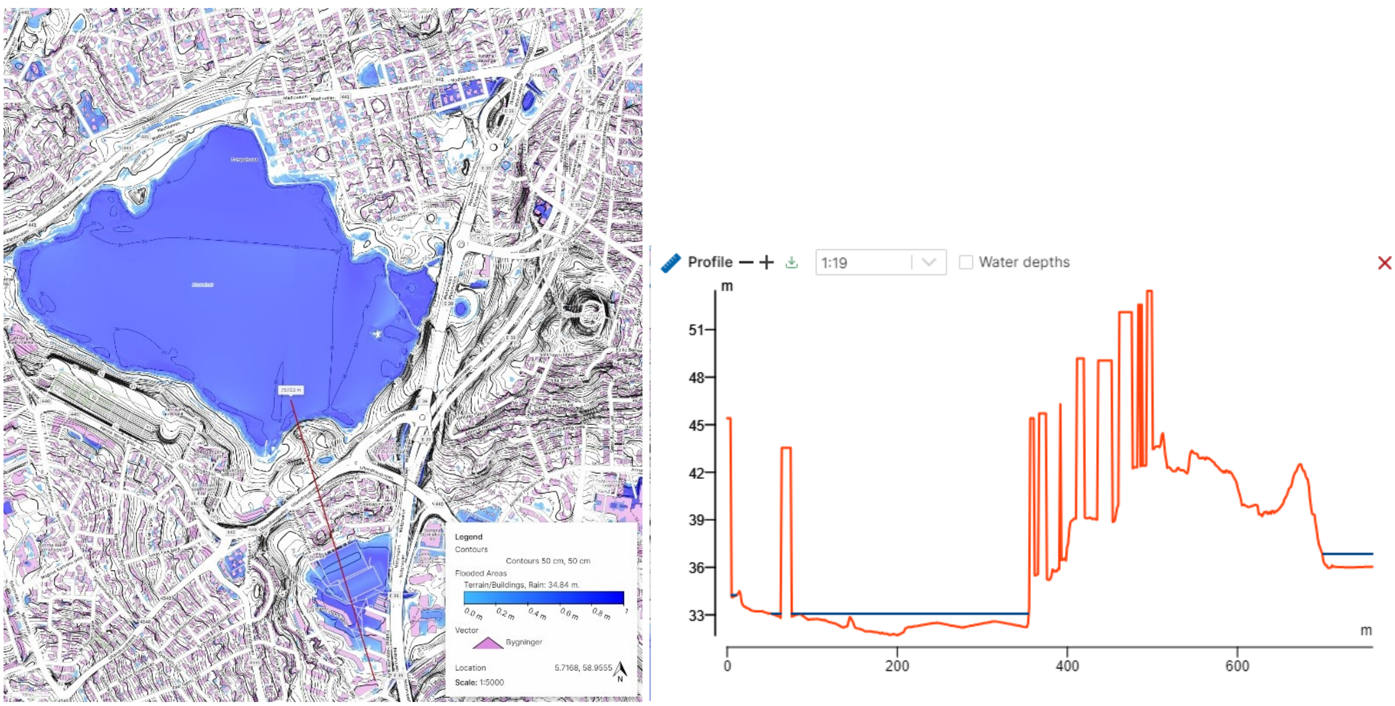

Figure 13 example of the modelling results at the Stavanger pilot site

Pilot case study

The municipality is currently improving the cycling infrastructure near the recreational facilities in Stavanger, such as the Mosvatnet lake. The area of extension of the Bicycle Highway in Stavanger region passes by another recreational area in Stavanger – the SIF stadium. This is the last stage of the Cykkelstamvegen between Stavanger and Sandnes, which is scheduled to open in 2026.

Located south of Mosvatnet Lake, it is placed in a depression, bordered by elevated areas in the north, west, and south, and the urban motorway on the eastern side. As revealed by the rainfall simulation, the area of the SIF stadium will constitute a flooding risk in the future.

Similarly, the Texaslunden project, situated in a depression near Mosvatnet, on the North side, faces potential flood risks due to increased rainfall and runoff. The project aims to mitigate these risks by directing stormwater from residential areas into Mosvatnet through a natural filtration system.

