PROTECTING THE BALTIC SEA

FROM UNTREATED WASTE WATER SPILLAGES

Handbook of the NOAH CONCEPT

Interreg Baltic Sea Region

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NOAH

The handbook is compiled as a result of the experience gained from Interreg Baltic Sea Region project NOAH – Protecting the Baltic Sea from untreated wastewater spillages during flood events in urban areas (2019-2021).
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FOREWORD

The NOAH project was launched with the aim of protecting the Baltic Sea from untreated wastewater spillages during flood events in urban areas. To achieve that goal, NOAH aggregated hydraulic modelling, spatial planning, water quality analysis and real-time control of urban drainage systems.

The pilot sites were selected on the basis of their location near a natural water body (sea, river, channel) which is connected directly to the Baltic Sea. At such sites, extra flow rates in the urban drainage system pose a risk of wastewater spillage during extreme weather events. All participating cities had an urban drainage system in place, which did not perform sufficiently under conditions of extreme weather events. The aim of the pilot activities was to test and implement a set of solutions which, as the NOAH concept, would be easily scalable to any urban area in the Baltic Sea region.

The current handbook gives a concise overview of the multifaceted challenge of reducing the risk of pluvial floods in urban environments. The handbook explains the background of the problem and introduces options to solve it. More specifically, the handbook provides an overview of what the NOAH Concept is in preventing and controlling urban floods, and proposes steps that local municipality governments and water utilities can take to follow the concept. The handbook is accompanied by a set of annexes containing project activity reports, which provide more detailed information on how the concept has been implemented and what have been the lessons learned during the process.

GLOSSARY

Fluvial flood – or river flood, occurs when the water level in a river, lake or stream rises and overflows onto the surrounding banks, shores and neighbouring land. Not directly targeted by NOAH, but considered in areas where it affects the performance of UDS.

Pluvial flood – occurs when an extreme rainfall event creates a flood independent of an overflowing water body. Surface water floods occur when an urban drainage system is overwhelmed and water flows out into streets and nearby structures.

Climate scenario – climate change scenarios or socioeconomic scenarios are projections of future greenhouse gas (GHG) emissions used by analysts to assess future vulnerability to climate change.

Real-Time Control (RTC) – the ability of water infrastructure to be adjusted in response to current or forecasted conditions.

Combined sewer overflows (CSOs) – combined sewer systems are sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. During periods of heavy rainfall or snowmelt, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other water bodies. These overflows, called combined sewer overflows (CSOs), contain not only storm water but also untreated human and industrial waste, toxic materials, and debris.

Rainfall intensity–duration–frequency (IDF) curves – the rainfall intensity–duration–frequency (IDF) curves are graphical representations of the probability that a given average rainfall intensity will occur within a given period of time.

Urban drainage system (UDS) – is generally defined as a runoff collection and transportation system and consists of grey (pipes, junctions, tanks and other technical elements) and green (nature-based solutions) infrastructures.

Extreme Weather Layer (EWL) – a non-structural (passive) measure in a form of decision support system in City GIS developed in NOAH with the objective to help reduce spillages of untreated wastewater during flood events.

CONTENTS

BACKGROUND OF THE PROBLEM

Urban flooding that follows intense short-term precipitation, when the volume of rainwater exceeds the capacity of urban sewerage systems, may lead to substantial damage in urban areas. The predominant direct cost of pluvial flooding is the physical damage to buildings and other infrastructure. However, the true impact is much larger, as such floods pose health and safety risks to the affected communities and hinder the provision of services, cause loss of business and interrupt operation of urban networks. Last but not least, urban runoff carries along pollutants that, when ending up in the receiving natural water bodies, degrade the natural water ecosystems. The pollutants that contaminate the end discharge from urban drainage systems are first accumulated and washed off to the system from the city streets and surfaces. In cases the cities have combined sewer systems for storm water, the contamination becomes even more significant, as in the case of heavy rains the combined drainage systems also discharge the untreated wastewater along with the storm water. All these pollutants from rainwater and storm overflows may end up in the Baltic Sea.

Fluvial flood risk induced by the high water level of natural water bodies is well assessed in Europe, as this is mandatory according to

Figure 1. Short cloudburst can seem fun for a second on a warm summer day, but it causes a loss of assets as well as damage to the natural environment.

the European Commission Directive 2007/60/EC on the assessment and management of flood risks[1] . The European Flood Awareness System under Copernicus Emergency Management Service, as well as national databases, provides access to static flood risk and flood hazard maps, and contributes information to emergency alert systems [2]. Fluvial floods, though affecting a large share of European cities, are not as universal as the risk of floods induced by heavy precipitation, which could affect any urban area. As shown in Figure 2, the pluvial flood risk affects cities across Europe.

Due to many catastrophic events that have occurred in recent decades, cities have become more aware of flood risks and understood that the costs of inaction cannot be understated. This means that investments in flood resilient urban drainage systems should be wisely planned; therefore, appropriate tools and training, also of decision makers, cannot be overestimated.

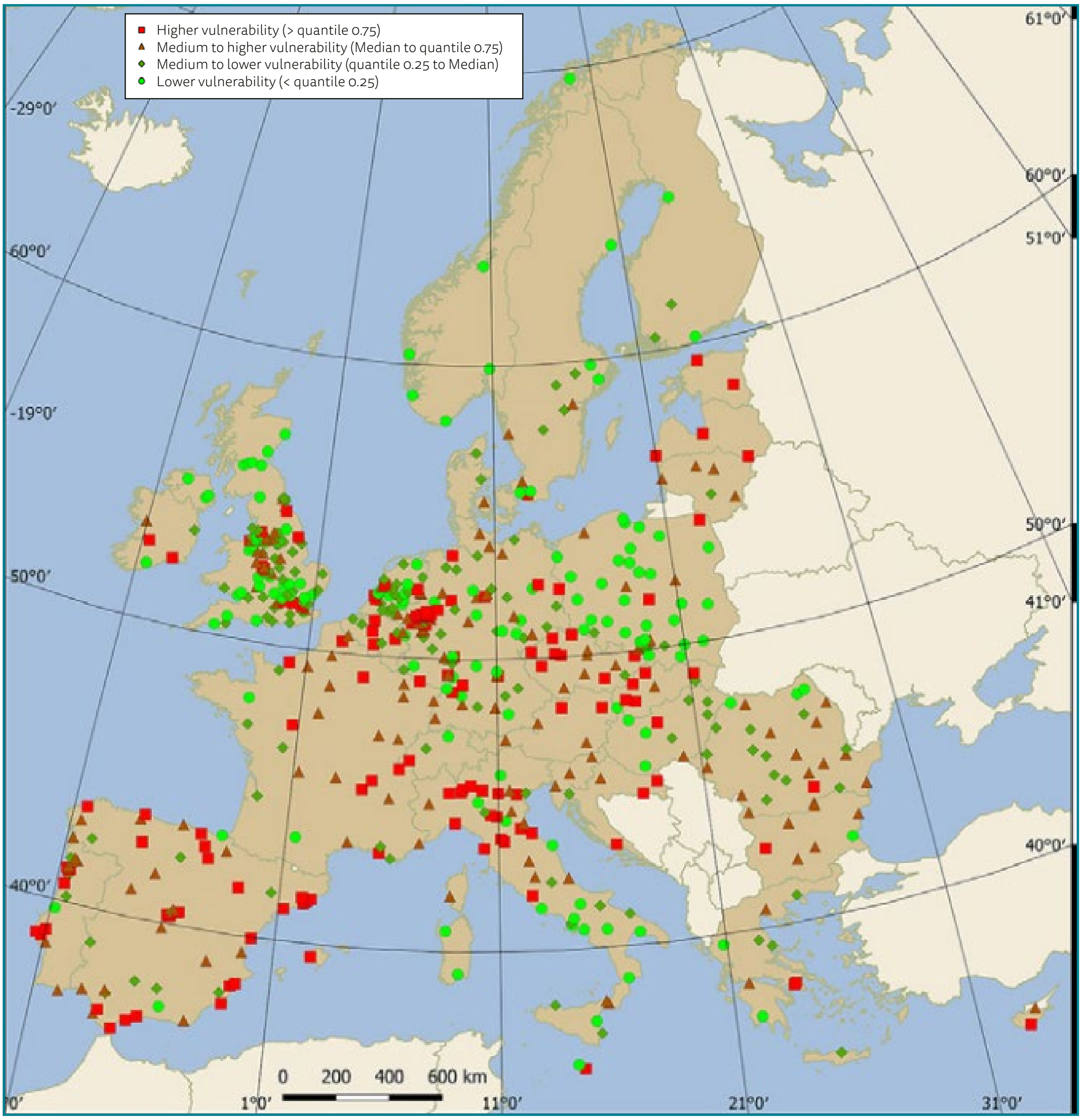

Figure 2. Indices of vulnerability to pluvial floods carried out in 571 European cities demonstrate that the majority of assessed cities suffer medium to higher vulnerability to pluvial floods. Among these are many cities in the Baltic Sea region [3].

Impact of untreated waste water spillages on the Baltic Sea

Eutrophication of the Baltic Sea was first recognised as a large-scale problem in the early 1980s. During the last 4 decades the nutrient inputs have decreased in most sub-basins of the Baltic Sea. However, as seen in Figure 3, the current nutrient inputs still do not correspond to the expected ecological status of the Baltic Sea agreed upon in the Baltic Sea Action Plan [4],[5]. A major portion of the anthropogenic part originates from diffuse sources. In terms of point sources, municipal waste water treatment plants prevail, as this contributes 12% and 24% of the riverine nitrogen and phosphorus loads, respectively [6].

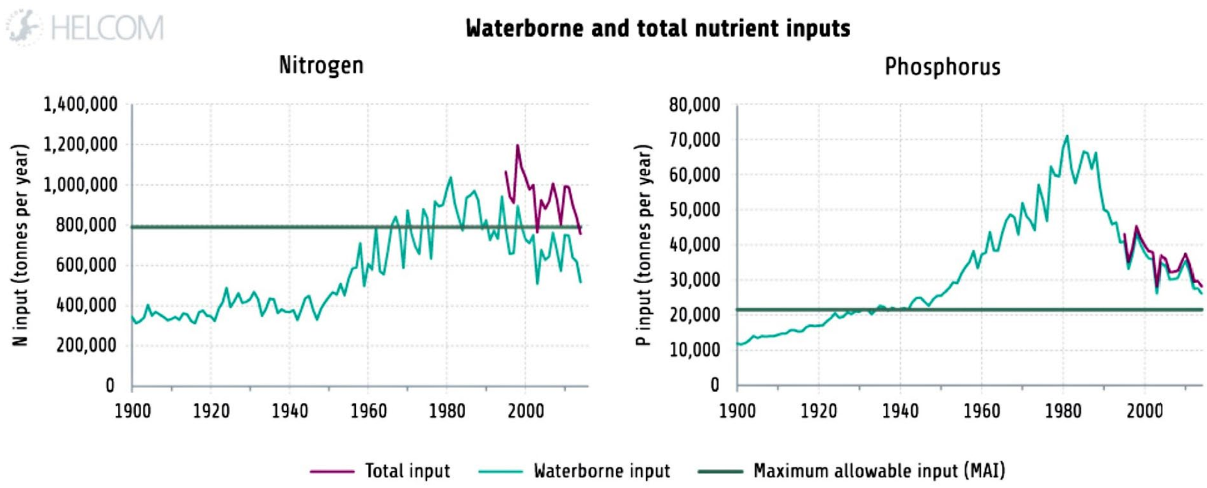

Figure 3. Temporal development of waterborne and total nutrient inputs to the Baltic Sea from 1900 to 2014 with inputs of nitrogen to the left and phosphorus to the right [6].

