REPORT ON MODELLING RESULTS

Output 2.3 of Interreg Baltic Sea Region project NOAH

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

Contents

Introduction

NOAH project aims to protect the Baltic Sea from untreated wastewater spillages during flood events in urban areas. For this purpose, passive and active methods like holistic urban planning, real time control of urban drainage systems and raising stakeholder awareness are harnessed.

The project's work package 2 focuses on decreasing discharges of nutrients and hazardous substances from urban stormwater run-off to the Baltic Sea by enhancing the capacity of public and private actors dealing with land use and spatial planning. For that, passive methods to improve urban planning will be implemented. Run-off volume is directly related to the quantity of pollutants that the rainwater is rinsing from the ground surface during rainfall events and flushing to the receiving waters, including combined sewer systems. To tackle the problem, WP2 demonstrates how holistic spatial planning can reduce the run-off and thus reduce the discharges of hazardous substances to the Baltic Sea. Therefore, the impact of different climate scenarios with surrounding water bodies will be modelled in conjunction with different land use patterns to minimize the urban run-off from the ground surface. The aim is to analyze individual sites (plots) on global context and with different climate scenarios (O2.2), taking into account how run-off from the sites induces excessive flows downstream and increases risks on water quality.

The project's work package 3 focuses on decreasing spillages of untreated wastewater from urban drainage network to the Baltic Sea by enhancing the capacity of water utilities responsible for urban drainage system operation. For that, WP3 will experiment and introduce new solutions in drainage system operation, which have not been widely used in urban conditions before. The aim is to install on-line sensors and actuators into the existing system to utilize the capacity of the pipeline to accumulate excessive flows and/or adjust the operation of existing pumping stations. These actions will help to avoid combined sewer overflows to the natural waters. The best possible algorithms for these solutions are determined by using modelling.

The preparatory tasks for modelling – data collection from pilot areas and choosing the climate scenarios – have been accomplished in prior groups of activities and are described in detail in internal reports [1], [2] & [3] available at the project web page [4].

Urban run-off models are created for all of the NOAH project's pilot areas: Söderhamn, Pori, Haapsalu, Rakvere, Jurmala, Liepaja, Ogre and Slupsk as part of activity 2.3 by the academies: Tallinn University of Technology (TalTech), Riga Technical University (RTU) and Gdansk University of Technology (GUT). Herein is the internal report (O2.3) on model building, applied approaches and initial results.

1 Methodology for building the models

The success of applying holistic spatial planning and self-adaptive drainage management depends directly on the quality of hydraulic models. For building proper hydraulic models, variety of different data is needed. Information from sources such as Computer Aided Design (CAD) drawings, Geographic Information System (GIS), Digital Elevation Maps (DEM) etc. has to be compiled.

Models for study areas are built in steps:

(1) Choosing the relevant pilot area

(2) Collecting pipeline data from sources such as:
   a. As-build drawings (on paper or CAD)
   b. Utility GIS systems
   c. Public GIS systems and databases (i.e. land use and DEM)
   d. Field measurements of pipeline elevations
   e. Design drawings of new and/or reconstruction projects

(3) Deciding on the model fidelity level that is necessary and possible to achieve, i.e. setting criteria for including/excluding conduits and nodes from the model

(4) Drawing a network representation of the physical components of the study area

(5) Collecting land use and elevation data for catchments, such as:
   a. Land use data (CORINE GIS layers etc.)
   b. Layout of streets, buildings and green areas (parks etc.)
   c. Elevation data (DEM)
   d. Groundwater elevation data

(6) Filling data gaps (interpolation of elevations etc.)

(7) Validating data and reducing uncertainties by the aid of specialists from local municipality/utility

(8) Conducting field measurements for model calibration and validation

1.1 From GIS to model

Creating a model from GIS database is preferable because of the similar structure and data logic. Building a model from GIS also simplifies the update of the model if any new data is imported to GIS. When building a model from GIS one should pay attention to several crucial points:

(1) Link direction has to be consistent with the slope (flow) - from upstream to downstream

(2) Link connections:
   a. Each link should have nodes (junctions) at both ends
   b. All links and nodes should have unique id-s (avoid duplicate names, avoid using fid as this will change automatically if changes are made in the database)
   c. Manholes (nodes) and link vertices have to have exact coordinate match (overlapping)

(3) Link start/end points have to be snapped to previous/consecutive links, avoid offsets

(4) Main pipes and household connections should have different notification or layer

(5) Different type of manholes (inlets, gutters, inspection manholes) should have different notification or layer
(6) Connections without inspection manholes should have different layer and notification
(7) Ditches connected to storm water system i.e. pipeline should be present in GIS with data about bottom elevations and measurements of cross sections
(8) Elevation data in GIS should comprise invert elevations, pipe offsets (if any) at connections to manhole, ground (lid) elevations
(9) Elevation data should have specification if it is measured on site (exact data) or taken from archives
(10) Pipe (link) data should comprise diameter, year of installation, material. It would also be useful to have separate layer for collection maintenance works done in the system (cleaning, repairing etc.)
(11) All outlets should have elevation data about height range of the water level at outlet (level of receiving pond, ditch, sea etc.)

2 Urban storm water run-off and land use models

Catchments form a crucial part of modelling, as the actual run-off to the underground system is directly dependent on their parameters. Run-off depends also on ground slope.

Different climate scenarios with surrounding water bodies are modelled in conjunction with different land use patterns to minimize the urban run-off from the ground surface. Land use of urban areas dictates the run-off to the drainage system.

Network representation is drawn or imported from data sources. For storm water run-off modelling EPA Storm Water Management Model (SWMM) is used.

RTU also tested the compatibility between the open source SWMM and commercial Bentley OpenFlows modelling products and used the latter to construct pipe geometry to some extent. During the initial stages of model creation for Latvian pilot sites, Bentley software solutions (mainly SewerGEMS) were used mainly to create user-specific workflows in order to decrease model creation times.

Information on land use is gathered from government databases, local municipality's existing general development plans and GIS databases.

2.1 Land use and elevations

Land use data (CORINE or similar) should be used to determine imperviousness of the catchment. Digital elevation model (DEM) should be used to determine the slope (%) for each catchment.

2.2 Geological data

Geological data should be used to determine infiltration rates for permeable areas in each catchment.

2.3 Catchments

Run-off and land use models are represented in modelling as catchments. Each catchment has unique information about infiltration, slope, impervious and pervious surfaces. One outlet node (connection to ditch or pipeline system) is determined for each catchment.

Numerical data of catchments is inserted to SWMM as part of the model while graphical features (shape) is represented in GIS database.

3 Modelling software overview and description

3.1 SWMM

The User's Manual of EPA Storm Water Management Model (SWMM) [5] is used for the following overview and description.

The EPA SWMM is a dynamic rainfall-run-off simulation model used for single event or long-term (continuous) simulation of run-off quantity and quality from primarily urban areas. The run-off component of SWMM operates on a collection of sub catchment areas that receive precipitation and generate run-off and pollutant loads. The routing portion of SWMM transports this run-off through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of run-off generated within each sub catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

SWMM accounts for various hydrologic processes that produce run-off from urban areas. These include:

- Time-varying rainfall
- Evaporation of standing surface water
- Snow accumulation and melting
- Rainfall interception from depression storage
- Infiltration of rainfall into unsaturated soil layers
- Percolation of infiltrated water into groundwater layers
- Interflow between groundwater and the drainage system
- Nonlinear reservoir routing of overland flow
- Capture and retention of rainfall/run-off with various types of low impact development (lid) practices

Spatial variability in all of these processes is achieved by dividing a study area into a collection of smaller, unique sub catchment areas, each containing its own fraction of pervious and impervious sub-areas, slope, area and maximum overland flow length. Overland flow can be routed between sub-areas, between sub catchments, or between entry points of a drainage system.

