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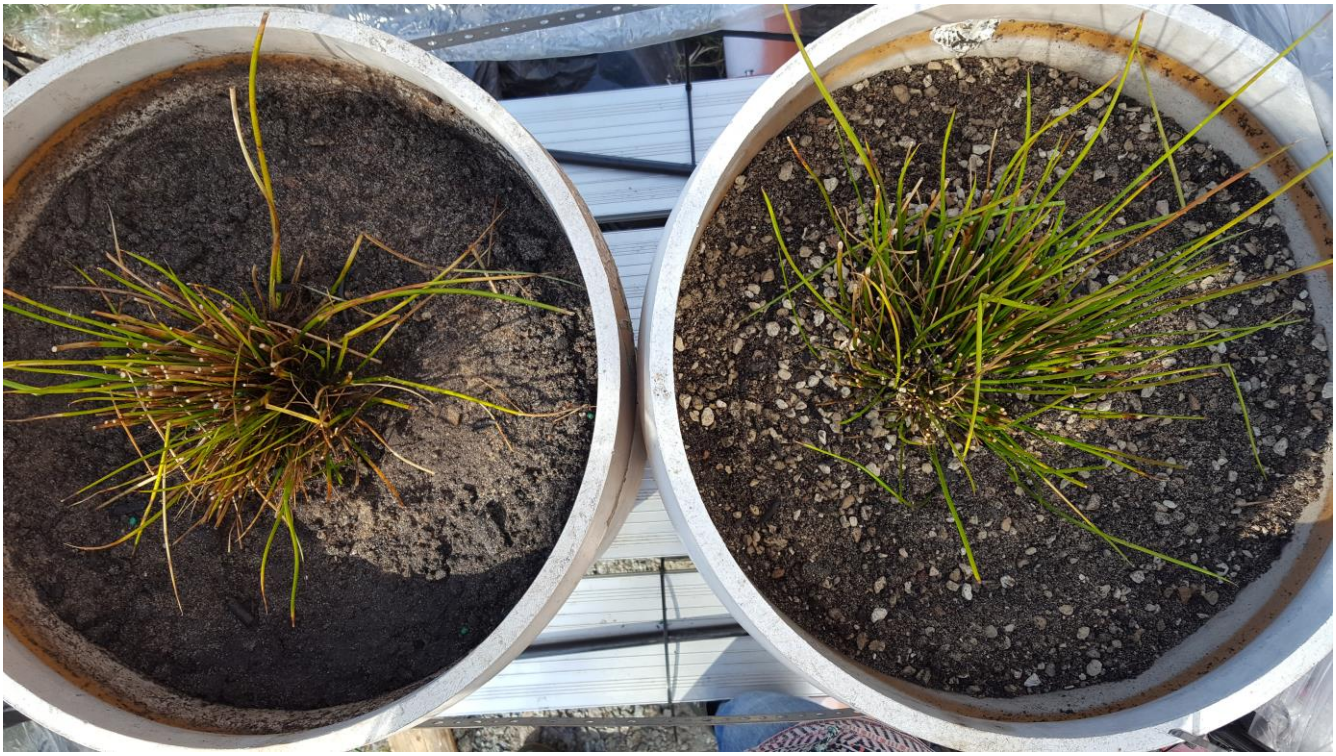

A pilot study of the pollutant removal in bioretention for urban runoff

Master's thesis in Civil Engineering and Water Management

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Abstract

Urbanization has negative effects on the water quality of receiving waters due to high concentrations of pollutants in urban runoff. Bioretention systems, shallow vegetated depressions in the landscape, help reducing flow volumes as well as promoting removal of contaminants in stormwater. In this thesis field studies were performed to evaluate the hydraulic performance and pollutant removal efficiency of two installed bioretention cells for petroleum hydrocarbons (TPHs) and polycyclic aromatic hydrocarbons (PAHs), contaminants that have been rarely investigated in such systems. Two columns were filled with two different filter media and subsequently treated alternately with “natural” stormwater and with diesel-spiked stormwater for a period of three months. In the laboratory, influent and effluent pollutant concentrations were measured, and the filter media was analysed before and after the construction of the stormwater treatment plant. Overall the results showed consistent high reductions of TPHs and PAHs concentrations (> 99%) and minimized outflow volumes, as compared to inflow volumes in both bioretention cells. Due to the initial leaching of soil material out of the system, total suspended solids (TSS) could not be removed efficiently. It was found that an appropriate filter media is essential to attenuate runoff flow and reduce pollutant concentrations and that the bioretention system takes time to operate effectively. However, when designed and applied correctly, bioretention is a promising stormwater management practice to control pollutant concentrations and flow volumes of urban runoff.

Keywords: bioretention; urban stormwater; total petroleum hydrocarbons (TPHs); polycyclic aromatic hydrocarbons (PAHs); chemical analysis; field studies

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1 INTRODUCTION

Stormwater runoff in urban areas is often prevented from percolating into the soil as green areas shrink, due to the expansion of industrial and residential areas, which is leading to an increase in surface runoff. Surface water transports various contaminants generated by human activity, including construction, transportation, and industrial activities from urban areas into sewer systems and receiving waters (Barbosa, Fernandes, & David, 2012). Suspended solids, heavy metals (e.g. Cu, Pb, Ni, Zn and Cd), nutrients but also anthropogenic organic pollutants such as total petroleum hydrocarbons (TPHs) and polycyclic aromatic hydrocarbons (PAHs), which show toxic and carcinogenic effects on human health, are often found in urban stormwater in concentrations exceeding the guidelines for water quality (Lefevre et al., 2014). Since it is the requirement of the European Water Framework Directive (WFD) to meet good water quality, this study aims to find a solution for decreasing the level of contaminants from urban runoff. The idea is a replacement of the traditional “grey” infrastructure, such as pipes and sewers, with green infrastructure, where stormwater runoff can percolate in green areas (Dhakal & Chevalier, 2017), for effective watershed management in urban areas, particularly including stormwater quality improvement.

Bioretention, also referred to as a rain garden or bioinfiltration, is a planted area lower than the surrounding surface, collecting stormwater runoff which percolates into the ground through a fertile soil (Lefevre et al., 2014). This reduces peak flows and flow volume, as well as promoting removal of both particulate-bound and dissolved contaminants in stormwater (Davis et al., 2009). The pollutants are separated from the infiltrated stormwater through sorption to soil particles, biodegradation, volatilization and plant uptake. Studies have shown that this kind of treatment is very effective for the removal of heavy metals and organic pollutants as well as having a long lifecycle before the soil is completely saturated (David et al., 2014; Diblasi et al., 2009). By enhancing the hydrological balance and water quality, bioretention facilities are likely to have a positive effect on the municipal infrastructure (Davis et al., 2012).

However, there are few published studies on the fate of pollutants, specifically organic contaminants, in bioretention. Data on the saturation of bioretention media used in the field are currently lacking, along with information on whether bioretention effluent water meets water quality guidelines. Also, the management of organic pollutants has not been fully investigated yet. In order to prevent pollution of groundwater and receiving waters, it is necessary to have a better understanding of the pollutants' paths and how they can be treated efficiently (Lefevre et al., 2014).

1.1 Aim and research questions

The aim of this thesis is to evaluate the removal efficiency and fate of total petroleum hydrocarbons (TPHs) and polycyclic aromatic (PAHs) in urban stormwater in bioretention cells. Analysed water and media pollutant concentrations are used to establish a mass-balance of the bioretention system, identifying major pollutant fates including sorption, degradation and transport out of the system.

The objectives of this thesis are to:

- investigate the removal efficiency of organic compounds such as PAHs as well as aliphatic and aromatic petroleum hydrocarbons in bioretention cells
- compare the results in this study with results from other bioretention cell facilities by performing a literature survey
- use the results to identify design changes needed to enhance pollutant removal processes
- determine whether the studied stormwater treatment method produces effluent water that meets quality standards, or whether additional treatment is necessary

The following questions were used as an aid in structuring the project:

- What is the removal rate of organic compounds in bioretention cells with two different soils?
- Which physical parameters influence the removal rate?
- What removal efficiency has been obtained in other bioretention cells?
- What alterations should be made to the bioretention cell design to improve the final design?

To answer these questions, a field study was performed near the Järnbrott pond in the south of Gothenburg, Sweden.

1.2 Limitations

The study was performed during a limited time, from the end of January to end of May 2019. Due to restraints in time and economy, only two bioretention cells with different soils were studied. The project focused on TPHs and PAHs as these are some of the most commonly detected organic pollutants, although there are other anthropogenic pollutants that may also be significant for stormwater management. Furthermore, only data from early March to end of May was used for this master's thesis project.

1.3 Outline of the thesis

This report is divided into five chapters. The introduction and definition of aims and contents of the thesis are given in Chapter 1.

Chapter 2 contains background information about stormwater pollutants in general as well as the properties of selected hydrocarbons. Moreover, this chapter discusses stormwater management and monitoring of stormwater runoff quality and the function and design of a bioretention cell.

The used method is presented in Chapter 3. First, the study area and the installation of the bioretention cells are described, followed by explaining of how the samples were collected and which analytical methods were performed in the laboratory, as well as which statistical methods were applied.

Chapter 4 covers the outcomes of the performed field studies. The results of the studied removal of TPHs as well as PAHs, TSS and TOC/DOC are presented and discussed. On-site measurements and laboratory results are compared with previous studies and are used to evaluate the procedure for the pollutant removal performance in urban runoff.

The report ends with Chapter 5 where conclusions are drawn and identified which questions should be answered by further research.

2 BACKGROUND

2.1 Stormwater Pollutants

2.1.1 The Water Framework Directive

In 2000, the Water Framework Directive (WFD) of the European Union was ratified, a legislation which sets binding quality targets to protect drinking water resources. The purpose of the WFD is to achieve good ecological and chemical status in waterbodies and to prevent degradation of the aquatic environment due to pollution (European Commission, 2000). The idea behind the directive was water management by river basin, and not by political or administrative boundaries. The WFD aims at achieving a "good ecological" and a "good chemical" status for all surface water and groundwater bodies, applying Environment Quality Standards (EQS).

Pollution of surface water caused by diffuse sources, such as urban runoff, is not directly commissioned in the WFD. However, it is crucial to protect receiving waters from both point and nonpoint pollutant sources to achieve a "good surface water status". To do so, the WFD established a list of 33 priority substances which cause serious risks to the aquatic environment (Annex X to Decision 2455/2001/EC). Contaminants addressed by the WFD include organic compounds such as PAHs and several heavy metals, among others (European Commission, 2016). While the EQS for heavy metals focus on the dissolved fraction, for organic pollutants the annual average and maximum allowable concentrations of organic pollutants are defined as total concentrations (Birch et al., 2012).

2.1.2 Sources and groups of stormwater pollutants

In various studies worldwide, more than 600 compounds have been detected in stormwater (Eriksson, 2002). The quality of urban runoff strongly correlates with the present impervious layer, such as roads and roofs, with which it comes into contact during the drainage process. Due to their diversity, the pollutants require particular needs for local treatment (Eriksson et al., 2007). The major sources of pollutants in stormwater are, beside wet and dry atmospheric deposition, traffic and agriculture, but also construction materials, such as concrete, impregnated wood, roof materials etc. are likely to release various types of pollutants (Björklund, 2011; Birch et al., 2012). Traffic is identified as an important source of stormwater pollutants, especially organic pollutants such as PAHs, which are emitted from vehicle emissions, as well as brake wear, spills of fuels and abrasion of road surfaces, to name but a few (Markiewicz et al., 2017).

Urban stormwater quality is highly influenced by the traffic volume and land use but is also affected by climate effects such as dry periods and heavy rainfalls. After being

emitted from their sources, stormwater pollutants undergo a series of processes, where the compounds either remain in the atmosphere bound to dust particles or deposit and accumulate on urban surfaces such as roads and roofs (Gunawardena et al, 2018). When contaminants, which are bound to particles in the atmosphere, are washed off by precipitation it is called wet deposition (Abdel-Shafy et al., 2016). Also, PAHs in the vapor phase may be removed from the atmosphere, but not as efficiently as PAHs which are attached to particles, studies of Dickhut & Gustafson (1995) found. On the other hand, dry deposition takes place during dry periods as the so-called build-up phase, and compared to wet deposition, these fluxes are most important for pollutants originating from traffic activities (Gunawardena et al., 2018). During rain events, parts of the deposited contaminants may be washed off the impervious surfaces: dissolved pollutants are likely to be transported by surface runoff at a storm event of lower intensity than pollutants bound to particles (Björklund, 2011). Subsequently, after the wash-off process, the pollutants are transported with stormwater to receiving waters, where the pollutants may endanger the aquatic environment.

Table 1: Commonly occurring groups of pollutants in stormwater (Barbosa et al., 2012; Björklund, 2011)

Pollutant group	**Parameter**	**Sources**	**Effects on the aquatic environment**
Suspended solids and sediment	TSS	Erosion from pavement wear, construction sites and roads; corrosion of vehicles and building materials; atmospheric fallout; anthropogenic wastes	Important for transportation of contaminants (PAHs are attached to the smaller particles); increased turbidity; interference with aquatic organisms
Oxygen-demanding compounds	BOD and COD	Degradation of organic material; vegetation and animals; combined sewer overflows (CSOs)	Low levels of dissolved oxygen or even anoxic conditions in receiving waters; organic matter is less biodegradable
Organic pollutants	TPHs, oil and grease PAHs	Release of petroleum products; car washing Incomplete combustion of organic material e.g. fuel and oil combustion, waste incineration; tire wear; fuels and lubricant oils;	Toxic effect on human health and environment; form thin film on water surface Many PAHs are carcinogenic, mutagenic and persistent against degradation
Heavy metals	e.g. Cu, Pb, Ni, Zn and Cd	Corrosion of vehicles; tire wear; industries; corrosion of building materials, atmospheric deposition	Toxic effects on aquatic plants, animals and human health
Nutrients	Nitrogen, Phosphorus	Fertilizers and atmospheric fallout; animal and human waste; CSOs	Eutrophication and water discoloration, toxic releases and overgrowth of plants
Pathogens	e.g. total coliforms	Animal and human feces; natural occurrence in soil and water	May cause disease in plants, animals or humans
Ions	Ca, Cl, Na	De-icing; atmospheric fallout; natural occurrence in soil	Potential groundwater contamination

Table 1 shows commonly occurring groups of pollutants in urban runoff including possible sources. TSS for example is an important parameter for runoff quality, as organic pollutants tend to be attached to particulate matter. Nutrients such as nitrogen and phosphorus may lead to eutrophication of receiving water bodies. Also, many of the listed pollutants have toxic effects on human health.

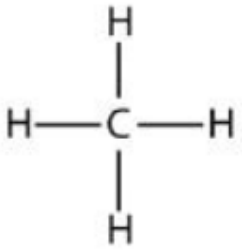
In the past, stormwater quality research has focused mostly on heavy metals and other inorganic compounds, whereas knowledge about PAHs and petroleum-derived compounds in stormwater is limited (Björklund, 2011).

2.1.3 Hydrocarbons in stormwater

Although there are numerous pollutants in urban runoff, focus in this study is on the organic pollutants TPHs and PAHs, which are commonly detected in urban runoff. These hydrocarbons are ubiquitous in urban environments as they are derived from petroleum, which includes fuel, lubricating and road oils, and PAHs are also by-products from combustion processes. Several TPHs and PAHs, are not readily biodegradable and can persist for long periods in the environment. PAHs are considered priority pollutants as they can be toxic to aquatic life even at low concentrations (U.S. EPA, 2014).

Hydrocarbons are made up primarily of carbon and hydrogen atoms and differ in their molecular structures, which include: aliphatic straight chained, aliphatic branch chained, alicyclic (cyclic aliphatics), and aromatic, shown in Figure 1 (Butler et al., 2018). The simplest aliphatic compound is methane (CH_4), which is in gas form (Figure 1). Aliphatic hydrocarbons can be saturated, meaning each carbon is bonded to four other atoms through single covalent bonds (alkanes), or unsaturated, which means hydrocarbons contain either double (alkenes) or triple (alkynes) bonds. In contrast to aliphatic compounds, aromatic compounds contain one or more benzene or heterocyclic rings. PAHs, for example, consist of at least two fused benzene rings (Neilson, 1998). According to the Agency for Toxic Substances and Disease Registry (1995), more than 100 different compounds can be found in the PAH group, which are formed during incomplete combustion of coal, oil, gas and other organic matter. Depending on their number of rings, they are usually classified into low-molecular-weight (LMW) PAHs with 2 and 3 aromatic rings (naphthalene, acenaphthene and acenaphthylene), medium-molecular-weight (MMW) PAHs with 3 to 4 rings (fluorene, phenanthrene, anthracene, fluoranthene and pyrene) or high-molecular-weight (HMW) PAHs with 4 to 6 rings (benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, dibenzo[a,h]anthracene, benzo[g,h,i]perylene and indeno[1,2,3-c,d]pyrene) as shown in Figure 2 (Gunawardena et al., 2018).

a)



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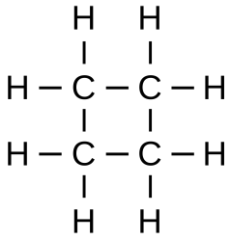

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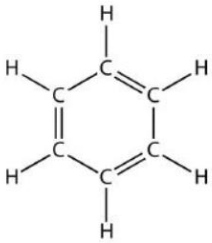

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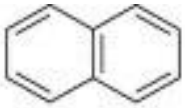

Figure 1: Examples for molecular structures of hydrocarbons: a) aliphatic chained (methane (CH_4)), b) branch chained (Cyclobutane (C_4H_8)), c) aromatic (Benzene (C_6H_6)), and d) aromatic (Naphthalene ($C_{10}H_8$)) (Carey, 2000).

