FEASIBILITY AND POLICY ANALYSIS

Output 4.1 of Interreg Baltic Sea Region project NOAH

Protecting Baltic Sea from untreated wastewater spillages during flood events in urban areas

Contents

Introduction

Effective management of urban stormwater is one of the largest environmental problem faced by cities around the Baltic Sea. Climate change brings along intense rainfalls and storms in the Baltic Sea region. Urban drainage systems are not capable to handle this, and therefore floods are becoming more common in the densely populated areas. Floods increase the risk of untreated wastewater being flushed from sealed surfaces and introduced in an uncontrolled way from urban drainage systems into the nature. This is harmful to the environment, but also to people due to the presence of excessive amounts of nutrients, hazardous substances and pathogenic microbes. In addition, the floods may have significant impact on social and economic costs.

Urban areas can be prepared for floods by improved planning and real-time controlled self-adaptive drainage operations. However, right solutions and tools are needed. NOAH Project is an ideal response to this demand. The project brought together 18 partners, i.e. seven academic and research institutions, three water companies, six municipalities and two umbrella organizations from six countries situated around the Baltic Sea to join their forces. For the purpose of the project, eight cities were selected as the research areas. The pilot sites were located in the following cities:

- Słupsk, Poland
- Haapsalu, Estonia
- Rakvere, Estonia
- Pori, Finland
- Söderhamn, Sweden
- Liepāja, Latvia
- Jūrmala, Latvia
- Ogre, Latvia

The main NOAH project's aim is to create and implement a concept for holistic planning and implement smart drainage systems in real urban environments. Holistic planning combines effective stormwater management with sustainable spatial planning. This is followed by the development of smart drainage systems to make the existing facilities resilient to the impacts of climate change. Partial aims of the project include:

- The reduction of discharges of urban stormwater runoff (containing nutrients and hazardous substances) to the Baltic Sea by increasing the capacity of public and private entities dealing with land use by spatial planning.
- Decreasing spillages of untreated wastewater from urban drainage network during puvial floods to the Baltic Sea by increasing the capacity of water utilities responsible for urban drainage systems operation.

Feasibility study was prepared to perform validation of undertaken activities in NOAH pilot sites. The report contains short description of the pilot sites, analysis of the rates and substances of untreated wastewater spillages included climate changes and descriptions of NOAH actions. The validation of undertaken activities in pilot sites was carried out on the basis of four criteria:

1) Economic affordability
2) Technical applicability
3) Environmental benefits and risk
4) Barriers in local policy and regulations that will put risk on the transfer of the results of NOAH

This document was prepared with the use of information from previous reports, modeling data, experience with the implementation of various solutions and lessons learned from the NOAH project. The complete O4.1. report will be used to create a solid basis for the next activities in WP4.
As the aim of NOAH is to distribute the novel urban runoff management solutions all over the Baltic Sea Region, transnational co-operation is a core issue to generalise the results from project pilot sites situated in different countries.
Activities under A4.1 do not serve directly pilot action purpose but are inseparable part of the pilots launched in A2.4 and A3.4 to provide validation and evaluation of the positive effect of these actions.

1 Short description of the pilot sites

1.1 Characteristics of the Słupsk pilot area (Poland)

Słupsk is located in north-western Poland 20 kilometers from the Baltic Sea. The area of the city is 43.15 km^2 and is dominated by urban areas (nearly 50%). The remaining part of the city is covered mainly by agricultural areas (36%) and forests or other green areas (13%). 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 of 22.03 km^2 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 stormwater. Therefore, it is necessary to assess sources of pollution in the inflow to the WWTP and in the overflow and to prepare tools that will give a basis for the wastewater and stormwater control system. In the pilot area there is one storage facility (tank) built for stormwater detention. There are no sustainable drainage systems (SUDS) (bioswales etc.) in the pilot area. There is automated control system used for the sewer system operation. There are two retention tanks (including WWTP) connected to Combined Sewer Overflow (CSO) structures.

1.2 Characteristics of the Haapsalu pilot area (Estonia)

Haapsalu is a town on West Estonia's Baltic coast, with 13 000 inhabitants. The town is located on a southeastern-northwestern oasis, typical of the north-west coast of Estonia. 67% of the town area is covered with greenery (parks, recreational areas, etc.). Due to the coastline length and ground elevation, the city is open to seawater flooding. Old drainage systems, bottlenecks in pipelines, and overall incomplete information on the town's drainage system are contributing to stormwater flooding. Haapsalu's drinking and wastewater system, which includes 21 wells and a WWTP using mechanical, chemical, and biological treatment technology, is managed by Haapsalu Waterworks (Haapsalu Veevärk AS). Haapsalu City Government manages the urban drainage system. Sewage and stormwater systems are separate. The pilot area (61.8 ha) is divided into two areas located on the south part of Haapsalu, corresponding to actual stormwater system catchment areas. The outflow of urban drainage system is buffered from the sea with an artificial lagoon. The lagoon has formed due a former railroad dam, later designed to protect seawater inflows into stormwater systems. The dam had 2 locks that are in very poor condition and release seawater to the wetland, which places a burden on stormwater systems. There are no pumping stations in the stormwater system nor are there storage facilities built for stormwater detention. SUDS in a form of a large bioswale is already in pleace in Haapsalu between the town and sea separated by a pedestrian road. No CSOs exist in Haapsalu, all wastewater is treated and the stormwater system is mostly separate. The main deficiencies to the present system are seawater intrusion to the drainage system, maintenance of the bioswale (suffers from heavy eutrophication). Due to the coastline length and ground elevation, the city is open to seawater flooding. Old drainage systems, bottlenecks in pipelines and overall incomplete information on the town's drainage system are contributing to stormwater flooding.

1.3 Characteristic of the Rakvere pilot area (Estonia)

Rakvere (area 10.73 km^2) is a town in northern Estonia and the capital of Lääne Viru County, 20 km south of the Gulf of Finland of the Baltic Sea. There are approximately 15 100 inhabitants in Rakvere. There are two main waterbodies in Rakvere: Soolikaoja creek and Tobia main ditch. Soolikaoja has been enclosed to 1.2 m tunnel in the central part of the town. Rakvere pilot catchments with an area of 177 ha is situated in the middle of the town and has a fully separate stormwater system built with several outflows to Soolikaoja stream (both stream and tunnel). The total length of the pipeline is ca 7.1 km and diameters vary from 0.2 to 1.2 meters. Upstream part of Soolikaoja takes stormwater from two residential areas and drains natural streams highly dependent on precipitaton and snowmelt. There are several static overflow weirs on the stream before water ends up in Süsta pond with an area of 7 000 m^2 and depth of ca 1.5 m. Inflow from Soolikaoja streams to the pond varies between ca 10 – 1 000 m^3/h (it is highly dependent on the precipitation and snowmelt). The pond has been transformed in NOAH project to a detention system with smart weirwall to temporarily hold an extra stormwater until the central town pipeline is free to take the stormwater from the southern part of the town. Currently no major historical flood events caused by the surcharge of the stormwater system have been registered in the pilot area. However, the risk of flood rises significantly if we take into account the climate projections, especially higher rainfall intensities forecasted for coming decades. Modelling shows that if the system is analysed with future storms, 46%-60% of the nodes in central part of the town are flooding with a total volume of 738 – 1 691 m^3. Flood volume is directly realted to the spillages of untreated water which will affect the water qality in Baltic Sea. Thefore, both active (smart weirwall + accumulation in Süsta pond) and passive (extreme weather layer for stormwater runoff-sensitive planning) methods are created for the pilot area in NOAH project to alleviate the risk of fulture floods.

1.4 Characteristic of the Pori pilot area (Finland)

Pori is a town on the south-west coast of Finland. The city is located about 10 kilometers from the Gulf of Bothnia on the estuary of the Kokemäenjoki river. The pilot area is Suntinoja ditch catchment area (1.62 km^2). Ditch water exits into the Kokemäenjoki river, which is the 4th largest waterbody catchment area in Finland. The catchment area is mostly rural: fields and forests. The northernmost area is an urban residential area. The ground surface is flat, which increases drainage problems and stormwater and snowmelt flood threat. Besides the risk to property, flooding increases contaminant and nutrient migration into the Baltic sea. In general, the city of Pori is responsible for stormwater management, and the Water supply company of Pori maintains the mainline for stormwater drains. The city of Pori, on the other hand, manages other stormwater structures like main ditches, drainage of streets and parks, etc. Suntinoja ditch is managed by the Lattomeri ditch drainage company, of which the City of Pori is a shareholder. The city of Pori is not responsible for the ditch because it is not completely in the town planning area. There are also beneficiaries other than residents of the town planning area. The ditch was originally designed for drainage of agricultural areas, so its capacity may not be enough in heavy rainfall situations, and the ditch may begin to flood residential areas through stormwater drains into the inland or properties near the ditch. There are high water levels in the surrounding ditches and river that restrict the stormwater outflow from the UDS. Ice blockages during winter that raise the water level in the pilot area are observed. The sewage system is quite old and not in the best conditions, which means it will need maintenance. Another problem is lack of some coordination data.

1.5 Characteristic of the Söderhamn pilot area (Sweden)

The town of Söderhamn is a coastal town located far into the bay of Söderhamn and at the outlet of Söderalaån. The city is surrounded by forested mountains. In addition to the Söderala River, Lötån also flows into the bay of Söderhamn which is affected by sea-level rise. Söderhamn pilot area consists of 11 sub-catchments with separate stormwater system. Four of these have outlets to the natural stream and rest to the narrow bay of the Baltic Sea. Outlets to the bay are typically submerged. Some stormwater catchments (roofs etc) are still connected to sewer system and therefore there are several CSO overflow structures in the system. These CSO-s are equipped with backflow valves to avoid seawater entering to the sewer. Ground slope is quite steep (10% or even more) towards the stream/bay, height difference is ca 10 meters. The pilot area was chosen to analyze the impact of heavy rainfall and sea level rise on urban environment and stormwater system. In addition, some densification is planned with new buildings and other changes regarding park areas, as well as streets in this area. Therefore some of the stormwater flows towards the outlet (a bay at the downstream) on the ground, by existing streets. This may trigger flood events (street curbs are overtopped during cloudbursts). There are also some bottlenecks in the pipeline system which have considerably smaller diameter than upstream pipeline. Söderhamn has constructed previously during the HEAWATER project two stormwater detention sites to cut the peak flow into the pipeline. Although there have been no major pluvial flood events registered in the town, modelling of future climate scenarios reveal that the risk is real (ca 30% of the nodes will flood) and municipality should start to plan mitigative measures already now.

1.6 Characteristic of the Liepāja pilot area (Latvia)

The city of Liepāja is in the Western part of Latvia, between the Baltic Sea and Lake of Liepāja. The NOAH pilot areas are located in two separate locations in the city - Tebras Street catchment basin and Cietokšņa channel/creek areas. The stormwater sewer (concrete pipe with diameter 500 mm) outlet of Tebras street catchment basin discharging water into Lake of Liepāja in the Natura 2000 protection area. The area of the catchment basin is approximately 19 ha. Low-rise residential buildings mostly occupy the area. Impervious surfaces are split as follows – roofs are 42% of the total area and paved roads are 8% of the total area. There is one pumping station in the UDS, located near Veidenbauma and Ganibu street junction. There are no storage facilities (tanks) built for stormwater detention, no SUDS (bioswales, etc.). The main problem is that if the Cietokšņa canal outlet into the Baltic Sea is clogged, the adjacent areas are flooded.

1.7 Characteristic of the Jūrmala pilot area (Latvia)

Jūrmala is a resort city located 25 km west of the capital Riga. It is the 5th largest city in Latvia by population (57 653) and 2nd largest by area (100 km^2). The city has an elongated shape and is located between two water bodies – river Lielupe in the South and the Gulf of Riga in the North. Jūrmalas udens Ltd manages water supply communications (total length 303 km), wastewater sewerage system (348 km), and maintains the stormwater system consisting of more than 50 km of closed pipelines and 115 km of ditches. The pilot area has been distributed into three main sections located along the city line. There are three pumping stations in Jūrmala UDS. No storage facilities (tanks) are built for stormwater detention and there are no SUDS. There are automated control systems - sensors, control devices - used for UDS operation in the pumping stations.

1.8 Characteristic of the Ogre pilot area (Latvia)

Ogre town is located 36 km from Riga on the right bank of the Daugava River near Ogre mouth of the Daugava. The total area of the town is 13.6 km² with a total population of 25 380. The pilot area is alongside Ogre river in Ogre town and Ogresgals parish. This area has been selected as it has a major flood problem and it is strongly affected by climate change. Accordingly, the municipality needs to understand the flood risks better and to adapt to climate change. The Loka Street neighborhood has developed from a low swampy meadow. The surface water runoff has been organized with a network of open ditches along the streets, draining into the Ogre River. Due to intensive detached housing construction, the traffic volume has increased, and part of the ditches have been arbitrarily filled or the culvert elevation marks after construction have not been aligned with each other. That has led to a loss of functionality of the existing drainage network. In order to control the surface runoff, the municipality must provide stormwater drainage from the street and adjacent areas by creating a single network. Therefore, the municipality has already started the gradual construction of a rain drainage piping system. A main stormwater collecting manifold is intended to be built with a possibility for house owners to connect their own local stormwater collection pipeline system without the need to rebuild the newly created road covers. There are four stormwater pumping stations in the UDS. There are storage facilities (tanks) built for stormwater detention. In Ogre there are SUDS (bioswales etc.) in the pilot area and automated control system - sensors, controlled devices (3 adjustable gates/weir/orifices) - used for UDS operation.

2 Analysis of the rates and substances of untreated wastewater spillages in the pilot sites

The main activities in the NOAH project aimed to generate new knowledge and develop new tools supporting the stormwater management at urban scales included implementing:

1) Extreme Weather Layer (EWL) for for mapping flood risk areas and
2) control and prevention measures to reduce wastewater spillages.

EWL is a combination of hydraulic modelling, climate scenarios and other urban planning datasets considered via GIS or otherwise. It connects the results of a stormwater system hydraulic model with urban planning to visualize the plots most vulnerable to present and future flooding risks (NOAH, 2021a). Preparation of inputs to EWL (hydraulic models and climate scenarios) required a broad range of data acquisition actions aimed at the characterization of stormwater systems and catchments in pilot areas as well as time series of precipitation and resulting stormwater flow and levels (NOAH, 2019).
The latter of main NOAH activities mentioned above included preparation and application of software enabling the virtual optimization of stormwater systems' operation (Pedersen, 2020). To enable the real optimization and (if needed) the real-time control of stormwater systems the measurement stations and weirwalls were installed in selected pilot sites (NOAH, 2021b).

The main objective of this chapter was to evaluate the effect of implementation of EWL and benefits resulting from real-time control of the stormwater systems which was tested either in a virtual (via hydraulic models) or real-life cases. The effect is understood as an achievable reduction of spillages or discharges (including combined sewer overflows), and consequently reduced load of pollutants reaching receiving waters. To meet this objective it was required to estimate volumes of water/wastewater spilled in the urban area or discharged to surface waters. These volumes are based on Extreme Weather Layers prepared for all pilot sites and described in NOAH (2021a). To estimate potential reduction in spillages and discharges at least two scenarios (RPC 4.5 and 8.5) were analyzed per pilot site:

(1) a baseline scenario representing
   a. an effect of rainfall of given duration and probability of occurrence (e.g. the 20 minute rainfall event with return period of 2 years)
   b. or observed rain event(s)
(2) the same kind of a rainfall but taking into account measures aimed at the reduction of spillages.

In case of pilot sites, where no measures minimizing the impacts of heavy rainfalls were implemented the current status was presented only. Even though such information is insufficient to estimate the achievable reduction of flooding and pollution, it is still a valuable information for planning purposes.
To estimate the reduction of loads of pollution it was needed to identify concentrations of pollutants in wastewater and stormwater during rainfall events which cause spillages and overflows. These concentrations were adopted based on measurements done in pilot sites which were described briefly below and in more details in the report "Water quality results" (Output 3.2 of Interreg Baltic Sea Region project NOAH). In addition to measurements done in the NOAH project a short review of concentrations reported worldwide was done and summarized in the "Appendix 1: Concentrations of pollutants in runoff [mg/l] (based on literature review)". This

review included also local sources of information provided by pilot cities. The review was aimed to complement measurements done in pilot sites, which could be insufficient to characterize runoff resulting from extreme rainfall events.
The assumption justifying the review is that the more severe rainfall events than observed during monitoring campaigns in pilot sites can cause more intensive pollutants dilution or wash-off. In such case the loads based on concentrations observed in pilot sites and based on forecasted spillages / discharges could be underestimated. The review summarized in the "Appendix 1: Concentrations of pollutants in runoff [mg/l] (based on literature review)" confirms that the concentrations observed in pilot sites are within the ranges reported in literature for various intensity of rainfalls including extreme ones. This conclusion was based not only on a literature but also an analysis of the NSQD (2015) database which includes over nine thousand runoff samples. The Słupsk pilot site was excluded from this comparison because the comparison includes the stormwater runoff only, while in Słupsk the observations represent a mixture of stormwater and wastewater. Despite the observed concentrations fall in the range of reported worldwide it is still not enough to be certain that the observed concentrations can represent heavy rainfalls. To confirm this hypothesis, at least partially, it was checked if the lower or upper bound of concentrations reported in literature and the NSQD database were correlated with more intensive rainfalls. The Pearson's correlation coefficient was calculated for the rainfall intensity and concentrations of 25 pollutants in the runoff (TDS, Cl, TSS, BOD_5, COD, TOC, TN, TKN, N org., NO_3, NO_2, NH_4, TP, PO_4, Cd, Cr, Cu, Fe, Cd, Pb, Hg, Ni, Zn and TPH). The correlation between the rainfall intensity and concentrations was negative, except for TSS, TN, Cr, Hg and Ni. Significant ($p<0.01$) negative correlations were observed for BOD, COD, TN, TKN, NH_4, NO_3+NO_2, TP and Cu. Significant positive correlation was observed for TN only and it was relatively large (0.59).
The Słupsk pilot site was analyzed a bit differently because it is the only site where the combined sewer system was present and where samplings were done during rain events of various intensities. In Słupsk there is a clear relation of the rainfall intensity and the concentration of (part of) pollutants. To be sure, that the concentrations observed during the largest rainfall should be used in the further analyses, all samples were tested in terms of the correlation with the rainfall sums (1-day and 4-days sum of precipitation preceding the sampling). It turned out that the statistically significant correlation existed for the parameters listed in the table 1.

