VALIDATION OF PILOTED NUTRIENT REMOVAL TECHNOLOGIES

Pilot watersheds as a practical tool to reduce the harmful inflows to the Baltic Sea (CB50)

Water Chain
Interreg Central Baltic
EUROPEAN UNION
European Regional Development Fund

This report refers pilot demonstration actions for nutrient removal in WaterChain project. During project six separated nutrient reduction units were tested in field experiments in Finland and in Latvia. In addition, hydraulics of nutrient reduction filter was tested in laboratory circumstances in Estonia. All described actions were performed on a time scale from 10/2015 to 6/2018. Different phosphorus reduction methods are presented at general level with operating principles and effectivity results.

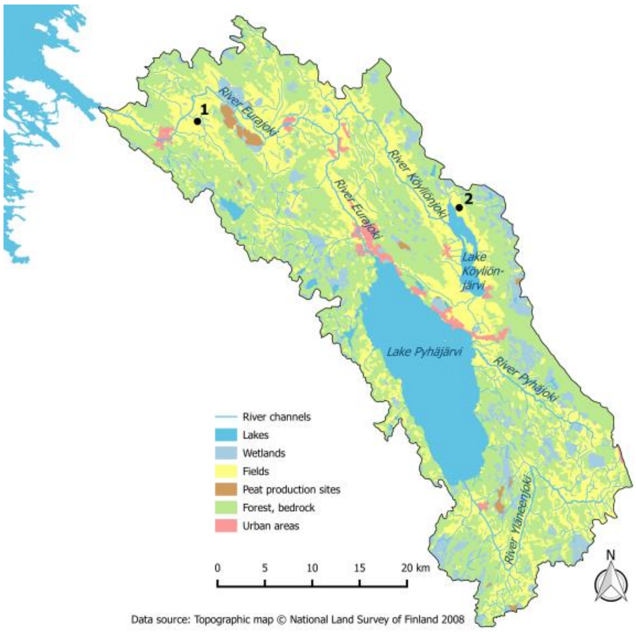
1.1. Pyhäjärvi Institute, Finland

Description of method and operating principles

PJI designed and constructed two demonstration filters with different operation principles. Both filters are situated in River Eurajoki pilot watershed in water sources of high concentration of phosphorus (picture 1.) originating in arable land. Kainu filter was built established in September 2016 to open ditch and Pere filter in underground drainage pipe in spring 2017. Pere filter was modified from cartridge filter to down to top model due to operational challenges in January 2018. In both filters filtering material is Nordkalk $Ca(OH)_2$, which could be recycled in arable land (Lahti Lakes 2018).

Kainu small scale filter operates as a down to top filtering system. Waters from ditch above are forced to emanate through layers of mass containing Nordkalk $Ca(OH)_2$ granules and crushed stone in relation 50/50 (picture 3). Granules restrain phosphorus and crushed stone mass enables comprehensive dispersion of incoming water, in order to increase reactive surface of granules. Filter operates by gravity and no external power for e.g. pumping is needed. Treated water exits through discharge pipe to drain. Filter structure is designed to tolerate extreme weather conditions such as overflow situations.

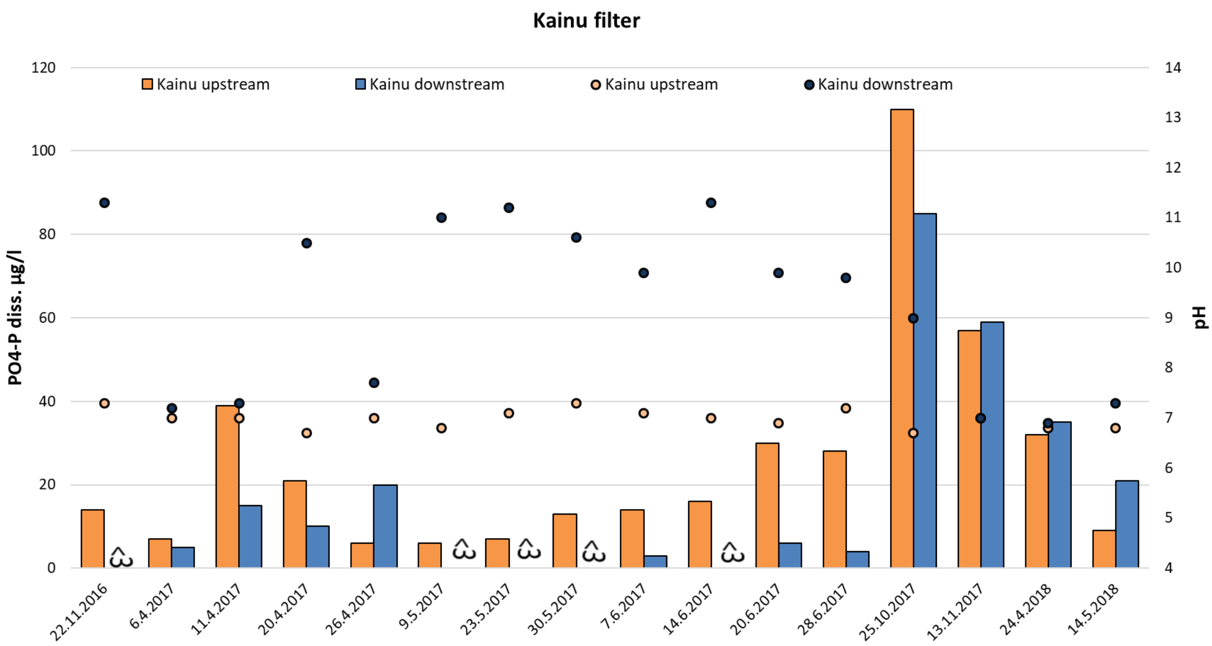
Pere filter was modified from cartridge filter to down to top box filter. It is situated after underground ditch. Waters to filter are conducted from field. In coming water contains high concentrations of Phosphorus. Filtering material is 100 % Nordkalk $Ca(OH)_2$ granules.