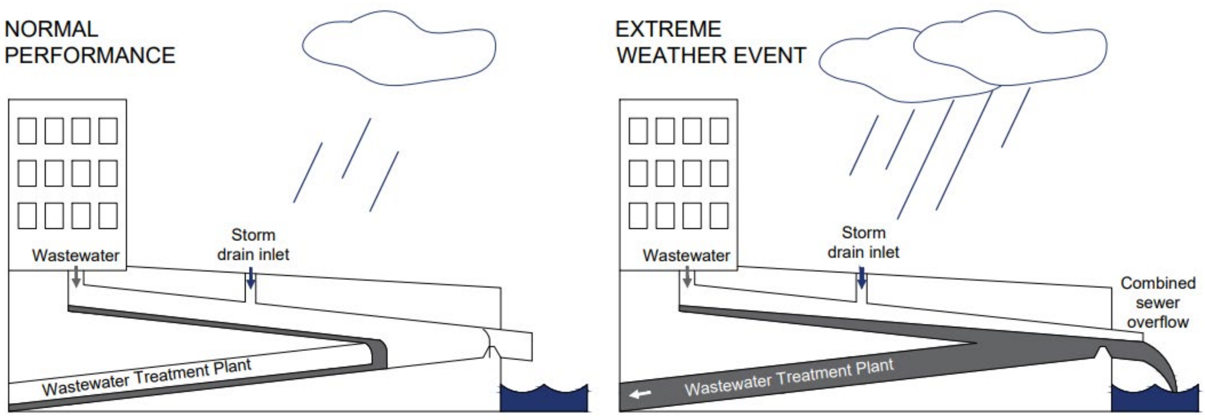

Figure 4. Typical layout of a combined sewer system, adopted from [7].

In the Baltic Sea region, the untreated wastewater can end up in the natural water bodies due to activation of combined sewer overflow.

Combined sewer systems are designed to transport domestic sewage, industrial wastewater and also urban runoff in the same pipes. Under normal circumstances, combined sewer systems transport all of their wastewater to a waste water treatment plant (WWTP), where it is treated to reach certain agreed quality norms prior to being discharged into natural water bodies. During periods of extreme downpours, however, the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant. For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater untreated. These overflows, called combined sewer overflows (CSOs), contain not only storm water but also untreated human and industrial waste, toxic materials, and debris, all polluting the marine environment.

Not only does higher runoff increase the flood risk but it also leads to a decrease of efficiency in wastewater treatment plants. Thus, even in cases where the increased runoff does not end up in the natural water bodies through CSOs, the reduced performance of the sewage treatment plants still results, with an increase in polluted discharges.

Factors increasing flooding risk in cities

According to the World Urbanization Prospects, it is estimated that 66% of the world's population will be living in urban areas by 2050 [8]. The growth of urban population makes cities larger and also increases the density of the existing urban areas. As urban areas are growing and becoming denser and more impervious, the floods occurring in the cities have more devastating effects. The following factors can be considered to have the biggest effect on the urban flooding risk induced by extreme weather events.

Surface sealing in cities

Impervious surfaces in cities lower the water infiltration potential of the soil as well as reduce the green areas, where vegetation would otherwise contribute to transpiration. The altered water cycle increases the runoff of water in urban environments and thus contributes to a higher flood risk in cities.

According to the European Environmental Agency's report "Urban adaptation in Europe: how cities and towns respond to climate change", the impermeable surfaces (such as concrete or asphalt) currently cover less than 5% of the total area of EEA member and collaborating countries (both urban and rural). However, due to the growth and densification of cities, the area is increasing. 16 600 km^2 became sealed between 2000 and 2018[9]. According to the unpublished EEA analysis of the Copernicus Imperviousness High Resolution Layer, the average proportion of surface sealing in the administrative areas of the Urban Audit cities in 2015 was around 19.5% (up from 19.1% in 2006), and in the urban morphological zone (UMZ) it was 35.6% (up from 34.9% in 2006) [10].

The combination of high soil sealing and increased precipitation increases the risk of pluvial flooding in most cities, especially in Northern Europe. Therefore, land cover changes within cities can play a central role in exposure of the cities to flooding and in their adaptation to a changed climate.

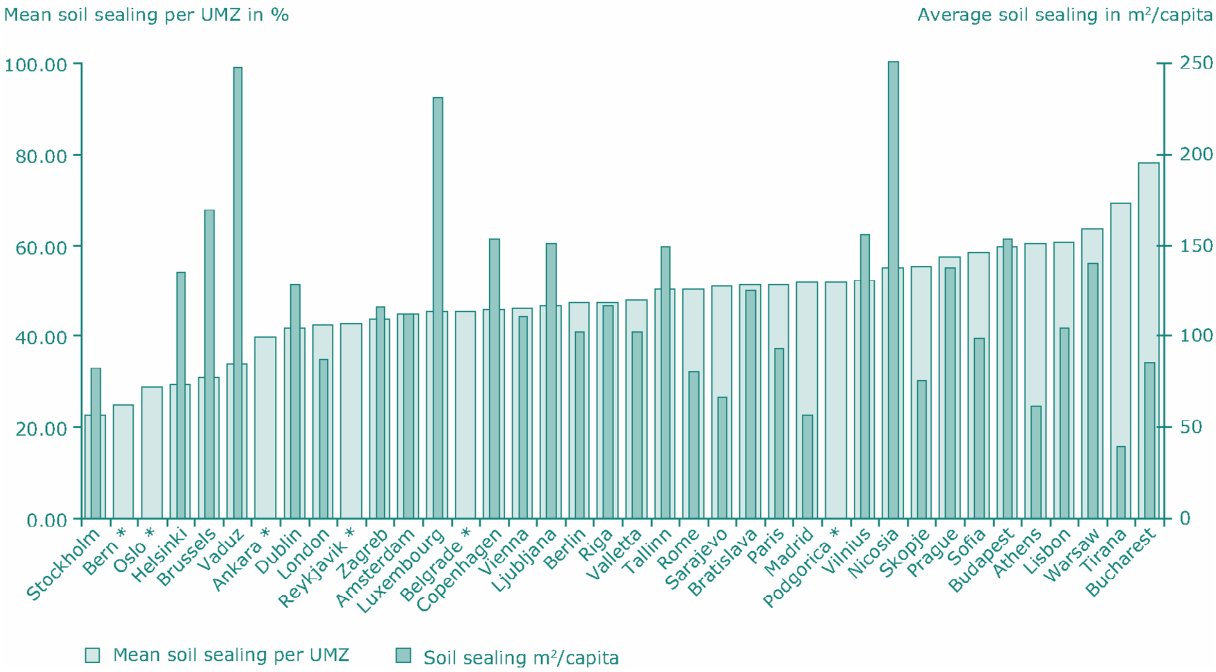

Figure 5. Mean soil sealing in European capitals and soil sealing per inhabitant (* no data)[11].

Ageing urban drainage systems and insufficient capacity

The risk of pluvial flooding is also influenced by the capacity and state of the storm water drainage systems in cities. Underground drainage pipe systems deteriorate over time, resulting in cracks and other defects, while poor maintenance of both pipes and ditches can cause blockages. In addition, hydraulic capabilities of an UDS can be severely hindered by poor design (e.g. bottlenecks caused by insufficient pipe diameters) and building (e.g. reverse slopes) practices.

Though all this can also contribute to the flood risk, a more significant performance failure is caused by the fact that old systems do not respond to the growing volumes induced by expanding cities and new climate extremes. The average age of the sewers for 36 cities included in the Urban water atlas for Europe is 40 years [12]. The systems have been built to perform in much different climatic conditions, which raises the question whether the relatively old sewer and drainage network infrastructure in European cities is capable of dealing with the much higher projected volumes of rainwater during the extreme weather events.

Spatial layout, urban arrangement and placing of critical infrastructure

Spatial layout in cities, meaning the way artificial space and natural conditions are in balance in the city, can either support the resilience of urban living or make it more vulnerable to climate extremes.

Very often cities have started to grow in locations with good access to natural water bodies, which means that urban growth takes place in areas that have historically performed as natural floodplains. When built up, these naturally flood-prone areas cause several land-use challenges. An occasional flooding is actually acceptable in many urban areas, but there is also a variety of urban critical infrastructure, where the tolerance is much lower. When assessing flood risks, health and safety issues need to be considered, as well as the flood resilience of the infrastructure built and the vulnerability of the environment of the natural water bodies.

Figure 6. Deteriorating UDS infrastructure reduces the capacity and ability of urban areas to cope with the extremes.

Uncontrolled drainage systems

All the abovementioned factors contributing to the pluvial flood risk in urban areas can result in limited possibilities to cope with the storm water excess. In some cases, mostly in densely built up areas, the modifications aimed at increasing the UDS capacity are not possible or economically justified. Therefore, controlling of the storm water which has already entered the drainage system should be considered as a flood prevention measure, and the lack of control as a factor contributing to the pluvial flood risk.

A real-time control (RTC) for drainage systems dates back to 1960s when the first process control computer became available; however, the first applications of RTC were rare, individual cases aimed at the reduction of transmission and treatment costs rather than the impact on receiving waters [13]. RTC systems developed rapidly in the 1980s and early 1990s when computers and sensors became more accessible and affordable; nonetheless, the full potential of such solutions is far from being fully exploited now, after the next three decades [14]. The limited application of RTC may result from various barriers, such as institutional and legal [15], and what is more, also from the insufficient dissemination and awareness of readiness and effectiveness of RTC technologies, despite the (1) large number of successful case studies, (2) new computation methods available to be applied in RTC (e.g. multi-objective optimisation or machine learning), and (3) high-performance computers and cloud-based computing services enabling the application of new methods.

To minimise the latter limiting factor, the NOAH project included a demonstration of real life and virtual application of the RTC and evaluation of the results of these applications in terms of reduced flooding, loads of pollutants and other benefits, including financial ones. The NOAH case studies and achievable results are described later in this document.

Climate change

By now it is well understood that all European cities are at risk from climate change [10]. The EU adaptation strategy has declared the urgent need for a faster, smarter and systematic approach to prevent and adapt to the effects of climate change [16]. However, the impacts of climate change can vary tremendously depending on the geographical region and also on the area's exposure and vulnerability. In the Baltic Sea region, it is expected that the extreme weather events induced by global warming will increase precipitation both in frequency and intensity. The risk of pluvial flooding is expected to increase in most parts of Europe with high confidence.

Urban drainage systems that are designed on the basis of historical climate regimes are

Continental region
Increase in heat extremes
Decrease in summer precipitation
Increasing risk of river floods
Increasing risk of forest fires
Decrease in economic value of forests
Increase in energy demand for cooling

Boreal region
Increase in heavy precipitation events
Decrease in snow, lake and river ice cover
Increase in precipitation and river flows
Increasing potential for forest growth and increasing risk of forest pests
Increasing damage risk from winter storms
Increase in crop yields
Decrease in energy demand for heating
Increase in hydropower potential
Increase in summer tourism

Figure 7. Projected climate change in the Baltic Sea region [10].

expected to either become less efficient or fail to perform completely. As explained above, their impacts are exacerbated by increasing surface sealing in cities, ageing sewerage infrastructure and under-dimensioned pipelines.

A variety of impacts of climate change are already perceptible across different sectors and regions, but it is predicted that the effects of it are to be much more worrying in the future. However, many factors affecting climate change are indeterminate and will be shaped by people's actions. That is why climate scenarios allow us to explore possible future developments, the assumptions they depend upon, and the courses of action that could bring them about. The 6th IPCC report on Climate Change declares it to be unequivocal that human influences have and will have an effect on warming the atmosphere, seas and land that brings along widespread and rapid changes [17].

To prevent the negative impacts of climate change, it is necessary to consider the climate change scenarios for analysing the performance of urban drainage systems. Integrated assessment models are an important tool to analyse a response to climate change. Since they capture the link between socioeconomic developments, energy and land use, and emissions, they can be used to investigate emission reduction strategies to stay below a certain warming limit (mitigation pathways). Likewise, biophysical and economic impact models can be used to study adaptation measures to limit the impact of climate change on socioeconomic activities (adaptation pathways).