Table. 1. Water quality parameters in combined sewer system significantly correlated with the rain intensity

Correlation			
Positive		Negative	
p<0.01	p<0.05	p<0.01	p<0.05
DO	Al, Cu	Conductivity, BOD, DOC, TOC, B, Fe, K, Na, Oil index	NH_4, TP, Mg, S, Si, Zn

Having regard to abovementioned considerations, it is acknowledged that loads presented in this chapter may not represent the loads generated by extreme rainfalls precisely as none of such events was observed in pilot sites during monitoring campaigns. Nonetheless, the concentrations observed during or after rain events in pilot sites were within a range of reported worldwide for various rainfall events, and therefore, they were used for the calculation of loads related to the current and projected rain events and for the calculation of possible reductions in these loads.

2.1 Impact of climate changes and flow control measures on the urban flooding (spillages) and discharges to receiving waters

Even though this chapter is focused on the evaluation of the EWL and thus on the urban flooding - “spillages”, the assessment of impact of climate changes and control measures was also applied to the direct discharge of stormwater and wastewater to receiving waters. The sum of urban flooding and direct discharge to receiving waters is referred in the report as “total outflow”. Urban flooding can pose a risk to human health, cause financial loses and traffic disruption. Yet, the flooding may be less harmful than the direct outflow of sewer system as far as the impact on receiving waters (and eventually the Baltic Sea) is concerned. Spillages usually occur around manholes and inlets of the stormwater system. The pollution may reach the surface water by reentering the system, via runoff or passing by soil or aquifer. The pollution of surface waters may thus be delayed and decreased. In contrast, the load of pollution at the outflow from stormwater system and in the combined sewer overflow affect the quality of surface waters directly. Therefore, equal attention was given to spillages and discharges from sewer systems.

The volumes of flooding and discharges estimated for all pilot sites using the EWL are presented in the tables 2-4. Because of the large differences in the pilot sites’ area, the data were also presented as a volume per area - a unit comparable between all sites.

Table. 2. Volumes of flooding and discharges estimated for all pilot sites using the EWL

Pilot site	Scenario			Flooding	Direct discharge	Total outflow	Flooding	Direct discharge	Total outflow	Flooding	Direct discharge	Total outflow
				m³			m³/ha			% of change in relation to the "Present" scenario		
Słupsk, Poland	2 year rainfall	Present		6 675	412	7 087	3.8	0.2	4.1	-	-	-
		RCP4.5	2051-2060	7 436	509	7 945.0	4.3	0.3	4.6	11.4	23.5	12.1
			2091-2100	9 055	714	9 769.0	5.2	0.4	5.6	35.7	73.3	37.8
		RCP8.5	2051-2060	9 981	818	10 799.0	5.7	0.5	6.2	49.5	98.5	52.4
			2091-2100	13 015	1 110	14 125.0	7.5	0.6	8.1	95.0	169.4	99.3
	20 year rainfall	Present		23 972	1 965	25 937	13.7	1.1	14.9	-	-	-
		RCP4.5	2051-2060	26 091	2 103	28 194.0	15.0	1.2	16.2	8.8	7.0	8.7
			2091-2100	27 972	2 260	30 232.0	16.0	1.3	17.3	16.7	15.0	16.6
		RCP8.5	2051-2060	31 036	2 500	33 536.0	17.8	1.4	19.2	29.5	27.2	29.3
			2091-2100	33 546	2 694	36 240.0	19.2	1.5	20.8	39.9	37.1	39.7
Haapsalu, Estonia	2 year rainfall	EVS 848*		85	345	430	1.4	5.6	7.0	-	-	-
		RCP 4.5,		114	363	477	1.8	5.9	7.7	34.1	5.2	10.9
		RCP 8.5,		272	402	674	4.4	6.5	10.9	220.0	16.5	56.7
	5 year rainfall	EVS 848		110	361	471	1.8	5.8	7.6	29.4	4.6	9.5
	10 year rainfall	EVS 848		138	374	512	2.2	6.1	8.3	62.4	8.4	19.1
Rakvere, Estonia	2 year rainfall	Local extreme (Estonian Design Standard + 20% climate change)		1 691			9.6			-		
		RCP4.5		738			4.2			- 56.4**		
		RCP8.5		1 124			6.4			- 33.5**		
Pori, Finland	2 year rainfall	Base, according to Hulavesiopas (duration 30 min)		607	4 411	5 018	3.7	27.2	31.0	-	-	-
		RCP4.5		1 325	5 097	6 422	8.2	31.5	39.6	118.3	15.6	28.0
		RCP8.5		3 276	6 232	9 508	20.2	38.5	58.7	439.7	41.3	89.5
Söderhamn, Sweden	2 year rainfall	Local extreme (Estonian Design Standard + 20% climate change)		1 731			43.3			-		
		RCP4.5		1 354			33.9			- 21.8**		

Pilot site	Scenario		Flooding	Direct discharge	Total outflow	Flooding	Direct discharge	Total outflow	Flooding	Direct discharge	Total outflow
			m³			m³/ha			% of change in relation to the "Present" scenario		
		RCP8.5	1 764			44.1			1.9		
Liepāja, Latvia	10 year rainfall	Present	1 907	2 903	4 810	136.2	207.4	343.6	-	-	-
		RCP 4.5	2 754	3 256	6 010	196.7	232.6	429.3	44.4	12.2	24.9
		RCP 8.5	8 531	5 609	14 140	609.4	400.6	1 010.0	347.4	93.2	194.0
Jūrmala, Latvia	10 year rainfall	Present	2 673	3 704	6 377	133.7	185.2	318.9	-	-	-
		2021-2050	3 615	3 984	7 599	180.8	199.2	380.0	35.2	7.6	19.2
		2070-2100	4 397	4 168	8 565	219.9	208.4	428.3	64.5	12.5	34.3
Ogre, Latvia	10 year rainfall	Present	906	2 848	3 754	36.2	113.9	150.2	-	-	-
		RCP 4.5	1 703	3 358	5 061	68.1	134.3	202.4	88.0	17.9	34.8
		RCP 8.5	3 739	4 283	8 022	149.6	171.3	320.9	312.7	50.4	113.7

* EVS 848 stands for Estonian Design Standard (2013). EVS 848:2013 Sewer Systems Outside Buildings. Estonian Centre for Standardization.

** Negative values because the current status already included a surplus rainfall attributed to climate changes.

In addition to the estimated volumes of flooding, the application of EWL included simulations of effects of measures aimed at the reduction of runoff in three pilot sites, i.e. Söderhamn, Rakvere and Słupsk. In case of Swedish and Estonian pilot sites the analysis took into account two sets of measures and a combination of them. For Söderhamn, the first set of measures were virtual SUDS & RTC (real-time control) in the system. For Rakvere, the first measure was installation of smart weirwall system & detention in Süsta pond located upstream of the central, analyzed part of the city. Süsta is a flow-through pond on the Soolikaoja stream which passes the town in a tunnel serving as a part of the stormwater system. In both pilot sites the second set of measures had a form of mitigative planning measures proposed for the cities as a result of the application of EWL. In the case of Słupsk one flood risk reduction scenario was analyzed only. The scenario assumed that 30 mm of runoff will be retained. The retention was limited to impervious areas in combined sewer system catchments only. The retention of 30 mm is quite an ambitious scenario, however, it is based on plans currently being implemented in other cities located in the coastal areas, e.g. Gdańsk (Poland). The effect of mitigative measures simulated for pilot sites is presented in the table below.

Table. 3. Estimated potential for the decrease in urban flooding volumes in pilot sites

<table>
<tr><th>Pilot site</th><th colspan="3">Scenario</th><th colspan="3">% of flooding volumes decreased</th></tr>
<tr><td rowspan="11">Słupsk, Poland</td><td colspan="3">Flood risk reduction scenario:</td><td colspan="3">Mitigative planning measures (EWL)</td></tr>
<tr><td rowspan="5">2 year rainfall</td><td colspan="2">Present</td><td colspan="3">77</td></tr>
<tr><td rowspan="2">RCP4.5</td><td>2051-2060</td><td colspan="3">75</td></tr>
<tr><td>2091-2100</td><td colspan="3">71</td></tr>
<tr><td rowspan="2">RCP8.5</td><td>2051-2060</td><td colspan="3">69</td></tr>
<tr><td>2091-2100</td><td colspan="3">64</td></tr>
<tr><td rowspan="5">20 year rainfall</td><td colspan="2">Present</td><td colspan="3">55</td></tr>
<tr><td rowspan="2">RCP4.5</td><td>2051-2060</td><td colspan="3">53</td></tr>
<tr><td>2091-2100</td><td colspan="3">52</td></tr>
<tr><td rowspan="2">RCP8.5</td><td>2051-2060</td><td colspan="3">51</td></tr>
<tr><td>2091-2100</td><td colspan="3">49</td></tr>
<tr><td rowspan="4">Rakvere, Estonia</td><td colspan="3">Flood risk reduction scenario:</td><td>Smart weirwall system & detention in Süsta pond</td><td>Mitigative planning measures (EWL)</td><td>Total decrease</td></tr>
<tr><td rowspan="3">2 year rainfall</td><td colspan="2">Local extreme (Estonian Design Standard + 20% climate change)</td><td>30</td><td>20</td><td>50</td></tr>
<tr><td colspan="2">RCP4.5</td><td>30</td><td>40</td><td>70</td></tr>
<tr><td colspan="2">RCP8.5</td><td>30</td><td>30</td><td>60</td></tr>
<tr><td rowspan="4">Söderhamn, Sweden</td><td colspan="3">Flood risk reduction scenario:</td><td>Virtual SUDS & RTC in the system</td><td>Mitigative planning measures (EWL)</td><td>Total decrease</td></tr>
<tr><td rowspan="3">2 year rainfall</td><td colspan="2">Local extreme (Estonian Design Standard + 20% climate change)</td><td>40</td><td>20</td><td>60</td></tr>
<tr><td colspan="2">RCP4.5</td><td>50</td><td>40</td><td>90</td></tr>
<tr><td colspan="2">RCP8.5</td><td>40</td><td>30</td><td>70</td></tr>
</table>

In the Słupsk pilot area the direct outflow has a form of combined sewer overflow and is an issue of particular relevance for the quality of receiving waters (Słupia river). In other pilot sites stormwater and wastewater systems are separated and the direct discharge does not pose as large risk of pollution as in Słupsk. Therefore, the effect of mitigative measures described above was also evaluated in terms of the decrease in overflows.

Table. 4. Estimated potential for the decrease in volume of overflows in Słupsk pilot site

Pilot site	Scenario			% decrease in CSO as a result of mitigative planning measures (EWL)
Słupsk, Poland	2 year rainfall	Present		100
		RCP4.5	100	75
			100	71
		RCP8.5	100	69
			100	64
	20 year rainfall	Present		84
		RCP4.5	79	53
			75	52
		RCP8.5	69	51
			60	49

2.2 Loads of pollution in spillages

The scope of water and wastewater quality parameters monitored varied in pilot sites. In part of sites only five parameters which can be used for the calculation of loads were analyzed. These included biological and chemical oxygen demand (BOD, COD), suspended solids (TSS) and total nitrogen and phosphorus. Loads calculated based on current climate scenarios are presented in the table 5.

Table. 5. Loads of selected pollutants calculated for all pilot sites and the current climate scenario

Pilot sites		Loads in urban flooding - current status					Area [ha]
		BOD	COD	Suspended solids	Total nitrogen	Total phosphorus	
[kg/rain event]							
Estonia	Haapsalu	0.473	6.549	10.639	0.192	0.023	61.8
	Rakvere	6.236	28.888	34.806	12.535	0.404	177
Finland	Pori	1.391		22.161	0.872	0.162	162
Latvia	Jūrmala	19.433		27.532	28.334	5.266	20
	Liepāja	11.328		61.024	3.070	1.306	14
	Ogre	2.790		24.462	4.403	0.125	25
Sweden	Söderhamn	6.924		95.205		0.320	40
Poland	Słupsk	3 023.775	9 456.250	1 753.300	452.788	54.157	1745
[kg/ha]							
Estonia	Haapsalu	0.008	0.106	0.172	0.003	0.000	
	Rakvere	0.035	0.163	0.197	0.071	0.002	
Finland	Pori	0.009		0.137	0.005	0.001	
Latvia	Jūrmala	0.972		1.377	1.417	0.263	
	Liepāja	0.809		4.359	0.219	0.093	
	Ogre	0.112		0.978	0.176	0.005	
Sweden	Söderhamn	0.173		2.380		0.008	
Poland	Słupsk	1.733	5.419	1.005	0.259	0.031	

Taking into account differences in the scope of monitoring, climate scenarios and simulated mitigative measures, the potential changes in loads has been presented below separately for each pilot site. In cases of parameters for which at least half of samples taken in a pilot site indicated values below the limit of quantification, the load was not calculated.

Estonia, Haapsalu

In Haapsalu no measures aimed at the reduction of flooding and loads were simulated, nonetheless, the loads presented below allow to realize what increase in loads can be expected as a result of climate change and avoided in future if appropriate preventive actions will be taken. Loads are based on an average concentration based on two measurements each of which included twelve samples picked at five minute intervals.

Table. 6. Urban flooding in Haapsalu - loads of pollution in all rainfall scenarios

Parameters	Load of pollution [kg/rain event]					Increase in load in the most severe climate scenario [kg/rain event]
	2-year EVS 848*	2-year RCP 4.5	2-year RCP 8.5	5-year EVS 848	10-year EVS 848	
Suspended solids	10.64	14.27	34.05	13.77	17.27	23.41
BOD7	0.473	0.634	1.513	0.612	0.768	1.04
Total nitrogen	0.192	0.258	0.615	0.249	0.312	0.42
Total phosphorus	0.023	0.031	0.073	0.030	0.037	0.05
COD	6.55	8.78	20.96	8.47	10.63	14.41

* EVS 8484 stands for Estonian Design Standard. (2013). EVS 848:2013 Sewer Systems Outside Buildings. Estonian Centre for Standardization.

Table. 7. Direct discharge to receiving waters in Haapsalu - loads of pollution in all rainfall scenarios

Parameters	Load of pollution [kg/rain event]					Increase in load in the most severe climate scenario [kg/rain event]
	2-year EVS 848	2-year RCP 4.5	2-year RCP 8.5	5-year EVS 848	10-year EVS 848	
Suspended solids	43.18	45.44	50.32	45.19	46.81	7.13
BOD7	1.919	2.019	2.236	2.008	2.080	0.32
Total nitrogen	0.781	0.821	0.910	0.817	0.846	0.13
Total phosphorus	0.093	0.097	0.108	0.097	0.100	0.02
COD	26.58	27.97	30.97	27.81	28.81	4.39

Estonia, Rakvere

For the Rakvere pilot site no increase of loads in relation to climate changes was calculated, because the current status scenario already included a rainfall surplus attributed to the climate change. For the site, however, the reduction of flooding by smart weirwall system and detention in Süsta pond was simulated as well as the reduction by mitigative planning measures (EWL). Expected effects of these scenarios are presented in the table. Loads are based on an average concentration based on two measurements each of which included twelve samples picked at five minute intervals. Total achievable reduction in loads of pollution was estimated by multiplication of concentration of pollutants observed in Rakvere during rain events by the volume of urban flooding reduction presented in Table 3.

Table. 8. Urban flooding in Rakvere - loads of pollution in all rainfall scenarios

Parameters	Load of pollution [kg/rain event]			Total estimated reduction in load (reduction by smart weirwall system & detention in Süsta pond) [kg/rain event]		
	Local extreme*	RCP4.5 2 year	RCP8.5 2 year	Local extreme*	RCP4.5 2 year	RCP8.5 2 year
Suspended solids	34.81	15.19	23.14	17.40	10.63	13.88
				(10.44)	(4.56)	(6.94)
BOD7	6.24	2.72	4.14	3.12	1.90	2.49
				(1.87)	(0.82)	(1.24)
Total nitrogen	12.53	5.47	8.33	6.27	3.83	5.00
				(3.76)	(1.64)	(2.50)
Total phosphorus	0.404	0.176	0.269	0.20	0.12	0.16
				(0.12)	(0.05)	(0.08)
COD	28.89	12.61	19.20	14.44	8.83	11.52
				(8.67)	(3.78)	(5.76)

* Estonian Design Standard + 20% climate change

Finland, Pori

In Pori no measures aimed at the reduction of flooding and discharge were simulated, nonetheless, the loads presented below allow to realize what increase in loads can be expected as a result of climate changes and avoided in future if appropriate preventive actions will be taken. Loads were calculated based on an average of data from two sampling points which represent two of eighteen outflows from the stormwater system in pilot area.

Table. 9. Urban flooding in Pori - Loads of pollution in all rainfall scenarios

Parameters	Climate scenarios			Increase in load in the most severe climate scenario [kg/rain event]
	Base*	RCP 4.5	RCP 8.5	
BOD7**	1.39	3.04	7.51	6.12
Suspended solids	22.16	48.37	119.60	97.44
DO	4.40	9.61	23.75	19.35
DOC	3.72	8.13	20.09	16.37
TOC	4.85	10.59	26.18	21.33
$N-NH_4$	0.311	0.678	1.676	1.366
$N-NO_3 + N-NO_2$	0.287	0.627	1.550	1.263
TN	0.872	1.904	4.707	3.834
$P-PO_4$	0.044	0.096	0.237	0.193
TP	0.162	0.354	0.876	0.713
Al	0.028	0.061	0.151	0.123
B	0.038	0.083	0.205	0.167
Ca	10.98	23.96	59.24	48.26
Cu	0.005	0.011	0.027	0.022
Fe	0.793	1.732	4.282	3.489
K	2.98	6.51	16.09	13.11
Mg	3.31	7.24	17.89	14.57
Mn	0.157	0.343	0.847	0.690
Na	12.06	26.32	65.08	53.02

Ni	0.003	0.007	0.018	0.014
P	0.050	0.109	0.269	0.219
S	8.22	17.94	44.37	36.14
Si	3.67	8.01	19.80	16.13
Zn	0.092	0.201	0.497	0.405

* According to Hulevesiopas (return period 2 y., duration 30 min)
** Loads calculated based on averaged sampling results, which included values below the limit of quantification. In case of such results, a half of the limit was used in calculations.