SWMM also contains a flexible set of hydraulic modelling capabilities used to route run-off and external inflows through a drainage system network of pipes, channels, storage/treatment units and diversion structures. These include the ability to:

- Handle networks of unlimited size
- Use a wide variety of standard closed and open conduit shapes as well as natural channels
- Model special elements such as storage/treatment units, flow dividers, pumps, weirs, and orifices
- Apply external flows and water quality inputs from surface run-off, groundwater interflow, rainfall-dependent infiltration/inflow, dry weather sanitary flow, and user-defined inflows
- Utilize either kinematic wave or full dynamic wave flow routing methods

- Model various flow regimes, such as backwater, surcharging, reverse flow, and surface ponding
- Apply user-defined dynamic control rules to simulate the operation of pumps, orifice openings, and weir crest levels

In addition to modelling the generation and transport of run-off flows, SWMM can also estimate the production of pollutant loads associated with this run-off. The following processes can be modelled for any number of user-defined water quality constituents:
- Dry-weather pollutant buildup over different land uses
- Pollutant wash-off from specific land uses during storm events
- Direct contribution of rainfall deposition
- Reduction in dry-weather buildup due to street cleaning
- Reduction in wash-off load due to best management practices (BMPs)
- Entry of dry weather sanitary flows and user-specified external inflows at any point in the drainage system
- Routing of water quality constituents through the drainage system
- Reduction in constituent concentration through treatment in storage units or by natural processes in pipes and channels

One typically carries out the following steps when using EPA SWMM to model a study area:
(1) Specify a default set of options and object properties to use
(2) Draw a network representation of the physical components of the study area
(3) Edit the properties of the objects that make up the system
(4) Select a set of analysis options
(5) Run a simulation
(6) View the results of the simulation

For building larger systems from scratch it will be more convenient to replace Step 2 by collecting study area data from various sources, such as CAD drawings or GIS files, and transferring these data into a SWMM input file.

3.2 Py_swmm software

PySWMM is a Python language software package for the creation, manipulation, and study of the structure, dynamics, and function of complex networks in SWMM model.

With PySWMM user can load and manipulate USEPA SWMM models. With the development of PySWMM, control algorithms can now be developed exclusively in Python which allows the use of functions and objects as well as storing and tracking hydraulic trends for control actions.

PySWMM is intended to provide [6]:
- Tools for the study of the structure and dynamics within USEPA SWMM5
- A standard programming interface and graph implementation that is suitable for many applications
- A rapid development environment for collaborative, multidisciplinary projects
- An interface to USEPA SWMM5

- Development and implementation of control logic outside of native EPA-SWMM Controls
- Methods for users to establish their own node inflows
- A coding interface to binary output files
- New modelling possibilities for the SWMM5 Community

In NOAH py_swmm routines were created for automated data validation, data error handling, analysis of the models and simulation of real time control systems.

3.3 GisToSWMM5

GisToSWMM5 is an automated sub catchment generator for SWMM model. The software is available and described in [7].

The input files for the tool can be prepared using GIS software and the resulting SWMM model can be studied in GIS. The tool takes elevation, land-use, and flow direction information from the user-prepared input files, creates sub catchments for the studied area, and routes water between sub catchments and into the storm water network.

The program automatically creates the SWMM model project file using the following [8]:

- A DEM raster describing the elevation in the catchment. No corrections (e.g. pit removal) are required for the DEM fed into GisToSWMM5
- A raster defining the land cover of each pixel classified into predefined types (e.g. roofs, roads, green areas). The values of pixels outside the catchment area are set as ‘No data’
- Junction (storm water sewer inlets), conduit and outfall geometry files describing the storm water network
- A text file connecting the SWMM parameter values (e.g. percent of impervious area, depth of depression storage, Manning’s n and soil hydraulic properties) to the land cover types depicted with index numbers in the land cover raster
- Settings files describing SWMM input file header, properties of rain gauges and snow packs, selected methods for evaporation and snow melt, and reporting details required for creating a SWMM project

The resolution of the DEM raster determines the minimum computational cell size of the grid. The process of dividing the catchment into sub catchments as well as routing the flow between the sub catchments and into the inlets of the storm water network is conducted as follows [8]:

(1) A Cartesian computation grid with a given resolution is laid upon the area equal to the extent of the land cover raster. Each grid cell becomes a sub catchment, i.e. a computational unit in the SWMM model. Resolution of the land cover and DEM rasters have to be the same as the computation grid resolution.

(2) Each cell of the computation grid is assigned an index value describing the land cover of the cell and an elevation value according to the underlying raster data. Cells residing outside of the catchment and having no land cover raster values are marked as inactive.

(3) SWMM parameter values are transferred to the grid cells from the text file linking the land cover index to parameter values.
(4) The average slope for each cell is computed as an arithmetic average of slopes between the current cell and the neighboring eight cells. Slopes between rooftops and other land cover types are ignored when computing the average slope.
(5) Flow routing is computed using the D8 method [9], i.e. flow from each cell is routed to the neighboring cell according to the direction of the steepest slope. Routing of water within rooftops and flow of water from other land cover types back to rooftops is prevented. Pit cells are marked.
(6a) Rooftop cells are routed either to the nearest inlet in the stormwater network, or to the adjacent yard if the rooftops are not connected to the network.
(6b) Cells containing an inlet are routed to the stormwater network.
(6c) Pit cells with man-made impervious land use types, i.e. paved surfaces, are routed to the closest inlet to prevent unrealistic water accumulation into cells having no infiltration capacity. Pit cells within permeable or naturally impervious areas, e.g. rock outcrops, are emptied only by infiltration and/or evaporation.

3.3.1 Linking catchments with nodes

GisToSWMM5 can be used to build a SWMM5 model in three modes: 1. Each raster cell forms an individual sub catchment; 2. (*Recommended*) Cells with the same land-use and same eventual outlet are merged to form sub catchments; 3. (*Legacy mode, not recommended*) Neighboring 2^N x 2^N cells, where N = 1, 2, 3, ..., are merged together into sub catchments and the most abundant land use among cells is set as the sub catchment land use. If the recommended variant is used, then in the set of output files there is a file with .ASC extension. This file contains all squares provided by the raster file with numbers of sub catchments for each of them. The elevations have been substituted with the numbers of the sub catchments. It has to be checked that it contains numbers only (s letter is removed). Letters may be present, because ArcMap creates raster from ASCII (.ASC) file containing integer (in this case sub catchment number) or float. Example of the .ASC file (with //comments):

```
NCOLS 480                          //(number of columns)
NROWS 450                          //(number of rows)
XLLCORNER 378922                   //(x-coordinate for left-lowest corner of the raster file)
YLLCORNER 4072345          //(y-coordinate for left-lowest corner of the raster file)
CELLSIZE 5                 //(size of the square in meters)
NODATA_VALUE 0
0 0 0 0 56 56 56 0 0 0 0 0 0 0 0 0 0 0 0………………
0 0 56 56 56 56 56 56 56 56 56 56 56 56 56 56…………
```

Using this .ASC file, a polygon file can be created to view created sub catchment squares. If one wants to see sub catchments belonging to a node as a group, they have to change sub catchment numbers to node numbers using info from the created .INP file. The .INP file shows where run-off from each sub catchment is directed. Example of the sub catchment info in .INP file:

```
[SUBCATCHMENTS]
;;Subcatchment   Rain Gage    Outlet      Area     %Imperv  Width    %Slope   CurbLen  SnowPack
;;------------ ------------ ------------ -------- -------- -------- -------- -------- --------
;31
s1   1   1   0.03000   100   12.12   1.9933   5.00   sp_imp_plowable
;61
```

```
s2   1   1   0.00250   10   3.50   1.2520   5.00   sp_per
;61
s3   1   1   0.00250   10   3.50   1.2602   5.00   sp_per
;31
s4   1   s2   0.00250   100   3.50   2.6270   5.00   sp_imp_plowable
;61
s5   1   s1   0.00250   10   3.50   1.5413   5.00   sp_per
```

Here, outlets for each sub catchment are seen. In this example, sub catchment s3 discharges to node 1, sub catchment s4 discharges to sub catchment s2 (in this case, it also has to be checked where discharge from s2 goes to. In our example, it is node 1). Thus, nodes for each sub catchment can be found. This task can be performed manually if the number of catchments is small.

