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StoPWa

# Scientific support of CDW-biofilters' performance: Technical report on the Estonian pilot site

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## Table of contents



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# 1. Introduction

The main goal of the StoPWa "**Sto**rmwater **P**urification with Construction and Demolition **Wa**ste" project is to develop and test multilayer stormwater filtration systems using construction and demolition waste (CDW). Cost-efficient and sustainable filters will be made from waste fractions that meet the criteria for effective stormwater treatment. The filters will be tested both in laboratory conditions and in field trials, during which full-scale stormwater filters will be constructed in Lahti (Finland), Rae municipality (Estonia), and Smiltene (Latvia). The main exploitable result of the StoPWa project is a proven solution for the use of CDW in stormwater filters. The main expected outcomes are increased levels of reuse and recycling of construction and demolition waste, and increased preparedness for hydroclimatic extreme events such as more frequent cloudbursts caused by climate change.

The purpose of this technical report is to present the results of a two-month intensive sampling campaign carried out to evaluate the performance of the Estonian pilot (bio)filter system, located in Rae Municipality. A brief description of the Estonian pilot site and the constructed filtration system, provided by the Union of Harju County Municipalities (HOL), is also included. The sampling campaign was conducted by Tallinn University of Technology (TalTech). Sample analyses were carried out partly at the Laboratory of Environmental Technology, Department of Materials and Environmental Technology, TalTech, and partly at an accredited external commercial laboratory. The performance of the field-pilot-scale CDW-based (bio)filter system was assessed by analysing stormwater quality before and after treatment.

## 2. Estonian pilot site

A cost-efficient stormwater filtration system has been designed and constructed at the Tähnase Road T5 property, located in Peetri Township, Rae Municipality, Estonia (**Figure A1**).

There are four stormwater catchment areas in Rae Municipality: the Mõigu Polder catchment, the Pirita-Ülemiste Canal catchment, the Pirita River catchment, and the Kurna Stream catchment. The pilot site is located within the Vaskjala-Ülemiste catchment area (also referred to as the Pirita-Ülemiste catchment), which extends from Vaskjala to Lake Ülemiste. The Pirita-Ülemiste Canal forms part of Tallinn's drinking water supply system. The catchment area covers approximately 28.6 $km^2$.

The filtration system consists of two multilift containers: Filter I (2530 × 6000 × 2000 mm), equipped with a double bottom that enables gravity flow to Filter II, and Filter II (2530 × 6000 × 1000 mm) (**Figures 1** and **2**). Filter I is filled with CDW concrete aggregate (crushed waste concrete, particle size 16-32 mm; European Waste Catalogue (EWC) code 17 01 01), while the Filter II is filled with a commercial filter medium consisting of Estonian limestone aggregate (particle size 16-32 mm). The CDW material originates from the Väo waste treatment facility operated by ATI Grupp OÜ in Estonia.