TPHs include besides aliphatics (n-alkenes), aromatic compounds such as benzene, toluene, ethylbenzene and xylenes (BTEX). Due to their large number of compounds, they are classified in “aromatic” and “aliphatic” carbon groups based on the number of carbon atoms in each compound (Brewer, Nagashima, Kelley, Heskett, & Rigby, 2013). In general, aromatic and large aliphatic compounds (C_9 and above) are more toxic than smaller aliphatic compounds, however smaller compounds are more volatile (Brewer et al., 2013). Petrol is characterized by branched alkenes with carbon ranges from C_2-C_{12} and lesser amounts of aromatic compounds such as BTEX. Diesel, on the other hand, is characterised by a wider variety of aliphatic compounds as well as PAHs and heterocyclic compounds (Brewer et al., 2013). Because of the lower molecular weights of the constituents, petrol has the greatest volatility and generally emits the most vapors, compared to diesel with less volatile constituents. The complex mixtures of aliphatic and aromatic compounds present human health concerns predominantly through exposure to vapors from contaminant sources and by direct contact with affected soils (Brewer et al., 2013). Table 2 summarises the compounds in petroleum fuels for BTEX and naphthalene as well as the typical TPH composition. It can be seen that fuels are dominated by aliphatic compounds, although petrol can contain a relatively large proportion of LMW aromatic compounds.

Table 2: Range of current and past BTEX, naphthalene and selected TPH concentrations in petroleum fuels (adapted from Brewer et al., 2013).

Chemical / Carbon range	Petrol	Diesel
Benzene	0.1–3.6%	0.003–0.1%
Ethylbenzene	0.1–3%	0.007–0.2%
Toluene	1–25%	0.007–0.7%
Xylenes	1–15%	0.02–0.5%
Naphthalene	< 1%	0.01–0.8%
aliphatics C_5 to C_8	45%	< 1%
aliphatics C_9 to C_{18}	12%	35%
aliphatics C_{19} to C_{35}	< 1%	43%
aromatics C_9 to C_{12}	43%	22%

PAHs can be of both natural origins or, more commonly, derived from human activities and are, along with TPHs, frequently found in urban runoff. PAHs found in stormwater, emerge on one hand from atmospheric deposition (by wet or dry fallout), produced by stationary combustion, and on the other hand, are commonly caused by traffic-related activities, such as the release of petroleum products (e.g. lubricating oils), vehicle exhaust, tire wear, and abrasion of road surface (Björklund, 2011; Gunawardena et al., 2018; Leroy et al., 2015). The presence of different PAHs can be seen as an indicator for a specific source. While HMV PAHs imply combustion processes as the main contributor, crude and refined oils are an indicator for LMW PAHs present in stormwater (Menzie et al., 2002). Urban runoff from roads and other surfaces contribute significantly to the transport of these contaminants to receiving waters and consequently have a negative impact on the aqueous environment. Studies have shown that stormwater releases between 14 and 36% of total PAH loading to receiving water bodies (DiBlasi et al., 2009; Menzie et al., 2002).

Sources of fuel-derived aliphatic and aromatic hydrocarbons in urban environments are leaky fuel storage tanks, car emissions, spills, and car washing (Lefevre et al., 2014). Most aliphatic compounds are flammable, allowing the use of hydrocarbons as fuel. Fuel is made of long hydrocarbon chains, particularly alkanes, cycloalkanes, and aromatics. Coming in contact with water, petroleum hydrocarbons cause films and emulsions on the water surface because of their lower density and the fact that these compounds are nearly insoluble (Butler et al., 2018).

Priority PAHs. In 1976, the US Environmental Protection Agency (US EPA) published a list with 16 PAHs which have been identified as high priority pollutants (also referred as “priority PAHs” or “16 EPA PAHs”). This list includes some of the more abundant PAHs with structures made of 2 to 6 rings and no alkyl side chains as illustrated in Figure 2. Several of these priority PAHs are of environmental concern due to their toxic impact on human health, including carcinogenicity. Today, these 16 priority PAHs are still of great importance and are accepted by many scientists to be representative for

all of the hundreds of existing PAHs. However, many relevant PAHs showing high toxicity are not represented in the list, including larger PAHs, alkylated polyaromatic compounds (PACs) and heteroatom containing compounds. This has raised the question whether these compounds should also be taken into consideration (Andersson & Achten, 2015).

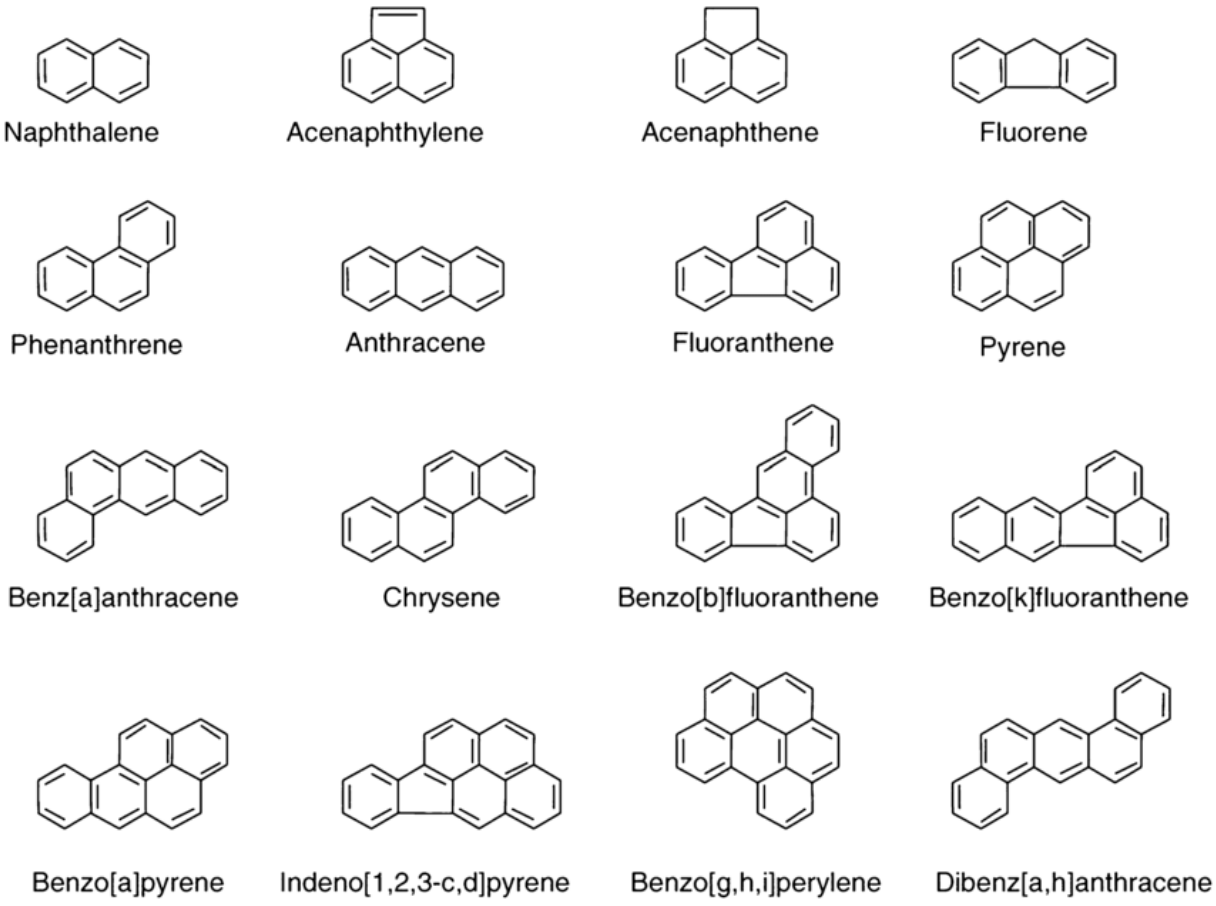

Figure 2: Molecular structure of the 16 PAHs considered priority pollutants by the US EPA (Shukla et al., 2014).

Partitioning of organic pollutants. Partitioning of organic pollutants in urban runoff is crucial to their toxicity, degradation and mobility, and for removal from water and soil in stormwater treatment facilities (Birch et al., 2012). As mentioned before, the EQS for organic pollutants are determined for total concentrations, which shows the lack of knowledge about the distribution of contaminants in urban stormwater. Compounds are distributed between the particle-bound, colloid-bound and dissolved phases in water, depending on water quality, environmental aspects and the characteristics of the compounds. Hydrophobic organic pollutants in stormwater, mostly the HMW compounds, tend to adsorb more easily to organic material and are attached to particles which can be removed through settling and filtration (Nielsen et al., 2015). In contrast, LMW PAHs which are present partially in dissolved and colloid-bound phase (particles < 1 µm) do not settle, which allows them to discharge directly into receiving

waters and may also end up in groundwater (Eriksson et al., 2007). The distribution of organic pollutants within the environment depends highly on their water solubility, which decreases with increasing molecular weight. Since the solubility of PAHs in water is very low, the compounds are liable to associate with particulates. Neilson (1998) reported different values for water solubility, varying from 32 mg/L for naphthalene to 0.004 mg/L for HMW PAHs such as benzo[a]pyrene (Table 3). The ranges in solubility for aliphatic and aromatic compounds in water are even wider, with 1790 mg/L for benzene and 1.5×10^{-6} for HMW aliphatics. Thus, lighter compounds such as benzene and toluene are slightly soluble, while heavier compounds are insoluble in aqueous water.

As an indication of how organic compounds are distributed between the aqueous and particulate phase, the octanol-water partition coefficient (K_{ow}) is frequently used, determining the sorption potential of organic contaminants (Tsai, 2007). While a value of log $K_{ow}>3$ implies non-polar hydrophobic compounds, log $K_{ow}<3$ represents polar, hydrophilic compounds (Lu et al., 2008). Hence, the higher the value of log K_{ow}, the greater the probability of an organic pollutant to attach to organic particles in water, and to bioaccumulate (Sahu & Pandit, 2003). Because of its great variation in magnitude, the partition coefficient for PAHs is commonly expressed in the logarithmic form (log K_{ow}). The values of log K_{ow} range from 3.37 (naphthalene) to approximately 6.50 (indeno(1,2,3-cd)pyrene). While BTEX compounds have smaller octanol-water partition coefficients than PAHs, the log K_{ow} coefficients for aliphatics are very high, indicating their high insolubility in water.

In general, the behaviour of hydrocarbons and how they are distributed between phases depends strongly on their molecular weight. Nielsen et al. (2015) investigated the partitioning of PAHs in different phases in urban runoff. The results show that over 50% of the HMW PAHs were detected in the particulate phase, while high loads of LMW and MWV PAHs were observed mostly in the filtrated fractions (dissolved and colloid-bound), thus behave hydrophobically and hydrophilic. However, according to findings of Kalmykova et al. (2013) even highly hydrophobic compounds such as HMW PAHs are likely to appear in the colloid-bound and/or dissolved phase. Additionally, the presence of colloids, often measured as DOC, is expected to decrease the particulate-bound fraction (Nielsen et al., 2015). These studies show the importance of the development of technologies for the removal of particulate-bound compounds, as well as colloidal-bound and truly dissolved compounds in stormwater.

*Table 3: Properties of priority PAHs and of selected aliphatic and aromatic hydrocarbons (adapted from Brewer et al., 2013; Lundstedt, 2003). *Mean concentrations for aliphatic and aromatic carbon ranges*

Hydrocarbon Category	Compound name / Carbon range	Number of rings	Molecular Formula	Molecular weight [g/mol]	Solubility in water [mg/L]	Vapor pressure [PA]	Log K_{ow}
PAHs	Naphthalene	2	$C_{10}H_8$	128	31	1.0×10^{2}	3.37
	Acenaphthylene	3	$C_{12}H_8$	152	16	9.0×10^{-1}	4.00
	Acenaphthene	3	$C_{12}H_{10}$	154	3.8	3.0×10^{-1}	3.92
	Fluorene	3	$C_{13}H_{10}$	166	1.9	9.0×10^{-2}	4.18
	Phenanthrene	3	$C_{14}H_{10}$	178	1.1	2.0×10^{-2}	4.57
	Anthracene	3	$C_{14}H_{10}$	178	0.045	1.0×10^{-3}	4.54
	Pyrene	4	$C_{16}H_{10}$	202	0.13	6.0×10^{-4}	5.18
	Fluoranthene	4	$C_{16}H_{10}$	202	0.26	1.2×10^{-3}	5.22
	Benzo[a]anthracene	4	$C_{18}H_{12}$	228	0.011	2.8×10^{-5}	5.91
	Chrysene	4	$C_{18}H_{12}$	228	0.006	5.7×10^{-7}	5.91
	Benzo[b]fluoranthene	5	$C_{20}H_{12}$	252	0.0015	-	5.80
	Benzo[k]fluoranthene	5	$C_{20}H_{12}$	252	0.0008	5.2×10^{-8}	6.00
	Benzo[a]pyrene	5	$C_{20}H_{12}$	252	0.0038	7.0×10^{-7}	5.91
	Dibenzo[a,h]anthracene	6	$C_{22}H_{14}$	278	0.0006	3.7×10^{-10}	6.75
	Indeno[1,2,3-cd]pyrene	6	$C_{22}H_{12}$	276	0.00019	-	6.50
	Benzo[ghi]perylene	6	$C_{22}H_{12}$	276	0.00026	1.4×10^{-8}	6.50
BTEX Compounds	Benzene	-	C_6H_6	78.1	1790	11.3×10^{5}	2.17
	Toluene	-	C_7H_7	92.2	526	4.0×10^{5}	2.69
	Ethylbenzene	-	C_8H_{10}	106.2	169	1.0×10^{5}	3.15
	Dimethylbenzene (m,p-Xylene, o-Xylene)	-	C_8H_{10}	106.2	161	1.0×10^{3}	3.16
Aliphatics*	C_5 - C_8	-		93	11	1.0×10^{4}	4.12
	C_9 - C_{12}	-		149	0.07	87	6.01
	C_{13} - C_{18}	-		170	3.5×10^{-4}	41	8.57
	C_{19} - C_{35}	-		280	1.5×10^{-6}	0.11	11.64
Aromatics*	C_8 - C_{10}	-		120	51	290	3.38
	C_{11} - C_{22}	-		150	5.8	3.2	5.29

2.2 Stormwater management

Efficient stormwater management practices are more important today than ever due to increasing extreme weather events as a result of climate change as well as an increase in environmental pollution. Proper stormwater management is a crucial factor for the urban environment to prevent flooding, reduce peak flows and improve the quality of urban runoff, with the ultimate goal to prevent degradation of the water quality in receiving waters and groundwater bodies (Lefevre et al., 2014). Customarily, surface runoff is collected in sewers and pipes, either in separate or combined drainage networks, carrying chemicals, bacteria, eroded soil, and other nonpoint source pollutants into water bodies. Separate drainage systems collect municipal wastewaters and surface runoff in different pipes (Butler et al., 2018). While wastewater is first

treated in a wastewater treatment plant, stormwater is usually discharged directly to receiving waters without prior treatment. Contrary, combined sewer systems collect domestic sewage, industrial wastewater and stormwater in the same pipe to a wastewater treatment plant. However, during rainy periods the pipes may reach their capacity. Hence, to prevent flooding, combined sewer overflows (CSOs) are installed where water is discharged untreated into receiving bodies (Butler et al., 2018). Generally, the existing drainage systems are not designed to transport extreme rain events. In Sweden, for example, the common design standard for the size of the pipes is a 2 to 10-year storm (Svenskt Vatten, 2016). Hence, to compensate for the more frequent overload of the sewers, the most common solutions are to increase the transport capacity by expanding the diameter of the pipes or/and build retention basins. However, none of these practices help to remove contaminants in urban stormwater.