In case of a large number of catchments, subroutines have to be used for this task. During the NOAH project, a number of subroutines were created in Excel VBA (Visual Basic for Applications) in TalTech, to automatically link all the sub catchments with the correct outlets i.e. nodes for each sub catchment were found using VBA routines. After replacing all sub catchment numbers with node numbers, one needs to use in ArcMap Conversion Tools the "ASCII to Raster" command. This works with numbers only, as was mentioned before. The raster created can be converted to a polygon file using "Raster to Polygon" (in Conversion Tools in ArcMap). As a result, one will receive polygons connected with nodes. Polygons for sub catchments can also be obtained this way (using the .ASC file that contains all squares provided by the raster file with numbers of sub catchments for each of them).

Example visual of automatically generated sub catchments is presented for Pori pilot area (Fig. 1.):

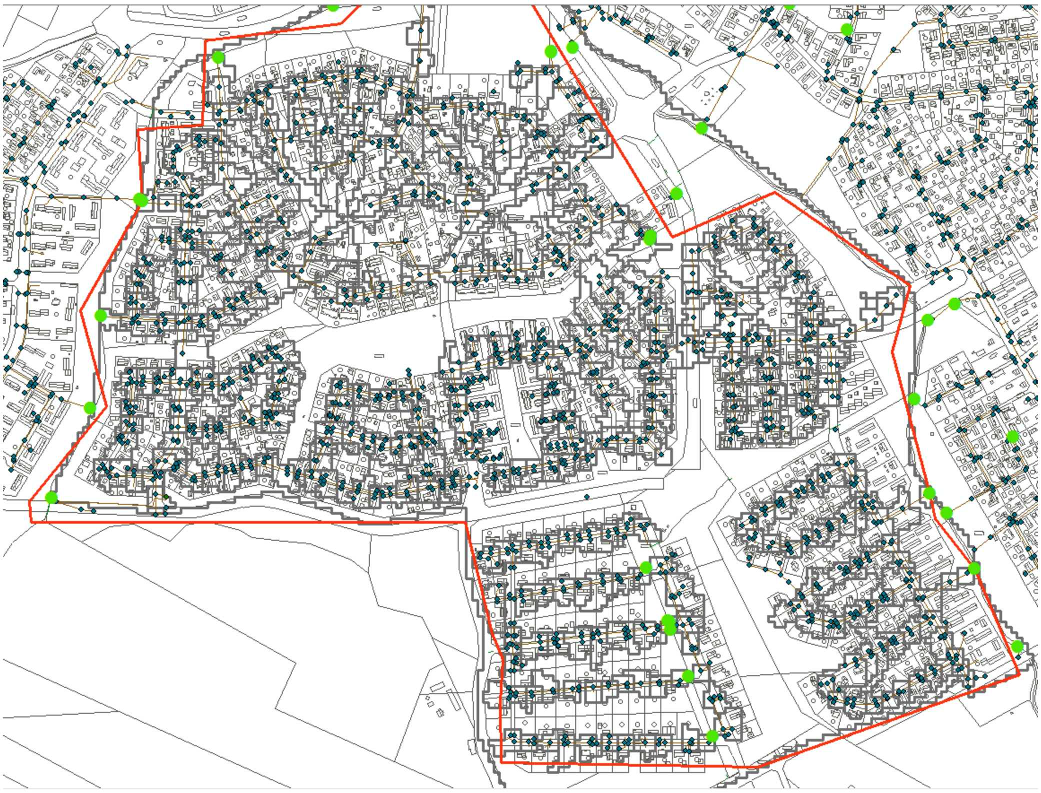

Fig. 1. Example of sub catchments in the Pori pilot area. Sub catchment borders are gray lines

4 Methodology for the modelling of climate scenarios

Climate change will put more pressure on the urban drainage systems in the future. Climate scenarios indicate critical factors such as:

(1) Increased volumes of rain i.e. increased intensity of precipitation (extreme weather events)
(2) Other extreme conditions like storms, ice and snow blockages
(3) Rising water levels

Climate models project systematic changes in climate and weather conditions. Types of scenarios considered for the future analysis are:

(1) Extreme – happening rarely but having severe consequences
(2) Medium – happening seldom and having mediate consequences
(3) Local measured extremum for every study area

Climate Scenarios have been selected based on local measurements and government strategies or local government projects as well as Intergovernmental Panel on Climate Change (IPCC) recommendations and are detailed in [3]. Each scenario comprises both rise in sea level and increase in precipitations.

Climate scenarios modelling is conducted using three specific scenarios for each study area for the estimation of future conditions and pin-pointing hot spots in the drainage system causing potential surface flooding. Field measurements are used as input for the different future climate scenario conditions in the model.

4.1 Synthetic design storms

Based on rainfall observations, Intensity-Duration-Frequency (IDF) curves can be compiled for any location (Fig. 2).

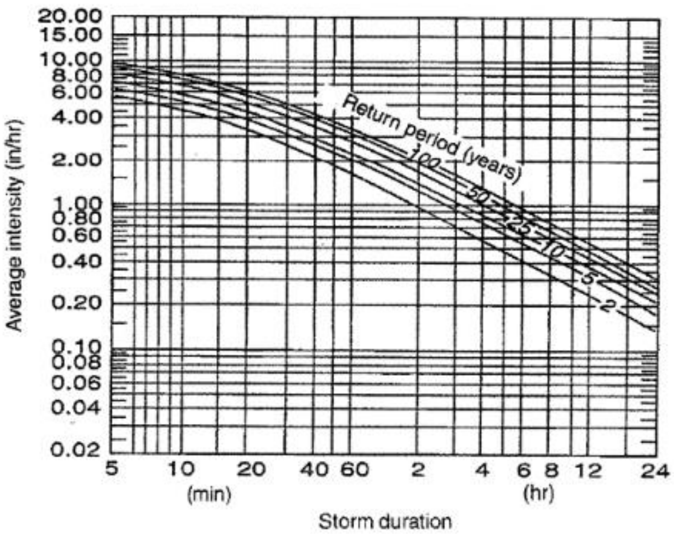

Fig. 2. Example Intensity-Duration-Frequency curve [10].

This curve indicates the relationship between the intensity and duration of a rainfall event with a given return period (T) for an area. Often, it is preferable to use exceedance probability (p) instead, where $p = 1/T$. Thus, a "25 year storm" actually designates a rainfall event which has a 4% chance of occurring in any given year. [11]

The IDF curve can be modified in accordance with climate scenarios to account for higher average intensity and/or return period.

The simplest form of design storm is block rainfall, which may be simply derived from an IDF curve. Block rainfall has the same intensity over its duration and therefore has a rectangular time distribution. This approach is used by TalTech for initial set-up in Haapsalu, Rakvere, Pori and Söderhamn pilot models.

Several other options to construct synthetic design storms, such as SCS[1] distributions, Yen and Chow Method, Huff Method, Synthetic Block Hyetograph Method and Chicago Method are described with examples in [10].

[1] Methodology developed by The Soil Conservation Service for synthetic 24-hr rainfall distributions

5 Methodology for risk assessment

At all pilot sites the characteristics of the spillages will be determined using either grab samples or flow proportional sampling. The flow proportional sample will be mixed into one sample and can be considered as describing one event and the concentrations of the analytes will be presented as an Event Mean Concentration (EVC). Different physical and chemical parameters will be determined as presented in Table 1. The different water quality parameters monitored are classified into six groups:

(1) Routine parameters including parameters such as pH and hardness (which influence the bioavailability of metals and metalloids) electrical conductivity (which is a measure of ions in a sample). Total Suspended Solids (TSS) is an estimate of the amount of particles in a sample and it can also be used as a correlate for other pollutants such as heavy metals because many metals bind to particulate matter.

(2) Organic sum parameters are measured in order to determine the amount of oxygen depleting substances in the samples [12].

(3) Eutrophying substances. Nitrogen and phosphorous are plant growth limiting substances in aquatic ecosystems. Depending upon the area of the Baltic Sea one or both substances can be growth limiting. Nitrogen is considered the growth limiting substance in Baltic Proper, in coastal areas south of Bothnian Bay both nitrogen and phosphorus limiting occurs while phosphorous is limiting growth in inland water.

(4) Heavy metals, metals and half metals. In this group several well-known pollutants commonly occurring in storm water are measured including Cd, Cu, Ni, Pb, Zn.

(5) Bacterial contamination of fecal origin is determined using membrane filtration.

(6) Oil measured as an oil-index.