Picture 1. Location of pilot demonstration sites in pilot watershed (1. Kainu and 2. Pere).

Results

Both filters contain $Ca(OH)_2$ granules which effectivity is based on rise of pH in water. According to water sampling, reduction of dissolved phosphorus for Kainu filter during sampling period was about 31 % in average (Picture 3.) However, effectivity in reduction of dissolved phosphorus remain in quite modest level. Technically filter itself seem to operate well.



Picture 3. Reduction of dissolved Phosphorus in Kainu filter.

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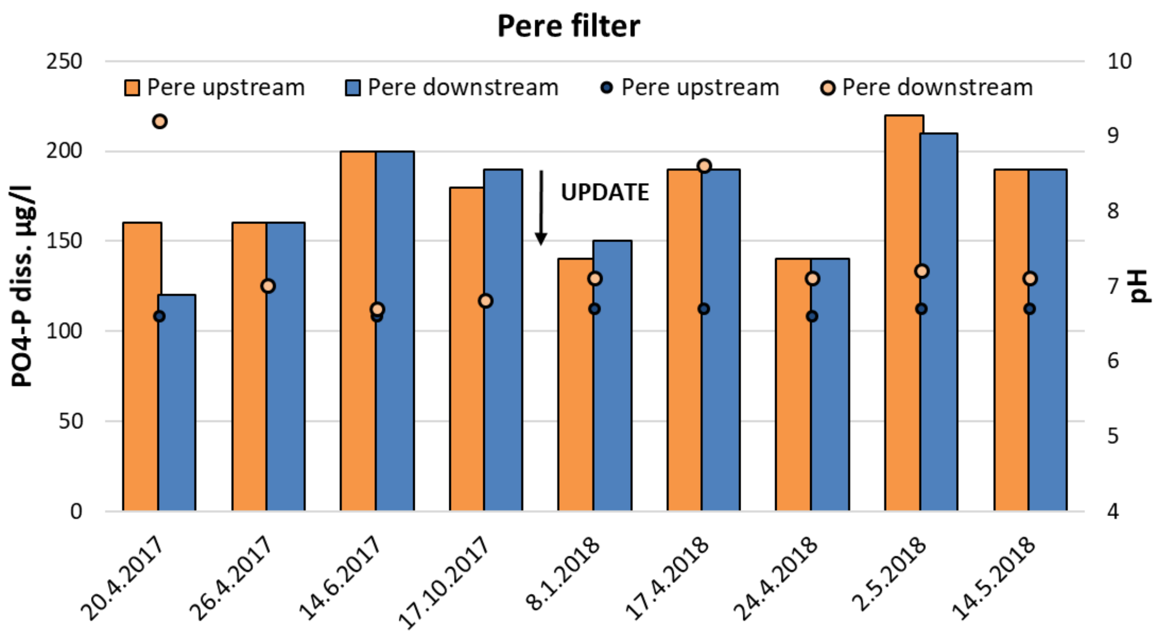
Pere filter was updated to down to top box filter in January 2018 and amount of water samples remained low related to unfavorable sampling conditions (picture 4.). Never the less filter reduction of dissolved phosphorus remained in very low level (average 2 %).



Picture 4. Reduction of dissolved Phosphorus in Pere filter.