2.2.1 Low-impact development

An alternative approach to the previously described traditional “grey” infrastructure based on pipes and sewers, is green infrastructure, also known as Low-Impact Development (LID), Sustainable Urban Drainage System (SuDS), or Best Management Practices (BMPs) (Fletcher et al., 2015). These are different terminologies which describe the fundamental functions of drainage systems in a uniformed way, whereby they differ globally in their designations. The main purpose of these systems is to use infiltration and storage capacities to manage urban stormwater close to the source and in a more natural way using non-pipe systems (Butler et al., 2018). Practices of LID are microscale drainage systems such as bioretention, pervious pavements and grassed swales (Fletcher et al., 2015). In addition to the already existing stormwater infrastructure, LID may manage flood control as well as reduce runoff volumes and pollutant concentration, and consequently improve water quality by physical, chemical and biological treatment (Liu et al., 2014). In addition, these green infrastructure practices may also involve economic, environmental and aesthetic benefits. For example, bioretention devices can easily be included in the road planning process to drain street runoff. Because of its vegetation, bioretention has a positive effect on the landscape and hence on the environment and is also cost saving in the site work due to the reduction of pipes and sewers (Prince George’s County, 2007).

However, this does not necessarily mean that green infrastructure systems alone are the best practices for sustainable stormwater management. Often, the integration of LID with existing conventional drainage systems is the best solution for certain situations (Butler et al., 2018).

Other stormwater management practices. Besides bioretention systems, urban runoff can also be managed by a range of other stormwater treatment technologies, for example sedimentation ponds, green roofs, infiltration systems, filter drains, and stormwater wetlands, to name but a few. However, these are not explained in more detail in this thesis.

2.2.2 First flush

Due to the initial mobilization of accumulated sediments and other organic pollutants, stormwater has the highest concentration of contaminants at the beginning of a rain event, with a subsequent fast decrease: a concept called “first flush” (Cording, 2016). The subsequent decrease of pollutant concentrations and sediment particle sizes is often credited to an increasing runoff rate due to a progressing storm event. This process leads to rapid changes in water quality. Especially after a long dry period, large loads of pollutants are accumulated on urban surfaces and highly concentrated in urban runoff during the “first flush”. Bioretention facilities, and many other LID techniques, are designed with the aim to collect small and frequent rain events and capture only the initial portion of large runoff events (Davis et al., 2009). To accomplish this target and thus provide a significant reduction of pollutant loads, Baek et al. (2015) recommend to provide enough volume in the bioretention system to store a certain depth of runoff from the contributing drainage area.

2.2.3 Bioretention function and design

Bioretention, also known as rain garden, is a globally used LID method (Lefevre et al., 2014). This drainage system is designed as a shallow depression in the landscape, consisting of different media layers (Figure 3), usually sand-based, which have different functions for enhanced stormwater treatment and drainage (Lucke & Nichols, 2015). Prince George’s County bioretention manual (2007) recommends a filter media depth of 70 – 120 cm, depending upon desired pollutant removal. The biofilter is usually planted with native vegetation which properties may have a great impact on pollutant removal (Davis et al., 2009). Incoming stormwater from impervious surfaces ponds temporarily in the bioretention depression followed by vertical infiltration through the underlying soil media. During this procedure, a range of physical, chemical and biological processes may take place, which contributes to the removal of contaminants (Lucke & Nichols, 2015). Finally, the treated stormwater is either collected in under-drains at the bottom of the bioretention cell to be diverted to receiving waters, or infiltrates the surrounding soil (Hatt et al., 2009).

Advantages of bioretention cells include improved water quality due to removal of different contaminants, runoff control and increased flow retention, low space requirements, and flexible integration into the landscape depending on used materials, vegetation and dimensions (Lefevre et al., 2014). To optimize the lifetime of bioretention systems, continuous maintenance is required. Poor construction, such as inadequate selection of soil media and/or vegetation and unfavourable size of the bioretention area can cause performance problems (Shafique, 2016). Moreover, clogging may occur at the surface of the bioretention cell due to the presence of solids in stormwater, which may have a negative impact on infiltration (Ballard et al., 2015). Clogging could be prevented with a mulch layer on top, which helps to retain larger particles.

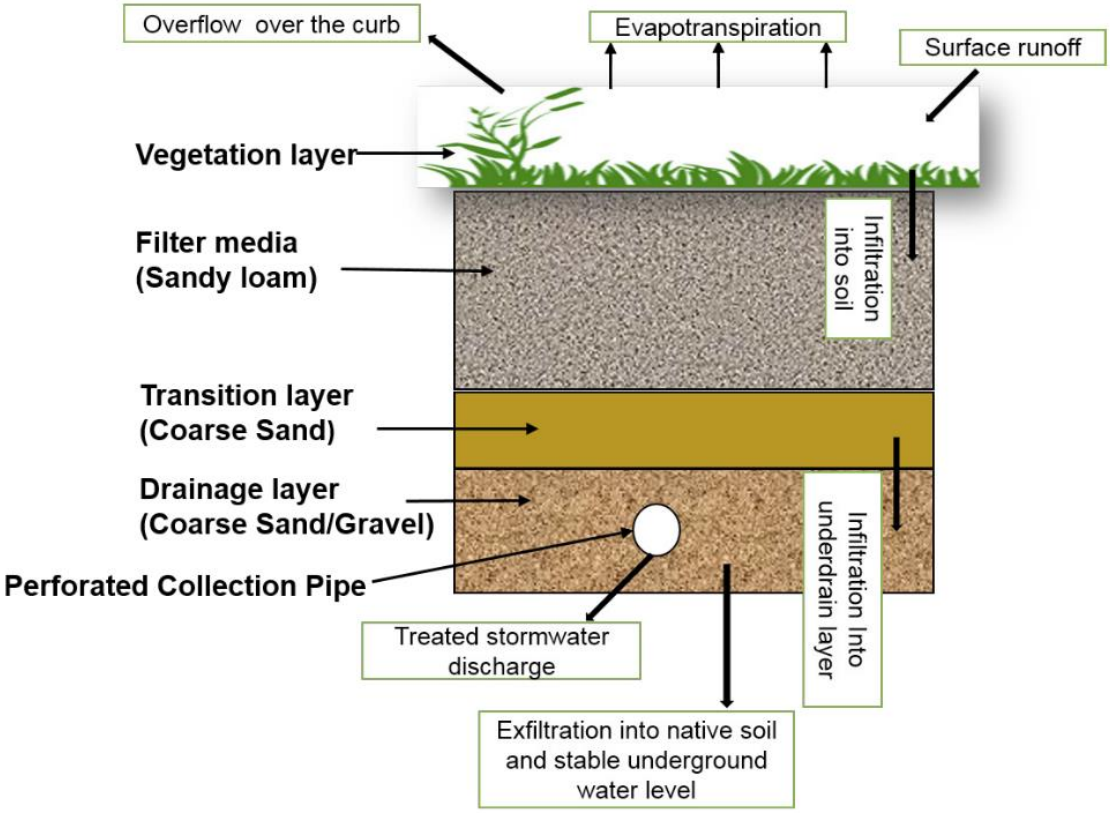

Figure 3: Schema of the structure and hydrologic function of a bioretention system (adapted from Shafique, 2016)

2.2.4 Removal and fate of hydrocarbon pollutants in bioretention

Bioretention cells are very efficient in removing hydrocarbons from the incoming stormwater, with documented PAHs reduction exceeding 90% (David et al., 2014; Davis et al., 2001; Diblasi et al., 2009; Muerdter et al., 2018), resulting in significant runoff quality improvement. Once released into the environment, the behaviour and fate of petroleum hydrocarbons can be very different (Schwarzenbach et al., 2003), determined by their different physicochemical properties (Table 3). As mentioned, LMW PAHs are present as vapor in the atmosphere, whereas they tend to be dissolved in aqueous environments. Contrarily, HMW PAHs are primarily attached to particles, hence are less available for degradation, in contrast to LMW PAHs (Schwarzenbach et al., 2003). Consequently, the interaction of several removal mechanisms including adsorption, volatilization, plant uptake, and biodegradation (Figure 4) is required for efficient removal of petroleum hydrocarbons in stormwater (Hvitved-Jacobsen et al., 2010), whereby biodegradation presents a long-lasting removal efficiency of pollutants. Studies of bioretention by Lefevre et al. (2012a) showed that for the removal of naphthalene, the simplest PAH, sorption is most important (up to 73%), while plant uptake accounts for 2 - 23% and biodegradation for 12 - 18%. More information about the different treatment processes in bioretention systems is given below.

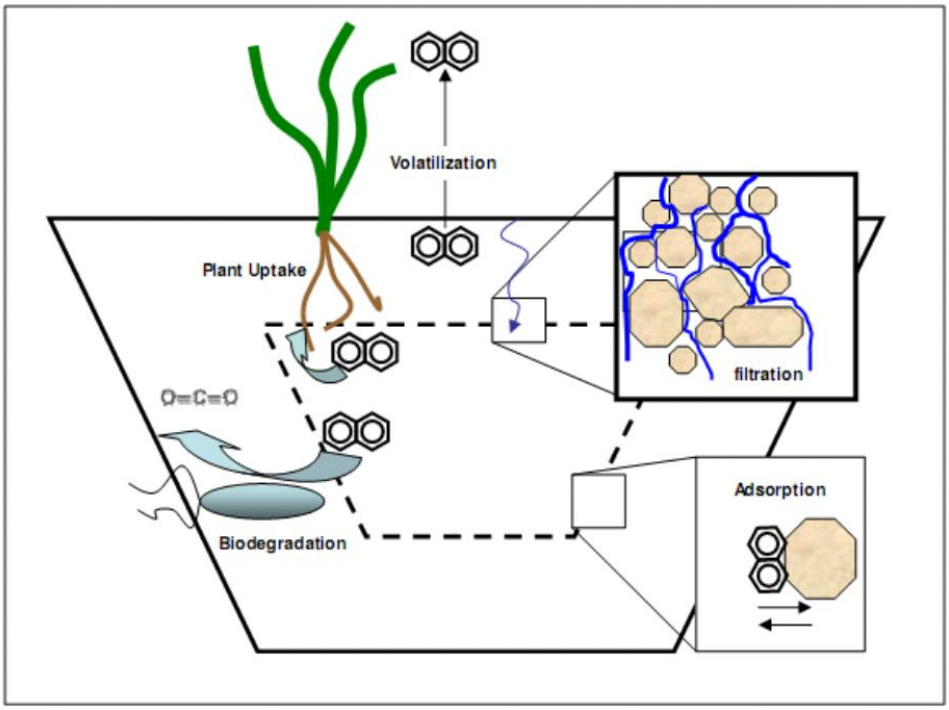

Figure 4: Processes and removal mechanisms for hydrocarbons in bioretention cells (adapted from LeFevre, 2012a)

Sorption. This physicochemical process is the most important method for removing nutrients, heavy metals and organic pollutants in the soil of a bioretention cell (Lefevre et al., 2014). Clay minerals and organic matter in the soil media have the ability to sorb organic pollutants during the filtration process (Cording, 2016). The soil's capacity to retain these constituents via sorption allows slower treatment processes such as biodegradation or plant uptake to take place (Lefevre et al., 2014). Due to its characteristics, a certain amount of organic matter is essential for effective pollutant removal in bioretention systems. Highly humified materials increase water infiltration into the soil, help strengthen the soil structure and retain water (Björklund & Mello, 2012). As stated, the inclination to sorb to soil particles depends also on the properties of the organic compounds. The compounds show different affinities to particles: less soluble and HMW PAHs tend to attach more readily to particles than LMW PAHs, a higher K_{ow} value also indicates a tendency to adsorb to particulate matter.

Biodegradation. Organic pollutants may also be removed by microbial degradation in bioretention. Microorganisms are capable to degrade or mineralize organic compounds, but to do so, the compounds have to be available for uptake by the bacteria (Lefevre et al., 2014). However, HMW PAHs show poor bioavailability due to their low water solubility and propensity to sorb to particles. Thus, hydrocarbons are more available for biodegradation when they are in the dissolved or vapor phase; consequently, two or three ring PAHs are more easily biodegradable. Efficient PAH removal with microbial degradation in the soil matrix is not only depending on the constituent's bioavailability, but also on environmental and microbial aspects such as soil type, moisture content, physical parameters of the soil, and concentration of the pollutants, among others (Cerniglia, 1993).

Plant uptake. Contaminants that are in the dissolved phase in the soil matrix can be taken up directly by the plant's roots and consequently evaporate (Lefevre et al., 2014). However, besides plant uptake, vegetation has the greatest effect on contaminated soils through microbial activity in the root system. Roots can promote permeability and thus support infiltration capacity in the soil matrix (Muerdter et al., 2018). Hence, vegetation plays also a great role in the hydraulic performance and makeup of the soil.

Volatilisation. The tendency of various organic pollutants to evaporate depends on their physicochemical properties. LMW aromatic compounds such as found in gasoline (e.g., BTEX) are more likely to volatilize from stormwater than PAHs (Brewer et al., 2013). Since bioretention cells are designed for rapid infiltration, resulting in short ponding time of the incoming water, this kind of pollutant removal may not be significant for bioretention facilities.

3 METHODOLOGY

3.1 Description of the study area

The pilot station was installed next to the Järnbrott stormwater pond which is located 5 km south of the city centre of Gothenburg (Figure 5). The pond is connected to an impervious catchment area of 160 ha, including the highway Dag Hammarsköldsleden. Besides contaminated runoff from surrounding residential and industry areas, the highway presents one of the most significant sources of pollutants (Pettersson, 1999).

Stormwater from that area drains into an overflow chamber before it is discharged via a pipe into the pond. Stormwater used for the bioretention studies was collected from this overflow device during both wet and dry weather. The pollutant removal was studied in two pilot bioretention cells for three months to mimic natural climate conditions. Two columns were filled with two different filter media according to current design criteria (e.g. media composition, density, infiltration rate), however, the same plant was used for both cells.

Figure 5: Location of the study area in Gothenburg.

3.2 Pollutant treatment

3.2.1 Column design

The experiments were performed in two separate identical bioretention columns made of PVC, with a total height of 700 mm, an inner diameter of 375 mm and an approximate cross-sectional area of 0.11 m² (
Figure 6). The total soil volume in the column was approximately 0.66 m³. A short plastic hose was attached vertically to the bottom of the columns to allow drainage into

a sample bottle with a storage capacity of 10.4 L. The total height of the three different filter media layers in the column was 600 mm, leaving a ponding depth of 100 mm for the stormwater (
Figure 6). The two columns were placed outside on a framework to assure the bottles for collecting the effluent would fit underneath. Additionally, the columns were protected from precipitation with a plastic cover, seen in Figure 7. The test facility was kept very simple and it was important that the bioretention columns were easily reachable to have no difficulties in applying the stormwater and collecting effluent samples.