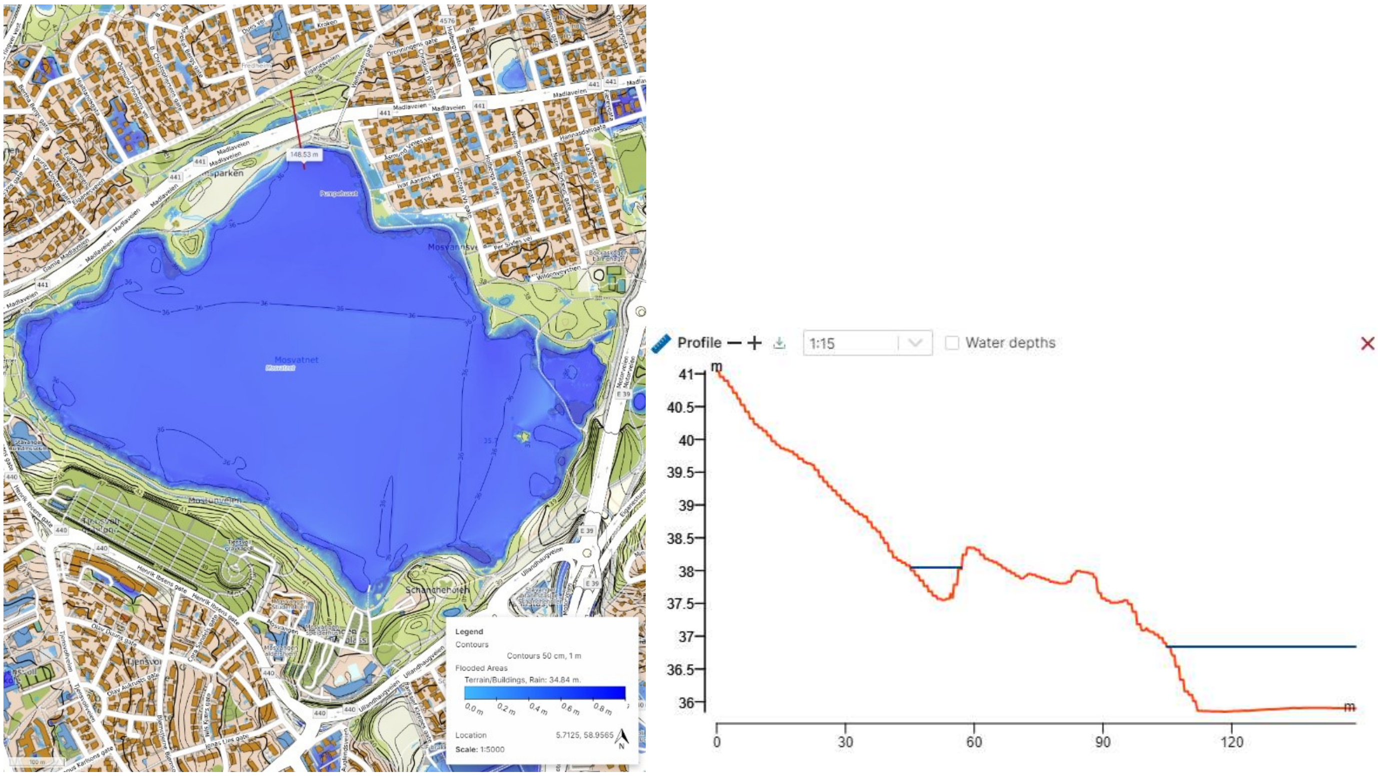

Figure 14 – example of the modelling results at the Mosvatnet pilot area

In addition to the SIF stadium and Texaslunden projects, the Nytorget development provides another opportunity to study the effectiveness of NBS in managing stormwater runoff and mitigating flood risks. The park's design incorporates various NBS elements, such as rain gardens, bioswales, and permeable pavements, which can be analyzed and modeled to assess their impact on the local hydrology.

Scalgo's ability to visualize runoff patterns and simulate the impact of terrain modifications, such as the addition of retention ponds or culverts, allows to explore potential NBS for mitigating flood risk. By strategically altering the terrain and incorporating NBS elements into the model, their effectiveness can be assessed in redirecting and managing stormwater runoff, ultimately enhancing the resilience of the recreational areas around Mosvatnet to future cloudbursts.

Tampere

Dimensioning of culverts

Based on the modelling results it is recommended to sink the culvert about 20 cm below the bottom of the channel. In this case, the culvert must be at least DN1400. The revised dimensioning backwater with the 1400 C culvert is about 5 cm, which can be considered acceptable.

The current Kuusimäenkatu 1200 St culvert is about 25-30 cm embedded in the existing channel. The longitudinal slope of the pipe is good, but the ratio of the opening to the cross-section of the channel causes about 10 cm of backwater. Backwater is acceptable due to other measures taken, but it is recommended to renew the culvert later to at least DN1400 size.

Below is a longitudinal section in the planned situation. Simulated water surfaces are shown in gold (1/1a), magenta (1/3a), red (1/50a) and blue (1/100a). The picture shows the effect of the planned 1400 C culvert and the current Kuusimäenkatu street 1200 St culvert on the water surface. The graph also shows the impact of the planned dam structure.

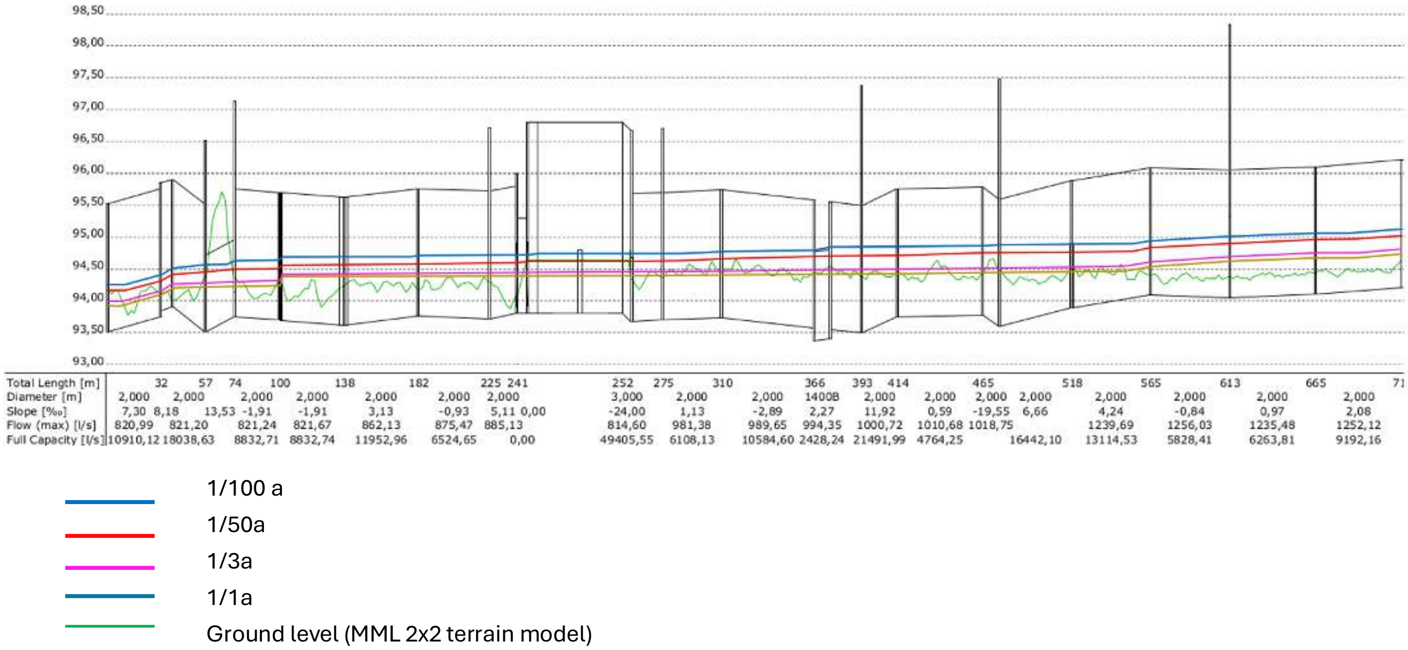

Figure 15 – modelled culverts in the Tampere pilot site

Dimensioning of dam structure

The dam opening was dimensioned as a vertical opening, with specified width of 20 cm. The opening will be implemented with parallel sheet pile walls, between which there is an opening. The dam will be landscaped with natural stones. About 120 l/s flow passes through the dam opening before overflowing.