Conclusions and recommendations

The ditch bottom filter type is suitable method for reduction of dissolved phosphorus in small ditches with low flow and high concentrations.

Box filter type is suitable for low flow underground drainage pipes. However, in this project challenges were faced especially with the box filter. Malfunction of box filter models tested in the project was related to operation of filtering material. Box filter was filled with 100 % $Ca(OH)_2$ granules. Further studies revealed that $Ca(OH)_2$ granules needs always adhesive material or post filtering to enable adsorption of phosphorus (Oral acknowledge, Anne-Mari Aurola, Nordkalk) More technical development of box filter with different adhesives is needed before box filter could be recommended to wider use.

Both filters need expertise in designing and implementation. Actual maintenance actions are in low level. Efficiency of filters have to be monitored by water sampling in order to gain understanding of operation. Random checks are needed to secure error-free operation e.g. stability of structures.

References

Lahti Lakes 2018: Abstract and Schedule. June 4.-6. 2018, Lahti, Finland.

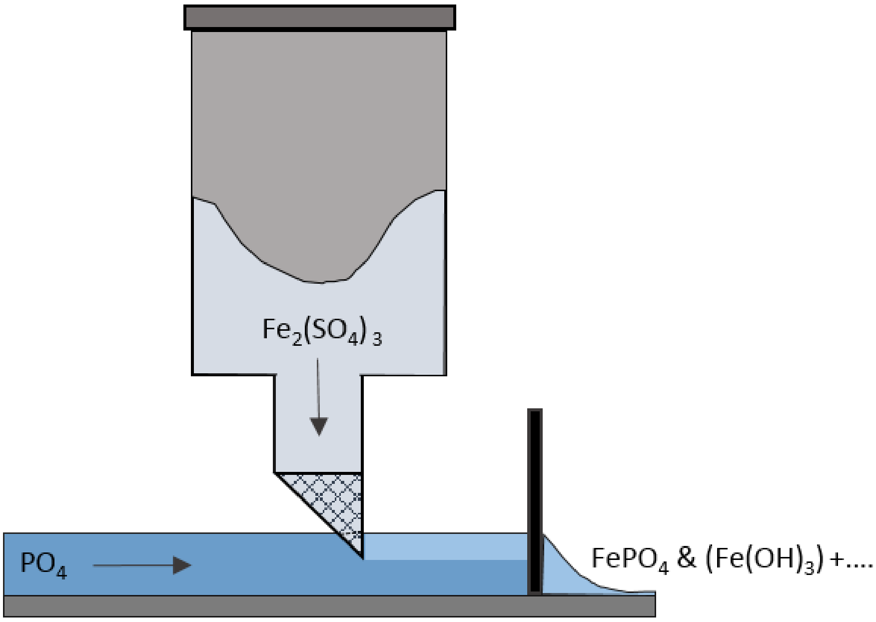
1.2. Turku University of Applied Sciences, Finland

Description of method and operating principles

Nutrient hot spots identified by the map survey have been verified with limited water sampling. Water samples were taken to compare nutrient levels of possible hot spots. Samples were analysed for total phosphorus, dissolved phosphate, total nitrogen, suspended solids, conductivity and pH.

Two small sized phosphorus precipitation devices were installed in nutrient load hot spots of Aurajoki river catchment. The device uses ferric sulfate (Kemira Ferrix-3) to convert dissolved phosphorus into particulate form, sparsely available to algae. Granular precipitant is dosed directly into stream water with dispenser unit originally developed by Aaro Närvänen at MTT (Närvänen et al. 2008). The dispenser devices used at the pilot sites are a small size adaptation of the original dispenser unit.