<table>
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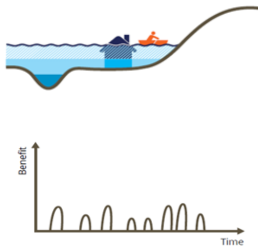
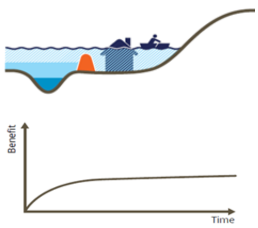
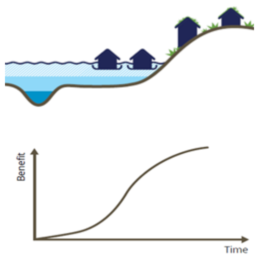
</td><td>Coping measures respond to the damages and try to find solutions to eliminate the consequences of the weather extremes. In terms of pluvial floods, the social acceptance with occasional floods can be relatively high, which results with low initiative in investing funds for flood prevention or control. This though, can be short- sighted as alternative cost for damage control as well as investments needed to floodproof other infrastructure (moisture proofing / elevating buildings, backing up energy systems) can significantly exceed the cost that would be needed to manage flood risk..</td></tr>
<tr><td>INCREMENTAL
</td><td>Incremental adaptation builds on existing adaptation measures and known solutions by improving these, bit by bit, and increasing their capacity to avoid any damage under future levels of risk. Approach aims to maintain or regain the city's current level of service and is based on proven knowledge gained over decades, for example in disaster risk management. Incremental adaptation often focuses on individual measures as appropriate and as opportunities appear.</td></tr>
<tr><td>TRANSFORMATIVE
</td><td>Transformative adaptation follows a broader and systemic approach. It addresses the root causes and considers the various multifaceted challenges of adaptation. Vulnerability to climate change is often a result of human actions, such as settling in risk- prone areas, inadequate building design or other behaviors that aggravate the impact of climate change. This would, however, require a large- scale approach by cooperating with other cities, regions or even countries.</td></tr>
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Figure 8. Examples of different adaptation approaches and complementary benefits at different water levels due to flooding [18].

Options to mitigate flood risks in urban areas

Pathways for adapting to the pluvial flood risk induced by climate change

Urban flooding is one of the most-cited extremes through which regions experience impacts of a changed climate. However, cities are far from being ready either for the current weather extremes or the coming climate. It is confirmed by numerous projects (like NOAH), reports and publications, as well as by continuously required and funded initiatives aimed not only at the preparation of urban areas for climate change, but also at the assessment of pluvial flood risk and preparation of data required for such assessments.

In terms of pluvial flood management, most cities are still trying to cope with extreme weather events through practicing incremental adaptation solutions (see Figure 8). These approaches aim to maintain cities at the current level of service and provide short-term solutions that are likely to fail in the case of future extreme events caused by climate change. For example, cities have traditionally responded to the increasing demands on urban drainage systems (UDS) by expanding their grey infrastructure, i.e. pipelines. However, rebuilding the existing UDS to handle extreme events is financially unrealistic and, in many cases, implausible due to spatial restrictions.

HELCOM has adopted a set of recommendations that integrate and promote the current best practice approaches of storm water management in urban landscape. [19] The recommendations cover aspects like 1) storm water planning; 2) reduction of discharges of urban areas by proper management of storm waters; and 3) management of high-risk storm waters. Based on these, the HELCOM committed parties have agreed to proceed with Integrated Storm Water Management (ISWM). The NOAH project aims to introduce the HELCOM suggestions into real action by implementing both passive and active mitigation measures. Moreover, implementing the NOAH Concept brings urban areas from the typical "coping" adaption level to the highest "transformative" approach.

Knowledge gaps regarding implementation of the integrated storm water management approach that led to NOAH

According to a survey conducted in NOAH among municipalities and water utilities, it is broadly understood that organisations need competence, data and financial resources to understand the impact of precipitation on city infrastructure. Moreover, they need easy tools that will help them prevent (reduce) overflows from combined sewage systems, and identify hot spots in the city and methods for their elimination. Developing these tools has been one of the main goals of NOAH.

II THE NOAH CONCEPT

Introduction

A decision support system (DSS) was developed in the NOAH project to provide an integrated overview of the performance of the existing UDS in case of various future urban development or climate scenarios. The DSS consists of two main packages – the NOAH Tool for analysing the potential of real-time control of UDS and the Extreme Weather Layer (EWL) that enables creation of dynamic interlinkages between land developments, the existing storm water system and the flood hazard in urban areas.

Extreme Weather Layer (EWL)

The Extreme Weather Layer is a passive measure developed in NOAH with the objective to reduce spillages of untreated wastewater during flood events.

The EWL is built on the digital twin of the existing storm water system, enabling planning specialists to consider and analyse the impact of various land use and soil types in the urban environment to simulate the response of the storm water system and catchments to different rainfall events. The DSS allows cities and water utilities to integrate the tool into

Figure 9. Example of the EWL flood risk map developed for NOAH pilot in Söderhamn, Sweden (RCP 4.5 rainfall period 2 years).

routine decision making, making it possible to improve flood resilience by applying it when planning both active (structural change) and passive (non-structural change) measures.

The EWL helps experts to prepare for future challenges in the field of water management and to develop climate resilience in urban areas. With the assistance of the new planning layer, the most suitable solutions for flood mitigation can be implemented in the areas with the highest flood risk. Further, the effects of the solutions can be analysed – how the new developments change the flooding risks on plot, district or city level in the selected area. An example of the EWL developed for Söderhamn is visualised in Figure 9.

The EWL can be implemented in a static or dynamic manner. In the first case, the municipality can analyse a number of different future scenarios to provide static maps about the changes in flood prone areas and flood risk classes in the urban environment. In the second case, the EWL can be used by the urban planner as an everyday tool to assess the flood risks and storm water system performance, taking into account changes in the urban environment and/or climate. The NOAH project mainly focused on developing the EWL methodology, providing the static flood risk maps for each pilot area, and proposing ideas how to further develop flood resilience PSS to be used in the holistic urban planning toolset (see Figure 10).

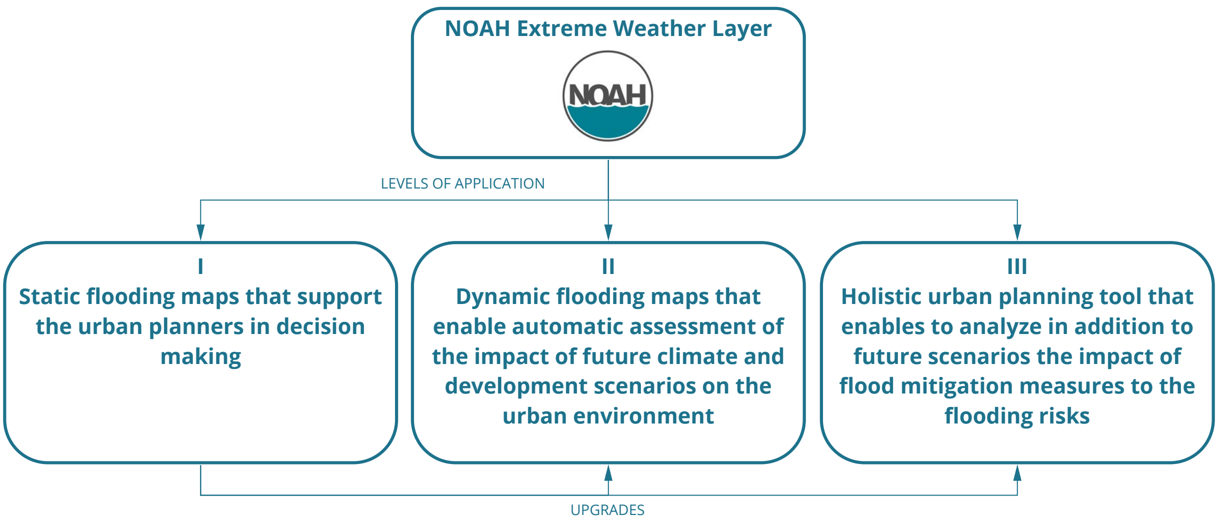


Figure 10. Levels of application of NOAH Extreme Weather Layer.

The EWL can be developed following the 7-step procedure described in Figure 11. The cities and water utilities managing the UDS have significant roles in data governance as well as in integrating the developed planning support tool into daily practice. It is advised that the EWL tool be developed by a team of experts with knowledge of UDS modelling, climate scenario application and GIS systems. In the case of NOAH, it was carried out by the participating academies; however, the proposed methodology is replicable also by consultancies with the aforementioned expertise. Key steps that the cities need to pay attention to when developing the flood resilience planning support system are elaborated in the subchapters below.

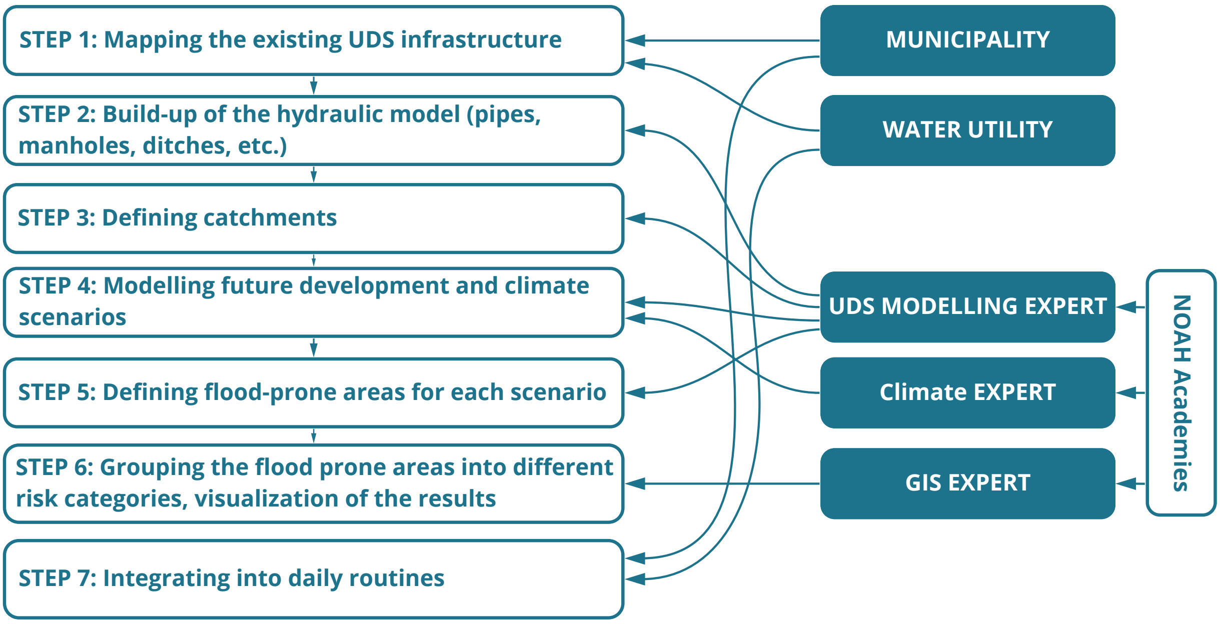


Figure 11. Key steps and responsibilities to follow when developing the Extreme Weather Layer for an urban area.

NOAH Tool

The NOAH Tool is a part of the active measures developed in NOAH with the aim of taking control over the existing UDS in order to mitigate the negative impact of flood events.

The NOAH Tool helps the user to explore the potential in implementing Real Time Control (RTC) solutions in urban drainage systems, based on an existing digital twin of the system. In case of NOAH, the models were built in EPA Storm Water Management Model (SWMM) [20], which is a Windows-based desktop program. It is open source public software and is free for use worldwide. Commercial alternatives are available on the market.

The NOAH Tool can further be used to calibrate a SWMM model based on in-situ measurements. The basic functionality of the tool can be used via its Graphical User Interface (GUI), while more options are available in the code repository of the tool.