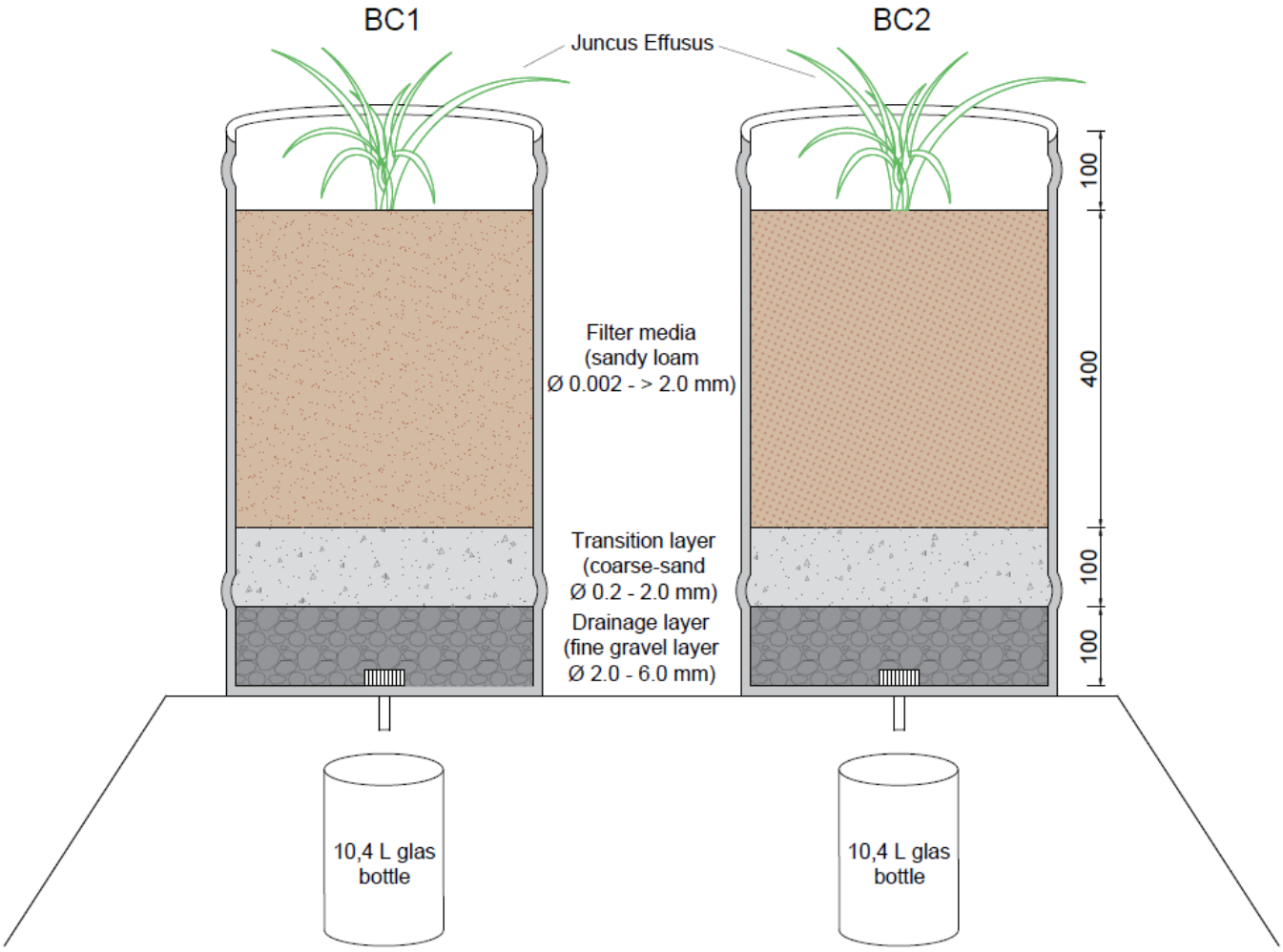

Figure 6: Design and media layers of the two bioretention cells.

3.2.2 Filter media selection

Figure 7: Bioretention cell 1 (BC1) on the left and bioretention cell 2 (BC2) on the right.

Bioretention cell 1 (BC1). The media used for bioretention is typically a homogeneous mix of sand, topsoil, and organic matter (Prince George's County, 2007). The soil texture of the top layer (h=40mm) in BC 1 was a loamy sand. Its properties are shown in Table 4. The high sand content was chosen to ensure sufficient infiltration to avoid standing water in the media which would be disadvantageous for the retention of subsequent rain events. The soil was acid with a pH only 4.77. In comparison, Prince George's County (2007) aims a soil pH between 5.5 and 6.5. The transition layer below consisted of approximately 100 mm deep coarse-sand fraction (Ø 0.2 – 2.0 mm) preventing fine sand and particles in the top layer from being washed into the drainage layer. At the bottom of the column, a 100 mm deep gravel layer (Ø 2.0 – 6.0 mm) provided drainage of the filter (Figure 6).

Bioretention cell 2 (BC2). The filter media of the second bioretention cell was a mixture of pumice stone (2-8 mm), green compost, biochar and sand (Figure 8b), a

product developed by Bara Mineraler, a company situated in Malmö. Pumice is a very well-suited material for bioretention systems due to its good water absorption and storage capacity. The particle sizes of this layer ranged from 0.002 to > 2.0 mm, with the exact composition shown in Table 4. The soils for the transition and drainage layer were the same as in BC1.

Table 4: Properties of the filter media introduced in bioretention cell 1 and 2.

soil material	BC1	BC2	Ø [mm]
Clay (%)	0.3	0.04	< 0.002
Silt (%)	6.61	3.67	0.002 – 0.063
Sand (%)	76.61	72.94	0.063 – 2.0
	very fine gravel (%)	pumice stone (%)	
	16.48	23.35	> 2.0

a)  b) 

Figure 8: a) Filter media of BC1 b) Filter media of BC2.

To assess the particle-size distribution from the top layer of both bioretention, a sieve analysis was performed by the ALS lab, followed by establishing a grain-size distribution curve (Figure 9). Particle-size distribution was determined using a laser particle size analyser for the fractions < 0.063 mm whereas fractions between 2 µm and 63 mm were determined using the wet sieve analysis with laser diffraction.

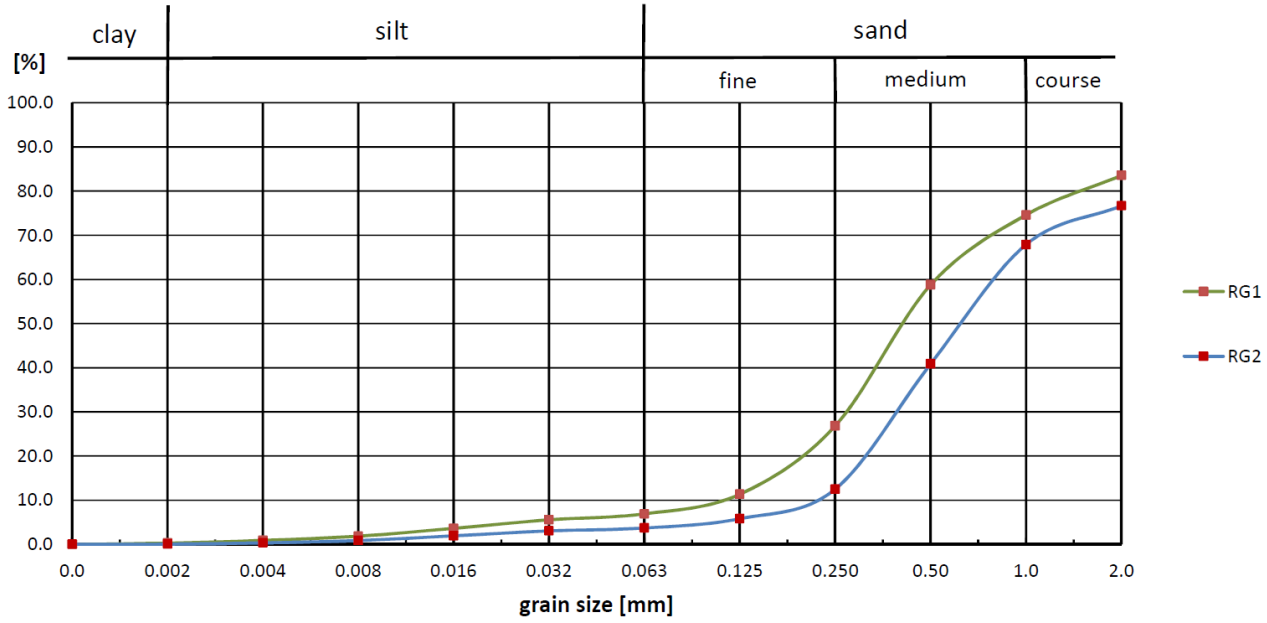

Figure 9: Grain-size distribution curve from the filter media layer of BC1 and BC2.

3.2.3 Vegetation

Both columns were planted with *Juncus Effusus (*Figure 10*)*, commonly known as soft rush, which is found primarily in cool temperate regions. The habitats of these plants include wet areas like marshes, ditches, edges of ponds and rivers, and poorly-drained areas of fallow fields. This plant, which performs well in standing water but also grows well in moist garden soil, is recommended to be used for bioretention cells, as previous studies have found (Leroy et al., 2015; Muerdter et al., 2018). Vegetation influences the function of bioretention systems considerably by improving pollution removal through biochemical activity and enhanced biodegradation (Prince George's County, 2007). Moreover, the surface layer is protected from erosion and the roots of the plants maintain porosity and permeability of the filtration layer to prevent clogging (Ballard et al., 2015).

Figure 10: Example for Juncus Effusus (adapted from StaudenStade).

3.2.4 Stormwater application

This study was intended to serve as a pre-study for future researches. To enable evaluation of different effects on the functional capability of bioretention regarding pollutant removal efficiency, three different scenarios in terms of adding stormwater to the bioretention cells were performed:

1) Water irrigation on a regular basis (3 times a week). Alternately with non-spiked stormwater and stormwater spiked with diesel.
2) Water irrigation with stormwater spiked with petrol at two occasions, at the very end of the study.
3) Dry period (no stormwater application for two weeks).
4) Wet period (irrigation of stormwater every day for one week).

Dosed stormwater volume. The calculation of the applied stormwater volume is based on runoff coefficients, typical rain events of the region and size of the bioretention cell area. According to the Minnesota Pollution Control Agency (MPCA, 2008) the size of a rain garden should be between 5 and 10% of the contributing impervious catchment, different from the Adoption Guidelines for Stormwater Biofiltration Systems (FAWB, 2009), which suggest 2 to 4%. This shows that the percentage is different depending on the study and on how polluted the drained area is. In this study a bioretention cell with an area of 5% of the contributing catchment was chosen. The mean annual rainfall in Gothenburg is 848 mm $year^{-1}$, and it rains on average every 2.1 days, meaning 4.66 mm precipitation per event. According to the Swedish Meteorological and Hydrological Institute (SMHI), the years 2015 and 2017 were rather wet with an average annual rainfall of 1029 mm $year^{-1}$. Nevertheless, the smaller rain event of 4.66 mm was chosen for this study, since the available columns only had a certain ponding capacity. Consequently, assuming a scenario of 85% impervious surfaces (i.e. runoff coefficient is 0.85), and a bioretention cell with an area of 5% of the contributing catchment (i.e., one column for 2.20 m^2 catchment), each cell was dosed with approximately 9 L stormwater per event (4.66 L/m^2 x 2.20 m^2 x 0.85 = 8.7 L).

After filling and planting the prefabricated bioretention columns, the cells were flushed several times with non-spiked municipal stormwater to promote natural bioretention development. In general, the bioretention cells were dosed three times weekly with approximately 9 L of stormwater to simulate storm events. The entire stormwater volume was always added to each of the bioretention cells at once to mimic a “first flush” and to assure always similar concentration loads. As natural stormwater was not available in the required quantity throughout the study, stormwater was spiked with 100 mL diesel (Preem Evolution) on several occasions and also with 100 mL petrol (Preem 95) on the last two events. This was done to simulate a mix of pollutants at varying concentrations and to achieve concentrations representative of typical pollution loads found in urban runoff. Table 5 gives and overview on which day and

what kind of stormwater (non-spiked or spiked) was applied to the bioretention cells during the field studies.

*Table 5: Timeline of the applied stormwater (non-spiked and spiked with 100 mL Diesel) to the bioretention cells during the whole duration of the field study. The green highlighted days represent the wet period. * Stormwater spiked with petrol instead of diesel.*

Day	Date	BC1		BC2	
		non-spiked stormwater	spiked stormwater	non-spiked stormwater	spiked stormwater
Day 1	03-05	x			
Day 2	03-06	x			
Day 3	03-07	-	-		
Day 4	03-13	x			
Day 5	03-14		x		
Day 6	03-15				
Day 7	03-18		x		
Day 8	03-20	x			
Day 9	03-22		x		
Day 10	03-25		x		
Day 11	03-26	x			
Day 12	03-29	x			
Day 13	04-01		x	x	
Day 14	04-03	x		x	
Day 15	05-05	x		x	
Day 16	04-08		x		x
Day 17	05-10	x			x
Day 18	04-12	x		x	
Day 19	04-15		x		x
Day 20	04-17				
dry period for 2 weeks					
Day 21	05-02	x		x	
Day 22	05-03		x		x
Day 23	05-06	x		x	
Day 24	05-08		x		x
Day 25	05-10	x		x	
Day 26	05-13		x		x
Day 27	05-14	x		x	
Day 28	05-15		x		x
Day 29	05-16	x		x	
Day 30	05-17		x		x
Day 31	05-20		x*		x*
Day 32	05-22		x*		x*
Day 33	05-23	x		x	

During the second half of the field studies, scenario 2 was tested: during, two weeks no water was added to the bioretention cells (Table 5). Thereafter, water was applied again continuously until the second last week of the study period. Scenario 3 was performed from day 26 to day 30 (highlighted in green in Table 5) when stormwater was added daily to both bioretention cells with the same water volume (9 L) as before. Table 6 summarises and compares the characteristics of the two bioretention cells.

Table 6: Summary of experimental design specifications of the bioretention cells.

	Bioretention Cell 1	**Bioretention Cell 2**
Study duration	33 days (Mar. 05 – May 23)	21 days (April 01 – May 23)
Top filter layer	loamy sand	loamy sand with pumice
Transition layer	coarse sand	
Drainage layer	fine gravel	
Vegetation	Juncus Effusus	
Applied stormwater volume	9 L	
Different contaminations of applied stormwater	non-spiked stormwater spiked stormwater with diesel (100 mL) every second day spiked stormwater with petrol (100 mL) on the last two days	
Dry period	14 days (April 18 – May 1st)	
Wet period	5 days (May 13 – 17)	

3.3 Sampling

Over the experiment, influent and effluent samples were taken to enable monitoring of the stormwater inflow and outflow qualities.

Added stormwater. Each time stormwater was applied to the bioretention cells (Table 5), one sample (1 L) from the stormwater overflow system was collected and brought to the lab (Figure 11), where it was analysed for general water quality parameters.

At the beginning of the field studies one sample of the diesel-spiked stormwater and later one sample of petrol-spiked stormwater were collected and sent to the ALS commercial lab to determine the concentrations of petroleum hydrocarbons and PAHs.

Effluent. For the whole duration of the research, effluent samples from each bioretention cell were collected and analysed in the lab for general water quality parameters (1 L) and organic pollutants (250 mL) to enable evaluation of the stormwater effluent quality (Figure 11).

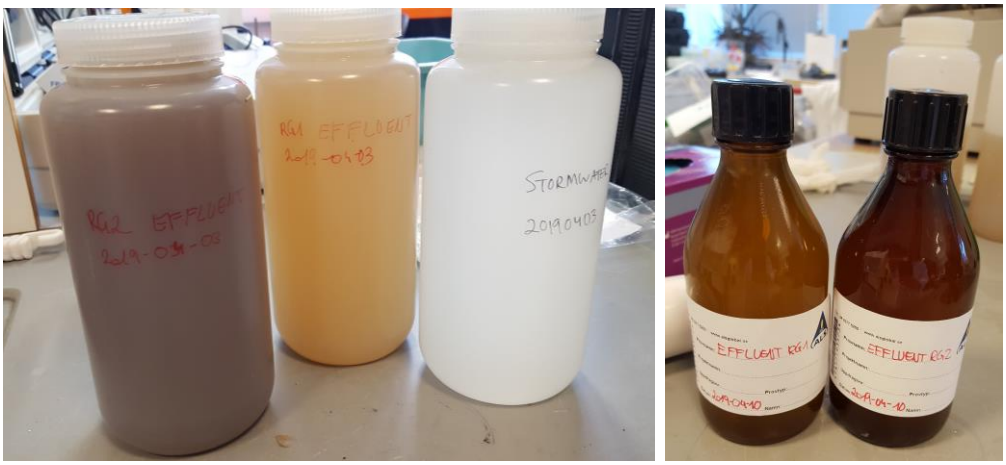

Figure 11: Collected stormwater and effluent samples from both bioretention cells.

Filter media. To compare the physical and chemical parameters, soil samples from each bioretention cell were taken before it was contaminated with stormwater and were send to the ALS commercial lab for analysis of particle size distribution and content of organic pollutants.

After the experiments were completed, several soil core samples of in total 400 mm depth (height of top layer) were taken at two different locations from each bioretention cell (Figure 12) to evaluate the effects of long-term pollution build up in the filter media. Each of the core samples were separated into four sub-samples with different depths: the top crust (0-30 mm), sub-sample 2 (30-100 mm), sub-sample 3 (100-250 mm) and sub-sample 4 (250 - 400 mm). To represent a certain depth profile of the entire column, these sub-samples were mixed into one composite sample and were then sent to the ALS lab for analysis of organic pollutants.

