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Implementing RTC in urban areas in the Baltic Sea Region

Output 3.3 of Interreg Baltic Sea Region project NOAH

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

Authors: Jonas Wied Pedersen, Magnus Bjerrum Johansen, Morten Borup

Technical University of Denmark, Department of Environmental Engineering (DTU Environment), Urban Water Systems section, 2800 Kgs. Lyngby Denmark.

Furthermore, various NOAH partners have contributed with case descriptions.

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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 runoff to the Baltic Sea by enhancing the capacity of public and private actors dealing with land use and spatial planning. Runoff 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 runoff and thus reduce the discharges of hazardous substances to the Baltic Sea.

While WP2 focuses on the use of passive methods WP3 focuses on taking control and ensuring prevention by gaining knowledge about the state of the system and recipients as well as investigating the use of Real Time Control (RTC) of the urban drainage system as a way of improving the system performance. The latter is the focus of this report that describes the RTC options relevant for the pilot areas of the NOAH project as one of the output from activity 3.3 in WP3. The basis for the RTC investigation is the urban runoff models build in WP2 for all of the NOAH project's pilot areas: Söderhamn, Pori, Haapsalu, Rakvere, Jurmala, Liepaja, Ogre and Slupsk.

In this document RTC potentials for the pilot areas in the NOAH project is investigated. For the cases where an RTC solution makes sense, this is implemented in a SWMM model of the drainage system and this is used to document the effect of the RTC. The SWMM models used as base for these investigations have been made by various partners of the NOAH project. The report itself is finalized but new documents based on the individual case specific chapters is likely to be produced later in the project as more information and better SWMM models for the individual cases are produced during the next part of the NOAH project.

RTC – what is it and where is it useful

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

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

While the application of local RTC often is pretty obvious, the possibilities and complexity of global RTC are more complex. The following shows examples of RTC options and their potential effect on the system and surroundings.

Emptying of basin, lake or subsystem without overloading downstream system

A frequent occurring situation in many urban water systems is that an upstream storage, such as a basin or lake, contributes to downstream flooding or CSO (Combined Sewer Overflow) because the storage is emptying regardless of the conditions downstream. The emptying will be through a throttle pipe or over a weir, and the dimensions of these have been estimated as a static trade-off between upstream and downstream problems. It is inevitable for such a setup that the upstream storage is emptying also under peak stress situation downstream even if there is plenty of capacity left in the storage. This situation can be mitigated with control that limits the emptying of the upstream, as illustrated in Figure 1.

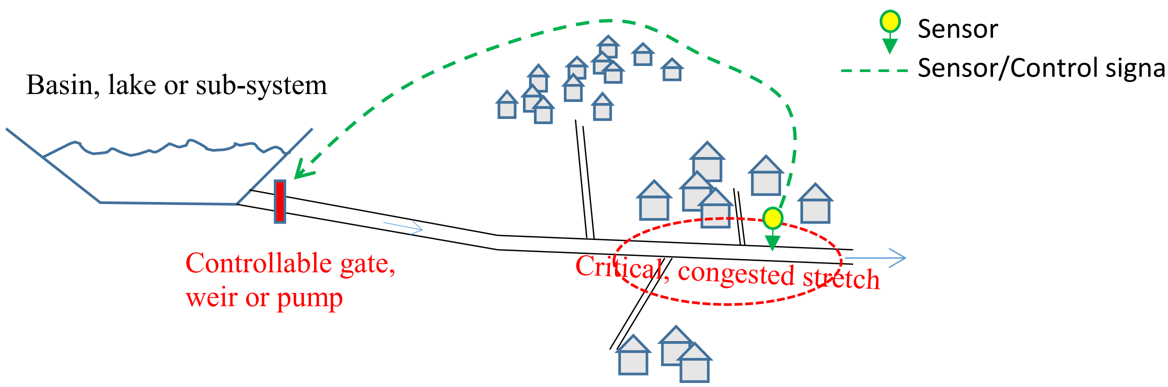


Figure 1: Control of the emptying of an upstream storage based on the conditions downstream in the system.

Potential effects

Such RTC setup can potentially alleviate downstream flood problems and/or reduce CSO volume and frequency at a very limited cost compared to the alternatives of enlarging the pipes though the city or building additional storage volume.

Requirements

Such control can be implemented using just a single sensor with communication with the controllable actuator if the upstream storage is equipped with a safety regulator such as an overflow weir that ensures that elevated water levels will not cause problems locally. If this is not the case, the actuator will need to be controlled based on the water level in the storage as well, and the setup will therefore require a local water level sensor as well, and a controller to calculate the setting of the actuator from the two sensor signals.

Prioritization of basin emptying to minimize CSO in multi-basin system

A typical use of RTC for larger systems is to control the emptying of basins in such a way that the CSO volume and frequencies are reduced. This can be done by ensuring that the basins with the least spare capacity relative to the (expected) inflow to the basin gets emptying priority over basins with sufficient spare capacity in real time during a rain event. Such a setup is illustrated in Figure 2. A similar situation is when controlling the emptying of a multi-basin system according to the capacity of the downstream wastewater treatment plant in order to reduce by-pass.

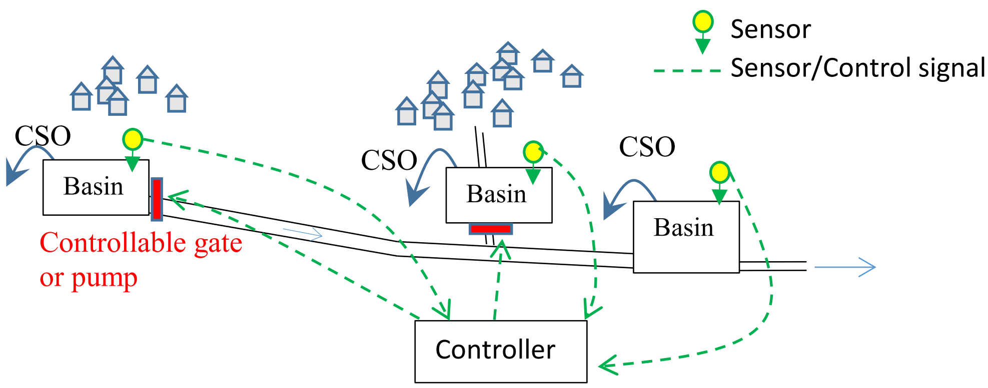


Figure 2: Control in a system with multiple basins, sensors and actuators.

Potential effect on system and surroundings

This setup gives a large degree of control and flexibility to the operators. The scope of the RTC can rather easily be changed from e.g. distributing the CSO evenly over all the basins to let the majority of the CSO happen where the waste water is the most polluted. The main potential benefit will be reduced CSO and thus reduced impact on the recipient water bodies. Such a setup usually can remove many of the small overflow events, but it is worth noting that events that vastly supersede the total storage volume in the system will still lead to overflow.

Requirements

Such a setup requires a sensor in each basin as well as actuators in as many basins as possible. In order to calculate the control based on the many signals, a central Controller is needed, and this will typically be part of the SCADA system that is also a requirement for such a system.

System failure prioritization based on water quality

A seldom used method for reducing the environmental impact of an urban drainage system is to deliberately block pipes leading relatively clean stormwater runoff to combined sewers in situations where CSO's or flooding from the combined system is expected, see Figure 3.

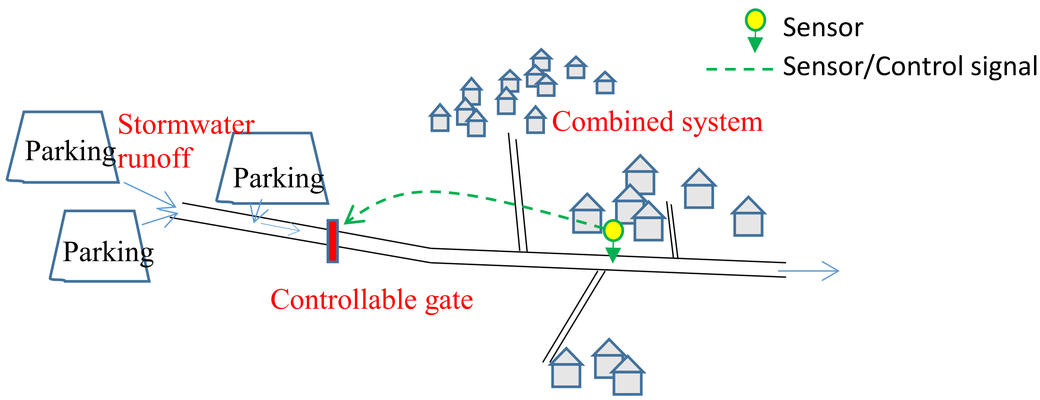


Figure 3: Controllable gate reacts on downstream water level sensor and possibly provoke an upstream flooding with stormwater runoff instead of a downstream flooding with combined sewerage.

Potential effect on system and surroundings

Such a setup can save the recipient water bodies from waste water and the city from flooding with combined sewerage. It does, however, come at the cost of more frequent overflow or flooding with the relatively cleaner stormwater upstream.

Requirements

As minimum a gate/orifice and a sensor.

Overview of RTC suggestions for the pilots

Table 1 shows an overview of suggested control solutions for the NOAH pilots described in rest of this document.

Table 1: Overview of the suggested control solutions for the NOAH pilots described in this document.

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

Rakvere

(The system description is made based on text and input from Nils Kändler.)

System description

Rakvere pilot catchment with an area of 177 ha has a fully separate stormwater system built with several outflows to Soolikaoja stream (both stream and tunnel). Soolikaoja is a natural stream passing the town and has been enclosed to 1.2 m wide tunnel in the central part of the town. There are no pumping stations and automatically adjustable actuators in the system. Upstream part of Soolikaoja takes stormwater from two residential areas and some roads. There are several static overflow weirs on the stream before water ends up in Süsta pond with an area of 7000 m2 and depth of ca 1.5m. Inflow from Soolikaoja streams to the pond varies between ca 10 – 1000 m3/h (it is highly dependent on the precipitation and snowmelt). *Figure 4* shows a map and images from the catchment.

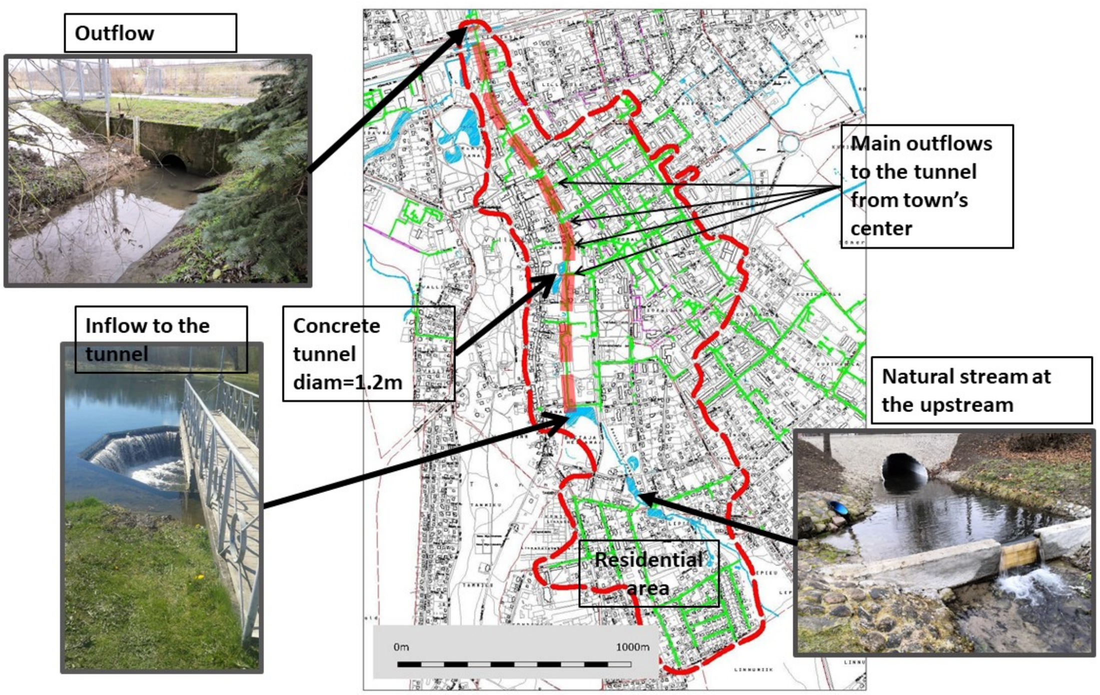


Figure 4: Images of water infrastructure and a map of the catchment.

The current outlet from the Süsta pond is a weir and since the water from this flows through the limited capacity stretch in the center of the city it can worsen problems with flooding. *Figure 5* shows a modelled situation in which the pipe system in the center of the city is close to surcharging and water is still flowing to this area from the pond.

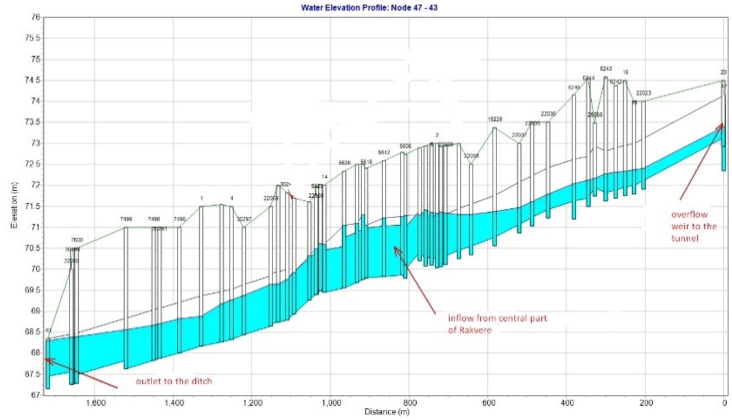


Figure 5: Profile plot of the stretch from the pond to the outlet.

There is hexagonal overflow well at the southern part of pond from where water enters to Soolikaoja tunnel. The tunnel has length of 1.7 km and diameter of 1.2 m, construction material is concrete. There are substantial sediments in some sections of the tunnel. Four main stormwater collectors situated at the center of the town are directing the water to this tunnel. After 1.7 km water will continue flowing in natural ditch leading to the Baltic Sea. Water level in the ditch + sediments are dictating the outfall elevation. A birds view of the SWMM model of the area is shown in *Figure 6*.