During the project, the first version of the NOAH Tool was developed. The functionality can be developed through the collaborative, open source nature of the code that can be accessed and improved by anyone using the repository linked in the callout.

More information on the NOAH Tool can be found in REPORT O3.3 and public repository at https://github.com/mbjjo/NOAH.

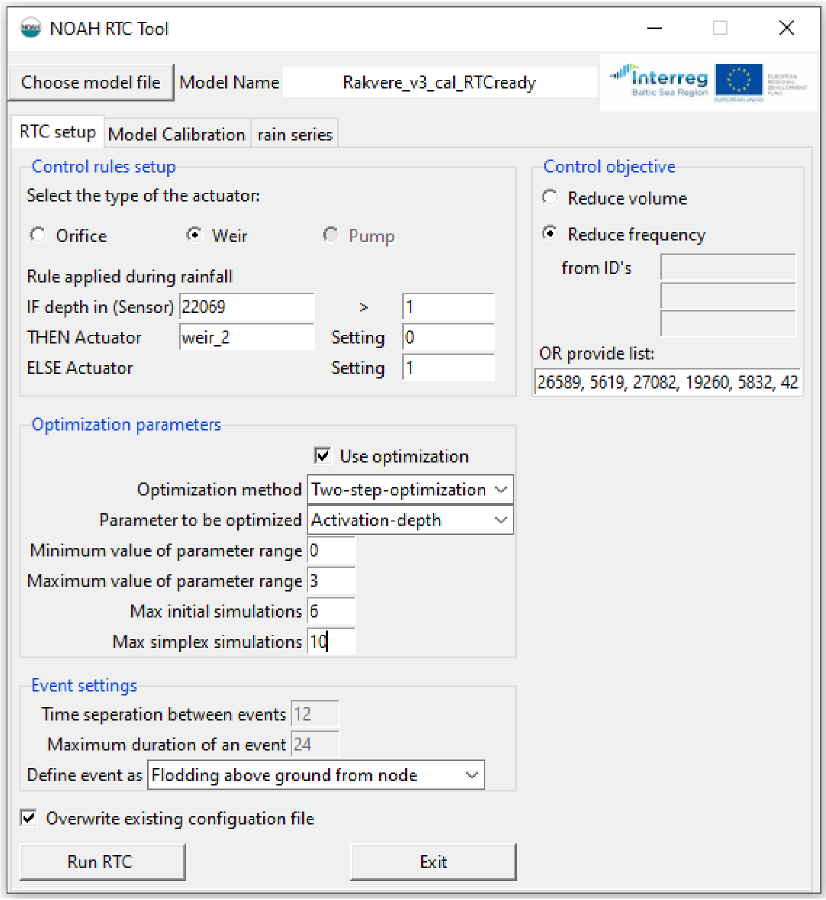


Figure 12. Graphical user interface of the NOAH Tool.

Mapping existing UDS infrastructure

Data collection procedure

The NOAH decision support system (DSS) is based on a digital twin of the UDS. Therefore, availability and the quality of the data needed to set up the digital twin is critical. In case of NOAH pilot towns, this work started from scratch. Most pilot cities had basic GIS about their urban drainage systems, but information was scattered and had significant data deficiencies. The layout of the setting up of the digital twin and DSS are presented in Figure 13.

More information on the data acquiring process and its challenges in NOAH pilots can be found in REPORT O2.1.

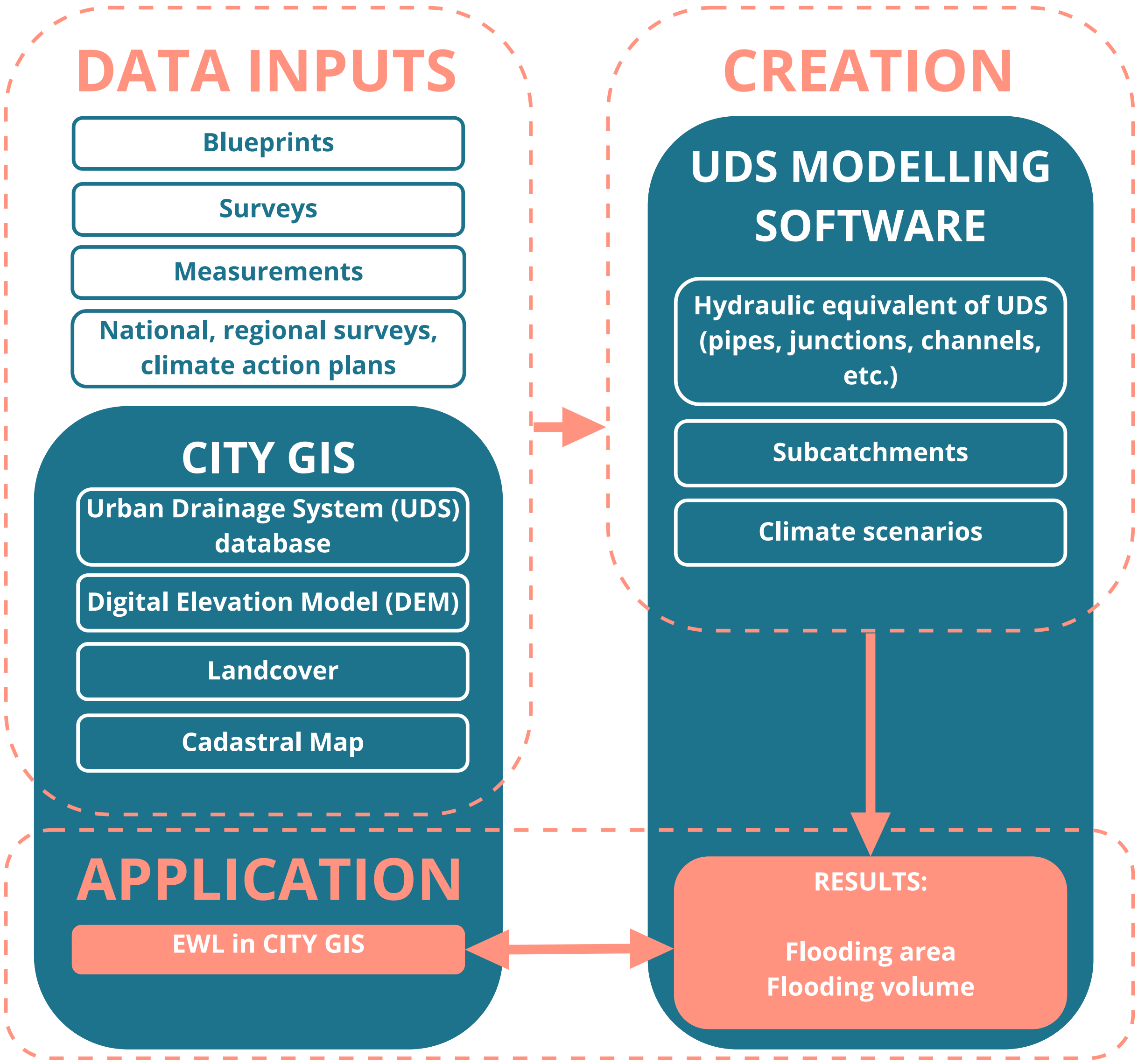


Figure 13. Data needed for creating the UDS and the proposed idea of how to integrate the flood resilience planning support tool as an integrated feature in the city GIS.

In case of UDS digital twins or mathematical models it is always necessary to estimate the optimum between the level of detail of the model and the resources needed for the calculations. A detailed model requires the existence of detailed data. Therefore, during the model build-up we need to consider:

- flow on the surface (pathway from the catchment to the manhole);
- flow under the surface (pipe capacity, hydraulic resistance, etc.); and
- if relevant to the local conditions, data on pumps, tanks and other system elements.

Defining the area for the decision support tool

The NOAH planning support tool can be set up for areas different in size and character. The average area of the pilot sites for which the tool was set up in the project is ~1 km^2 (See ***Table 1***). In case of the NOAH project, the pilot sites followed the borders of local catchment basins, though the tool can also be set up for areas covering several catchments.

The DSS is best applied to areas that have existing urban drainage systems built and have high potential for alteration of urban space (i.e. inclusion of built-up territories and impermeable surfaces). In addition, the tool can be applied to areas where the drainage system is yet to be planned (to assess its efficiency and adjust spatial planning in the city), or to areas where the possible alteration of urban space is limited but there is potential to implement the control of the storm water system (i.e. there are some detention possibilities in the system which could be supplied with the actuators to regulate the flow). All NOAH pilot sites were also situated next to natural water bodies connected to the Baltic Sea (see the different pilot sites briefly described in Table 1); however, this should not be considered a precondition for the DSS. The DSS is not targeted mainly towards preventing fluvial flooding induced by the rise of the water level in the natural water bodies. However, as the model is capable of analysing also the water rise risk in the outflows, using the DSS provides possibilities of making knowledge-based decisions regarding the cross-effects of the pluvial and fluvial flooding risks.

Table 1. Characteristics of NOAH pilot sites for which the DSS was set up.

Name of the pilot site	**Town size** (population)	**Pilot site area** (km^2)	**UDS type**
Haapsalu, EST	9 500	0.66	A separate sewage system, includes new pipelines, but also deteriorated sections with old pipelines. A significant part of the system consists of ditches. Outflow to a wetland through a culvert to the artificial lagoon of a shallow bay in the Baltic Sea. The storm water drainage system threatened by the seawater inflows in periods of high water level.
Rakvere, EST	15 000	1.8	A separate sewage system including pipes of different age and condition. Storm water is collected into an underground collector that directs excess water from the area to the nearby river. The collector has a constant flow as a natural stream is directed into the collector at the centre of the city.
Pori, FIN	84 000	1.6	A separate sewage system including pipes of different age and conditions. The pilot area consisted of more than 10 subcatchments with outlets to surrounding ditches directing water into the Baltic Sea. The sub-areas have different land use topology. The water level in the outflows varies spatially and temporally.
Söderhamn, SWE	12 000	0.98	A separate sewage system including pipes of different age and conditions. The outlet of the subcatchments is a river / bay where the water level changes can submerge the outlet pipes. The storm water collected from some of the rooftops is directed into the sewage pipeline.

Liepāja, LAT	68 000	0.14	An urban drainage system with an underwater outfall into lake Liepāja. Future expansion of the catchment is planned, but the current capacity of the system is insufficient.
Jūrmala, LAT	50 000	0.19	The UDS consists of pipes and ditches which discharge into the river Lielupe. Several known untreated or partially treated sanitary sewer connections. Several pipeline segments with reverse slopes, resulting in obstructed rainfall runoff flow.
Ogre, LAT	23 000	0.25	The pilot area is located next to the river Ogre. Rainwater drainage is organised via a system of underground pipes, as well as a network of ditches.
Słupsk, POL	91 000	22.03	The study area (pilot site) does not include the entire sewer system operated by the Słupsk Water Supply but the most densely built-up area where both, the separate and combined sewer systems exist. Just before the main pumping station (which serves as an outfall in the pilot area), there is an overflow, which separates an excess of the wastewater and directs it to the Słupia river. The pilot area is the main source of inflow to the Wastewater Treatment Plant (WWTP) of which 30% is storm water.

Typical data deficiencies in building UDS digital twins based on NOAH experience

Throughout the data collection and model build-up process, data validation is needed to understand data deficiencies. Additional geodetic and other surveys may be needed in order to fill in the critical data gaps essential for the development and implementation of the EWL. In some cases, the existing GIS system needs to be improved to enable automatic data transfer between the DSS and the GIS. The main obstacles and guidelines for overcoming such deficiencies are described in the following paragraphs.