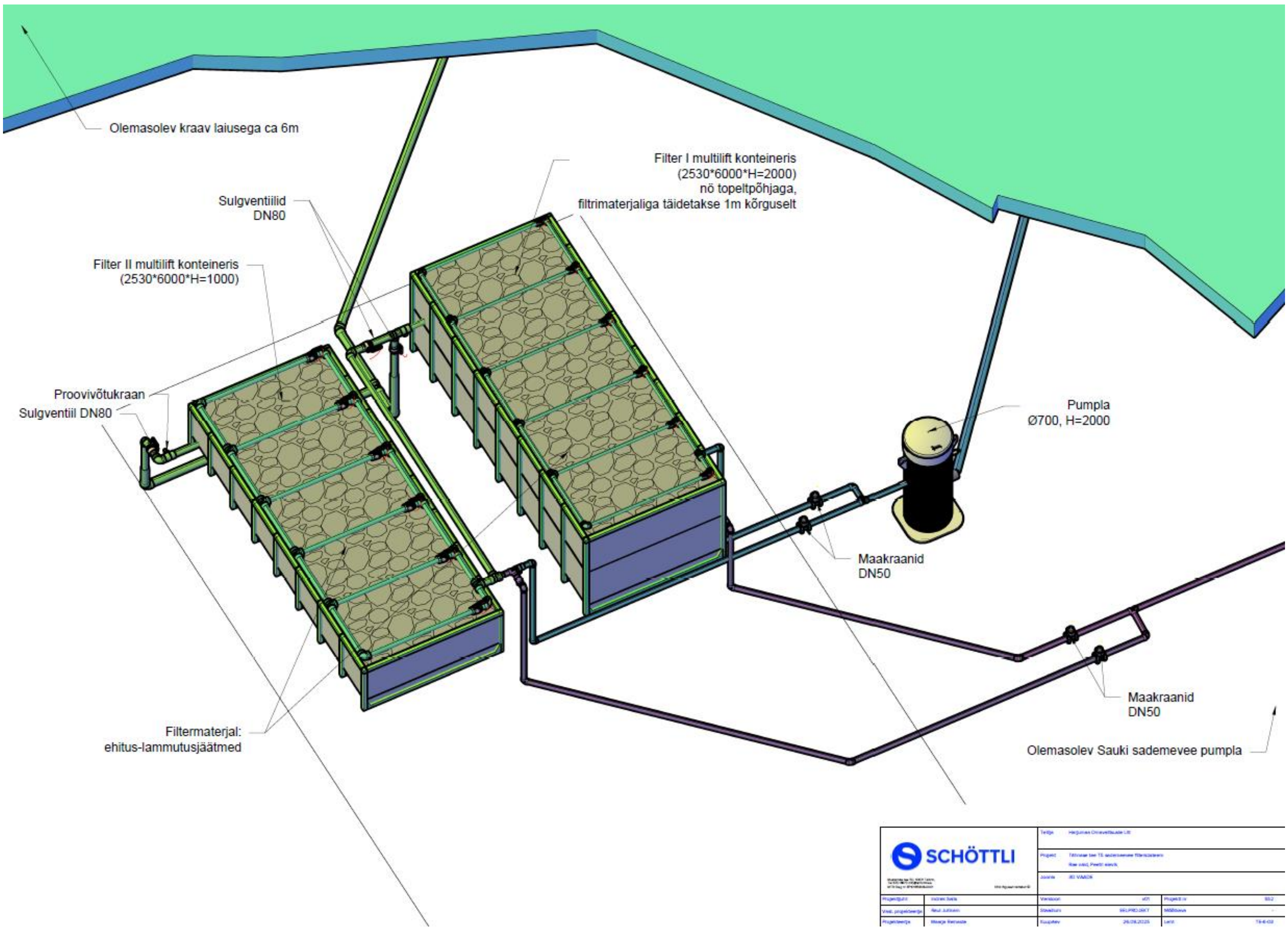


**Figure 1**. 3D view of the stormwater filtration system in Estonian pilot site.

**Figure 2**. Aerial view of the Estonian pilot site and the filtration system.

A distribution pipeline, installed above the containers in the form of a frame, ensures that stormwater is distributed as evenly as possible across the filter media (**Figures 3** and **4**). The filters can be operated either in parallel or in series. After passing through the filtration system, the treated stormwater is discharged back into the nearby drainage ditch.

**Figure 3.** Piping connections of the filtration system at the Estonian pilot site.

**Figure 4.** The filtration system during operation.

Stormwater flows by gravity through PVC DN160 piping from a nearby ditch into an IWS plastic pumping station. The stormwater originates from paved asphalt surfaces within Peetri Township. New KSB pumps (Ama Porter 500 ND and Ama Porter 501 ND) have been installed in both pumping stations to convey stormwater to the filtration system.

To replace the filter media, the distribution pipeline located above the containers must first be disconnected using quick couplings and removed. The multilift container, together with the spent filter material (e.g. crushed concrete aggregate), can then be transported by a truck equipped with a multilift hook to a licensed waste management facility for replacement or disposal.

The pilot filtration system will remain the property of the Union of Harju County Municipalities (HOL) for at least five years following the final project payment (**Figure A2**). The landowner, Rae Municipality, has granted HOL a personal right of use for the land on which the system has been constructed.