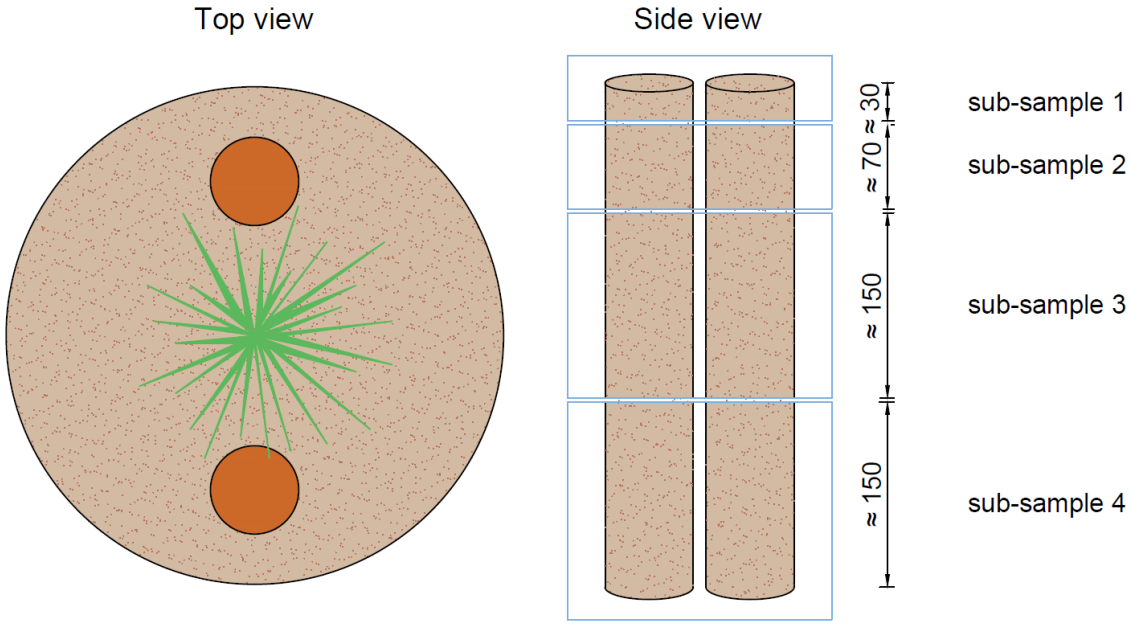

Figure 12: Illustration from where the soil samples were taken in each bioretention cell.

Plants. Since the vegetation in both bioretention cells did not survive the dry period neither the loads of diesel concentrations, there was no need to analyse their roots or stems as they were probably not significantly involved in the removal of the organic pollutants.

3.4 Analysis and data treatment

3.4.1 Stormwater sample analysis

For all events general water quality parameters including pH, electrical conductivity and turbidity were measured in the field right after sampling using a field multi-meter (HI 9892, Hanna Instruments). In addition, analyses were performed on each sample for Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC) and Total Suspended Solids (TSS) in the laboratory. The samples were stored in 50 ml falcon tubes and kept in the same tube through the whole analysis procedure.

DOC is a measurement of the amount of organic matter in water. Before analysing, the sample was filtered using 0.7 µm pore size glass microfibre filters. Subsequently, TOC as well as DOC were analysed in the laboratory with the *SHIMADZU - TOC-V CPH Total organic carbon analyser*, which is based on the subtraction of the inorganic carbon (IC) of the total carbon (TC): TOC = TC – IC.

The content of TSS was determined according to Swedish Standard Methods. To analyse TSS in the collected water samples, the samples were filtered through GF/F 1.6 µm pore size glass microfibre filters and subsequently dried in the oven at 105°C for at least 2 hours. The dried weight subtracted from the weight of the filter disc divided by the sample volume yields TSS.

3.4.2 Effluent sample analysis

Effluent samples were analysed for the same general water quality parameters as stormwater samples (pH, conductivity, turbidity, TOC, DOC, and TSS). In addition, nearly all effluent samples contaminated with diesel were analysed for organic pollutants. TPHs and PAHs analyses were completed by the ALS Scandinavia laboratory using combined gas chromatography/mass spectrometry (GC/MS). After extraction of the samples the analysis process consists of four steps (source: EL-Science): first, the samples are diluted in a solvent and subsequently vaporized to become a gas. This gas carries the sample through a column where the compounds travel at different speeds, depending on partitioning with the columns stationary phase layer through which they get separated. In the end, the compounds leave the column and enter the mass spectrometer detector. The mass spectrometer measures the mass-to-charge ratio of ions and creates a matrix of data consisting of each compound identified and showing the intensity measures of every compound in the sample. A

distinction is made between non-detected values, values below the detection limit and detected values.

The compounds included in the analysis were aliphatic (n-alkanes) C_5 – C_{35} and aromatic hydrocarbons (C_8 – C_{22}), BTEX (e.g. benzene, toluene, ethylbenzenes, and xylenes) and all priority PAH compounds (as listed by the US EPA) together with the sums of LMW (Low Molecular Weight), MMW (High Molecular Weight) and HMW (High Molecular Weight). Due to their large number of compounds, TPHs were classified in “aromatic” and “aliphatic” carbon groups based on the number of carbon atoms in each compound (Brewer et al., 2013) as shown in Table 3.

3.4.3 Soil sample analysis

The moisture content of the unused and used filter media was measured by placing approximately 5 g of each sample in an oven at 105°C for 12h. Triplicate samples were used, and the moisture content was calculated as mass percentages of water in the media. Subsequently, for determining the organic matter, the same samples were placed in a furnace at 550°C for 4 h. The difference from the weight of the samples after burning and the dry state yields the organic content.

For determining the pH of the filter media, 50 g of soil was mixed with a solution containing 0.01 M $CaCl_2$. After stirring the mixture for 30 minutes the sediments settled, and the pH of the suspension could be measured.

All filter media samples taken from the unused and the used soil of both bioretention cells were sent to the ALS lab where the concentrations of aromatic and aliphatic hydrocarbons, as well as the 16 priority PAHs were analysed.

4 RESULTS AND DISCUSSION

4.1 Hydraulic performance of the bioretention cells

Effluent samples from BC1 and BC2 were collected for 33 and 21 simulated events, respectively. Tests for BC1 started at the beginning of March 2019 while the operation of the second bioretention BC2 started one month later. The experiments for both cells lasted until the end of May 2019.

Both bioretention cells were spiked with 9 L of stormwater (alternately non-spiked stormwater or stormwater spiked with diesel) approximately two to three times a week (Table 5). Usually, part of the infiltrating water was retained by the soil, resulting in a reduced effluent volume. However, Figure 13 shows that the effluent volume from BC1 was higher (up to 10 L) than the applied stormwater volume (9 L) during the first ten days (three events). The observed increase in the effluent volume could be attributed to higher influent volumes due to natural precipitation at the beginning of the field studies as the test facility was not yet covered at that time. However, the effluent volume in BC2 was always lower than the influent (maximum effluent was 8 L), except for the last event on day 33. For both bioretention cells, the last effluent was ~10 L. The reason is that on day 32 non-spiked stormwater was applied to the columns before the whole volume of the previously applied stormwater had time to fully drain. Without consideration of this last effluent event, stormwater volume reductions varied from 0% to 44% in BC1 and 11% to 44% in BC2 (Table 7). This demonstrates that during the tests a part of the applied stormwater volume could be retained by both soils in most occasions. Lucke (2015) studied street-side bioretention basins for a period over 10 years, showing also varying but very positive results of 33% to 84% for volume reduction.

At the beginning of the experiment, the effluent volumes of BC1 varied considerably: from 5 to >10 L. However, after the dry period, the effluents were more or less constant between 7 and 8 L. Figure 13 of BC2 shows that the drier the filter media was when stormwater was applied, the larger the volume of water it could retain (up to 44%). However, the stormwater retention time decreased over the study period due to the high infiltration rates of the sandy soils and the higher water saturation of the filter media towards the end of the research. Compared to the beginning of the experiment period, when the applied stormwater in BC1 ponded for approximately 15 minutes and thus infiltrated slowly, the ponding time at the end of the field studies was approximately 3 minutes. This leads to a high infiltration rate of 2.7 cm/min for BC1 and an extremely high infiltration rate of 8.1 cm/min for BC2. Generally, it took approximately 1 h 40 min to fill up the bottles that collected the effluents. Prince George's County (2007) recommends a filtration rate for the soil medium of at least 1"/hr (0.042 cm/min). The infiltration rate of the bioretention media tested by Hsieh & Davis (2005) in the field was found to be up to 8.15 cm/min. Even with this high infiltration rate, pollutant removal rates were good.

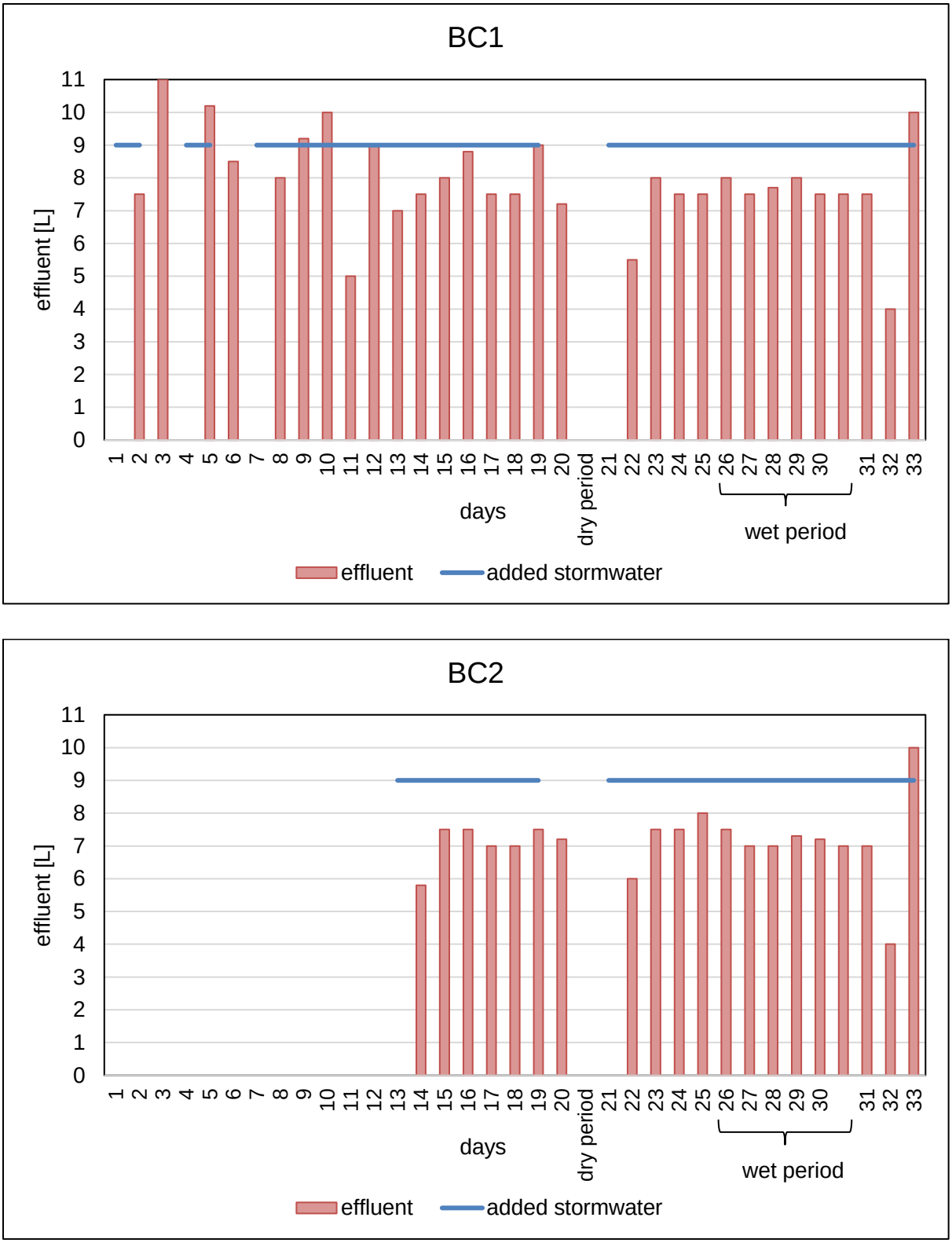

Figure 13: Irrigation of stormwater [9 L] to the bioretention cells and subsequent effluent volumes of BC1 and BC2.

Table 7: Hydrologic properties of bioretention cells observed during testing.

Treatment	Influent volume [L]	Highest effluent [L]	Lowest effluent [L]	Effluent volume reduction range [%]	Time to reach outlet [min.]
BC1	9	> 10.4	5	0 - 44	5*
BC2	9	8	5	11 - 44	3*

* at the end of the study

Figure 14 shows how the vegetation (*Juncus Effusus*) of the bioretention cells changed during the study period. Unfortunately, the plant in BC1 (on the left) did not survive for long. Especially after the two dry weeks (day 21 in Figure 14) when no stormwater was added to the bioretention cells, the plant was very dehydrated and did not recover in the process of the research. The condition of the plant in BC2 also deteriorated over time. This is probably because the plants had too little time to acclimatise but also the high amount of diesel could have a negative effect on the vegetation. Also, since both bioretention soils consisted to a certain amount of coarse-grained sands, the infiltration rates were high, so the available water needed for plant growth was low. Additionally, the high acid content of the filter media in BC1 (pH = 4.77) may have caused a rapid degradation of the plant.

Figure 14: Degradation of the planted vegetation (Juncus Effusus) over the study period in the bioretention cells.

4.2 Influent and effluent on-site measurements

The collected stormwater used for the experiments was generally very “clean” because of dry weather. There was very little or no rain at all during the study period. Only on a few occasions, the collected stormwater was notably contaminated, transported from the catchment area into the overflow device due to precipitation. In fact, the analysed chemical parameters of the influent samples (pH, conductivity and turbidity) were generally lower than those of the effluents. Table 8 shows the mean values for pH, conductivity and turbidity of the in total 80 collected samples (30 stormwater samples, 30 effluent samples of BC1, 20 effluent samples of BC2).

Both the influents and the effluents of all events showed a relatively constant pH. Only after the dry period, there was a slight decrease in effluent pH to below 7. This could be an effect of increased leaching of humic and fulvic acids out of the soil which decrease the pH level in the effluents. Humic substances are produced by the degradation of plant and animal matter (Gaffney et al., 1996). Fulvic acids are a type of humic acid that only differ in their water solubility. However, the pH level of both soils returned to its initial level within a few days, indicating that saturated conditions in the soil raise the pH.

The conductivity and turbidity were higher at the beginning of the measurements but decreased steadily over time. For example, turbidity in the effluents of BC2 decreased from 330 to 31 FNU during the study period. The high turbidity in the effluent samples especially at the beginning of the experiments was caused by the initial leaching of sediment particles out of the bioretention media (Figure 17). Conductivity measures the water’s ability to conduct electricity, which provides a measure of what is dissolved in water. In the first two effluent samples of BC1 the conductivity was extremely high (1700 and 2100 µS/cm, respectively), but was one week later down to 400 µS/cm and remained at this level for the rest of the study. These results could also be attributed to the high initial wash out of the particles.

Table 8: On-site measurements of general chemical parameters for all collected influent and effluent samples (n=80).

Parameter	Influent		Effluent			
			BC1		BC2	
	mean	Std. deviation	mean	Std. deviation	mean	Std. deviation
pH [-]	7.2	0.6	7.1	0.5	7.4	0.5
Conductivity [µS/cm]	370	58	440	400	480	42
Turbidity [FNU]	7	8	170	110	93	74

4.3 Removal efficiency of bioretention cells

4.3.1 Total concentrations of organic pollutants

Pollutant concentrations in the influent samples. Table 9 shows the pollutant concentration levels in the influents with which the bioretention soils were contaminated. The spiked influents contained high concentrations of TPH, which could also be found in very high concentration levels in both filter media (Table 12). The concentrations of aliphatic hydrocarbons were as expected in both spiked influent samples high. Only the aromatics >C_{16}-C_{35} as well as benzene and toluene were below the quantification limits in all samples. In the stormwater sample spiked with petrol, high concentrations of aliphatics >C_5-C_{16} and aromatics >C_8-C_{10} could be observed. These measurements correlate with the data in Table 2 for selected TPH concentrations in petrol. The high concentrations of ethylbenzene and dimethylbenzene (3300 µg/L and 9800 µg/L, respectively) are explained by the high concentrations of these compounds in petrol (Yang et al., 2017). Also, most analysed PAHs could be detected in the petrol-spiked stormwater sample but in very low concentrations, except for naphthalene that occurred in high concentrations of 160 µg/L. Aside from the low concentrations of aromatic compounds in the diesel-spiked stormwater sample, the sample contained the expected compounds.