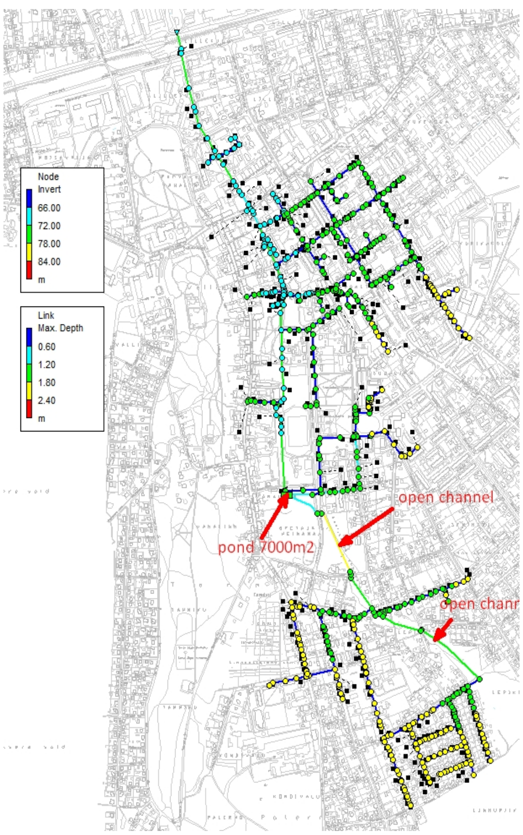


Figure 6: The key elements of the SWMM model

The SWMM model has been calibrated and validated against the result from the first measurement set done in February-March 2020.

Existing control, actuators, sensors, SCADA system

All wastewater pumping stations (ca. 20) in the region, wastewater treatment plant, water treatment plant and district water metering zones are connected to the centralized remote monitoring and control system (SCADA) that is operated by local water utility AS Rakvere Vesi. The system is based on SIEMENS controllers and central server. Data exchange is done by using bi-directional radio link. There are no sensors nor monitoring/control systems currently applied to separate stormwater network. Control and monitoring system of NOAH pilot will be connected and aggregated to the existing SCADA.

Potential RTC locations

The idea is to control outflow from the upstream pond (Süsta) to the main stormwater collector and thus avoid system surcharge in the center of the city during heavy rainfall events. It is possible to raise the level of the pond up to 30 cm from the current elevation, allowing thus to accumulate ca 2000 m^3 of extra water. A remote water level sensor will be installed in the manhole 22069 to measure the water level in the tunnel and activate the control algorithm. A second sensor will be installed to monitor the water level in Süsta pond.

Weirwall should have an algorithm that adjusts the height on the basis of these two sensors. Currently the procurement has been announced to find contractor to build and install the system, including installation of the remote sensor and establishing connection to the utility's SCADA system. An illustration of the planned installation is shown in *Figure 7*.

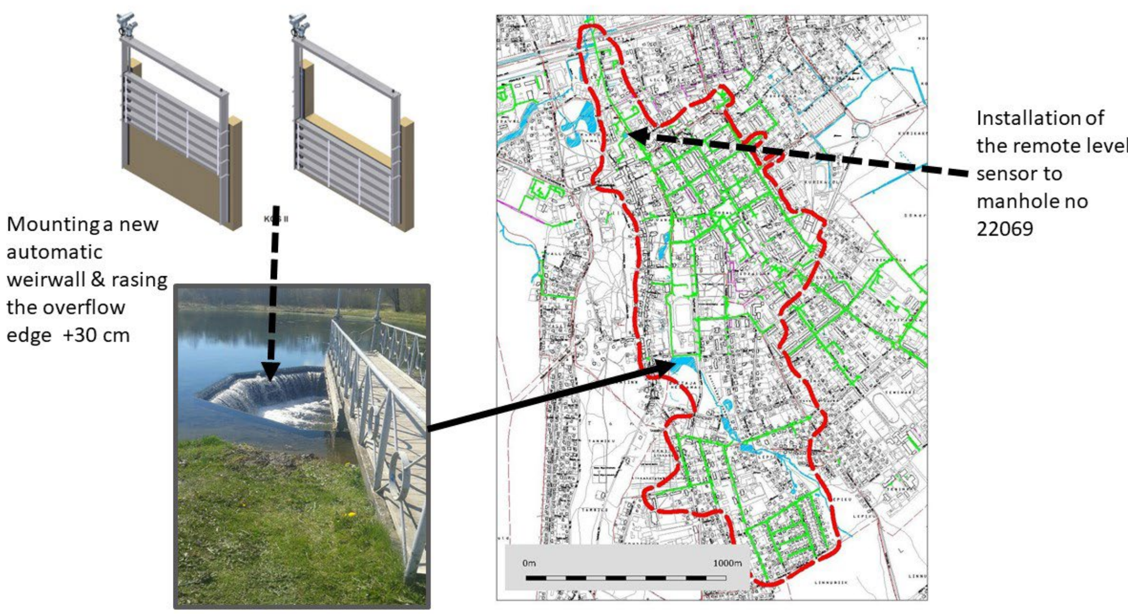


Figure 7: Illustration of the existing weir (bottom left), the planned new Weirwall (top left), and location of the sensors and actuator (right).

RTC Implementation

The scope of the RTC setup in the Rakvere pilot is to reduce flooding in the downstream city by using the storage capacity in the upstream lake. The RTC setup in the Rakvere pilot is done by installing a movable weir (Smart Weirwall System) that can raise its weir crest based on a signal from a sensor in the city and thus providing 30 cm of additional depth in the lake.

The downstream sensor is located at manhole no 22069 as described above. The movable weir has a width of 2 meters and has a bottom height 1.45 meters above the bottom of the lake. A fixed weir is installed at a height of 1.75 meters which ensures that water will continue downstream in the system when the lake is full. The additional storage is used when the water level in the city is high and the RTC setup looks like the following:

If depth in node 22069 > X m
Weir height = 1.75 m
ELSE weir setting = 1.45 m

The NOAH Tool was used to estimate what setting that should be used to raise the crest of the weir. The target was to reduce the number of flooding events from 8 selected manholes distributed in the city center, disregarding the amount of water that flooded, since the removal of a single flood event can be more important than a reduction of the extent of an event that is still occurring. Some of the nodes were deliberately chosen to be in areas that were not expected to be affected much by the control. This was done in order to enable the optimization to have something to improve if all flood problems were solved during the first iterations.

In order to optimize the settings for a wetter future climate or simply extreme situations with the current climate, we chose to set the inflow to the pond to 1200 m^3/h and then use the rainy period from May 1st – August 1st 2016 for the estimation.

The configuration of the NOAH tool used for the estimation of the RTC settings is shown in Figure 8.

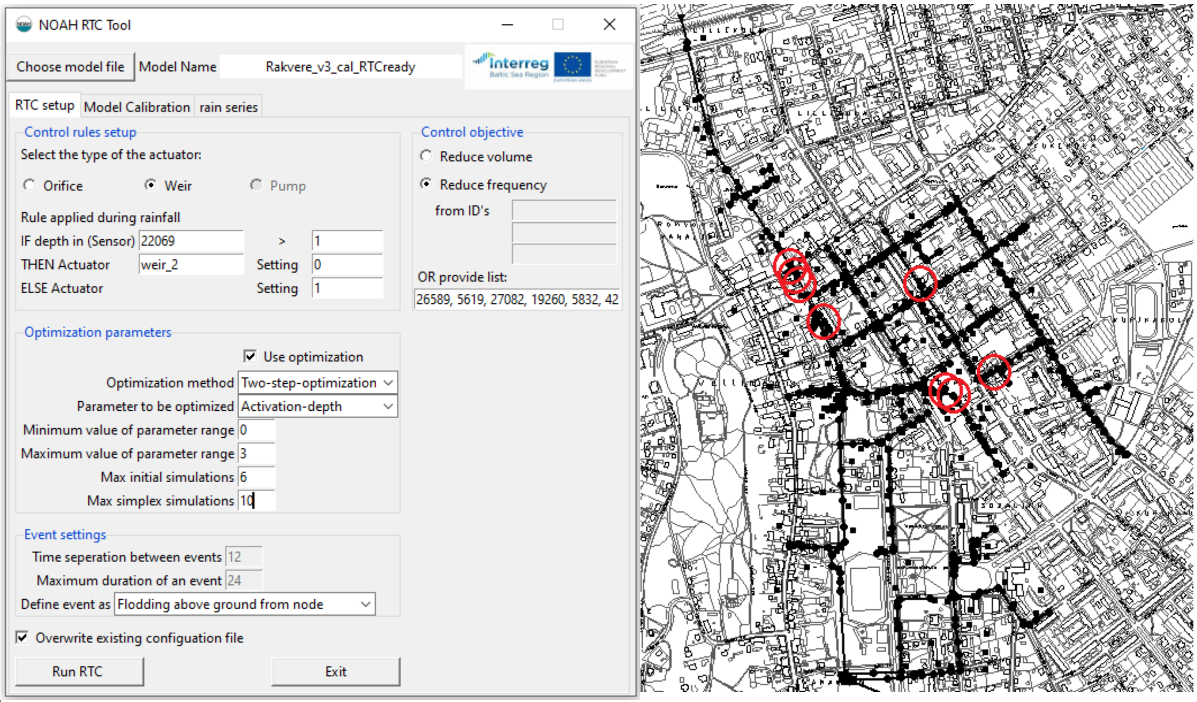


Figure 8: Configuration of the NOAH tool used for Rakvere (left). Location of the nodes used for the control objective (red circles in right).

Effect of the proposed RTC scheme

The RTC can in this case delay the water and thus reduce the pressure in the downstream part of the system. When the additional storage capacity is fully used the water will flow over the weir and downstream in the system. Because the water will continue downstream in the city, it is not possible to remove all flooding events, but the delay and additional storage might reduce the amount of water that are surcharging onto the streets. In some cases, the delay is enough to fully avoid flooding from a node.

The initial 6 simulations (see configuration in Figure 8) result in the objective function values shown in Figure 9. From this it is seen that the number of events ranges from 37 to 43 depending on the RTC setting. Note that each event is representing a single flooded node for one event irrespective of other nodes are flooded at the same time. A high setting corresponds to a situation where the weir is always open and therefore this is comparable to a situation without RTC. The 10 simplex simulations furthermore optimized the control to 36 events with a setting of 0.51 m.

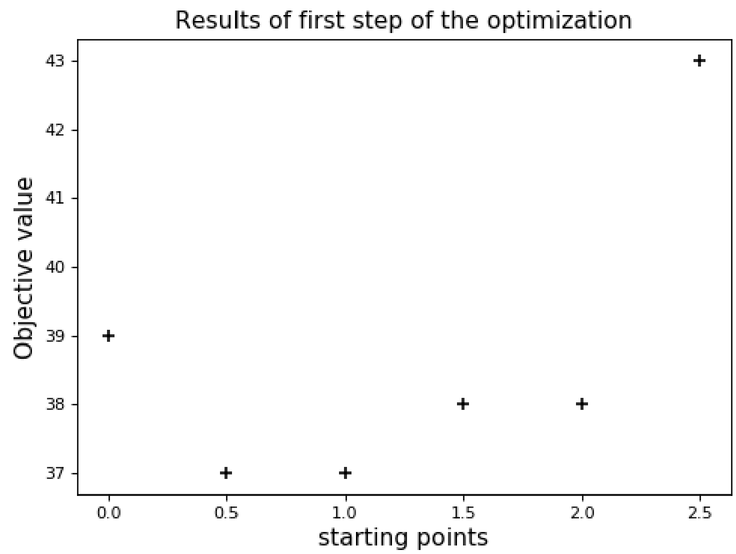


Figure 9: Results of the initial simulations of the Rakvere RTC optimization.

As mentioned, the optimizer aims at reducing the number of flooding events disregarding the volume. However, by delaying the water during rain events the volume in the flooded downstream nodes will also be reduced as is seen in Table 2. In two of the nodes (number in green) flooding can be completely avoided when implementing the RTC setup.

Table 2: The volume of the flooding (in m3) from the selected nodes with and without RTC for the period May 1st – August 1st 2016 with an elevated inflow to the pond of 1200 m^3/h.

NODE ID	WITH RTC	WITHOUT RTC
19260	1158.15	1157.81
14	46.1	63.39
26589	0	0
5619	0	23.17
27082	516.75	490.54
22065	0	103.29
5832	909.87	909.15
42	458.99	468.83
TOTAL	3089.86	3216.18

It is seen from these results that there is a potential of reducing both the volumes and frequency of the flooding events when implementing Real Time Control. Based on the SWMM model the weir should close when the water level in node 22069 reaches 0.51 meters. Physical limits by the chosen weir and model uncertainties should be considered when doing the actual implementation, but the NOAH Tool provided this setting as the suggested solution.

In the SWMM model the weir opens and closes instantaneously. This causes some “waves” down in the system because water is quickly released from the lake that will not appear if the weir opens and closes slowly as will most likely be the case in an actual implementation. This should be considered when comparing model results and implementing the weir, but it is not likely to have any significant influence on the results. From Figure 9 it is seen that the performance is roughly the same if the weir is set to raise when the water level is 0.5 or 1.0 m and in both these cases the objective function value is close to the optimum. This indicate that if the final implementation allows for a gradual lowering and raising of the weir depending on the downstream water level, this graduate change can be set to happen from a downstream level ranging from 0.5 to 1.0 m.

Haapsalu

(System description based on text and input from Janet Roosimägi)

System description

Figure 10. Aerial Photo of Haapsalu with pilot area (blue) and outfall of the stormwater system (red).

The stormwater system in Haapsalu is managed by Haapsalu City Government. Sewage and stormwater systems are separate.

The pilot area is located at the south part of Haapsalu, corresponding to actual stormwater system catchment areas.

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 rainwater flooding.

Stormwater outflow is a wetland that is a buffer before reaching the sea. The wetland is surrounded by a dam designed to protect seawater inflows into stormwater systems. The dam has 2 manually closable weirs that are in a very poor condition and release seawater to the wetland, which places a burden on stormwater systems.

The NOAH project aims to replace the existing depreciated concealment system (Figure 12 and Figure 13) with a new automatic weirwall system. The location is indicated by a red circle in the Figure 10.

Figure 11. Hydraulic model of the pilot area of Haapsalu

Existing control, actuators, sensors, SCADA system

There are no existing control, actuators, sensors or SCADA system in use at the moment.

Potential RTC locations

The expected location of the RTC could be at the new automatic weirwall system. The system consist of moveable gate (see the figure below) and two sensors situated at the opposite sides of the gate. All the equipment will be installed into a new manhole that will replace the existing obsolete gate. Local street-lighting control system will be used to host the remote control and monitoring environment.

RTC can have two objectives:

1. Prevent seawater backflow in case of storms and other situations rising the sea level higher than level in the wetland (flood protection);
2. Ensure sufficient retention time of the urban stormwater in the wetland before letting the water to the sea (water treatment).