Water quality assessment will be made for both grab samples and EVCs comparing concentration of measured pollutants and sum parameters according to lowest national standard for wastewater treatment plants (WWTP) (Table 1). Comparison with physical and chemical characteristics of storm water from other studies using the storm water data base for the Baltic Sea currently under construction in the NOAH project will also be conducted.

For individual pollutants measured as EVC and for which an Environmental Quality Standard (EQS) has been derived within the EU an ecological risk assessment will be made. EQS developed for the protection of freshwater under the Water Frame Work Directive (COM 2011, 2011/042) will be used as EQS because EQS for marine waters are scarce and most of the pilot site will discharge into a freshwater recipient before entering the Baltic Sea. The EQS-AA (annual average) can be considered as Predicted No Effect Concentration (PNEC) and will be used in the effect assessment. In case no EQS-AA has been derived, guidelines for good status assessment under the WFD in Sweden (HVMFS 2019:25) will be used as PNECs. The EVC are used in the exposure assessment for the effluent and is considered as the Predicted Environmental Concentration (PEC) i.e. in this case Measured Environmental Concentrations (MEC).

Risk Quotients (RQ) for each pollutant will consequently be calculated for each site and EVC as:

$$RQ=MEC/EQS\text{-}AA$$

The RQs will be classified according to a commonly used scale where 0.01 < RQ < 0.1 is defined as "low risk", 0.1 < RQ < 1 is defined as a "medium risk"; and RQ>1 shows "high risk".

Calculation of load of pollutants will also be made where flow has been measured in combination with flow proportional sampling i.e. where EVC has been determined. Percent reduction before and after the installation of the technical innovation implemented at some of the pilot site can then also be evaluated.

Table 1. Monitored pollutant parameters (Priority list 1)

Pollution parameters	**Reduction or PNEC (EQS)**		**Comments**
	Value	**Reference**	
Routine parameters			
pH	6.5-8.5	Lithuania, WWTP	Influence the bioavailability of metals.
Temperature	n.a.		
Hardness	n.a.		Calculated from Ca+Mg below. Influence bioavailability of metals.
Electrical conductivity	n.a.		
Total Suspended Solids	35 mg/l 90 % reduction	Finland WWTP	
Organic sum parameters			
BOD_7	30 mg/l 70 % reduction	Finland/Sweden, WWTP	
Dissolved Organic Carbon (DOC)	Not regulated		Influence the bioavailability of metals.
Total Organic Carbon (TOC)	Not regulated		Replace COD
Eutrophying substances (mg/l)			
Total phosphorus	0.2 mg/l	Sweden, WWTP	Inland areas
$P\text{-}PO_4$	Not regulated		Amount of TP that is bioavailable
Total Nitrogen	15 mg/l	Finland/Sweden, WWTP	
Ammonium nitrogen	Not regulated (0,0010 mg/l)[3]	(HVMFS 2019:25[3])	Unionized ammonia will be calculated
Sum of nitrate and nitrite nitrogen	Not regulated		
Organic N	Not regulated		Calculated
Half-metals, metals and metalloids (µg/l)			
Bor (B)	Not regulated		
Phosphorus (P)	Not regulated		
Sulphur (S)	Not regulated		
Potassium (K)	Not regulated		
Calcium (Ca)	Not regulated		Ca+Mg is used to calculate hardness
Magnesium (Mg)	Not regulated		
Aluminium (Al)	Not regulated		

Iron (Fe)	Not regulated		
Copper (Cu)	Not regulated (0.5)[3]	(HVMFS 2019:25)[3]	
Zink (Zn) and its compounds	Not regulated (Baltic Sea, 1.1)[3]	(HVMFS 2019:25)[3]	
Manganese (Mn)	Not regulated		
Sodium (Na)	Not regulated		
Silicon (Si)	Not regulated		
Lead (Pb)	1.2[1] (7.2)[2]	EQS, WFD	
Cadmium (Cd) and its compounds	0.08-0.25	EQS, WFD	Depends on hardness
Chromium (Cr)	Not regulated (3.4)[3]	(HVMFS 2019:25)[3]	
Nickel (Ni) and its compounds	4.0[1] (20)[2]	EQS, WFD	
Arsenic (As)	Not regulated (0.5)[3]	(HVMFS 2019:25)[3]	
Microorganisms (cfu/100 ml)			
Enumeration of Escherichia coli and coliform bacteria	Not regulated for WWTP		Indicator of faecal contamination monitored
Oil			
Oil index	Not regulated		

[1] The bioavailable fraction is used for nickel and lead since 2013(2013/39/EU)
[2] EQS on total concentration used up to 2013
[3] No EQS derived in EU, value used for water quality assessment in Sweden for coastal waters and transition zones (HVMFS 2019:25)

6 Modelling and risk assessment results for pilot sites

Models are created for eight pilot areas with different scale. Relative to each other, three model scales are represented (Figures 3-5):

(1) Small models, detailing an area of a set of streets in Latvia. In Jurmala the modelled area (C area in Fig. 3.) is 0.19 km^2, in Liepaja the Tebras street model area is 0.51 km^2 and in Ogre the Loka street area is 0.25 km^2

(2) Intermediate models, covering relevant districts in municipalities in Sweden (Söderhamn - 0.98 km^2), Finland (Pori - 1.6 km^2) and Estonia (Rakvere - 1.8 km^2 and Haapsalu - 0.66 km^2)

(3) A large model with an area of 43 km^2, covering the entire city of Slupsk in Poland