*Table 9: Concentrations of the collected influent samples (four in total) for non-spiked stormwater, stormwater spiked with diesel and stormwater spiked with petrol. *Petrol spiked stormwater was fed to the bioretention cells in the last two field days.*

Compound [µg/L]	Non-spiked stormwater n = 2	Stormwater spiked with diesel n = 1	Stormwater spiked with petrol* n = 1
Aliphatics >C_5-C_{16}	<20	51000	2900
Aliphatics >C_{16}-C_{35}	19.5	101000	351
Aromatics >C_8-C_{10}	<0.30	18.6	7920
Aromatics >C_{10}-C_{16}	<0.775	11.2	85.3
Aromatics >C_{16}-C_{35}	<1.0	<1.0	<1.0
Benzene	<0.20	<1.0	<1.0
Toluene	<0.20	<1.0	<1.0
Ethylbenzene	<0.20	<0.20	3330
Dimethylbenzene	<0.20	4.9	9800
Naphthalene	<0.010	2.1	157
Acenaphthylene	<0.010	1.41	0.098
Acenaphthene	<0.010	2.95	0.586
Fluorene	<0.010	0.083	1.19
Phenanthrene	<0.010	0.315	1.63
Anthracene	<0.010	<0.014	0.303
Fluoranthene	0.016	0.039	0.156
Pyrene	0.016	0.027	0.272
Benzo[a]anthracene	<0.010	<0.014	0.062
Chrysene	0.012	<0.014	0.045
Benzo[b]fluoranthene	<0.010	<0.014	0.03
Benzo[k]fluoranthene	<0.010	<0.014	<0.014
Benzo[a]pyrene	<0.010	<0.014	0.021
Dibenzo[a,h]anthracene	<0.010	<0.014	<0.014
Benzo[ghi]perylene	<0.010	<0.014	0.038
Indeno[1,2,3-cd]pyrene	<0.010	<0.014	<0.014
PAH ∑ 16	0.044	6.9	160
∑ carcinogenic	0.012	<0.049	0.16
∑ non-carcinogenic	0.032	6.9	160
∑ LMW	<0.015	6.5	160
∑ MMW	0.032	0.46	3.6
∑ HMW	0.012	<0.056	0.2

For most of the analysed effluent samples the organic pollutant concentrations were below the quantification limit (QL > 95%) which means the compounds may be detected but not correctly quantified. The concentrations of all analysed compounds of the collected influent and effluent samples are summarized in Table 10. PAHs could not be detected in any of the effluent samples. That was expected, as the concentrations of PAHs in the spiked influent were very low (only LMW PAHs = 7 µg/L, Table 10). Although aromatic compounds were present in the influent sample in low concentrations, they could also not be detected in the effluent samples. Since the concentrations of aliphatic compounds were extremely high in the influent sample, it was not surprising that they would be the most frequent detected pollutants in the effluent samples. That is probably because the ponding time of the bioretention cells was very short to the end of the experiment (approximately 3 min. for BC1 and 1 min. for BC2). This means smaller aliphatic compounds did not have time to vaporise and subsequently, since they tend to occur in the dissolved or colloidal phase, indicated by a low log K_{ow} value (Table 3), leached out of the bioretention soil. Hence, aliphatics C_5–C_{16} could be detected in some samples with the highest concentrations of 32 µg/L in the effluent of BC1 and 25 µg/L in BC2. The aliphatics C_{16} - C_{35} were found in the highest concentrations in the effluent samples (77 µg/L and 39 µg/L for BC1 and BC2, respectively). The reason for that could be the high content of leached TSS from the bioretention soil and the tendency of aliphatics with high molecular weight to sorb to organic matter, but also the high content of these compounds in diesel. The higher the value of log K_{ow}, the greater the probability of an organic pollutant to attach to organic particles in water, and to bioaccumulate.

However, the effluent concentrations of all compounds were always below the inlet concentrations, resulting in positive removal rates of > 99% for all measured organic pollutants in both bioretention cells. Even though the infiltration rate was very high towards the end of the study (2.7 cm/min. in BC1, 8.1 cm/min. BC2) and both soils drained very fast, the removal efficiency of the contaminants through the soil was nevertheless considerable. The results in this study are very similar to findings in pollutant removal of bioretention in other studies (David et al., 2014; Diblasi et al., 2009; LeFevre, 2012; Muerdter et al., 2018). A comparison of PAH concentrations in the effluent samples to Canadian Environmental Quality Standards (CEQGs) for the protection of Aquatic Life formulated by European Commission showed that the measured compounds were always lower than the guideline values. The same applied for guideline values of TPH concentrations for drinking water according to Swedish guidelines (Svenska Petroleum Institutet, 2010).

As both aliphatic groups (>C_5-C_{16} and >C_{16}-C_{35}) could be found in extremely high concentrations in the filter media, it is suggested that most of the removal took place by sorption to organic matter and biodegradation. In contrast, since the vegetation, especially the plant in BC1, was in a bad condition, removal of pollutants by plant uptake can be excluded. It is also assumed that pollution, since the inflow infiltrated very quickly, hardly had time to evaporate.

Table 10: Range (and median) of effluent pollutant concentrations of both bioretention cells and reference influent (non-spiked stormwater and stormwater spiked with diesel) concentrations.

Compound [µg/L]	Non-spiked influent n = 2	Spiked influent n = 1	BC1 effluent range (median) n = 20	BC2 effluent range (median) n = 15
Aliphatics >C_5-C_{16}	<20	51000	<20 - 32 (<20)	< 20 - 25 (<20)
Aliphatics >C_{16}-C_{35}	19.5	101000	<10 - 77 (36)	12 - 39 (21)
Aromatics >C_8-C_{10}	<0.30	18.6	<0.30 (<0.30)	<0.30 (<0.30)
Aromatics >C_{10}-C_{16}	<0.775	11.2	<0.775 (<0.775)	<0.775 (<0.775)
Aromatics >C_{16}-C_{35}	<1.0	<1.0	<1.0 (<1.0)	<1.0 (<1.0)
Benzene	<0.20	<1.0	<0.20 (<20)	<0.20 (<20)
Toluene	<0.20	<1.0	<0.20 (<20)	<0.20 (<20)
Ethylbenzene	<0.20	<0.20	<0.20 (<20)	<0.20 (<20)
Dimethylbenzene	<0.20	4.9	<0.20 (<20)	<0.20 (<20)
Naphthalene	<0.010	2.1	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Acenaphthylene	<0.010	1.41	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Acenaphthene	<0.010	2.95	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Fluorene	<0.010	0.083	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Phenanthrene	<0.010	0.315	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Anthracene	<0.010	<0.014	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Fluoranthene	0.016	0.039	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Pyrene	0.016	0.027	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Benzo[a]anthracene	<0.010	<0.014	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Chrysene	0.012	<0.014	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Benzo[b]fluoranthene	<0.010	<0.014	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Benzo[k]fluoranthene	<0.010	<0.014	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Benzo[a]pyrene	<0.010	<0.014	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Dibenzo[a,h]anthracene	<0.010	<0.014	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Benzo[ghi]perylene	<0.010	<0.014	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
Indeno[1,2,3-cd]pyrene	<0.010	<0.014	<0.010 - <0.014 (<0.010)	<0.010 - <0.014 (<0.010)
PAH ∑ 16	0.044	6.9	<0.080 - <0.11 (<0.80)	0.017 - <0.080 (<0.080)
∑ carcinogenic	0.012	<0.049	<0.035 - <0.049 (<0.035)	0.017 - <0.055 (<0.035)
∑ non-carcinogenic	0.032	6.9	<0.045 - <0.063 (<0.045)	<0.045 - <0.063 (<0.045)
∑ LMW	<0.015	6.5	<0.015 - <0.021 (<0.015)	<0.015 - <0.021 (<0.015)
∑ MMW	0.032	0.46	<0.025 - <0.035 (<0.025)	<0.025 - <0.035 (<0.025)
∑ HMW	0.012	<0.056	<0.040 - <0.056 (<0.040)	0.017 - <0.040 (<0.040)

Figure 15 presents the concentrations of aliphatic C_{16}-C_{35} compounds in all analysed effluent samples of BC1 and BC2 and it also shows which kind of influent was added to the bioretention cell (expressed by a letter). The observed concentrations vary, especially in BC1. The concentrations are generally higher in the second half of the experiment, but they do not increase until the end. However, as soon as non-spiked stormwater was applied to the columns, there was a decrease in the effluent concentrations.

It appears that the wet period has no significant impact on the removal efficiency. The effluent concentrations behave similarly to the time when stormwater was only added every second day. On field day 29 (05-16) the concentration in the effluent was even lower than the day before, although it resulted from a with diesel spiked influent.

It should be added that not every effluent sample was analysed for organic compounds. Especially at the beginning of the study only a few samples were analysed, whereas after the dry period each collected effluent sample was analysed. This should be considered when looking at Figure 15.

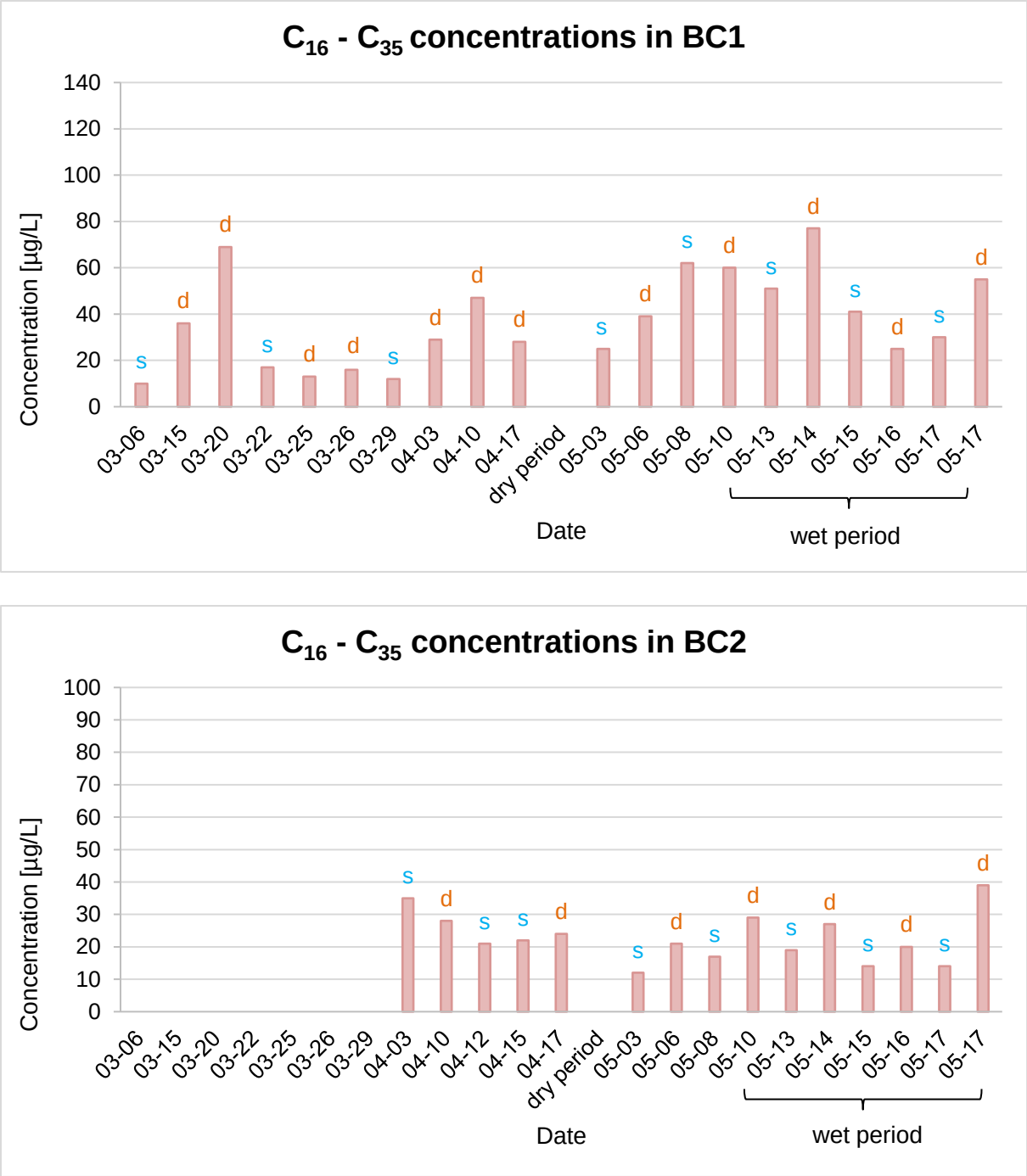

Figure 15: Concentrations of C_{16} - C_{35} aliphatic compounds in effluents of BC1 and BC2. The letters above the columns present the different influents: s = non-spiked stormwater, d = stormwater spiked with diesel.

Stormwater spiked with petrol. To test the effect of another contamination source, stormwater was spiked with petrol instead of diesel the last week of the study period. Petrol spiked stormwater was applied twice to the bioretention cells (on the 20th and 22nd of May). At the very last day of the field study (23rd of May) both bioretention cells were flushed with non-spiked stormwater. Since PAHs could not be detected in any of the effluent samples, except from naphthalene, Table 11 shows only TPH compounds.

Table 11: Effluent pollutant concentrations of both bioretention cells and reference influent (non-spiked stormwater and stormwater spiked with petrol) concentrations.

Compound [µg/L]	Non-spiked influent n = 2	Spiked influent n = 1	BC1				
			Effluent 05-20	Effluent[1] 05-22	Effluent[2] 05-22	Effluent[3] 05-22	Effluent 05-23
Aliphatics >C_5-C_{16}	<20	2900	19	20	18	39	29
Aliphatics >C_{16}-C_{35}	19.5	351	83	35	30	135	90
Aromatics >C_8-C_{10}	<0.30	7920	3.42	0.58	0.69	0.74	1.13
Aromatics >C_{10}-C_{16}	<0.78	85.3	<0.78	<0.78	<0.78	0.07	0.05
Aromatics >C_{16}-C_{35}	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	<0.20	<1.0	8.3	<0.20	54.9	23.3	0.6
Toluene	<0.20	<1.0	22.5	<0.20	61	13.7	<0.20
Ethylbenzene	<0.20	3330	1.03	0.67	1.25	<0.20	<0.20
Dimethylbenzene	<0.20	9800	8.1	1.7	8	16	37
Naphthalene	<0.01	157	0.23	<0.01	<0.01	<0.01	<0.01
			BC2				
Aliphatics >C_5-C_{16}	<20	2900	14	<110	<110	29	15
Aliphatics >C_{16}-C_{35}	19.5	351	51	<10	<10	96	62
Aromatics >C_8-C_{10}	<0.30	7920	11.3	4.25	2.83	24.2	15.4
Aromatics >C_{10}-C_{16}	<0.78	85.3	<0.78	<0.78	<0.78	0.06	<0.78
Aromatics >C_{16}-C_{35}	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	<0.20	<1.0	130	<2.00	75.9	228	122
Toluene	<0.20	<1.0	278	<2.00	105	467	179
Ethylbenzene	<0.20	3330	14.8	<2.00	3.58	28.1	14.4
Dimethylbenzene	<0.20	9800	110	8.3	25	210	180
Naphthalene	<0.01	157	0.31	0.06	0.06	0.56	0.23

[1] Retained water (in filter media) from previous event (05-20)
[2] Initial effluent from this event (05-22)
[3] Effluent from this event (05-22) towards the end

Figure 16 shows the concentrations of the effluents of BC1 of the last three days of sampling for both aliphatic groups (>C_5-C_{16} and >C_{16}-C_{35}). On field day 32 (05-22) after stormwater spiked with petrol was added to the bioretention cells, three effluent samples were collected from each bioretention cell. The initial effluent was the water retained in the filter media from the previous day. Thereafter, the effluent originating from this event and lastly, the effluent towards the end was collected as long as water was still draining. It was assumed that the concentrations in the first sample (effluent 05-20) would be very low since this effluent was retained in the soil for more than two days, but this was not the case (Table 11). The reason for that may be that the petrol compounds are transported faster than the water through the media filter and act as a solvent extracting the hydrocarbons sorbed in the soil matrix from the earlier diesel additions. Also, the concentrations in the other samples (effluents form 05-22) are different than expected. It can be assumed that either the pollutant concentrations in the effluents are not correct (falsified by transport, storage, etc.) or that the pollutant concentrations in the influent samples are not accurate. However, it can be shown that

the bioretention cells demonstrate excellent pollution removal efficiency also with petrol-contaminated stormwater.