Impact of alluvial meadows

With alluvial meadows, flow peaks can be cut at Varsanpuisto by about 120 l/s (30%) in the 1/3a situation and 200 l/s (24%) in the 1/50a situation. The flow of Varsanpuisto after the dam is shown below.

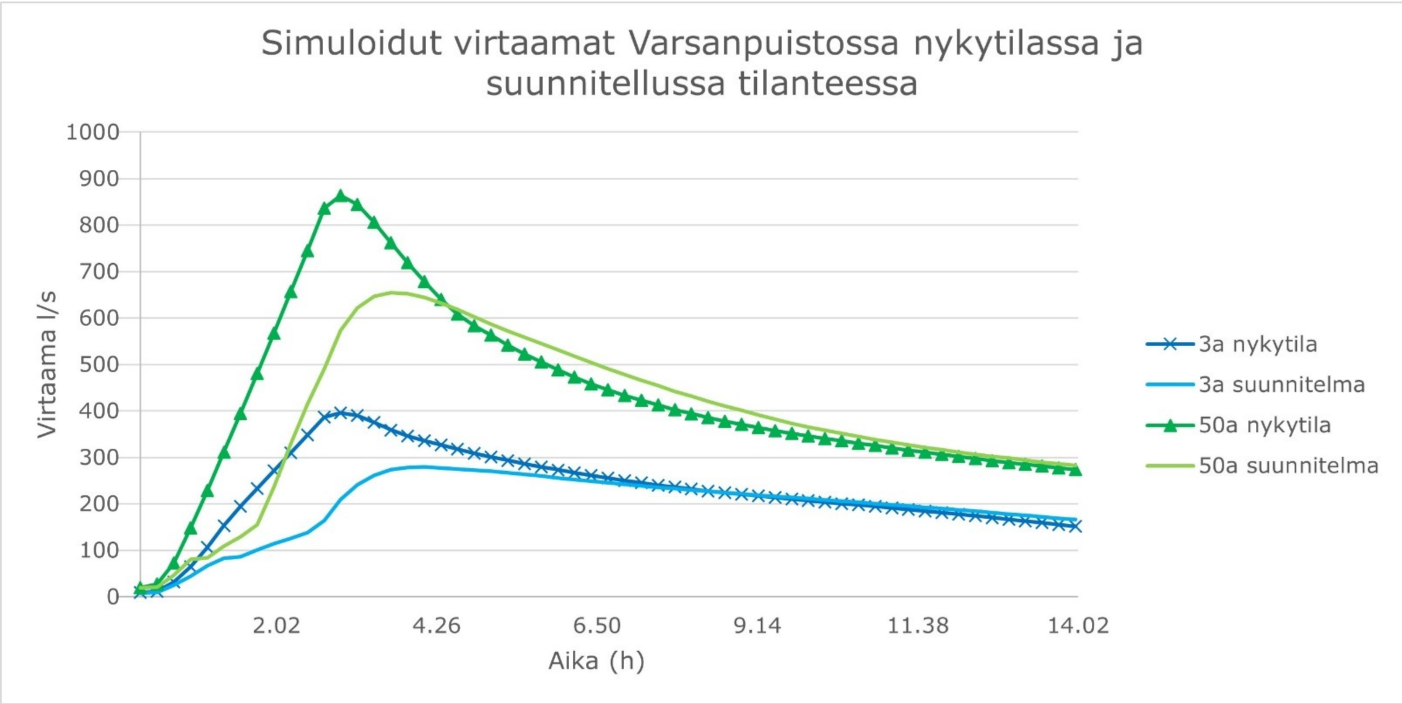

Figure 16 – example of the modelling results presenting the effect of the proposed intervention in Varsanpuisto

At Takahuhdintie street, the peak flow is about 14% in the 1/3a situation, and about 12% lower in the 1/50a situation. The simulated flow rates of Takahuhdintie street are shown below.