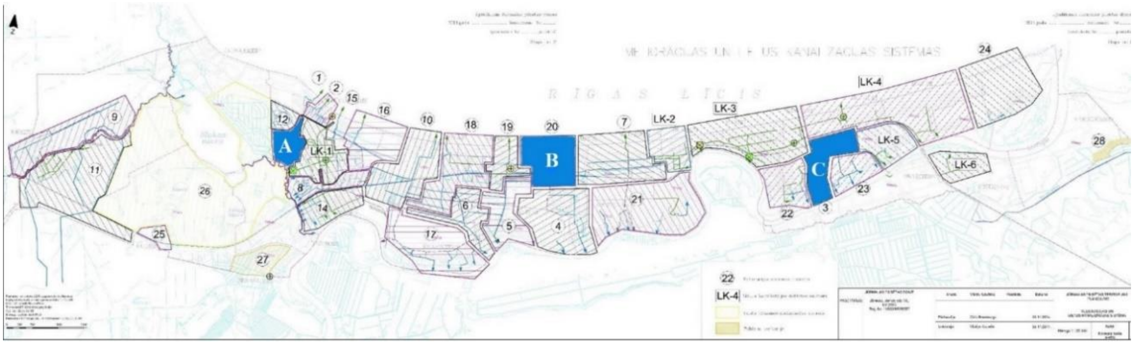

Fig. 3. The model is built for section C in Jurmala

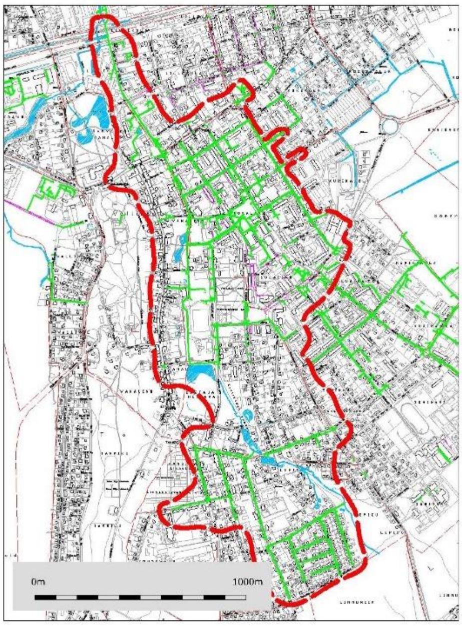

Fig. 4. Intermediate pilot area in Rakvere

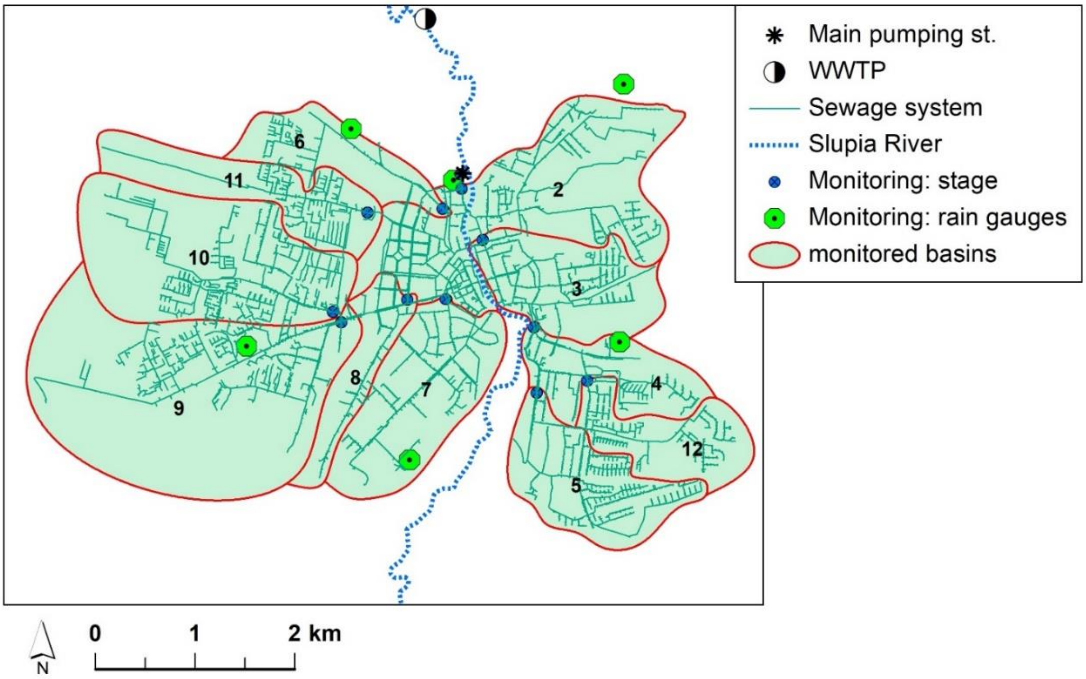

Fig. 5. Large pilot area in Słupsk

6.1 Fidelity level

Stemming from model scales, different fidelity levels are used. In the Söderhamn model 372 (40%) conduits and 169 (30%) manholes were included in the model and 202 new junctions were created for modelling purposes (Fig. 6).

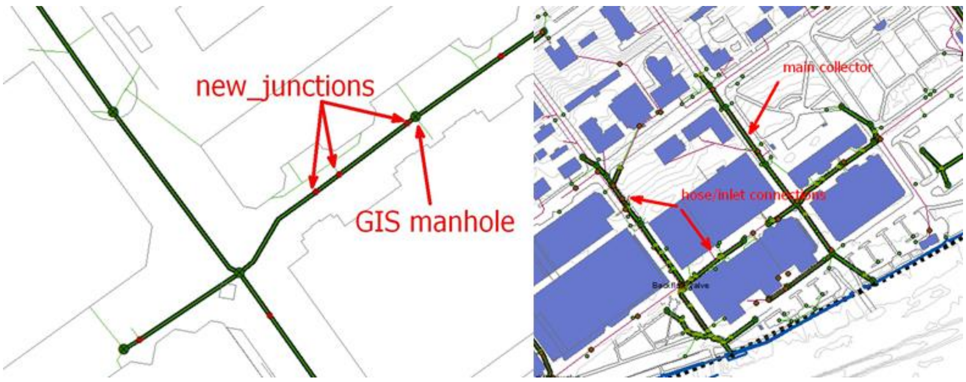

Fig. 6. Skeletonization in Söderhamn

In Slupsk, the model consists of 5 608 pipe sections and 5 511 nodes (junctions). The model structure was also simplified by exclusion of:

- Sanitary sewer laterals, i.e. pipes connecting home's or business' plumbing to the city's sewer system
- A part of road crossing pipe lines and other short connection pipes (provided that these pipes can be considered as linking individual buildings or parcels with the main sanitary line)

The type of excluded pipes in the Slupsk model is presented on Figure 7.

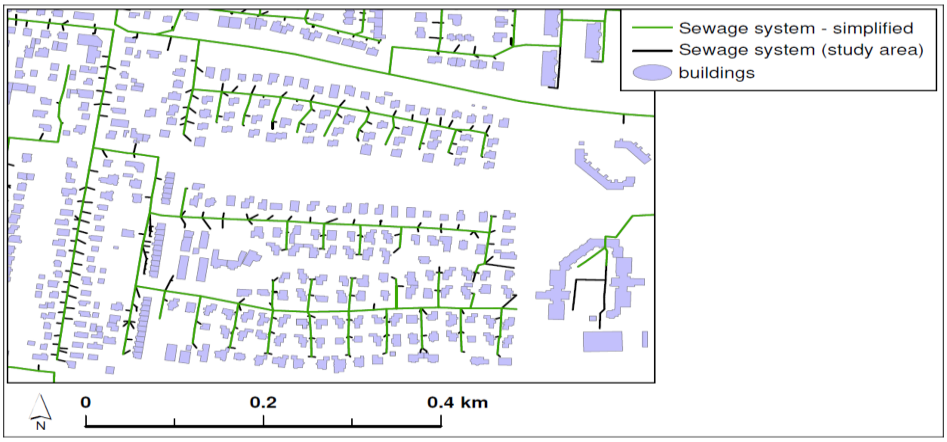

Fig. 7. Example of pipes excluded from the model in the Słupsk pilot area

The Tebras street catchment model of Liepaja city (Latvia) was also slightly simplified. Since the catchment is small, more detail can be preserved, retaining fast simulation times and a more visually representative model. Few drainage pipes in the system were omitted due to the relatively small inflow into the system from them.

During the initial stages of Miera street catchment basin model creation of Jurmala city (Latvia), all of the contributing assets were input into the model. As a result, the hydraulic model doubled as a tool for keeping track of existing assets.

To simplify the model and improve simulation times, areas not contributing to the run-off collection system were excluded from the Miera street catchment model (mainly forested areas due to lower elevations than the rest of the catchment). To decrease the computational burden, the initial model was simplified - nodes with no lateral connections and pipeline segments with constant diameters and slopes were combined. As a result, the end model includes 98 nodes and links (see Fig. 8.)

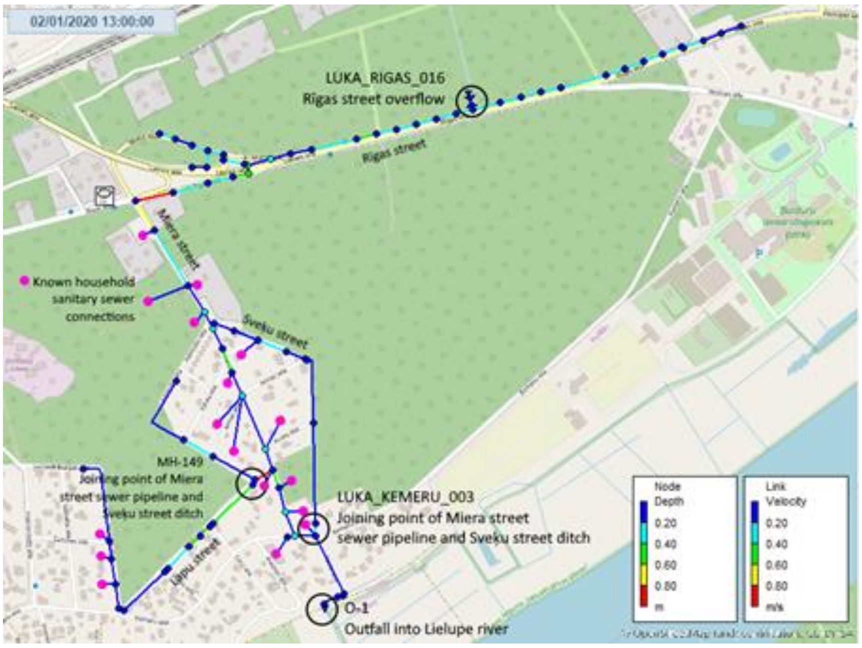

Fig. 8. Miera street model layout

6.2 Modelling results

In this section, some examples of the modelling results at different pilot sites are presented.