Table. 10. Direct discharge in Pori - loads of pollution in all rainfall scenarios

Parameters	Climate scenarios			Increase in load in the most severe climate scenario [kg/rain event]
	Base*	RCP 4.5	RCP 8.5	
BOD7**	10.11	11.68	14.28	4.17
Suspended solids	161.04	186.09	227.53	66.48
DO	31.98	36.95	45.18	13.20
DOC	27.05	31.26	38.22	11.17
TOC	35.25	40.73	49.80	14.55
$N\text{-}NH_4$	2.257	2.608	3.189	0.932
$N\text{-}NO_3 + N\text{-}NO_2$	2.087	2.412	2.949	0.862
TN	6.337	7.323	8.953	2.616
$P\text{-}PO_4$	0.319	0.369	0.451	0.132
TP	1.179	1.362	1.666	0.487
Al	0.203	0.235	0.287	0.084
B	0.276	0.319	0.390	0.114
Ca	79.77	92.17	112.70	32.93
Cu	0.036	0.041	0.050	0.015
Fe	5.766	6.662	8.146	2.380
K	21.66	25.03	30.60	8.94
Mg	24.09	27.83	34.03	9.94
Mn	1.141	1.318	1.612	0.471
Na	87.63	101.26	123.81	36.18
Ni	0.024	0.028	0.034	0.010
P	0.362	0.418	0.512	0.150
S	59.74	69.03	84.40	24.66
Si	26.65	30.80	37.66	11.00
Zn	0.669	0.772	0.945	0.276

* According to Hulevesiopas (return period 2 y., duration 30 min)
** Loads calculated based on averaged sampling results, which included values below the limit of quantification. In case of such results, a half of the limit was used in calculations.

Sweden, Söderhamn

For the Söderhamn pilot site no increase of loads in relation to climate changes was calculated, because the current status scenario already included a rainfall surplus attributed to the climate change. For the site, however, the reduction of flooding by virtual SUDS & RTC in the system was simulated as well as the reduction by mitigative planning measures (EWL). Expected effects of these scenarios are presented in the table. Loads were calculated based on averaged concentrations observed in the pilot site.

Table. 11. Söderhamn - loads of pollution in all rainfall scenarios

Parameters	Load of pollution [kg/rain event]			Total estimated reduction in load (reduction by smart weirwall system & detention in Süsta pond) [kg/rain event]		
	Local extreme*	RCP4.5 2 year	RCP8.5 2 year	Local extreme*	RCP4.5 2 year	RCP8.5 2 year
Mineral oils >C16-C35	0.26	0.20	0.26	0.156 (0.104)	0.183 (0.102)	0.185 (0.106)
Mineral oils >C10-C40	0.26	0.20	0.26	0.156 (0.104)	0.183 (0.102)	0.185 (0.106)
PAH-M Fenantren	3.03E-05	2.37E-05	3.09E-05	1.82E-05 (1.21E-05)	2.13E-05 (1.18E-05)	2.16E-05 (1.23E-05)
PAH-M Fluoranten	4.41E-05	3.45E-05	4.50E-05	2.65E-05 (1.77E-05)	3.11E-05 (1.73E-05)	3.15E-05 (1.80E-05)
PAH-M Pyren	4.41E-05	3.45E-05	4.50E-05	2.65E-05 (1.77E-05)	3.11E-05 (1.73E-05)	3.15E-05 (1.80E-05)
PAH-M sum	1.19E-04	9.27E-05	1.21E-04	7.11E-05 (4.74E-05)	8.35E-05 (4.64E-05)	8.46E-05 (4.83E-05)
PAH-H Krysen	6.58E-05	5.15E-05	6.70E-05	3.95E-05 (2.63E-05)	4.63E-05 (2.57E-05)	4.69E-05 (2.68E-05)
PAH others	1.38E-04	1.08E-04	1.41E-04	8.31E-05 (5.54E-05)	9.75E-05 (5.42E-05)	9.88E-05 (5.64E-05)
PAH 16 EPA's Prioryty	2.47E-04	1.93E-04	2.51E-04	1.48E-04 (9.87E-05)	1.74E-04 (9.65E-05)	1.76E-04 (1.01E-04)
Al	2.47	1.93	2.51	1.48 (0.99)	1.74 (0.96)	1.76 (1.01)
As	2.08E-03	1.62E-03	2.12E-03	1.25E-03 (8.31E-04)	1.46E-03 (8.12E-04)	1.48E-03 (8.47E-04)
Pb	1.04E-02	8.12E-03	1.06E-02	6.23E-03 (4.15E-03)	7.31E-03 (4.06E-03)	7.41E-03 (4.23E-03)
Fe	3.76	2.94	3.83	2.25 (1.50)	2.64 (1.47)	2.68 (1.53)
Cd	2.16E-04	1.69E-04	2.21E-04	1.30E-04 (8.66E-05)	1.52E-04 (8.46E-05)	1.54E-04 (8.82E-05)
Ca	7.36	5.75	7.50	4.41 (2.94)	5.18 (2.88)	5.25 (3.00)
K	3.72	2.91	3.79	2.23 (1.49)	2.62 (1.46)	2.65 (1.52)
Si	6.32	4.94	6.44	3.79 (2.53)	4.45 (2.47)	4.51 (2.58)
Cu	2.61E-02	2.04E-02	2.65E-02	1.56E-02 (1.04E-02)	1.83E-02 (1.02E-02)	1.86E-02 (1.06E-02)
Cr	8.31E-03	6.50E-03	8.47E-03	4.99E-03 (3.32E-03)	5.85E-03 (3.25E-03)	5.93E-03 (3.39E-03)
Mg	1.25	0.97	1.27	0.748 (0.499)	0.877 (0.487)	0.889 (0.508)
Mn	0.07	0.05	0.07	0.042	0.049	0.049

				(0.028)	(0.027)	(0.028)
Na	4.41	3.45	4.50	2.65	3.11	3.15
				(1.766)	(1.726)	(1.799)
Ni	2.94E-03	2.30E-03	3.00E-03	1.77E-03	2.07E-03	2.10E-03
				(1.18E-03)	(1.15E-03)	(1.20E-03)
S	1.03	0.81	1.05	0.62	0.73	0.73
				(0.412)	(0.403)	(0.420)
Zn	0.21	0.16	0.21	0.12	0.15	0.15
				(0.083)	(0.081)	(0.085)
O2	19.99	15.64	20.37	12.00	14.07	14.26
				(8.00)	(7.82)	(8.15)
NO3-N+NO2-N	0.39	0.30	0.40	0.234	0.274	0.278
				(0.156)	(0.152)	(0.159)
TOC	6.40	5.01	6.53	3.843	4.509	4.569
				(2.562)	(2.505)	(2.611)
DOC	4.24	3.32	4.32	2.545	2.986	3.025
				(1.696)	(1.659)	(1.729)
P	0.32	0.25	0.33	0.192	0.225	0.228
				(0.128)	(0.125)	(0.131)
Suspended solids	95.21	74.47	97.02	57.12	67.02	67.91
				(38.08)	(37.24)	(38.81)

* Design Standard + 20% climate change (20 min rainfall, 51 mm/hr)

Latvia: Jūrmala, Liepāja, Ogre

In all Latvian sites no measures aimed at the reduction of flooding and loads were simulated, nonetheless, the loads presented below allow to realize what increase in loads can be expected as a result of climate changes and avoided in future if appropriate preventive actions will be taken. Loads were calculated based on concentrations observed in wet weather conditions.

Table. 12. Urban flooding in Jūrmala, Liepāja and Ogre - loads of pollution in all rainfall scenarios [kg/rain event]

Parameter	Jūrmala				Liepāja				Ogre			
	Present	2021-2050	2070-2100	Increase in load in the most severe climate scenario	Present	RCP 4.5	RCP 8.5	Increase in load in the most severe climate scenario	Present	RCP 4.5	RCP 8.5	Increase in load in the most severe climate scenario
BOD_5	19.43	26.28	31.97	12.53	11.33	16.36	50.67	39.35	2.79	5.25	11.52	8.73
Susp. Solids	27.53	37.23	45.29	17.76	61.02	88.13	272.99	211.97	24.46	45.98	100.95	76.49
DOC	50.39	68.14	82.88	32.50	below the limit of quantification				1.63	3.07	6.73	5.10
TOC	52.56	71.09	86.47	33.90	2.09	3.02	9.34	7.25	1.18	2.21	4.86	3.68
N-NH_4	18.55	25.09	30.52	11.96	0.06	0.09	0.26	0.21	0.02	0.05	0.10	0.08
N-NO_2	3.64	4.92	5.98	2.34	0.23	0.33	1.02	0.79	below the limit of quantification			
N-NO_3	5.48	7.41	9.01	3.53	1.87	2.70	8.36	6.49	2.80	5.26	11.55	8.75
N-NO_2+N-NO_3	9.11	12.33	14.99	5.88	2.10	3.03	9.38	7.29	2.80	5.26	11.55	8.75
TN	28.33	38.32	46.61	18.27	3.07	4.43	13.73	10.66	4.40	8.28	18.17	13.77
P-PO_4	1.20	1.62	1.97	0.77	0.79	1.13	3.51	2.73	0.10	0.18	0.40	0.30
TP	5.27	7.12	8.66	3.40	1.31	1.89	5.84	4.54	0.13	0.24	0.52	0.39
Al	0.23	0.31	0.37	0.15	0.05	0.07	0.23	0.18	0.01	0.01	0.03	0.02
B	0.27	0.36	0.44	0.17	0.37	0.54	1.67	1.30	0.07	0.14	0.30	0.23
Ca	152.63	206.42	251.07	98.44	106.41	153.67	476.03	369.62	72.84	136.92	300.62	227.77
Cd	below the limit of quantification				0.0005	0.0007	0.0021	0.00	0.0002	0.0003	0.0007	0.00
Cr	0.011	0.015	0.018	0.007	0.0062	0.0090	0.0278	0.022	0.0047	0.0089	0.0195	0.015
Cu	0.017	0.023	0.028	0.011	0.0219	0.0317	0.0981	0.076	0.0141	0.0266	0.0583	0.044
Fe	6.47	8.75	10.64	4.17	2.97	4.30	13.31	10.33	0.82	1.53	3.37	2.55
K	24.06	32.54	39.57	15.52	25.17	36.35	112.61	87.44	8.24	15.48	33.99	25.75
Mg	57.20	77.36	94.10	36.89	14.51	20.96	64.92	50.41	16.85	31.68	69.55	52.69

Mn	0.49	0.66	0.80	0.32	0.17	0.25	0.77	0.60	0.10	0.19	0.41	0.31
Na	216.78	293.18	356.60	139.82	93.63	135.22	418.87	325.24	50.10	94.18	206.77	156.66
Ni	0.011	0.015	0.018	0.007	0.0090	0.0131	0.0404	0.031	0.0054	0.0102	0.0224	0.017
TP (filtrated)	1.45	1.96	2.38	0.93	1.14	1.64	5.08	3.95	0.11	0.20	0.43	0.33
Pb	below the limit of quantification				2.36	3.41	10.58	8.21	1.99	3.75	8.23	6.23
SO_4	149.42	202.08	245.79	96.37	53.01	76.56	237.16	184.15	29.26	55.01	120.77	91.51
Cl	0.00	0.00	0.00	0.00	129.68	187.27	580.11	450.43	85.25	160.25	351.84	266.59
Si	12.75	17.24	20.97	8.22	9.94	14.35	44.45	34.51	2.25	4.22	9.27	7.03
Zn	0.29	0.39	0.47	0.18	0.27	0.39	1.19	0.93	0.10	0.19	0.41	0.31
E. coli	6.7E+10	9.0E+10	1.1E+11	4.3E+10	1.7E+12	2.5E+12	7.7E+12	6.0E+12	3.6E+09	6.8E+09	1.5E+10	1.1E+10
Coli. Bacteria	2.6E+11	3.5E+11	4.23+11	1.7E+11	9.5E+13	1.4E+14	4.3E+14	3.3E+14	2.7E+11	5.1E+11	1.1E+12	8.5E+11
Oil Index	0.32	0.43	0.53	0.21	below the limit of quantification				below the limit of quantification			

Table. 13. Direct discharge in Jūrmala, Liepāja and Ogre - loads of pollution in all rainfall scenarios [kg/rain event]

Parameter	Jūrmala				Liepāja				Ogre			
	Present	2021-2050	2070-2100	Increase in load in the most severe climate scenario	Present	RCP 4.5	RCP 8.5	Increase in load in the most severe climate scenario	Present	RCP 4.5	RCP 8.5	Increase in load in the most severe climate scenario
BOD_5	26.93	28.96	30.30	3.37	17.24	19.34	33.32	16.07	8.77	10.34	13.19	4.42
Susp. Solids	38.15	41.04	42.93	4.78	92.90	104.19	179.49	86.59	76.90	90.67	115.64	38.75
DOC	69.82	75.10	78.57	8.75	below the limit of quantification				5.13	6.04	7.71	2.58
TOC	72.84	78.35	81.96	9.12	3.18	3.57	6.14	2.96	3.70	4.37	5.57	1.87
$N\text{-}NH_4$	25.71	27.65	28.93	3.22	0.09	0.10	0.17	0.08	0.08	0.09	0.12	0.04
$N\text{-}NO_2$	5.04	5.42	5.67	0.63	0.35	0.39	0.67	0.32	below the limit of quantification			
$N\text{-}NO_3$	7.59	8.17	8.54	0.95	2.84	3.19	5.50	2.65	8.80	10.38	13.23	4.43
$N\text{-}NO_2+N\text{-}NO_3$	12.63	13.59	14.21	1.58	3.19	3.58	6.17	2.98	8.80	10.38	13.23	4.43
TN	39.26	42.23	44.18	4.92	4.67	5.24	9.03	4.36	13.84	16.32	20.82	6.97
P-PO4	1.66	1.79	1.87	0.21	1.20	1.34	2.31	1.11	0.30	0.36	0.46	0.15
TP	7.30	7.85	8.21	0.91	1.99	2.23	3.84	1.85	0.39	0.46	0.59	0.20
Al	0.31	0.34	0.35	0.04	0.08	0.09	0.15	0.07	0.02	0.02	0.03	0.01

B	0.37	0.40	0.42	0.05	0.57	0.64	1.10	0.53	0.23	0.27	0.35	0.12
Ca	211.50	227.49	237.99	26.49	161.99	181.68	312.98	150.99	228.98	269.98	344.35	115.37
Cd	below the limit of quantification				0.0007	0.0008	0.0014	0.00	0.0006	0.0007	0.0008	0.00
Cr	0.015	0.016	0.017	0.002	0.0095	0.0106	0.0183	0.009	0.0149	0.0175	0.0224	0.007
Cu	0.023	0.025	0.026	0.003	0.0334	0.0374	0.0645	0.031	0.0444	0.0524	0.0668	0.022
Fe	8.96	9.64	10.09	1.12	4.53	5.08	8.75	4.22	2.56	3.02	3.85	1.29
K	33.34	35.86	37.51	4.18	38.32	42.98	74.04	35.72	25.89	30.52	38.93	13.04
Mg	79.27	85.26	89.20	9.93	22.09	24.78	42.68	20.59	52.97	62.46	79.66	26.69
Mn	0.68	0.73	0.76	0.08	0.26	0.29	0.50	0.24	0.31	0.37	0.47	0.16
Na	300.39	323.10	338.02	37.63	142.54	159.87	275.40	132.86	157.49	185.70	236.85	79.36
Ni	0.015	0.016	0.017	0.002	0.0138	0.0154	0.0266	0.013	0.0171	0.0201	0.0257	0.009
TP (filtrated)	2.01	2.16	2.26	0.25	1.73	1.94	3.34	1.61	0.33	0.39	0.50	0.17
Pb	below the limit of quantification				3.60	4.04	6.96	3.36	6.27	7.39	9.42	3.16
SO_4	207.05	222.71	232.99	25.94	80.70	90.52	155.93	75.23	91.99	108.46	138.34	46.35
Cl	0.00	0.00	0.00	0.00	197.40	221.41	381.41	184.01	268.00	315.99	403.03	135.03
Si	17.67	19.00	19.88	2.21	15.12	16.96	29.22	14.10	7.06	8.33	10.62	3.56
Zn	0.40	0.43	0.45	0.05	0.41	0.46	0.79	0.38	0.31	0.37	0.47	0.16
E. coli	9.2E+10	9.9E+10	1.0E+11	1.2E+10	2.6E+12	2.9E+12	5.0E+12	2.4E+12	1.1E+10	1.3E+10	1.7E+10	5.7E+09
Coli. Bacteria	3.6E+11	3.8E+11	4.0E+11	4.5E+10	1.5E+14	1.6E+14	2.8E+14	1.4E+14	8.5E+11	1.0E+12	1.3E+12	4.3E+11
Oil Index	0.44	0.48	0.50	0.06	below the limit of quantification				below the limit of quantification			

Poland, Słupsk

For the Słupsk pilot site the effect of climate changes were estimated as well as the reduction of flooding by mitigative planning measures (EWL). Expected effects of these scenarios are presented in the table below. Loads of pollutants in urban flooding were calculated based on average concentrations observed during the most intensive rainfall event (one of six events) in three sampling points. In the case of loads in discharge (CSO), one sampling point closest to the CSO was used only.