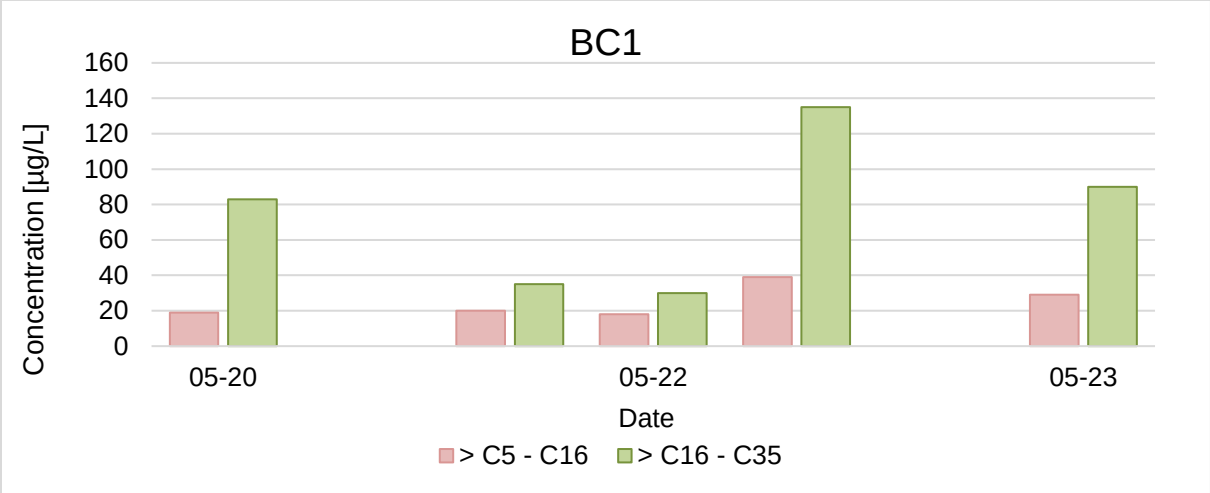

Figure 16: Concentrations of >C15 - C36 and >C16 - C36 aliphatic compounds in effluents of BC1.

4.3.2 Total suspended solids

In the first few events total suspended solid (TSS) concentrations in the collected stormwater were high, resulting from heavy rains at the beginning of the field studies which washed off particles from the surfaces and subsequently into the overflow device. Since the following weeks were very dry, stormwater and thus the inflow to the bioretention cells contained low concentrations of TSS. The median of TSS concentrations in all stormwater samples was 6.0 mg/L.

Figure 17 shows the TSS concentrations in the collected samples of stormwater and effluents of BC1 and BC2 during the whole study period. What stands out in this figure are the high concentrations of TSS in the effluent from both bioretention cells. The effluent concentrations of TSS in BC1 were between 2.0 and 93.0 mg/L, while the decreasing concentrations in BC2 ranged from 220 to 23 mg/L. Because the bioretention cells were newly established and in use for only a short time (BC1 was in operation for approximately 3 months, BC2 for approximately 2 months), soil particles were released from the columns leading to high concentrations of TSS in the effluent samples, similar to the results of Hsieh & Davis (2005). As HMW organic pollutants tend to be attached to particulate matter, TSS is an important parameter for runoff quality. Despite the high release of TSS out of the bioretention system, organic pollutant concentrations in the effluent samples were still very low compared to the spiked influent (Table 10), which may be due to a high sorption rate of the contaminants by organic matter in the filter media.

What also can be seen in
Figure 17 is the steady decline of TSS effluent concentrations for both bioretention cells over time, indicating that the washout of particles will most likely decrease during

operation. What stands out is the rapid decrease in TSS concentrations in the effluent of BC2. Hence, the initial release of particles is depending on the filter material, its structure and composition, but also settling of the soil media might reduce pore sizes which improves retention of particulate matter.

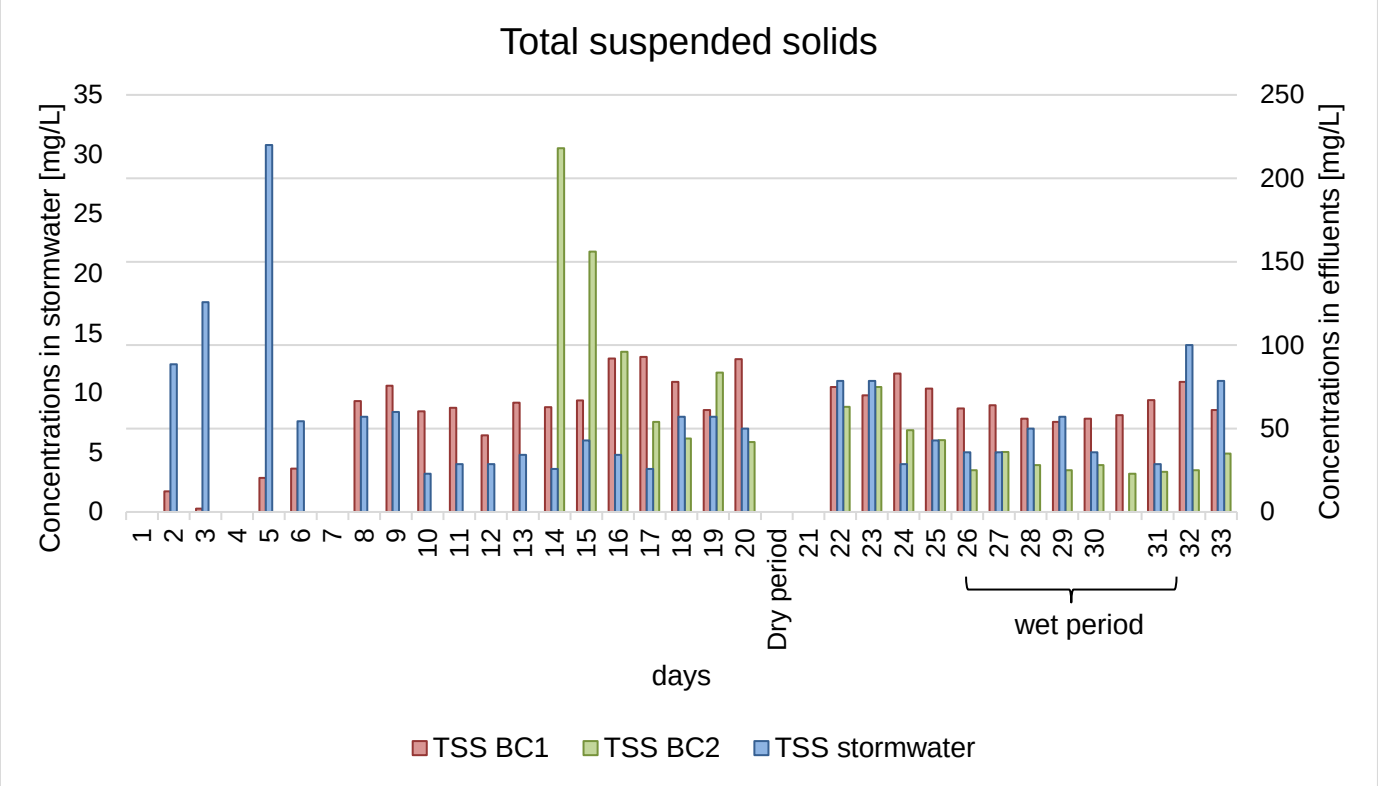

Figure 17: Total suspended solids concentrations in stormwater and effluent samples. Note the different scales of the y-axes.

4.3.3 Total organic carbon and dissolved organic carbon

Dissolved organic carbon (DOC) is used as a measurement for dissolved organic material, found both in the dissolved and colloidal phase. Colloids are smaller than particles and remain dispersed and do not settle. As noted, the behavior of organic pollutants to distribute among particulate, colloidal, and truly dissolved phases depends on their chemical properties.

The TOC and DOC concentrations in all collected water samples (stormwater and effluents of both bioretention cells) were measured. Due to instrumental issues, there was an error in the measurements. TOC and DOC data are presented in Appendix C. Even when a statistical analysis of fluctuations in the effluent concentrations between HMW aliphatics (> C_{16}-C_5) and DOC was made, only a moderate correlation coefficient could be observed (Pearson r = 0.58). Therefore, as so many results were uncertain, there was too little data to draw reliable conclusions on the correlation between DOC and organic pollutants.

4.4 Laboratory measurements of the soil

TPH and PAH concentrations of the filter media were measured in both bioretention cells to assess the soil's ability to retain and/or remove stormwater pollutants and the effect of long-term pollution build-up in the filter media (Table 12). To evaluate the mitigation of pollutants through the filter media, soil core samples were taken at two different locations at four different depths (Top crust 0 - 3 cm, 3 – 10 cm, 10 – 25 cm and 24 – 40 cm) from both bioretention cells (Figure 12). It was anticipated that the bioretention filter media would contain significant hydrocarbon pollution loads due to the high level of contamination of the added stormwater.

In Table 12 concentrations of the unused soil are compared with the contaminated soils (four samples of each bioretention cell). As expected, organic pollutant concentrations were found to be highest in the top crust (0 – 3 cm) of both bioretention cells. The vertical media profile shows a general decrease with depth of the measured organic pollutants (Figure 18).

The pollutant concentrations in both soils varied considerably, from 15000 mg/kg for HMW aliphatics to quantification limits of below 0.1 mg/kg for most PAHs. The extremely high concentrations of the aliphatic compounds were mainly caused by the diesel-spiked stormwater. The concentrations in the top crust are far above the target values of less sensitive soil given by the SEPA (2009) of 500 mg/kg for C_5-C_{16} and 1000 mg/kg C_{16}-C_{35} aliphatics. However, concentrations in the lower layer fall below the limits. The same applied for the aromatic group.

Of all PAH compounds, only naphthalene could be identified in both soil with the highest concentrations in the top crust (6.1 mg/kg in BC1 and 7.5 mg/kg in BC2). This is surprising as light PAHs occur in soils in lower proportions than heavier ones, due to their higher water solubility, volatility and biodegradability, and lower sorption ability (log K_{ow}) to soil organic matter or particles (Neilson, 1998). It is assumed that the concentrations of naphthalene are derived from the influent spiked with petrol (naphthalene = 157 µg/L). However, concentrations of LMW PAHs, MMW PAHs and HMW PAHs were far below the reference values (15, 20 and 10 mg/kg DS respectively) for less sensitive soil given by the SEPA (2009).

The filter media layer of BC1 was found to contain the highest concentrations of nearly all compounds. This was expected as BC1 was 10 days longer in operation than BC2, which means more diesel was added in total to BC1. However, comparing the concentrations in the effluent samples (Table 10), the concentrations for all measured compounds are lower in BC2 than in BC1. Even though the retaining time of the water in the bioretention media was extremely short and the infiltration rate was high in both BCs, pollutant removal was still considerable. Furthermore, it is assumed that the organic pollutants are mainly removed by sorption and biodegradation, but less by evaporation and hardly or not at all by plant uptake (Diblasi et al., 2009).

*Table 12: TPHs and PAHs concentrations of the unused filter media before the experiment and of the used filter media after the experiment from BC1 and BC2. * Ranges are ordered from concentrations of the top crust (0-3 cm) to concentrations of the bottom layer (- 40 cm).*

Compound [mg/kg]	BC1			BC2		
	Unused soil	Used soil (n = 4)		Unused soil	Used soil (n = 4)	
		Range*	Median		Range*	Median
Aliphatics >C_5-C_{16}	<30	5600 - 250	755	<30	6000 - 150	260
Aliphatics >C_{16}-C_{35}	45	15000 - 690	1680	<20	15000 - 500	800
Aromatics >C_8-C_{10}	<1	180 - <1	6	<1	370 - 4.3	7.15
Aromatics >C_{10}-C_{16}	<1	3.7 - <1	<1	<1	5.7 - <1	<1
Aromatics >C_{16}-C_{35}	<1	<1	<1	<1	<1	<1
Benzene	<0.01	0.097- < 0.01	0.01	<0.01	0.21 - 0.023	0.085
Toluene	<0.05	18 - <0-05	1	<0.05	39 - 0.13	0.54
Ethylbenzene	<0.05	16 - <0.05	0.52	<0.05	20 - <0.05	0.18
Dimethylbenzene	<0.05	120 - 0.06	4.8	<0.05	130 - 0.18	3
Naphthalene	<0.05	6.1 - < 0.1	0.29	<0.1	7.5 - 0.14	0.21
Acenaphthylene	<0.05	<0.1	<0.1	<0.1	<0.1	<0.1
Acenaphthene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fluorene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Phenanthrene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Anthracene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Fluoranthene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Pyrene	<0.1	<0.1	<0.1	<0.1	0.13 - <0.1	<0.1
Benzo[a]anthracene	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Chrysene	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Benzo[b]fluoranthene	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Benzo[k]fluoranthene	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Benzo[a]pyrene	0.33	<0.08	<0.08	<0.08	<0.08	<0.08
Dibenzo[a,h]anthracene	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
Benzo[ghi]perylene	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Indeno[1,2,3-cd]pyrene	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
PAH ∑ 16	<1.5	6.1 - <1.5	<1.5	<1.5	7.6 - <1.5	<0.1
∑ carcinogenic	0.33	<0.3	<0.3	<0.3	<0.3	<0.3
∑ non-carcinogenic	<0.5	6.1 - <0.5	0.29	<0.5	7.6 - 0.14	0.21
∑ LMW	<0.15	6.1 - <1.5	0.29	<0.15	7.5 - 0.14	0.21
∑ MMW	<0.25	<0.25	<0.25	<0.25	0.13 - <0.25	<0.25
∑ HMW	0.33	<0.3	<0.3	<0.3	<0.3	<0.3

Figure 18 shows the steady decline with depth of all measured aliphatic compounds for both bioretention filter media. The top crust indicated extremely high levels of LMW and HMW aliphatics (6000 – 15000 mg/kg). However, the concentrations have already been significantly reduced in the second layer. The same findings were noted in previous studies of Diblasi et al. (2009). The study showed that removal of PAHs occurred in the first few centimetres of the bioretention filter media by sorption, while the deeper layer was almost free from pollution.

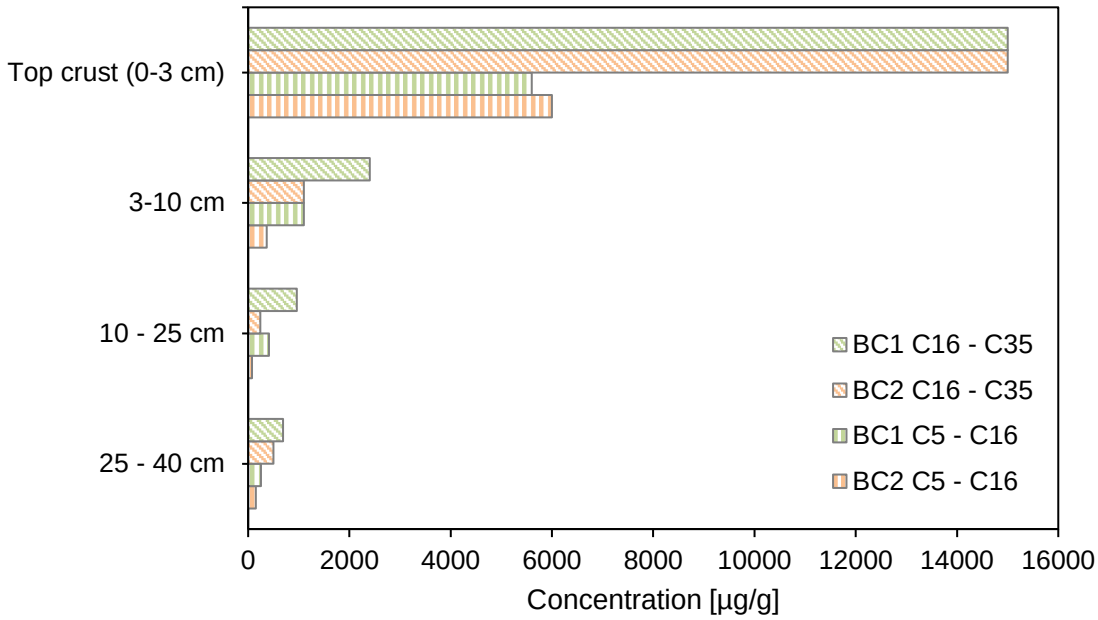

Figure 18: Concentrations of C_5-C_{16} and C_{16}-C_{35} aliphatics of the collected media core samples of both bioretention cells.

To evaluate the changes of the soil's properties over time physical and chemical parameters (pH, moisture content and organic matter) in the soil were analysed. The moisture content of the filter media samples was high compared to the concentrations of the unused soil (Table 13). Particularly in the filter media of BC2 the moisture content doubled (from 9.08% to average 17.41%). Deeper core segments showed higher values, as evapotranspiration is expected to be less significant in the subsurface. Also, pH level and organic matter slightly increased compared to the concentrations in the unused soil, whereas the organic matter content of the filter media decreased downwards in the soil core. Thus, the highest concentrations of organic matter remained near the surface. The lower levels of organic matter in the bottom layer may be due to their leaching. A certain percentage of organic matter is crucial for a well-functioning bioretention system, as it affects water retention, bulk density, pH and absorbs organic pollutants (Björklund & Mello, 2012). Both soils got more compact through settling of the filter media over time which leads to improved retention of the soil particles.