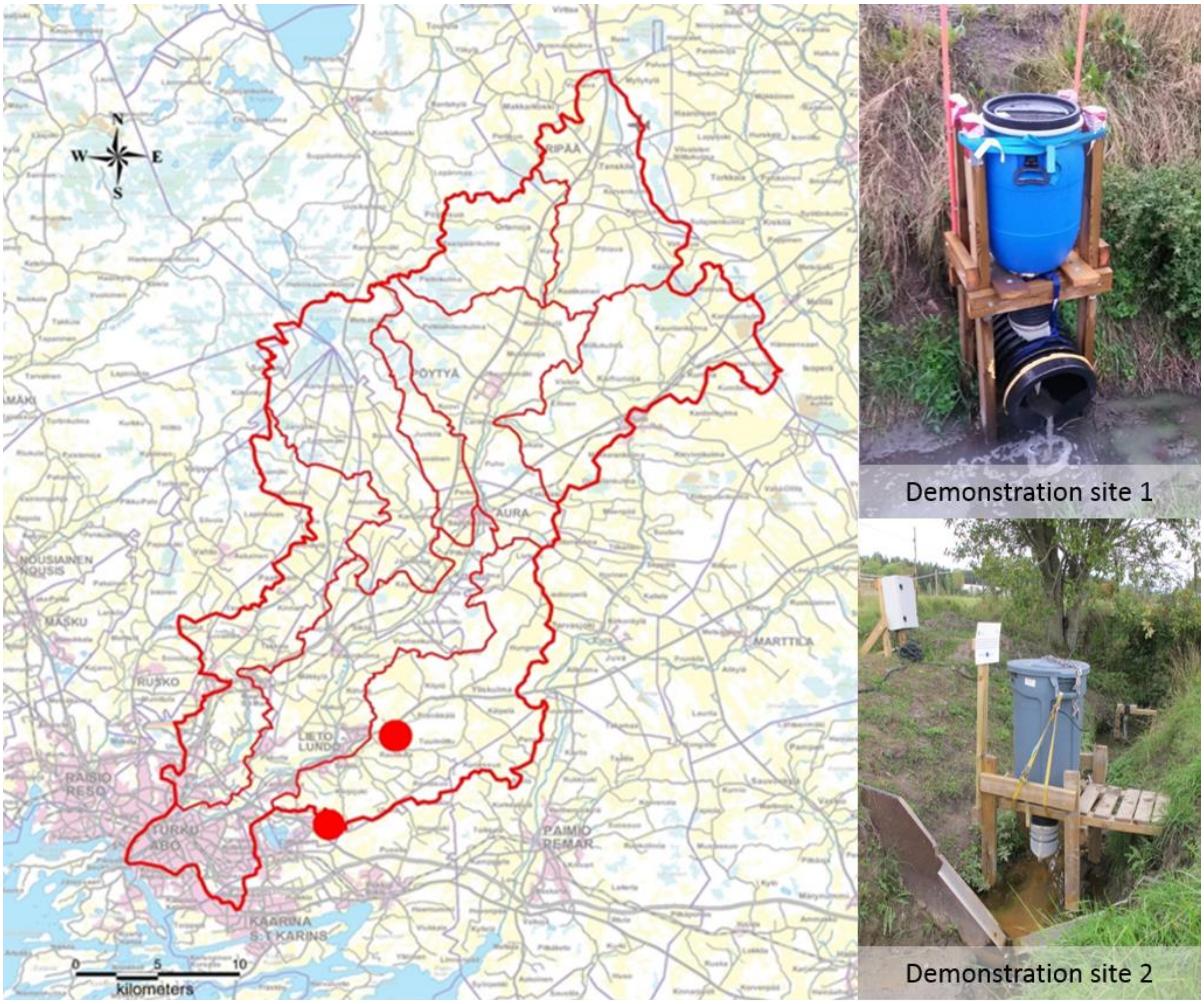
The dispenser unit consists of a cone shaped polyester dosing headpiece, chemical container, dosing pipe and mounting part (picture 1.). Precipitant is dissolved into stream water from dosing headpiece that is partly submerged in water. At the demonstration sites, V-shaped pipe outflow (demonstration site 1) and V-notch weir (demonstration site 2), was used to change the water level and volume of submerged headpiece in relation to water flow in the ditch. As the flow increases, also the contact with precipitant increases, and more ferric sulfate is dispersed into the stream.



Picture 1. Chemical dispencer unit

Both demonstration sites were established at small sized agricultural ditches at the municipality of Lieto. These ditches are located in Savijoki catchment area, which is one of the biggest sub catchments of river Aurajoki (picture 2). The demonstration sites were chosen for pilot studies due to high dissolved phosphorus concentrations, verified by water samples taken from potential nutrient hot spots.

Field ditch at demonstration site 1 collects water from a small catchment of under two hectares in size. Catchment area includes horse stable, horse pens, agricultural field and housing. Pilot site 2 is located in a small ditch, downstream from cattle pasture areas of organic cattle farm. Total area of the catchment is 19,4 hectares, including horse stable and horse pens, agricultural field and housing.



Picture 2. Pilot site locations (●) in Aurajoki catchment area (—). © NLS. Contains data from the National Land Survey of Finland Background map series, 09/2016. Catchment areas, Source SYKE.

Results

In the phosphorus precipitation efficiency studies, both water samples and online water quality monitoring were utilised. Water samples before and after the phosphorus precipitation units were taken in the efficiency studies of the demonstrated method. These samples were analysed for Tot P, PO4-P, Tot N, TSS, turbidity, pH, conductivity and alkalinity. First water samples for efficiency studies were taken from demonstration site 1 in December 2016. Water quality and discharge measurements in demonstration site 2 started in the summer 2017. Sampling has been carried out until January of the year 2018.

