heaWater

Deliverable report on implemented solutions in Tallinn, Turku and Söderhamn with assessment of system performance

EUROPEAN UNION
European Regional Development Fund

Interreg Central Baltic

The present document is a summary report for the Heawater[1] project's deliverables DI1.2.1, DI1.2.2, DI1.3.1, DI1.3.2, DI1.4.1 and DI1.4.2, detailing the implementation of pilot solutions to protect and restore urban streams and the performance assessment of these solutions.

The report was compiled by Turku University of Applied Sciences, with contributions by the City of Tallinn, Tallinn Technical University, and the Municipality of Söderhamn.

Turku, Finland, November 2020

Söderhamns kommun
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[1] The HEAWATER project (*Achieving healthier water quality in urban small rivers of the Baltic Sea catchment by restoration of water bodies and preventing of nutrients and hazardous substances inflow from watershed*), 2018-2021 was financed by the European Regional Development Fund's Interreg Central Baltic programme.

CONTENT

APPENDICES

1 INTRODUCTION

The results of the Heawater project's investment work package are compiled in Deliverables D.I 1.2.1, D.I 1.3.1 and D.I1.4.1. and as an input to the decision support tool (DST). This deliverable report summarizes the results and gained experiences from the pilot investments in Tallinn, Turku and Söderhamn on implemented solutions with assessment of system performance, transferability between different urban streams and recommendations. The functionality and performance of the pilot investments has been monitored and is analysed here in detail, including whether the investments achieved set goals for the reduction of certain pollutants. Based on these analyses, recommendations on future use or developments are made.

While the overall aim of the project was to reduce pollution load in urban pilot streams and/or to restore their ecological state, each project partner addressed different problems related to water quality, quantity, or ecological state. The solutions and their results are transferable between urban environments in the Baltic Sea region, that share similar environmental conditions and problems. Sharing of the lessons-learned, and alternative solutions to mitigate negative environmental impacts on urban streams and eventually the Baltic Sea into which they drain, is facilitated by the DST that combines the projects results and other tried and tested solutions.

The environmental target parameters were specified for each pilot stream by the corresponding project partner. These parameters are:

- In Tallinn: reduction of bank erosion and associated loading with phosphorus and suspended solids
- In Turku: reduction of suspended solids and nutrients and heavy metals that adsorb to them; reduction of litter.
- In Söderhamn: Reducing of phosphorus, nitrogen, and suspended solids (micro-littering) in stormwater runoff and stormwater flooding.

2 BACKGROUND AND SITE SELECTION

The process of site selection for the pilot studies was carried out in Tallinn, Turku and Söderhamn. This chapter explains the research made in all participant countries to identify the conditions and problems e.g. in water quality and quantity in the areas chosen for pilot studies. Possible lab tests and test set-ups are also explained with main results.

2.1 Tallinn

Monitoring of the Mustjõgi river water quality was included into the state's permanent monitoring program in 1990s. The water quality records indicate distinct periods with different trends in water quality. These trends seem to be linked to the shift in society at the beginning of the 1990s and economical fluctuations. A more detailed description of the river status, including scientific analysis, was given in the project work package "Implementation" in August 2019.

Previous studies and investigation on Mustjõgi River include environmental studies like geological and hydrological surveys, as well as engineering studies. In 1996, engineers considered different options like the construction of a concrete canal or conversion of the river into a pipeline. However, any of the considered solutions were regarded as disproportionately expensive and associated with too many environmental risks.

In 2007, a design study considered a range of options to address mainly two problems: bank erosion and low water-carrying capacity. Because of the specific and unique milieu of the banks of Mustjõgi River, a major requirement was to maintain the natural appearance of the river. There are many bank protections types, but only traditional river engineering techniques were under consideration: timber piling, geotextile with flint stones, and concrete blocks. Timber piling was selected as the best solution. The design project was completed but due to lack of funding, the construction work was not completed.

In 2014, the Mustjõgi drainage basin survey was carried out. The survey aimed to characterize the water regime of the basin: main inflows, sea level impact on the water level of the river, stormwater management, land use, and primary causes of flooding. Further, engineers sketched a design for a sedimentation basin with a hydro-engineering complex on River Mustjõgi to prevent impacts of see level rise. However, the plans did not proceed.

During the HEAWATER project, the Mustjõgi River was selected as pilot stream for restoration activities for the following reasons:

a) Bank erosion. Bank erosion endangers some buildings at the riverbanks and causes loading with large amounts of suspended solids.

b) Alluvial deposits. Increasing hydraulic load and low maintenance of the river has caused accumulation of the alluvial deposits. This causes a low water-carrying capacity and release of phosphorus from alluvial deposits.

c) Poor river water quality. This affects the local community and the public beach of Stroomi, at the Baltic Sea. This is one reasons for the beach not, yet, having received a Blue Flag status.

d) Flooding. River Mustjõgi is prone to flooding because imperviousness increases in the catchment. According to the Estonian Land Board Estonian Topographic Database ETAK, approximately 50% of hard surfaces in Mustoja catchment area are made up of roads, production areas, and buildings. Therefore, hydraulic load increases, which triggers more intensive bank erosion.

The specific aim of the actions carried out in Headwater is to decrease water turbidity and total phosphorus concentration up to 10 % in River Mustjõgi.

2.2 Turku

The initial three pilot streams have multiple functions that are characteristic for many urban streams: they are important habitats for fauna and flora, they have recreational value for citizens that walk by the streams or play with them and they have an important drainage function by collecting and conveying stormwaters from mixed urban catchments.

The three pilot streams have been intensively monitored and surveyed by TUAS during the past decade. Several years of continuous discharge monitoring data is available for Jaaninoja and Kuninkoja, and point data for the Topinoja stream. Water quality studies concentrated on assessing the suspended matter loads and associated nutrients

(Phosphorus and Nitrogen). Further, data on water quality parameters such as pH, electrical conductivity and turbidity are available. Previous monitoring programs showed that robust correlations between in-situ measurements of turbidity and nutrient load may be established as well as those parameters and discharge. Abnormal pH excursions have been monitored in Jaaninoja and its tributary Itäharjunoja. Additional monitoring carried out within the HEAWATER project, indicated local elevations in heavy metal concentrations in Jaaninoja and Kuninkoja as well as slightly increased concentrations of PFAS in Kuninkoja when compared to average background concentrations. All Heawater measurements and samplings have been done during dry or base flow conditions.

Amongst the water quality and quantity measures made in Jaaninoja, Kuninkoja and Topinoja, littering problem of the urban streams in Turku area has been considered as a problem. As all the pilot streams directly or indirectly run in to the Baltic Sea, littering problems have an effect in the urban areas and in the sea.

2.2.1 Laboratory tests

Research for different methods available for managing water quality problems in the pilot streams was conducted. Small sized filtering structures were chosen to be developed. Two separate laboratory tests were conducted during summer and fall 2019 to help with the decision making for the best materials. In the first test set-up gravel and Leca® LWA (Light Weight Aggregate) were tested with standing and flowing water. Water used in both tests was collected from the pilot stream in Itäharju, Turku. The aim of the first test was to see if there are chemical processes between the impurities in the water and Leca® LWA or is there only physical filtration of the impurities. The second laboratory test was made to compare two different pore size Leca® LWA and their ability to retain heavy metals from the ditch water. Leca® LWA, pore size 0–3mm and 1–8mm, were first flushed with tap water and then placed in the test boxes (Fig. 1).

Fig 1. Laboratory set-up for the second test with Leca® LWA.

Test results implicate, that Leca® LWA did not have chemical reactions with the impurities in the test water but works well as a physical filter retaining suspended solids. Smaller pore size 0–3mm did not work well in the test set-up. Finest particles packed together, creating dense layer, which disturbed the water flow and led clogging of the filter. However, the bigger particle size Leca® LWA decreased the amount of suspended solids, nutrients and heavy metals in the test water, while maintain its hydraulic conductivity. Therefore, pore size 1–8mm Leca® LWA was chosen for further studies in the pilot stream.

2.3 Söderhamn

The municipality of Söderhamn has recently adopted a stormwater strategy. The aim with the strategy is to make the stormwater management more sustainable. During the Heawater project this work was continued and the implementation of the strategy was started by building two stormwater measures.

2.3.1 Environmental conditions affecting the investments

Söderhamnsån runs through the city of Söderhamn and ends in the narrow bay to Söderhamn and finally in the Baltic Sea (Fig. 2). It is highly affected by human activities. The river runs through a flat agricultural landscape with clayey soils and few lakes that can stabilize the flow. During flood events the water level quickly rises. During peaks the flow can be up to 20 times the normal flow in the river. During peaks there is a big rise in transport of suspended matter and nutrients, mainly phosphor, which leads to over fertilisation in the Bay of Söderhamn. Much of the nutrients stem from farming upstream but the Heawater project provided the possibility to learn more about how the stormwater affects the water quality in the river.

The water quality in Söderhamnsån and Söderhamnsfjärden has been monitored since 2004 by LjusnanVoxnan Waterboard. Söderhamnsån is one of the rivers in their control program with the highest nutrient concentration. The present status does not fulfil the requirement for good ecological status. The water quality in Söderhamnsfjärden is unsatisfactory and the coastal water ecosystems are degraded. The reason for choosing Söderalaån/Söderhamnsån for investments in the Heawater project is that it is nutrient rich and the coastal water where the river ends is of great recreational value for the community. Further, flooding puts pressure on the stormwater systems in the city.

Fig 2. The last bridge over the river Söderhamnsån before it flows in the bay of Söderhamn.

Delaying the stormwater before it reaches Söderhamnsån to avoid flooding and leakage of nutrients is an important factor for improving the water quality. Since both Heawater construction sites are in the city centre the stormwater also carries hazardous substances and microplastic which affects Söderhamnsån and coastal water.

2.3.2 Selection of technical solutions

A local project group with members from technical-, environmental- and planning department was invited to find the pilot area. Participants from Söderhamn Nära, the municipality owned infrastructure company, were also part of the group as it knows the weak points of the stormwater network.

The area for the implementation of the pilot investments was decided prior to the project. The site is in the central part of Söderhamn City where the Söderhamnsån river flows (Fig. 3). The project group analysed and listed several sites that were suitable to the pilot implementations. All possible sites were then analysed using an array of aspects such as:

- Effect of investment
- What problem will the investment solved?
- What water related problems do we have?
- Cost for the investment, what can we do with our budget?
- Is it possible to build at the site without damaging the infrastructure like electricity, water- and sewer pipes?
- Pedagogic value
- Green area factor
- Will the investment add an aesthetic value to the place, are there any special requirements we must consider?
- Who owns the land? (If the land is owned by the municipality the implementation of stormwater measures is easier than if private estate owners have to be involved)?
- Need of permissions such as intrusion into ancient memory, permission to excavate etc.
- Possible cooperation with other projects

- Are there plans for the area made by the municipality with restrictions of land use etc.

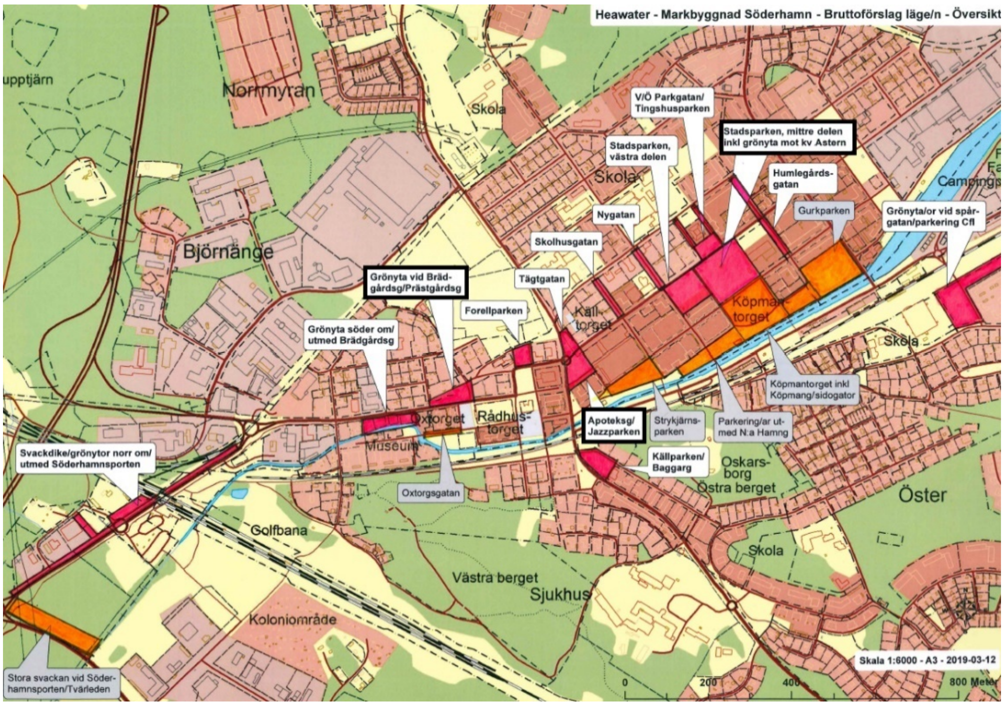

Fig. 3. The pilot area marked in black.

When all aspects described above were weighed against each other, two sites stood out as the most suitable. Both investments are placed in the centre of the city and will be visible and add aesthetic value to the site. Both investments are located along a street with heavy traffic. The raingarden is placed at a low point which is frequently flooded during heavy rains. The pilot implementations will serve as an example for the inhabitants to demonstrate how the municipality manages stormwater and to raise the awareness for the need of sustainable stormwater handling.

3 METHOD AND OPERATION

The background research and studies were followed by further technical development and the construction work started in the chosen pilot sites. The individual technical solutions chosen in the pilot cities are detailed in the following paragraphs along with an assessment of the structures' functionality and performance.

3.1 Tallinn

Investment works at River Mustojajõgi finished in the end of July 2020. Altogether 610 meters of bank protection were built, Ojaveere street culvert was reconstructed, and alluvial sediments were removed from the riverbed (see Fig. 4)

Fig 2. Map of the pilot area in Tallinn.

The planning and construction work took 26 months from preparation till the end of construction (May 2018 to July 2020). The permitting (Construction Permit, Special permit for water use including environment assessment evaluation), project design and procurement processes took 15 months. Construction works lasted 12 months, from signing the contract on 23 July 2019 to the final inspection act on 23 July 2020. The *Delivery and Receipt* document was signed on the 27 July 2020. On 3 September 2020, the authorization (notice of use) of the construction works was accepted by the Tallinn Urban Planning Department.

3.1.1 *Construction of riverbank protection*

During the construction of the pilot, unnecessary vegetation clearance was avoided but invasive plants (mainly *Fallopia sachalinensis*) were removed. The bank protection construction consisted of three stages: 1) river slope profiling, 2) geotextile placement, and 3) placement of gabions (stone-filled baskets) on the geotextile.

It was necessary to isolate and drain the work area to create dry working conditions for constructing the bank protection structure. Isolation of the working area also reduced the risk of sediment entering the river. This was done by using four different methods:

1. An area of the river was isolated and kept dry with the use of barriers (often referred to as a *cofferdam*, Fig. 5), that allowed for unobstructed flow in the remaining part of the river. This method did not work well as the cofferdams placement and removal was time consuming and the water started to leak between the barriers when river flow was high.

Fig. 5: Use of cofferdams to keep parts of the river bed and banks dry for construction works.

2. A section of the river was isolated using barriers that span the full width of the river. The barriers keep a stretch of the river dry and the water was transferred downstream of the work area by pumping (Fig. 6). For this, two pumps were used. The larger one pumping approx. 170-180 litre/second and smaller one 90-100 litre/second. Due to machine rents and energy consumption this solution was expensive.

Fig. 6. Section of the river were damed and drained with two large pumps.

3. The third method used for temporary draining of the river during construction works utilized barriers (both upstream and downstream) and downstream transfer of water using through gravity-fed flumes/pipes (Fig. 7). See *here* for a time-lapse video of the construction works. The pipe diameter was Ø 600 mm and it turned out to be the most effective method to keep dry the work area.

Fig. 7. Temporary draiage of the stream using barriers and drainage pipes.

4. As fourth approach to temporarily keep the riverbed dry, the culvert of Kõrgepinge street was closed by gates to lower the water level downstream for three hours. The last half of the work was made using this technique (Fig. 8).

Fig. 8: Blocking of a road culvert to keep the downstream section of the river dry for the period of a few hours to allow for construction works.

Compared to the initial design, some stream stretches were straightened to make them fit better into the environment and further erosion control mats were placed to prevent soil erosion during wintertime. Eventually, the gabions were placed on the banks on the straightened banks (Fig. 9).

Fig. 9: Placement of the gabions for bank enforecement.

3.2 Turku

In Turku, different methods were tested for the collection of macro litter and retention of micro litter and suspended solids.

3.2.1 *Litter surveys*

Macro litter removal from streams was tested with fence structures and with floating litter collector prototypes in the streams Jaaninoja and Kuninkoja. The aim of the study was to gain better understanding of the litter volumes that are transported by the streams and to find ways to reduce these.