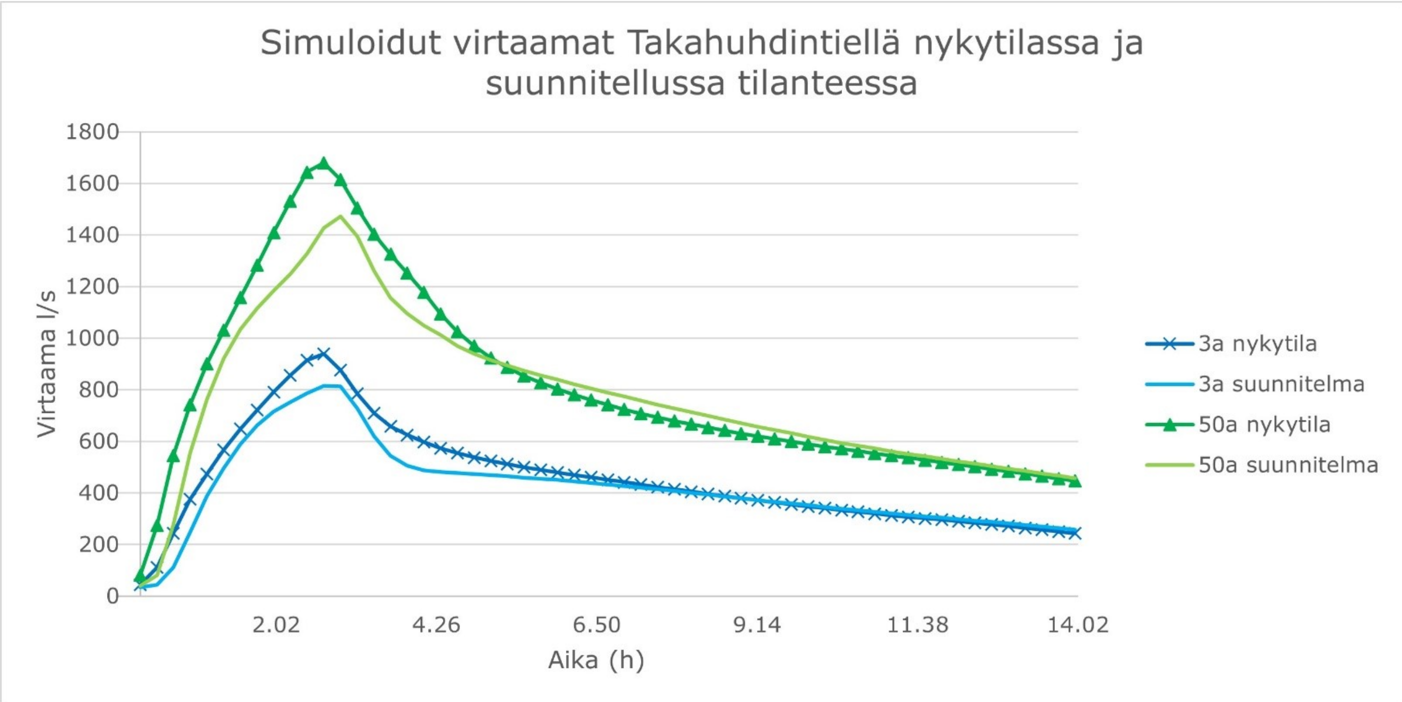

Figure 17 – example of the modelling results presenting the effect of the proposed intervention in Takahuhdintie

The impact of alluvial meadows on flow peaks is positive, when the large size of the catchment area is taken into consideration.

The longitudinal section below shows the current situation in red and the simulated water levels of the planned situation in blue in the 1/50a situation. At Takahuhdintie street, the difference in water levels between the examined situations is about 10 cm.

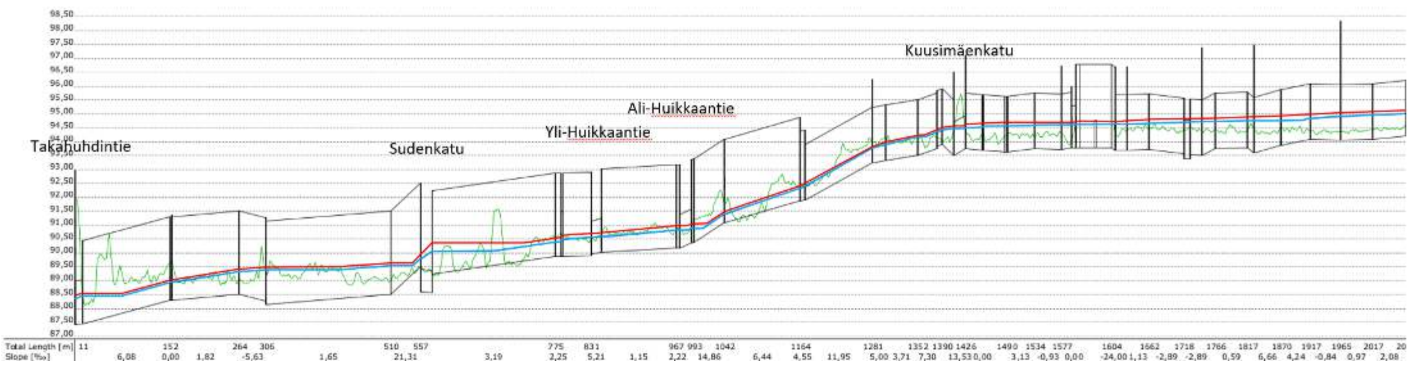

Figure 18 – example of the changes in the water level prior and after the intervention

Modelling reveals that the designed floodplains cut the peak flow about 24…30 %.

Flood maps

The pictures below show the flood areas according to the modelling made based on the plan, in areas colored from light to dark blue, with flows recurring once every 3, 50 and 100 years.

In a situation that occurs on average once every 100 years, the densifying land use has also been taken into account by increasing 10% of impervious surface above the catchment area. In this situation, the culverts and stormwater sewers above the study area significantly curb the flow peaks, which considerably limits the flood area in the situation that occurs on average once in a century.

Figure 19 – Flood map with flows recurring once every 3 years.

Figure 20 – Flood map with flows recurring once every 5 years.

Figure 21 – Flood map with flows recurring once every 100 years.

Tartu

Tartu Waterworks will construct new stormwater main pipeline along Sadamaraudtee green corridor which will alleviate flood risk at the upstream area of the catchment. Due to the budget limitations this collector will not reach to the outlet at the river, instead being connected with the existing collector in Tähe street. The situation was modelled using 5 year storm with duration of 20 minutes (leaving analysis with other rain types for detailed design). According to the modelling results, the peak flowrate from Sadamaraudtee planned pipeline is 1.8 m^3/s and flow in Tähe street is also ca 1.8 m^3/s. These two flows will join at Tähe – Sadamaraudtee crossroad causing potential flood with flowrate of 1.6 m^3/s, duration 30 minutes and depth 70 cm. As Tähe street is a lively transportation corridor in Tartu, this situation will cause potential major disturbances. Therefore, the major objective of City Blues pilot site is to alleviate that situation by providing retention volume to capture excess stormwater, reduce peak flow and slowly redirect that water (leftover from infiltration and evaporation) back to the pipeline.