According to the water samples taken, ferric sulphate precipitation has reduced significantly the concentrations of dissolved phosphorus in the pilot ditches. Dissolved phosphorus reduction at demonstration site 1 was 85-99 % (average 96 %) and in demonstration site 2 11-98 % (average 66 %) (Figures 1. and 2.).

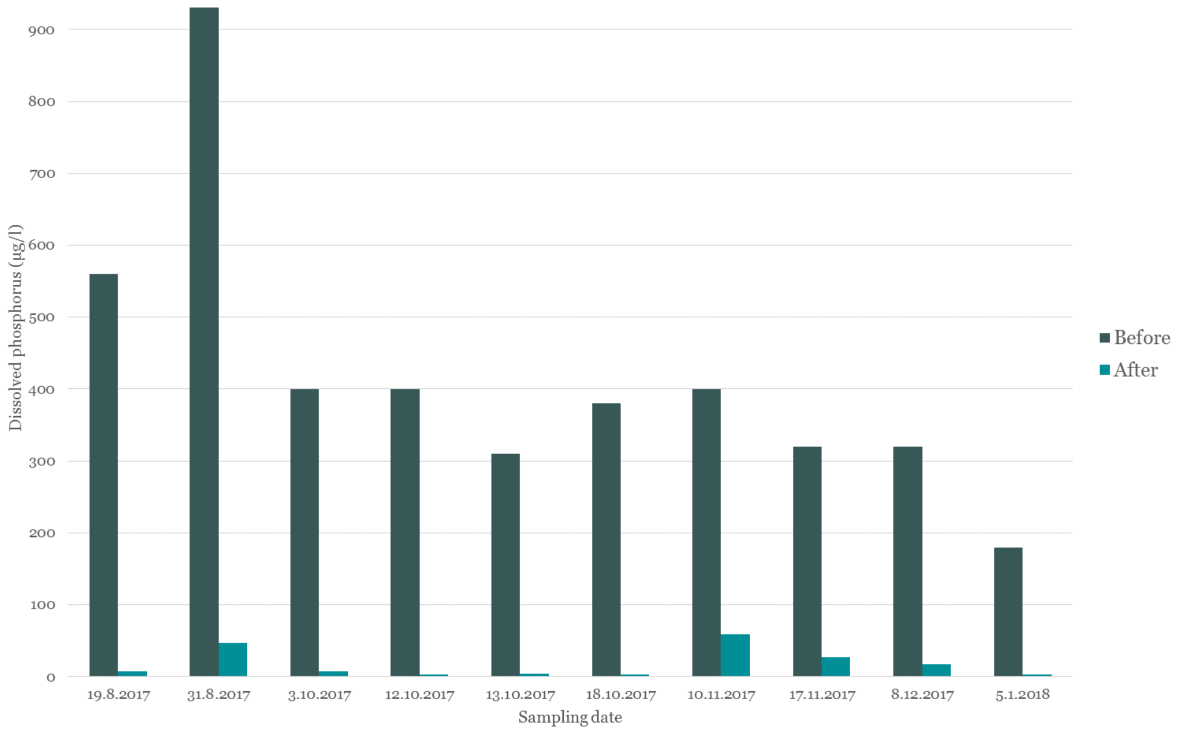


Figure 1. Results of dissolved phosphorus concentrations from demonstration site 1 according to water sampling.