As stated in the StoPWa project application, "*Rae Municipality is responsible for appointing a professional maintenance contractor for the stormwater system and for ensuring that maintenance is carried out with adequate funding. AS ELVESO, a utility company wholly owned by Rae Municipality, is responsible for the construction and maintenance of stormwater treatment systems and stormwater management within the municipality*." At the moment, a tripartite agreement has been concluded between Rae Municipality, AS ELVESO, and HOL, defining the allocation of operational costs, maintenance responsibilities, and the evaluation of the filtration system performance.

## 3. Sampling campaign

An intensive sampling and filtration system performance monitoring campaign was carried out over a two-month period (April-May 2026). In total, seven sampling events were conducted. During each event, stormwater samples were collected at three points: before the filter system (influent), after the first filter stage (intermediate effluent), and after the second filter stage (final effluent). The main water quality parameters analysed and methods used are summarized in **Table 1**. In addition, a broader range of auxiliary parameters was measured to provide a more comprehensive assessment of the filter performance, including various cations and anions, as well as colour and turbidity.

**Table 1.** Water quality parameters measured and analysed in the influent and effluents.

| Parameter | | Unit | Analytical instrument/method |
|---|---|---|---|
| **Total suspended solids, 105°C** | **TSS** | mg/L | ISO 11923:1997 (Water quality - Determination of suspended solids by filtration through glass-fibre filters) |
| **pH** | | - | pH-meter |
| **Electrical conductivity** | **EC** | µS/cm | EC-meter |
| **Total organic carbon** | **TOC** | mg/L | TOC/TN analyser |
| **Total inorganic carbon** | **TIC** | mg/L | TOC/TN analyser |
| **Total nitrogen (*)** | **TN** | mg/L | TOC/TN analyser; SFS 5505: modified Kjeldahl method* |
| **Total phosphorous* (7 sec)** | **TP** | mg/L | EVS-ENISO 6878:2004 (Water quality - Determination of phosphorus - Ammonium molybdate spectrometric method) |
| **Dissolved oxygen** | **DO** | mg/L | DO-meter |
| **Biochemical oxygen demand* (7 days)** | **$BOD_7$** | $mgO_2/L$ | ISO 5815-2:2003 (Water quality - Determination of biochemical oxygen demand after n days ($BOD_n$) - Part 2: Method for undiluted samples) |
| **Chemical oxygen demand* (dichromate)** | **COD** | mg/L | ISO 15705:2002 (Water quality - Determination of the chemical oxygen demand index (ST-COD) - Small-scale sealed-tube method) |
| **Ammonium** | **$NH_4^+$** | mg/L | Ion chromatography with conductivity detector (IC-CD) |
| **Sodium** | **$Na^+$** | mg/L | IC-CD |
| **Potassium** | **$K^+$** | mg/L | IC-CD |
| **Chloride** | **$Cl^-$** | mg/L | IC-CD |
| **Nitrate** | **$NO_3^-$** | mg/L | IC-CD |
| **Sulphate** | **$SO_4^{2-}$** | mg/L | IC-CD |
| **Phosphate** | **$PO_4^{3-}$** | mg/L | IC-CD |
| **Zinc*** | **Zn** | µg/L | EVS-EN ISO 17294-2:2023 (Water quality - Application of inductively coupled plasma mass spectrometry (ICP-MS) - Part 2: Determination of selected elements including uranium isotopes) |
| **Copper*** | **Cu** | µg/L | EVS-EN ISO 17294-2:2023 |
| **Nickel*** | **Ni** | µg/L | EVS-EN ISO 17294-2:2023 |
| **Lead*** | **Pb** | µg/L | EVS-EN ISO 17294-2:2023 |
| **Hydrocarbon oil index* ($C_{10}$–$C_{40}$)** | | µg/L | EVS-EN ISO 9377-2:2000 (Water quality - Determination of hydrocarbon oil index - Part 2: Method using solvent extraction and gas chromatography |

**analysed by a commercial laboratory Eesti Keskkonnauuringute Keskus OÜ*

## 4. Results and discussion

To evaluate the performance of the pilot filtration system, stormwater was treated using two filters connected in series. Stormwater was pumped from the Sauki pumping station to the filtration system, and the treatment performance was assessed based on water quality analyses of samples collected at the influent, after the Filter I (intermediate effluent), and after the Filter II (final effluent).