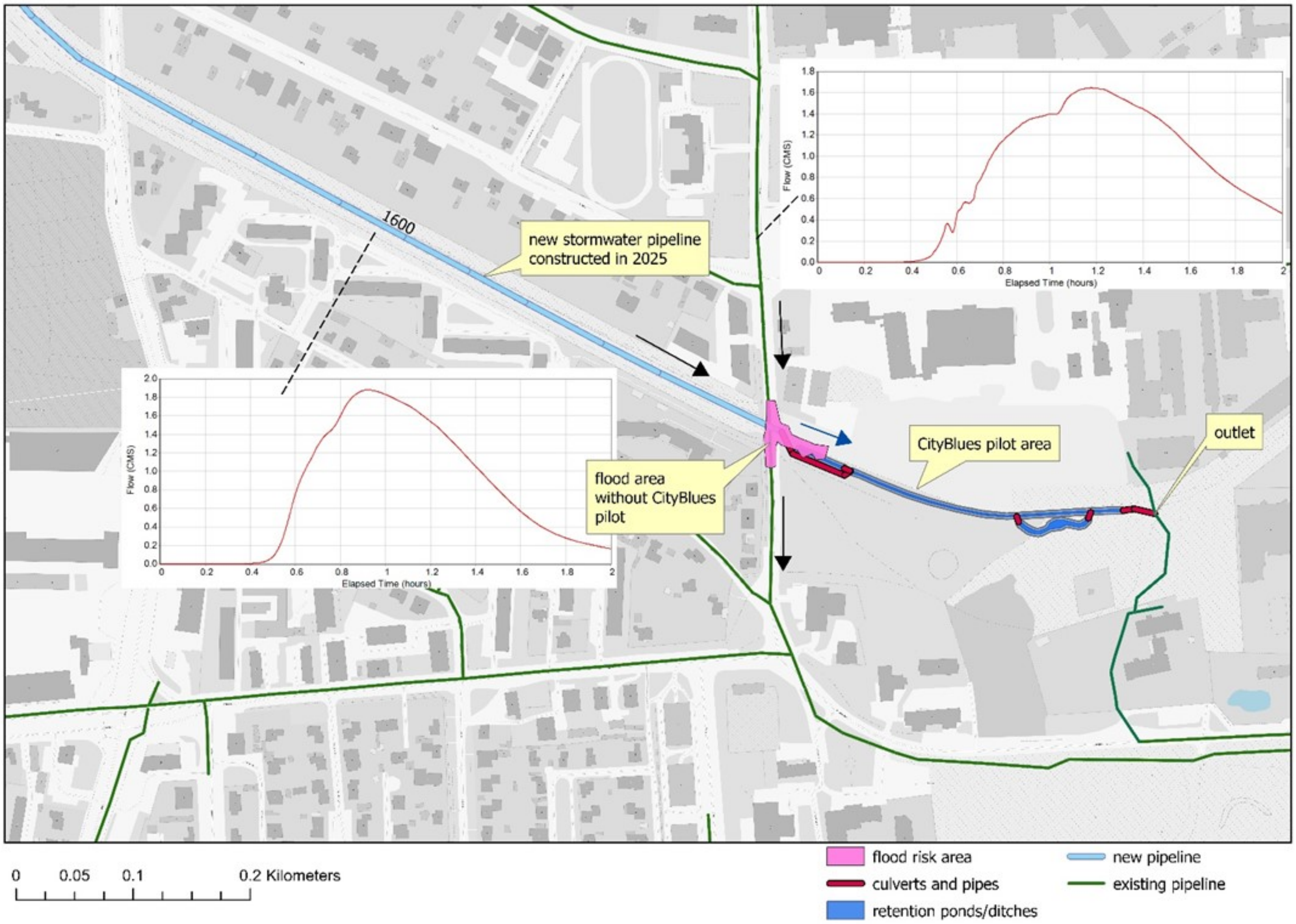

Figure 22 – example of the modelling results at the Tartu pilot site

Potential impact of the selected solution

Aarhus

Potential solutions are now in planning and will be defined in detail during the pilot.

The proposed solutions:

1. **Restoration and reopening of Ravnbakke Stream**

   The small stream Ravnsbakke is a protected stream in accordance with the EU Water Framework directive, that is highly susceptible to changes in its hydrology, existing pressures from agriculture and physical limits of the stream. Downstream stretches of Ravnsbakke, and its subsequent parent stream Lisbjerg stream are biologically rich and species diverse, with several red listed and rare invertebrates present and phytobenthic algae showing very good quality to downstream reaches where stream runs more naturally through narrow forested zone. The susceptibility of the stream encompasses risk of fluvial flooding, erosion of stream banks, capacity limitation, pollution from stormwater runoff and agricultural discharge. Additionally, drought and water scarcity may pose additional problems.

Figure 23 – Photos from Ravnbakke Stream on project site on April 24, 2023

The detail project was prepared in Scalgo and VASP.