Table. 14. Urban flooding in Słupsk - loads of pollution in all rainfall scenarios (2 y. rainfall return period) [kg/rain event]

Parameter	Total volume of spillages [m3/rain event]					Increase in load in the most severe climate scenario	Reduction by mitigative planning measures (EWL).				
	present, 2 year rainfall	RCP4.5, 2 year rainfall (2051-2060)	RCP4.5, 2 year rainfall (2091-2100)	RCP8.5, 2 year rainfall (2051-2060)	RCP8.5, 2 year rainfall (2091-2100)		present, 2 year rainfall	RCP4.5, 2 year rainfall (2051-2060)	RCP4.5, 2 year rainfall (2091-2100)	RCP8.5, 2 year rainfall (2051-2060)	RCP8.5, 2 year rainfall (2091-2100)
BOD_5	3 023.78	3 368.51	4 101.92	4 521.4	5 895.8	2 872.0	2 335.7	2 518.2	2 895.6	3 106.7	3 793.0
Susp. Solids	1 753.30	1 953.19	2 378.45	2 621.7	3 418.6	1 665.3	1 354.3	1 460.2	1 679.0	1 801.4	2 199.3
COD	9 456.25	10 534.33	12 827.92	14 139.8	18 437.9	8 981.7	7 304.3	7 875.3	9 055.3	9 715.5	11 861.8
DO	38.14	42.48	51.73	57.02	74.36	36.22	29.46	31.76	36.52	39.18	47.84
DOC	505.30	562.91	685.46	755.6	985.2	479.9	390.3	420.8	483.9	519.2	633.8
TOC	506.41	564.14	686.97	757.2	987.4	481.0	391.2	421.7	484.9	520.3	635.2
$N\text{-}NH_4$	274.57	305.87	372.46	410.55	535.35	260.79	212.08	228.66	262.92	282.09	344.41
$N\text{-}NO_2+N\text{-}NO_3$	11.19	12.47	15.18	16.73	21.82	10.63	8.64	9.32	10.72	11.50	14.04
TN	452.79	504.41	614.23	677.0	882.9	430.1	349.7	377.1	433.6	465.2	568.0
$P\text{-}PO_4$	114.14	127.16	154.84	170.68	222.56	108.41	88.17	95.06	109.30	117.27	143.18
TP	54.16	60.33	73.47	80.98	105.60	51.44	41.83	45.10	51.86	55.64	67.93
Al	5.39	6.01	7.31	8.06	10.51	5.12	4.16	4.49	5.16	5.54	6.76
B	0.26	0.29	0.35	0.39	0.51	0.25	0.20	0.22	0.25	0.27	0.33
Ca	420.97	468.96	571.07	629.47	820.81	399.84	325.17	350.59	403.12	432.51	528.06
Cu	0.18	0.20	0.24	0.27	0.35	0.17	0.14	0.15	0.17	0.18	0.22
Fe	2.60	2.90	3.53	3.89	5.08	2.47	2.01	2.17	2.49	2.67	3.27
K	135.73	151.20	184.12	202.95	264.64	128.91	104.84	113.03	129.97	139.45	170.25
Mg	48.77	54.33	66.16	72.93	95.10	46.32	37.67	40.62	46.70	50.11	61.18
Mn	0.47	0.52	0.63	0.70	0.91	0.44	0.36	0.39	0.45	0.48	0.59
Na	474.59	528.70	643.81	709.65	925.37	450.77	366.59	395.24	454.47	487.60	595.32
P	38.54	42.93	52.28	57.62	75.14	36.60	29.77	32.09	36.90	39.59	48.34
S	114.81	127.90	155.75	171.67	223.86	109.05	88.68	95.61	109.94	117.96	144.02
Si	39.09	43.55	53.03	58.46	76.22	37.13	30.20	32.56	37.44	40.17	49.04
Zn	0.13	0.15	0.18	0.20	0.26	0.13	0.10	0.11	0.13	0.14	0.17
Coli. Bacteria	1.58E+13	1.76E+13	2.15E+13	2.4E+13	3.1E+13	1.5E+13	1.2E+13	1.3E+13	1.5E+13	1.6E+13	2.0E+13
Oil Index	5.682	6.330	7.708	8.496	11.078	5.397	4.389	4.732	5.441	5.838	7.127

C10-C12	0.077	0.086	0.104	0.115	0.150	0.073	0.059	0.064	0.074	0.079	0.097
C12-C16	0.132	0.147	0.179	0.197	0.257	0.125	0.102	0.110	0.126	0.135	0.165
C16-C35	2.316	2.580	3.142	3.463	4.516	2.200	1.789	1.929	2.218	2.380	2.905
C35-C40	0.316	0.351	0.428	0.472	0.615	0.300	0.244	0.263	0.302	0.324	0.396
C10-C40	2.841	3.165	3.854	4.249	5.540	2.699	2.195	2.366	2.721	2.919	3.564

Table. 15. Urban flooding in Słupsk - loads of pollution in all rainfall scenarios (20 y. rainfall return period) [kg/rain event]

Parameter	Total volume of spillages [m3/rain event]					Increase in load in the most severe climate scenario	Reduction by mitigative planning measures (EWL).				
	present, 20 year rainfall	RCP4.5, 20 year rainfall (2051-2060)	RCP4.5, 20 year rainfall (2091-2100)	RCP8.5, 20 year rainfall (2051-2060)	RCP8.5, 20 year rainfall (2091-2100)		present, 20 year rainfall	RCP4.5, 20 year rainfall (2051-2060)	RCP4.5, 20 year rainfall (2091-2100)	RCP8.5, 20 year rainfall (2051-2060)	RCP8.5, 20 year rainfall (2091-2100)
BOD_5	10 859.3	11 819.2	12 671.3	14 059.3	15 196.3	4 337.0	5 928.9	6 310.7	6 640.5	7 181.9	7 503.0
Susp. Solids	6 296.6	6 853.2	7 347.3	8 152.1	8 811.4	2 514.8	3 437.8	3 659.2	3 850.4	4 164.3	4 350.5
COD	33 960.3	36 962.3	39 627.0	43 967.7	47 523.5	13 563.2	18 541.3	19 735.6	20 766.9	22 459.8	23 464.3
DO	136.96	149.07	159.81	177.32	191.66	54.70	74.78	79.59	83.75	90.58	94.63
DOC	1 814.7	1 975.1	2 117.5	2 349.4	2 539.4	724.8	990.8	1 054.6	1 109.7	1 200.1	1 253.8
TOC	1 818.7	1 979.4	2 122.1	2 354.6	2 545.0	726.3	992.9	1 056.9	1 112.1	1 202.8	1 256.6
$N\text{-}NH_4$	986.05	1 073.21	1 150.58	1 276.61	1 379.86	393.81	538.35	573.03	602.97	652.13	681.29
$N\text{-}NO_2+N\text{-}NO_3$	40.19	43.75	46.90	52.04	56.25	16.05	21.94	23.36	24.58	26.58	27.77
TN	1 626.1	1 769.8	1 897.4	2 105.3	2 275.5	649.4	887.8	945.0	994.4	1 075.4	1 123.5
$P\text{-}PO_4$	409.92	446.16	478.32	530.72	573.64	163.72	223.80	238.22	250.67	271.10	283.23
TP	194.49	211.68	226.95	251.81	272.17	77.68	106.19	113.03	118.93	128.63	134.38
Al	19.36	21.07	22.59	25.07	27.09	7.73	10.57	11.25	11.84	12.80	13.38
B	0.93	1.02	1.09	1.21	1.31	0.37	0.51	0.54	0.57	0.62	0.65
Ca	1 511.83	1 645.47	1 764.10	1 957.34	2 115.63	603.80	825.42	878.58	924.49	999.86	1 044.57
Cu	0.64	0.70	0.75	0.83	0.89	0.26	0.35	0.37	0.39	0.42	0.44
Fe	9.35	10.18	10.91	12.10	13.08	3.73	5.10	5.43	5.72	6.18	6.46
K	487.43	530.52	568.76	631.07	682.10	194.67	266.12	283.26	298.07	322.36	336.78
Mg	175.16	190.64	204.38	226.77	245.11	69.95	95.63	101.79	107.11	115.84	121.02
Mn	1.68	1.83	1.96	2.17	2.35	0.67	0.92	0.98	1.03	1.11	1.16

Na	1 704.41	1 855.07	1 988.81	2 206.66	2 385.12	680.71	930.56	990.49	1 042.25	1 127.22	1 177.63
P	138.40	150.63	161.49	179.18	193.67	55.27	75.56	80.43	84.63	91.53	95.62
S	412.32	448.77	481.12	533.82	576.99	164.67	225.11	239.61	252.13	272.69	284.88
Si	140.40	152.81	163.82	181.77	196.47	56.07	76.65	81.59	85.85	92.85	97.00
Zn	0.48	0.52	0.56	0.62	0.67	0.19	0.26	0.28	0.29	0.32	0.33
Coli. Bacteria	5.7E+13	6.2E+13	6.6E+13	7.4E+13	8.0E+13	2.3E+13	3.1E+13	3.3E+13	3.5E+13	3.8E+13	3.9E+13
Oil Index	20.405	22.209	23.810	26.418	28.554	8.149	11.141	11.858	12.478	13.495	14.098
C10-C12	0.276	0.301	0.323	0.358	0.387	0.110	0.151	0.161	0.169	0.183	0.191
C12-C16	0.473	0.515	0.552	0.612	0.662	0.189	0.258	0.275	0.289	0.313	0.327
C16-C35	8.318	9.054	9.706	10.769	11.640	3.322	4.542	4.834	5.087	5.501	5.747
C35-C40	1.133	1.233	1.322	1.467	1.586	0.453	0.619	0.658	0.693	0.749	0.783
C10-C40	10.204	11.106	11.907	13.211	14.279	4.075	5.571	5.930	6.240	6.749	7.050

Table. 16. Combined sewer overflow in Słupsk - loads of pollution in all rainfall scenarios (2 y. rainfall return period) [kg/rain event]

Parameter	Total volume of spillages [m3/rain event]					Increase in load in the most severe climate scenario	Reduction by mitigative planning measures (EWL).				
	present, 2 year rainfall	RCP4.5, 2 year rainfall (2051-2060)	RCP4.5, 2 year rainfall (2091-2100)	RCP8.5, 2 year rainfall (2051-2060)	RCP8.5, 2 year rainfall (2091-2100)		present, 2 year rainfall	RCP4.5, 2 year rainfall (2051-2060)	RCP4.5, 2 year rainfall (2091-2100)	RCP8.5, 2 year rainfall (2051-2060)	RCP8.5, 2 year rainfall (2091-2100)
BOD_5	148.32	183.24	257.04	294.5	399.6	251.3	100%				
Susp. Solids	88.58	109.44	153.51	175.9	238.7	150.1					
COD	657.55	812.36	1 139.54	1 305.5	1 771.6	1 114.0					
DO	4.08	5.04	7.07	8.10	10.99	6.91					
DOC	26.86	33.19	46.55	53.3	72.4	45.5					
TOC	27.07	33.44	46.91	53.7	72.9	45.9					
$N\text{-}NH_4$	8.45	10.43	14.64	16.77	22.76	14.31					
$N\text{-}NO_2+N\text{-}NO_3$	0.65	0.80	1.13	1.29	1.75	1.10					
TN	17.51	21.63	30.35	34.8	47.2	29.7					
$P\text{-}PO_4$	4.24	5.24	7.35	8.43	11.43	7.19					
TP	2.08	2.57	3.61	4.13	5.61	3.52					
Al	0.39	0.48	0.68	0.78	1.06	0.66					

B	0.01	0.02	0.02	0.03	0.03	0.02
Ca	20.35	25.14	35.27	40.41	54.83	34.48
Cu	0.01	0.01	0.01	0.02	0.02	0.01
Fe	0.19	0.23	0.32	0.37	0.50	0.31
K	6.63	8.19	11.50	13.17	17.87	11.24
Mg	2.11	2.61	3.66	4.19	5.68	3.57
Mn	0.05	0.06	0.08	0.09	0.12	0.08
Na	16.27	20.11	28.20	32.31	43.85	27.57
P	1.54	1.90	2.67	3.06	4.15	2.61
S	5.03	6.21	8.71	9.98	13.54	8.52
Si	1.86	2.30	3.23	3.70	5.02	3.15
Zn	0.01	0.01	0.01	0.02	0.02	0.01
Coli. Bacteria	1.27E+12	1.57E+12	2.21E+12	2.5E+12	3.4E+12	2.2E+12
Oil Index	0.293	0.362	0.508	0.582	0.790	0.497
C10-C12	0.006	0.008	0.011	0.012	0.017	0.010
C12-C16	0.007	0.009	0.012	0.014	0.019	0.012
C16-C35	0.116	0.144	0.201	0.231	0.313	0.197
C35-C40	0.017	0.021	0.030	0.035	0.047	0.029
C10-C40	0.147	0.181	0.254	0.291	0.395	0.248

Table. 17. Combined sewer overflow in Słupsk - loads of pollution in all rainfall scenarios (20 y. rainfall return period) [kg/rain event]

Parameter	Total volume of spillages [m3/rain event]					Increase in load in the most severe climate scenario	Reduction by mitigative planning measures (EWL).				
	present, 20 year rainfall	RCP4.5, 20 year rainfall (2051-2060)	RCP4.5, 20 year rainfall (2091-2100)	RCP8.5, 20 year rainfall (2051-2060)	RCP8.5, 20 year rainfall (2091-2100)		present, 20 year rainfall	RCP4.5, 20 year rainfall (2051-2060)	RCP4.5, 20 year rainfall (2091-2100)	RCP8.5, 20 year rainfall (2051-2060)	RCP8.5, 20 year rainfall (2091-2100)
BOD_5	707.4	757.1	813.6	900.0	969.8	262.4	593.3	600.5	609.8	617.4	579.6
Susp. Solids	422.5	452.1	485.9	537.5	579.2	156.7	354.3	358.6	364.2	368.7	346.2
COD	3 136.1	3 356.4	3 607.0	3 990.0	4 299.6	1 163.5	2 630.2	2 662.1	2 703.6	2 737.1	2 569.6
DO	19.45	20.82	22.37	24.75	26.67	7.22	16.32	16.51	16.77	16.98	15.94
DOC	128.1	137.1	147.4	163.0	175.6	47.5	107.4	108.8	110.4	111.8	105.0

TOC	129.1	138.2	148.5	164.3	177.0	47.9	108.3	109.6	111.3	112.7	105.8
$N\text{-}NH_4$	40.28	43.11	46.33	51.25	55.23	14.94	33.78	34.19	34.73	35.16	33.01
$N\text{-}NO_2$+$N\text{-}NO_3$	3.10	3.32	3.57	3.95	4.26	1.15	2.60	2.64	2.68	2.71	2.54
TN	83.5	89.4	96.1	106.3	114.5	31.0	70.0	70.9	72.0	72.9	68.4
$P\text{-}PO_4$	20.24	21.66	23.28	25.75	27.75	7.51	16.97	17.18	17.45	17.66	16.58
TP	9.92	10.62	11.41	12.63	13.60	3.68	8.32	8.42	8.55	8.66	8.13
Al	1.87	2.00	2.15	2.38	2.56	0.69	1.57	1.59	1.61	1.63	1.53
B	0.06	0.07	0.07	0.08	0.08	0.02	0.05	0.05	0.05	0.05	0.05
Ca	97.07	103.89	111.64	123.50	133.08	36.01	81.41	82.40	83.68	84.72	79.53
Cu	0.04	0.04	0.05	0.05	0.05	0.01	0.03	0.03	0.03	0.03	0.03
Fe	0.88	0.95	1.02	1.13	1.21	0.33	0.74	0.75	0.76	0.77	0.72
K	31.64	33.86	36.39	40.25	43.37	11.74	26.53	26.85	27.27	27.61	25.92
Mg	10.06	10.77	11.57	12.80	13.79	3.73	8.44	8.54	8.67	8.78	8.24
Mn	0.22	0.23	0.25	0.28	0.30	0.08	0.18	0.18	0.19	0.19	0.18
Na	77.62	83.07	89.27	98.75	106.41	28.80	65.10	65.89	66.91	67.74	63.60
P	7.35	7.87	8.45	9.35	10.08	2.73	6.16	6.24	6.34	6.41	6.02
S	23.97	25.66	27.57	30.50	32.87	8.89	20.11	20.35	20.67	20.92	19.64
Si	8.88	9.51	10.22	11.30	12.18	3.30	7.45	7.54	7.66	7.75	7.28
Zn	0.04	0.04	0.05	0.05	0.05	0.01	0.03	0.03	0.03	0.03	0.03
Coli. Bacteria	6.1E+12	6.5E+12	7.0E+12	7.7E+12	8.3E+12	2.3E+12	5.1E+12	5.2E+12	5.2E+12	5.3E+12	5.0E+12
Oil Index	1.399	1.497	1.609	1.780	1.918	0.519	1.173	1.187	1.206	1.221	1.146
C10-C12	0.029	0.031	0.034	0.037	0.040	0.011	0.025	0.025	0.025	0.026	0.024
C12-C16	0.033	0.035	0.038	0.042	0.045	0.012	0.028	0.028	0.028	0.029	0.027
C16-C35	0.554	0.593	0.637	0.705	0.760	0.206	0.465	0.470	0.478	0.484	0.454
C35-C40	0.083	0.089	0.095	0.106	0.114	0.031	0.070	0.070	0.071	0.072	0.068
C10-C40	0.700	0.749	0.805	0.890	0.959	0.260	0.587	0.594	0.603	0.611	0.573

2.3 Summary of results

In most of pilot sites at least three climate scenarios were analyzed including the current status, RCP 4.5 and RCP 8.5. When the rain event of return period equal to 2 years is concerned the expected increase in the urban flooding in pilot sites ranges from 11 to 118% in the RCP 4.5 scenario and from 50 to 440% in the RCP 8.5 scenario (Fig. 1). When the direct outflow from sewer systems is considered instead of the urban flooding, the estimated impact of climate changes is even more diversified. In pilot sites the estimated increase in discharge is 5-199% and 16-786% in the RCP 4.5 and RCP 8.5 scenarios, respectively. Such broad ranges of expected impacts of climate change suggest that the adaptive potential of cities varies widely. These variati ons should be attributed mostly to the character of cities, i.e. land use, slopes, type and condition of sewer systems.

These estimations are of a general character, because of (1) differences in the methods used in cities to estimate the current rainfall, (2) differing time horizons of RCP scenarios used in participating countries, (3) different duration of analyzes rainfall events (30 minutes in Pori instead of 20 minutes in other cities) and (4) different return period (10 years in Latvian pilot sites instead of 2). In some cities (Rakvere and Söderhamn) the current status already included a surplus rainfall (20%) attributed to climate changes.

Irrespective to the site specific approach to the inclusion of climate changes into the EWL, there is a clear evidence, that the estimated flooding and discharges in all pilot sites tends to increase significantly.

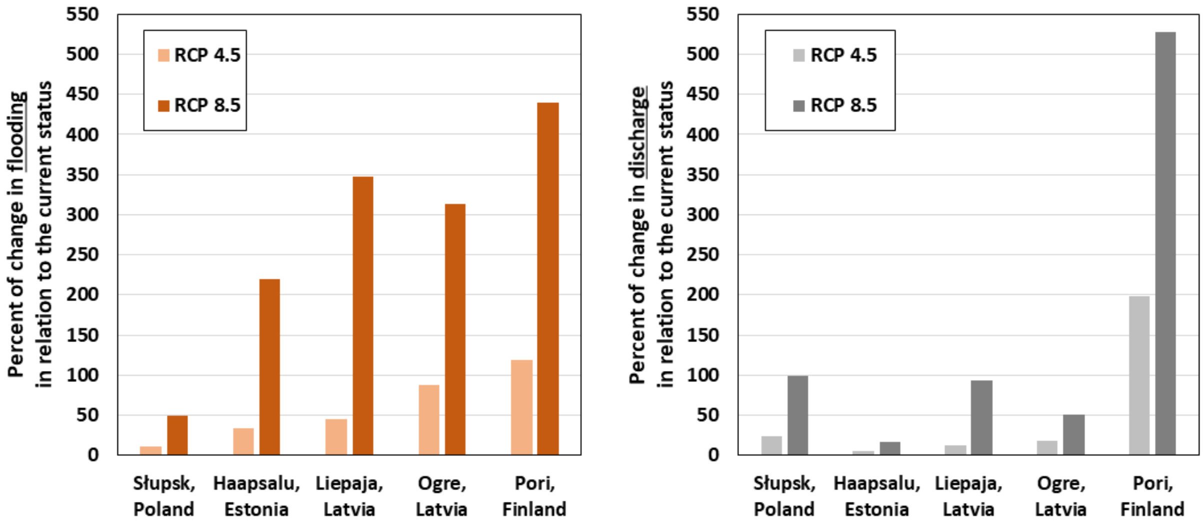

Fig. 1. Percent of flooding and discharge in pilot sites as a result of the climate change

In all pilot sites where the separated stormwater system exists, the rainfall intensity affects mostly the urban flood risk and to a lesser extent the direct outflow to receiving waters. Therefore, in these sites the flooding-discharge ratio increases along with the severity or horizon of climate changes (Fig. 2). In this respect, Słupsk differs from other pilot sites, because it includes a combined sewer system which is aimed to prevent the discharge (overflow) at any time except for extreme events.