Water samples collected during all sampling events were analysed at the in-house analytical laboratory of the Laboratory of Environmental Technology, Department of Materials and Environmental Technology (TalTech). In addition, samples from five sampling events were transported to an accredited external commercial laboratory for analyses that could not be performed in-house as well as for verification of selected in-house analytical results. A stormwater sample representing the influent was also collected immediately before the filtration system commenced operation on 31 March 2026. Subsequently, sampling was conducted almost weekly during April-May 2026 (**Table 2**).

**Table 2.** Water quality parameters measured in the influent (inlet) (31 March 2026).

| Parameter | Unit | Value |
|---|---|---|
| **TSS, 105°C** | mg/L | 15 |
| **pH** | | 7.7 |
| **EC** | µS/cm | 650 |
| **TOC** | mg/L | 21.4 |
| **TIC** | mg/L | 56.3 |
| **TN** | mg/L | 3.3 |
| **TP** | mg/L | 0.1 |
| **DO (T°C)** | mg/L | 8.98 (5.5) |
| **$BOD_7$** | $mgO_2/L$ | 9.2 |
| **COD** | mg/L | 84.0 |
| **$NH_4^+$** | mg/L | 1.4 |
| **$Na^+$** | mg/L | 27 |
| **$K^+$** | mg/L | 15.1 |
| **$Cl^-$** | mg/L | 47 |
| **$NO_3^-$** | mg/L | 6.0 |
| **$SO_4^{2-}$** | mg/L | 77.6 |
| **Zn** | µg/L | 67.0 |
| **Cu** | µg/L | 7.5 |
| **Ni** | µg/L | 2.2 |
| **Pb** | µg/L | 0.13 |
| **Hydrocarbon oil index ($C_{10}$–$C_{40}$)** | µg/L | <20 |

The main results for the influent (inlet), intermediate effluent (outlet I), and final effluent (outlet II) are presented in **Table 3**.

**Table 3.** Water quality parameters measured in the influent (inlet), intermediate effluent (outlet I), and final effluent (outlet II) during monitoring period of April-May 2026.