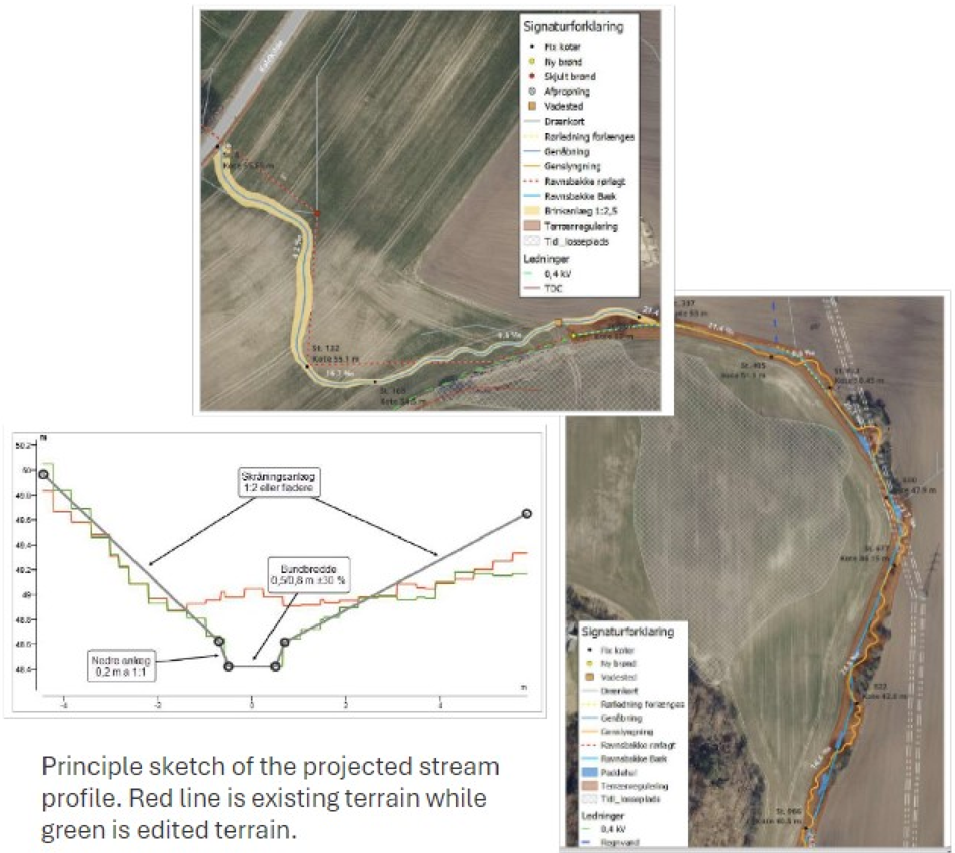

Figure 24 – principle sketch of the proposed solution

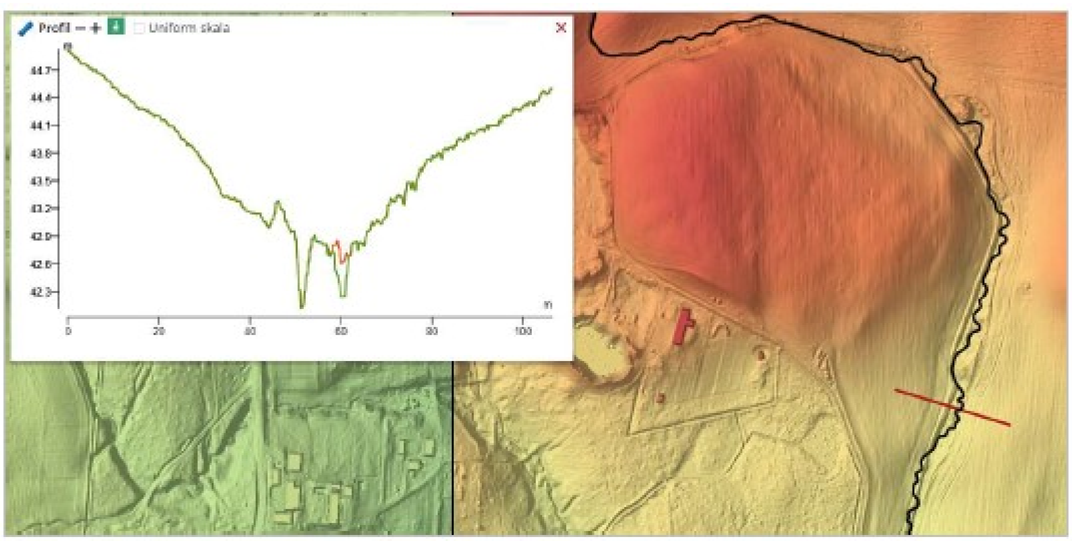

Figure 25 – example of a profile after restoration

Figure 25 shows an example of the profile across the river valley after restoration, where it appears that the terrain rises significantly on both sides. Green is edited terrain with the re-meandering stream while red is the unedited terrain model from SCALGO Live.

Ravnsbakke Stream has a large natural fall (slope) of 20 ‰ and in the new profile there will be laid out bottom substrate, spawning gravel and bigger stones, which ensures a great variety in flow and depth conditions. The physical conditions of the stream will thus be improved, and a better connection will be created between the stream and the surrounding areas.

Due to the fact that the stream will be raised in terrain, it must be expected that it will be wetter on the areas closest to streams. Since Ravnsbakke Stream runs in a clearly defined narrow river valley, where the terrain rises sharply to both sides, it is assessed that the change will not cause noticeable changes to the drainage conditions on the adjacent circulation areas.

2. **Infiltration rainwater pond**

An infiltration basin is a shallow impoundment that infiltrates stormwater into the soil. This control is effective at increasing groundwater recharge (thus increasing baseflow to nearby streams) and can also help remove pollutants from stormwater. Infiltration basins have specific underlying soil requirements, which can preclude them from being feasible on all sites. Pretreatment design and regular inspection and maintenance procedures are crucial to ensure they do not fail. Infiltration basins are an excellent option for streams to assure the continual flow though the soil layer to the stream and because they encourage infiltration of stormwater and maintain dry weather flow. Because stormwater travels underground to the stream, it has little opportunity to increase in temperature. The ponds have positive effect on stream biota.

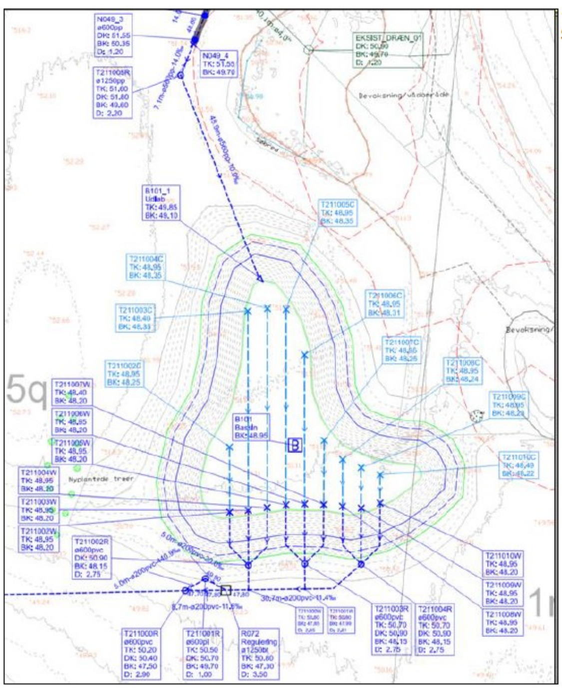

Figure 26 – Principle sketch of infiltration pond inflow, outflow and drains.

Malmö

Since the Malmö pilot only does a strategy document there are no selected solutions yet. The strategy will on the other hand show examples of possible NBS and the potential impact it can have on the stream and its surroundings, even if it's not with detailed modeling in this stage, but this will be further explored during the pilot.

Stavanger

Proposed solution

The modeling exercise in Scalgo Live has highlighted the vulnerability of the SIF stadium area to future flooding events due to its topographic location and the ongoing construction activities. Similarly, the Texaslunden area, located near Mosvatnet, faces potential flood risks due to its topography and the planned development. To mitigate this risk, the potential impact of implementing NBS was explored, specifically retention ponds, to manage stormwater runoff.

By strategically placing retention ponds within the SIF stadium area, the excess stormwater runoff during heavy rainfall events can be captured and stored. The modeling results indicate that this intervention could significantly reduce the extent and depth of flooding in the area, potentially preventing damage to infrastructure and surrounding properties.

Retention ponds can also act as natural filtration systems, removing pollutants and sediment from stormwater runoff before it is released into the environment. This can contribute to improved water quality in nearby water bodies. Retention ponds can create valuable habitats for aquatic plants and animals, enhancing biodiversity in the urban environment.

While the Nytorget project does not involve the construction of retention ponds, it does incorporate other NBS features, such as rain gardens and bioswales, which can provide similar benefits in terms of stormwater management, water quality improvement, and biodiversity enhancement.