Figure 12. An existing concealment system in Haapsalu (spring 2020)

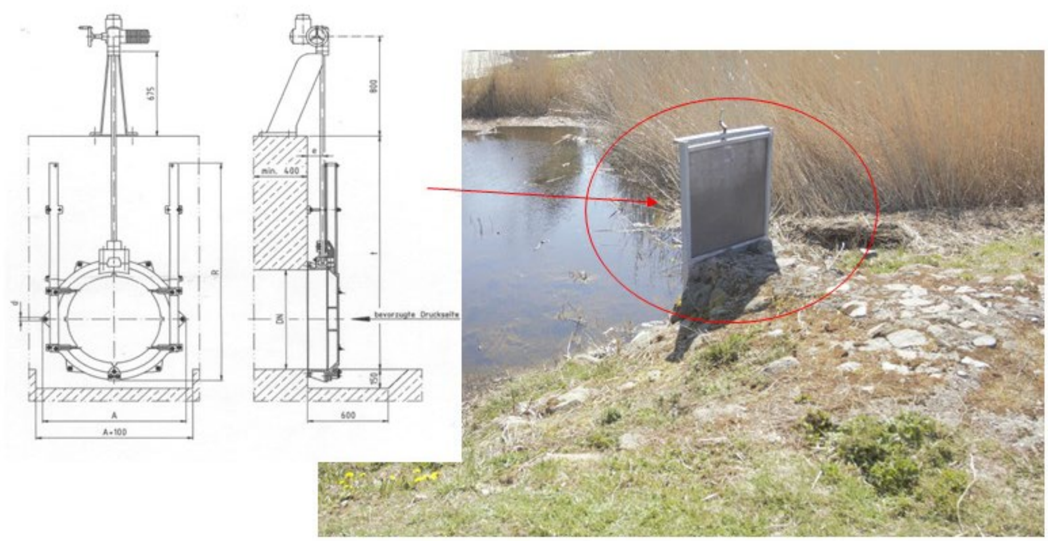


Figure 13. An existing concealment system and sketch of the new gate

RTC Implementation

Description

The analysis of the RTC setup for Haapsalu consists of a weirwall with the purpose of protecting the city against flooding during high sea levels. Rules for when to open and close the weirwall can also be used to retain water in the wetland for improved settling of stormwater particles.

The RTC setup requires a weirwall and two water level gauges – one inside the wetland and one outside in the sea.

A simulation analysis has been set up to test the efficiency of the control setup. For this analysis five years of rainfall and sea level observations were available in the period 2015-2020. The control setup was tested on the largest sea surge event within the dataset, which occurred on the evening of December 6th, 2015. The simulated period consists of the days before and after this event (December 1-8, 2015).

Three scenarios of how to operate the weirwall has been tested:

1. **Status quo:** No control (equivalent to leaving the weirwall open at all times).
2. **Maximum flood protection:** The weirwall closes whenever the sea level is higher than the water level inside the wetland, which gives maximum protection against high sea levels. This strategy will also keep the water level in the wetland as low as possible. However, this strategy would also turn the wetland into a freshwater wetland rather than a brackish mix of freshwater and salty sea water.
3. **Protection only above 1 meter:** The weirwall closes when the sea level is above one meter. This lets sea water into the wetland during normal everyday situations as is currently the case, while the wall closes in high risk situations. This strategy protects against flooding, without affecting the current water quality of the wetland.

Effect

Figure 14 shows the simulated effect of applying the three different RTC scenarios on the water levels inside the wetland. The observed sea level is identical for all three cases, while the only thing that varies is the control of the smart weirwall.

The scenario with no control (top panel in Figure 14) shows how the system works today, where the water level inside the wetland follows the water level in the sea outside of the dam. The small openings at the weir locations limit the flow of water between the sea and the wetland, which results in a delay between the dynamics of the two sides of the dam (e.g. a rise in sea level leads to a rise in wetland water level with a delay of a few hours). In the status quo scenario with no control the wetland water level rises to 1.4 m meters, which is problematic for the parts of the sewer system immediately upstream of the wetland.

The scenario with maximum protection (middle panel in Figure 14) shows that the water level in the wetland is kept at low levels throughout the entire week, as water is not allowed to leave the wetland in case the sea level is higher than the wetland water level (which is true throughout most of the simulation period). The slight increase in the wetland water level from day 4 to day 7 in the figure are due to small amounts of rainfall running into the wetland.

The scenario where the weirwall closes only during high sea levels is shown in the bottom panel of Figure 14. Here, the simulated wetland water level is allowed to follow its natural variations in the first three days of the simulated period where the sea levels are low. However, as the high impact event happens at days 4-7 in the figure the weirwall closes, and the water level in the wetland is kept at a moderate level.

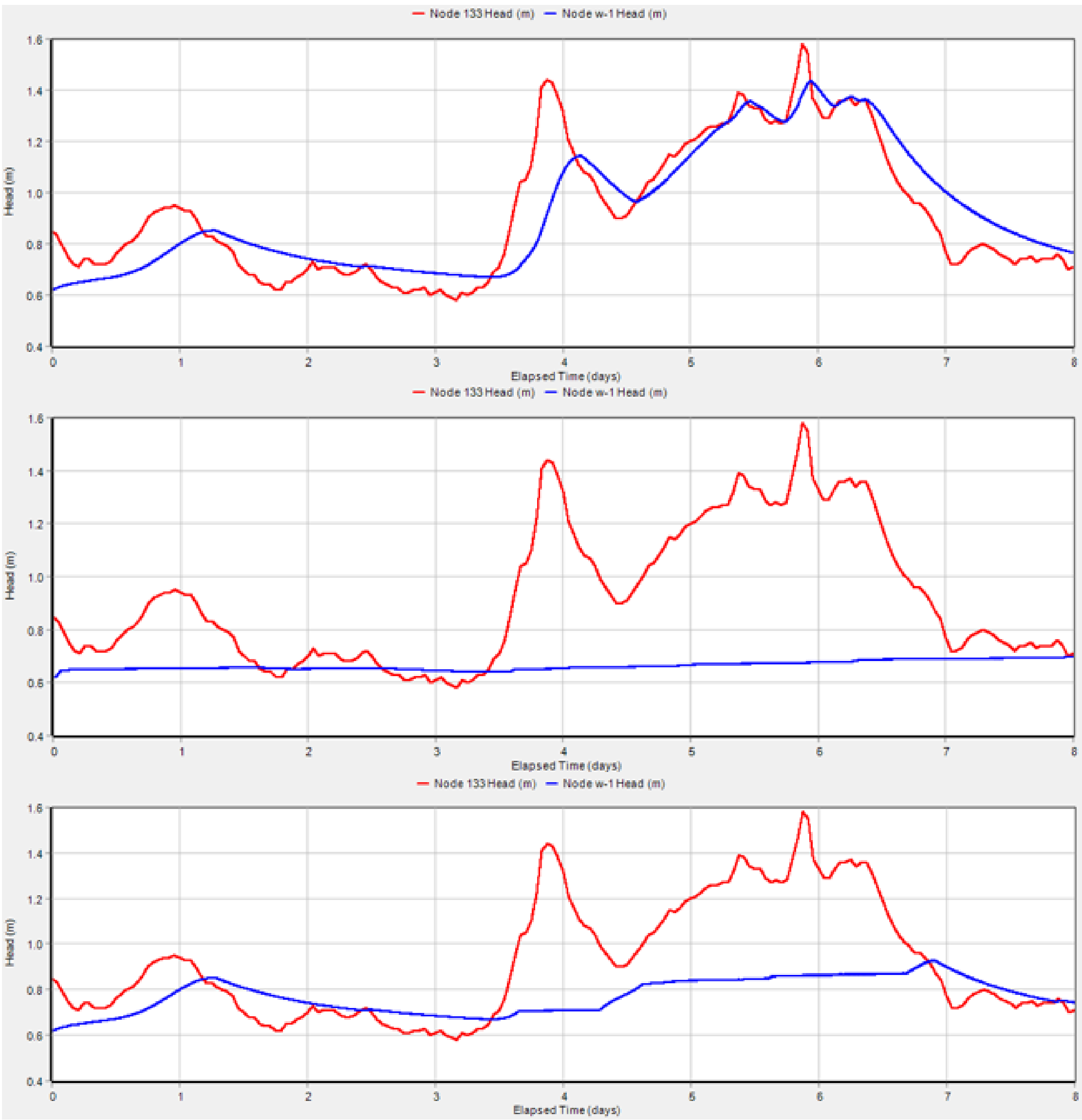


Figure 14: Simulated water levels for the three RTC setups for the period of December 1-8, 2015. Top: No control; Middle: Maximum protection; Bottom: Protection above 1 meter sea level. Red line: observed sea level; blue line: simulated water level inside the wetland depending on the chosen RTC scenario.

Figure 15 shows summary statistics of node flooding from three simulated scenarios. The table in the top of the figure shows that there is flooding in several model nodes, which means that water is surcharging up through manholes in the sewer system. Most of these nodes are located in the immediate surroundings of the wetland as highlighted by the red circles on Figure 16. The middle and bottom tables of Figure 15 show that node flooding is heavily reduced both in terms of the number of nodes that flood during the simulation period and in terms of the total flood volume.

Summary Results

Topic: Node Flooding — Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate LPS	Day of Maximum Flooding	Hour of Maximum Flooding	**Total Flood Volume 10^6 ltr**	Maximum Ponded Depth Meters
26	47.02	337.17	5	20:28	2.615	0.318
170	23.96	314.39	6	03:18	2.065	0.138
169	22.28	353.59	6	03:17	1.532	0.128
9930	48.94	5.10	5	20:17	0.053	0.327
128	0.01	493.44	0	03:22	0.002	0.262
9929	0.03	63.91	5	20:15	0.001	0.002
131	0.01	1652.17	5	20:36	0.001	0.000
104	0.01	693.29	6	08:03	0.001	3.721
101	0.15	13.74	6	03:16	0.001	0.001
9928	0.01	15.14	6	03:16	0.000	0.000
9927	0.01	4.53	6	03:16	0.000	0.000

Summary Results

Topic: Node Flooding — Click a column header to sort the column.

	Hours Flooded	Maximum Rate LPS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
9930	0.01	106.21	0	00:40	0.000	0.001
128	0.04	813.17	6	07:32	0.072	1.296

Summary Results

Topic: Node Flooding — Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate LPS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
97	0.01	15.39	5	15:03	0.000	0.000
9929	0.01	9.13	5	09:44	0.000	0.000
9930	0.05	148.56	5	15:03	0.002	0.005
128	0.01	1599.00	5	15:03	0.027	3.182
104	0.01	1047.10	5	09:43	0.005	0.740

Figure 15: Summary statistics of node flooding in the sewer system. Top: No control; Middle: Maximum protection; Bottom: Protection above 1 meter sea level.

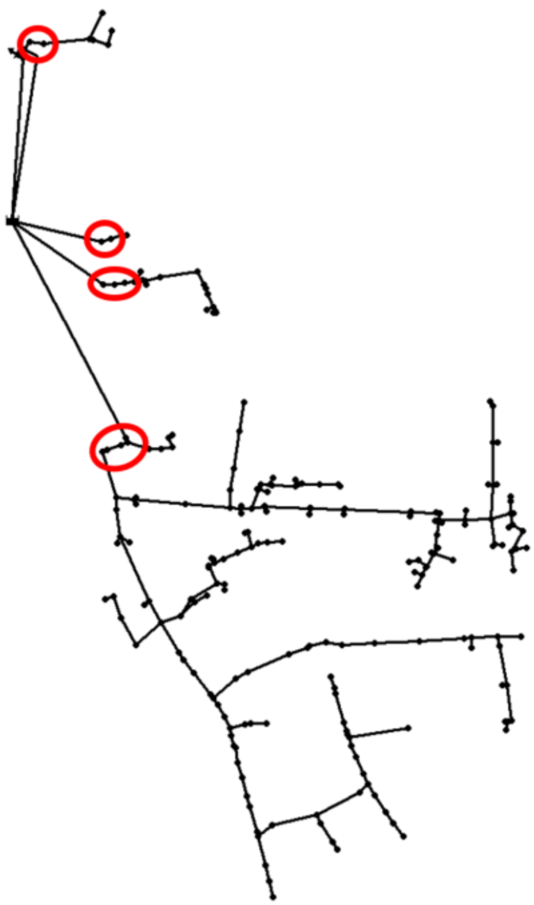


Figure 16: Nodes with flooding issues near the wetland.

Jurmala - Miera Street Pilot

(System description based on text and input from Valts Urbanovičs and Gints Dakša)

System description

Miera street is located in the Eastern part of Jūrmala, Latvia (see Figure 17). The pilot area consists mainly of forested areas and low-rise residential buildings. Landscape can be characterized as rather flat since invert elevations of the highest point in the system (LUKA_RIGAS_001 in the model) and the outfall differ by 3.08 m (distance between the points 1.4 km). Roofs constitute around 9.5% of the total catchment area. Paved roads add up to 14% of the total catchment area.

Figure 17: Miera catchment location and discharge point.

The rainfall collection system can be characterized as a separate sewer system with several sanitary sewer connections from households. Runoff is conveyed by means of gravity pipelines (total length 2.2 km; diameters ranging from DN250 to DN1000) and roadside ditches (total length 1.6 km; trapezoidal cross-section; grass surface). System discharges into Lielupe river – outfall is located 10 km from the spot where Lielupe flows into the Gulf of Riga. The SWMM model can be seen in Figure 18.

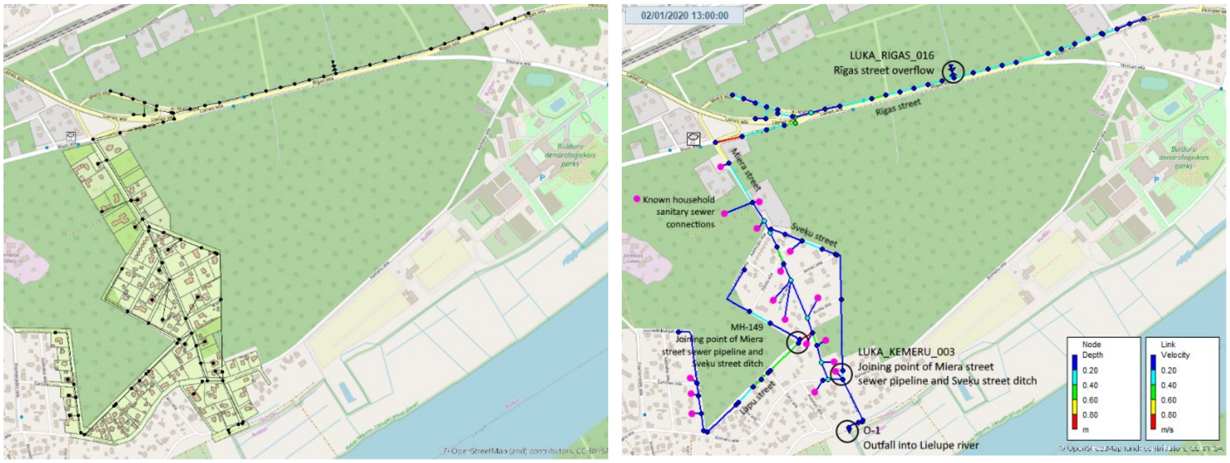


Figure 18: Miera street catchment model in SWMM

Existing control, actuators, sensors, SCADA system

As of now, there are no existing means of controlling the system.