Insufficient knowledge on UDS

In case of NOAH pilots, the biggest data gaps were, firstly, in the data available about the storm water system and secondly, in the quality of the data. The layout of the sewage networks, including the whole pipeline as well as ditches, manholes and storm water gullies, was in most cases not fully mapped for the cities. Most cities participating in NOAH had an existing GIS on UDS. However, the GIS did not cover all elements in the sewage system (smaller pipes, ditches) and missed necessary attribute information (physical properties, condition, etc.). Sometimes, even if there is a spatially accurate database representing the UDS geometry, it may still be insufficient because of the deficiencies in the integrity, e.g. pipelines are not snapped exactly to the centre of the manholes or there is missing height information about the inverts of the manholes. Usually GIS data serves as a modern way of asset inventory, as it helps to update the information instantly in the field, and it enables more efficient management including regular or emergent maintenance works. For the purposes of modelling, however, it is not enough to know where the pipelines and manholes are located – we need to know if and how they are connected to each other or just pass by or intersect on the map.

Documentation on UDS network does not respond to the situation in the field

Additionally, many storm water manholes and/or pipes have been rebuilt and new connections were added in the past with insufficient documentation. This can be due to emergency repairs of the sewage, soil filling and other reconstruction affecting UDS (road repairs, etc.). As a result, the existing information in the GIS or even in the as-built design drawings does not correspond to reality. In some cases, only design drawings were available, but as-built reports were missing. All such cases should be carefully inspected and site visits have to be carried out to confirm the validity of the data. The GIS system should include a special field in the database to make notes about this type of cases.

No information available about the rainfall data and water flow rate from the storm water outlets

In addition to the availability of the data on the physical properties of the UDS, data about the precipitation and concurrent flow rates and water depths are needed to calibrate and validate the digital twins of the storm water system. In the NOAH project there were cases where no rain gauge was present at or near the pilot site or the measurement timestep was too large for utilising the data in the modelling. Without the local information about precipitation, hydraulic model results can be subject to a high degree of uncertainty. It is because the model needs to be calibrated on the basis of observed flows or/and storm water stages but the input comes from a distant rain gauge. Consequently, the model parameters can be wrongly adjusted in the calibration process to obtain satisfying matching of simulated and observed flows. Therefore, it was decided to install new rain gauges at an early stage of the project implementation and collect accurate data representing the analysed area. An alternative option was also taken into account and tested, and it was to apply high resolution precipitation estimates, which can be based on a combination of rain gauge network, a weather radar network, and the meteorological satellite[21].

Missing or inadequate data on water quality

At all pilot sites the characteristics of the spillages were determined using either grab samples or flow or time proportional sampling. The flow proportional sample could be mixed into one sample and it can be considered as describing one event; the concentrations of the analytes will be presented as an Event Mean Concentration (EMC). The recommended water quality parameters to be analysed at each pilot site were pH, temperature, electrical conductivity, BOD7, suspended solids, dissolved oxygen, dissolved organic carbon (DOC), total organic carbon (TOC), ammonia nitrogen, sum of nitrate and nitrite nitrogen, total nitrogen, phosphate phosphorus, total phosphorus, some heavy metals, metals and half metals, coliformic bacteria and oil Index.

The water quality assessment can be conducted according to five different methods, by comparing the analytical results to limit values derived from different legislations and types of water representing treated wastewater, surface water, storm water data from the storm water database in StormTac, guideline values for storm water in Gothenburg, Sweden and water quality parameters for storm water in Estonia. The selection of assessment methods depends on the interest of the municipalities, the type of spillages and the type of recipient (freshwater or coastal and transitional zones). In case different national limits have been set by the Baltic Sea Region countries, the lowest limit was selected for the assessment. Also, a guideline for following water quality sampling is presented, based on ISO standards [22], and lessons learned at the pilot sites. Special attention should be paid to the acquisition, installation and operation of the autosampler. In addition, the planning of sampling, the effect of weather conditions on sampling, and the timetable of laboratories to receive samples must be taken into account.

The assessment made according to the StormTac database showed that water quality characteristics vary extensively from site to site, and also according to the sampling date and the weather conditions at a sampling site. The most contaminated water came from the untreated wastewater (CSO) from Słupsk, which was a very different effluent than the water sampled at the other sites. The measured parameters for samples were found to be above, within, and below the interval for storm water in the StormTac database. This was the case even if Słupsk samples were excluded from the assessment. Pollutant concentrations above interval were sometimes found for parameters TN, TP and/or indicator bacteria. It may indicate that the sample is contaminated with wastewater, but other explanations cannot be ruled out, such as dry weather samples taken from standing water in a manhole containing residues. Municipalities should regularly monitor the quality of storm water in different catchment areas during different seasons of the year. The quality of storm water should be compared to the values set by national and international standards or, in the Baltic Sea Region, the city of Gothenburg [23]. If concentrations exceed limit values, action should be taken in accordance with Helcom Recommendation 23/5 [19].

More information about the water quality can be found in REPORT A3.2.

Recommendations as to how to improve local data governance for setting up the NOAH DSS

TOP UDS DATA GOVERNANCE TIPS

- **Data quality** (data model which allows compatibility with other applications):
  - link (pipe/ditch) direction has to be consistent with the slope (flow);
  - each link should have nodes (junctions, manholes) at both ends;
  - link start/end points have to be snapped to consecutive links, avoid offsets;
  - each element should have a linkage to the database file to provide information about the object (type, date of installation, material, dimensions, is the object measured or is the data derived from the blueprints);
  - all elements should have unique IDs; data about different element types must be kept on separate layers (or identification attribute); IDs should be numerical not string type of values;
  - for all elevation data, a specification is needed about how the data has been acquired (field measurement, archive, as-built drawings, etc.);
  - during GIS to model conversion, pay attention to overlapping features. Sometimes during map creation elements are drawn on top of each other multiple times, which is not necessarily problematic for illustration purposes but will cause problems during the modelling.
- **Data governance** (updating when the system is affected by reconstruction, repair, etc.):
  - keep the data up to date, update the GIS accordingly, keep the dates in the database;
  - consider data and data precision types – reference manuals are linked below;
  - ensure smooth communication between in-field personnel and data managers;
  - set up a system which includes a photobank of the elements in GIS.
- **Critical attributes in GIS**:
  - for pipes: diameter, year of installation, material, inlet and outlet manholes, inlet and outlet elevation;
  - for ditches: bottom elevation, measurements of cross sections, maintenance information, inlet and outlet elevations, connections (culverts, manholes);
  - for elevation data: invert elevations, pipe offsets (if applicable) at connections to manhole, ground (lid) elevations;
  - outlets: water level height at the outlet (level of receiving pond, ditch, sea).
- Technical matters (flow direction for gravity pipelines).

Guidelines:

See more specific information in NOAH report O2.3.

Developing the digital twin for an urban drainage system

The success of applying the NOAH DSS depends directly on the quality of hydraulic models. For setting up proper digital twins for urban drainage networks, a variety of data are needed (as explained in the previous chapter). When all the required data are aggregated, it is possible to draw a network representation in a software capable of simulating dynamic rainfall runoff.

More information on building the models for NOAH pilots can be found in REPORT O2.3.

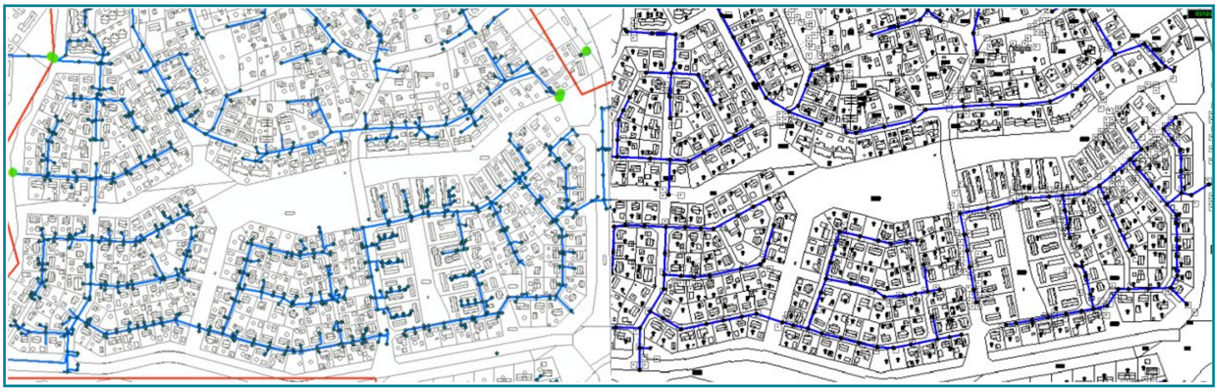


Figure 14. Skeletonization of the model, example of Pori. Left: whole system, right: pipes that were included in the model.

Building the hydraulic equivalent of the UDS

The process of building the hydraulic equivalent of the UDS system is described in detail in report O2.3. The key steps in the process are explained below.

I Data aggregation and validation. The data collected from utility GIS, as-built drawings and site visits are to be analysed for modelling. Data deficiencies are identified and solutions are identified for filling in the data gaps.

II Determining the model fidelity level. Deciding which pipelines will be included in the model and defining the expected accuracy of the model.

III Building the model. Setting up the hydraulic equivalent of the UDS system (pipes, ditches, junctions and other technical features of the network).

IV Validation and calibration. Validating data and reducing uncertainties with the aid of specialists from the local municipality/utility. Conducting field measurements for model calibration and validation.

Catchments

Catchments form a crucial part of developing the digital twin, as the actual runoff into the underground system is directly dependent on their parameters. Runoff also depends on the slope of the ground.

In the NOAH project different approaches were used to define the catchments. At first it is necessary to define the size of the catchments – the resolution and size of the flood

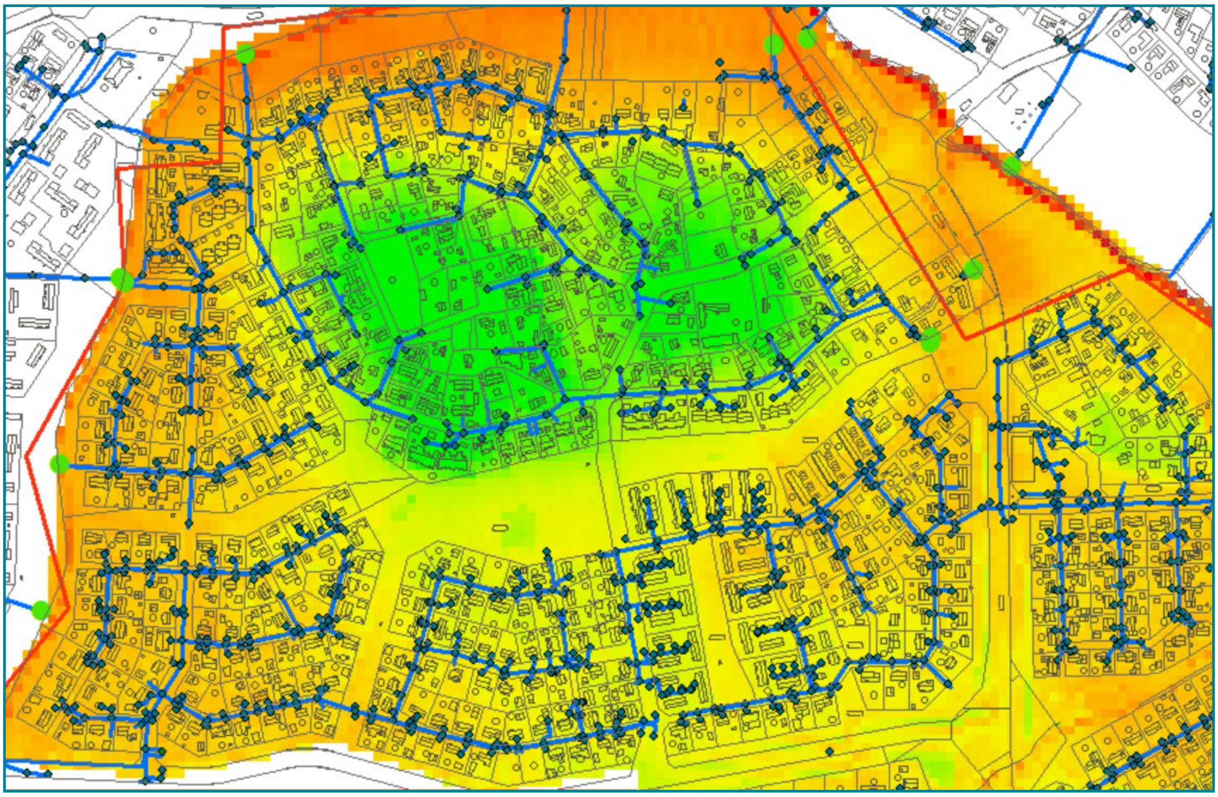


Figure 15. A baseline for creating the catchments was a good-quality digital elevation model (DEM) and data about the land use (Corine or alternative). The catchments were created automatically with a module of GIStoSWMM. A subcatchment was created for every manhole.

prone areas is directly related to the definition of the catchments. In some of the NOAH pilots the catchments were derived just on the basis of the topography and elevation maps. In some cases, the catchments were automatically derived from digital elevation models (DEM) using GIStoSWMM software [24]. In such cases the catchments were automatically generated for each inlet gully, considering the land use of the catchment and flow direction in that catchment. In the second phase the automatically generated catchments were updated on the basis of the feedback from the specialist in the water utilities and local municipalities. Smaller catchments enable visualisation of the flood prone areas in more detail but require high resolution elevation data as input.