Pilot site	Return Period [y]	Scenario	
Słupsk, Poland	2	Present	
		RCP4.5	2051-2060
			2091-2100
		RCP8.5	2051-2060
			2091-2100
	20	Present	
		RCP4.5	2051-2060
			2091-2100
		RCP8.5	2051-2060
			2091-2100
Haapsalu, Estonia	2	Present	
		RCP 4.5,	
		RCP 8.5,	
	5	EVS 848	
	10	EVS 848	
Pori, Finland	2	Present	
		RCP4.5	
		RCP8.5	
Liepaja, Latvia	10	Present	
		RCP 4.5	
		RCP 8.5	
Jurmala, Latvia	10	Present	
		2021-2050	
		2070-2100	
Ogre, Latvia	10	Present	
		RCP 4.5	
		RCP 8.5	

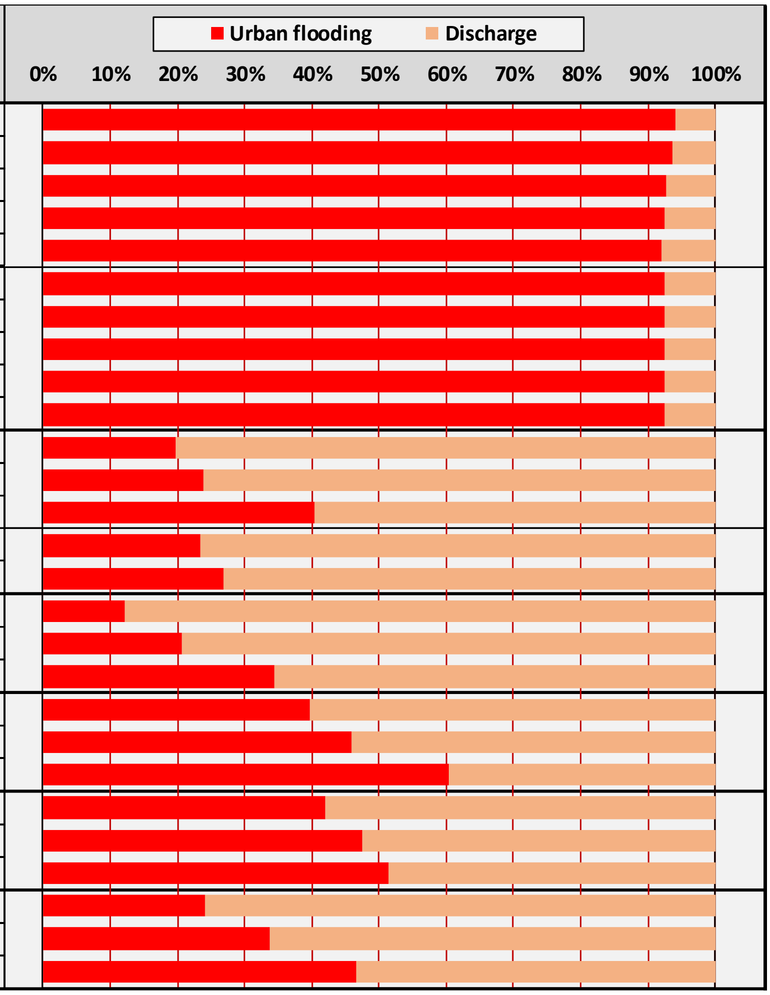

Fig. 2. Impacts of climate change on urban flooding (volume of spillages in the city) and discharges (volume of storm water / wastewater at the outflow to receiving waters) in pilot sites

In three pilot sites, Słupsk (Poland), Rakvere (Estonia) and Söderhamn (Sweden), measures aimed at the minimization of flooding volumes were evaluated using the EWL. These measures, when simulated using hydraulic models, have proved to be effective. **They allowed to decrease the flooding resulting from the rainfall of the 2-year return period by 60 to 90%.** The efficiency of measures is lower when more severe rainfall events are analysed (Fig. 3).
Most of climate change scenarios and mitigative measures were applied in Extreme Weather Layers to assess the spatial distribution of flood risk in pilot sites (NOAH, 2021a). Furthermore, for part of pilot sites (Rakvere, Söderhamn), these assessments were used to estimate possible savings related to the change in the number of flooded properties. Results are presented in the chapter 4.1" Economic benefits – construction and maintenance costs".

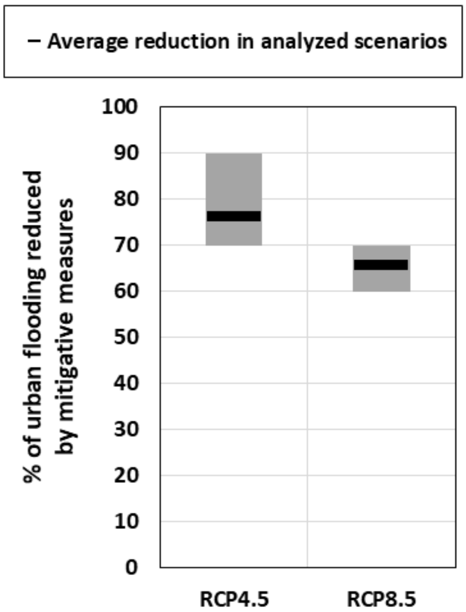

Fig. 3. Decrease in urban flooding volumes as a result of mitigative measures simulated for pilot sites and RCP scenarios

Depending on national and regional regulations, there may be fees for water services for the discharge of stormwater and wastewater into surface waters. These fees were introduced in some of European countries in 1970's, and various approaches to the fees / taxes were applied worldwide since then (Tasca et al., 2018). As an example, such fees were reported for Słupsk in the chapter 4.1" Economic benefits – construction and maintenance costs".
This chapter presents the climate change-driven increase in loads of pollutants and the achievable decrease in loads due to implementation of mitigative measures. These changes in loads, if put together with fees for discharges may be used for the planning of city's financial resources.

3 Description of NOAH actions

3.1 Słupsk (Poland)

3.1.1 Investments done in the pilot site

- Devices for measuring the amount of precipitation (rain gauges) were purchased - 6 pieces.
- Devices for measuring the water level at the main sewers with a system for automatic data archiving, remote transmission, and visualization - 12 pieces.

3.1.2 Measurements done in the pilot site

- Six composite samples taken with an automatic sampler have been collected from three different canals leading into the wastewater treatment plant in Słupsk, stormwater was also sampled at the same time (the first samples were taken in December 2019 and the second samples were taken in May 2020).
- Continuous rainfall measurement in individual districts.
- Continuous measurement of the level of the wastewater in selected manholes.
- Wastewater flowrate and quality at the outflow from the pilot site (pre-existing monitoring system operated by Słupsk Water Supply).
- Water stage and flow rate in the Słupia River in the location of the CSO (pre-existing monitoring system operated by Słupsk Water Supply).
- Periodical measurements of wastewater and stormwater flow rate and level individual catchments.

3.1.3 RTC implemented in the pilot site

- None.

3.1.4 Scenarios simulated in the pilot site

- Increase of flood risk related to climate change (EWL).
- Rain events, probability rain events.
- Real weather data.
- Implementation of measures aimed at retention of stormwater in a part of the city, where the combined sewer system exists.

3.1.5 Implementing RTC and EWL in practice

- Preparation of support for spatial planning on a city scale in the form of an inflation tool called "Extreme Weather Layer". It is a tool in the form of geographic information system (GIS) map layers based on the results of mathematical modeling of water flow and forecast meteorological conditions. Extreme weather layer analyses can be considered as a screening tool capable of the indication of districts at risk and estimation of the relative increase of flood risk related to climate change.

- A large part of the study area is classified as degraded and is a subject of the “Regeneration Programme”. One of the Programme’s actions is the restoration of the recreational and natural areas and maintenance of the ecological corridor along the Słupia River crossing the study area. The development of blue and green infrastructure is one of the priorities in the “Strategy of the Słupsk Development for 2017-2022”. This document proposes measures aimed at the protection of water resources, improvement of the land management procedures, stormwater harvesting, and use. These priorities and actions are consistent with the “Climate change adaptation plan” which defines water management and biodiversity as key sectors vulnerable to the effects of climate changes.
- Collection of data on meteorological conditions and the sewage system.
- Model results can be used as a virtual sensor for the real-time control of the sewer system.
- Users have been trained and prepared to work with the measurement devices independently.

3.2 Haapsalu (Estonia)

3.2.1 Investments done in the pilot site

- Smart weirwall system.
- Adjusting culvert pipe bottom height to sea level.
- Old secondary damper/weirwall repair work.

3.2.2 Measurements done in the pilot site

- Quality and quantity measurements - there have been two sets of measurements (March 2020 and December 2020).
- Geodetic survey – identification of data gap in the stormwater system.
- Rainfall intensities.

3.2.3 RTC implemented in the pilot site

- Controlling the flow through the outlet from the downstream wetland using a Smart Weirwall System and two sensors can keep the water level in the downstream wetland low during high water levels at the sea and rain events, which leads to reduced risk of flooding and sewer overflows in the city. The general idea was to install a SWS (smart weirwall system) between the sea and the bioswale in order to prevent the inflow from the sea to the urban drainage system (in case of the high sea level) and enable the free outflow from the UDS to the bioswale. The SWS is equipped with water level sensors to automatically adjust the position of the weirwall based on the water levels at the upstream and downstream of the weirwall.

3.2.4 Scenarios simulated in the pilot site

- Smart weirwall system.
- 2-year EVS 848.
- 2-year RCP 4.5.
- 2-year RCP 8.5.
- 5-year EVS 848.
- 10-year EVS 848.
- Local rain.

3.2.5 Implementing RTC and EWL in practice

- Collection data about the stormwater system.
- Major obstacles occurred during the design process - geodetic survey revealed that the existing culvert at the location of planned SWS was installed higher than it was estimated initially before the procurement. Therefore, additional works had to be planned to reconstruct the culvert by installing the pipe approximately 0.5 m deeper. Without the adjustment, water would not have had a free pass from the bioswale to the sea and smart weirwall installed on the culvert would not have met the objectives set by the NOAH project.
- Smart weirwall system works with RTC, the valve is automatically adjusted according to the water levels in the sea and the outflow of the stormwater system.
- There have been several discussions and meetings between TalTech and Haapsalu Municipality related to the EWL.
- The first version of EWL is created and the second version is in progress, which takes into account Haapsalu's amendments.

3.3 Rakvere (Estonia)

3.3.1 Investments done in the pilot site

- Smart weirwall.
- Water level sensors.
- Data transmissions equipment.

3.3.2 Measurements done in the pilot site

- Automatic, time regulated (wet weather) sampling – stormwater, one sample representing 12 subsamples taken every fifth minute during an hour during a rain event, the samples were collected from the outlet of the main stormwater collector – Soolikaoja (March 2020 and November 2020).
- The amount of the stormwater.

3.3.3 RTC implemented in the pilot site

- In addition to the smart weirwall, a water level sensor with data transmission equipment is installed to the observation well on the Soolikaoja collector to measure the collector water level and transmit the corresponding information to the weirwall. During heavy rainfalls, when the water level in the Soolikaoja collector begins to reach a critical limit, a signal is sent to the weirwall, which begins to close thus reducing the water flow to the collector and buffering extra water to the Süstatiik pond. When the rainfall ends and the water level in the collector drops, the weirwall starts lowering the water level in Süstatiik as well. Such buffering reduces the risk of flooding in the center of Rakvere, which the collector of Soolikaoja passes through.
- Users who directly supervise the work of the purchased devices have been trained and prepared to work with the devices independently.

3.3.4 Scenarios simulated in the pilot site

- EWL – flood risks level.
- RTC gate to restrict natural inflow to the collector.

3.3.5 Implementing RTC and EWL in practice

- Control of the discharge from an upstream lake using the Smart Weirwall System controlled by the water level in the downstream system can reduced downstream flooding and risk of pollution spillages from wastewater system during flood events.
- This is a pilot project, the results of which can be applied in other regions of Estonia in the future.
- Users who directly supervise the work of the purchased devices have been trained and prepared to work with the devices independently.

3.4 Pori (Finland)

3.4.1 Investments done in the pilot site

- None.

3.4.2 Measurements done in the pilot site

- Manual sampling during wet weather – water quality of the stormwater, three samples have been taken in Suntinoja catchment during a rain event with one-hour intervals starting 1 h after the rain had begun, the samples were taken from the end of the catchment area where the outflow is to the stream.
- Quality of the stormwater it in different flood situations.
- Sampling water quality analysis.
- Water table and discharge measurements.

3.4.3 RTC implemented in the pilot site

- None.

3.4.4 Scenarios simulated in the pilot site

- Base scenario according to stormwater standard Hulevesiopas, rainfall duration 30 min, return period 2 years.
- Risk scenario 1 according to RCP4.5.
- Risk scenario 2 according to RCP8.5.

3.4.5 Implementing RTC and EWL in practice

- Extreme weather layer can be used to look at the impact of residential construction on Suntinoja's capacity.
- Water sampling is conducted to analyze the quality of the stormwater and for modeling it in different flood situations.
- Onsite and online meetings in Pori to clarify the modelling inputs and parameters, manholes in the model linked with catchments and properties in order to present the EWL risk assessment in both catchment and property view.

3.5 Söderhamn (Sweden)

3.5.1 Investments done in the pilot site

- No investments were planned to implement in NOAH project.

3.5.2 Measurements done in the pilot site

- Geodetic survey – identification of data gaps in the stormwater system.
- Composite sample taken with automatic sampler during the wet weather event from one outlet – quality of stormwater.
- Water flowrate and depth measured at one outlet.
- Precipitation measured ca 1.5 km from the outlet.

3.5.3 RTC implemented in the pilot site

- Only virtual RTC cases will be tested in Söderhamn.

3.5.4 Scenarios simulated in the pilot site

- EWL – flood risks level for three rainfall events (local, RCP4.5, RCP8.5).
- Impact of sea level rise in drainage system.
- Impact of HEAWATER pilots on existing UDS.

3.5.5 Implementing RTC and EWL in practice

- EWL will be implemented (currently in test phase) and embedded to urban planning procedures in Söderhamn.
- Söderhamn has mapped potential areas (owned by the municipality and have high EWL risk level) where stormwater facilities can be constructed.

- Söderhamn has also marked other existing measures like impervious asphalt, green areas.

3.6 Liepāja (Latvia)

3.6.1 Investments done in the pilot site

- Automatic hydrological stations.

3.6.2 Measurements done in the pilot site

- Manual sampling during the rain – water quality of the stormwater (4 samples collected).

3.6.3 RTC implemented in the pilot site

- A tidal gate and a pump at the outlet to prevent seawater from backing up into the drainage system. The gate to control the inflow from a newly connected area was not recommended.

3.6.4 Scenarios simulated in the pilot site

- Additional subcatchment added to the system.
- Smart weirwall system which would allow stormwater flow only in one direction.
- EWL maps.
- 10-year return period synthetic rainfall and climate scenarios of nowadays, RCP 4.5 and RCP 8.5.

3.6.5 Implementing RTC and EWL in practice

- EWL and SWMM model is used in the planning of new connections and possible renovation activities to assess the capacity of an existing network.

3.7 Jūrmala (Latvia)

3.7.1 Investments done in the pilot site

- Automatic hydrological station:
  - mobile multiparameter probes,
  - wastewater flow meters,
  - stormwater level sensor complete with automatic sampler,
  - local meteostations.
- Jūrmalas Ūdens Ltd. has obtained an automated sampling device, three local meteo-stations, four flow meters for wastewater flow measurements and a multiparameter probe/sensor for potential contamination detection at household outlets into storm water drainage system.

3.7.2 Measurements done in the pilot site

- Water quality of the stormwater - manual sampling; stormwater quality – manual and autosampler.
- Precipitation, stormwater level and wastewater flow measurements automatic hydrological stations.
- So far Jūrmalas Ūdens Ltd. has collected 20 samples during rain events, including pure stormwater samples (in 2019-2021). Majority of samples collected during 2020-2021 were taken using automatic sampler.

3.7.3 RTC implemented in the pilot site

- None.

3.7.4 Scenarios simulated in the pilot site

- EWL maps.
- Virtual RTC.
- Far and near future climate correction approach.

3.7.5 Implementing RTC and EWL in practice

- Training of the customer's personnel to work with the equipment.

3.8 Ogre (Latvia)

3.8.1 Investments done in the pilot site

- Automatic hydrological stations.

3.8.2 Measurements done in the pilot site

- Manual sampling during wet and dry weather – water quality of the stormwater, the first sample was taken during a rain event and the second sample was taken during dry weather.
- Measurements of the Ogre riverbed upwards from Daugava river water reservoir.
- River water level monitoring during the flood event.
- Fully automated data retrieval, processing, forecasting and visualization from sensors integrated with high resolution DEMs and short-term flood model (LISFLOOD-FP).

3.8.3 RTC implemented in pilot the site

- System for river-flood short-term prediction.

3.8.4 Scenarios simulated in the pilot site

- RTC - a non-return valve/tidal gate and a pump.
- EWL.
- Development plans.

- 10-year return period synthetic rainfall and climate scenarios of nowadays, RCP 4.5 and RCP 8.5.

3.8.5 Implementing RTC and EWL in practice

- According to automatic hydrological stations that are built in the project municipality has developed a description of the principle of operation of the stations.
- The municipality has signed a contract about data collection and maintenance of automatic hydrological stations with external experts.
- In case of Ogre, an important part of EWL is the river flood model. A 3D model of a city-part of River Ogre was generated from a combined drone-created point-cloud and LIDAR data. Further, the gained model results are used in short-term forecasting (24 h), that is also connected to civil-protection system, and, in case of flood-warning, it is able to inform the potentially affected citizens via SMS or e-mail. The results of the forecast can be seen on Grafana platform.

4 Analysis of the impact of NOAH actions

The main objective of the project was to take specific actions and investments to prepare cities for climate change. Analyzed 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 the investment complexity. Moreover, different activities were undertaken in pilot sites. In some partner countries there were only passive measures (targeted at modelling and monitoring) whereas in others - both passive and active measures were introduced (such as modernization of the existing infrastructure or implementation of smart urban drainage system). In the analyzed cases, there were also various problems to be solved, hence: different solutions.