Potential RTC locations

The most feasible option of using RTC for system control is transforming node LUKA_KEMERU_003 into a pumping station. During dry weather, the pumping station would pump everything (household sanitary sewer connections) to the nearby sewage. During rainfall, the system would discharge into the Lielupe river.

RTC Implementation

Since the majority of the pollution load to the recipient comes during everyday conditions with little or no rainfall, the situation can be alleviated with a small pump that just needs to be able to pump the dry weather flow. If it is possible in a cost efficient way to connect the pump to the sanitary sewer systems, this option might be substantially cheaper than other ways of reducing the pollution load to the river. In order to be able to catch as much of the dry weather flow as possible, the LUKA_KEMERU_003 node is ideally placed when viewing the system from a birds view. There is, however, a large belly sag on the main pipe stretch leading to this node, see Figure 19. This sag will inevitably be filled with a rather large volume of stagnant wastewater. This water will suddenly be flushed out when stormwater runoff flushes the system and the pumping based solution will only be able to capture this water if the pump sump has a rather large volume. Therefore it was decided to place the pump in the node MH_MIERA_014 instead (highlighted with a green circle on Figure 19), which will solve the problem with stagnant waste water and will not require the installation of any additional storage volume for the wastewater pump.

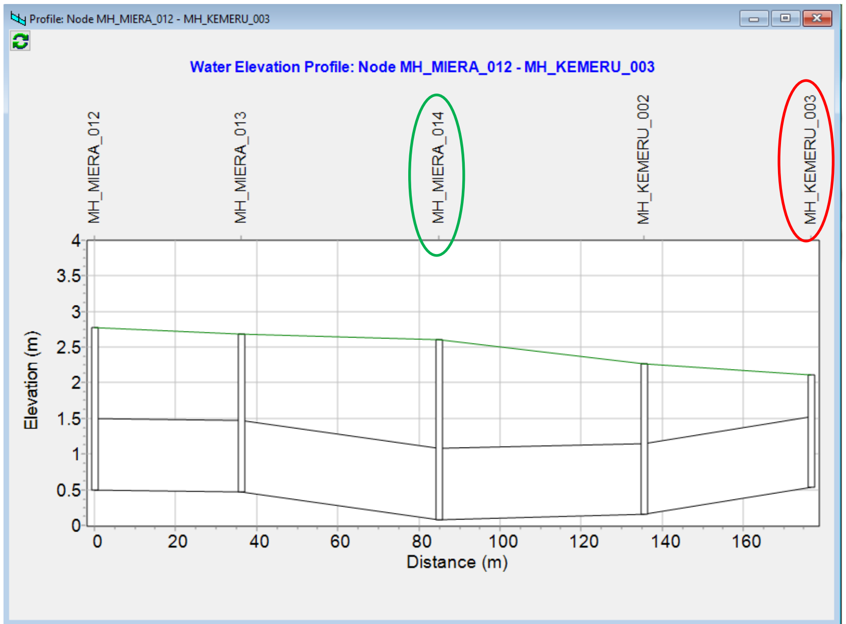


Figure 19: Longitutional profile showing the belly sag on the main strech to MH_KEMERU_003 (red cicle).

Pump setup

A pump with a capacity of 2 l/s is installed in node MH_MIERA_014, and set to turn on when the water level at the node exceeds 0,40 m. This level is lower then the invert level of the node at MH_KEMERU_003 which means that the belly sag is effectively used as a pump sump. The pump is connected to an outlet that represents a connection to the sanitary sewer.

Figure 20: Added pump connection (red circle) from MH_MIERA_014 (green circle) to the outlet representing the sanitary sewer (blue circle).

Adding Water Quality to the model

In order to assess the impact of the solution in terms of reduced pollution to the recipient, it is necessary to add a water quality parameter to the SWMM model. We chose to do this by adding the virtual substance "Stuff" to all dry weather flow with a concentration of 50 mg/L (corresponding to typical concentrations of ammonia in wastewater). Since phosphorous and COD can be modelled in the same way for smaller systems like this with little time for reactions and setting, the water quality results can be used to give an indication of the relative savings of pollutant loads.

Effect

The effect of the solution was tested using the Riga rainfall data for the entire year of 2019. A plot of the flows in and out of the node with the pump for the period day 130-135 in the simulation is shown in Figure 21. The concentration in the water standing in the belly sag slowly increases towards that of the waste water of 50 mg/L. As soon as it starts to rain the concentration drops as the cleaner stormwater fills the system. The magnitude of the pumping flow is so small that it is barely visible on the plot but none the less this pumping catches the vast majority of the pollutant load for longer periods of time.

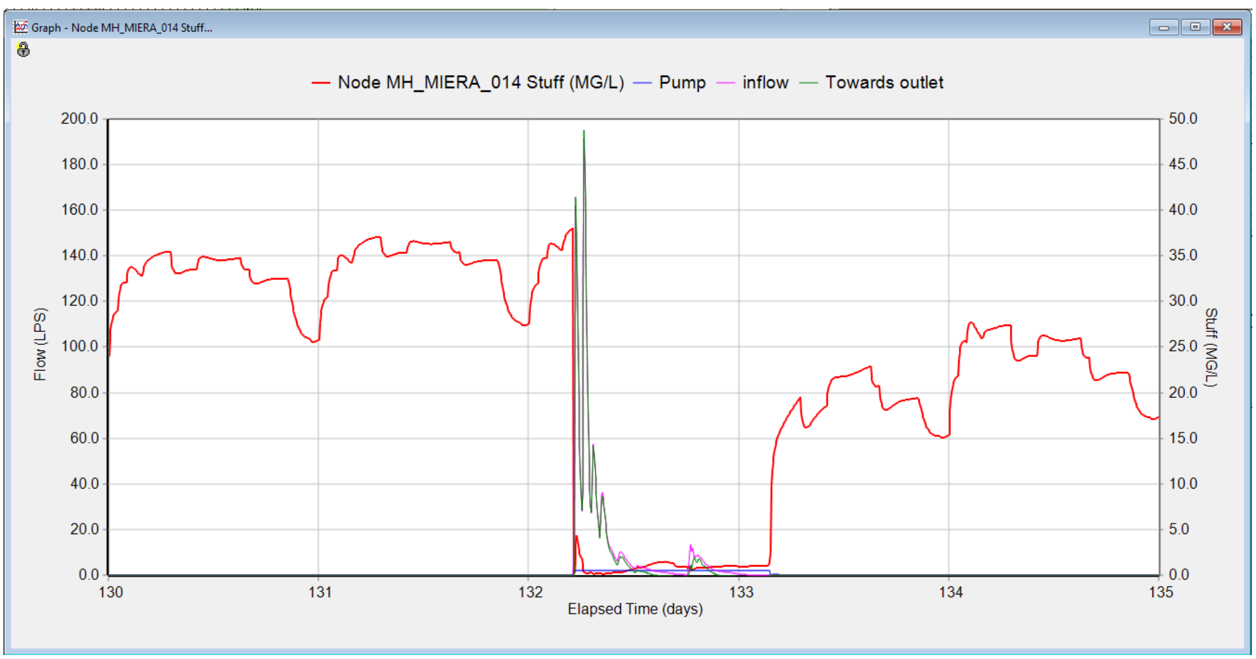


Figure 21: Flows in and out of the node with the pump and the pollutant concentration in the node in a five day period with a rainfall event in the middle.

The summary statistics from SWMM with and without the proposed solution can be seen in Figure 22. It shows that the total pollutant load trough the outlet to the recipient (outfall O-1) is 159,5 kg while the corresponding number after implementing the pumping solution is down to 46,9 kg, which is a reduction of 71%.

Summary Results

Topic: Outfall Loading   Click a column header to sort the column.

Outfall Node	Flow Freq. Pcnt.	Avg. Flow LPS	Max. Flow LPS	Total Volume 10^6 ltr	Total Stuff kg
O-1	97.73	6.40	952.69	113.021	159.501
O-2	0.12	97.79	1131.18	0.945	0.000

Summary Results

Topic: Outfall Loading   Click a column header to sort the column.

Outfall Node	Flow Freq. Pcnt.	Avg. Flow LPS	Max. Flow LPS	Total Volume 10^6 ltr	Total Stuff kg
O-1	20.04	27.94	953.33	95.631	46.913
O-2	0.12	97.47	1129.71	0.943	0.000
1	98.39	0.58	2.00	17.471	104.925

Figure 22: Result summary for 2019 with (buttom) and without (top) the proposed solution. Outfall node "1" is the virtual outlet that represent the connection to the sanitary sewer.

Liepaja, Tebras street

(The system description is based on info and text from Valts Urbanovičs)

System description

The Tebras street catchment in Liepaja (Latvia) is a paved street area with low rise residential buildings (Figure 23). The area in orange is also a low rise residential area, but it is paved with gravel and no gullies. The area is fairly flat and the outfall is connected to the lake.

There is a problem with backflow from the lake from the outfall to the pump with water standing still all the way to the pump. There are areas planned to be connected to the catchment which are shown in the first picture and there is doubt about the system's capacity to take in such connections.

Currently in the model there is real world j106 level, lake level and hourly precipitation data from the Liepaja meteorological station from 07.09.2019 to 09.09.2019. In this period there is a moment where the model of the existing system is already almost full which raises doubts about the system's ability to handle the discharge from the now connections.

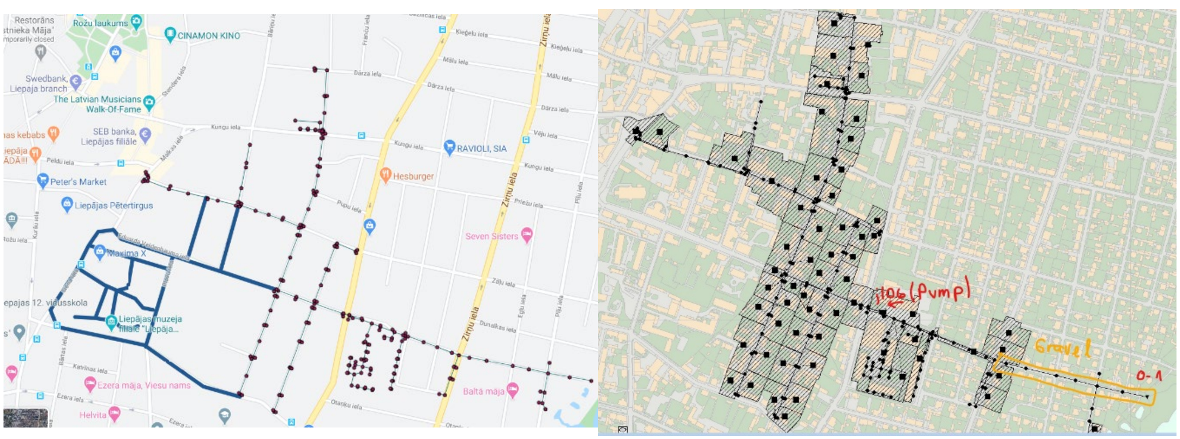


Figure 23: (left) Map of the area. The blue lines indicate streets and pipes in the new area that might be connected to the existing system. (Right) Image of the SWMM model of the existing system. The pumping station is indicated with a hand written "Pump" and the outlet is just below the "0-1" annotation.

Existing control, actuators, sensors, SCADA system

There are two pumps without a frequency modulator working in tandem in manhole j106, see Figure 23 (Right). The pumps are connected to a SCADA system, from which the following information can be received: j106 level, pump on/off times.

Potential RTC locations

A pump at the outfall which pulls water out of the system and discharges it into the lake, bypassing the existing outfall, which most of the time is under water.

If the potential connections in the first picture would be added, then a gate, which holds back rain water in the system until the pump has pumped enough water to be able to take in the extra water from the planned connections. A gate would make sense at j32 to hold back water from planned connections. This of course raises problems with sedimentation but could be a potential solution.

RTC possibilities

Installing a tidal gate and pump at the outlet

To avoid the issues related to the backflow from the lake a tidal gate was added to the outlet and a pump was installed from node j70, as suggested above. The pump curve from the existing pumps at j106 was used, and the pump was set to start when the water level in node j70 exceeds 0.5 m. Since the water will rise in this node both in case of a closed outlet and during big rain events, this might cause the pump to turn on also in situations without backflow.

Figure 24 shows the modelled depth in the node j6 that is located between the pump and the outlet. The figure clearly shows that the tidal gate and pump works as intended, since the elevated water levels due to backwater from the lake from day 40 to 60 that is visible in the top figure (system without alterations) is almost completely gone on the bottom figure, that shows the modelled water level with an added tidal gate and pump. There is no need to introduce any complicated RTC in such a system, since the downstream pump should always try to pump water above everyday levels. If the power consumption of the pump was to be considered then an RTC scheme could be implemented that would allow the water level upstream the pump to be higher. This would, however, lead to other problems such as increased sedimentation and a system that was less ready for a large rainfall event, so such an implementation is not likely to be cost-effective.