Calibration

A typical hydraulic model of the existing UDS contains hundreds or even thousands of pipes and subcatchments, each of these having more than 20 parameters that need to be defined by the users. Most of these cannot be measured directly and giving estimates of these parameters is challenging. Therefore, calibration of these parameters becomes crucial in achieving the desired accuracy of the modelling results. The goal of the calibration is to match simulated and observed outflow from the study area and/or depth of storm water / wastewater in the system.

Calibration and/or modelling reliability analysis was performed for each pilot area. The models were calibrated and reliability was analysed on the basis of sampled storm events and historical measurements, where possible. Measuring campaigns for flow rates and water levels coupled with rainfall intensity in strategic locations in networks were conducted.

NOAH approach to climate scenario selection and application

IPCC states with high confidence that the increase of heavy precipitation in Northern Europe is estimated to be influenced by human actions [17]. Due to this, different climate scenarios are needed to be considered in planning for the adaptation of the urban drainage networks. In terms of planning climate change adaptation, various adaptation frameworks have been proposed that follow the described climate scenarios. Various approaches – such as the Intergovernmental Panel on Climate Change (IPCC) approach, risk approaches, or human development approaches [25], [26] – either focus clearly on climate parameters, analyse the effects of climate on specific risks or assess the climate issues in the context of human adaptive capacity and development alternatives. For UDS, it is necessary to combine the climate scenarios, system performance risks and urban development alternatives.

The NOAH project focused on the adaption of urban drainage system which, as explained afore, is affected not only by climate change but also a list of other factors. To meet the objective, it was necessary to estimate the volumes of urban runoff (in case of a combined sewage system the focus is on the volumes of spilled wastewater) both for guaranteeing the system performance under normal circumstances and for planning for extreme events. This resulted in the need to build different scenarios for each pilot:

- a baseline scenario developed either according to the current design standards with given duration and probability of occurrence (e.g. 20-minute rainfall event with return period of 2 years) or observed rain event(s);
- Different Adaptation scenarios (including scenarios for the changing climate).

To design the pathways for adapting urban drainage to future climate conditions, NOAH applies a combined framework and integrates various climate scenarios along with other factors. To select precipitation related boundary conditions for different scenarios, the IDF curves proposed in the national standards were modified according to the selected climate scenarios. On the basis of these, various rainfall intensity–duration–frequency curves (IDF curves) were developed (see Figure 17), which were later used to assess the performance of the system.

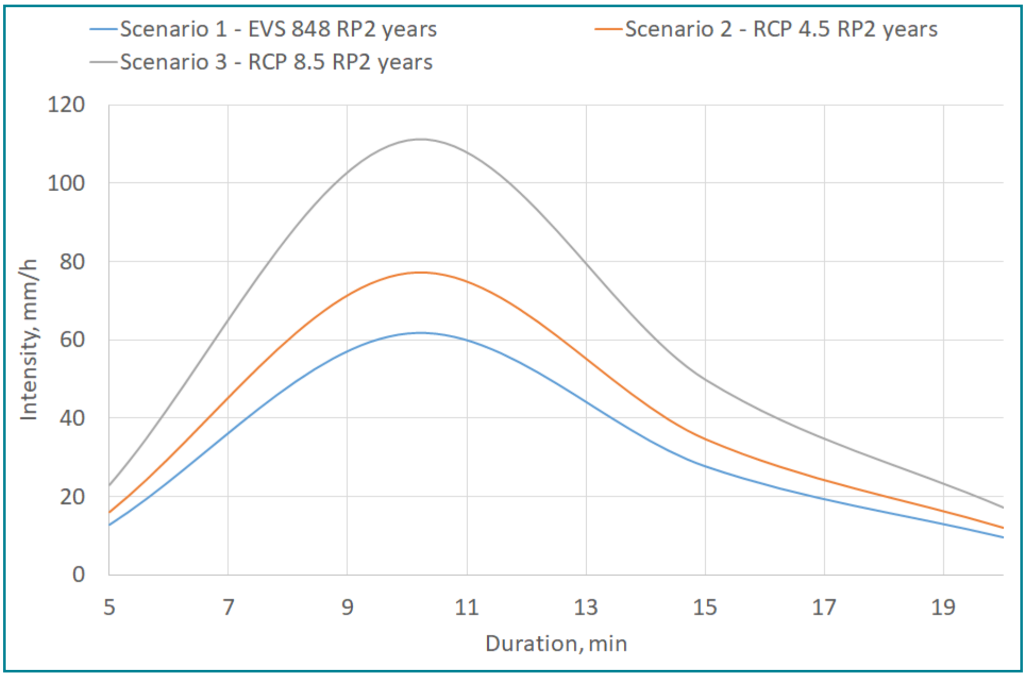


Figure 16. Alternative rainfall IDF curves considered for Haapsalu pilot. These are compiled according to the national design standard (EVS 848) [27] and the national adaptation plan (RCP 4.5 and RCP 8.5) [28].

The selection of the appropriate climate change scenarios, which was relevant for realisation of the NOAH project tasks, was based on the pathways selected by governments in the national adaptation plans (NAPs). In most cases these were elaborated on the basis of the guidelines of IPCC on the Representative Concentration Pathways (RCP). However, as NOAH DSS allows comparison of different scenarios, also regional scenarios as well as historical extremities were analysed. In most NOAH pilot cases at least three climate scenarios were analysed: the current status, RCP 4.5 and RCP 8.5.

Results of the climate scenario analysis

Climate change scenarios were used in the NOAH project to quantify the risk of flooding and to assess the potential increase in storm water and pollutants discharges into surface water bodies. The overall results indicated that if the rain event of a return period equal to 2 years is concerned, the expected increase in the urban flooding at the pilot sites ranges from 11 to 118% in the RCP 4.5 scenario and from 50 to 440% in the RCP 8.5 scenario. In case of a direct outflow to receiving waters, the estimated impact of climate changes is even more diversified, i.e. 5–199% and 16–786% in the RCP 4.5 and RCP 8.5 scenarios, respectively. A similar order of magnitude was also estimated for changes in the loads of pollution. Relatively broad ranges of expected impacts of climate change suggest that the adaptive potential of cities varies widely. These variations should be attributed mostly to the character of cities, i.e. land use, slopes, type and condition of sewer systems.

Concluding, it can be stated that even though some patterns can be identified in the impact of climate changes on the flooding risk in cities and drainage systems of a specific character, the impact should be considered as site-specific, especially if dedicated mitigative measures are to be proposed for the city. The impact assessment should also have multiple objectives, not focus on one emerging problem only. Consequences of such an omission can be illustrated on the basis of one of NOAH pilot sites, where short-term effects of climate change are expected to result in an increase in urban flooding volume by "merely" 11%. If we stop here and focus solely on the near-future flood risk problem, another major issue may be missed – the long-term impact on receiving waters – and consequently, the set of mitigative measures proposed may be short-sighted and ineffective. To finish with this example, it should be noted that at the pilot site mentioned the discharge of storm water and pollutants (including CSO) is expected to be at least doubled in the longer-term climate change scenario. The NOAH project also identified opposite cases, in which the impact of climate changes on receiving waters was a tenth of the impact on urban flooding (case studies in Estonia and Finland).

More detailed information on how and which climate change scenarios were selected for NOAH pilots can be found in report O2.2 "Climate Scenario Selection".

Detailed outputs regarding the impact of climate changes on the water excess in drainage systems and loads of pollution at pilot sites can be found in report O4.1 "Feasibility and policy analysis".

Recommendations

THE MAIN RECOMMENDATIONS FOR MODELLING

See more specific information in NOAH report O2.3.

- Modelling
    - Presence of GIS and quality of the data are crucial cornerstones of modelling.
    - A budget should be allocated for the field measurements to fill in the data gaps.
    - Automatically generated catchments should always be revised by the local water utility.
    - Infiltration should be considered in areas with high groundwater tables.
    - Calibration should be done both for the dry and wet period, if possible.
    - It should be determined for each manhole if the water can escape from the system during flood events or not (i.e. flowing into a nearby ditch, etc.).
- Measurements
    - Flow and precipitation measurements are costly; a special budget should be allocated for that.
    - In many cases some minor construction works are needed for installation of the measurement devices.
    - The client should reserve a right to extend the measurement contract with no extra fees in case suitable conditions do not occur (i.e. rainfall with certain intensity, etc.) in the agreed time limit.
- Analysis
    - Different climate scenarios should be analysed with the model.
    - Rainfall events with various duration and intensity curves should be used for that.
    - Results of the modelling scenarios should be exported to GIS to create an EWL.
    - All the work should be documented to make the analysis reproducible.

From model to passive measures – anchoring the EWL in daily practices

The EWL tool was created for each urban area individually. It is based on the hydraulic model of the urban drainage system (UDS), unique for each city, and the geographic information system (GIS) data of the city, which is also unique. Flood prone areas can be visualised on the map either as plot-based or in a catchment view. Easy-to-understand traffic light coding displays which areas are affected by pluvial floods and which are not under flooding risk in case of different scenarios.

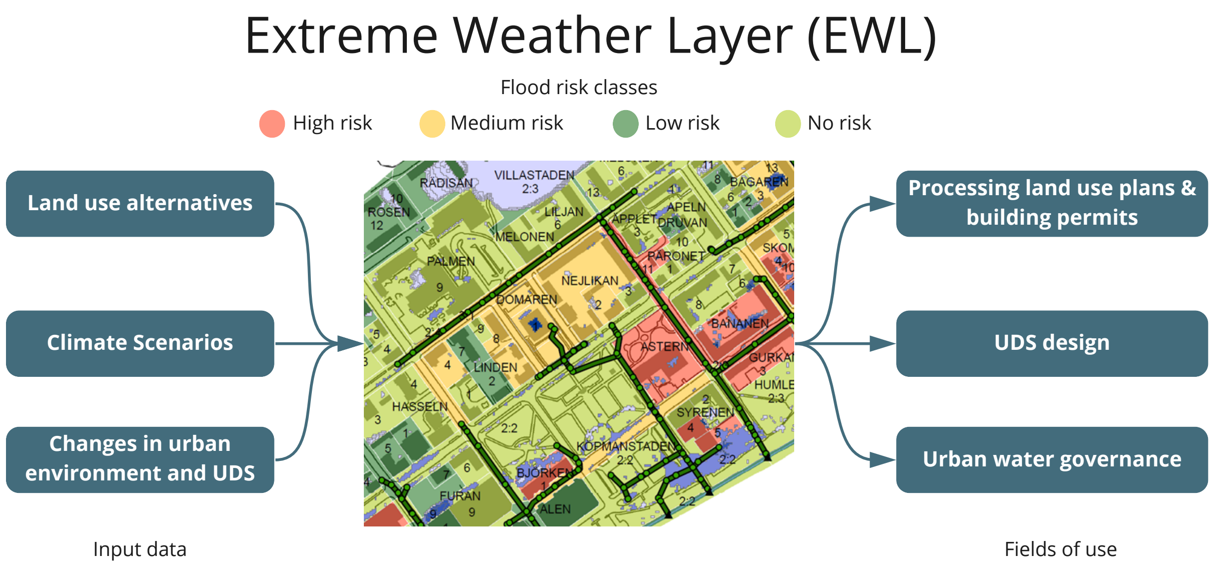


Figure 17. The concept of EWL implementation.