Fence structures were installed for two-week periods in summer 2019 (Fig. 10). Plastic net was tightened between wooden poles and sealed from the banks. Mesh size was chosen to be big enough for small fishes and other aquatic animals to pass the structure. Wooden poles we also installed before the net structure, to catch sticks, hay, and other organic materials. The sites were visited every other day to see the material caught in the net.

Fig. 10. Litter removal fence in Kuninkoja.

Results from the test periods indicate, that during low or intermediate flow conditions very little macro litter is moving along the streams. Regardless of the mesh size being larger, findings from the net were small, e.g. cigarette buds, candy wrappers and small unidentified pieces of plastic. Also leaves and other organic material was regularly found from in the net.

Testing of a floating litter trap prototype was done during high flow conditions in Kuninkoja. The litter trap consisted of a wire mesh basked, flotation buoys and booms arranged in a funnel shape to guide floating debris in the basket (Fig. 11 & Fig. 12).

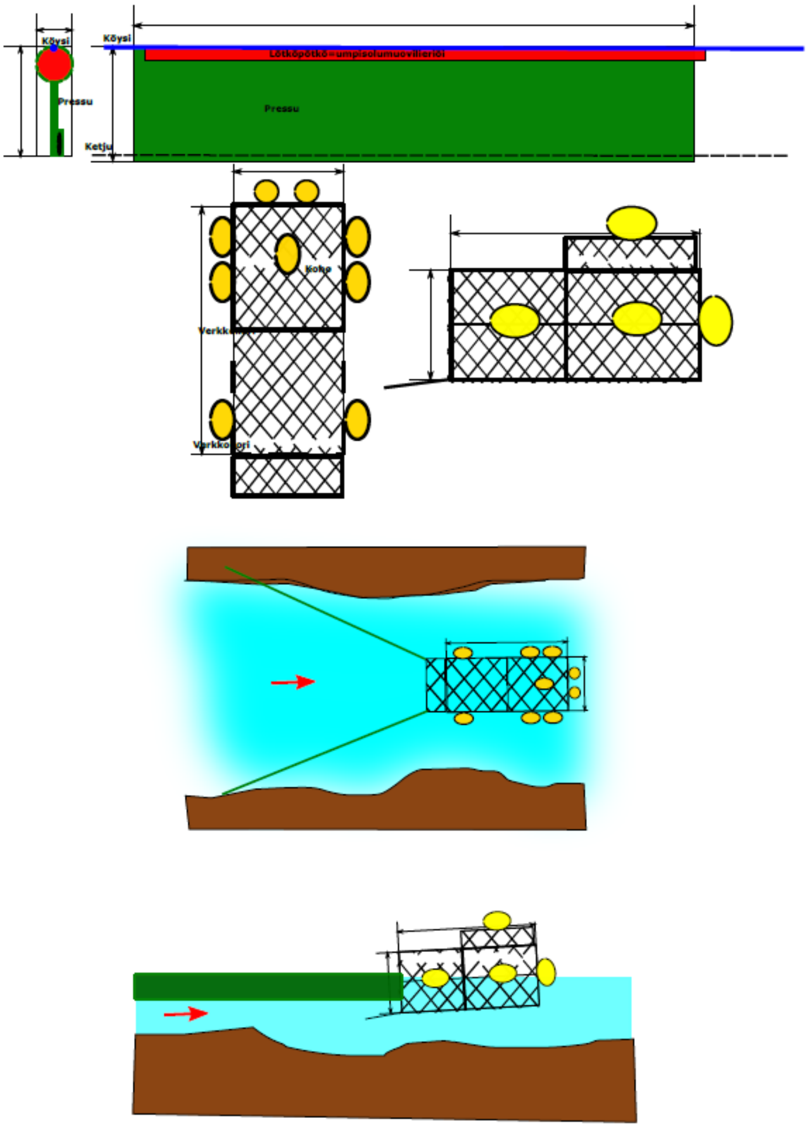

Fig. 11: Schematic drawing of the floating litter trap prototype.

Fig. 12. Litter trap testing during high water level but low flow velocities in left) Jaaninoja and right) Kuninkoja, March 2019.

3.2.2 Litter collection

Within a B.Sc. work carried out under the umbrella of the project, detailed litter collection surveys along parts of the banks of the Jaaninoja and Kuninkoja streams have been carried out in summer 2019 (Salmi, 2019). The surveys indicated that significant amounts of macro litter are deposited along the streams (see Salmi, 2019 for details). Most of the mapped and removed litter was deposited at or near the stream banks.

Within a student project carried out in Heawater, a litter collection campaign within the *Let's Do It!* campaign was organized at a small part of the Kuninkoja stream in the vicinity of a large shopping area (Fig. 13). The campaign yield about 27 kg of litter.

Fig. 13. Students collecting litter found along the Kuninkoja stream on a nearby parking lot.

During the intensive testing periods, both the litter fences and floating traps proved to be inefficient in removing significant amounts for litter from the streams. Results from the prototype testing and the litter collection, suggests that litter is transported by the stream flow only during high discharge conditions. As soon, as the flow reduces, larger debris accumulates in the vegetation of the stream banks. Further, the surveys suggest that macro litter is especially abundant in 1) areas that are used commercially, e.g. shopping centres, industry or 2) near construction sites. To effectively remove floating litter during occasional high discharge condition, litter traps should be installed in many places along the streams. The opportunities for this are restricted by technical and financial reasons (installation, maintenance) and by the fact that multiple litter collection units might negatively impact the migration of aquatic animals. Therefore, it was concluded that a combination of awareness rising to avoid littering and litter collection events are more effective.

3.2.3 *Suspended solids and micro litter*

After the laboratory tests described in section 2 "Background and site selection", the first prototype of an in-stream filter structure was built. Between early 2019 and summer 2020 three major iterations of the system were designed, built, and constructed. The design of the final system was supported by extensive hydraulic modelling.

1. Prototype:

The purpose of the initial filter system was to test how well Leca® LWA works for particle removal in natural streams and under, varying conditions. The first filter was a plywood box with an internal wall with a height of about 50% of the overall box height that partitioned the filter into two parts. The entire box was filled with Leca® LWA. The stream flow was guided into the filter through a mesh covered inlet. The internal partitioning wall forced the flow to the upper part of the filter and increasing the internal flow path. This increase also the contact time with the filter material and thus the particle filtration capacity. The filtered water exited the filter in the upper half through a fine mesh, that kept the filter material in the box but posed minimal restriction to the flow. (Figs. 14 & 15)

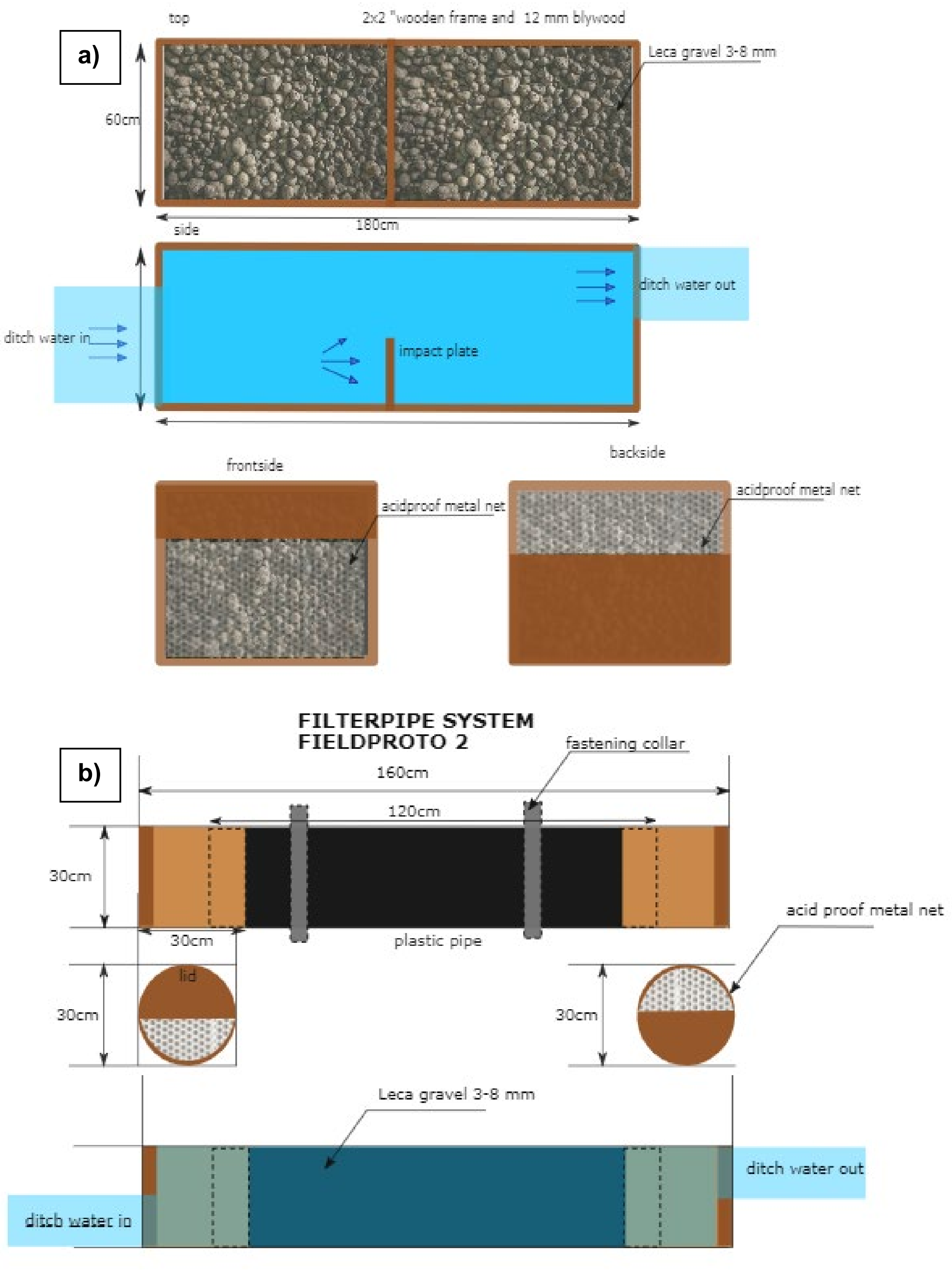

Fig. 14. a) Schematic drawing of the first filter prototype. b) Pipes added to allow water to bypass the filter during high discharge conditions.

Fig15. Testing of the first filter prototype. View from downstream/outlet side.

The initial test with the first prototype were promising but also revealed some conceptual problems. During low flow conditions, most stream water passed through the filter, however with increasing flow, the limited capacity of the filter caused the upstream flow to bypass the filter box. This let to bank erosion next to the filter. Subsequently, much of the stream flow also passed the filter during low flow conditions.

To prevent the bank erosion, bypass pipes were added to the sides of the filter, to allow some of the water to pass the filter in a controlled manner (Figs. 14b & 16). Further, the water inlet was modified such that some perforated piping was added at the bottom of the filter. The pipes extended to the central divider of the filter and allowed water to enter the filter system with minor resistance. With increasing hydraulic head, the water would raise up through the perforation of the pipes and the filter material above.

This modification improved the performance of the filter. Yet, bypassing and/or overspilling of the filter during high flow conditions remained a problem as well as the associated bank erosion. Therefore, the entire filter concept was revised.

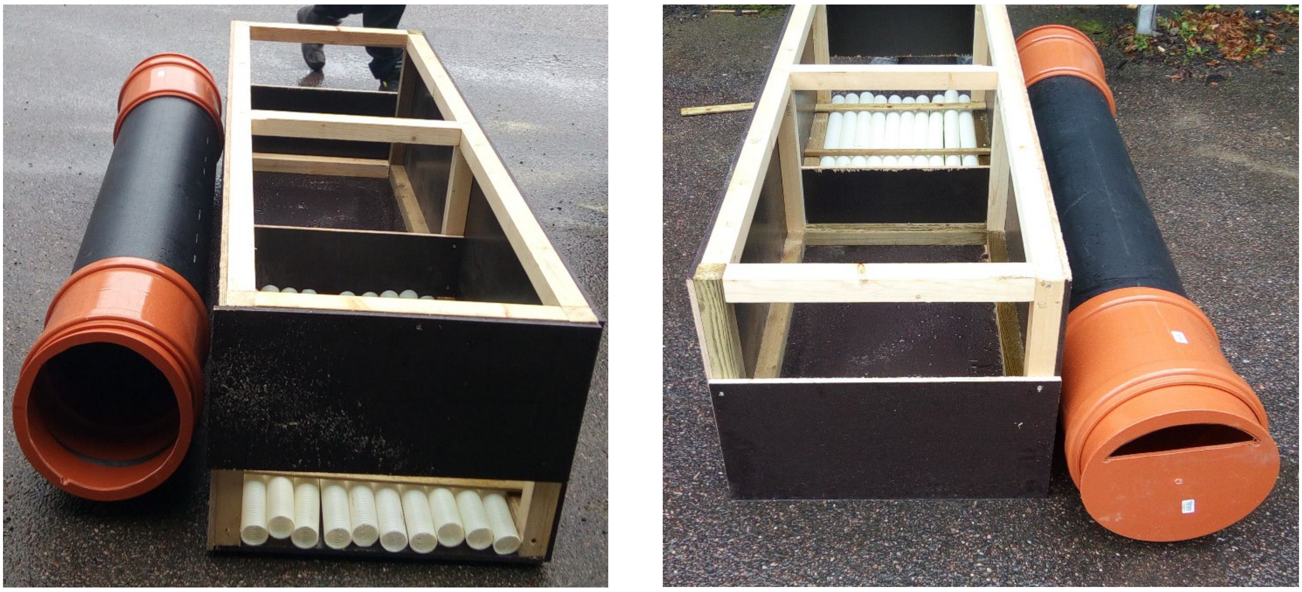

Fig. 16. Modification of the initial filter design: addition of bypass pipes and water inlet at the bottom of the filter.

2. Prototype “pipe filter”

To allow parts of the stream flow to bypass the filter permanently and thus reduce the rise of the water level during high discharge conditions and bank erosion, a pipe-based prototype was constructed. 10 cm diameter PVC piping was filled with LECA® granulate and the ends closed with a fine mesh that kept the filter material in the pipes but allowed water to percolate through the pipe. Several LECA® filled pipes were then bundled to cover the cross-section of the pilot stream (Figs. 17 & 18). The voids between the individual pipes allowed some part of the water to flow unobstructed by the filter.

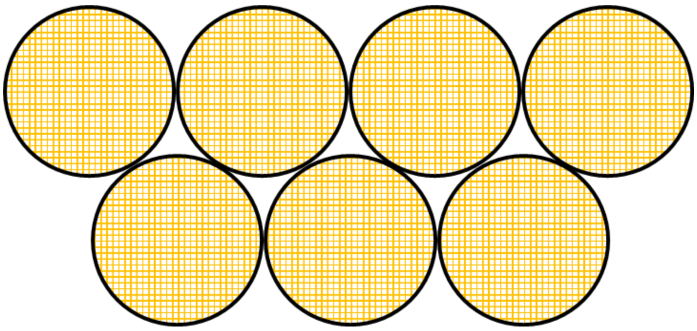

Fig. 17. Schematic cross-section of the pipe filter.

Fig. 18. Pipe filter prototype. View of the downstream sections. Part of the flow passes through the voids between the pipes while the rest passes through the pipes filled with filter granulates. The yellow arrow shows water dripping from a pipe above the downstream water level, indicating a higher water level on the upstream side.

To avoid any bank erosion next to the filter, the stream bed, and banks upstream of the filter were covered with a large tarpaulin (Fig. 19). This concept worked well and was kept until the end of the project's testing period. The functionality of the pipe filter was fair during low discharge condition but other than expected, too much water passed the filter material during intermediate and high discharge conditions. The design also suffered from structural weaknesses during high discharge. Essentially, it was not possible to avoid dislocation of pipes. To prevent the dislocation of pipes, the voids on the upstream end of the filter had to be closed which resulted in a structure like the first prototype but with less filter granulates. Therefore, the filter design was revised another time.

Fig. 19. The pipe filter design during the testing phase. The tarpaulin in the upstream section was added to minimize erosion during higher discharge conditions.

3. Final design

During the conceptualization of the third filter design, the extensive knowledge and lessons-learned from the previous tests where integrated. The main elements that had proven to be effective were:

1) Reserve some empty space (free of filter material) at the lower upstream section of the filter to calm the flow and allow the water to rise through the filter material,
2) Extent the flow paths inside the filter by means of dividers and barriers,
3) Include an empty area at the bottom of the downstream side of the filter as sedimentation area, and
4) To use different filter granulates sizes.

Despite the extensive data and knowledge gained from the previous developments, some uncertainties remained regarding the optimal internal structure of the filter and the used filter granulate size. Therefore, various structural options and filter granulate combinations were modelled using *Computational Fluid Dynamics* (CFD) using the Ansys Fluent © software. The main objective was to analyse the residence time of the water inside the filter and the determination of flow velocities for different setups. Figures 20-22 illustrate some of the results of the modelling. The modelling helped to predict the range of flow conditions under which the filter will work. The collection of monitoring data will support the model calibration and validation for future work.