| Parameter | Unit | Sample | April 9 | April 16 | April 27 | May 5 | May 12 | May 19 | May 25 |
|---|---|---|---|---|---|---|---|---|---|
| **TSS, 105°C** | mg/L | inlet | 9.7 | 5 | 11.7 | 10.3 | 7.3 | 18.7 | 6.7 |
| | | outlet I | 3.3 | 3 | 6.0 | 7 | 10 | 7.5 | 5.7 |
| | | outlet II | 1 | 3 | 12.0 | 5 | 7.5 | 4 | 5.3 |
| **pH** | | inlet | 7.64 | 7.45 | 7.43 | 7.28 | 7.64 | 7.36 | 7.27 |
| | | outlet I | 7.54 | 7.57 | 7.7 | 7.55 | 7.71 | 7.8 | 7.47 |
| | | outlet II | 7.76 | 7.64 | 7.74 | 7.55 | 7.76 | 7.81 | 7.61 |
| **EC** | µS/cm | inlet | 872 | 882 | 643.0 | 683 | 977 | 245 | 596 |
| | | outlet I | 886 | 911 | 622.0 | 601 | 971 | 243 | 598 |
| | | outlet II | 868 | 925 | 578.0 | 553 | 950 | 244 | 558 |
| **TOC** | mg/L | inlet | 6.8 | 1.7 | 6.8 | 4.2 | <1 | 3.6 | 7.7 |
| | | outlet I | 8.3 | 2.3 | 7.4 | 8.4 | <1 | 3.2 | 6.6 |
| | | outlet II | 6.5 | 2.4 | 7.1 | 8.9 | <1 | 2.3 | 7.3 |
| **TIC** | mg/L | inlet | 67.5 | 74 | 62.2 | 55.2 | 105.4 | 30 | 67.1 |
| | | outlet I | 67.8 | 74.4 | 59.9 | 60.5 | 97.1 | 27.8 | 63.4 |
| | | outlet II | 67.9 | 74.5 | 56.3 | 72.3 | 94 | 30.4 | 57.6 |
| **TN** | mg/L | inlet | 9.4 | 1.8 | 1.5 | 1.9 | 1 | 1 | 1 |
| | | outlet I | 9 | 1.8 | 1.3 | 1.9 | 1.3 | 0.4 | 1 |
| | | outlet II | 7.3 | 1.8 | 1.2 | 1.7 | 1.2 | 0.4 | 0.8 |
| **TP** | mg/L | inlet | 0.41 | 0.06 | 0.077 | 0.1 | | 0.12 | |
| | | outlet I | 0.23 | 0.072 | 0.069 | 0.082 | | 0.077 | |
| | | outlet II | 0.34 | 0.046 | 0.068 | 0.074 | | 0.056 | |
| **DO (T°C)** | mg/L | inlet | 9.04 (5.3) | 8.56 (8.4) | 8.53 (7.3) | 8.14 (9.0) | 8.46 (8.5) | 8.72 (12.3) | 7.42 (11.2) |
| | | outlet I | 9.46 (5.9) | 9.16 (6.0) | 8.36 (8.3) | 8.27 (11.7) | 8.56 (9.7) | 7.52 (13.8) | 7.36 (12.6) |
| | | outlet II | 9.00 (5.0) | 9.3 (6.3) | 8.47 (9.4) | 7.94 (11.9) | 8.72 (9.3) | 7.97 (13.2) | 7.59 (14.2) |
| **$BOD_7$** | $mgO_2/L$ | inlet | 9.2 | 1.8 | 3.6 | 3.7 | | 3.4 | |
| | | outlet I | 7.4 | 1.5 | 3.2 | 3.7 | | 1.9 | |
| | | outlet II | 3.9 | 1.1 | 3.2 | 3.5 | | 1.5 | |
| **COD** | mg/L | inlet | 45 | 25 | 43.0 | 33 | | 24 | |
| | | outlet I | 47 | 25 | 43.0 | 33 | | 18 | |
| | | outlet II | 35 | 20 | 42.0 | 33 | | 20 | |
| **$NH_4^+$** | mg/L | inlet | 6.9 | 0.2 | 0.4 | 0.8 | 0.5 | 0.2 | 0.5 |
| | | outlet I | 7.1 | 0.3 | 0.3 | 0.7 | 0.2 | | 0.1 |
| | | outlet II | 5.8 | 0.4 | 0.2 | 0.5 | 0.03 | | |
| **$Na^+$** | mg/L | inlet | 35 | 32.8 | 20.9 | 19.5 | 30.6 | 4 | 14.4 |
| | | outlet I | 34 | 33.8 | 19.7 | 16.8 | 31.3 | 4.2 | 14.3 |
| | | outlet II | 33.1 | 34.4 | 18.1 | 15 | 32 | 6.2 | 13.5 |
| **$K^+$** | mg/L | inlet | 13.2 | 9.8 | 7.6 | 7.8 | 11.7 | 1.9 | 7.2 |
| | | outlet I | 12.9 | 10.9 | 7.2 | 6.8 | 12.2 | 3.2 | 7.4 |
| | | outlet II | 13.1 | 11.4 | 6.4 | 6.2 | 12.1 | 3.9 | 6.5 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **$Cl^-$** | mg/L | inlet | 68.2 | 62.8 | 37.4 | 33.5 | 58 | 4.8 | 22.8 |
| | | outlet I | 68.8 | 66.2 | 34.6 | 27.6 | 59.6 | 4.4 | 23.1 |
| | | outlet II | 65.9 | 68.1 | 31.3 | 24 | 61.9 | 7.3 | 21.3 |
| **$NO_3^-$** | mg/L | inlet | 3.4 | 3.1 | 2.0 | 3.4 | 2.5 | 2.1 | 2.3 |
| | | outlet I | 3.4 | 3.1 | 2.0 | 3.8 | 3.3 | 2.6 | 3.1 |
| | | outlet II | 3.4 | 3.1 | 2.1 | 4.3 | 3.4 | 2.7 | 3.1 |
| **$SO_4^{2-}$** | mg/L | inlet | 118.5 | 122.7 | 92.7 | 97.9 | 159.3 | 26.4 | 85.2 |
| | | outlet I | 118.6 | 132 | 86.8 | 80 | 158 | 23.7 | 85.7 |
| | | outlet II | 119.9 | 138.3 | 74.4 | 71.4 | 151.5 | 28.1 | 73.9 |
| **Zn** | µg/L | inlet | 8.4 | 12 | 23 | 22 | | 23 | |
| | | outlet I | 8.6 | 22 | 27 | 43 | | 29 | |
| | | outlet II | 23 | 16 | 35 | 33 | | 20 | |
| **Cu** | µg/L | inlet | 3.3 | 2 | 4.0 | 2.9 | | 3.3 | |
| | | outlet I | 3.2 | 3 | 3.8 | 4.7 | | 3.8 | |
| | | outlet II | 4.6 | 2.4 | 4.4 | 4.2 | | 2.8 | |
| **Ni** | µg/L | inlet | 1.3 | 1.2 | 1.4 | 1.5 | | 0.64 | |
| | | outlet I | 1.3 | 1.4 | 1.5 | 1.6 | | 0.82 | |
| | | outlet II | 3.6 | 2.2 | 2.5 | 2.5 | | 1.5 | |
| **Pb** | µg/L | inlet | <0.05 | <0.05 | 0.052 | 0.061 | | 0.29 | |
| | | outlet I | <0.05 | 0.055 | 0.150 | 0.35 | | 0.89 | |
| | | outlet II | <0.05 | <0.05 | 0.260 | 0.27 | | 0.63 | |
| **Hydrocarbon oil index (C10–C40)** | µg/L | inlet | <20 | <20 | <20 | <20 | | <20 | |
| | | outlet I | <20 | <20 | <20 | <20 | | <20 | |
| | | outlet II | <20 | <20 | <20 | <20 | | <20 | |