4.1. Economic benefits – construction and maintenance costs

- ✓ **COST**

Case study: Słupsk (Poland)

1. Cost of investments (included pipes, equipment, realization of investment etc.)

Cost of installing rain gauges with data transmission:

As a part of the NOAH project, 6 devices to measure the amount of precipitation were purchased (rain gauges), which were installed in 6 points in the city of Słupsk. Moreover, dedicated software with the system of automatic data archiving, remote transmission and visualization was also acquired. The total cost of purchasing 6 rain gauges with software was about 10 591 EUR (net.).

Cost of installing measuring devices of channels filling:

12 measuring devices of channels filling were installed with the total cost of 26 520 EUR (net.)

2. Cost of maintenance of installed devices

Waterworks workload necessary to run rainfall monitoring (e.g. time needed to prepare a procurement, make a purchase and technical service of the installation); the number of people from the administration and the number of technical employees involved in this work

Two administrative staff worked during the procurement procedure, including one person who is not a member of the NOAH project team (the cooperating person). This work consisted in preparation of documentation and all necessary descriptions for the first and repeated orders – working time approx. 3 days. Whereas, in technical arrangements, installation and commissioning of the devices, three technical employees were involved, including one person who is not a member of the NOAH project team. The time of the work was 2 days.

3. Cost of monitoring

For Słupsk pilot site, samples are taken from 3 reference points (Orzeszkowej, Mickiewicza, Nad Śluzami/Wiejska). Periodically also pure stormwater is tested (as a background) or outflow from wastewater treatment plant. Due to the fact that the sewage network in Słupsk is a combined network, the quality test concerns a mixture of sewage and stormwater. It covers a wider range of parameters than for stormwater transported separately, such as: pH, turbidity, total suspended solids, nitrite nitrogen (NO_2^-), nitrate nitrogen (NO_3^-), ammonia nitrogen (NH_4^+), total nitrogen, phosphate phosphorous (PO_4^{3-}), total phosphorus.

The work of technical/laboratory staff should also be taken into account. On average, sample quality analysis takes 2 to 3 days. The work includes collecting and transporting samples to the laboratory and carrying out the necessary physico-chemical analyzes.

The total cost of stormwater quality monitoring consist in the cost of chemical reagents and laboratory materials. The estimated total cost of a single sampling campaign is approx. 100 EUR. Detailed calculations are available in **Appendix 2**.

4. Cost of models

Model:

· Model creation time: 6 months (which is not a number of person-months, but only the time from the beginning to the end of the work).

· Total cost: approx. 13 300 EUR (total salary; net).

5. Cost of EWL

EWL:

· EWL creation time: 2 months (which is not a number of person-months, but only the time from the beginning to the end of the work).

· Total cost: approx. 3 325 EUR (total salary; net).

6. Cost of trainings required to make the NOAH results useful in the spatial planning procedures
Due to pandemic situation, NOAH trainings were not conducted. Therefore, such information is not available.

Case study: Haapsalu (Estonia)

1. Cost of investments

1.1. Smart weirwall system – includes construction project, components (engine, damper, electronic command system, generator, well) construction etc.
Cost = 47 820 EUR

1.2. Adjusting culvert pipe bottom height to sea level – includes excavation, new culvert pipe installation, restoration of pavements, installation of reinforced concrete slab at the seaward end of the culvert, construction of shore protection.
Cost = 4 692 EUR

1.3. Old secondary damper/weirwall repair work – includes dredging of the culvert ends with an excavator, pressure washing of the culvert pipe and installation of a grate at the seaward end of the culvert.
Cost = 1 044 EUR

2. Cost of maintenance of installed devices
2.1. Uniflex electronic system maintenance – 240 EUR per year.
2.2. Harvesting beach wrack from seaward culvert ends maintaining the normal flow – 1 000 EUR per year.

3. Cost of monitoring of sewage system as well as stormwater and wastewater quality
3.1. Stormwater quality measurement – includes two measurements (between 01.11.2019 – 31.03.2020 and between 01.09.2020 – 31.12.2020).
Quality parameters: pH, Suspended solids, BOD7, Total nitrogen, Total phosphorus and COD.
Cost = 9 480 EUR

3.2. Geodetic survey stormwater runoff/drainage system – mapping manholes – ditches – drainage pipes, their specific profiles and parameters.
Cost = 15 933,96 EUR

3.3 Taking the third stormwater quality measurement by grab-sampling (May - June 2021).
Cost = estimated 500 - 700 EUR

4/5. Cost of models and EWL:
About 450 man-hours.

6. Cost of trainings
About 60 hours.

Case study: Rakvere (Estonia)

1. Cost of investments
Total costs = 101 899.30 EUR + VAT.

2. Cost of maintenance of installed devices
2 man-hours a week, average hourly rate for in Estonia is 10 EUR / hrs (including all taxes), total cost per month = 80 EUR (including all taxes).
In every five years a major maintenance has to be done: replacement of UPS batteries, sensor batteries and other consumables with total cost of 700 EUR + VAT.

3. Cost of monitoring of sewage system as well as stormwater and wastewater quality
The cost of one set was 4 000 EUR + VAT, totally 2 sets were ordered with a total cost of 8 000 EUR + VAT

4./5. Cost of models and EWL
Total cost = 67 200 EUR*
*calculated from TalTech staff cost budget on the basis of approximate workhours and hourly rate.

6. Cost of trainings
Budget for TalTech and Estonian Water Association for trainings is 17 000 EUR including VAT. Translation of the materials to Estonian language 9 000 EUR including VAT. Actual expenditures will be smaller because of the covid restrictions.

Case study: Pori (Finland)

1. Cost of investments: none.

2. Cost of maintenance of installed devices
It cost around 1 330 EUR to maintain, install and dismantle the monitoring system.

3. Cost of monitoring of sewage system as well as stormwater and wastewater quality.
The rent of the monitoring equipment was 1050 EUR for three weeks.

4./5. Cost of models and EWL
450 man hours.

6. Cost of trainings required to make the NOAH results useful in the spatial planning procedures 60 man hours.

Case study: Söderhamn (Sweden)

1. Cost of investments
No investments have been done in NOAH (0 EUR).
Investments for virtual RTC + LID (low impact development) for 5 sites is ca 500 000 EUR.

2. Cost of maintenance of installed devices
No investments have been done in NOAH (0 EUR).
Maintenance costs for 5 virtual RTC sites is ca 500 EUR / month. In every five years a major maintenance has to be done: replacement of UPS batteries, sensor batteries and other consumables with total cost of 3 000 EUR + VAT.

3. Cost of monitoring of sewage system as well as stormwater and wastewater quality
Approximate cost: 5 000 EUR.

4./5. Cost of models and EWL
48 000 EUR including all taxes*
* calculated from TalTech staff cost budget on the basis of approximate workhours and hourly rate

6. Cost of trainings required to make the NOAH results useful in the spatial planning procedures
Budget for TalTech and Estonian Water Association for trainings is 17 000 EUR including VAT. This will be reduced due to covid restrictions.

Case study: Liepāja (Latvia)

1. Cost of investments
No investments done in the pilot territory.

2. Cost of maintenance of installed devices
No costs associated.

3. Cost of monitoring of sewage system as well as stormwater and wastewater quality
No costs associated.

4./5. Cost of models and EWL
The cost of EWL comprised the cost of data (surveying of the sewers) amounting to 4 600 EUR and overhead personnel cost, amounting to 1 800 EUR, together 6 400 EUR, or approximately 450 EUR per ha.

6. Cost of trainings required to make the NOAH results useful in the spatial planning procedures.
These costs have not been incurred but estimated to be around 600 EUR (excluding the time/personnel cost of trainees).

- ✓ **BENEFITS**

Case study: Słupsk (Poland)

1. Existing fees related to the discharge of pollutants to surface waters
According to the Polish law, in the case of discharging untreated stormwater to the receiver (also with storm overflows), only two parameters of quality are limited: TSS not higher than 100 mg/L and petroleum hydrocarbons in amounts not exceeding 15 mg/L *(based on: the Regulation of the Minister of Maritime Economy and Inland Navigation of 12 July 2019 on the substances that are particularly harmful to the aquatic environment and conditions to be met upon discharging them*

into water or ground, and upon discharging stormwater and thaw water into water or water facilities [Journal of Laws of the Republic of Poland 2019, Item 1311]). However, stormwater rinses numerous (also hazardous) contaminants from paved surfaces and in fact, becomes a sewage. It is therefore reasonable to assume a wider range of control parameters than for pure stormwater. Moreover, in combined sewage system, a mixture of sewage and stormwater is transported to the receiver (ground or surface water), which also confirms the need to increase the number of tested quality parameters.

At the moment, Słupsk Waterworks do not incur charges for the drainage of stormwater. Nevertheless, it is estimated that implementation of the NOAH solutions (including model) can reduce the fees related to the discharge of mixed sewage and stormwater as well as untreated stormwater from storm overflows to the receiver. These fees result from the following legal acts:

- ✓ The Water Law Act of 20 July 2017 [Journal of Laws of the Republic of Poland 2020, Item 310, as amended]
- ✓ Regulation of the Council of Ministers of 22 December 2017 on unit rates for water services [Journal of Laws of the Republic of Poland 2017, Item 2502, as amended]

Fees for water services for the discharge of sewage into surface waters or into the ground consist of two charges:
- **fixed charge:** 55.4 EUR per day for 1 m^3/s
- **variable charge,** which is the product of unit fee rate and the load of the substance discharged with sewage into waters or into the ground (expressed in kg), including substances expressed as the parameters/indicators of:
1) BOD : 0.38 EUR/kg
2) COD: 0.19 EUR/kg
3) TSS: 0.12 EUR/kg
4) sum of chlorides and sulphates ($Cl^-+SO_4^{2-}$): 0.011 EUR/kg
5) other parameters:
    - volatile phenols: 10.10 EUR/kg
    - selected persistent organic pollutants and heavy metals: 27.62 EUR/kg

The fees paid by the Słupsk Waterworks do not apply to stormwater, but to sewage but, in combined sewage system, a mixture of sewage and stormwater is transported to the receiver.
If above mentioned fees would be applied to cities like Słupsk, the cost of overflow occurring one a two years can be estimated at 100 EUR and can be increased by 160 EUR by the adverse effecte of climate changes. These estimations include fees for COD, COD and TSS only as these parameters were in the scope of NOAH monitoring; and these parameters are subjects of relatively low charges. When the overflow occurring once a twenty years is concerned, the cost increases to nearly 500 EUR/rainfall event and can be further increased to 670 EUR by the outflow surplus resulting from climate changes. These costs, even though may seem low at a city scale, would be much greater if more frequent overflows and remaining pollutants would be added to the calculation.

2. Number of floods , their costs (= financial loses; if available)

- reduction of financial losses related to floods

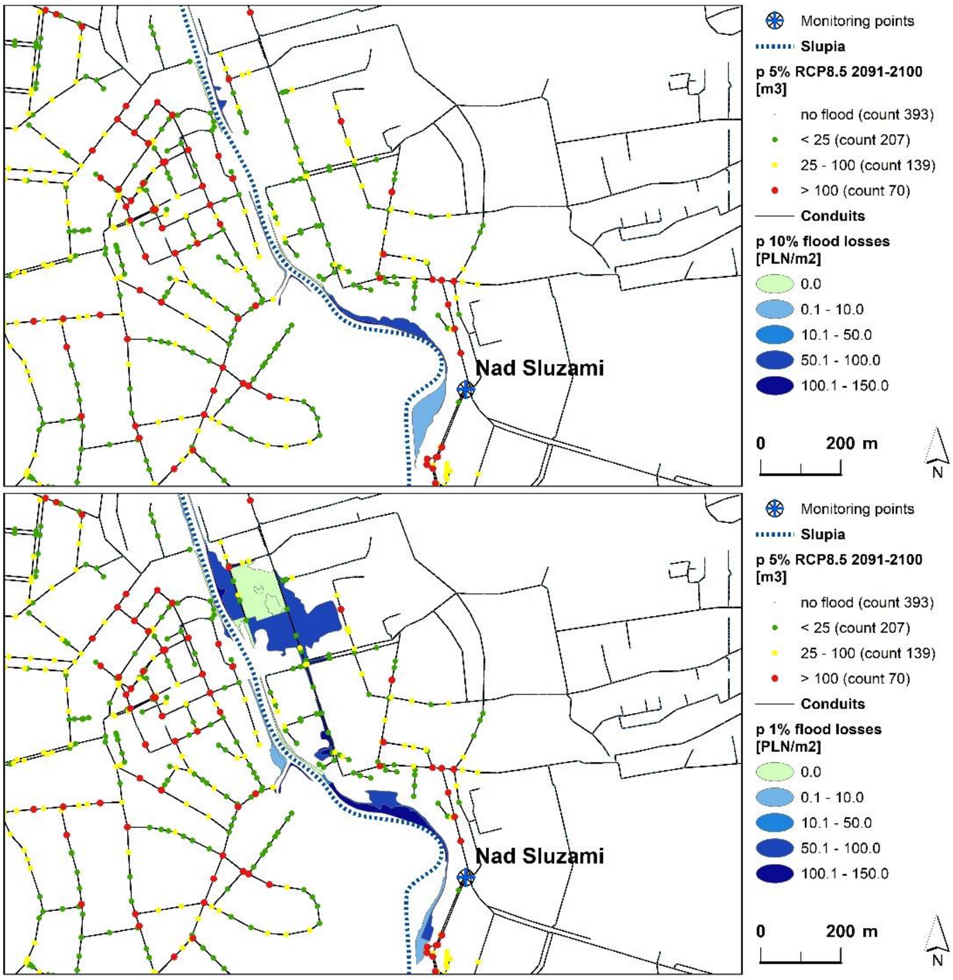

Fig. 4. Flooded area (p =10%, where p is probability) based on the national scale flood risk maps

The figure 4 presents flooded area (p=10%) based on the national scale flood risk maps. The color scale for polygons represents losses related to the flooding. The second figure presents the same, however, for the p=1% flooding.

When we combine these maps with locations, where the sewer flooding occurs according to the NOAH models (EWL's green, yellow and red dots) we can assume, where the losses can be decreased in case of successful RTC or other solutions tested in our project.

There are limitations to this approach. E.g. in Poland such flood risk and losses maps are available for the probability of 0.2, 1 and 10% only, while in the EWL we have analysed p=5 and 50%. The next limitation results from the scope of outputs from our SWMM model – the flooded area in the NOAH project was not calculated so it is not possible to simply compare area from the official flood map with the flood map.

The flooding costs per area unit used in the flood risk maps, can be potentially applied to results of the EWL (urban flooding simulations). However, it requires a further development of the EWL in Słupsk and addition of the flood area mapping modlule.

3. Other measurable costs (benefits) from the application of the project:

- protection of the wastewater treatment plant against excessive water inflow during rainfall,
- savings in cities connected with actions consistent with "Climate Change Adaptation Plans" (e.g. "Climate change adaptation plan for the City of Słupsk"). Due to actions implemented in frame of NOAH project, the city of Słupsk partially obtained equipment for adaptation and mitigation of the effects of climate change.

Case study: Haapsalu (Estonia)

Not applicable

Case study: Rakvere (Estonia)

Number of flooded properties & related savings:

Scenario	Flooded properties	Financial losses per one event	Savings due to EWL and RTC (less properties flooded) per one event
Local	372	886 104.00 EUR	443 052.00 EUR
RCP4.5	337	802 734.00 EUR	561 913.80 EUR
RCP8.5	499	1 188 618.00 EUR	713 170.80 EUR

Flood loss per property was taken 2 382 € assuming that the depth will not exceed 0.2m. This is a number from a previous study (https://www.researchgate.net/publication/268071767)

Case study: Pori (Finland)

1. Existing fees related to the discharge of pollutants to surface waters

No pilot investment was made.

2. Number of floods, spatial extent, their costs

Pori is one of the most significant flood risk areas of Finland. Flooding from the river tends to occur on a 10-20 years regular basis, if the flood protection levees are overtopped, the estimated damages in Pori in the worst case scenario could increase to 3 billion euros. The size of the river flood risk area in Pori is about 50 km^2 of which less than half of this area is built up. The rest is

made up of agricultural and sparsely populated areas. There are about 5 000 apartments and 15 000 inhabitants in the flood risk area.
It is harder to estimate the occurrence of stormwater floods, but the occurrence of said flood event can affect the whole of urban area of the City of Pori. The City of Pori is protected by dams on both sides of the river and during a stormwater flood event the water needs to pumped into the river from the ditches by pumping stations. The flatness of Pori does not help with the flow either, which contributes to the wide spread of the stormwater floods. In 2007's stormwater flood the losses amounted to EUR 21.7 million. For private properties, insurances paid 8.2 million euros, the city of Pori paid 4 million euros and the estimate for other damages paid was EUR 3 million.

3. Other measurable costs of the system before the NOAH and benefits from the application of the project.
As in Pori there were no pilot investment, the benefits cannot be estimated in the economic sense. Most of the benefits are in the training and networking opportunities through the program. As well as the tools and lessons learned acquired from NOAH which will be beneficial in creating the own Stormwater Program in Pori.

Case study: Söderhamn (Sweden)

Number of flooded properties & related savings:

Scenario	Flooded properties	Financial losses per one event	Savings due to EWL and RTC (less properties flooded) per one event
Local	108	257,256.00 EUR	154,353.60 EUR
RCP4.5	168	400,176.00 EUR	360,158.40 EUR
RCP8.5	230	547,860.00 EUR	383,502.00 EUR

Flood loss per property was taken 2 382 € assuming that the depth will not exceed 0.2m. This is a number from a previous study (https://www.researchgate.net/publication/268071767).

Case study: Liepāja (Latvia)

1. Existing fees related to the discharge of pollutants to surface waters: none.

2. Number of floods, spatial extent, their costs: no data available.

3. Other measurable costs of the system before the NOAH and benefits from the application of the project.
The benefits of spillage reduction activities implemented as a result of NOAH actions will come in the future - as of now, the project has provided the basis for these actions to take place. It is

planned to further validate the EWL by modelling different system improvement and expansion options, as well as detailing flooding extent, flooding costs and benefits from improving the system. The model and EWL will be especially useful in assessing SUDS / green infrastructure options.