In NOAH, the concept of creating an EWL and generating static flood risk maps was developed and implemented in partner municipalities. In addition, the tool allows further application in a more dynamic mode. As seen in Figure 18, various input data could be considered by the end-user of the EWL. This allows applying the EWL in processing various permits; planning and designing the UDS; implementing different mitigation and adaptation measures as well as control and management strategies; and managing the urban water resources (planning reuse, measures to improve water quality, etc.).

Further information on how to set up the EWL can be found in the EWL user manual.

TOP TIPS FOR CITIES PREPARING TO DEVELOP AN EWL

- More details and better quality of the data results in finer resolution in the digital twin of the UDS.
- The smaller the catchments, the finer the resolution in the flood prone areas and risk assessments.
- GIS should reflect the real system, not only visualise it. Include pictures in the database for a better overview of the system.
- Innovation is not a standalone process; it requires cooperation between academies, municipalities, water utilities, general public and other affected stakeholders.
- Learn from others how to set up procurements and technical descriptions of the system to ensure that you get what you go after.

As seen in Figure 19, it is possible to use the EWL in the routine GIS system (QGIS, ArcGIS, etc.) that allows visualisation of data according to the georeferences and other attributes. As already declared above, the EWL can either be visualised plot-based, to determine urban flood hazard on property level, or in the catchment view. In the latter case it is possible to understand the comprehensive performance of the system.

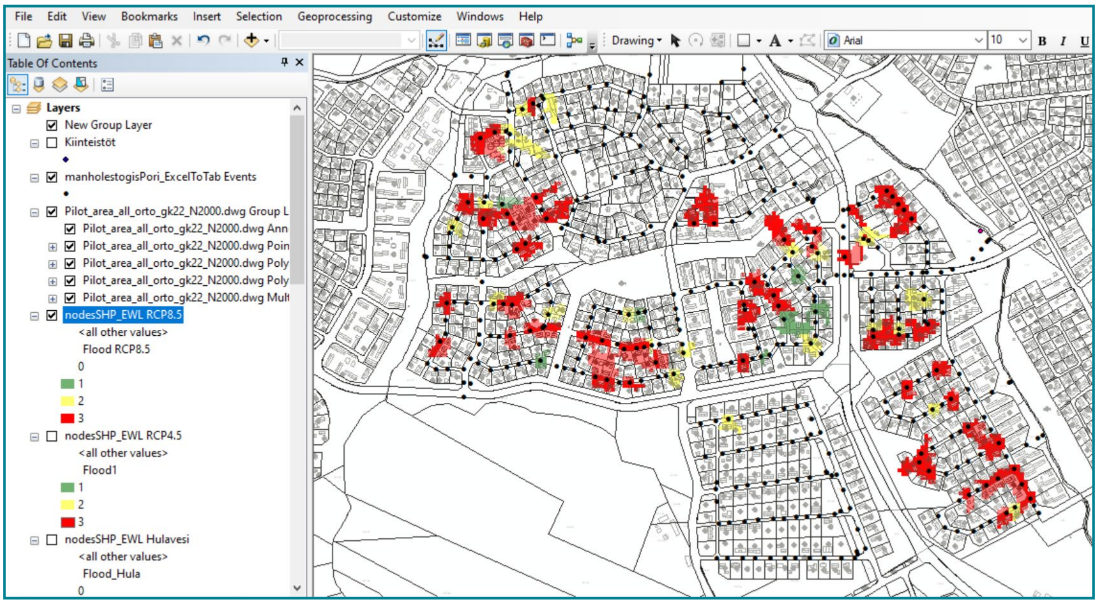


Figure 18. The *EWL of the NOAH pilot site Pori* being integrated in the city GIS desktop.

From model to active measures – when can active control be useful?

Urban drainage systems are in most cases designed to work passively, i.e. without any possibilities that allow the operator to regulate the flow. Most systems operate without any options to adapt the system even with modifications in the urban environment, not to mention much more abrupt changes like extreme downpours. However, there is a variety of possibilities to apply smart actuators in the existing system to increase its performance. Active flooding control is seen as a smart urban drainage system, in which one or several actuators (a pump, gate, movable weir, etc.) are controlled on the basis of the conditions in the system in real time. Such a system allows increasing the performance of the existing system, thus creating a list of benefits in improved management of urban drainage systems.

What is RTC

RTC (real-time control) of the system means that an actuator (a pump, gate, movable weir, etc.) is controlled on the basis of the conditions in the system in real time. The conditions are typically measured on-line by various sensors (flow, water level, etc.). The most common application of RTC is a pump that is turned on when the water level at inlet to the pump is high and stops when the water level is low. This can be called a local RTC since it only reacts to local conditions without considering the overall state of the system. If the RTC can react on sensor signals from elsewhere in the system, it can take more global considerations about the system performance as a whole. Such globally-oriented RTC solutions require more communication infrastructure than local control, but this can be a relatively small investment if this means that e.g. an upgrade of the existing system components can be postponed or entirely avoided. In general, however, RTC should only be applied when there is something to gain, since it does raise system complexity and requires the maintenance of actuators and sensors.

Active measures like RTC allow predicting the performance of the system in various situations, and by this makes the static system adaptive to dynamic situations. Real-time control allows combining the pipe-based traditional drainage systems with sustainable urban drainage systems (SUDS), which is a key prerequisite for a well performing integrated storm water management system.

The potential of applying RTC to UDS

A prerequisite for implementation of global RTC is either that it is possible to delay or store water locally, which requires storage capacity in terms of basins or large diameter pipes, or that there is a big difference in the concentration of pollutants in the waste water and that it is possible to prioritise to keep the most polluted water in the system by provoking e.g. overflows for the cleaner water.

The main three types of RTC analysed in NOAH are listed below.

- **Emptying of basin, lake or subsystem without overloading downstream system.** Water from an upstream basin or lake contributes to downstream flooding or CSO because the basin is emptying regardless of the conditions downstream. This can be mitigated with control as shown in the drawing below. A controllable device reacts to sensor data on the water level in a critical area. Such an RTC setup can potentially alleviate downstream flood problems and/or reduce CSO volume and frequency at a very limited cost compared to the alternatives of enlarging the pipes throughout the city or building additional storage volume and/or water level in the basin/lake and/or rainfall data (see Figure 20 A).

More detailed information about RTC and the application in NOAH pilots can be found in report O2.3 "Implementing RTC in urban areas in the Baltic Sea Region".

- **Prioritisation of basin emptying to minimise CSO in a multi-basin system.** This can also aim at reducing by-pass from the wastewater treatment plant. A controllable device reacts primarily to water level sensor data in basins, but also to rainfall data if available (see Figure 20 B). This setup gives a large degree of control and flexibility to the operators. The scope of RTC can rather easily be changed from e.g. distributing the CSO evenly over all the basins to letting the majority of the CSO happen where the wastewater is the most polluted. The main potential benefit will be reduced CSO and thus a reduced impact on the recipient water bodies. Such a setup can usually remove many of the small overflow events, but it is worth noting that events that vastly supersede the total storage volume in the system will still lead to overflow.
- **System failure prioritisation based on water quality,** e.g. provoking flooding where water is cleanest or it will do the least harm. A controllable gate reacts to downstream water level sensor (see Figure 20 C). Such a setup can save the recipient water bodies from waste water and the city from flooding with combined sewerage. It does, however, come at the cost of more frequent overflow or flooding with the relatively cleaner storm water upstream.

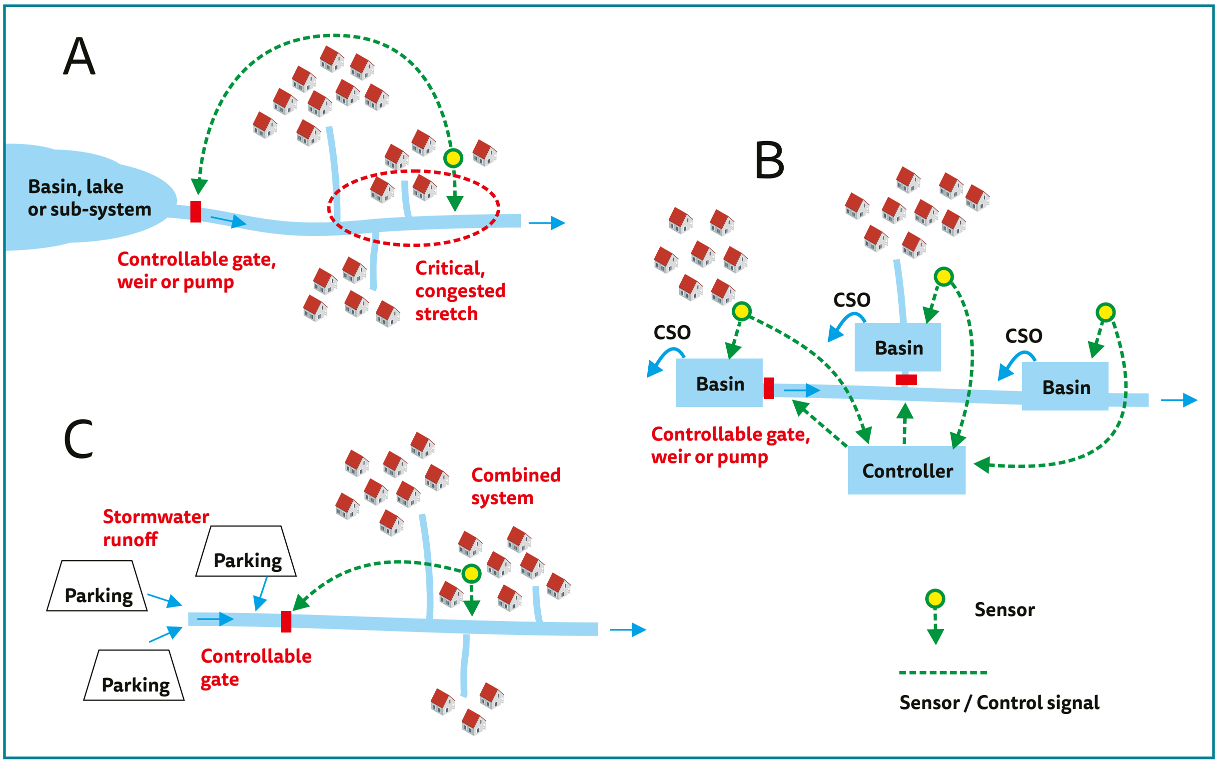


Figure 19. Three main types of RTC analysed in NOAH.

In addition to the RTC options, the selection of the sites has crucial importance in the performance of the system. The NOAH RTC Tool was designed and coded to aid the designers in this process.