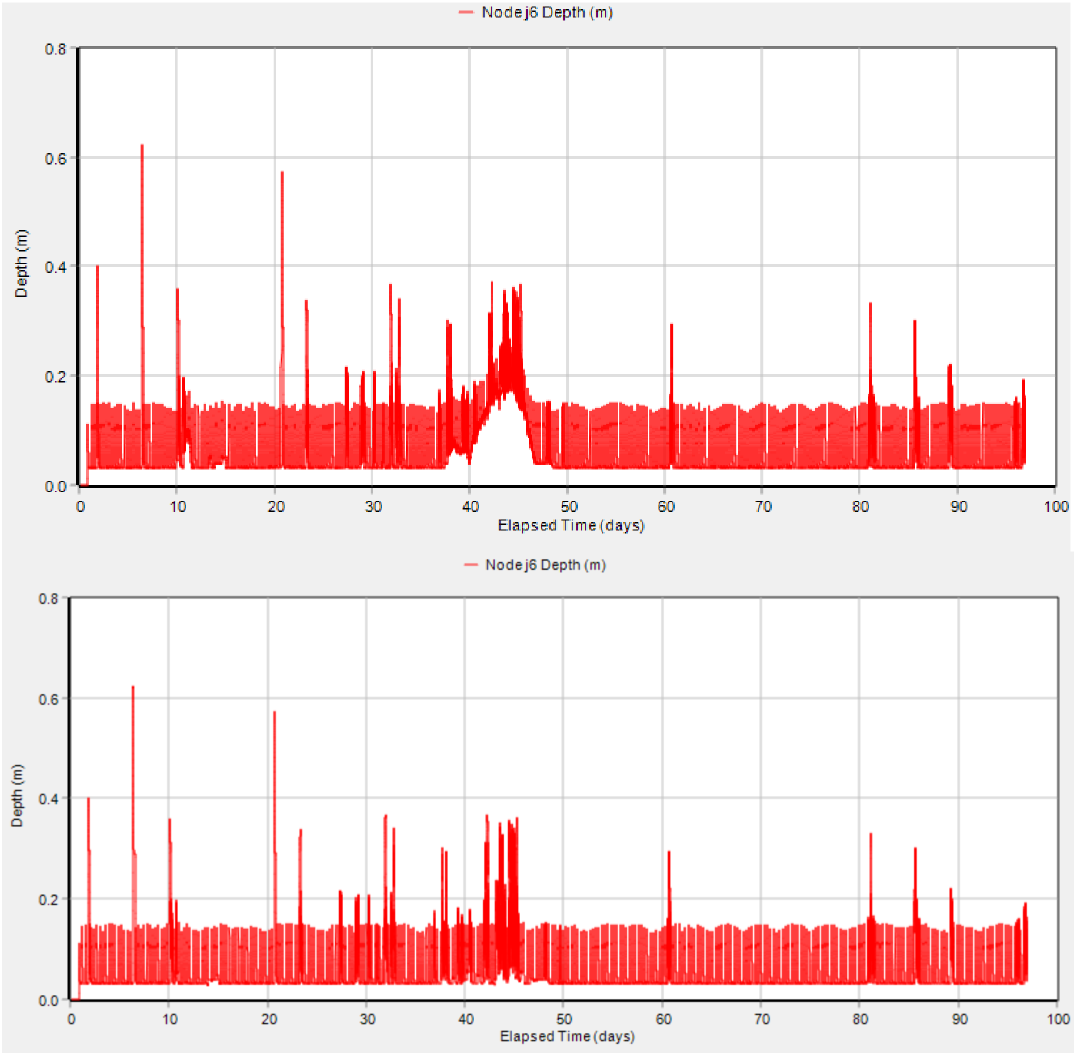


Figure 24: Modeled water levels at node J6 before (top figure) and after (bottom figure) implementing a tidal gate at the outlet and a pump to bypass the gate.

RTC possibilities when connecting the addition area

In order to test the feasibility of adding a controlled gate to j32 where the new system is to be connected to the existing system, the model with the new system added was used. This model shows widespread flooding for the focus event (07.09.2019 to 09.09.2019), see Figure 25.

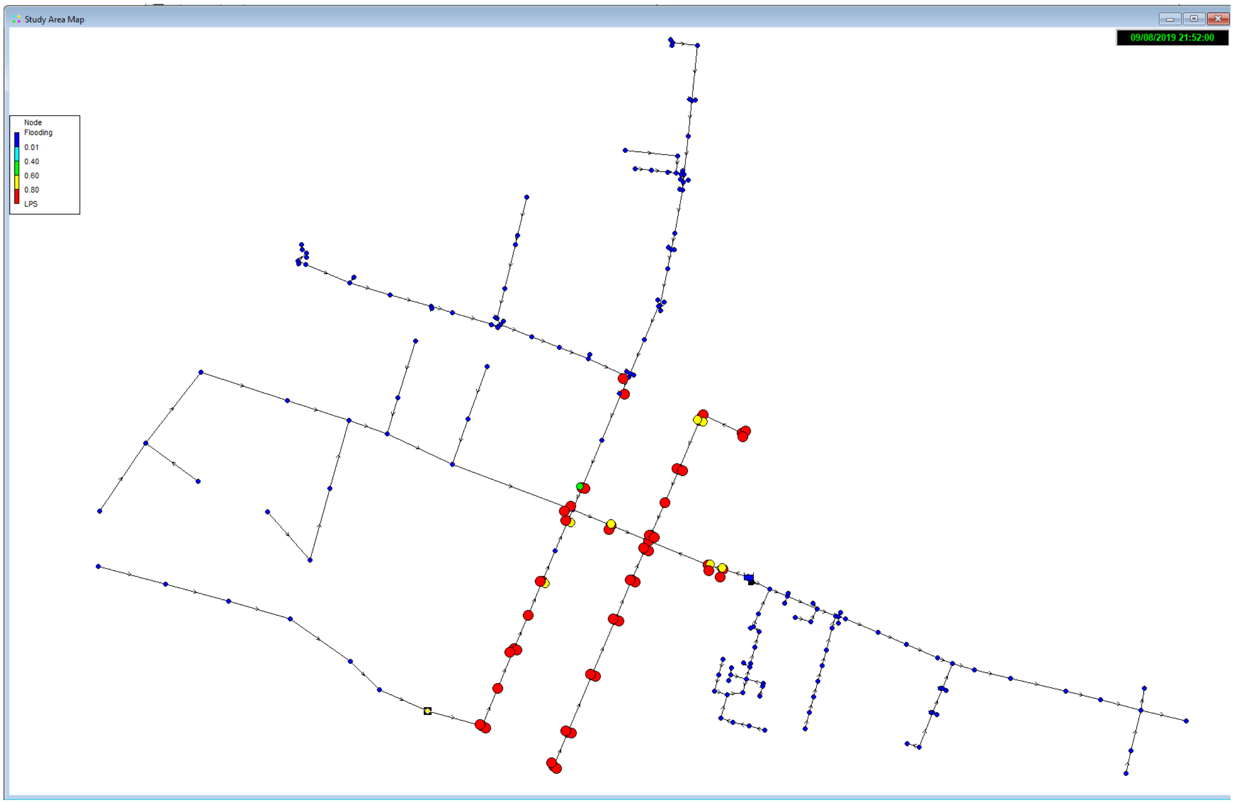


Figure 25: Snapshot of flooding discharge when no flow restriction.

The result summary from this simulation showed that 73 nodes had more than 1 m^3 of flooding. The flood volumes for the most flooded nodes can be seen in Figure 26. In order to test the maximum potential of restricting the flow from the new connections, the pipe to j32 was restricted to a maximum flow of 0.1 l/s. The result summary from this simulation with the focus period can be seen in Figure 27. The numbers show that only four nodes now have more than 1 m^3 of flooding. Only the three of these nodes are downstream of the location of the potential gate at j32 and these three nodes are only flooded by a few cubic meters of water. This mean that a gate at j32 could solve the downstream flood problems. The cost of this solution, however, would be large extend of flooding upstream. The top line in Figure 27 show that node 38, which is situated just upstream of the pipe leading to j3, would flood with 447 m^3. Without a storage like a basin or a planned natural depression to handle this volume, the water will anyway find its way downstream on the surface of the city which means that the flooding in the city will still happen. The pipe system upstream of node 38 is completely filled during the periods where the node is surcharging, which shows that moving the gate to a more upstream location would not be a solution either. Therefore, the conclusion must be that it is not advisable to try to reduce flooding in the city by restricting the flow from the new connections without adding some storage or retention volume to the upstream system.

Summary Results

Topic: Node Flooding   Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate LPS	Day of Maximum Flooding	Hour of Maximum Flooding	**Total Flood Volume 10^6 ltr**	Maximum Ponded Depth Meters
j12	2.38	18.40	3	21:48	0.012	0.902
j10	2.64	25.79	3	21:43	0.011	1.135
j32	1.75	21.10	3	21:54	0.010	0.499
j24	2.18	25.46	3	21:47	0.008	0.776
j9	2.60	22.19	3	21:44	0.007	1.103
j21	2.60	7.22	3	21:45	0.007	1.056
j20	2.43	9.59	3	21:46	0.006	0.935
j22	2.45	6.58	3	21:46	0.006	0.957
j15	2.33	8.32	3	21:46	0.005	0.873
j31	1.92	22.67	3	21:49	0.005	0.754
j19	2.47	10.59	3	21:45	0.005	0.974
j29	2.14	5.63	3	21:49	0.004	0.814
j30	1.94	7.65	3	21:49	0.004	0.727
j23	2.38	4.93	3	21:47	0.003	0.907
j14	2.18	6.47	3	21:48	0.003	0.773
j13	2.39	5.34	3	21:47	0.003	0.912
j11	2.46	8.90	3	21:44	0.003	0.963
j16	2.27	5.34	3	21:47	0.003	0.834
j38	2.51	6.63	3	21:45	0.003	1.004
j27	1.90	5.44	3	21:50	0.003	0.616
j33	1.86	7.33	3	21:51	0.003	0.563
j28	1.92	4.65	3	21:50	0.003	0.651
j26	1.70	3.43	3	21:55	0.002	0.487
j25	1.70	3.49	3	21:54	0.002	0.476
j18	2.10	4.94	3	21:49	0.002	0.724
j36	1.46	6.52	3	21:54	0.002	0.359
j35	1.60	6.38	3	21:53	0.002	0.428

Figure 26: SWMM result summary when the new area is connected (73 nodes in total have > 1 m3 of flooding).

Summary Results

Topic: Node Flooding   Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate LPS	Day of Maximum Flooding	Hour of Maximum Flooding	**Total Flood Volume 10^6 ltr**	Maximum Ponded Depth Meters
38	8.43	100.41	3	21:52	0.447	0.000
j10	0.52	12.01	3	22:00	0.002	0.238
j9	0.49	11.68	3	22:00	0.001	0.205
j21	0.46	4.89	3	21:57	0.001	0.162
j1024	0.56	2.71	3	21:57	0.000	0.306
j1026	0.56	3.02	3	21:58	0.000	0.308

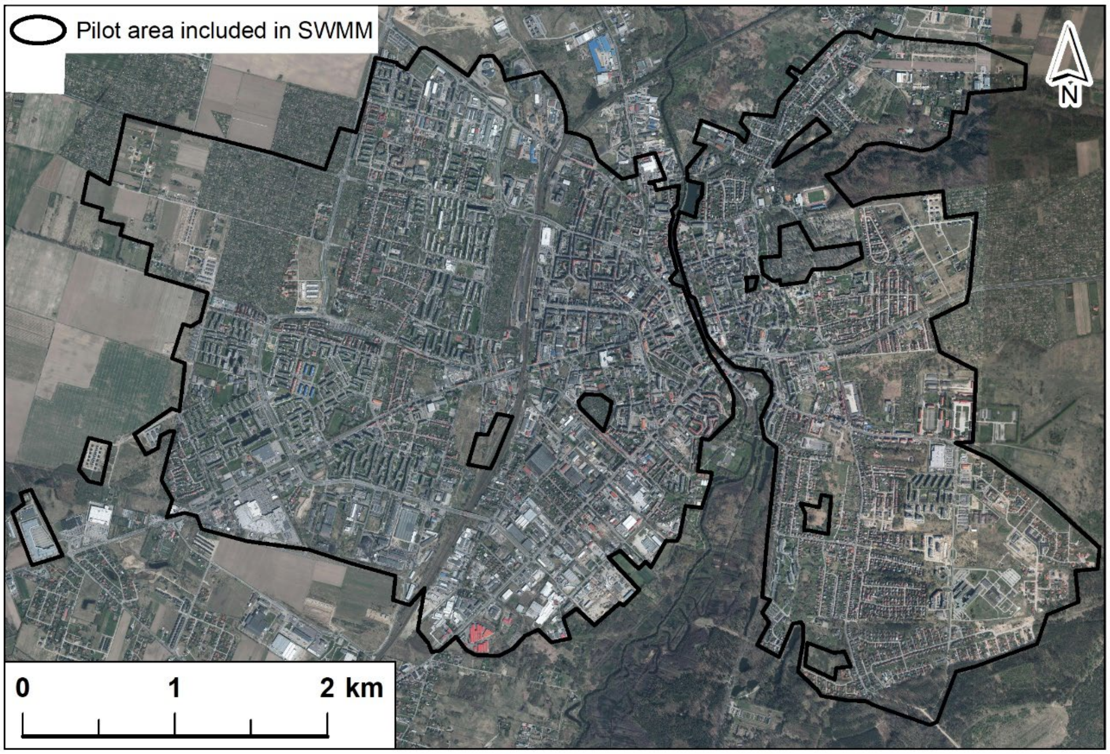
Figure 27: With flow restriction to 0.1 l/s to node j32 to test the potential effect of a gate at that location. Note only 4 nodes with > 1 m^3 of flooding. The red line highlight the nodes in the system downstream of j32.

Slupsk

(System description based in text and input from Rafał Ulańczyk)

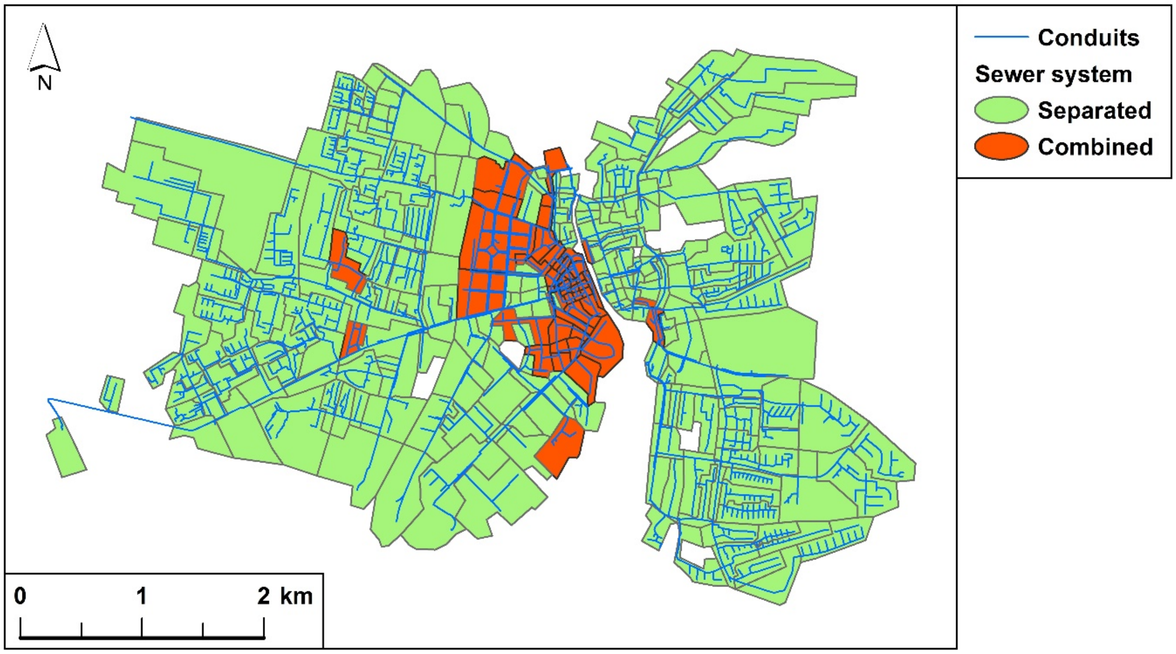
System description

Aerial Photo



System description + picture of SWMM model

The pilot area network model covers the entire city of Słupsk (22 km^2). The model consists of 5608 pipe sections and 5511 nodes (junctions). The sewer system includes 2% of combined sewer pipes only which drain 7% of the analysed area. Even though the share of combined sewer system is small, approximately 30% of the total flow originates from the storm water entering the sewer system via unsealed manholes and pipes. Such contribution poses a risk to the wastewater treatment plant (WWTP) and to the Słupia River, which is a recipient of overflows. The modelled network has one main outflow from which the wastewater and storm water is pumped to the WWTP. The excess which cannot be pumped is stored in the retention tank upstream the pump or discharged to the Słupia River. The total capacity of the tank is 493 m^3, however the retention capacity of the system (tank + main pipes) is nearly 2000 m^3. The modelled network is presented below.