One such **retention pond** has been created with Scalgo Terrain edits. The exterior area for the retention pond is 2364.90 m^2, starting at a level curve of 32 meters, and a blending area around it of 10 meters. The other retention pond is in the southern area of the study location, with an area of 1078.87 m^2 and starting at a level curve of 31.83 meters.

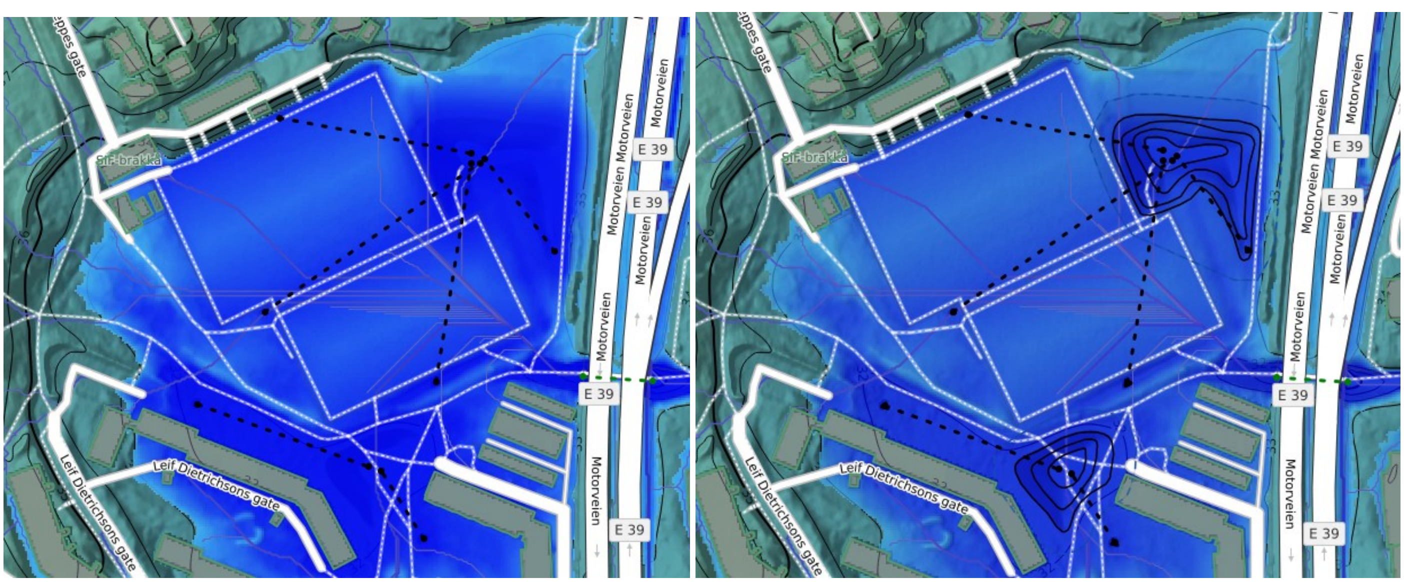

Figure 27 – Water levels in the study area before and after the intervention

SIF Stadium Area

In the Texaslunden project, an underpass will be strategically constructed to transport stormwater runoff from the surrounding residential areas to Mosvatnet, where it will undergo natural filtration before entering the lake. The modeling results indicate that these interventions could significantly reduce the extent and depth of flooding in the area, potentially preventing damage to infrastructure and surrounding properties.

The Texaslunden project is a planned initiative by the Stavanger municipality to manage stormwater runoff and enhance the area's resilience to flooding.

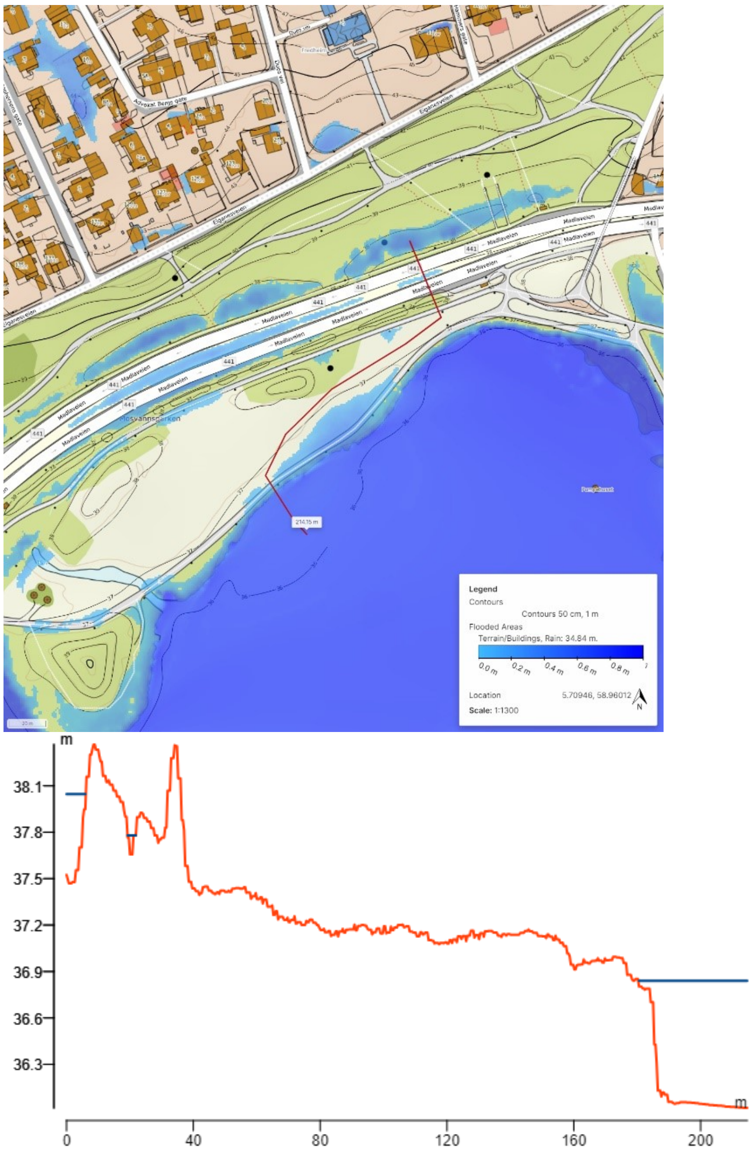

Figure 28 – Planned underpass in Texalunden area

Tampere

The Vuohenoja ditch in the Varsanpuisto and Huhmarpelto area is badly overgrown and it occasionally floods, for example, into the allotment garden area. Downstream, Vuohenoja suffers from erosion and flooding problems. Attempts are made to mitigate the problems caused by the volume of stormwaters by flood zones implemented in the areas of Varsanpuisto and Huhmarpelto. Modelling results were used in construction planning of the pilot site structures and to analyze the impact of the solution.