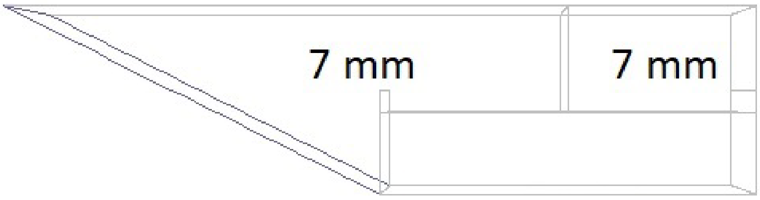

Fig. 20. Parameterisation of the initial filter structure for CFD modelling. For the show scenario, two chambers of the filter were filled with filter granulate with an average diameter of 7 mm, and two chambers were kept empty to allow for particle sedimentation. For this set up an average of 10.3 m^3/h were passing the filter, with an average residence time of 180 s.

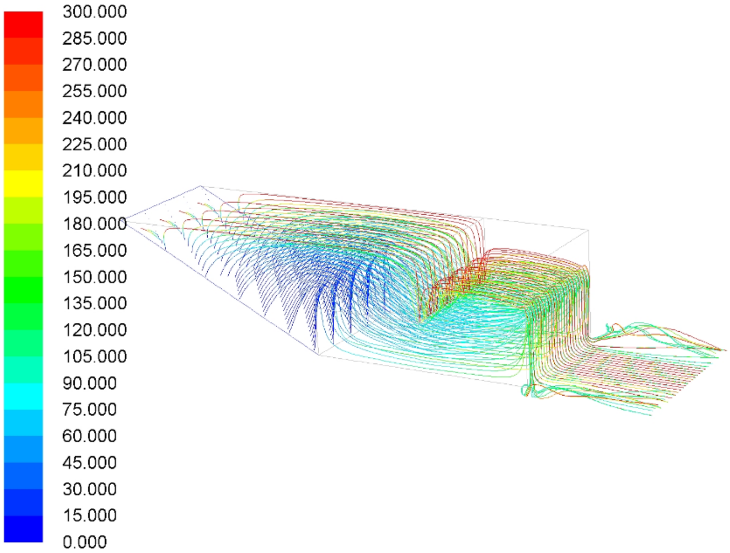

Fig. 21. Modelling of residence time of the water in different section of the filter in [s]. Cooler colours indicate shorter residence time and warmer colour longer ones.

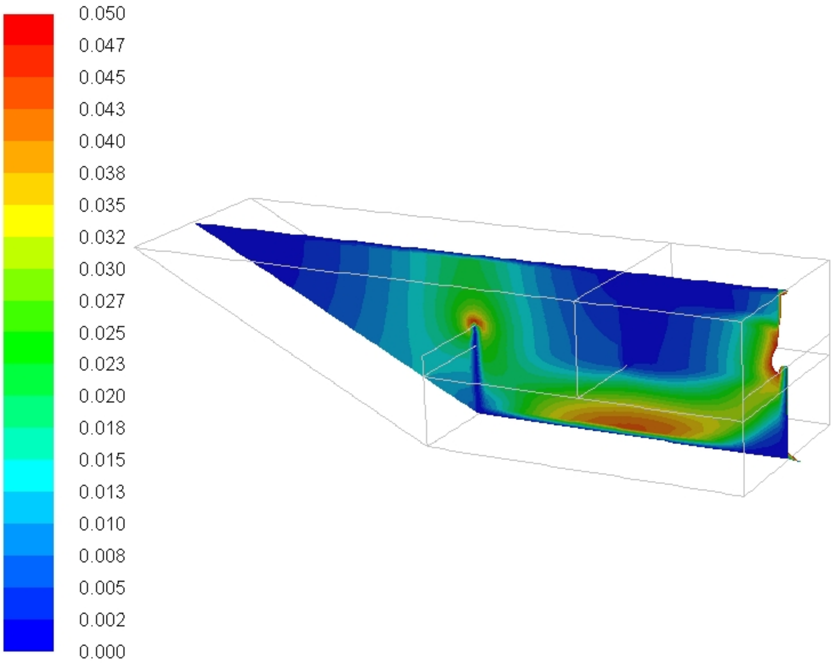

Fig. 22 Cross section of the flow velocities in [m/s] inside the filter, Cooler colors indicate slower flow, warmer colours faster flow.

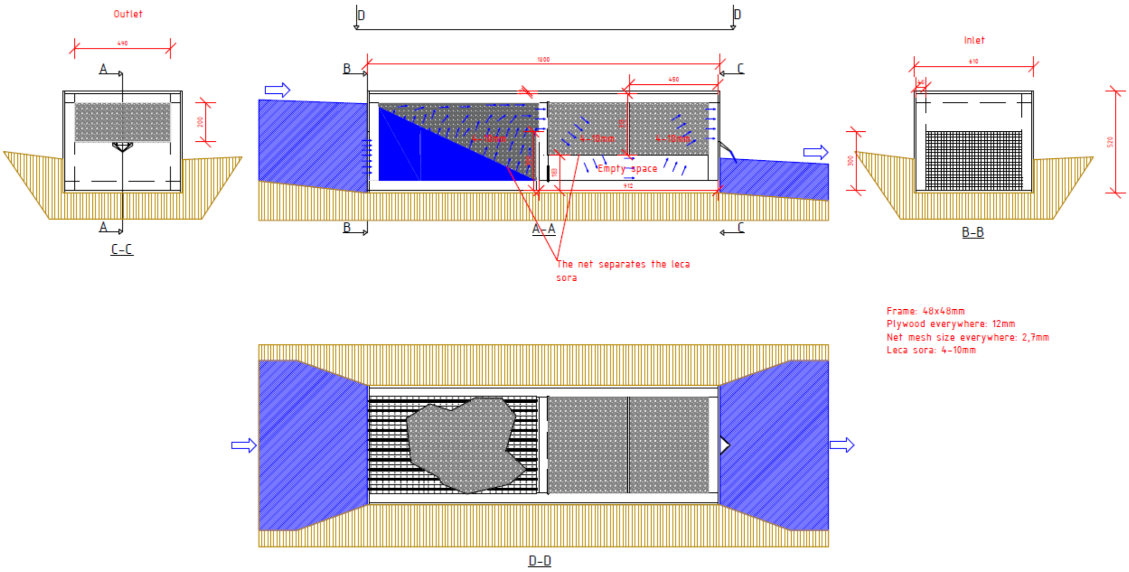

Fig. 23: Schematic drawing of the final filter design.

The final filter structure (Fig. 23) was designed to allow for geometric changes inside the filter and for variable in- and outlet heights and shapes using a rail system and exchangeable dividers (Fig. 24). The construction drawings and manufacturing of the filter was subcontracted based on a bid-of-three. Only one company was able to provide the required solution.

Two individual filter systems were ordered, including a system that allows to combine the two in-line or side-by-side to scale it to different streams and flow conditions. The system was made of aluminium profiles and transparent side walls to ease the handling and observation of internal flow behaviour.

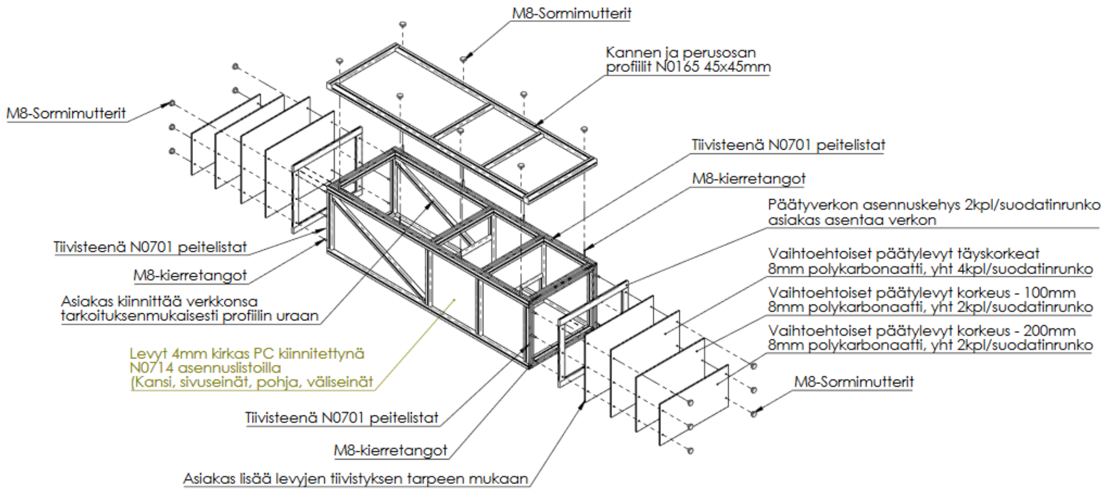

Fig. 24. Explosion drawing of final filter elements.

The final system was deployed in July 2020 (Figs. 25 & 26) and its performance monitored intensively. To obtain data that is suitable for the validation of the performance difference between different filter granulates, the filter was setup with only one filter granulate type at a time, though the structure allows to use different materials in different sections of the filter. The filter was deployed with a vertical inlet and all chambers filled with filter material to test a setup with a maximum flow path lengths and contact time between water and the filter granulate. The final testing included to main periods during which two different filter granulates were tested.

Fig. 25. Final stream filter being prepared for deployment, July 2020.

Fig. 26. Final stream filter deployed and in operation. The filter was covered with plywood to protect it from vandalism at the pilot site.

The monitoring included the regular collection of water samples up- and downstream of the filter and in-situ measurements. The water samples were analysed for nutrients, TSS, conductivity, heavy metals, and some, for PFAS. The results are detailed in 4.2.2.

3.3 Söderhamn

Before choosing the structure to be build, an extensive literature study was done. In conclusion, no technical solution exists that can solve all problems at the Söderhamn pilot sites. Based on the literature study and the previous work done in the project group, a raingarden and a vegetated detention pond were selected as best solutions to address most of the problems.

The raingarden is located at a low point that is frequently flooded. There is also a lot of traffic in the area. Thus, the raingarden will have a dual effect, delaying stormwater and cleaning it from hazardous substances that originate mainly from traffic. The water that is led into the raingarden comes from an area covered with impermeable surface.

The vegetated detention pond is also situated next to a mayor street. It will collect water from the street and a ridge above. The principal function is to delay stormwater, but the vegetation is expected to have a filtering function as well.

The pilot site construction was hampered by the failure of the public procurement. The work needed to be to re-organized and eventually be done within the municipality. Yet, these imponderables also provided valuable experience for the municipal planners for the future and a better technological knowledge than in a situation where the construction work would have been done by an external contractor. The technical department of Söderhamn was positive on doing the constructions and felt that they learned a lot and gained experiences. The development and implementation work by the municipality re-sulted in several information meetings about the project and the stormwater strategy in general, which may be seen as positive reaction to the need of doing the planning and construction work within the municipality.

3.3.1 *Vegetated detention pond at Brädgårdsgatan*

The purpose of the vegetated detention pond (Fig. 27 & 28) is to collect rainwater from the streets and the sloping lawn. It delays the water and at the same time some of the hazardous substances transported by stormwater are absorbed.

Fig. 23. Digging for the vegetated detention pond and installation of pipes.

Fig. 24. Finished detention pond at Brädgårdsgatan.

3.3.2 Raingarden at Jazzparken

The raingarden is built on a parking lot on the area of two previous parking spaces (Fig. 29). The raingarden is collects rainwater that flows over the impermeable surfaces of the parking lot and surrounding streets. The water flows into the flower bed (Fig. 30) where the water is filtered and delayed on its way towards Söderhamnsån via underdrains.

Fig. 25. Excavating the raingarden and installing pipes.

Fig. 30. Left) bed and overflow of the raingarden. Right) finished rain garden.

4 MONITORING AND PERFORMANCE ASSESSMENT

The water quality was monitored at the pilot sites before, during and after the pilot solution were built to document the impact of pilot solution on the stream water quality and therewith on the targeted project outputs to reduce pollution. This section details the monitoring schemes applied in the three pilot cities and the results gained from the monitoring work and the derived assessment of the technical performance of the chosen pilot solutions.

The main objective of the project's investments was to reduce seven nutrient, hazardous substance and/or toxin sources by at least 10 % (Output I1.1.1). The substances addressed in Tallinn, Turku, and Söderhamn include suspended solids (including micro and macro particles), phosphorous and heavy metals.

The achieved average reductions in the three pilot areas are presented in Tab 1. At least 16 different parameters have been monitored and analysed in the three pilot cities and the set goal of reducing seven parameters by at least 10 % was overachieved with reduction percentages ranging between 6 and 91 %. The targeted and monitored parameter differed between the pilot sites, but suspended solids (min. -43 %), total phosphorous (min. -23 %), cadmium (min. -35 %), chromium (min. -63 %), copper (min. -39 %), lead (min. -10 %), and zinc (min. -34 %) were reduced at *all* sites. Concentrations of some parameters increased locally, however the cause for this cannot be identified with the available data. The results and achievements per pilot site are further detailed in the following sections.

Tab. 1. Change in concentrations of selected water quality parameters after the implementation of pilot solutions in percent. Negative values indicate a reduction compared to the situation before construction, positive value an increase. Abbreviations: n.a. = not analysed, n.d. = not defined due to at least one value (before or after) being below detection limit.

Parameter	Tallinn change [%]	Turku change [%]	Söderhamn change [%]
Turbidity	*n.a.*	-64	*n.a.*
Suspended solids	-47	-66	-71
Conductivity	*n.a.*	7	*n.a.*
pH	*n.a.*	-1	*n.a.*
Alkalinity	*n.a.*	12	*n.a.*
O2	15	*n.a.*	*n.a.*
CODMn	*n.a.*	-14	*n.a.*
BOD	-48	-18	*n.a.*
TOC	*n.a.*	*n.a.*	-24
P tot	-57	-23	-58
PO4-P	*n.a.*	15	*n.d.*
N tot	-49	12	*n.a.*
NO2-N	*n.a.*	2	*n.a.*
NO3-N	*n.a.*	-6	*n.a.*
NH4-N	-14	181	*n.d.*
NO3-N+NO2-N	*n.a.*	*n.a.*	100
Arsenic	-14		100
Cadmium	-69	-35	-61
Copper	-83	-39	-57
Cromium	-91	-63	-67
Iron	-59		*n.a.*
Lead	-83	-60	-10
Mercury	*n.a.*	25	*n.d.*
Nickel	-53	-8	*n.a.*
Zinc	-73	-34	-40
Bens(s)pyren	*n.a.*	*n.a.*	*n.d.*

4.1 Tallinn

During the study, three sites of River Mustojajõgi were sampled: profile 1 - intersection of Mustjõe and Marja streets, high-voltage line - Kõrgepinge Street profile, and Paldiski Road profile (Fig. 31). During the study period May 2018 - September 2020 66 samples were taken, before, during and after the construction works.

Fig. 31. Mustoja River catchment area (left side) and monitoring stations: Profile 1- intersection of Mustjõe and Marja streets); 2 - High-voltage line-Kõrgepinge street profile; 3 - Paldiski Road profile (right side)

Measured water quality parameters included pH, electrical conductivity, turbidity, biological oxygen demand (BOD_7), suspended solids, total phosphorus (TP), total nitrogen (TN), ammonium, dissolved oxygen, chlorides, heavy metals, hydrocarbons, and microbiology and stream flow. Microbiological data include salmonella, Escherichia coli and enterococci. Heavy metals as lead, nickel, cadmium, copper, zinc, iron, mercury, chromium, and arsenic were analysed. The analyses of the water samples were done using standardized methods in accredited laboratories (Estonian Environmental Research Centre, Health Board Central Laboratory, Tallinn Water Ltd. Laboratories).

The flow meter was installed in the culvert under Paldiski road in January 2019. The last measurements were made at the beginning of October 2019. During dry weather the flow rate fluctuated between 0.07 m^3/s and 0.3 m^3/s. In the first half of 2019, there was little rainfall, especially in April. The average runoff in January was 0.14 m^3/s, in April 0.18 m^3/s. In March and from May to August around 0.9 m^3/s. There was more rainfall in the second half of 2019 from August. The rainiest was in September and in October, which has also caused rather high flow rate in River Mustjõgi. Maximum flow rate in September was measured to be 1.4 m^3/s and at the beginning of October over 1.8 m^3/s (Fig.32).