Conduits and catchments simulated in the Słupsk pilot area using SWMM

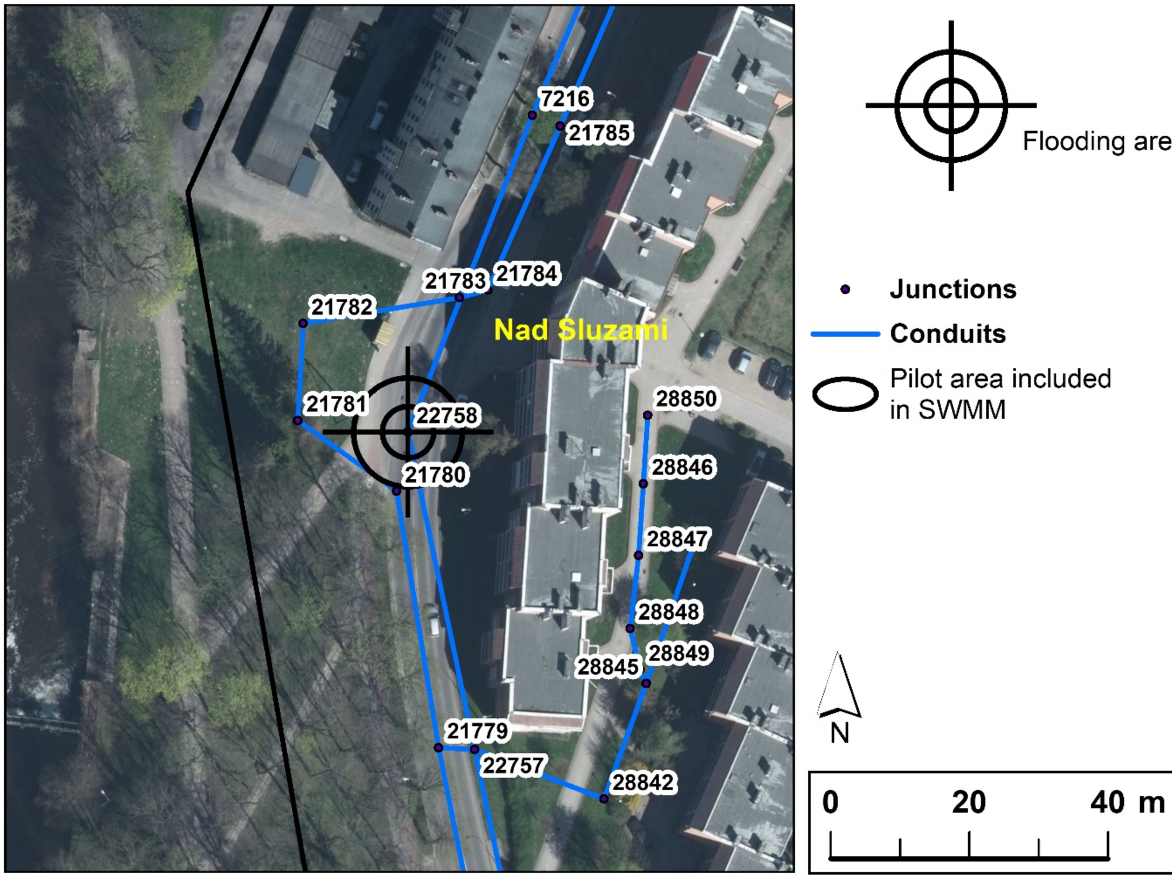
Existing control, actuators, sensors, SCADA system

The total volume of wastewater and storm water pumped out of the analysed area is monitored in the main pumping station with a temporal resolution of 10 minutes. The data is available online for the Słupsk Water Supply, however, for the external use (e.g. for the modelling purposes) can be exported periodically only.

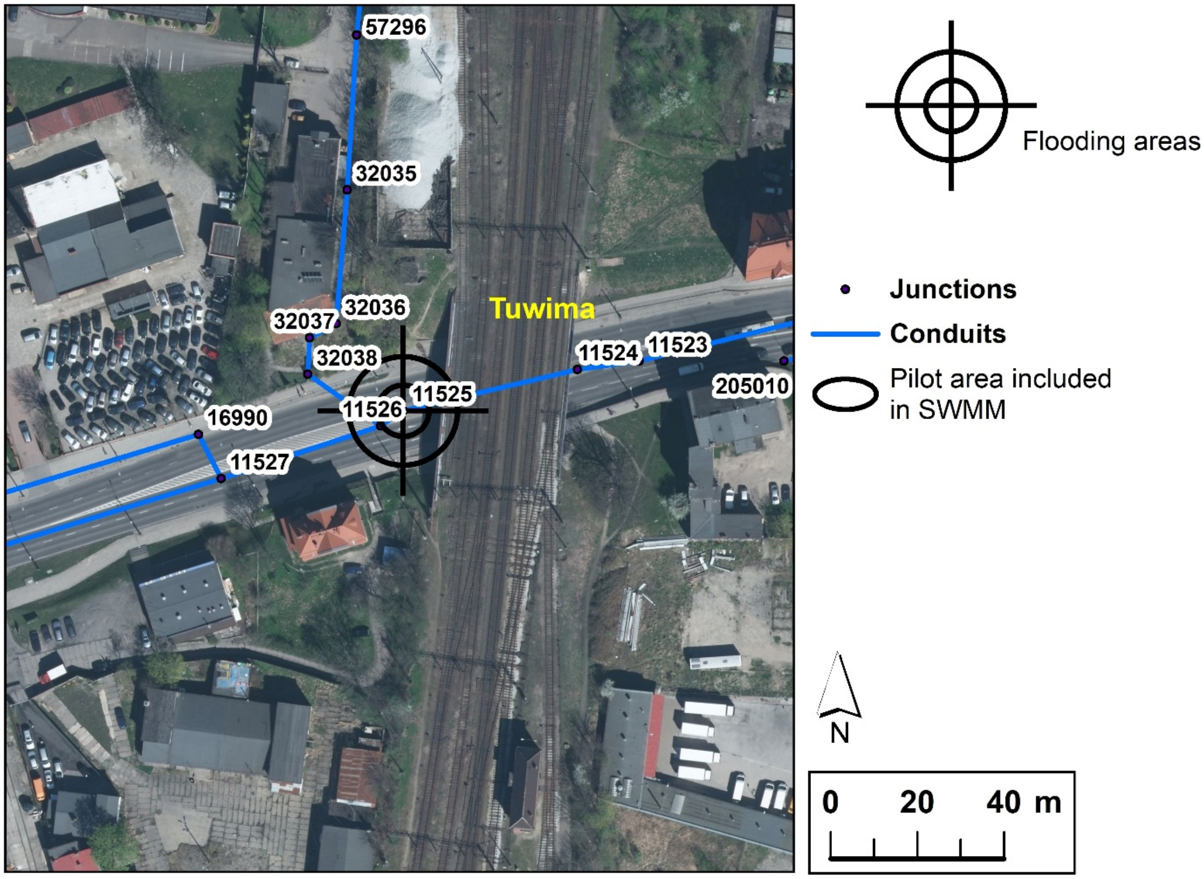
There are also twelve wastewater/stormwater level sensors and six rain gauges installed in the pilot area in December 2019 as a part of the NOAH project. Both types of monitoring devices operate with a temporal resolution of 10 minutes and transmit data once a day. One of level sensors is installed in the sewer overflow just before the outlet of the analysed area – in the storage tank upstream the main pumping station.

Potential RTC locations

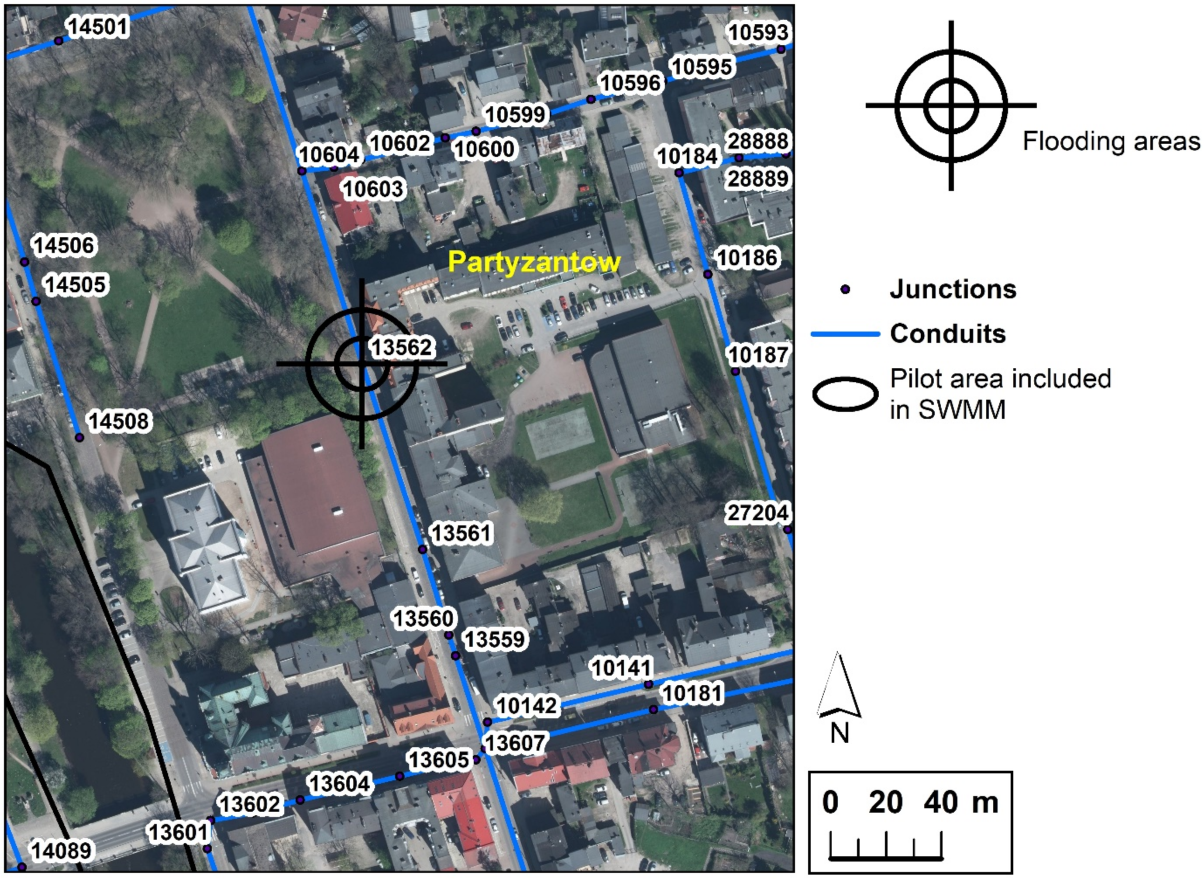
There are three locations indicated by the Słupsk Water Supply as prone to flooding during heavy rainfalls. These locations and the closest SWMM nodes are presented in figures below.



Location [1]: Nad Śluzami Str. (SWMM node 22758)



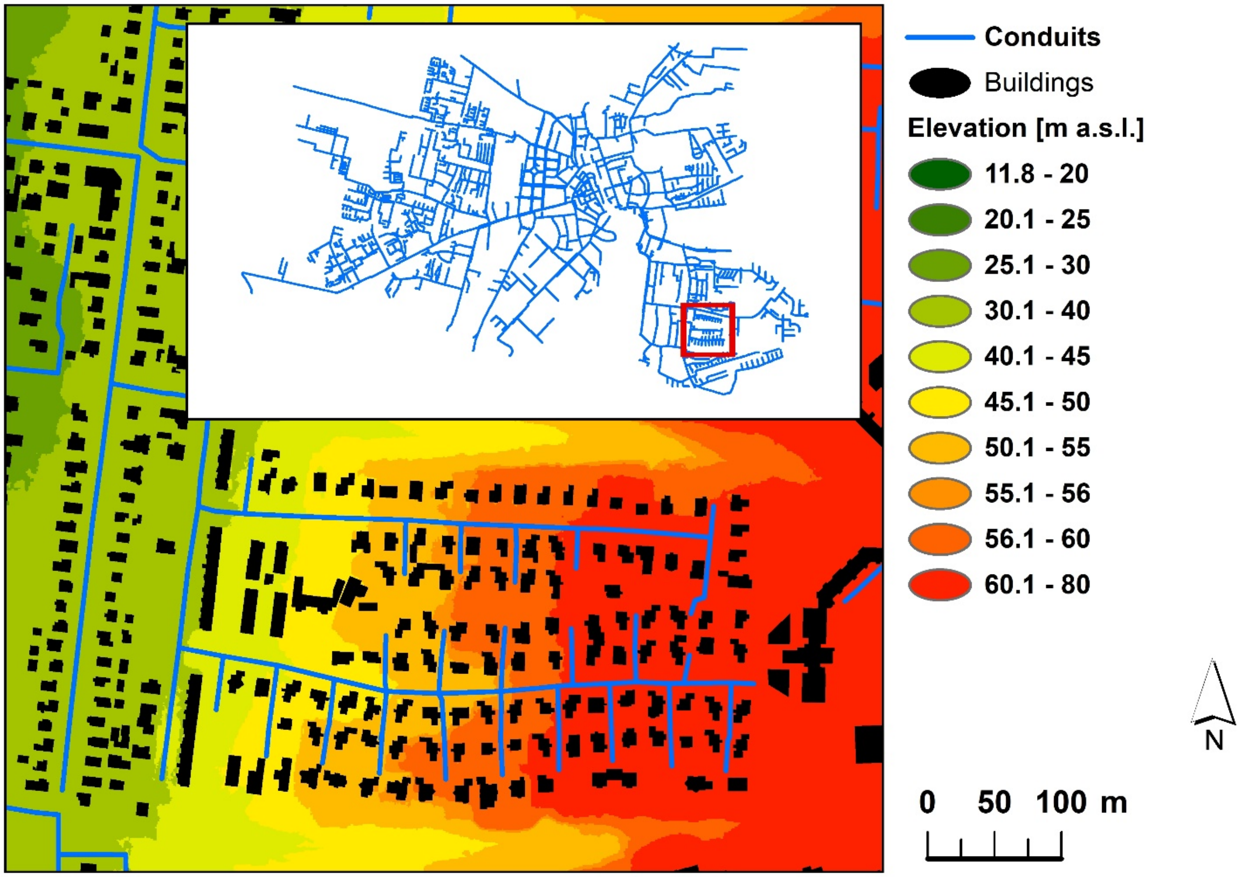
Location [2]: Tuwima Str. under the railroad overpass (SWMM node 11525)