6.2.1 Rakvere

Water elevation profiles in Rakvere (Figures 9-10) indicate that there is a potential for smart control in the system. The model was fed with standard rainfall data.

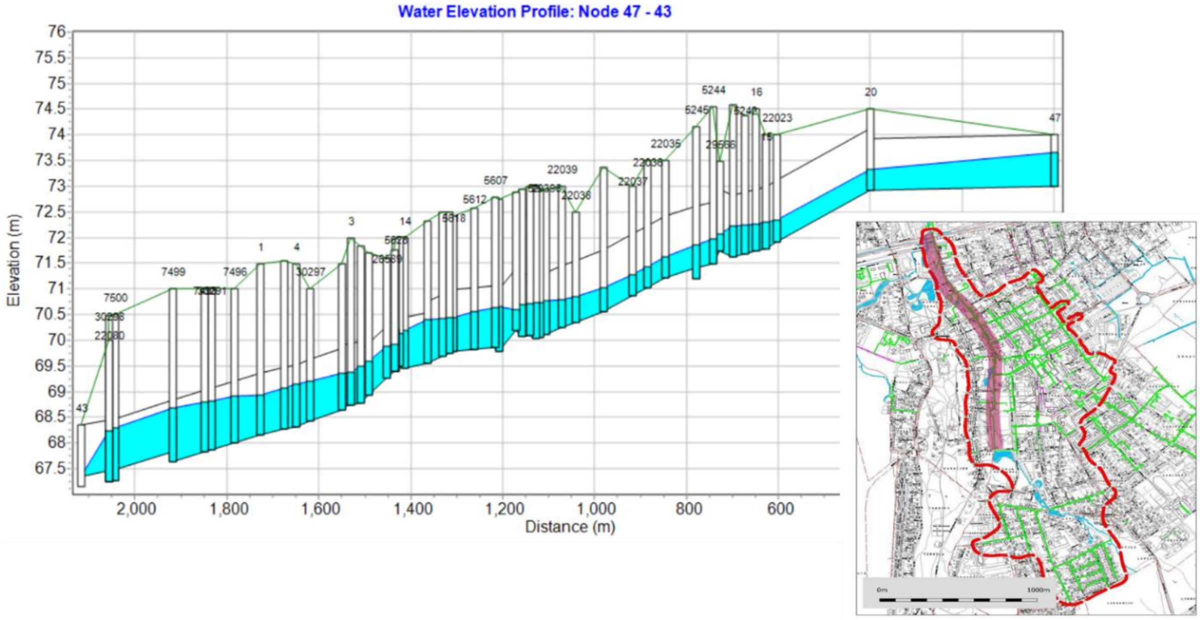

Fig. 9. Example of water elevation profiles in Rakvere model. Plotted pipeline section is highlighted in pink on the pilot area map

Installing a real time control (RTC) gate to restrict natural inflow to the collector might help avoid flooding downstream.

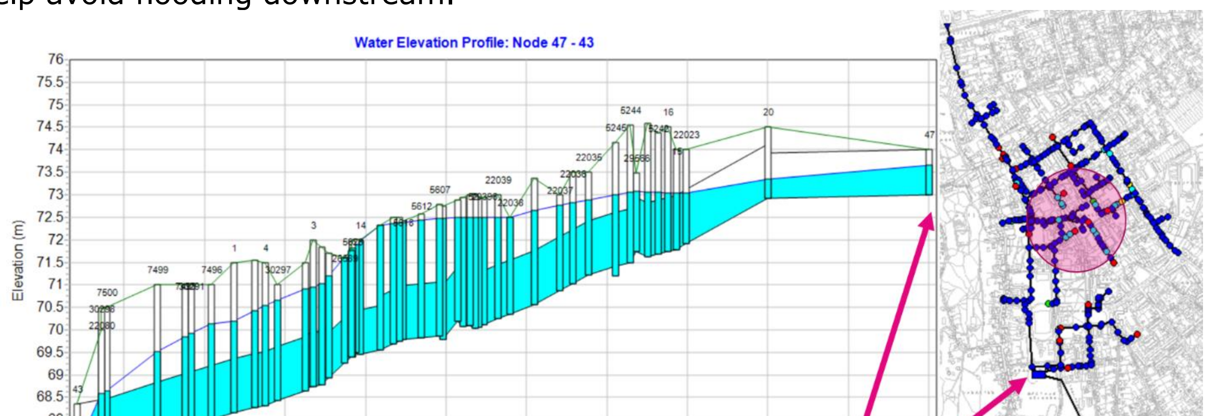

Fig. 10. Example of water elevation profiles in Rakvere model. A possible location for RTC gate is indicated with the pink arrow.

6.2.2 Söderhamn

Water elevation profiles obtained from modelling in Söderhamn (Figures 11-12) show that lower parts of the pilot area network, adjacent to river pose a flooding risk. The model was fed with standard rainfall data.

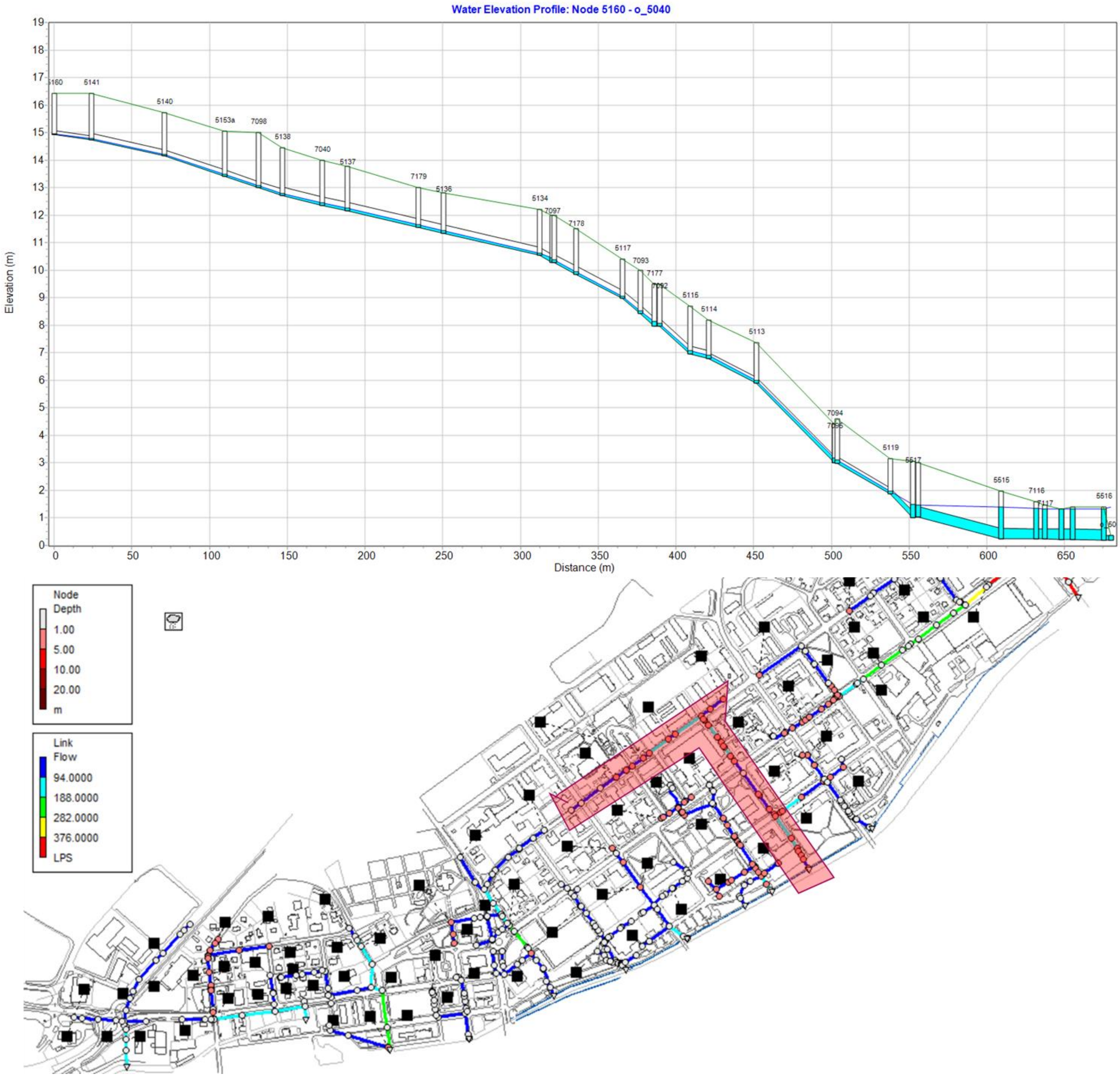

Fig. 11. Example of water elevation profiles in Söderhamn model. Plotted pipeline section is highlighted in pink on the pilot area map