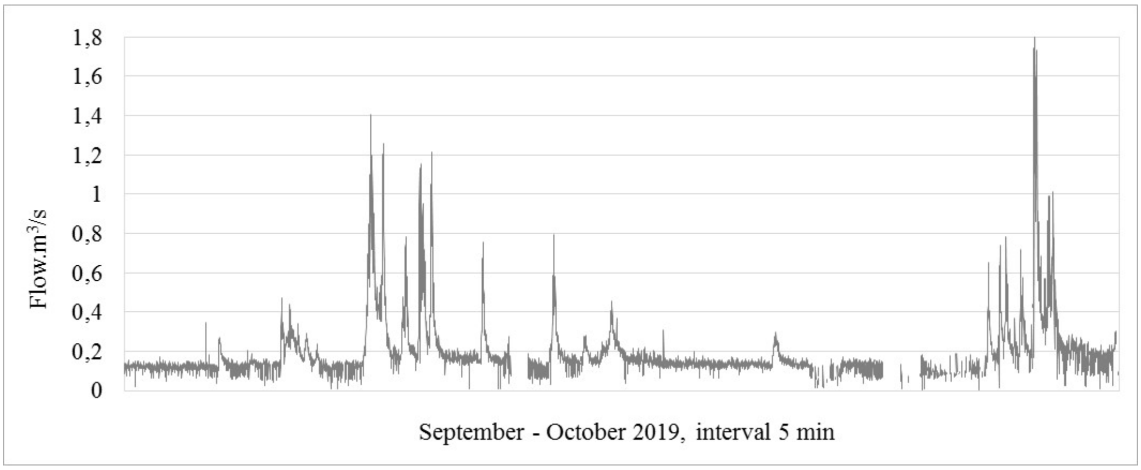

Fig. 32. Flow rate of River Mustoja during the time-period from 1.09.to 6.10.2019

Preliminary monitoring results indicate that the water quality of the Mustojajõgi river improved after the construction works. Comparison of TP and suspended solids concentrations before and after constructions works reveals a 50% decrease for both, which is well beyond the set target of a 10 % reduction. The concentrations for all measured parameters were evaluated based on the national limit values for a good environmental state of surface waters (Regulation of the Ministry of the Environment nr 28).

Organic matter expressed as BOD_7 varied between 1.0 and 13.0 mgO_2/l. Average values before construction works varied between 5.1 and 5.6 mgO_2/l. During the works, average values were between 5.8 and 3.5 mgO_2/l. After the construction works corresponding values were between 2.6 and 3.0 mgO_2/l (Fig. 33, left). National limit value for the good quality class is 3 mgO_2/l.

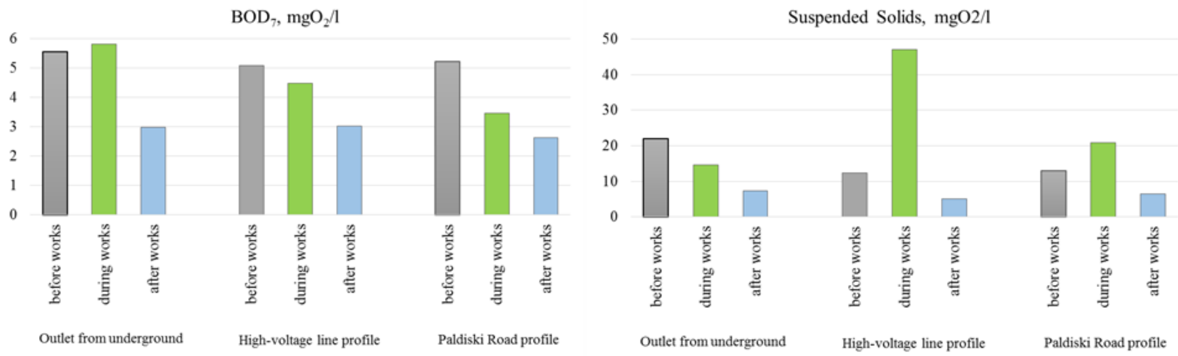

Fig. 33. Average organic matter parameter content (left) and Suspended Solids content (right).

For suspended solids, high values up to 40 mg/l were detected before and during the construction. After the works were finished, average content was less than 8 mg/l (Fig. 33, right). The ammonium content was high during the entire study period. With values being mostly above the national limit for a good environmental state of 0.3 mgN/l. The average content was slightly higher during the construction than during the pre-construction period. However, after completion of the construction work, the content reduced to 1.2 mgN/l (Fig. 34, left). The TP content was high before and during the construction works. Values as high as 1.3 mgP/l were observed, but the average value was about 0.3 mgP/l. After the works, TP content decreased remarkably, with average values of about 0.13 mgP/l (Fig. 34, right). The national good status value for surface watercourses is 0.08 mgP/l.

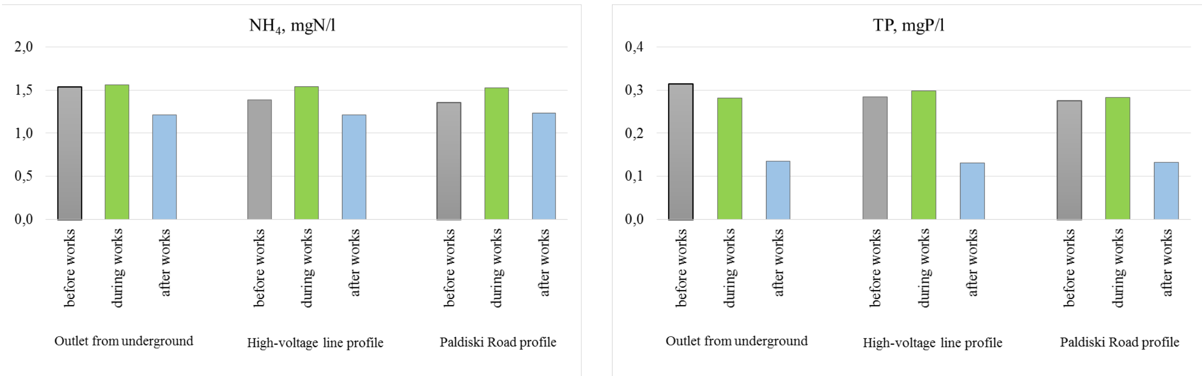

Fig. 34. Average ammonium content (left) and total phosphorus content (right)

During the monitoring period, nitrogen values were between 18 and 1.6 mgN/l. The average TN contents decreased by almost 50 % compared to pre-construction period (Fig. 35, left). After the works measured values were all under the 3 mgN/l and therewith belong to the good class. The oxygen content was rather high during the whole study period and increased after the renovation works (Fig. 35, right) up to 9.2 mgO_2/l which correspond to an oxygen saturation of 85%. This is indicative of a good environmental state.

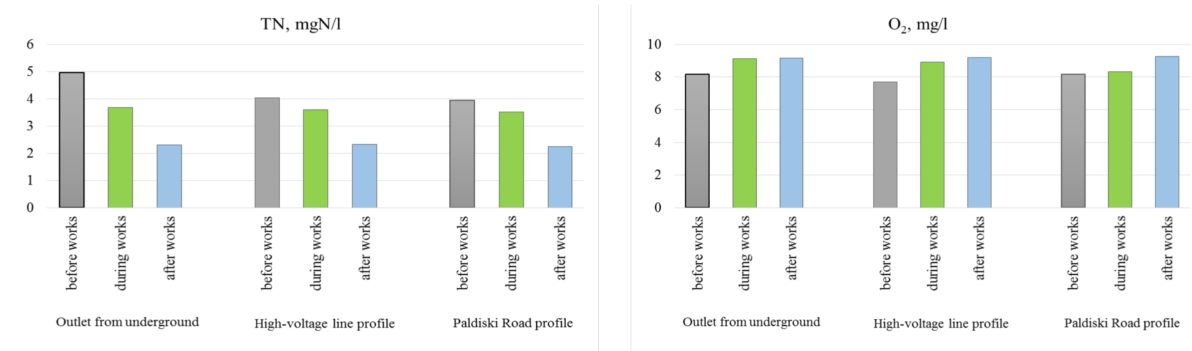

Fig. 15. Average total nitrogen content (left) and oxygen content (right)

Heavy metals content changed significantly during the study period with better results obtained after the construction work were completed. Due to the removal of polluted sediments and riverbank protection, the status of the river, as indicated by the content of heavy metals, improved. For example, cadmium content decreased to a quarter and chromium to about a tenth of the initial values (Fig. 36). The national annual average limit value for cadmium and chromium in the surface water are 0.25 µg/l and 5 µg/l, respectively (Regulation of the Ministry of the Environment nr 28).

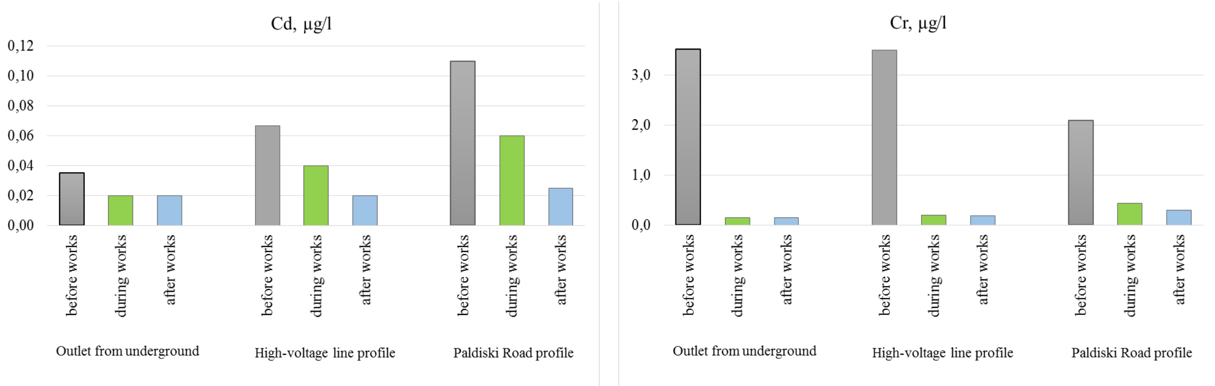

Fig. 36. Average cadmium content (left) and chromium content (right)

National annual average surface water limit values for nickel is 4 µg/l and for lead 1.2 µg/l. Both parameters average values were higher before renovation works but improved already during the renovation works (Fig. 37).

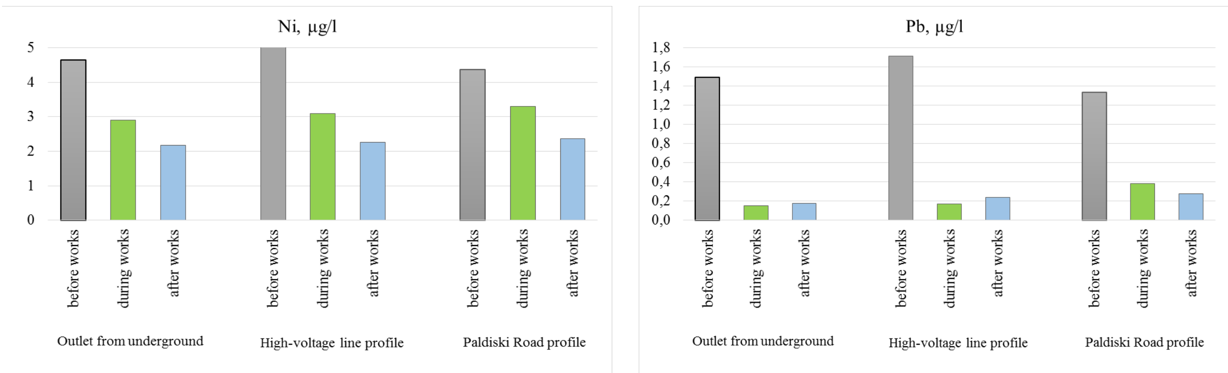

Fig. 37. Average nickel content (left) and lead content (right)

National limit values for copper and zinc concentrations in surface water are 15 µg/l and 10 µg/l, respectively. High values for both parameters were detected before the river renovation works, with up to 28 µg/l for copper and 112 µg/l for zinc. However, the decrease after renovation works is remarkable (Fig. 38).

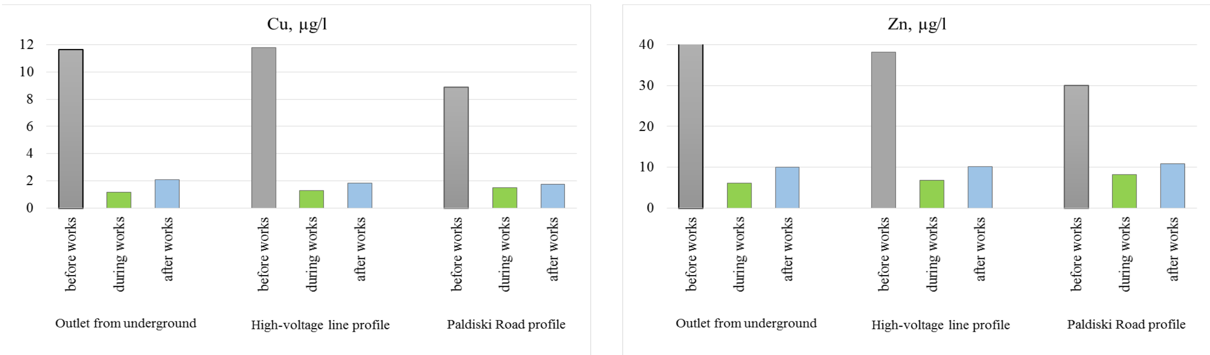

Fig. 38. Average copper content (left) and zinc content (right)

There is no national limit value for iron in surface waters. During the monitoring program, a considerable decrease was detected during and after the renovation works. The national limit value for arsenic in surface water is 10 µg/l which has not been exceeded during the study period and slightly decreased after completion of the renovation works (Fig. 39).

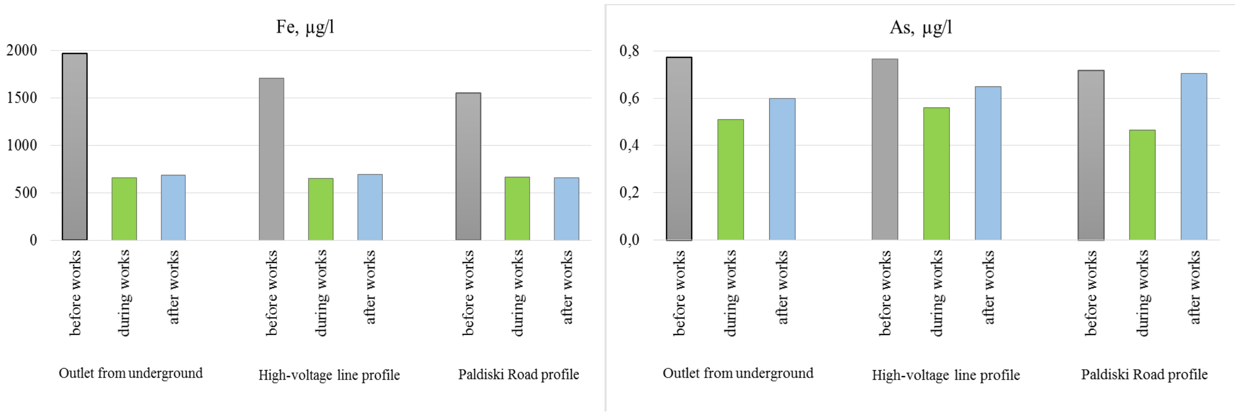

Fig. 39. Average iron content (left) and arsenic content (right)

The hydrocarbons content was mostly measured to be less than 20 µg/l, well below the national limit value in surface of 100 µg/l (Regulation of the Minister of the Environment nr 28).

4.2 Turku

TUAS carried out intensive water quality monitoring in the pilot streams through the project. The monitoring during different phases of the project served several purposes:

- Characterisation of water quality in different sections of the pilot streams and different land uses in the catchments
- Identification of pollution hotspots and most problematic pollutants
- Characterisation of pollutant variations under different discharge conditions and seasons
- Monitoring of the filter performance

4.2.1 Monitoring of filter performance

After the initial tests with the plywood boxes, pipe filter, and CFD modelling, the final filter structure was constructed and deployed. The objectives of the final monitoring scheme were:

- to validate the flow modelling done earlier and to gain knowledge of the modelling versus reality.
- to assess the filter's permeability, and monitor its changes, when used with two different granule sizes (Leca® LWA 3–8mm and 4–10mm).
- to monitor and document the functionality and performance of the filter over time.

Water samples were taken weekly between July and 13 October 2020. Water level measurements, outflow from the filter and possible other observations were noted during sample collection. Water samples were analysed in an accredited laboratory*[2] for 20 parameters, including: suspended solids, turbidity, electrical conductivity, pH, COD, BOD, total Nitrogen and total Phosphorus, NO_2, NO_3, NH_4, PO_4, heavy metals (Hg, Cd, Cr, Cu, Pb, Ni, Zn) and alkalinity. First, the filter system was deployed with 3–8mm Leca® LWA for six weeks, then and with 4–10mm Leca® LWA for another five weeks. For the first setup five samples pairs (one sample taken at the inlet and one at the outlet) were taken and for the second setup six sample pairs (Tab. 2 & Annex 1).

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*[2] Lounais-Suomen vesi- ja ympäristötutkimus Oy (https://www.lsvsy.fi/oy/); Turku UAS has a framework agreement for water sample analyses with the laboratory.

During the first monitoring period with the smaller filter granule size, no bigger rain events occurred. The outflow from the filter slowly decreased over the monitoring period, due to accumulation of suspended solids, causing clogging of the filter. The filtering capacity decreased simultaneously with the outflow, causing the filter to release particles at the end of the period.

Right after the first monitoring period, the 3-8 mm filter granules were replaced by 4–10 mm granules. The major outcome of this second test setup is, that though bigger rain events occurred during this period, the filter material did clog as rapidly as during the first period. Only accumulation of leaves and other organic debris at the inlet obstructed in inflow and required regular manual removal. The only decrease in filtering capacity was observed for mercury. While the filter was able to reduce all other pollutant concentrations, it had no effect on the nitrogen loading.