Conclusions from subsection 4.1.:
The costs incurred for NOAH activities in pilot sites can be divided into costs related only to monitoring (passive measures costs, like in Słupsk, Pori or Söderhamn) and costs of both – passive and active measures in form of investments (Haapsalu). The common cost across all facilities was the cost of the model and EWL. Which is obvious, complex tasks generated higher costs. Moreover, costs were related to the size of pilot site are and local conditions. However, in pilot sites where a pilot investment have not been done, it is very hard to estimate the benefits in the economic sense. In this cases most of the benefits are found in the training and networking opportunities through the project. An added value is the NOAH tools, useful for gathering important information that can be used for more sustainable flood risk management. Therefore, even in pilot sites where only monitoring was carried out, benefits were also observed. It is connected with gaining the knowledge how to make it easier to adapt Baltic cities to climate change. Moreover, it was confirmed that in almost each pilot site, the introduction of model will allow measurable savings in reducing flood damages.

4.2. Technical complexity – description form planning to implementation

Case study: Słupsk (Poland)

1. Scale of the project
In Słupsk the scale of the project pilot is the central part of city. The pilot site covers a relatively large area of 23 km^2 (more than 50% of the city area).

2. What was the purpose of these solutions
The activities done in the NOAH project were aimed to provide data required for the development of hydraulic model and to analyse the potential for decreasing the inflow of stormwater to WWTP and CSO.

3. Limitations/technical problems in implementation
During the implementation of the NOAH project the problem with inaccuracies in the inventory of the sewage network was identified. Even though the large extent of spatial data was available in Słupsk the data formats and structure did not allow to use these data for the parameterisation of hydraulic model and characterization of catchments in a time shorter than two months. The proper calibration of hydraulic model was not possible before the local rainfall monitoring became operational.

4. Technical benefits after implementation of NOAH solutions (what actions are facilitated)
Before installing the rain gauges, the Słupsk Waterworks did not collect rainfall data. Due to the NOAH project investment, the Słupsk Waterworks are able to obtain such data as: amount of precipitation and intensity of rainfall, current filling level of the channels (and the relationship between the amount of precipitation and the filling of the sewage system channels).

Other technical benefits:

- hydraulic model/EWL for Słupsk pilot site,
- automated data gathering,
- monitoring of the operation of the combined sewage system.

Case study: Haapsalu (Estonia)

Limitations/technical problems in implementation (spatial data gaps, errors in a sewage system inventory):

- Lack of geodetic data about the stormwater drainage and the ditches at pilot catchment
- Malfunctioning of the initially installed weirwall that lead to the need of replacement of the electrical motor and the spindle bearings.

Technical benefits after implementation of NOAH solutions
The city planner has the opportunity to use the EWL to identify the properties in the area under flooding risk to make recommendations for the implementation of mitigation measures.
The smart weirwall-system is operated decentrally, based on the water levels at inlet and outlet of the weirwall. Therefore, there is no need for an operator to manually adjust the weirwall.

Case study: Rakvere (Estonia)

Limitations /technical problems in implementation (spatial data gaps, errors in a sewage system inventory);

- Providing power for the remote sensor (level sensor in the tunnel). It is situated in densely developed area with limited possibilities to install a solar panel. The communication unit of the sensor is mounted on street lighting posts which has a grid power only during nighttime. Therefore, batteries were installed to provide power during the time street lights are off.
- Avoiding birds (ducks) feeding on the pond to be sucked into the inlet chamber of the weirwall. Floating barrier (buoys) will be installed to solve that problem.
- Get permissions for ponding water (raising the level of the existing pond for temporal stormwater storage) from the authorities and owners of the neighboring properties.

Technical benefits after implementation of NOAH solutions (what actions are facilitated)

- Fully automatic system to increase the capacity of the main stormwater tunnel up to 30% during cloudbursts.
- Planning layer (EWL) for reducing future flood risk up to 40% in central part of the town. The properties with higher runoff and flood risk are shown in color coding in order to facilitate planning the mitigative measures.

Case study: Pori (Finland)

Limitations/technical problems in implementation (spatial data gaps, errors in a sewage system inventory);
Spatial data gaps and errors in the pipeline data as well and some of the data was not compatible with SWMM and needed to be modified for the program.

Technical benefits after implementation of NOAH solutions (what actions are facilitated)
Implementation of the EWL enables the urban planners to detect the flood prone areas in the city and therefore plan mitigative measures in order to reduce the flood risks caused by e.g. future constructions and developments. At the same time the EWL enables to analyze the flood risks in the current urban environment to plan technical solutions and notifying of general public to reduce the potential flood damages.

Case study: Söderhamn (Sweden)

Limitations/technical problems in implementation (spatial data gaps, errors in a sewage system inventory);

- Missing data about stormwater system (heights, diameters).
- Properties are not represented in GIS as polygons which is needed for color coding of EWL risk levels.

Technical benefits after implementation of NOAH solutions (what actions are facilitated)
- Better knowledge of stormwater system and which properties are at risk of flooding and where measures are most effective.
- Pilot projects modelled on measures in other parts of the municipality and other municipalities.
- Basis for planning future buildings and basis for prioritizing measures within existing built areas.
    - Significant (up to 90%) reduction (in case of virtual investments + EWL) of flood spillages without the need for enlargement of underground pipelines.

- Planning layer (EWL) for reducing future flood risk up to 40% in central part of the town. The properties with higher runoff and flood risk are shown in color coding in order to facilitate planning the mitigative measures.

Case study: Liepāja (Latvia)

Limitations/technical problems in implementation (spatial data gaps, errors in a sewage system inventory);
In absence of detailed data on the infrastructure, surveying can take a lot of resources. However, this is a needed investment which will pay out in the future. Integration of open-source software with municipality IT systems and keeping information up to date may be challenging, thus special attention should be paid to adoption of and training for the use of the model by the municipality.

Conclusions from subsection 4.2:
In most of the analyzed pilot areas the greatest technical obstacle in the implementation of the project solutions were various types of inventory problems, like missing or inaccurate data concerning the structure and technical condition of the existing sewage network.

Thanks to the NOAH activities, the municipalities and water companies obtained such data and tools for effective operation and management of stormwater and sewage systems. The obtained data will help to reduce the risk of flooding caused by further intensive development of urban areas and increase the capacity of the utilities and municipalities. Modeling and the EWL will enable sustainable spatial planning, taking into account density of urban tissue and the flood risks in the present and future urban environment. Moreover, NOAH ideas will help to plan and implement technical solutions to minimize potential flood damages and effectively inform the public about the impending risk.

4.3. Environmental benefits and risk - the positive impact of NOAH

1. Social gains:
   - Demonstrating flood mitigative measures for climate proof cities in public space.
   - Stressing the importance of concrete climate actions and benefits on urban environment.
   - Raising the capacity of local municipality and water utility to plan flood mitigative measures.
   - Filling gaps in existing UDS operation and deficiencies in urban spatial planning.
   - Better knowledge on the flood risks.
   - More information to be shared with general public to reduce potential flood damages.
   - Networking opportunities.

- Highlighted need for mitigative measures may result in new blue and green infrastructure which can provide additional benefits such as: leisure/recreation areas, decreased peak temperatures, aesthetic values, reduced noise and air pollution etc.

2. Other positive environmental effects:
- **Reduced amount of contaminated stormwater to the sea**
- Decrease in the number (and volume) of floods which reduces the spillages of untreated wastewater to the receivers (local rivers) and Baltic Sea.
- Flood and pollutants runoff reduction.
- Regular monitoring of the quality of stormwater (including emerging pollutants).
- Methods of NOAH prevent the domino effect of water quality impairments starting from intense rainfall events and ending with polluted runoff and untreated wastewater spillages.
- Supporting function in spatial planning.
- Identification of flood risk areas – recommendations for implementing green infrastructure (NBS) or other solutions, e.g.
  - Formation of rain gardens.
  - Formation of retention reservoirs.
  - increasing the share of green areas in the city.
  - transformation/reconstruction of impermeable surfaces into permeable ones
    General advantages:
    - ✓ impact on increasing biodiversity,
    - ✓ habitat-forming function,
    - ✓ improvement of urban microclimate,
    - ✓ reduction of “the urban heat island”,
    - ✓ improvement of local water management,
    - ✓ supply of groundwater resources
    - ✓ reduction of flood risks – increasing the safety of residents
    - ✓ creation of new recreational areas.
- Possible use of EWL in larger scale in the future, which is beneficial for future planning to reduce potential flood damages.
- Smart weirwall systems implemented demonstrate efficient methods to actively interfere to urban drainage system in order to reduce the flood and pollution risk.

Conclusions from subsection 4.3.:

The impact of NOAH project is undoubtedly positive. It is predicted that NOAH will contribute not only to increase the sense of security of urban residents, but most of all it will enable convenient access to hydrological and hydraulic data and use of EWL on a larger scale in the future, which is beneficial for spatial planning in the context of potential flood damages. Lesson learned from NOAH will also increase the capacity of local municipalities and water utilities to implement flood prevention and mitigative actions.

Among many environmental advantages, during the NOAH project an 'action path' was developed for effective monitoring and in some cases (like in Haapsalu) for treatment, preventing pollution of Baltic Sea by stormwater runoff and incidental spillages of untreated wastewater.

5 Policy environment - barriers in local policy and regulations that will put risk on the transfer of the results of NOAH

Barriers in local policy and regulations should be considered in two aspects:

1. quality of stormwater and surface runoff in the context of its discharge into the environment
2. spatial planning in the context of climate change.

Environmental aspect of policy and regulations is presented below, whereas spatial planning aspect is available in a broader context in the O2.4 report.

The evaluation of the current Urban Waste Water Treatment Directive (91/271/EEC) identified some gaps related to lack of compliance and differences in implementation. One of the problematic issue are overflows from combined sewers. It is important to recognise the multiple purposes achieved by the sewer networks across Europe and to fix 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 waterbodies. CSOs must be properly designed and maintained to prevent flooding and minimise adverse impacts on the water environment and protect public health.

It seems that this problem applies also to other NOAH partner countries. The legal regulations regarding the quality and possibility of stormwater discharge into the receiver are very general. Below are several examples of different approaches to the stormwater management in urban areas

In Latvia, CSO`s are not monitored, nor controlled. WWTP bypasses and overflows are supposed to be monitored, however, whether it is respected and controlled, is a responsibility of treatment plant itself and local municipality, respectively.

Pollutant emissions into environment are regulated by the law “On Pollution”. A water management company obtains a polluting activity permit (based on Republic of Latvia Cabinet Regulation No.404 and No.1082) according to the location of the treatment equipment, and this permit determines pollutants limits that can be exposed into environment for treatment facilities with a capacity starting from 5 m^3/d.
The State Environmental Service of the Republic of Latvia determines the emission limits based on Republic of Latvia Cabinet Regulation No. 34 and the law “On pollution”, which in Section 10 part 4 specifies that emission limits are determined for normal operating conditions. Therefore, the polluting activity permit does not set limits for pollutants in the event of an accident or flooding. “Water Management Law” in Section 13 defines Temporary Exceptions for the Achievement of Environmental Quality Objectives, stating that such exceptions are possible if pollution occurs due to exceptional circumstances or extreme weather events and all measures are taken to further minimize such events. Based on “Natural Resources Tax Law” Section 22 , the

tax for pollution during extreme conditions is calculated for emitting period based on permit`s limit values if reported to authorities, or tenfold the amount if not reported. An operator must inform the Authority in writing of the emergency due to force majeure and submit for approval a plan of measures to prevent further pollution within 1 business day. Republic of Latvia Cabinet Regulation No. 404 reports the procedure of calculation and payment for Natural Resources Tax. Republic of Latvia Cabinet Regulation No. 34 in Section 36.3 refers to the need to minimize surface water pollution caused by overload or accidents during rainfall. In Section 41.4 it refers to treatment plant design that allows taking samples in stormwater overflow chambers and emergency overflows. Republic of Latvia Cabinet Regulation No.327 regulates the construction of sewerage structures, stating that stormwater overflow chambers and emergency by-passes need to be constructed according to wastewater supply regime. If any equipment of treatment facility stops operation, the quality of the wastewater treatment plant effluent shall not be lower than that specified by the Regional Environmental Board. Wastewater treatment parameters in wastewater treatment plants during renovation or reconstruction shall be coordinated with the Regional Environmental Board. By the 1st of March each year the operator must submit the official statistical environmental protection form to the LEGMC (Latvian Environment, Geology and Meteorology Centre) with information about the previous calendar year, in accordance with the Cabinet Regulation No. 271. The form includes information about the amount of overflow and bypass wastewater discharge, gained either by calculations or from respective flow meter reading. The control and supervision of the building regulations is the responsibility of the respective building authority.

Whereas in Estonia, according to the Water act (Veeseadus) stormwater from the combined sewer system can be directed into the receiving waterbody during cloudbursts with wastewater in the ratio of at least four to one. Combined sewer overflows have to be designed in such a manner that they are activated only if the discharged water is one part wastewater and at least four parts stormwater. The ratio of storm-to wastewater is determined computationally in the construction project.

In Polish law, stormwater runoff was considered to be a sewage until 2017 - in accordance with the Water Law, legal act transposed from UE Water Framework Directive. After the adoption of a new law (entry into force in 2018) stormwater is no longer included in the definition of wastewater. Although it is obvious that precipitation at the moment of contact with the surfaces (also during surface runoff from roofs) - and during transport via sewage system - becomes a sewage, as it rinses accumulated contaminants. Furthermore, the lack of detailed regulations on charges for collecting stormwater, causes significant shortages in financing the infrastructure. It is necessary to develop regulations and guidelines that will enable obtaining funds for stormwater infrastructure.

However, according to Polish law it is possible to transport sewered runoff (stormwater or snowmelt) without treatment directly to the receiver (such as water, water devices or - in some cases -ground), if it is discharged from unpolluted areas (i.e. residence areas, pavements etc.).

From heavily contaminated areas (i.e. industrial areas, roads, airports, fuel storage and distribution facilities) it is permitted, if following quality parameters are not exceeded: TSS concentration of 100 mg/L and concentration of petroleum substances of 15 mg/L. In case of water reservoirs (including lakes) with constant inflow/outflow of surface waters, it is allowed to discharge stormwater from overflows, if the average annual number of discharges from individual overflows does not exceed 5. Under no circumstances, can stormwater be discharged to groundwater as well as to water devices - in case of stormwater that contains substances, which are considered to be particularly harmful to aquatic environment. In exceptional situations (with the permission of the competent authority):

1) runoff or stormwater from overflows can be discharged into receiver (surface water or ground) less than 1 km from bathing areas,

2) it is possible to discharge stormwater to lakes and their tributaries, if the time of inflow of these waters to the lake is shorter than 24 hours, only if it does not interfere with water quality requirements.

To sum up: two parameters of stormwater quality are limited: TSS and petroleum hydrocarbons and only these two parameters are taken as a reference and required for monitoring of stormwater.

General conclusions on Baltic Sea Region policy environment and legal acts:
Regardless of the location of the urban area, stormwater during transformation to surface runoff rinses numerous (also hazardous) contaminants from paved surfaces and in fact, becomes a sewage. Moreover, in combined sewage system a mixture of sewage and stormwater is transported (and incidentally discharged directly to the receiver - ground or surface water) which means that some quality parameters may be completely different than expected. It is therefore reasonable to assume a wider range of control parameters in regular monitoring than for pure stormwater and to make every effort to develop regulations aimed at limiting the uncontrolled spillages of untreated runoff into environment, also those aimed at forcing appropriate pretreatment methods.

6 Conclusions and summary of the positive impact of NOAH solutions

Urban stormwater systems management has become an important issue due to increased awareness of the load of pollution (nutrients and hazardous substances) that may be introduced into the waters of receiver during intense rainfall events. Climate change that causes more frequent extreme weather events like storms with high water levels, as well as unsustainable urban planning accelerates surface runoff and causes rapid transport of pollutants. Unfortunately, existing drainage systems are ineffective and undersized to meet the demands of future climate situations, which contributes to the incidental discharge of untreated sewage directly to the receiver.

It is worth mentioning that it is financially unrealistic to rebuild all drainage systems in Baltic Sea Region cities to avoid these discharges. Both innovative passive and active methods like holistic urban planning, real time control of urban drainage systems should be used to solve this problem. Therefore the NOAH project brings together the partners with the same interest to take up the challenge of reducing urban stormwater runoff and the spillages of untreated wastewater into the receiving waters. The joint implementation of innovative solutions to limit natural waters quality deterioration by contaminated surface runoff is one of the main objectives of NOAH.

When the direct outflow from sewer systems is considered, the estimated impact of climate changes is very diversified. In pilot sites the estimated increase in discharge is 5-199% and 16-786% in the RCP 4.5 and RCP 8.5 scenarios, respectively. Such 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. Despite the fact that the estimations are quite general, regardless of the site-specific approach to integrating of climate changes into the EWL, there is a clear evidence that the estimated floods and discharges at all pilot sites tend to increase significantly.

In all pilot sites where the separate sewage system exists, the rainfall intensity mainly influences the risk of urban floods and, to a lesser extent, the direct discharge of untreated stormwater runoff to receiving waters. In three pilot sites, Słupsk (Poland), Rakvere (Estonia) and Söderhamn (Sweden), measures aimed at the minimization of flooding volumes were evaluated using the EWL. These measures, when simulated using hydraulic models, have proven to be effective. They allowed to reduce the floods caused by the rainfall of the 2-year return period by 60 to 90%. The efficiency of measures is lower when more severe rainfall events are analysed. Most of climate change scenarios and mitigative measures were applied in Extreme Weather Layers to assess the spatial distribution of flood risk in pilot sites. Furthermore, for part of pilot sites (Rakvere, Söderhamn), these assessments were used to estimate the possible savings related to the change in the number of flooded properties.

Generally, the analysis of the impact of NOAH project was rather difficult as the analyzed pilot sites differ in many aspects and different activities were implemented. In some pilot sites, no real investment were made but benefits of the future activities were analysed by modelling.

The costs incurred by the pilot sites was divided into passive and active investments. The common cost in all objects was the cost of the model and EWL. Modeling and the EWL are very important because they will enable sustainable spatial planning, taking into account density of urban tissue and the flood risks in the present and future urban environment. Moreover, NOAH ideas will help to plan and implement technical solutions to minimize potential flood damages and effectively inform the public about the impending risk. Which is obvious, larger investments generated higher costs but also gave the better tool for protection against floods.

It is worth emphasising that all undertaken activities (passive and active) helps to get important information that can be used for running more consciously risk management. Even in pilot sites which invest in monitoring, economic benefits were observed. It was connected with acquiring knowledge that will make it easier for the city to adapt to climate change. In most pilot sites, the implementation of models will allow measurable savings in reducing flood damages.

Thanks to all investment (active and passive), the pilot sites also gained the ability to obtain data to which there was no access before. These data allow to prepare to reduce the flood risks caused by future constructions and development of urban areas.

Among many environmental advantages, during the NOAH project an 'action path' was developed for effective monitoring and in some cases (like in Haapsalu) for treatment, preventing pollution of Baltic Sea by stormwater runoff and incidental spillages of untreated wastewater.