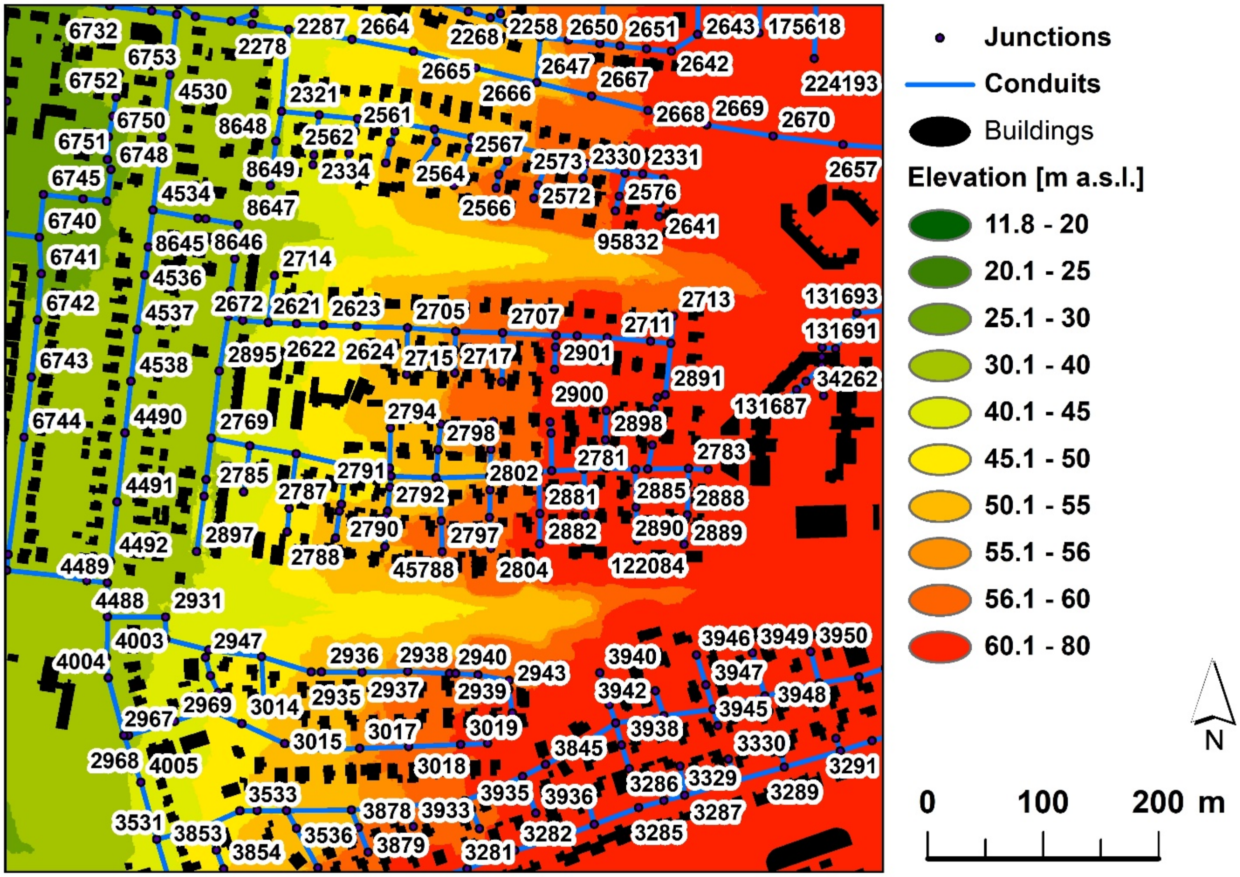
Location [3]: Partyzantów Str. along a school and a park (SWMM node 13562)

These locations may serve as virtual sensors which will control actuators (orifices) upstream. According to the information provided by the Słupsk Water Supply there is no sufficient capacity of the sewer system upstream these locations to retain the excessive water during periods of flooding. Therefore, there is a need of additional retention capacity in a form of tanks, or preferably low impact development solutions which allow to store storm water before it enters the sewer system.

One of options which may prevent flooding in locations [1] and [3] is to decrease runoff on steep slopes where no separate storm water system exists, e.g. residential areas along Bukowa and Modrzewiowa Streets (see figures below).

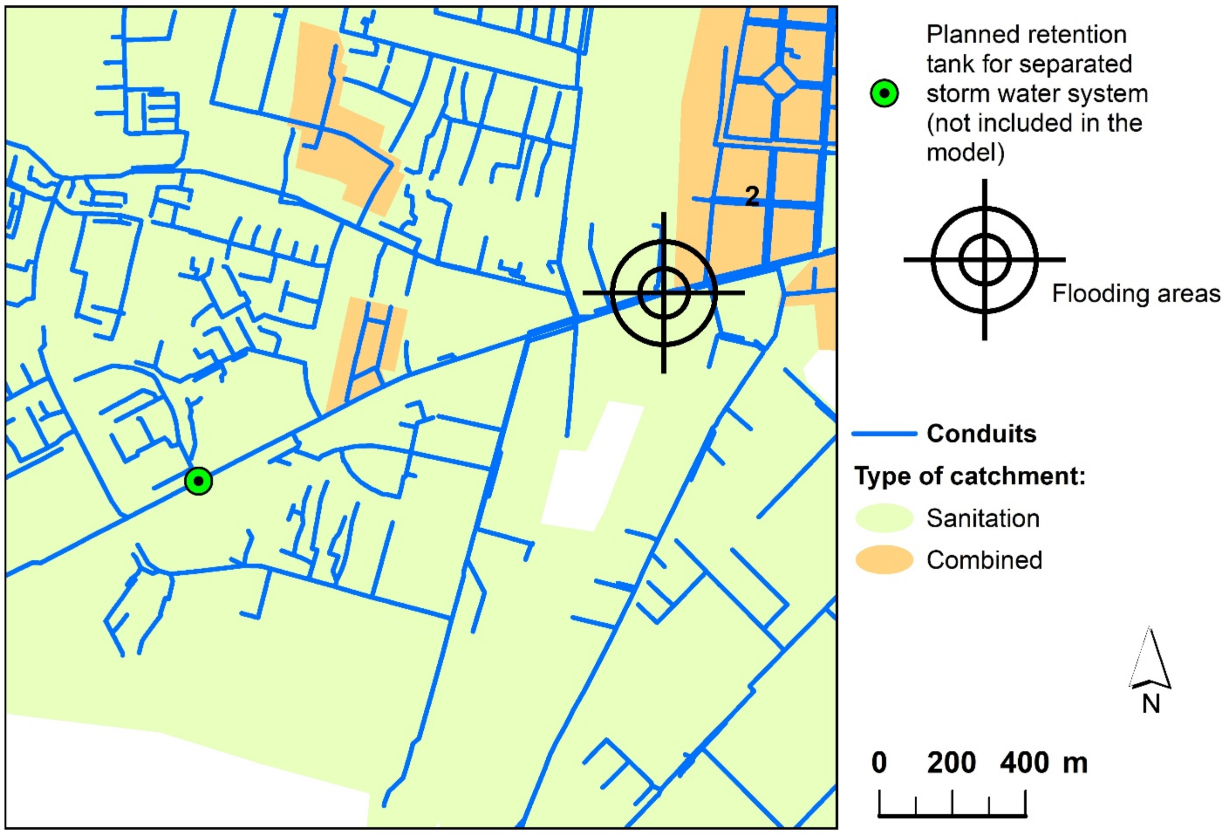


Residential area along Bukowa and Modrzewiowa Streets where large inflows of storm water to the sanitation system exists



Residential area along Bukowa and Modrzewiowa Streets where large inflows of storm water to the sanitation system exists (numbers represent nodes of the SWMM model)

There is a plan to build a storm water retention tank in the western part of the city, next to the model node 6465, upstream the flooding location [2] (see figure below). However, the tank will not be connected to the sewer system operated by the Słupsk Water Supply, i.e. system included in the NOAH pilot and modelling task, but to the separated storm water drainage system operated by the Słupsk Municipality. As a result, the tank will not have a direct impact on the modelled system, but nevertheless it can reduce peak flows in the analyzed sewer system.



Location of planned storm water retention tank in Słupsk and the closest flooding area indicated by the Słupsk Water Supply

There is one more point which can serve as a virtual sensor for the real-time control of the sewer system in Słupsk. It is the tank located upstream the main pumping station which serves as an outlet of the SWMM model. The tank has a volume of 493 m^3 and an overflow at 14.1 m a.s.l. It is included in the model as node "T1-20811". The pumping station has been substituted in the model by the outfall pipe, which is an outflow from the retention tank, and which has the maximum flow of 1 m^3/s which is equal to the maximum pumping rate. It is assumed, that any retention of storm water may decrease the volume and frequency of overflows, especially retention in areas where combined sewer system exists. All these areas are included in the model in a form of subcatchments.

RTC Implementation

Description

In order to improve on the flooding issues in Slupsk, there is a need for retaining and delaying water upstream of the affected areas. A real-time control scheme with a detention volume has the potential to do this by controlling the outflow from the basin based on downstream water level sensors in the vulnerable areas.

It has, however, not been possible to investigate such a scheme based on the current state of the SWMM model for this case. At a key location downstream in the model (node “16643”) there is a node with a much higher invert elevation than its neighbouring nodes. This would be a highly unusual construction if the model truly reflects what the system looks like, and it is therefore possible that this is a database entry error. For the deadline of this output report, it has not been possible to verify this.

The high invert level causes water to back up into the pipes upstream of the node with constant standing water – also during dry weather. The effect of this is large amounts of flooding along an upstream pipe stretch (see Figure 28).

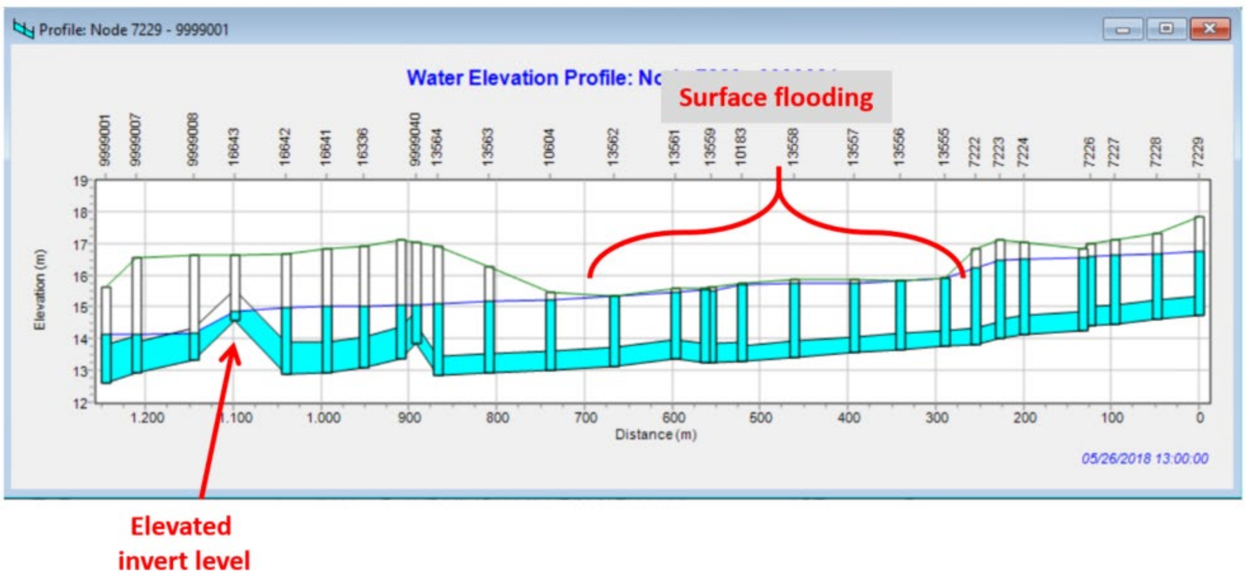


Figure 28: Profile plot of the part of the system where the node with high invert elevation and the flooded areas are located.

If the high invert level is a database entry error then it would be straightforward to fix this in the model and continue the RTC investigation. If, on the other hand, it is a true representative of the real system, then this bottleneck will have to be fixed to avoid water backing up into the upstream pipes. However, in both of these cases, it would make sense to investigate the effect of a detention basin located around the green circle on Figure 29. This location makes sense as it is immediately upstream of the flooded area and sits at the outlet of a large part of south-western Slupsk.

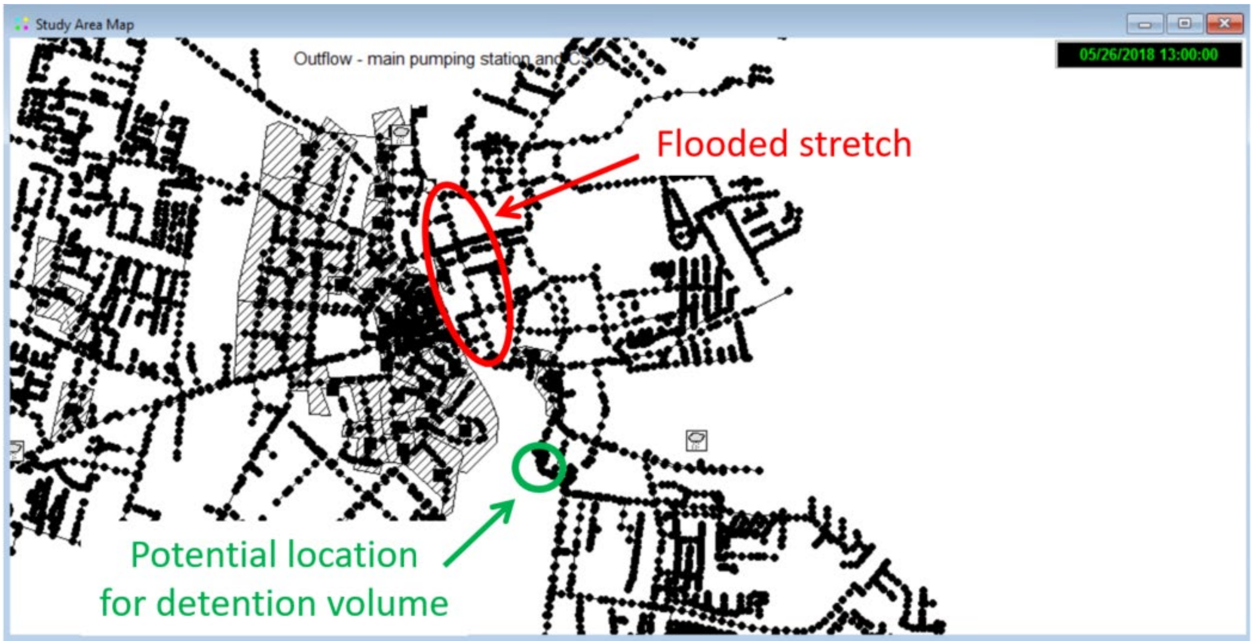


Figure 29: Highlights of the flooded stretch and the potential location for a detention volume with RTC functionality.