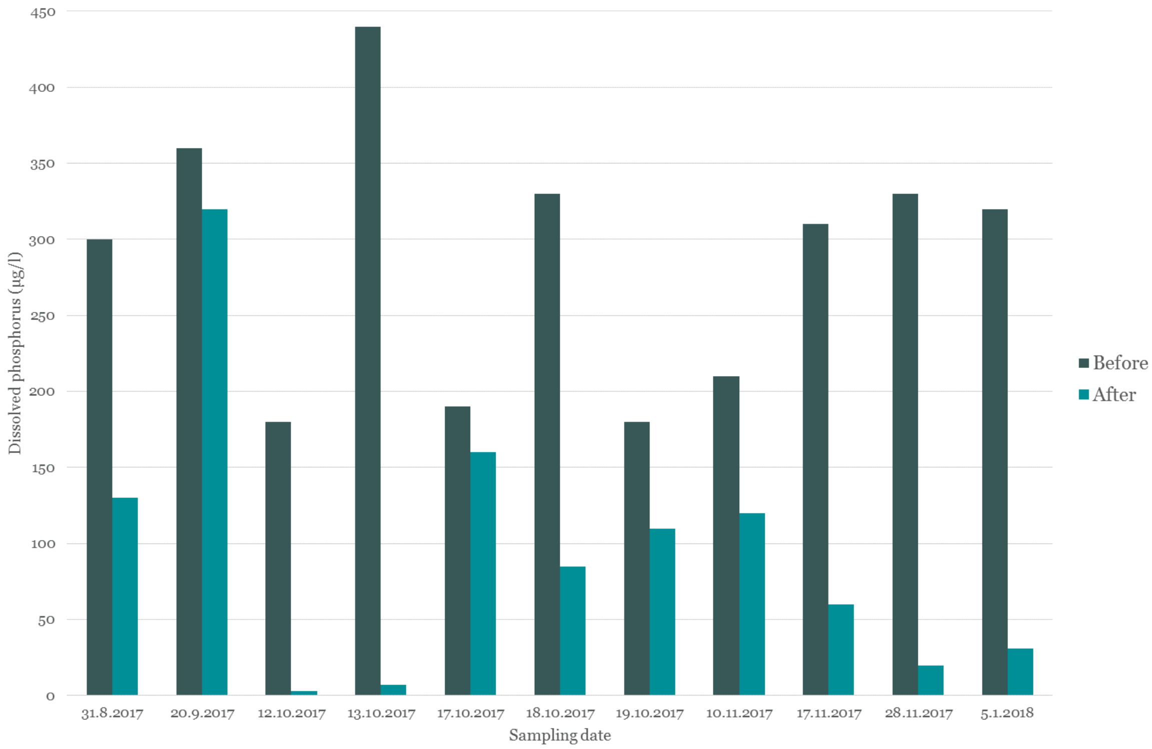


Figure 2. Results of dissolved phosphorus concentrations from demonstration site 2 according to water sampling.

Because of the chemical properties of Ferric sulphate, pH values were monitored in both demonstration sites. In demonstration site 1 three occasions of low pH (values under 5) were observed. Range in pH values between the samples taken before and after the dosing unit varied from 0,3 to 4,4 units at demonstration site 1 (average 2,19). According to field observations, bigger decrease in pH values was caused by high flow situations in demonstration site 1. It is considered that higher velocity of the flow, in closed pipe structure, caused increased friction to the chemical dispenser, leading to over dosing of the chemical. In demonstration site 2, notable difference in pH did not occur between the sampling points. Changes varied from 0 to 0,3 units (average 0,06).

Conclusions and recommendations

The method was proven to have high reduction rate for dissolved P, when operational and can be recommended for high dissolved P load hotspots. Dissolved phosphorus reduction percentage on both demonstration sites was considerable. Based on the field measurements and observations, the higher reduction percentage on demonstration site 1 was result of higher ferric sulphate dosing ratio. The dispenser unit is easy to install, but selection of suitable site needs practical experience. Regular follow up and skilled maintenance is needed to guarantee wanted operation. Right dosing should be confirmed with pH measurements. Dispenser unit can be implemented with low investment cost and can be considered as a cost-effective method for phosphorus reduction.

During the demonstration site test period some methodical challenges occurred. Because of the hygroscopic properties of ferric sulphate granules, the precipitation chemical clogged several times in dispenser unit dozing pipe and headpiece. Clogging was partly prevented by improving the waterproofness of the chemical container and dozing pipe. Dispenser unit functioning was also limited during winter time due to subzero temperatures and icy conditions. Winter conditions can be seen as a methodical limitation on streams with ice cover, as the function principles on tested method cannot be fulfilled during that period. Dispenser unit maintenance and chemical container filling was considered to be laborious at times. Tested method could be further developed to be more convenient, by improving the properties for more extensive implementation of the method.

Excluding dissolved phosphorus and pH, ferric sulphate precipitation did not affect considerably other analysed water quality parameters. Pilot studies were based on limited amount of parameters analysed from water samples. Further research is needed for evaluation of the environmental effects of used precipitation chemical. Cost-effectiveness of the tested method used on small scale hot spot locations needs to be also evaluated on higher resolution.

References

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1.3. Riga Technical University, Latvia

Description of method and operating principles

RTU pilot is based on a relatively new biological wastewater treatment technology called aerobic granular biomass. This type of technology is usually applied in sequencing batch reactor systems. Comparing with common activated sludge treatment, this technology has many advantages, such as excellent settleability, short settling times for good liquid-solid separation. Within a pilot sludge forms granules, which have stronger microbial structure, good biomass retention, simultaneous phosphate and nitrogen removal, and high resistance to toxicity (Adav et al. 2008 & Li et al 2014).