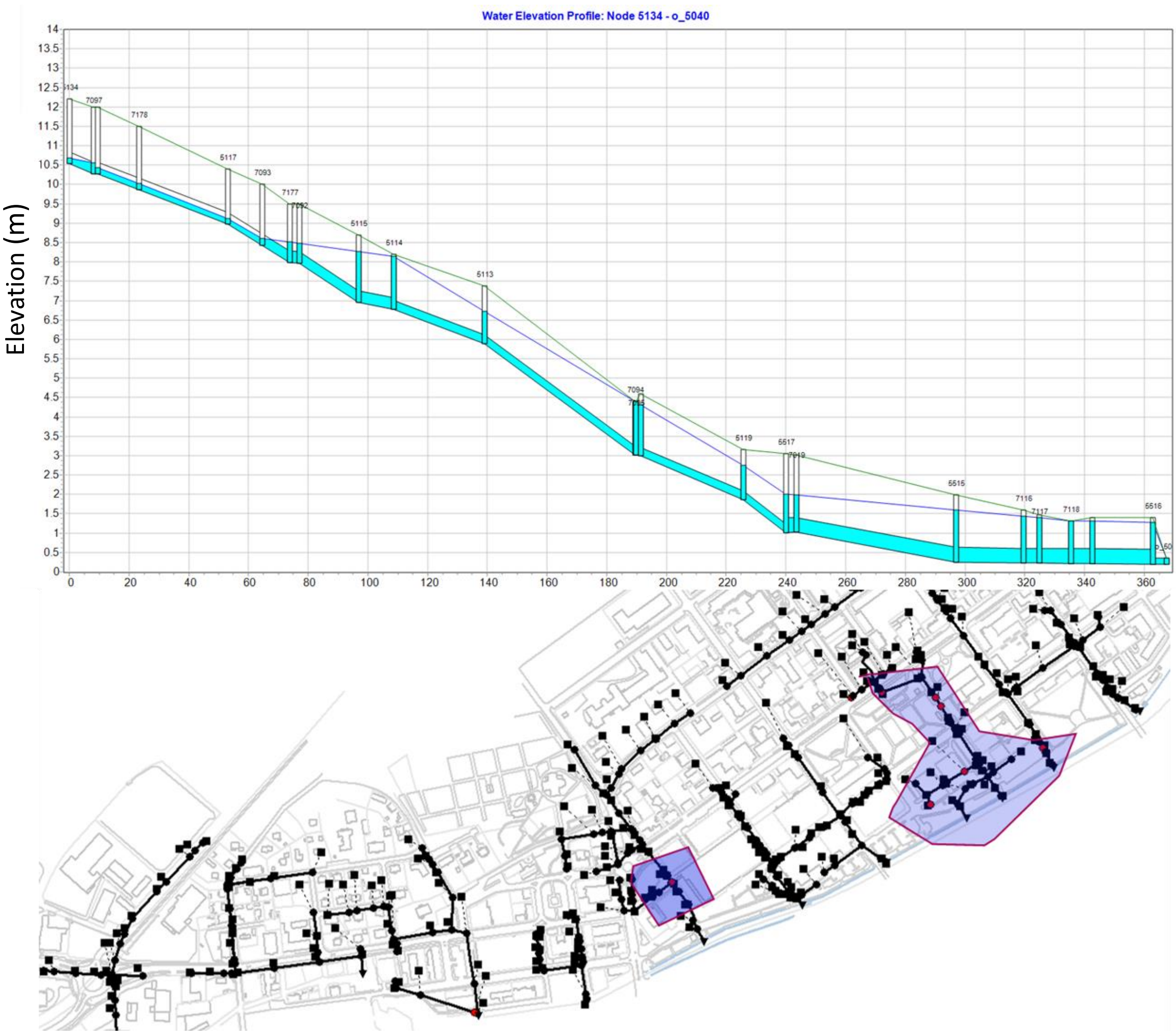

Fig. 12. Example of water elevation profiles in Söderhamn model for 2x design rainfall. Possible flooded areas are indicated in blue.

6.2.3 Pori

In Figure 13, preliminary results for Pori pilot area model are presented. Block rainfall event is applied and possible flooding can be seen from several manholes in the area.

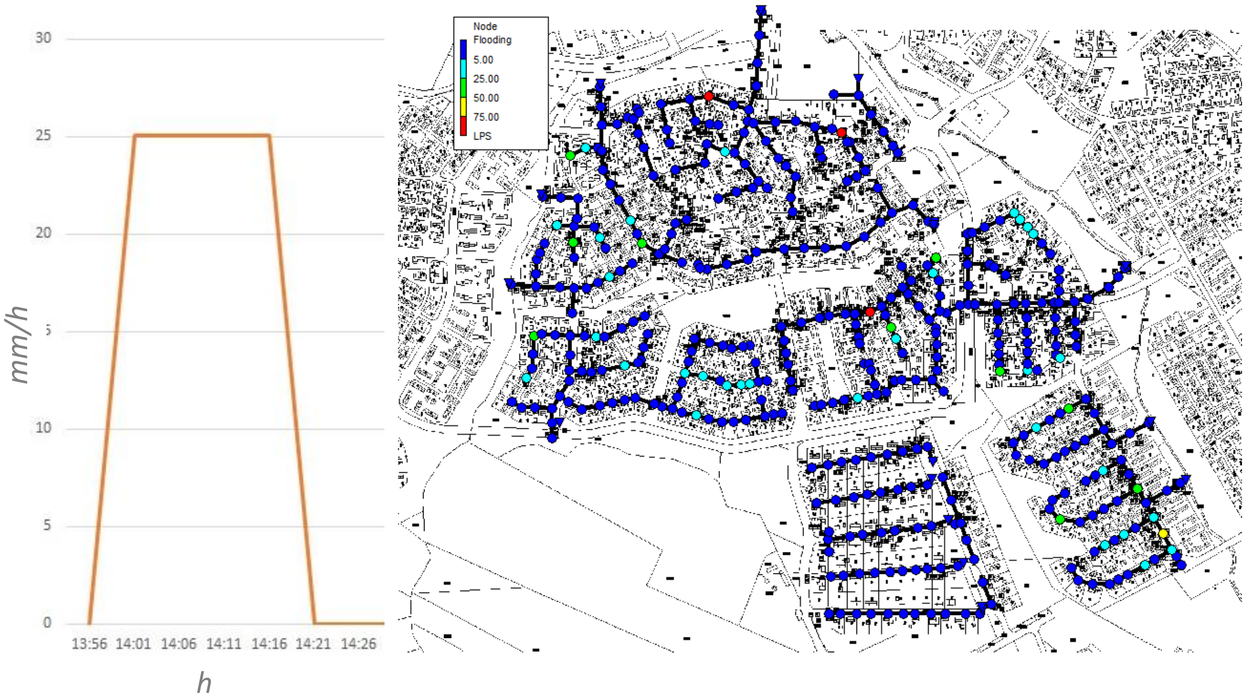

Fig. 13. Pori pilot area modelling result for one block rainfall event

6.2.4 Slupsk

The model for Slupsk is fed with a general type of dynamic input data (inflows) at present. These data are based on a uniform spatial distribution of the entire observed outflow from the system. An example of model results for a rain event is presented in figures below (Figures 14-15).