Effect

The effect of a detention basin with RTC functionality would be to reduce the amount of flooding downstream. Further investigation of this would determine the degree to which an RTC scheme can mitigate the flooding issues.

Ogre

(System description based in text and input from Marta Zemīte)

System description

The city of Ogre is situated in Latvia close to the river Ogre, see Figure 30.

Figure 30: Areal picture of the catchment.

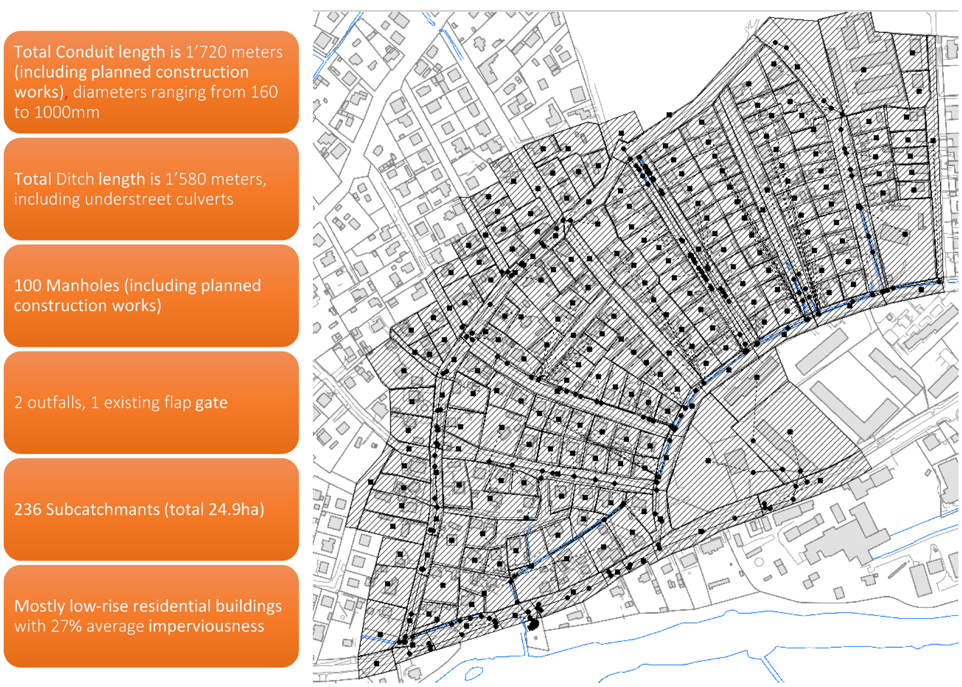


Figure 31: Data of the system and a birds view of the SWMM model.

The stormwater system of the pilot area drains to the river. The biggest problem for this pilot site is that when the water level in the river rises due to ice blockages in the spring, the outlet from the stormwater can become blocked, which causes flooded basements due to stormwater that cannot be drained to the river, or due to river water that runs backwards through the drainage system.

Existing control, actuators, sensors, SCADA system

Sensors are being placed only for water level measurements in Ogre river. There are no control systems in the stormwater system, except for one flap gate (“C” on Figure 32).

Figure 32: The outlets from the system.

Potential RTC locations

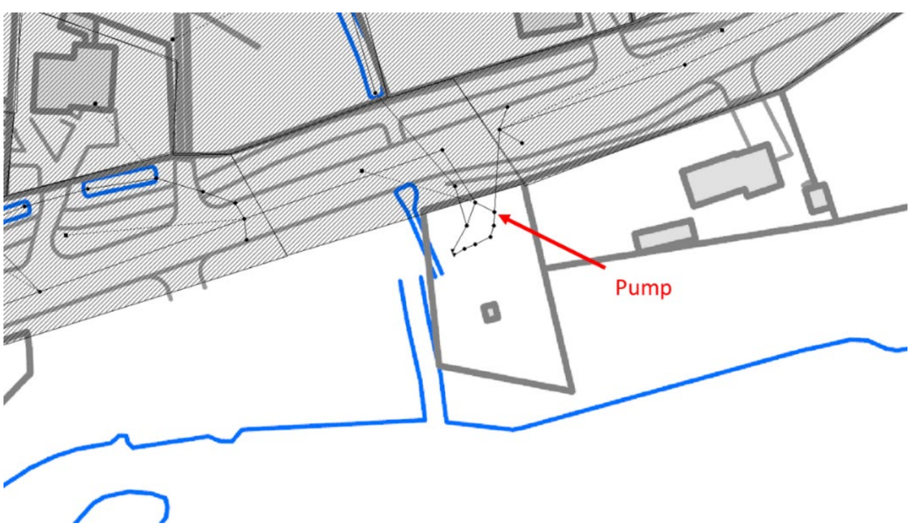


Figure 33: Suitable location of a pump.

As the biggest problem for this pilot site is when water level rises in Ogre river (caused by ice blocking in the spring), the pump (see Figure 33) could be used to pump floodwater from rainwater sewerage system to the riverside, in such a way ensuring floodwater pumping out of the basements of inhabitants, who are connected to the drainage system.

RTC Implementation

The suggested location of a pump, in combination with well-functioning tidal gates/flaps would be able to keep water from backing in trough the outlet. The main challenge will probably not be to dimension or implement the pump or to determine a suitable pumping scheme, but rather to find a tidal gate that does not block or become stuck due to ice and frost. Besides the issues with ice the case is very similar to Liepaja in which the negative impact of high water levels at the outlet is mitigated with a tidal gate and a pump. No specific RTC implementation was tested in SWMM for this pilot.

Söderhamn

(System description based on input from Nils Kändler)

System description

Söderhamn pilot area consists of 11 sub-catchments. Four of these have outlets to the natural stream and the rest to the narrow bay of the Baltic Sea. The outlets to the bay are typically submerged. The stormwater from some areas such as roofs are still connected to sewer system and therefore there are several CSO overflow structures in the system. These CSOs are equipped with backflow valves to avoid seawater entering to the sewer. Ground slope is quite steep towards the stream/bay with a height difference of approximately 10 meters, see Figure 34.

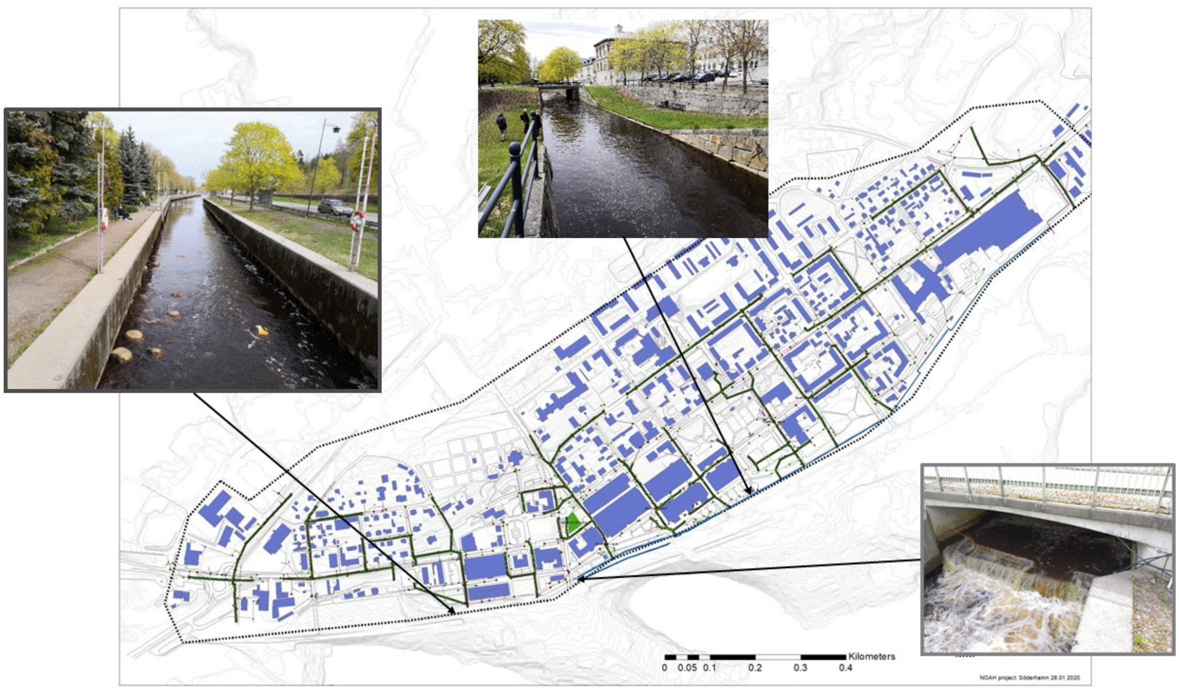


Figure 34: Height map of the pilot site and some photos of water infrastructure.

Figure 35: System description and picture of SWMM model

Existing control, actuators, sensors, SCADA system

The main pumping station of the wastewater system in the pilot area is equipped with remote control system. There are no actuators and sensors installed to separate stormwater system.

Potential RTC locations

There is not much RTC potential in the system as the ground slope is very steep and stormwater system has enough capacity because of several outlets. As a result, water flows quickly to the bay. There are problems related to sea level rise – which will be focused in NOAH in terms of urban planning improvement (see the blue areas on the Figure 36).

A possibility for RTC could be to protect the blue areas with dyke and then control the pumping/opening gates according to sea level elevations and precipitation. This is, however, more a dimensioning issue than a control issue.

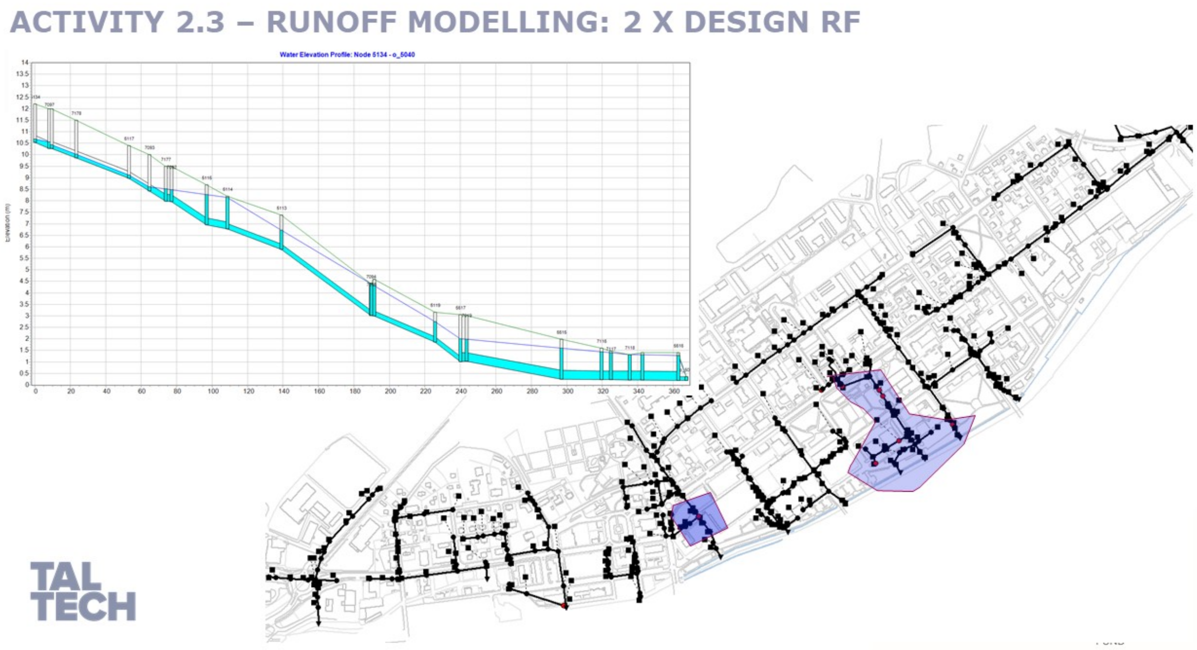


Figure 36: Areas negatively affected by sea level rise (blue areas on the map).

RTC Potential

The combination of steep gradients and little storage volume in the system makes it difficult to achieve much with RTC. If additional storage was build upstream in the catchment, then RTC could be used to control the emptying of this storage based on downstream conditions. While RTC can improve the utilization of upstream storage volumes, it does not change the overall cost-benefit analysis of implementing basins that much. In a well-run utility like Söderhamn such storage would already have been added to the system if it was worth the investment. This more than indicates that it is not worth implementing even though RTC should be used to control the emptying of the storages.

Pori

(System description based on input from Ivar Annus)

System description

The city of Pori (Finland) is located close to a river which maximum water level frequently is higher than the outlets of the drainage system, in which case the stormwater from the city need to be pumped into the river. Figure 37 shows an aerial photo of the city.

Figure 37: Areal photo of Pori (Googlemaps)

The SWMM model of the Pori pilot area is skeletonized so that only pipes with D>200 mm and the related manholes are included. The main reason for that was the data availability. Most of the pipes with smaller diameters (and the related manholes) did not have any elevation data in the GIS.

The urban drainage system has 16 outlets that direct the water from the system to the surrounding ditches. The water level in some of the ditches is measured but the data is not included in the model. This means that the outlet pipes are not submerged. The model is not calibrated, as there were no measurement data available when the model was constructed. During the water quality measurement campaigns, it is assumed to have data about the flow rates at some parts of the system. Manning roughness coefficients for all the pipes are set the same although the pipe materials vary between different sections of the system. A birds view depiction of the SWMM model is shown in Figure 38.

Figure 38: Birds view of SWMM model the drainage system of Pori.

The model results from an extreme rain event, see Figure 39, indicates that the current system has a rather uniform performance, since the magnitude of the surcharging flows are more or less the same throughout the city. Some individual nodes do have significant high surcharging flows than the average but there is no areas that stand out as more flood prone than others.

Figure 39: SWMM model result showing the flow from surcharging nodes for an extreme rainfall event.

Existing control, actuators, sensors, SCADA system

There are no existing actuators in the pilot area, just one pump that is not included in the model. Due to elevation differences near one outlet 2574180_out (marked with red circle in figure 38), water from the UDS is directed to a tank and then pumped to the surrounding ditch. The pump and tank are not included in the model as it is assumed that the capacity of the pumping station is larger than the outflow from the UDS.

Potential RTC locations

Since the outflow from the system is not restricted due to the large capacity of the pump at that outlet, and since the system performs similar in terms of flooding throughout the city there is not much control potential. The actual problem is more linked to the water level in the surrounding ditches and the related flooding risk, which cannot be solved by RTC.