Main results of the final filter monitoring:

The results of the final filter monitoring between July and November 2020 are shown below. Table 2 provides average concentration of all samples taken before and after filtration with different filter granulate sizes and the percentage change between water samples taken from the filter inlet and outlet. The results indicate that each filter granulates were able to retain more than 50% of suspended solids, approx. 20 % of total phosphorous and reduce BOD and COD by approx. 20%. However, total nitrogen concentrations increase slightly. The results for heavy metals are more differentiated. Cadmium, chromium, copper, and zinc were retained with each filter granulates, while lead and nickel were released by the Leca ® 3-8 mm and retained with Leca ® 4-10 mm. Mercury was released during both test setups. The data is not sufficient to assess, whether the filter granulate itself is the source, or if increases in concentrations at the filter outlet are related to enrichment processes inside the filter.

Tab. 2. Average concentrations of different parameters before and after filtration in the filter box (Avg. in/Avg. out), when using 3-8 mm Leca® and 4-10 mm Leca ® granulates and the average change. Negative values (green) indicate a reduction, positive values (red) an increase in concentration.

	LECA ® 3-8 mm			LECA ® 4-10 mm		
	Avg. Inlet	Avg. Outlet	Avg. change [%]	Avg. Inlet	Avg. Outlet	Avg. change [%]
Turbidity	4.1	1.86	-55%	17.46	6.36	-64%
Suspended solids	4.82	2.2	-54%	14.28	4.92	-66%
Conductivity	46.6	46.6	0%	41.4	44.4	7%
pH	7.92	7.92	0%	7.74	7.64	-1%
CODMn	6.32	4.72	-25%	5.38	4.62	-14%
BOD 7	2.72	2.05	-25%	5.2	4.26	-18%
N tot	1258	1292	3%	1250	1400	12%
NO2-N	64.4	88.5	37%	25.4	25.8	2%
NO3-N	641.4	670	4%	650	610.6	-6%
NH4-N	166	205	23%	108.6	305.2	181%
P tot	129.6	105.6	-19%	93.8	72.2	-23%
PO4-P	67.6	77.8	15%	28.6	32.8	15%
Mercury	0.022	0.0275	25%	0.034	0.0425	25%
Cadmium	0.026	0.025	-4%	0.046	0.03	-35%
Cromium	0.978	0.976	0%	2.652	0.986	-63%
Copper	8.56	5.18	-39%	7.78	4.72	-39%
Lead	0.2775	0.73	163%	0.896	0.36	-60%
Nikkel	2.5	2.98	19%	3.06	2.82	-8%
Zinc	15.8	14.82	-6%	33.8	22.46	-34%
Alkalinity	3.16	3.22	2%	2.34	2.62	12%

To exemplify some of the major results, figures 40-49 visualize the inlet and outlet concentrations for total suspended solids, total phosphorous, total nitrogen, zinc and copper, each for the field test with Leca ® 3-8 mm and Leca ® 4-10 mm granulates. All results are included in Appendix 1, Tab. A4.

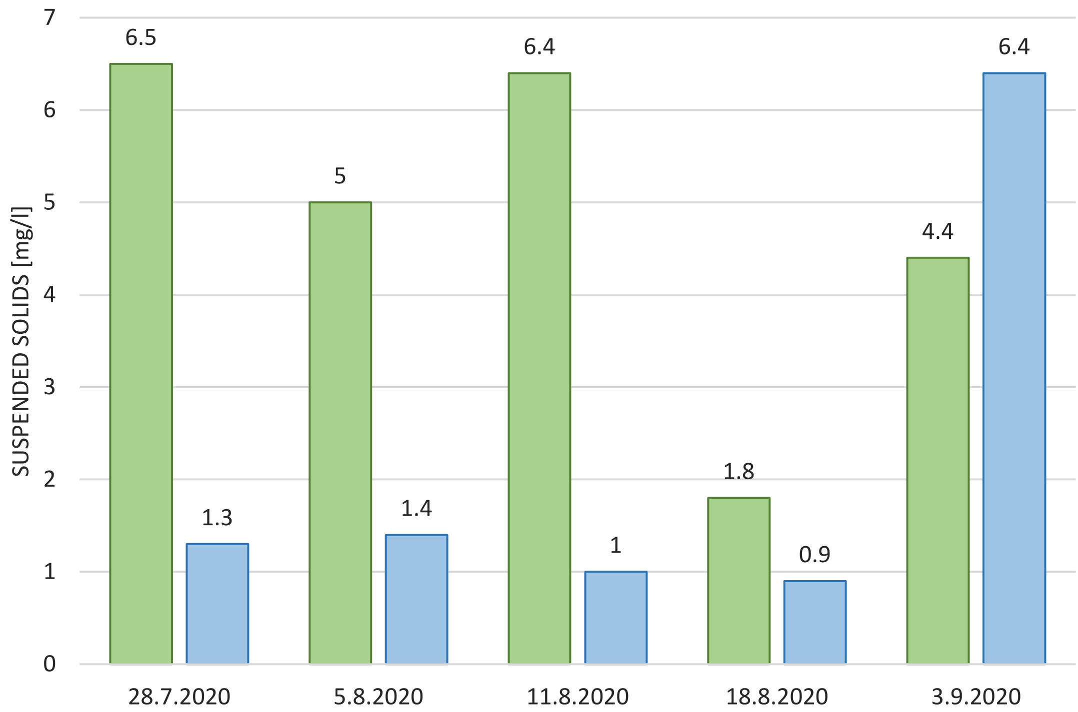

Fig. 40. Concentration of suspended solids before (green) and after (blue) filtering with Leca® LWA 3–8mm.

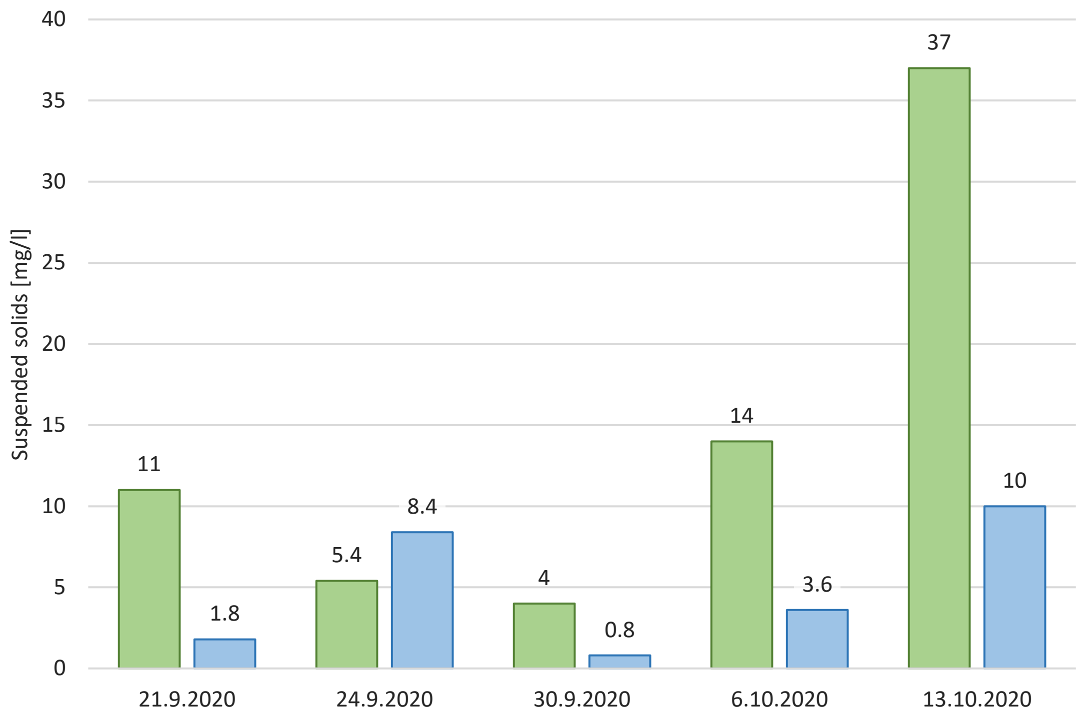

Fig. 41. Concentration of suspended solids before (green) and after (blue) filtering with Leca® 4-10 mm.

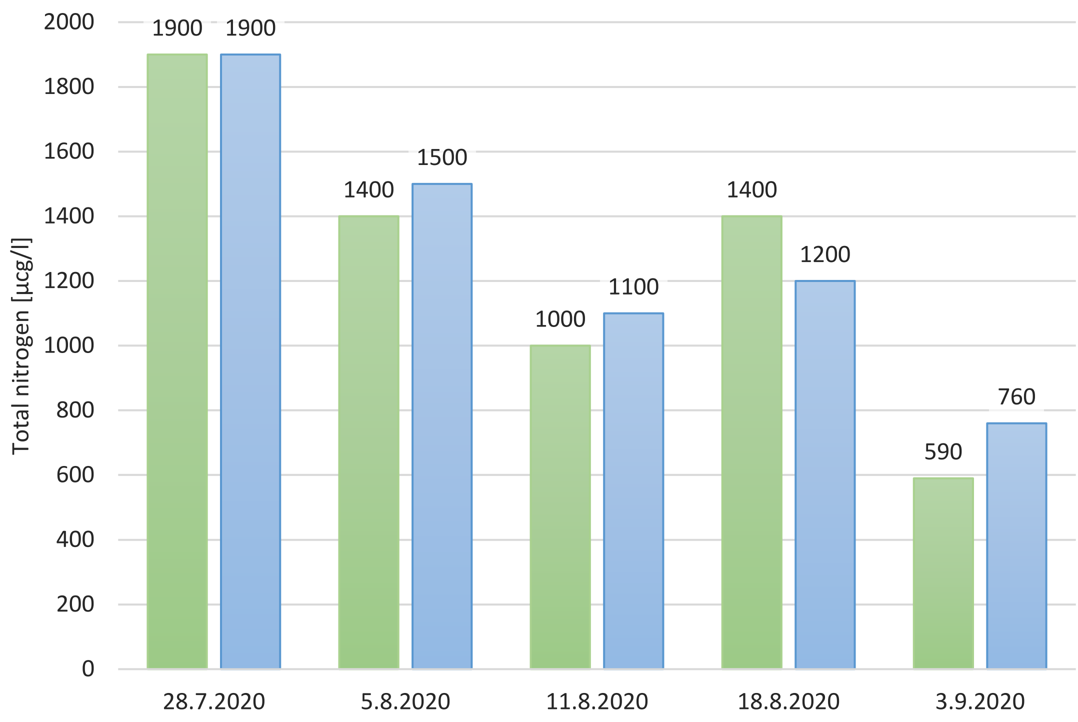

Fig. 42. Total nitrogen concentration before (green) and after (blue) filtering with Leca® LWA 3–8mm

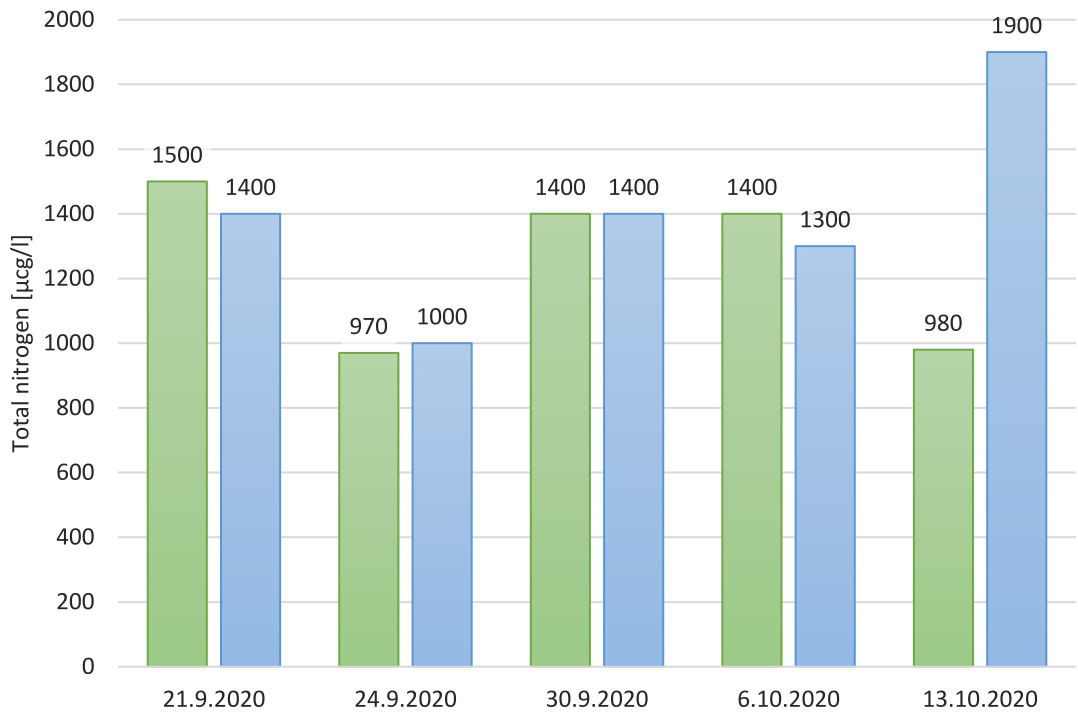

Fig. 43. Total nitrogen concentration before (green) and after (blue) filtering with Leca® 4-10 mm

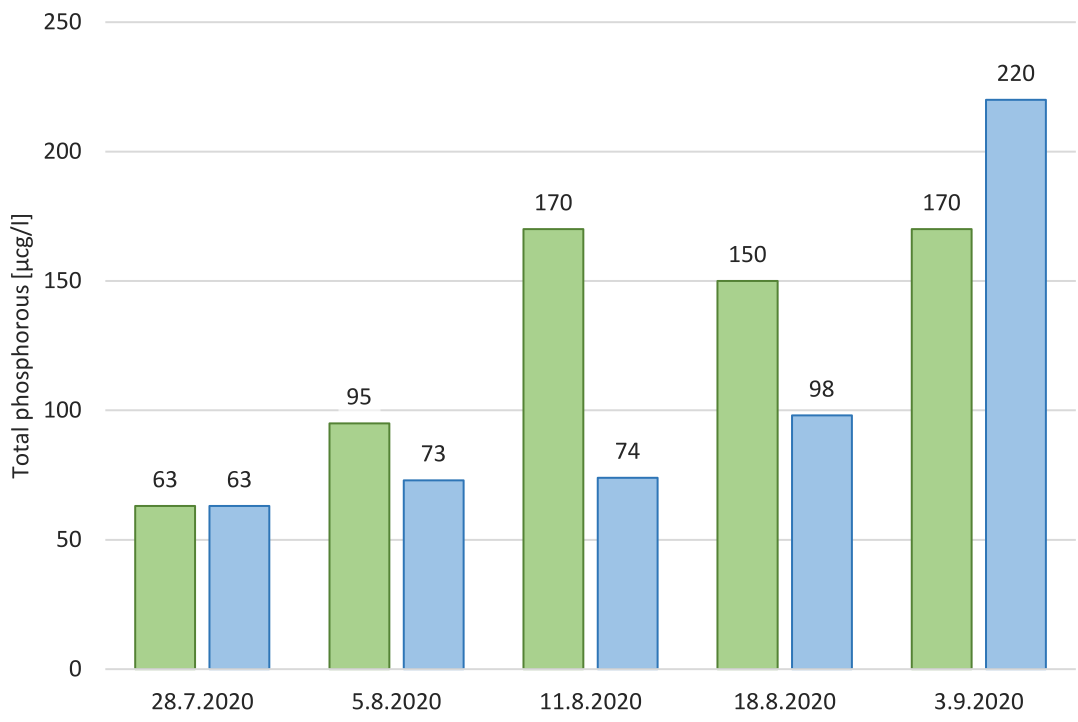

Fig. 44. Total phosphorous concentration before (green) and after (blue) filtering with Leca® LWA 3–8mm