The obtained results showed that the quality of the treated stormwater, both at outlet I and outlet II, was generally equal to or better than that of the influent (**Tables 2** and **3**). For all analysed parameters, the treated effluent complied with the requirements established in Estonia by Regulation No. 61 of 2019 of the Minister of the Environment: *Requirements for wastewater treatment and the discharge of effluent, stormwater, mine water, quarry water, and cooling water into receiving water bodies, measures for assessing compliance with the requirements, and pollutant concentration limit values*.

Throughout the monitoring period, the pH values of both the influent and effluents remained close to neutral, ranging between 7 and 8. In addition, even during the first sampling event (9 April 2026), no evidence of inorganic contaminant leaching was observed from either of the filter media used, namely the CDW concrete aggregate (EWC 17 01 01, particle size 16-32 mm) or the commercial limestone aggregate (particle size 16-32 mm). This observation indicates that both filter materials were environmentally stable under the operating conditions of the pilot system.

No concerns related to heavy metals were identified during the monitoring campaign. The concentrations of all analysed heavy metals, namely zinc (Zn), copper (Cu), nickel (Ni), and lead (Pb), remained below the regulatory limit values in both the influent and treated effluents. However, it should be noted that the concentrations of these metals in the influent were already relatively low. Consequently, the ability of the filtration system to remove elevated concentrations of heavy metals could not be adequately evaluated under the conditions encountered during the study. A similar situation was observed for petroleum hydrocarbons (hydrocarbon oil index, $C_{10}$-$C_{40}$), whose concentrations also complied with the regulatory requirements before treatment.