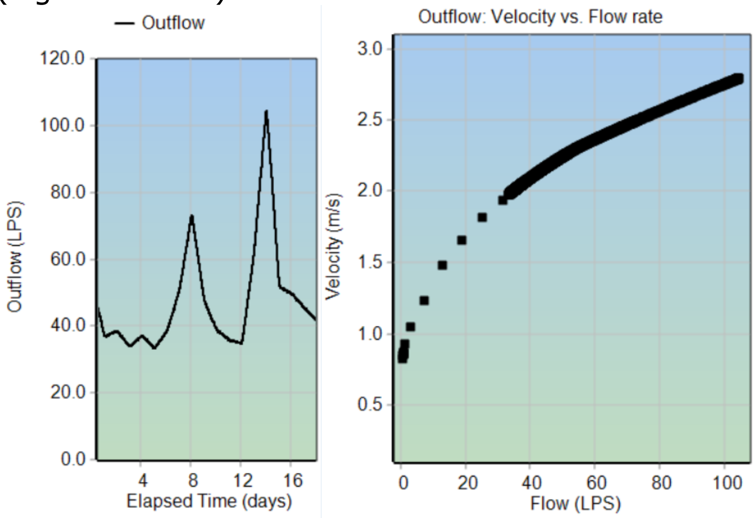

Fig. 14. An example of the total simulated outflow during a rain event (left) and relation of the flow rate and flow velocity in the most downstream section of the sewer system (right)

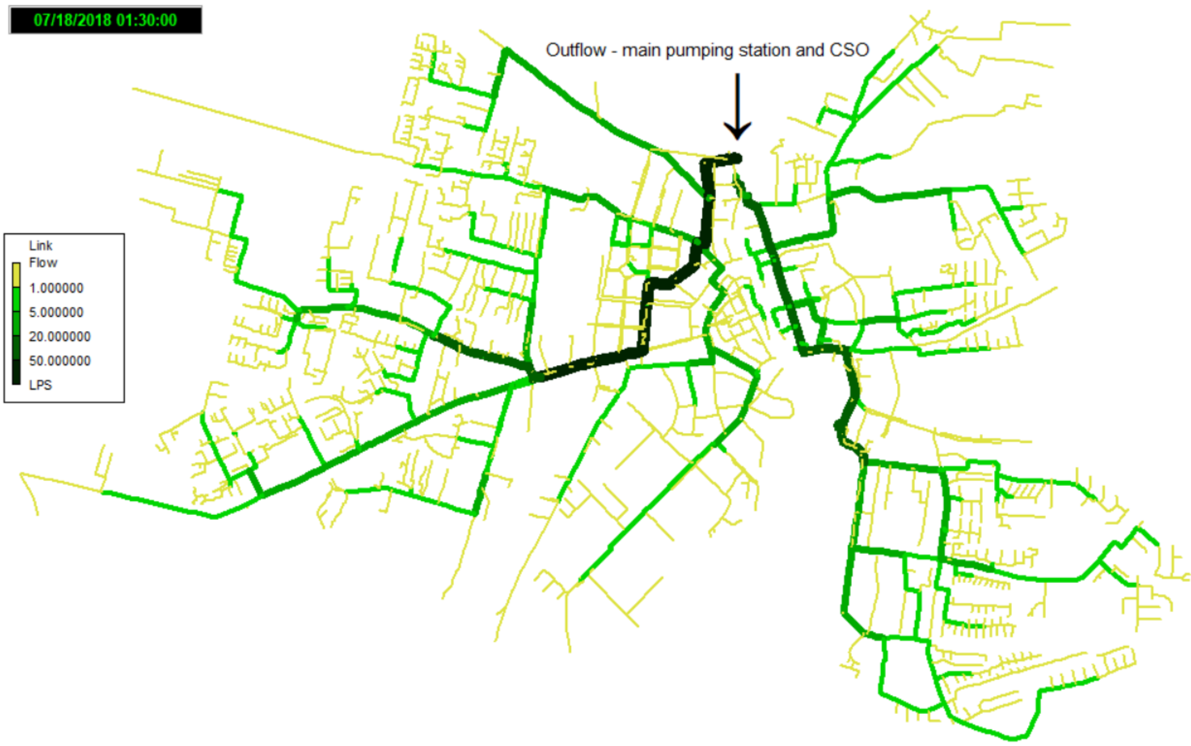

Fig. 15. An example of the simulated flow rate during a rain event in Słupsk

7 Calibration methodology and modelling reliability analysis

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

An example calibration procedure is presented for Slupsk pilot area. In Slupsk the model is calibrated based on four types of data: outflow from the system reported several times per day, water / wastewater level monitored with use of newly installed devices, precipitation measured by new rain gauges and inflow of water to the water distribution system in Słupsk measured in four points with a resolution of 10 minutes.

There are twelve wastewater / storm water level meters and six rain gauges installed in the pilot area in December 2019 (Fig. 5.). Both types of monitoring devices are operating with a temporal resolution of 10 minutes and are in use since January 2020. Automatic data acquisition for the purpose of the NOAH project is scheduled for March 2020.

The goal of calibration is to match simulated and observed outflow from the study area and levels of storm water / wastewater in the system. Inflow of sanitary sewage will be based on hourly patterns prepared based on the water consumption for weekdays, weekends and holidays. These patterns are not supposed to give an exact flow rate in dry periods. Therefore, this part of inflow to the system is calibrated based on (1) the observed rate of outflow from the system and (2) observed levels (stage) of wastewater during dry seasons. This kind of calibration can optionally be done in a real-time mode in dry seasons.

Calibration of the storm water inflow is more difficult as the analyzed area does not include a classic example of the combined sewer system. Only a part of storm water reaches the modelled sewer system via leaking pipes and unsealed manholes. Consequently, this part of inflow cannot be directly calculated using physically based (rainfall-run-off) models. The initial run-off and infiltration contribution is assessed based on the difference between the water use (production of wastewater) and the total outflow from the system. That gives an overview regarding the total inflow, which has to be spatially distributed. The distribution will be based on the (1) monitoring of the wastewater / storm water level, (2) characteristics of individual catchment areas and (3) differences in the monitored rainfall in six rain gauges.

8 References

[1] NOAH project, "Report on pilot areas and acquired data," Tallinn, 2019.

[2] NOAH project, "Report on pilot areas and acquired data - Taking control of the Urban Drainage System," Tallinn, 2019.

[3] K. Fitobór, K. Kołecka, D. Wróblewska and M. Gajewska, "Report on Activity 2.2: Climate scenario selection," NOAH, Gdansk, 2019.

[4] "NOAH - Protecting Baltic Sea from untreated wastewater spillages during flood events in urban areas," [Online]. Available: https://sub.samk.fi/projects/noah/.

[5] L. A. Rossman, "Storm Water Management Model (SWMM) version 5.1 User's Manual," September 2015. [Online]. Available: https://www.epa.gov/water-research/storm-water-management-model-swmm-version-51-users-manual. [Accessed January 2020].

[6] [Online]. Available: https://pyswmm.readthedocs.io/en/latest/overview.html#who-uses-pyswmm. [Accessed 6 March 2020].

[7] Aalto University School of Engineering Urban Water research team, "AaltoUrbanWater/GisToSWMM5," February 2019. [Online]. Available: https://github.com/AaltoUrbanWater/GisToSWMM5. [Accessed January 2020].

[8] L. Warsta, T. J. Niemi, M. Taka, G. Krebs, K. Haahti, H. Koivusalo and T. Kokkonen, "Development and application of an automated subcatchment generator for SWMM using open data," *Urban Water Journal,* vol. 14, no. 9, pp. 954-963, 2017.

[9] S. K. Jenson and J. O. Domingue, "Extracting topographic structure from digital elevation data for geographic information system analysis," *Photogrammetric Engineering and Remote Sensing,* vol. 54, no. 11, p. 1593–1600, 1988.

[10] A. Osman Akan and R. J. Houghtalen, Urban Hydrology, Hydraulics, and Stormwater Quality - Engineering Applications and Computer Modeling, John Wiley & Sons, 2003.

[11] P. Smart, "Understanding Hydrology. A Comparison of Hydrologic Methods," 2004. [Online]. Available: https://www.hydrocad.net/understanding.htm. [Accessed March 2020].

[12] W. Arts, "BOD, COD, TOC and TOD – sum parameters in environmental analysis," [Online]. Available: https://www.chemeurope.com/en/whitepapers/126405/bod-cod-toc-and-tod-sum-parameters-in-environmental-analysis.html. [Accessed March 2020].