The main aim of RTU was to evaluate if granulated active sludge technology can be used to remove phosphorus in relatively cold Baltic climate. It is important to understand, that granulated activated biomass technology is only a part of wastewater treatment. Also, activated sludge represents living organisms, which, to work sufficiently, need a proper care and non-toxic wastewater. If treatment cycle is disturbed, most of the sludge will die off and granules will disaggregate.

Because of all abovementioned reasons, unqualified staff cannot handle such technologies.

The technology, tested in project is not an outbreak. Aerobic granulation technology was first time reported in 1997 (Mishina et al 1991). Later followed the world's first pilot-scale research of aerobic granular sludge reactor, so-called Nereda® technology. It was built for real wastewater treatment plant (WWTP) in 2005 in Ede, the Netherlands, consisting of two parallel reactors (De Kreuk 2006). Nowadays SBR type reactors are widespread (WaterChain).

Results

Two parallel aerobic sequencing batch reactors (SBR) were operated WTP Ltd. "Ādaži water".

Each cylindrical SBR had an inner diameter of 0,6 m and a height of 1,53 m, and a working volume of 333 L. Air was provided by an aeration system at treatment plant and air diffuser. The reactors were operated in successive cycles of 4 h each. One cycle consisted of 5 min feeding from the bottom of the reactors, 210 min aeration, 25 min settling. Feeding and discharge of wastewater was conducted simultaneously. The procedures of the reactors operation, including feeding, aerating, setting and discharging, were controlled automatically (Controller, Adrona, Latvia – special design for WaterChain project). The effluent was at the height of 1,18 m from the bottom of the reactors. The reactors were operated at room temperature in range from 4 to 20˚C.

Several ISO methods were used for sample characterization. The pH, EVS, RedOx (Multi 340i SET B, WTW, Germany) and turbidity level (HACH 2100, USA) was monitored, but not controlled.

Chemical oxygen demand (COD), biological oxygen demand (BOD) of influent and effluent, nitrite, nitrate, ammonium and total nitrogen, total and reactive phosphorus concentrations in wastewater and in sludge, and also composition of microorganisms were measured once per two weeks in accredited subcontracted laboratory.

Conclusions and recommendations

Firstly, it is important to find a proper cycle for effective wastewater treatment and formation of granules. Usually process consists of simultaneous influent feed and effluent discharge, effective P, N, organic matter removal. After fast settling phase, the biomass is separated from the effluent and reactors are ready for a new cycle (Anonymous 2018). Previous literature studies showed that granules form only when COD in wastewater should be 1000 mg/L at minimal.

For used wastewater, the best cycle consisted of: 5 min feeding, 210 min aeration, 25 min settling and 5 min effluent discharge. Feeding and discharge of wastewater was conducted at one time. The procedures of the reactors operation, including feeding, aerating, setting and discharging, were controlled automatically by a digital process controller.

Secondly, it is important to monitor the quality (especially toxicity) of inlet wastewater, since granules at the formation stage are sensitive towards high concentrations of toxic substances.

Thirdly, it is of high importance to support system with uninterrupted electricity and aeration supply. Too intensive, too long or too short aeration can lead to disaggregation of granules.

Our results showed, that by changing aeration intensity, it is possible to move process either to effective COD, suspended solids and phosphorus, or nitrogen removal (but not both, P and N, simultaneously). Previous tests should be performed to find an optimal cycle.

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1.4. Institute for Environmental Solutions, Latvia

Description of method and operating principles

In summer 2016 IES identified a smaller area (around Ogre town) within the larger WaterChain pilot territory containing a high density of potential agricultural ditches for the possible small-scale P removing filter installation. After examining more than 50 sites, 6 potential ditches were identified for further inspection. All the sampling sites were in a near vicinity to agricultural lands. The highest P values were observed in ditch No.2, where a pig farm is located nearby. Thus, it was decided to build a filter in this location. The most important component of the filter is a large plastic pipe (4m x 1.2m) dug in the earth and filled with P absorbing calcium granules (fig.1.). The pipe is preceded by a sedimentation basin where large, solid particles settle. The slowly flowing water enters the bottom of the filter and driven by pressure moves upwards through the granules, where P is adsorbed. Most of the P from the inflowing water (60 – 80%) is thus removed.

Figure 1. The small-scale P filter. A) The filter with inlet/outlet pipes; B) The functioning filter with the sedimentation basin.

Results

The effectivity of the field scale filter was tested by measuring P contents at the inflow and outflow of the filter. The samples were analyzed in an accredited laboratory (Valmieras udens). In the first month after installation the filter removed 70 – 90% of phosphate ions. However, after that the filter became inefficient – the P concentrations did not change at the outlet of the filter. In August 2017 it was probably explained by the very heavy rains observed during the end of August/beginning of September. The increased water flowrates may then have led to the lowered efficiency of the filter. In addition to this, the sector of the filter that ensures the overflow of the water when it reaches the critical level in the sedimentation basin, was damaged by the heavy rain resulting in a need to perform some structural reconstruction. Even after the structural reconstruction the filter did not remove the expected amount of phosphorus and kept overflowing.