The most pronounced treatment effect was observed for total nitrogen (TN), total phosphorus (TP), biochemical oxygen demand ($BOD_7$), and total suspended solids (TSS), all of which showed reduced concentrations following treatment. It should be noted that phosphate concentrations were below the detection limit in most of the analysed samples, indicating that phosphorus was predominantly present in other forms, such as particulate or organic phosphorus. The removal of nutrients and biodegradable organic matter is likely associated with the development of a biofilm on the both filter media, the growth of which was clearly observed during the monitoring period (**Figure 5**). Microorganisms within the biofilm are capable of assimilating nitrogen and phosphorus compounds while simultaneously degrading biodegradable organic matter, thereby contributing to the observed reductions in TN, TP, and $BOD_7$ concentrations.

**Figure 5.** Visually observable biomass growth in the filtration system during the monitoring period.

Furthermore, by the end of May 2026, extensive biomass development was observed in the second crushed limestone filter (**Figure 6**), which was filled with the commercial limestone aggregate. This observation provides clear evidence that, in addition to physical filtration, biological degradation processes had become established within the pilot-scale filtration system.

**Figure 6**. Extensive biomass growth observed in the crushed limestone filter at the end of the sampling campaign.

The obtained results therefore indicate that, in the Estonian pilot system, both the CDW-based filter (EWC 17 01 01) and the commercial crushed limestone filter (particle size 16-32 mm) function not only as physical filters but also as biologically active treatment systems, with microbial processes making an important contribution to stormwater purification.

## 5. Conclusion

The two-month intensive sampling and monitoring campaign demonstrated that the Estonian pilot-scale stormwater filtration system operated reliably and effectively under real field conditions. Throughout the monitoring period, the treatment system consistently maintained or improved the quality of stormwater passing through the two filtration stages, namely Filter I filled with CDW concrete aggregate (EWC 17 01 01, particle size 16-32 mm) and Filter II filled with crushed limestone aggregate (particle size 16-32 mm). The quality of the treated effluent from both the first and second filters complied with the requirements established in in Estonia by Regulation No. 61 of 2019 of the Minister of the Environment for all analysed parameters.

One of the key findings of the sampling and monitoring campaign is that no evidence of inorganic contaminant leaching was observed from either of the filter media, namely the CDW concrete aggregate (EWC 17 01 01) or the commercial limestone aggregate. This confirms that both materials remained environmentally stable during operation and demonstrates that construction and demolition waste-derived concrete aggregate can be safely used as a filter medium under the investigated operating conditions.

The most significant treatment effects were achieved for total suspended solids, total nitrogen, total phosphorus, and biochemical oxygen demand, indicating effective removal of particulate matter, nutrients, and biodegradable organic matter. The monitoring results also suggest that treatment performance was not based solely on physical filtration. The gradual development of biofilm on both filter media, together with the extensive biomass growth observed in the second (limestone) filter towards the end of the monitoring campaign, clearly indicates that biological treatment processes became established within the filtration system. These microbial processes most likely contributed to the observed removal of nutrients and biodegradable organic matter through assimilation and biodegradation.

The concentrations of heavy metals (zinc, copper, nickel, and lead), and petroleum hydrocarbons ($C_{10}$–$C_{40}$) remained below the applicable regulatory limits throughout the monitoring period. However, because the concentrations of these contaminants were already low in the influent, the ability of the filtration system to remove elevated levels of heavy metals and hydrocarbons could not be comprehensively assessed. Continued long-term monitoring under a wider range of stormwater quality conditions would therefore be beneficial to further evaluate the treatment efficiency for these pollutants.

Overall, the results confirm the technical feasibility of using CDW-derived concrete aggregate as an alternative filter medium for stormwater treatment. The field-scale pilot demonstrated stable operation, no adverse environmental impacts associated with the filter materials, and effective removal of key stormwater pollutants. The Estonian pilot therefore provides valuable evidence supporting the circular use of construction and demolition waste in nature-based stormwater treatment systems and contributes to the development of sustainable, resource-efficient solutions for urban stormwater management.

## Annex


**Figure A1.** StoPWa project billboard during the construction phase at the Estonian pilot site.


**Figure A2.** Permanent StoPWa project billboard at the Estonian pilot site.