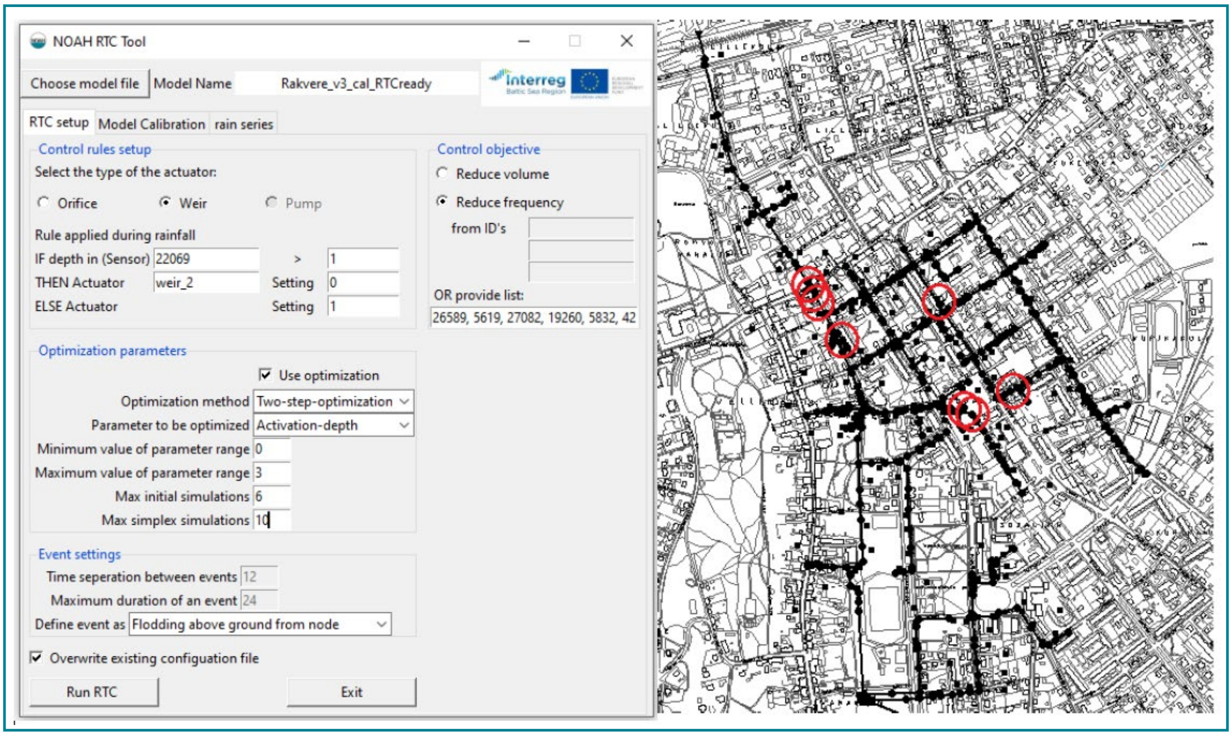


Figure 20. Configuration of the NOAH Tool used for analysing the impact of RTC on the flood nodes at the centre of the town.

Examples of applicability

Applying RTC is a tailor-made effort, as every urban catchment is different. Readiness of the local water utility to aggregate new type of regulative devices into the existing remote-control systems varies. Therefore, having a calibrated model with catchments and pipelines is a crucial step towards the implementation of active measures, i.e. RTC. All the options can be analysed prior to real investments and the benefits evaluated against other methods, like pipeline replacements. In the NOAH project the potential of RTC was analysed with UDS models at 8 pilot sites, of which 6 remained on the theoretical level and two (Rakvere, Haapsalu) were implemented in real life. The result of the RTC analysis is presented in Table 2.

More detailed information about the NOAH RTC Tool can be found in

Output O 3.3 "NOAH Tool User Manual and Documentation".

The tool can be downloaded at https://github.com/mbjjo/NOAH

Table 2. *Overview of the suggested RTC solutions for NOAH pilots.*

Pilot name	Suggested control solution	Effect of solution
Rakvere	Control of the discharge from an upstream lake using the Smart Weir Wall System controlled by the water level in the downstream system.	Reduced downstream flooding.
Haapsalu	Controlling the flow through the outlet from the downstream lake using a Smart Weir Wall System and two sensors.	Keeps the water level in the downstream lake low during high tide and rain events, which leads to a reduced risk of flooding and sewer overflows in the city.
Jūrmala	Pump installed at the outlet from a part of the storm water system where the dry weather flow is particularly polluted. The pumping is controlled so that the dry weather flow is transported to the sanitary sewer system, but the much cleaner water during rain events is allowed to flow into the recipient.	Potentially a 71% reduction in the nutrient load in the recipient.
Liepāja	A tidal gate and pump at the outlet to prevent sea water from backing up into the drainage system. The gate to control the inflow from a newly connected area was not recommended.	A less negative effect of the high tide in the recipient.
Słupsk	No control recommended since the system as implemented in the SWMM model would not benefit from this.	–
Ogre	A non-return valve / tidal gate and a pump could be implemented. The implementation and result of this would be similar to the Liepāja case.	Storm water would still be able to get out of the system when the water level in the river is high.
Pori	No need or potential for RTC.	–
Söderhamn	No potential for RTC unless additional storage is added to the system.	–

It should be noted that both in Rakvere and Haapsalu the actual systems have shown the expected efficiency and are fully embedded in other control systems used locally by the managing authorities.

TOP TIPS FOR CITIES PREPARING TO DEVELOP RTC

- Planning RTC
  - **A calibrated model** is a crucial prerequisite for RTC.
  - **Different locations** should be analysed with various climate scenarios to select the most feasible solution.
  - **The NOAH RTC Tool** can be used to analyse the effect of the planned RTC.
  - **All stakeholders should** be engaged when planning the locations for RTC.
- Designing and construction
  - **The existing SCADA systems** should be investigated to find possibilities of connecting RTC with the existing control system.
  - **Supplying RTC elements – gates and sensors** with electricity should be carefully considered and off-grid solutions implemented where possible.
  - **Raising the water levels in ponds and ditches for detention** might need special permits from the Environmental Agency and neighbours.
  - **The what-if scenario should be taken into account** for the cases of system failure.
- Tuning RTC

A hydraulic model can be utilised to pre-tune RTC commands.

III MAINSTREAMING THE NOAH CONCEPT

Costs and benefits of considering following the NOAH Concept

NOAH project pilot sites differ in many aspects – not only in environmental and location conditions, but also the size of the research area and the level of investment complexity. Moreover, the pilot cities undertook the NOAH Concept to different depths and scales. In some partner towns, only passive measures were implemented (targeted at modelling and monitoring), whereas in others both passive and active measures were introduced (such as modernisation of the existing infrastructure or implementation of the smart urban drainage system).

No elaborate cost-benefit analyses had been planned in the frame of the project, which would have considered the ecosystem services and broader socioeconomic effects of improving the flood resilience of the communities in the targeted areas. However, the validation survey that was carried out to assess the overall efficiency of the actions aggregated the overall costs incurred in the project pilots (details in Report O4.1). In terms of benefits, NOAH estimated the potential savings resulting from improved flood resilience on account of implementation of both passive and active measures. At two pilot sites it was estimated that the damage to infrastructure can be decreased by approximately EUR 150 000–450 000 per flooding event in the current climate scenario, and by EUR 360 000–560 000 and EUR 380 000–710 000 in the RCP4.5 and RCP8.5 climate scenarios, respectively. It should be highlighted that the pilot sites for which these estimations were done are of an area in a range of 1–2 km^2 – in a full-city scale implementation such savings could be much greater.

Another aspect of financial benefits addressed by NOAH was the cost of fees for water services for the discharge of pollutants into surface waters. For example, the cost of overflow occurring once in two years (including adverse effects of climate changes) was estimated at EUR 160 per rainfall event at the Słupsk pilot site, and it rises to EUR 670 when less frequent (5% probability) rainfall is considered. These costs, even though they may seem low on a city scale, would be much greater if more frequent overflows and pollutants other than those included in the NOAH monitoring were added to the calculation.

Compared to direct financial benefits, others seem to be of even greater importance. There is added value in the NOAH tools, useful for gathering important information that can be used for more sustainable flood risk management. Therefore, even at the pilot sites where only monitoring was carried out, benefits were also confirmed by end-users. It is connected with gaining knowledge of how to make it easier for the Baltic cities to adapt to climate change. Moreover, it was confirmed that at almost each pilot site, the introduction of a model will allow measurable savings in reducing flood damages.

Need for changing policies and regulations

Helcom recommendations 23/5-Rev.1 on Reduction of Discharges from Urban Areas by the Proper Management of Storm Water Systems [19] foresee an elaborate list of actions necessary to improve the flood resilience of cities as well as limit the pollution caused by unsuitable sewerage systems. This includes adaptive planning of integrated storm water solutions (with consideration of urban development and the changing climate) and proper management (including implementation of various proactive measures) for transformative adaptation. In general terms, national legislation is coherent with the recommendations and allows the implementation of an integrated storm water management system proposed by Helcom 23/5.

The European Green Deal has brought along an ambitious Zero Pollution Action Plan [29], which requires a drastic reduction in the runoff of pollutants into the waters. The evaluation of the current Urban Waste Water Treatment Directive has identified some gaps related to lack of compliance and differences in implementation. One of the problematic issues is overflows from combined sewers. It is important to recognise the multiple purposes achieved by the sewer networks across Europe and to determine clear commitments from Member states to tackle urban runoff and discharges from combined sewer overflows (CSOs) where and when they have a significant impact on the receiving water bodies. CSOs must be properly designed and maintained to prevent flooding, minimise adverse impacts on the water environment, and protect public health.

Also, the EU Strategy on Adaptation to Climate Change foresees the smarter, faster and more systematic adaptation [16], the principles that correspond in a straightforward manner to the NOAH Concept for flood prevention. The NOAH Concept can furnish several steps in the iterative Climate Adapt framework, proposed for urban climate adaptation in the EU [30].

1. Preparing the ground for adaption

2. Assessing climate change risks and vulnerabilities

3. Identifying adaptation options

4. Assessing adaptation options

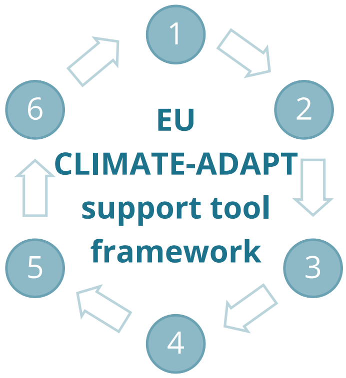
5. Implementing Adaptation

6. Monitoring and Evaluating Adaptation

Figure 21. EU Climate-Adapt adaptation support tool [30].

However, the cities in the BSR still suffer from urban pluvial floods and lack resources, both for preparing the urban environments with precautionary planning and for setting up active flood protection measures. Therefore, it is important to implement the costs recovery principle (rainwater management) and encourage nature-based solutions where possible.

Roadmap for implementing the NOAH Concept



SMART

FAST

MORE SYSTEMATIC

1 PREPARING THE GROUND FOR ADAPTATIONS

GOVERNANCE

- Establishing partnerships
- Setting up the process and planning the resources
- **Setting up adequate UDS GIS**

2 ASSESSING CLIMATE CHANGE RISKS AND VULNERABILITIES

PASSIVE MEASURES FOR BETTER PLANNING AND RISK MITIGATION

- **Identifying flood prone areas and flood volume**

3 IDENTIFYING ADAPTATION OPTIONS

PASSIVE MEASURES FOR BETTER PLANNING AND RISK MITIGATION

- **Applying EWL for precautionary urban planning**
- **Applying EWL for designing active measures for flood mitigation**

4 ASSESSING ADAPTATION OPTIONS

PASSIVE MEASURES FOR BETTER PLANNING AND RISK MITIGATION

- **Identifying flood prone areas and flood volume according to alternative adaptation scenarios**

5 IMPLEMENTING ADAPTATION

ACTIVE MEASURES FOR TAKING CONTROL AND ENSURING POLLUTION PREVENTION

- **Smart actuators for improving UDS performance**
- **Real-time monitoring for control and improved performance**

6 MONITORING AND EVALUATING ADAPTATION

GOVERNANCE & MANAGEMENT

- Monitoring and adaptive control of UDS
- City policies in tune and fit with adaptive UDS measures
- Replication of solutions

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