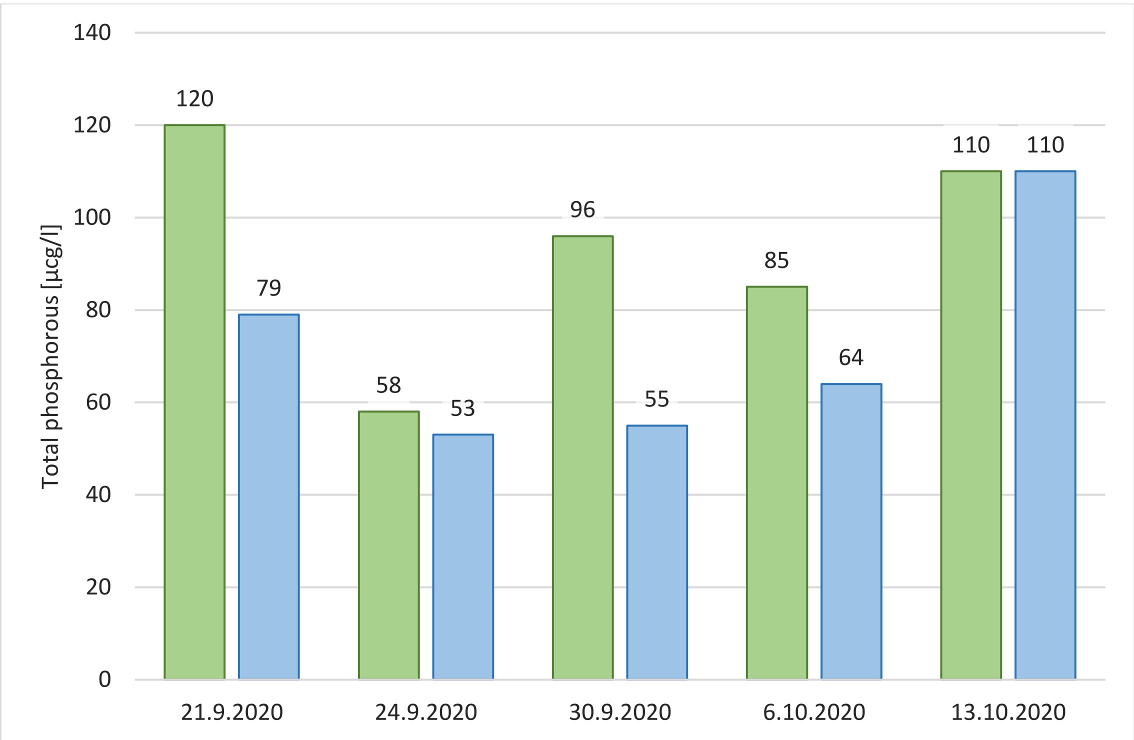

Fig. 45. Total phosphorous concentration before (green) and after (blue) filtering with Leca® 4-10 mm

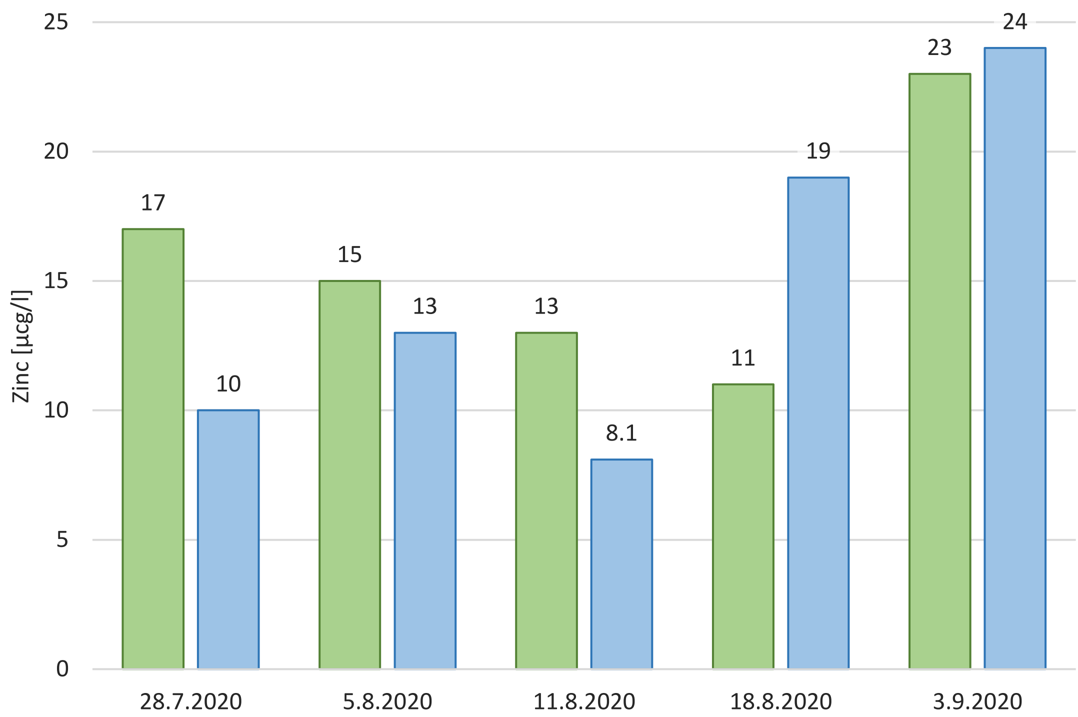

Fig. 46. Zinc concentration before (green) and after (blue) filtering with Leca® LWA 3–8mm

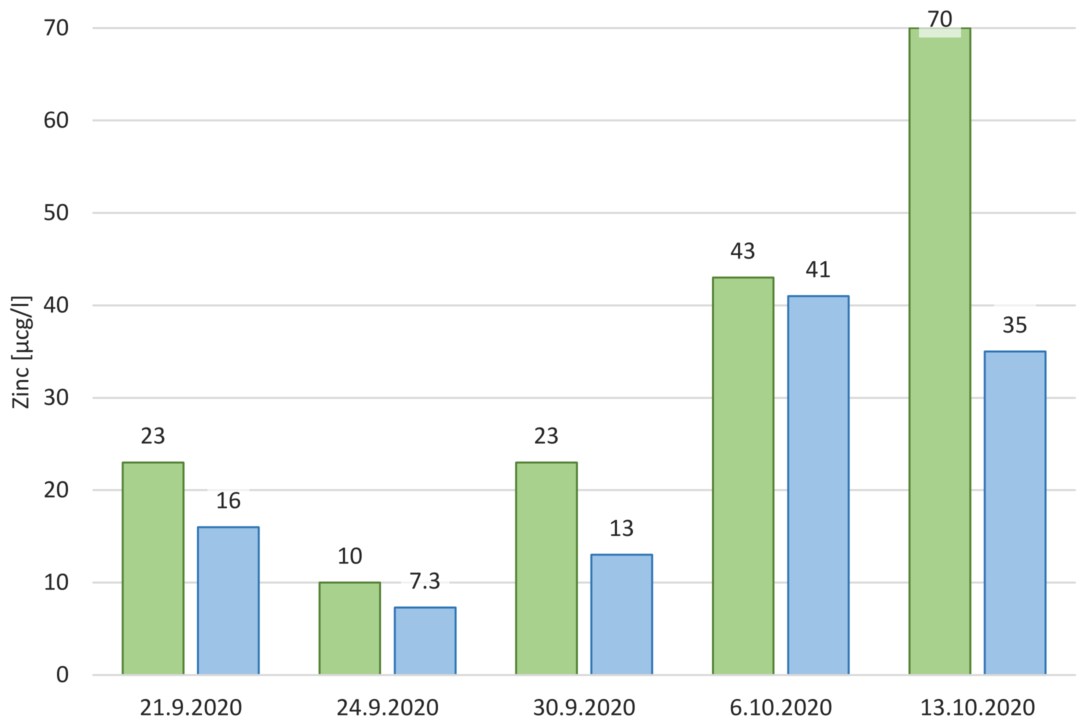

Fig. 47. Zinc concentration before (green) and after (blue) filtering with Leca® 4-10 mm

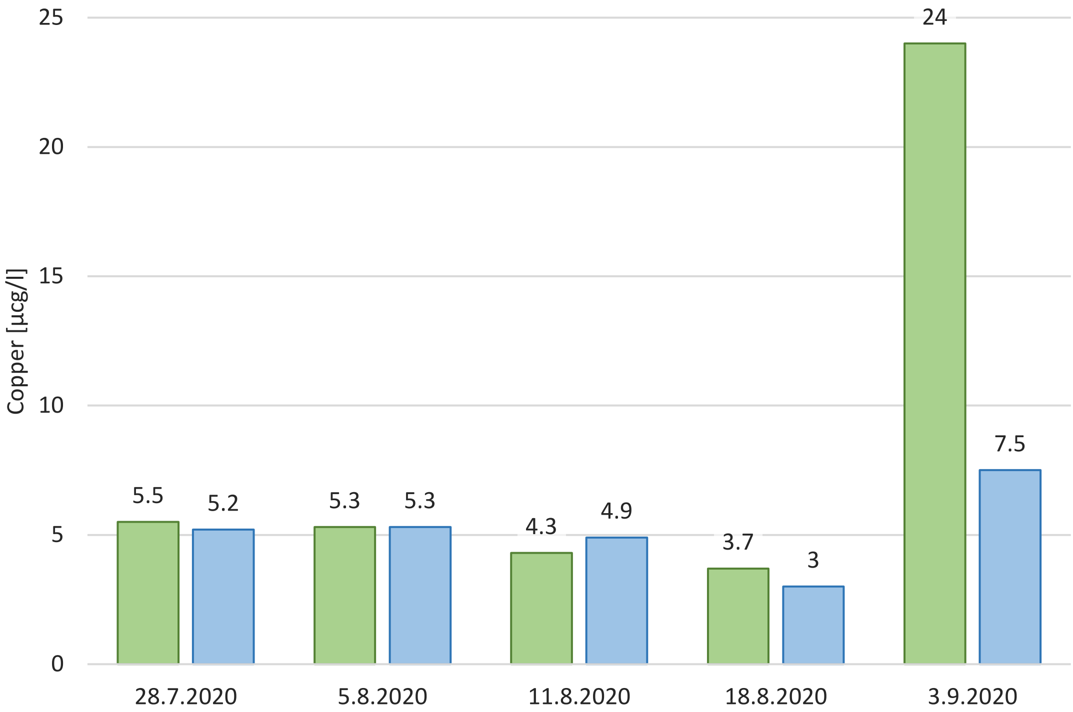

Fig. 48. Copper concentration before (green) and after (blue) filtering with Leca® LWA 3–8mm

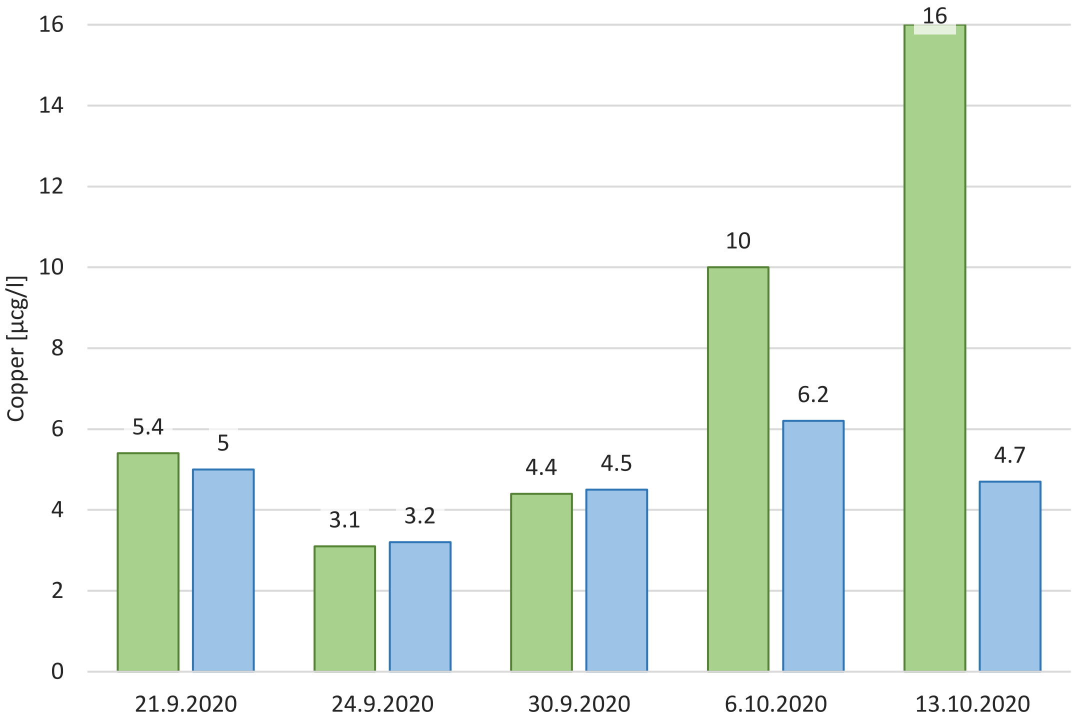

Fig. 49. Copper concentration before (green) and after (blue) filtering with Leca® 4-10 mm

4.2.2 Monitoring of pilot streams for hot spot identification and selection of future filter deployment sites

The review and analyse of water quality data existing prior to the project (*Deliverable D.T1.11 Report on local water quality monitoring and assessments of ecological problems in the pilot water bodies*) was complemented by the collection of additional data between September 2019 and November 2020 to validate the initial findings, assess the effect of the filter in the pilot stream and to identify future deployment sites for the filter solution after the project end. During the development of the filter solution knowledge on its functionality and application range was gained and collection of further monitoring data in the pilot streams helps to identify the locations where the filter may be used most effectively in future.

Water samples were collected from the same location as detailed in Deliverable D.T1.1. and a few additional sites (Fig. 50). The main objective was to identify locations that are especially affected by heavy metal and PFAS contamination. Prior knowledge on these was gained during a baseflow sampling campaign in May 2019. During autumn 2020 these sites were sampled again to obtain data on the pollution load during a period with higher runoff and potential leaching of contaminants. All results of these sampling campaigns are presented in Appendix 1, Tab. A1-A3.

In summary, the concentrations of analysed parameters were higher during the November sampling on most occasions. This was to be expected as the May sampling was done at baseflow discharge, i.e. after an extended dry period, while the November sampling was preceded by frequent rains. The most noticeable results were obtained from the upstream part of Kuninkoja (K1, 11, 12) and the L1 and L2 locations (sampled only November 2020). Near the source of Kuninkoja, different PFAS compounds were detected at higher concentrations than elsewhere during both sampling campaigns. This is remarkable as there are no major industries or residential areas in the vicinity of the sampling locations. However, the Turku airport is very close and a possible source.

The samples from the L1 and L2 locations revealed extreme concentrations of ammonium nitrogen of 110,000 µg/l and 18,000 µg/l, respectively. The locations are most likely affected by runoff from the nearby landfill.

These two areas are the primary candidates for future deployment and further development of the filter system.

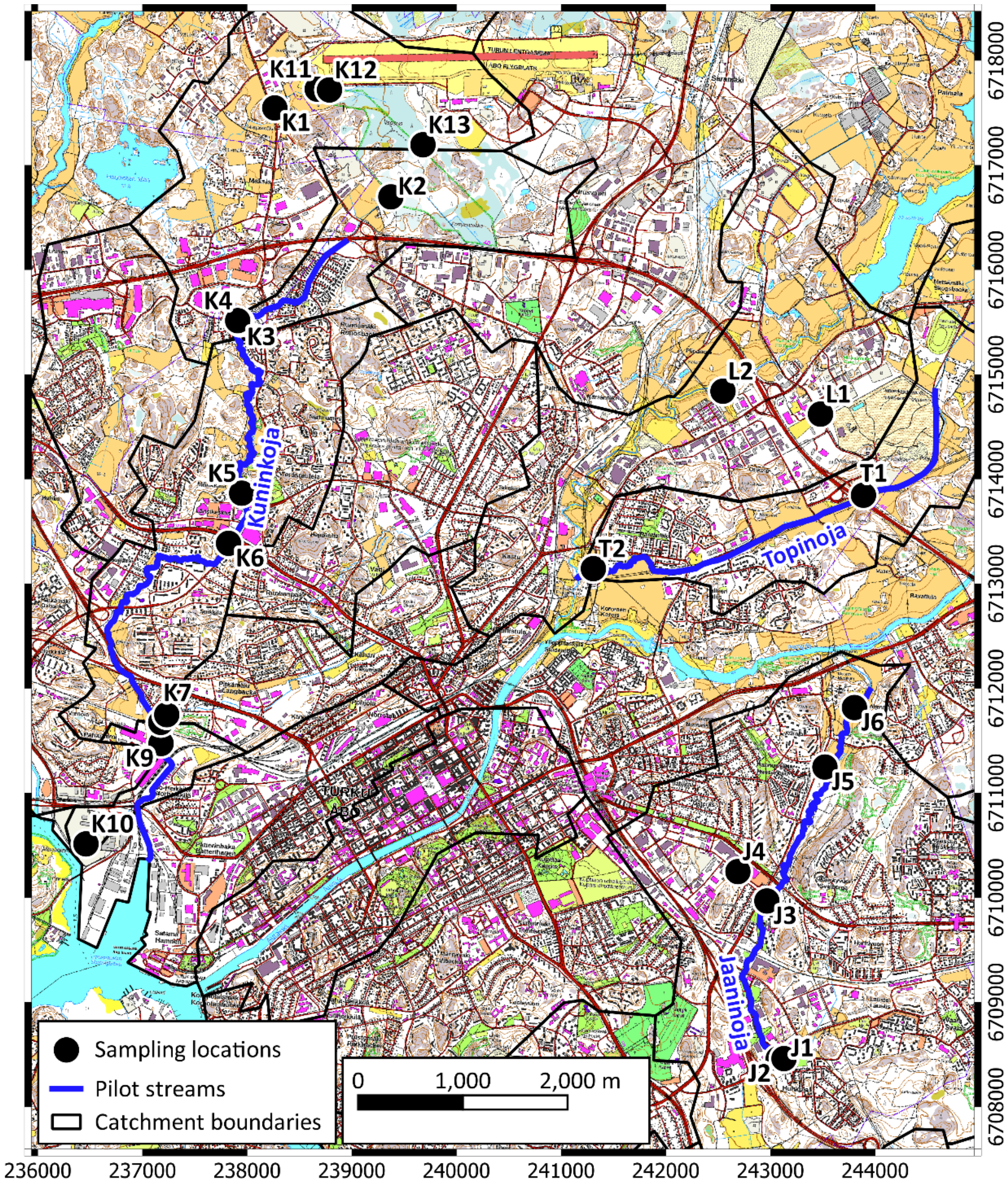

Fig. 50. Map of water sampling locations in the three prior streams. Samples have been collected in May 2019 and November 2019. Locations K9, K10 and J6 were sampled only 2019. T1, L1, L2 were sampled only 2020.