Thereby during a partner meeting in Turku (12-13.09.2017) the involved partners (TUT, PJI, IES) identified a common need to achieve better understanding on the function of phosphorus reducing filters and to modify and optimize it based on the observed problems in the field. It was decided that the most cost-effective and reasonable way to construct the last pilot by IES would be doing it in the laboratory scale in TUT.

Lab-scale filter test results

During December 2017 to March 2018 hydraulic tests for the phosphorus retention filter were carried out. The experiment was hosted by the Laboratory of Fluid Mechanics at the Tallinn University of Technology. Four different design configurations were tested to identify the means for increasing the water flow rate that the filter can handle before overflow conditions develop. The tests were run using an open structure with dimensions of 1.7 x 0.6 x 0.4 m (Fig.2.). The inlet was split into two water distribution pipes placed on the bottom of the structure. PVC pipes of 75 cm diameter were used. The structure was mounted into a laboratory flume. It was filled with crushed granite (8-16 mm in diameter) and Nordkalk™ granules (pelletized calcium hydroxide) mixed in even volumes for the first test and only granite for the 2nd to 4th test.

The following design configurations were tested:

- **A.** 5 cm elevation difference between the filter inlet and outlet, and evenly distributed hole pattern at the water distribution pipes;
- **B.** 5 cm elevation difference between the filter inlet and outlet, and denser hole distribution at the other half (towards the outflow) of the water distribution pipes;
- **C.** 15 cm elevation difference between the filter inlet and outlet, and evenly distributed hole pattern at the water distribution pipes;
- **D.** 15 cm elevation difference between the filter inlet and outlet, and denser hole distribution at the other half of the water distribution pipes.

For the evenly distributed pattern, holes with diameter of 4.8 mm were drilled every two cm in six lines covering all the pipe in the length of 1.35m. The total surface area of the holes was ~72 cm^2. For increased hole pattern the first half of the distribution pipe was covered with the evenly distributed pattern, while for the other half a hole every two cm in 10 lines were drilled. The total surface area of the holes for this pattern was ~98 cm^2.

Figure 2. Filter during a test.

During the run of design configuration-A, it was observed that after one week the distribution pipes become clogged by the dissolved calcium hydroxide, thus lowering the equilibrium water flow rate to ~2 l s^{-1}. In total, ~43% of the holes, mainly on the bottom part and ending of the pipe, were covered by dissolved calcium hydroxide. To avoid further contamination of laboratory water reservoir by the calcium hydroxide, following tests were run without the Nordkalk™ granules in the filtering media. Such approach was accepted, because no difference in the equilibrium flow rates were observed for preliminary test without filtering media and test of design configuration-A. Tests for design configurations B, C and D were run for one hour to detect the equilibrium water flow rate.

The conducted test runs clearly indicated that major increase in flow rate that the filter can handle without an overflow can be achieved by increasing the elevation between the inlet and outlet. Change in the hole patter had a minor impact on the equilibrium water flow rate (Table 1). This design improvement should be considered when other full-scale phosphorus retention filters are constructed. Current installation has relatively small height difference (~10 cm) between the inlet and outlet.

Table 1. Equilibrium water flow rates and their relative difference for the tested design configurations.

	Equilibrium flow (l s^{-1})	**Relative improvement (%)**
Configuration **A**	2.5±0.2	reference
Configuration **B**	2.6±0.2	4%
Configuration **C**	3.1±0.2	24%
Configuration **D**	3.5±0.2	40%

Conclusions and recommendations

During the laboratory tests it was observed that at the filter inlet together with water the air is taken in. Afterwards the air is released through the water distribution pipes. It was concluded that such a phenomenon must be the reason behind blockage of a closed design filter that is installed in the nature. If the air is released inside the filter tube, eventually it becomes saturated and pressurized, and no more water can enter through the inlet. Because the inlet is covered by water at all times, no water or air can leave the filter tube. Therefore, the closed design filter should be supplemented with air outlets on the top of the structure. Additionally, further investigations on the clogging of the pipes with dissolved granules are deemed necessary. Overall it was concluded that laboratory experiments are a very useful tool helping to understand the workings of real life filters. Despite the faced problematic issues, we believe that the small scale P removing filters can be a useful tool to help in reducing agricultural nutrient loading to natural waterbodies.