With the drowned weir to be built along the ditch, water can already be dammed up to the new flood zones with flows occurring once a year, in which case the flow peaks that occur once a year can be lowered. The dam also regulates the water level in the Varsanpuisto and Huhmarpelto area so that water does not flood critical areas even in the rarest of situations.

In addition to the flood zones and the dam, the vegetation of the channel should be removed, and the channel should be kept more open than it is now.

Depending on the frequency, these measures will lead to a reduction of about 15...30% in the downstream flow peaks. The result is good considering the large size of the catchment area, and it is partly result of the fact that there are already retention areas in the catchment area such as Alasjärvi and Sikosuo.

The design calculations for the culverts, bottom dam and floodplains were used as input data for the design. For example, the reduction in flow during different rainfall events on the Takahuhdintie Road, which is currently experiencing flooding problems, was examined. The result of the modelling was that the solution can achieve a 15-30% reduction in flows, which, together with other planned actions, has a significant reduction in flood risk.

Tartu

Modelling results were use in preliminary design of the pilot site structures (ditches, ponds, pipelines) and to analyze the impact of the solution. As a result of modelling preliminary dimensions – length and cross-sections were calculated for the nature-based flood derivation cascade. The structure should have volume minimum of 1400 m^3 to sufficiently accumulate the stormwater. It is possible to create adjacent retention ponds to increase the volume. Outlet peak flowrate was also calculated by the aid of modelling – in case of ditches and ponds shown below, it is presumably below 0.3 m^3/s. This is several times lower that the peak inflow, reducing thus the flood risk at the downstream of the pilot. There is also significant water purification effect envisaged, especially during warm seasons when plantation is active.

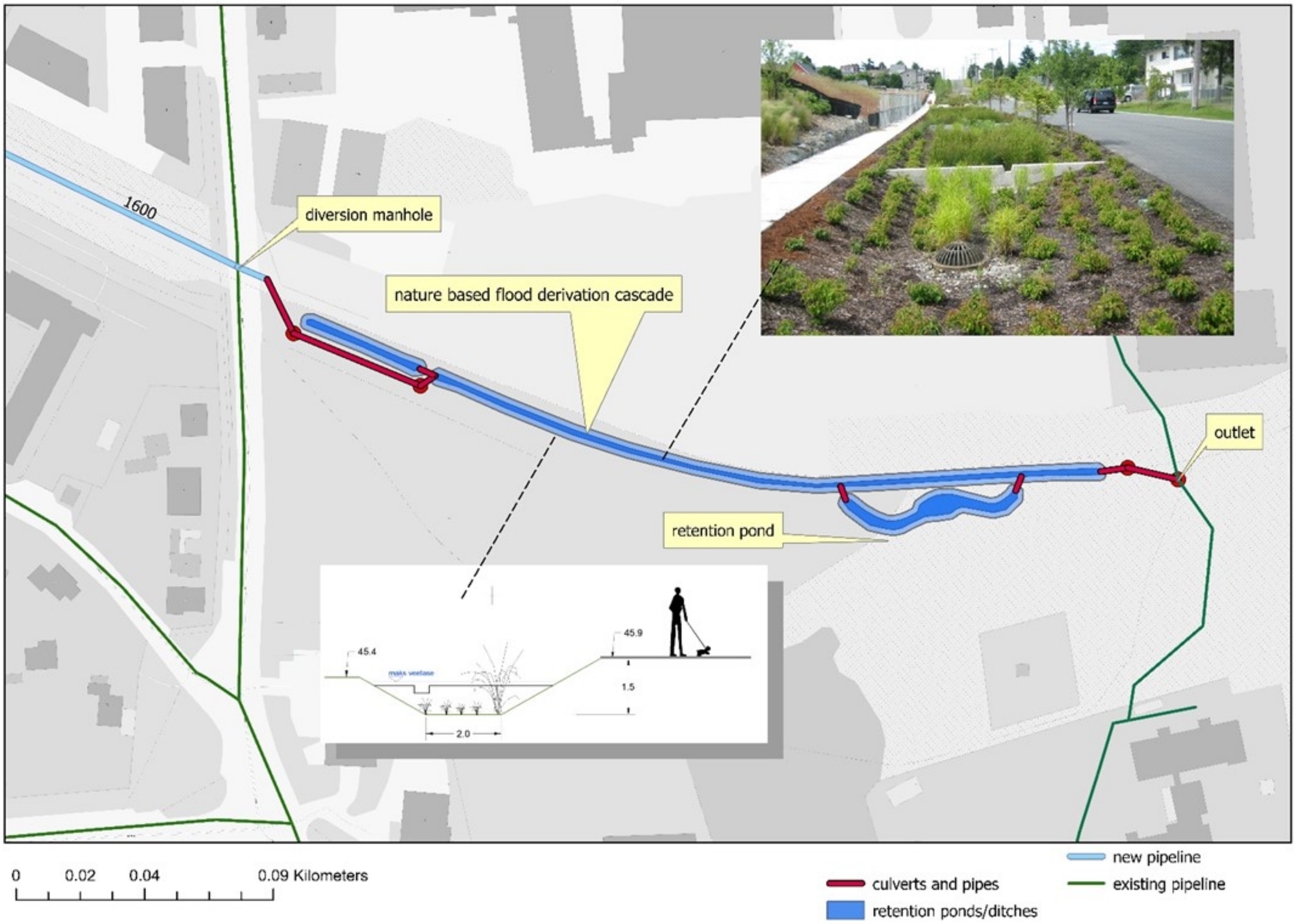

Figure 29 – layout of the preliminary design of the Tartu pilot site

This data was used as an input for technical description for detailed design. In that phase geodetic survey, including allocation of underground infrastructure and investigating other constraints in the area will be conducted in conjunction with geological surveys. The technical solution will be adjusted and evolved after that information is available.

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