4.3 Söderhamn

Before the project started, a one-year study was performed in Söderhamnsån during which the flow and nutrient levels were measured. This study provides the reference for the monitoring work done in Heawater.

During the project, two stormwater samples taken in the vicinity of the pilot sites were analysed (Fig. 51). The samples were taken before and after the construction of the raingarden.

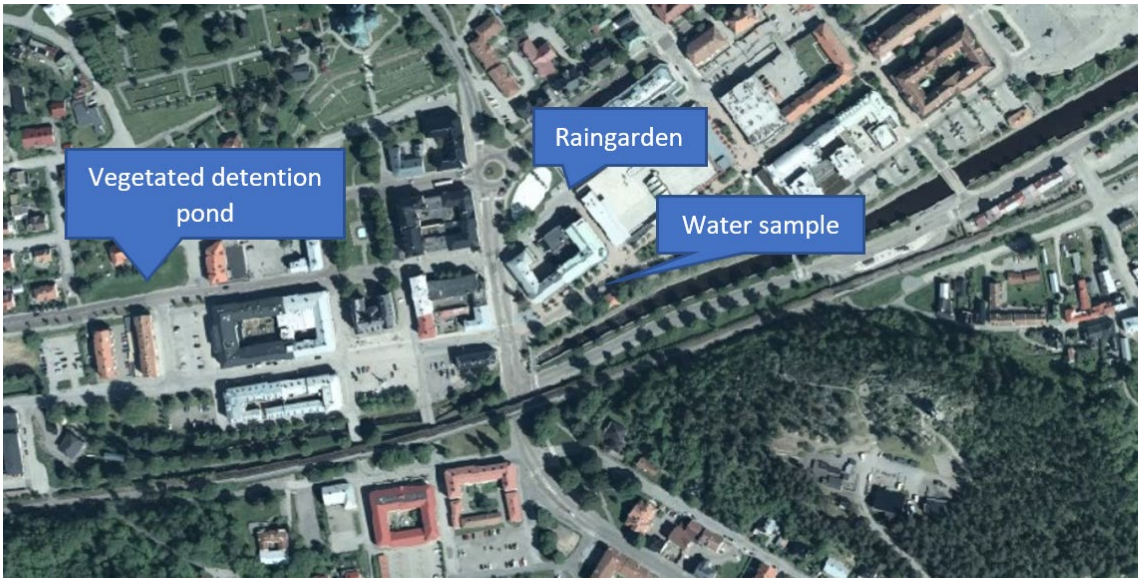

Fig. 51. Construction sites for the raingarden and vegetated detention pond. Place for stormwater sampling.

The water was taken in a stormwater well downstream of the raingarden (Fig. 52) using an autosampler. Samples were taken 8 June 2020 and 7 October 2020. The timing of the sample collection was critical as it should be a long period of rain. The rain should

have a duration of at least 4 hours and the first flush should be avoided. 24 bottles were collected during the sampling period and subsequently mixed to generate a composite sample. The samples were sent to an accredited laboratory (Synlab) for analysis. The sample taken in June was also analysed for microplastics.

Fig. 52. Installation of the sampling equipment.

4.3.1 Results of stormwater sampling in Söderhamn and effect of the pilot solutions

Overfertilization is one of the mayor problems for Söderhamnsån. Phosphorus is often bound to particles. Thus, when the concentration of suspended matters is reduced it also affects the concentration of phosphor. The sample analyses confirm this. The results show that the concentration of suspended matter has gone from 85 mg/l before the construction of the raingarden to 25 mg/l after the construction (Fig. 53). At the same time the concentration of phosphor went from 0,26 mg/l to 0,11 mg/l (Fig. 54).

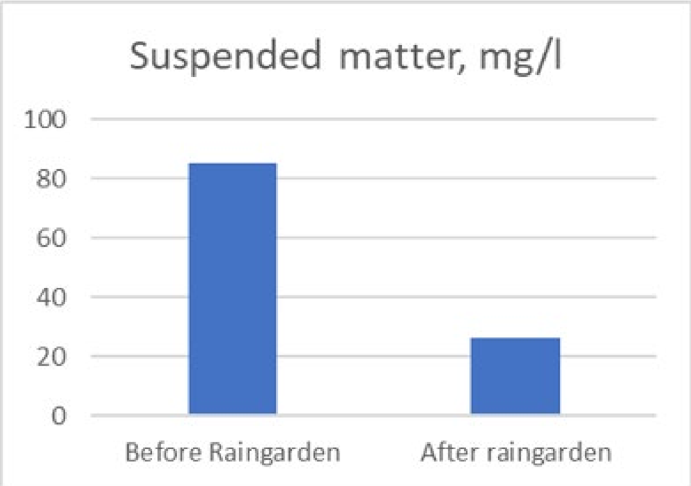

Fig. 53. Suspended solids concentrations in stormwaters before and after the construction of the raingarden.

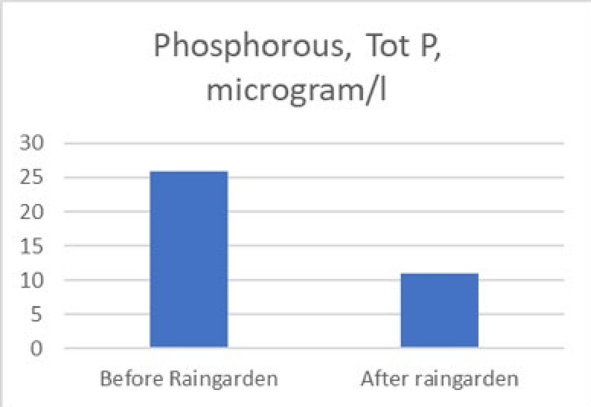

Fig. 54. Phosphorous concentrations in stormwaters before and after the construction of the raingarden.

For PO4 the result was not as clear as for particle bound phosphor. Here the first sample had a concentration of <0,05 mg/l and the second sample 0,041 mg/l (Tab. 3). For nitrogen the analyses indicated an increase in the concentration of NO2-N and NO3-N. For and for NH4-N, no conclusions can be drawn since laboratory analysed the samples with methods with different detection limits (the first sample results is <1,0 and the second 0,01mg/l).

The raingarden is in the centre of Söderhamn and it was expected that the stormwater quality is affected by traffic. Substances that originate from traffic are zinc and copper but also other heavy metals. Table 3 presents the results of the complete water analyses before and after the construction of the raingarden. The concentration for all substances, except arsenic, was lower or equal after the construction. Since there are no national guidelines for runoff quality in Sweden, the results have been compared to the limit values set by the City of Gothenburg. The only value that is higher that the recommendations for Gothenburg is zinc. The source for these high zinc concentrations is difficult to determine and needs further investigation, however traffic is a possible reason.

*Tab. 3. Results of the stormwater composite samples. *Limit values recommended by the municipality of Gothenburg, used as reference in absence of national limit values.*

	Sample 8 June	Sample 7 October	Gothenburg*	Unit
Arsenic (As)	0,8	1,6	15	µg/l
Chromium (Cr)	7,2	2,4	15	µg/l
Cadmium (Cd)	0,18	0,07	0,4	µg/l
Lead (Pb)	6,3	5,7	14	µg/l
Copper (Cu)	21	9,1	10	µg/l
Zinc (Zn)	150	90	30	µg/l
Mercury (Hg)	8	<5	50	ng/l
TBT	<1,0	<1,0	1	ng/l
Bens(s)pyren	<10	<1,0	50	ng/l
pH	6,9	6.9	6 to 9	
P tot	0,26	0,11	0,05	mg/l
PO4-P	<0,05	0,041		mg/l
NO3-N+NO2-N	150	300		µg/l
NH4-N	<1,0	0,01		mg/l
TOC	4,2	3,2	12	mg/l
Suspended solids	85	25	25	mg/l

The first sample was analysed for microplastic content by IVL (Svenska Miljöinstitutet). The analysis contained one stormwater sample and a blank sample. Both samples were filtered through three different filters, 300 µm, 100 µm and 50 micrometres (Figs. 55-57; translation from Swedish: SBR =Rubber particles, non-synthetic fibres, plastic fragments, and plastic fibres.)

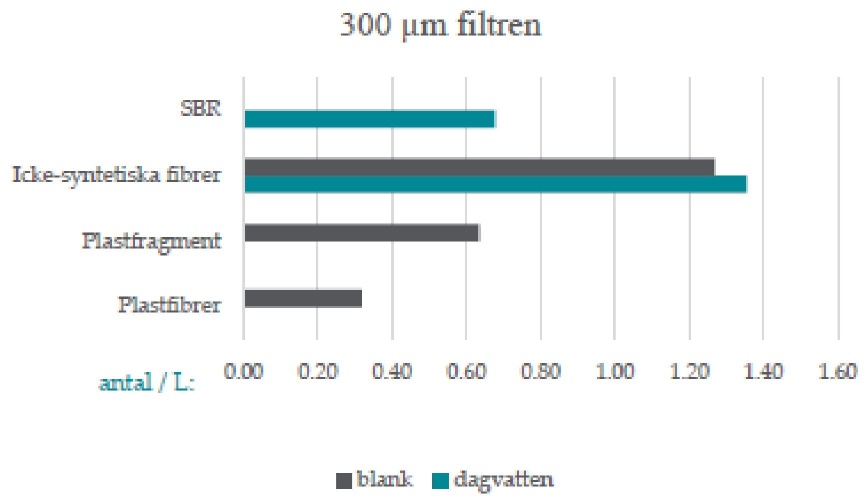

Fig. 55. Microliters 300 µm filter

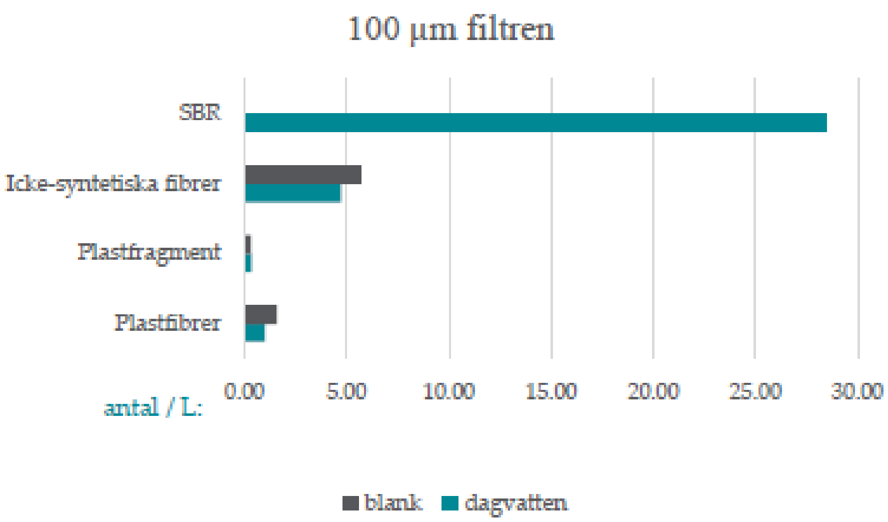

Fig. 56. Microliters 100 µm filter

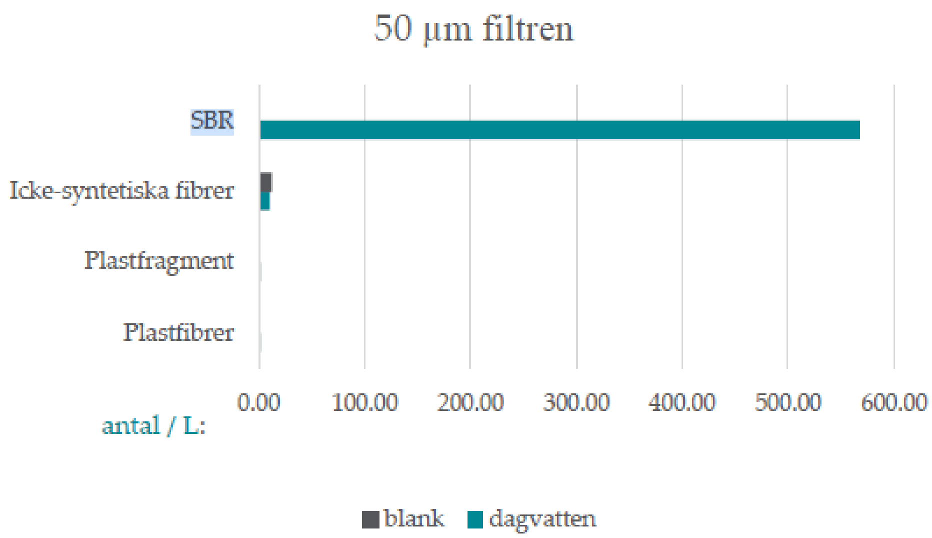

Fig. 57. Microliters 50 µm filter

The stormwater contained 618 microliter particles/L. In the 300 µm filter non-synthetic fibers dominated. These were probably fibers from plants. The dominating category on the other two filters was SBR-particles. The SBR-particles probably derive from rubber from tires. A previous study by IVL shows that is the biggest source of land-based microliter comes from streets and tires (Magnusson et al., 2016). Rubber from tires are estimated to generate 7 670 tons of microplastics per year in Sweden.

5 CONCLUSIONS

In the following paragraphs the main conclusions drawn from the pilot developments and investments made in Tallinn, Turku and Söderhamn are summarized. The conclusion includes experiences made related to the planning and implementation process, the effectiveness of the technical solutions and the stakeholder engagement.

5.1 Tallinn

Construction works in urban areas need good communication with residents. The citizens in the Mustjõe residential area were active and had a strong community sense. For example, they were concerned about a local bird population - mallard ducks (Anas platyrhynchos) and whether the construction works will have adverse effect during the hatching season and if there was any danger for the ducklings walking to the gabions. The residents were included into the project from the very beginning of the project. The first information letter was sent out in summer 2018. In April 2019, Tallinn city organized a first stakeholder meeting, where the design project and construction plans were explained. The good communication with all stakeholders facilitated a smooth implementation of the construction works just next to the residents' yards along the River Mustojajõgi.

Initially, it was estimated that obtaining all necessary permits and completing the public tender process would take nine months. However, it took 15 months. There was little interest in the open call for offers for the construction of the bank protection structure. A possible reason for the limited response might be the strict regulations concerning construction works within the city. Further, the tendered works might have been challenging for companies due to the limited space for operation of machinery in the pilot area and the need to coordinate and communicate the works with the residents. The development and design of the most suitable technical solution was impeded by the tight schedule of the project.

Technically, the most challenging was the temporary drainage of the work area. Though the pilot stream has an average flow of only 0.8 m^3/s, it posed a challenge. During heavy rainfalls, the water level rose within a few tens of minutes and hampered the works in the riverbed as the applied drainage techniques were not efficient under these conditions. Therefore, the success of the works was also dependent on the meteorological conditions. However, the warm winter of 2019/2020 favoured construction works. The ambitious schedule precluded detailed analyses of the soil properties. Other than expected, the soil conditions were not favourable in some river sections and required extra stabilization to place the gabions. Also, the degree of soil contamination was underestimated prior to the construction works. Slope profiling exposed domestic waste, oil, and petroleum products. Laboratory analyses of soil samples suggest that the pollution dates back ck to the Soviet time. The replacement and disposal of the contaminated soil caused unforeseen expenses. More detailed investigation of the pilot area during the starting phase together with a more generous implementation schedule could have minimised these unplanned interventions and costs.

The following six risks were foreseen in the project proposal:

1) The required permits for the construction of the pilot are not granted

2) The environmental conditions change such that the solutions selected in WP T1 are not feasible.

3) The selected solution proves not suitable for the pilot stream and the selected target substances.

4) The foreseen budget is insufficient to realize the pilot investment.

5) Environmental circumstances hamper the construction of the planned pilot site.

6) Extreme weather events, which may cause damage or overflow of the pilot solutions and subsequent transport of retained substances to receiving waters.

In Tallinn, the probability of occurrence of the fourth risk was assessed to be very low. Yet, this case occurred. The review of the procurement outcomes revealed that the planned constructions would be almost twice the available budget. However, with financial support from the Tallinn City Government it was possible to realize the project as planned. Other, previously considered risks did not occur

Based on initial monitoring data and residents' feedback, the implemented solutions were a success and may be recommended for similar urban rivers.