Lesson learned from NOAH project will be reflected in the capacity building of local municipalities and water utilities to implement flood prevention and mitigation measures.

Although the problems undertaken in the NOAH project are very important, the legal acts and regulations regarding the quality and possibility of stormwater discharge into the receiver are very general.

Summarizing, the impact of NOAH project is undoubtedly positive. Solutions and ideas developed within the project provide the appropriate tools to prepare Baltic urban areas to climate change and will enable to make Baltic Sea Region much more resistant to the climate change effects. At the same time, the knowledge generated by the project allowed to understand the magnitude of risk posed by urban runoff to the Baltic Sea, and to assess quantitatively the climate change - driven increase in risks and achievable reduction of risk by appropriate spatial planning.

Appendix 1: Concentrations of pollutants in runoff [mg/l] (based on literature review)

- Values marked with the bold font are reported by countries hosting pilot sites of the NOAH Project.
- Values highlighted with green are those used in the calculation of the loads of pollution in cities participating in the NOAH project. These values represent average concentrations observed in individual cities or the single observation if there was only one sampling of runoff in the city. The Słupsk pilot site was excluded from this comparison because the comparison includes the stormwater runoff only, while in Słupsk the observations represent a mixture of stormwater and wastewater.

Pollut.	Value	From	To	Remarks	Source
TSS	101.0			Median for residential urban runoff (USA)	US EPA (1983); Strassler et al. (1999)
	69.0			Median for commercial urban runoff (USA)	US EPA (1983); Strassler et al. (1999)
	150.0	20.0	2890.0	Mean - Urban runoff with domestic wastewater (USA)	Bastian (1997); Strassler et al. (1999)
	23.7	1.1	85.0	Mean of 25 samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha.	Milukaitė et al. (2010)
	3220.0			Mean of samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha. Concentrations for relatively high rainfall intensity (10.2 mm/h)	Milukaitė et al. (2010)
	62.0			Median - Mixed land use urban areas (over 8 000 samples, USA).	NRC (2009); NSQD (2008)
	128.0	0.1	4800.0	Mean of 5232 samples of runoff from urban areas with at least 50% of impervious surface.	NSQD (2015)
	108.5	0.0	10505.0	Mean of 9034 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
	300.0			**Value used in Poland for the assessment of impacts of pressures** **runoff from medium and high density residential, communication, industrial and commercial areas.**	**DHI (2019)**

	100.0			**in bodies of surface water**	**runoff from low density residential and green urban areas.**	**DHI (2019)**
		74	**3496**	**5-years monitoring campaign of runoff in the city of Łódź in Poland**	**communication areas**	**Sakson et al. (2014)**
		58	**561**		**mixed urban areas**	**Sakson et al. (2014)**
	43.79	**10.3**	**125.17**			
COD	73.0			Median for residential urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	57.0			Median for commercial urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	75.0	20.0	275.0	Mean - Urban runoff with domestic wastewater (USA)		Bastian (1997); Strassler et al. (1999)
	53.0			Median - Mixed land use urban areas (over 8 000 samples, USA).		NRC (2009); NSQD (2008)
	82.2	1.0	1674.0	Mean of 3278 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	88.1	1.0	1058.0	Mean of 1102 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	40			**Value used in Poland for the assessment of impacts of pressures in bodies of surface water**	**Runoff from green urban areas**	**DHI (2019)**
	50				**Runoff from residential areas**	**DHI (2019)**
	70				**Runoff from commercial and industrial areas**	**DHI (2019)**
	100				**Runoff from communication areas**	**DHI (2019)**
	47.06	**17.08**	**77.04**			
BOD	10.0			Median for residential urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	9.3			Median for commercial urban runoff (USA)		US EPA (1983); Strassler et al. (1999)

<table>
<tr><td rowspan="6"></td><td>11.7</td><td>0.2</td><td>297.0</td><td colspan="2">Mean of 1217 samples at the inflow to stormwater BMPs</td><td>ISBMPD (2019); Clary et al.. (2020)</td></tr>
<tr><td>13.8</td><td>0.1</td><td>433.4</td><td colspan="2">Mean of 3786 samples of runoff from urban areas with at least 50% of impervious surface.</td><td>NSQD (2015)</td></tr>
<tr><td>10</td><td></td><td></td><td rowspan="3">Value used in Poland for the assessment of impacts of pressures in bodies of surface water</td><td>Runoff from green urban areas</td><td>DHI (2019)</td></tr>
<tr><td>20</td><td></td><td></td><td>Runoff from plazas/squares, commercial and industrial areas</td><td>DHI (2019)</td></tr>
<tr><td>30</td><td></td><td></td><td>Runoff from other urban areas</td><td>DHI (2019)</td></tr>
<tr><td>4.55</td><td>2.29</td><td>7.27</td><td colspan="3"></td></tr>
<tr><td rowspan="6">TN</td><td>2.000</td><td>0.400</td><td>20.000</td><td colspan="2">Mean - Urban runoff with domestic wastewater (USA)</td><td>Bastian (1997); Strassler et al. (1999)</td></tr>
<tr><td>3.049</td><td>0.195</td><td>90.100</td><td colspan="2">Mean of 911 samples of runoff from urban areas with at least 50% of impervious surface.</td><td>NSQD (2015)</td></tr>
<tr><td>1.970</td><td>0.005</td><td>53.257</td><td colspan="2">Mean of 3346 samples at the inflow to stormwater BMPs</td><td>ISBMPD (2019); Clary et al.. (2020)</td></tr>
<tr><td>1.750</td><td></td><td></td><td rowspan="2">Value used in Poland for the assessment of impacts of pressures in bodies of surface water</td><td>Runoff from communication areas</td><td>DHI (2019)</td></tr>
<tr><td>7.500</td><td></td><td></td><td>Runoff from other urban areas</td><td>DHI (2019)</td></tr>
<tr><td>4.7</td><td>1.44</td><td>10.6</td><td colspan="3"></td></tr>
<tr><td rowspan="4">TKN</td><td>1.900</td><td></td><td></td><td colspan="2">Median for residential urban runoff (USA)</td><td>US EPA (1983); Strassler et al. (1999)</td></tr>
<tr><td>1.179</td><td></td><td></td><td colspan="2">Median for commercial urban runoff (USA)</td><td>US EPA (1983); Strassler et al. (1999)</td></tr>
<tr><td>1.300</td><td></td><td></td><td colspan="2">Median - Mixed land use urban areas (over 8 000 samples, USA).</td><td>NRC (2009); NSQD (2008)</td></tr>
<tr><td>2.099</td><td>0.045</td><td>175.000</td><td colspan="2">Mean of 4739 samples of runoff from urban areas with at least 50% of impervious surface.</td><td>NSQD (2015)</td></tr>
</table>

	1.963	0.001	175.000	Mean of 5219 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
	2.61	**0.51**	**7.19**		
N org.	3.066	0.130	13.448	Mean of 50 samples of runoff from urban areas with at least 50% of impervious surface.	NSQD (2015)
	0.886	0.000	19.446	Mean of 1308 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
	0.73	**0.25**	**1.74**		
N-NH3	0.124	0.002	0.657	Mean of 29 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
	0.481	0.000	53.000	Mean of 4036 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
N-NH4	0.514	0.016	12.880	Mean of 2052 samples of runoff from urban areas with at least 50% of impervious surface.	NSQD (2015)
	0.456	0.032	2.192	Mean of 165 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
	1.5	**0.01**	**6.94**		
N-NO2	0.126	0.014	6.540	Mean of 589 samples of runoff from urban areas with at least 50% of impervious surface.	NSQD (2015)
	0.112	0.000	3.000	Mean of 912 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
N-NO3	0.895	0.007	21.700	Mean of 870 samples of runoff from urban areas with at least 50% of impervious surface.	NSQD (2015)
	1.124	0.000	86.550	Mean of 3152 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
N-NO3 + N-NO2	0.736			Median for residential urban runoff (USA)	US EPA (1983); Strassler et al. (1999)
	0.572			Median for commercial urban runoff (USA)	US EPA (1983); Strassler et al. (1999)
	0.588	0.000	41.600	Mean of 3804 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
	1.66	**0.23**	**3.41**		

TP	0.383			Median for residential urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	0.201			Median for commercial urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	0.360	0.020	4.300	Mean - Urban runoff with domestic wastewater (USA)		Bastian (1997); Strassler et al. (1999)
	0.200			Median - Mixed land use urban areas (over 8 000 samples, USA).		NRC (2009); NSQD (2008)
	0.364	0.005	19.900	Mean of 5314 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	0.383	0.002	28.900	Mean of 8060 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	0.600			**Value used in Poland for the assessment of impacts of pressures in bodies of surface water**	**Runoff from green urban and low density rresidential areas**	**DHI (2019)**
	1.750				**Runoff from other urban areas**	**DHI (2019)**
	0.54	**0.14**	**1.97**			
P-PO4	0.187	0.005	6.000	Mean of 672 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	0.203	0.000	83.245	Mean of 4030 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	0.07	**0.01**	**0.15**			
DOC	10.5	3.4	28.4	Flow-weighted mean concentration in runoff from low-density residential catchment of 3.89 ha measured continouosly during 25 storm events in Manatee County, Florida, USA.		Kalev, Toor (2020)
	16.1	0.5	130.0	Mean of 1277 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	7.31	**1.8**	**18.85**			
TOC	12.52	3.78	29.28	Flow-weighted mean concentration in runoff from low-density residential catchment of 3.89 ha measured continouosly during 25 storm events in Manatee County, Florida, USA.		Kalev, Toor (2020)

	16.59	2.30	350.10	Mean of 583 samples of runoff from urban areas with at least 50% of impervious surface.	NSQD (2015)
	20.52	0.10	187.00	Mean of 2625 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
	6.75	**1.1**	**19.67**		
Prtrol. Hydroc .(C14-C28)	920.0	48.0	3640.0	Mean of 25 samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha.	Milukaitė et al. (2010)
	11.7			Mean of samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha. Concentrations for relatively high rainfall intensity (10.2 mm/h)	Milukaitė et al. (2010)
	150 (C16-C35)				
TPH	2.9	0.3	37.5	Mean of 253 samples of runoff from urban areas with at least 50% of impervious surface.	NSQD (2015)
	6.4	0.3	40.0	Mean of 45 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
B(a)P	0.00048	0.00004	0.00402	Mean of 25 samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha.	Milukaitė et al. (2010)
	0.00292			Mean of samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha. Concentrations for relatively high rainfall intensity (10.2 mm/h)	Milukaitė et al. (2010)
Cl	22.995	0.600	900	Mean of 728 samples of runoff from urban areas with at least 50% of impervious surface.	NSQD (2015)
	50.925	0.002	5300	Mean of 1568 samples at the inflow to stormwater BMPs	ISBMPD (2019); Clary et al.. (2020)
	81.05	**68**	**94.1**		
Cd	0.0097	0.0053	0.0184	Mean of 25 samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha.	Milukaitė et al. (2010)
	0.0131			Mean of samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha.	Milukaitė et al. (2010)

				Concentrations for relatively high rainfall intensity (10.2 mm/h)		
	0.0014	0.0000	0.2749	Mean of 3272 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	0.0011	0.0000	0.1050	Mean of 3100 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	0.0010			**Value used in Poland for the assessment of impacts of pressures in bodies of surface water**	**Runoff from other urban areas**	**DHI (2019)**
	0.0020				**Runoff from commercial and industrial areas**	**DHI (2019)**
	0.0040				**Runoff from communication areas**	**DHI (2019)**
	0.00019	**0.00013**	**0.00025**			
Cr	0.0069	0.0007	0.5590	Mean of 1744 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	0.0099	0.0002	0.5450	Mean of 1973 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	0.00434	**0.00326**	**0.00522**			
Cu	0.0330			Median for residential urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	0.0290			Median for commercial urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	0.0500	0.0100	0.4000	Mean - Urban runoff with domestic wastewater (USA)		Bastian (1997); Strassler et al. (1999)
	0.0492	0.0224	0.1062	Mean of 25 samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha.		Milukaitė et al. (2010)
	0.0661			Mean of samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha. Concentrations for relatively high rainfall intensity (10.2 mm/h)		Milukaitė et al. (2010)

	0.0150			Median - Mixed land use urban areas (over 8 000 samples, USA).		NRC (2009); NSQD (2008)
	0.0291	0.0003	7.2700	Mean of 4366 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	0.0468	0.0001	4.0100	Mean of 5300 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	0.1000			**Value used in Poland for the assessment of impacts of pressures in bodies of surface water**	**Runoff from other urban areas**	**DHI (2019)**
	0.1500				**Runoff from commercial and industrial areas**	**DHI (2019)**
	0.2000				**Runoff from communication areas**	**DHI (2019)**
	0.0113	**0.0063**	**0.0156**			
Fe	2.3325	0.0170	193.0	Mean of 513 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	1.9694	0.0005	57.0	Mean of 1398 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	1.67	**0.9**	**2.42**			
Ni	0.0067	0.0010	0.2810	Mean of 1663 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	0.0111	0.0000	0.4960	Mean of 1864 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	0.0200			**Value used in Poland for the assessment of impacts of pressures in bodies of surface water**	**Runoff from other urban areas**	**DHI (2019)**
	0.0300				**Runoff from communication, commercial and industrial areas**	**DHI (2019)**
	0.0044	**0.0017**	**0.006**			
Pb	0.1440			Median for residential urban runoff (USA)		US EPA (1983); Strassler et al. (1999)

	0.1040			Median for commercial urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	0.1800	0.0100	1.2000	Mean - Urban runoff with domestic wastewater (USA)		Bastian (1997); Strassler et al. (1999)
	0.0489	0.0249	0.0744	Mean of 25 samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha.		Milukaitė et al. (2010)
	0.0641			Mean of samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha. Concentrations for relatively high rainfall intensity (10.2 mm/h)		Milukaitė et al. (2010)
	0.0140			Median - Mixed land use urban areas (over 8 000 samples, USA).		NRC (2009); NSQD (2008)
	0.0248	0.0001	1.2000	Mean of 3767 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	0.0289	0.0000	3.0200	Mean of 4427 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	0.0500			**Value used in Poland for the assessment of impacts of pressures in bodies of surface water**	**Runoff from other urban areas**	**DHI (2019)**
	0.0600				**Runoff from commercial and industrial areas**	**DHI (2019)**
	0.0130				**Runoff from communication areas**	**DHI (2019)**
	0.0031	**0.0012**	**0.006**			
Zn	0.1350			Median for residential urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	0.2260			Median for commercial urban runoff (USA)		US EPA (1983); Strassler et al. (1999)
	0.0200	0.0100	2.9000	Mean - Urban runoff with domestic wastewater (USA)		Bastian (1997); Strassler et al. (1999)
	0.2281	0.0616	0.6170	Mean of 25 samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha.		Milukaitė et al. (2010)

	0.2720			Mean of samples from 5 monitoirng points in Vilnius, Lithuania. Drainage areas varied from 10 to 42 ha. Concentrations for relatively high rainfall intensity (10.2 mm/h)		Milukaitė et al. (2010)
	0.0900			Median - Mixed land use urban areas (over 8 000 samples, USA).		NRC (2009); NSQD (2008)
	0.2166	0.0007	22.5000	Mean of 4551 samples of runoff from urban areas with at least 50% of impervious surface.		NSQD (2015)
	0.1326	0.0002	27.5000	Mean of 6167 samples at the inflow to stormwater BMPs		ISBMPD (2019); Clary et al.. (2020)
	0.4000			**Value used in Poland for the assessment of impacts of pressures in bodies of surface water**	**Runoff from other urban areas**	**DHI (2019)**
	0.5500				**Runoff from commercial and industrial areas**	**DHI (2019)**
	0.6000				**Runoff from communication areas**	**DHI (2019)**
	0.13	**0.11**	**0.15**			

Appendix 2: The total cost of stormwater quality monitoring, including cost of chemical reagents and laboratory materials (Słupsk, Poland case study)

Parameter	Laboratory materials	Unit cost of determination/per sampling point	Total cost of determination/per campaign
TSS	Glass microfiber filters	82 EUR/100 pcs 1 pcs: 0,82 EUR	 3*8,20 = **2,46 EUR**
Nitrite nitrogen (NO_2^-)	Cuvette Test LCK 342 + pipette tips (1pcs)	85 EUR/box (25 tests); 1 test: 3,40 EUR 1 pcs = 0,15 EUR	 3*3,40 = **10,2 EUR** 3*0,15 = **0,45 EUR**
Nitrate nitrogen (NO_3^-)	Cuvette Test LCK 339 + pipette tips (2pcs)	111 EUR/box (25 tests); 1 test = 4,5 EUR 2 pcs = 0,3 EUR	 3*4,50 = **13,5 EUR** 3*0,3 = **0,9 EUR**
Ammonia nitrogen (NH_4^+)	Cuvette Test LCK 302 + pipette tips (1pcs)	100 EUR/box (25 tests); 1 test = 4,0 EUR 1 pcs = 0,15 EUR	 3*4,0 = **12 EUR** 3*0,15 = **0,45 EUR**
Total nitrogen	Cuvette Test LCK 338 + pipette tips (4pcs) + reaction vessels	129 EUR/box (25 tests); 1 test = 5,16 EUR 4 pcs = 0,6 EUR 1 vessel: 3,92 EUR	 3*5,16 = **15,5 EUR** 3*0,6 = **2,4 EUR** 3*3,92 = **11,8 EUR**
Phosphate phosphorous (PO_4^{3-})	Cuvette Test LCK 350 + pipette tips (2pcs)	113 EUR /box (25 tests); 1 test: 4,6 EUR 2 pcs = 0,3 EUR	 3*4,6 = **13,8 EUR** 3*0,3 = **0,9 EUR**
Total phosphorus	Cuvette Test LCK 350 + pipette tips (2pcs)	113 EUR /box (25 tests); 1 test: 4,6 EUR 1 pcs = 0,15 EUR	 3*4,6 = **13,8 EUR** 3*0,3 = **0,9 EUR**
-	Other materials: Nitrile gloves (2 pairs)***	2 pairs/ 4 pcs = **0,5 EUR**	
			TOTAL: 99,56 EUR ≈ <u>100 EUR</u>

* Pipette tips Brand 500-5000 µl; bag: 200 pcs.; 30,9 EUR; price of 1 pcs: 0,15 EUR
** Reaction vessels (Ø 20 mm) with screw caps, 5 pcs: 19,6 EUR (5 pcs); price of 1 pcs: 3,92 EUR
*** Nitrile gloves; box: 100 pcs; 13,3 EUR (price of 1 pcs: 0,13 EUR)

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