5.2 Turku

TUAS developed and piloted several technical and non-technical solutions to reduce the macro- and micro pollutant loading in small urban streams. The testing of these different solutions proved their potential to remove various pollutants from the environment when applied at larger scale. The project yielded valuable data and insights for future applications and developments of these solutions. If pollution cannot be avoided, at least its transport should be avoided. The removal of micro pollutants, including particles, nutrients and heavy metals should be done as close to the source as possible. That is, preferably at the outlet of small sub-catchments as individual lots or in small stormwater ditches or swales. Macro pollutants such as litter are removed from small urban streams most efficiently through occasional cleaning campaigns.

5.2.1 Removal of micro pollutants from streams

The filter system developed during the project proved to be effective in reducing the loading with suspended solids, most heavy metals and phosphorous significantly from small streams during intermediate to low discharge conditions. The system removes primarily particles, the removal of dissolved compounds has not been investigated in detail. Due to the short contact time between water and filter material, it may be assumed that the adsorption of dissolved pollutants is minimal. Though the removal of solids is very effective, it is at the same time the limitation of the system as the retained solids clog the pore space of the filter granulate after a few weeks of operation. Therefore, future application of the system should focus on runoff treatment from individual lots or small side-streams.

5.2.2 Macro pollutant removal from streams

The most effective method to reduce macro litter pollution in urban streams is to avoid littering. The removal of macro pollutants from small urban streams has not been efficient. This is mainly because small streams carry litter only during high discharge conditions, unlike larger rivers that might transport litter continuously over longer distances.

Awareness rising, litter collection campaigns and effective waste management are ways to ensure the best results. Within the Heawater project, two cleaning campaigns along the Jaaninoja and Kuninkoja streams were held (Fig. 58). These campaigns gained visibility in the regional media and should be used on regular basis to create a consciousness of the problem. Littering is a problem especially in the vicinity of construction sites and commercial areas. A combination of stricter waste management requirements and increased environmental consciousness among all actors, including companies and citizens might provide low-cost, effective ways to avoid littering. Marco litter like food packaging and plastic wrappings are also a source of micro pollutants, including plastics and PFAS compounds.

Fig. 58. Student group with litter collected from Jaaninoja. Total amount of litter was 80 kg, from which 20 kg of plastic.

5.2.3 Awareness rising and education as mean to protect urban streams

The education, awareness rising, and communication activities carried out in Turku revealed a great interest among schools and pupils, students, public planners and decision makers and citizens to improve the state of urban environments, especially aquatic systems. Teaching pupils about urban stream ecosystems and methods to monitor and improve these might be the most effective way to support the development of environmental consciousness of young people. The work with students and planners may result in changing behaviours and creation of new management practises. During the project a comprehensive education package on urban stream ecosystems was developed, after it became clear that such is not existing in Finnish language, while a demand for such exists.

5.2.4 The importance of monitoring

Monitoring and assessment of water quality but also littering along streams in different seasons and discharge conditions is essential to identify environmental problems. Though the main sources of, e.g. nutrients or heavy metals, are known, their pathways and local concentration hot spots are usually not known on city scale, which impeded the implementation of effective counter measures and the best use of limited resources. The monitoring of pilot streams has identified several hot spots within Turku. Identification of sources and immediate reaction by the legislative in one case, removed a major inflow. Sites for future actions have been identified. Monitoring of the filter solution did not only prove it functionality but also highlighted the need for and integration of long-term monitoring and modelling to achieve the best functionality.

5.3 Söderhamn

As the public procurement process was not successful, the design and construction of the two pilot sites was done entirely by Söderhamn Kommun. This provided valuable experience for the future and, through an intense learning process, a better technological knowledge and understanding. This knowledge gain would not have been possible if the measurements were done by an external company. The project highlights the need of good planning and sufficient time to cater of possible delays and be successful. The final solutions, a raingarden and a vegetated detention pond, clean stormwater, add biodiversity, and delay discharge and serve as a multifunctional area for recreation, respectively.

Both the raingarden and the vegetated detention pond are quite simple yet effective constructions. Stormwater management and construction of decentralized solutions are a complex task that require consideration of several aspects. There is no one measure that solves all problems. Therefore, one should consider the main problem and the local conditions at the site. The project implementation also showed that it is much easier if the development of stormwater management structures starts at an early stage of the planning of a new development project. That is, it is easier to account for problems related to stormwater management at the beginning than trying to solve them later. When working in already developed areas, the problems are more complex and possible solutions need to be a trade-off between more, possibly contradicting aspects.

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Appendix

1. Monitoring results TUAS

The analyses results of water samples collected by TUAS during the project are listed below. Samples were collected to monitor the functionality and performance of the in-stream filter and to identify pollutant hotspots within the pilot streams Jaaninoja, Kuninkoja and Topinoja.

Tab. A1. *Analyses results of water samples collected on 14 May 2019 and 4 November 2020 from three pilot streams. For sampling locations see Fig.49.*

	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Location	Turbidity [FNU]	Turbidity [FNU]	TSS [mg/l]	TSS [mg/l]	Conductivity [mS/m]	Conductivity [mS/m]	pH	pH	CODMn [mg/l O2]	CODMn [mg/l O2]	BOD 7 [mg/l]	BOD 7 [mg/l]
J1	8.8	39	6.6	37	34	31	7.8	7.7	4.8	9.2	2.5	1
J2	3	18	1.4	17	42	51	8.1	7.7	3.8	5.6	1.7	0.9
J3	23	44	20	46	45	38	7.9	7.7	5	8.3	2.1	1
J4	3.7	14	3.3	8.1	93	47	10.1	7.9	6.2	5.7	8.4	3.2
J5	24	x	23	x	38	x	7.8	x	4.1	x	2.3	x
J6	15	42	13	45	38	37	7.8	7.7	3.9	8.8	2	1.1
T1	x	180	x	170	x	54	x	6.8	x	16	x	1.8
T2	15	110	11	93	62	47	8.1	7.6	7.3	13	2.8	2.2
L1	x	38	x	24	x	110	x	8.9	x	15	x	4.8
L2	x	17	x	13	x	51	x	7.8	x	7.6	x	9.1
K1	85	65	69	55	23	19	7.6	7.3	10	22	2.9	1.7
K2	5.2	4.2	5	2.5	9.2	9.4	6.5	5.6	21	69	2.2	2.2
K3	9.6	28	7.5	30	40	29	7.8	7.3	11	36	2.4	1.5
K4	25	76	18	56	49	33	8.1	7.6	7	18	2.3	1.5
K5	22	x	16	x	43	x	8.2	x	8.5	x	2.8	x
K6	22	92	15	83	43	31	8.1	7.8	8.2	21	2.5	1.5
K7	8.4	31	5.9	27	45	37	8.1	7.5	4.7	7.8	2.8	1.7
K8	31	110	25	97	49	31	8	7.7	7.8	19	1.6	1.4
K9	18	x	13	x	49	x	8	x	6.7	x	2.6	x
K11	x	27	x	12	x	23	x	7.2	x	3.8	x	0.6
K12	x	27	x	21	x	16	x	6.9	x	17	x	1.3
K13	x	1.2	x	1.7	x	7.2	x	6.3	x	15	x	1.7

Tab. A2. Analyses results of water samples collected on 14 May 2019 and 4 November 2020 from three pilot streams. For sampling locations see Fig.49.

	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Location	N tot. [μg/l]	N tot. [μg/l]	NO2-N [μg/l]	NO2-N [μg/l]	NO3-N [μg/l]	NO3-N [μg/l]	NH4-N [μg/l]	NH4-N [μg/l]	P tot. [μg/l]	P tot. [μg/l]	PO4-P [μg/l]	PO4-P [μg/l]
J1	1600	2100	27	32	1200	1800	180	88	65	90	31	32
J2	790	870	3	5	580	600	20	53	18	51	11	18
J3	1400	1600	22	25	880	1300	68	51	64	95	17	31
J4	6600	1300	64	14	1100	880	580	<3	100	61	20	16
J5	1000	x	11	x	770	x	36	x	63	x	12	x
J6	970	1600	11	20	730	1200	32	30	45	94	14	33
T1	x	5400	x	51	x	4500	x	290	x	360	x	92
T2	2800	3300	6	44	850	2600	14	110	69	240	25	91
L1	x	110000	x	170	x	660	x	110000	x	350	x	190
L2	x	20000	x	63	x	690	x	18000	x	230	x	96
K1	1000	1700	9	17	360	1100	300	85	130	120	10	43
K2	590	1200	2	8	71	75	50	57	24	36	9	7
K3	690	1800	2	11	350	900	12	17	36	70	15	23
K4	810	1500	12	29	500	940	48	59	57	160	21	75
K5	720	x	8	x	350	x	10	x	51	x	19	x
K6	730	1600	7	22	350	930	13	17	50	170	17	66
K7	830	910	12	9	450	400	34	15	66	100	22	43
K8	810	2300	6	20	370	970	22	29	60	190	14	68
K9	770	x	8	x	380	x	36	x	53	x	18	x
K10	x	x	x	x	x	x	x	x	x	x	x	x
K11	x	560	x	2	x	350	x	94	x	25	x	6
K12	x	1200	x	9	x	740	x	200	x	47	x	21
K13	x	420	x	2	x	<5	x	17	x	23	x	<3

Tab. A3. *Analyses results of water samples collected on 14 May 2019 and 4 November 2020 from three pilot streams. For sampling locations see Fig.49*

	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Location	Hg [µg/l]	Hg [µg/l]	Cd [µg/l]	Cd [µg/l]	Cr tot. [µg/l]	Cr tot. [µg/l]	Cu [µg/l]	Cu [µg/l]	Pb [µg/l]	Pb [µg/l]	Ni [µg/l]	Ni [µg/l]	Zn [µg/l]	Zn [µg/l]	Alkal. [mmol/l]	Alkal. [mmol/l]	PFAS	PFAS
J1	<0.01	0.02	0.07	0.09	0.9	4.8	4.5	12	0.4	1.9	2.8	5	18	41	1.7	1.7	x	detected
J2	0.02	0.03	0.06	0.08	0.46	2.8	5.3	8.1	0.17	1.2	2.2	5.3	8.5	23	2	2.7	x	detected
J3	0.01	0.03	0.08	0.08	1.4	5	4.6	12	0.39	2.1	3.6	5.8	14	40	2.1	2	x	detected
J4	0.03	0.02	0.12	0.07	5.6	1.9	9.1	12	1.1	0.7	2.4	3.4	4.1	46	2.4	3.2	detected	detected
J5	0.02	x	0.13	x	1.9	x	4.9	x	0.66	x	9.4	x	29	x	1.6	x	x	x
J6	0.01	0.02	0.11	0.08	1.6	4.5	4	12	0.45	2	7.6	6.3	17	38	1.6	1.9	x	detected
T1	x	0.03	x	0.31	x	16	x	18	x	6.3	x	33	x	83	x	0.91	x	detected
T2	<0.01	0.02	0.05	0.16	1	9.8	3.6	14	0.35	3.4	8.7	19	15	51	1.9	1.2	x	detected
L1	x	0.03	x	0.09	x	6.8	x	9.4	x	1.5	x	10	x	59	x	9.8	x	detected
L2	x	0.01	x	0.05	x	2.2	x	6.7	x	0.79	x	5.8	x	34	x	3.3	x	detected
K1	0.01	<0.01	0.12	0.08	4.4	5.1	3.6	6.2	1.3	2	4.6	4.1	20	13	1.4	1.2	detected	detected
K2	<0.01	<0.01	0.12	0.09	1.3	2	2.6	11	4.6	23	3.1	5.7	6.7	14	0.15	0.08	detected	not detected
K3	<0.01	0.01	0.09	0.09	1.2	3.7	3.7	12	1.6	7.6	4.3	7.4	20	27	1.1	0.96	detected	detected
K4	<0.01	0.02	0.08	0.08	1.9	6.4	3.5	10	0.51	2.4	3.6	5.8	11	24	1.8	1.7	detected	detected
K5	<0.01	x	0.07	x	1.6	x	3.5	x	0.74	x	3.4	x	17	x	1.6	x	x	x
K6	0.01	0.01	0.16	0.11	1.6	8.4	3.4	12	2	4.2	3.4	7.1	22	32	1.7	1.5	detected	detected
K7	<0.01	0.01	0.05	0.05	0.65	3	3.6	8.8	0.52	1.6	4.3	4.2	12	34	2	1.3	x	detected
K8	0.01	0.02	0.13	0.12	2.4	9.3	4.7	14	1.2	4.2	5.8	8.7	17	39	1.7	1.5	x	detected
K9	<0.01	x	0.07	x	1.4	x	3.9	x	0.61	x	5.3	x	12	x	1.8	x	x	x
K10	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
K11	x	<0.01	x	0.03	x	0.94	x	2	x	0.26	x	1.8	x	4.3	x	1.3	x	detected
K12	x	<0.01	x	0.06	x	3	x	200	x	1.2	x	2.9	x	36	x	1.1	x	detected
K13	x	<0.01	x	0.01	x	0.95	x	0.7	x	0.27	x	1	x	11	x	0.11	x	detected

Tab. A4. *Analyses results of water samples collected at the inlet and outlet of the in-stream filter (final design).*

Sampling date	Filter in/out	Turbidity [FNU]	TSS [mg/l]	Conductivity [mS/m]	pH	CODMn [mg/l O2]	BOD 7 [mg/l]	N tot. [µg/l]	NO2-N [µg/l]	NO3-N [µg/l]	NH4-N [µg/l]	P tot. [µg/l]	PO4-P [µg/l]	Hg [µg/l]	Cd [µg/l]	Cr [µg/l]	Cu [µg/l]	Pb [µg/l]	Ni [µg/l]	Zn [µg/l]	Alkalinity [mmol/l]
28/07/2020	in	3.6	6.5	55	8.1	4.1	1.6	1900	68	1500	130	63	26	0.01	0.03	0.83	5.5	<0,05	3	17	3.4
28/07/2020	out	1.6	1.3	55	8.2	4.1	1.2	1900	69	1500	210	63	48	<0,01	0.02	0.44	5.2	<0,05	2.8	10	3.4
05/08/2020	in	4.9	5	49	8	4.6	2.1	1400	45	740	100	95	47	0.02	0.03	0.62	5.3	0.09	2.7	15	3.3
05/08/2020	out	2.2	1.4	50	8	4.3	1.5	1500	65	830	77	73	43	0.01	0.03	0.4	5.3	<0,05	2.5	13	3.4
11/08/2020	in	5.6	6.4	48	7.9	8.3	3.7	1000	35	410	130	170	57	0.03	0.03	1.2	4.3	0.45	2.6	13	3.2
11/08/2020	out	0.9	1	48	7.9	3.7	<0,5	1100	70	650	8	74	63	0.02	0.02	0.34	4.9	0.23	2.3	8.1	3.4
18/08/2020	in	2.7	1.8	56	8	6.5	3	1400	160	480	310	150	88	0.03	0.02	1.3	3.7	0.29	2.3	11	3.9
18/08/2020	out	0.7	0.9	56	7.9	4.3	1.2	1200	150	360	360	98	75	0.03	0.03	1.8	3	1.8	2.5	19	4
03/09/2020	in	3.7	4.4	25	7.6	8.1	3.2	590	14	77	160	170	120	0.02	0.02	0.94	24	0.28	1.9	23	2
03/09/2020	out	3.9	6.4	24	7.6	7.2	4.3	760	<2	10	370	220	160	0.05	<0,01	1.9	7.5	0.16	4.8	24	1.9
21/09/2020	in	9.9	11	54	7.9	4.1	4	1500	36	960	190	120	34	0.03	0.04	2.8	5.4	0.37	3.2	23	3.6
21/09/2020	out	2.5	1.8	52	7.9	3.4	2.4	1400	37	1100	170	79	45	0.02	0.02	1.3	5	0.05	2.7	16	3.6
24/09/2020	in	5.7	5.4	36	7.8	2.1	2.5	970	23	810	190	58	33	0.01	0.02	2.1	3.1	0.82	1.8	10	1.9
24/09/2020	out	10	8.4	36	7.8	1.9	2	1000	26	820	190	53	36	<0,01	0.02	1	3.2	0.88	1.6	7.3	1.9
30/09/2020	in	3.7	4	47	7.8	4.3	3.2	1400	31	930	90	96	42	0.01	0.04	0.76	4.4	0.21	2.3	23	2.7
30/09/2020	out	1.5	0.8	55	7.7	3.5	1.9	1400	59	1100	140	55	37	0.01	0.02	0.46	4.5	0.09	1.9	13	2.9
06/10/2020	in	13	14	54	7.6	9.2	8.6	1400	21	280	10	85	20	0.04	0.05	2.6	10	0.58	4.2	43	2.3
06/10/2020	out	4.8	3.6	46	7.5	8.1	8.4	1300	2	9	26	64	18	0.08	0.04	1.3	6.2	0.37	2.8	41	2.2
13/10/2020	in	55	37	16	7.6	7.2	7.7	980	16	270	63	110	14	0.08	0.08	5	16	2.5	3.8	70	1.2
13/10/2020	out	13	10	33	7.3	6.2	6.6	1900	5	24	1000	110	28	0.06	0.05	0.87	4.7	0.41	5.1	35	2.5