Table 13: Laboratory measurements of the unused and used filter media from both bioretention cells, analysed after the experiment.

Parameter	BC1		BC2	
	unused	used	unused	used
pH [-]	4.8	5.0	6.2	6.6
Moisture content (%)	16.0	18.7	9.1	17.4
Organic matter (%)	5.7	8.2	4.2	5.5

5 CONCLUSIONS

This study evaluated the pollution removal and hydrologic performance of two bioretention cells in a field study that lasted three months. Bioretention cell 1 was filled with a filter media consisting of loamy sand and fine gravel (5.8% organic matter), while bioretention cell 2 was filled with loamy sand and pumice stone (4.2% organic matter). In a period of 33 days and 21 days respectively (BC2 went in operation 12 days later than BC1), non-spiked stormwater and stormwater spiked with diesel was alternately applied to the bioretention cells to assess organic pollutant removal of the bioretention cells.

The field study has demonstrated that bioretention is a promising practice for the removal of organic pollutants from stormwater runoff. Petroleum-derived aliphatic and aromatic compounds, as well as PAHs, could be effectively treated through the systems. Although the infiltration rate for both bioretention soils was extremely high, the removal of pollutants in the incoming stormwater was still considerable (> 99%). TPHs and PAHs accumulated in the top media layer (0-3 cm) and pollutant concentrations in the bioretention media decreased with depth. As demonstrated in this research, most of the pollutant retention takes place in the top crust of the filter media through sorption and particulate capture. Therefore, systems that focus on petroleum-derived pollutants only require a shallow bioretention depth. Further long-term investigation of TPH and PAH compounds is needed to understand their partitioning behaviour in the system and the possible impacts of leaching colloids on the removal efficiency of hydrophobic compounds.

The negative results regarding TSS removal are because the system needs more time to stabilise. It is assumed that both soils are compacted through settling of the filter media over time, which leads to improved retention of the soil particles. However, TSS removal does not correlate with the removal of organic pollutants in this study as the removal efficiency was, despite high leaching of TSS, very high.

Despite insufficient plant growth and very short stormwater detention time for both bioretention soils, the overall hydrological performance of the bioretention cells was found to be positive, with both bioretention cells attenuating flows resulting in outflow volume reductions. The detention time of the stormwater was low for both bioretention cells, but temporary storage of stormwater is important to control discharge rates, allow infiltration and help improve water quality. For future studies, soils with more silt and clay content are recommended as they contain more nutrient and water holding capacity than sand. Besides, selected filter media are necessary for plant growth in the top media layer. It is not recommended to use *Juncus Effusus*, as this plant must always be kept moist, which cannot be achieved during longer natural dry periods. Additional investigation may also be recommended to understand the potential of pollutant uptake by plants in the bioretention media.

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Appendix A – EU WATER FRAMEWORK DIRECTIVE

ANNEX I

ENVIRONMENTAL QUALITY STANDARDS FOR PRIORITY SUBSTANCES AND CERTAIN OTHE POLLUTANTS

PART A: ENVIRONMENTAL QUALITY STANDARDS (EQS)

AA:annual average;

MAC: maximum allowable concentration.

Unit: [µg/l]

(1)	(2)	(3)	(4)	(5)	(6)	(7)
No	Name of substance	CAS number (1)	AA-EQS (2) Inland surface waters (3)	AA-EQS (2) Other surface waters	MAC-EQS (4) Inland surface waters (3)	MAC-EQS (4) Other surface waters
(1)	Alachlor	15972-60-8	0,3	0,3	0,7	0,7
(2)	Anthracene	120-12-7	0,1	0,1	0,4	0,4
(3)	Atrazine	1912-24-9	0,6	0,6	2,0	2,0
(4)	Benzene	71-43-2	10	8	50	50
(5)	Brominated diphenylether (5)	32534-81-9	0,0005	0,0002	not applicable	not applicable
(6)	Cadmium and its compounds (depending on water hardness classes) (6)	7440-43-9	≤ 0,08 (Class 1) 0,08 (Class 2) 0,09 (Class 3) 0,15 (Class 4) 0,25 (Class 5)	0,2	≤ 0,45 (Class 1) 0,45 (Class 2) 0,6 (Class 3) 0,9 (Class 4) 1,5 (Class 5)	≤ 0,45 (Class 1) 0,45 (Class 2) 0,6 (Class 3) 0,9 (Class 4) 1,5 (Class 5)
(6a)	Carbon-tetrachloride (7)	56-23-5	12	12	not applicable	not applicable
(7)	C10-13 Chloroalkanes	85535-84-8	0,4	0,4	1,4	1,4
(8)	Chlorfenvinphos	470-90-6	0,1	0,1	0,3	0,3
(9)	Chlorpyrifos (Chlorpyrifos-ethyl)	2921-88-2	0,03	0,03	0,1	0,1
(9a)	Cyclodiene pesticides: Aldrin (7) Dieldrin (7) Endrin (7) Isodrin (7)	 309-00-2 60-57-1 72-20-8 465-73-6	Σ = 0,01	Σ = 0,005	not applicable	not applicable
(9b)	DDT total (7) (8)	not applicable	0,025	0,025	not applicable	not applicable
	para-para-DDT (7)	50-29-3	0,01	0,01	not applicable	not applicable
(10)	1,2-Dichloroethane	107-06-2	10	10	not applicable	not applicable
(11)	Dichloromethane	75-09-2	20	20	not applicable	not applicable
(12)	Di(2-ethylhexyl)-phthalate (DEHP)	117-81-7	1,3	1,3	not applicable	not applicable
(13)	Diuron	330-54-1	0,2	0,2	1,8	1,8
(14)	Endosulfan	115-29-7	0,005	0,0005	0,01	0,004
(15)	Fluoranthene	206-44-0	0,1	0,1	1	1
(16)	Hexachloro-benzene	118-74-1	0,01 (9)	0,01 (9)	0,05	0,05
(17)	Hexachloro-butadiene	87-68-3	0,1 (9)	0,1 (9)	0,6	0,6
(18)	Hexachloro-cyclohexane	608-73-1	0,02	0,002	0,04	0,02

(1)	(2)	(3)	(4)	(5)	(6)	(7)
No	Name of substance	CAS number (1)	AA-EQS (2) Inland surface waters (3)	AA-EQS (2) Other surface waters	MAC-EQS (4) Inland surface waters (3)	MAC-EQS (4) Other surface waters
(19)	Isoproturon	34123-59-6	0,3	0,3	1,0	1,0
(20)	Lead and its compounds	7439-92-1	7,2	7,2	not applicable	not applicable
(21)	Mercury and its compounds	7439-97-6	0,05 (9)	0,05 (9)	0,07	0,07
(22)	Naphthalene	91-20-3	2,4	1,2	not applicable	not applicable
(23)	Nickel and its compounds	7440-02-0	20	20	not applicable	not applicable
(24)	Nonylphenol (4-Nonylphenol)	104-40-5	0,3	0,3	2,0	2,0
(25)	Octylphenol ((4-(1,1′,3,3′-tetramethylbutyl)-phenol))	140-66-9	0,1	0,01	not applicable	not applicable
(26)	Pentachloro-benzene	608-93-5	0,007	0,0007	not applicable	not applicable
(27)	Pentachloro-phenol	87-86-5	0,4	0,4	1	1
(28)	Polyaromatic hydrocarbons (PAH) (10)	not applicable	not applicable	not applicable	not applicable	not applicable
	Benzo(a)pyrene	50-32-8	0,05	0,05	0,1	0,1
	Benzo(b)fluor-anthene	205-99-2	Σ = 0,03	Σ = 0,03	not applicable	not applicable
	Benzo(k)fluor-anthene	207-08-9				
	Benzo(g,h,i)-perylene	191-24-2	Σ = 0,002	Σ = 0,002	not applicable	not applicable
	Indeno(1,2,3-cd)-pyrene	193-39-5				
(29)	Simazine	122-34-9	1	1	4	4
(29a)	Tetrachloro-ethylene (7)	127-18-4	10	10	not applicable	not applicable
(29b)	Trichloro-ethylene (7)	79-01-6	10	10	not applicable	not applicable
(30)	Tributyltin compounds (Tributhyltin-cation)	36643-28-4	0,0002	0,0002	0,0015	0,0015
(31)	Trichloro-benzenes	12002-48-1	0,4	0,4	not applicable	not applicable
(32)	Trichloro-methane	67-66-3	2,5	2,5	not applicable	not applicable
(33)	Trifluralin	1582-09-8	0,03	0,03	not applicable	not applicable

(1) CAS: Chemical Abstracts Service.

(2) This parameter is the EQS expressed as an annual average value (AA-EQS). Unless otherwise specified, it applies to the total concentration of all isomers.

(3) Inland surface waters encompass rivers and lakes and related artificial or heavily modified water bodies.

(4) This parameter is the EQS expressed as a maximum allowable concentration (MAC-EQS). Where the MAC-EQS are marked as 'not applicable', the AA-EQS values are considered protective against short-term pollution peaks in continuous discharges since they are significantly lower than the values derived on the basis of acute toxicity.

(5) For the group of priority substances covered by brominated diphenylethers (No 5) listed in Decision No 2455/2001/EC, an EQS is established only for congener numbers 28, 47, 99, 100, 153 and 154.

(6) For cadmium and its compounds (No 6) the EQS values vary depending on the hardness of the water as specified in five class categories (Class 1: < 40 mg $CaCO_3$/l, Class 2: 40 to < 50 mg $CaCO_3$/l, Class 3: 50 to < 100 mg $CaCO_3$/l, Class 4: 100 to < 200 mg $CaCO_3$/l and Class 5: ≥ 200 mg $CaCO_3$/l).

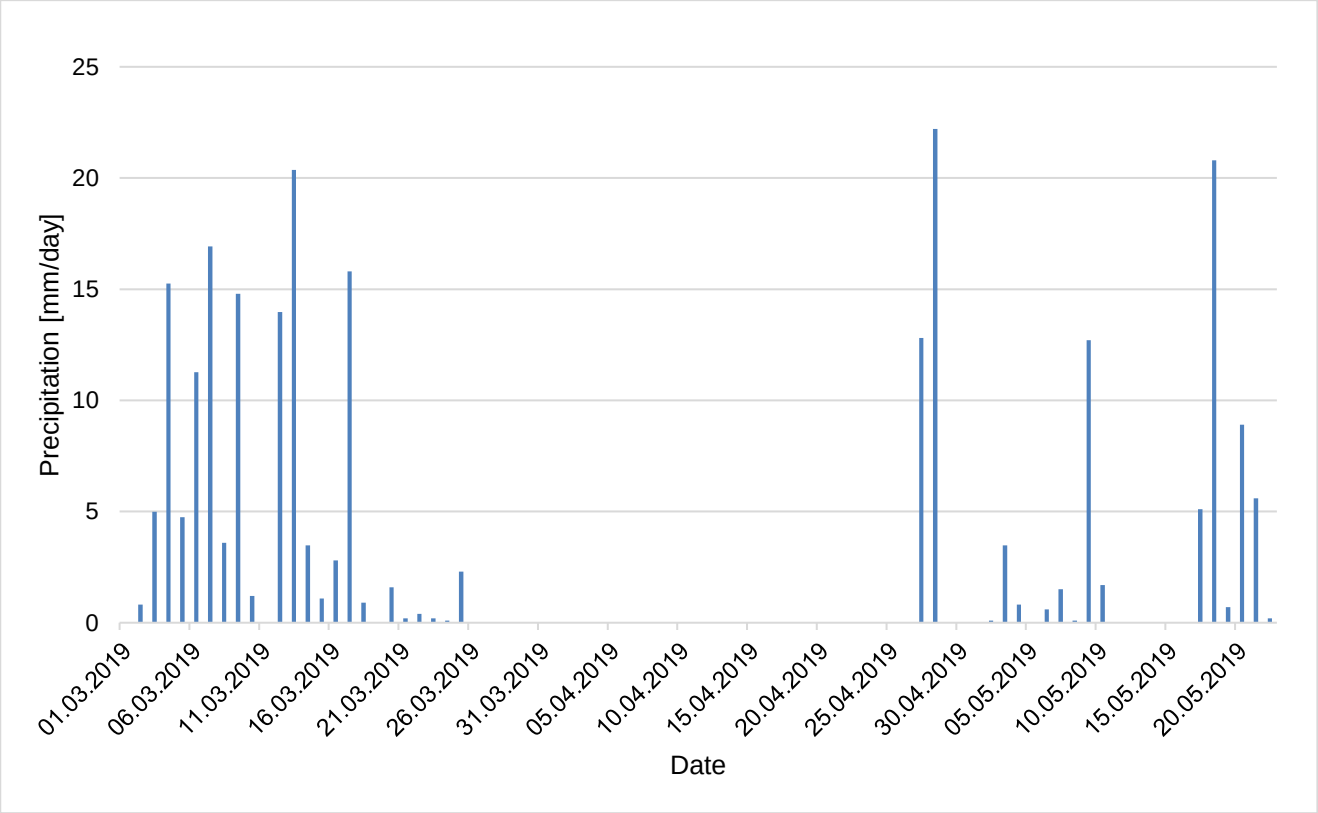
(7) This substance is not a priority substance but one of the other pollutants for which the EQS are identical to those laid down in the legislation that applied prior to 13 January 2009.

(8) DDT total comprises the sum of the isomers 1,1,1-trichloro-2,2 bis (p-chlorophenyl) ethane (CAS number 50-29-3; EU number 200-024-3); 1,1,1-trichloro-2 (o-chlorophenyl)-2-(p-chlorophenyl) ethane (CAS number 789-02-6; EU number 212-332-5); 1,1-dichloro-2,2 bis (p-chlorophenyl) ethylene (CAS number 72-55-9; EU number 200-784-6); and 1,1-dichloro-2,2 bis (p-chlorophenyl) ethane (CAS number 72-54-8; EU number 200-783-0).

(9) If Member States do not apply EQS for biota they shall introduce stricter EQS for water in order to achieve the same level of protection as the EQS for biota set out in Article 3(2) of this Directive. They shall notify the Commission and other Member States, through the Committee referred to in Article 21 of Directive 2000/60/EC, of the reasons and basis for using this approach, the alternative EQS for water established, including the data and the methodology by which the alternative EQS were derived, and the categories of surface water to which they would apply.

For the group of priority substances of polyaromatic hydrocarbons (PAH) (No 28), each individual EQS is applicable, i.e. the EQS for Benzo(a)pyrene, the EQS for the sum of Benzo(b)fluoranthene and Benzo(k)fluoranthene and the EQS for the sum of Benzo(g,h,i)perylene and Indeno(1,2,3-cd

Appendix B – PRECIPITATION JÄRNBROTT



Appendix C – MEASUREMENT RESULTS

Water quality parameters (pH, conductivity, turbidity, TSS)

Bioretention Cell 1

Date / Sample	**pH**	**Conductivity [µS/cm]**	**Turbidity [FNU]**	***TSS=(B-A)/C [mg/l]**
Day 1 _ 2019-03-05				
Stormwater	7.42	158	22.5	12.4
Day 2 _ 2019-03-06				
Stormwater	7.62	381	16.9	17.6
Effluent	7.22	1689	15.5	12.4
Day 3 _ 2019-03-07				
Effluent	7.16	2081	727	2.0
Day 4 _ 2019-03-13				
Stormwater	7.07	369	30.7	30.8
Day 5 _ 2019-03-14				
Stormwater	7.55	345	9.8	7.6
Effluent	6.94	720	61.2	20.4
Day 6 _ 2019-03-15				
Effluent	7.28	422	113	26.0
Day 7 _ 2019-03-18				
Stormwater	7.52	307	13.3	8.0
Day 8 _ 2019-03-20				
Stormwater	7.48	280	16	8.4
Effluent	7.44	325	177	66.4

* A=weight of filter in mg
B=weight of filter + residue in mg
C=volume of sample filtered in L

Day 9 _ 2019-03-22				
Stormwater	7.54	336	0.6	3.2
Effluent	7.37	292	198	75.6
Day 10 _ 2019-03-25				
Stormwater	7.48	324	6.7	4.0
Effluent	7.11	267	179	60.4
Day 11_ 2019-03-26				
Stormwater	7.84	318	4.3	4.0
Effluent	7.64	290	197	62.4
Day 12_ 2019-03-29				
Stormwater	7.93	351	2.6	4.8
Effluent	7.62	289	169	46.0
Day 13_ 2019-04-01				
Stormwater	7.64	406	1.4	3.6
Effluent	7.58	309	166	65.6
Day 14_ 2019-04-03				
Stormwater	7.79	429	2.0	6.0
Effluent	7.66	313	158	62.8
Day 15_ 2019-04-05				
Stormwater	7.87	363	1.2	4.8
Effluent	7.81	312	158	66.8
Day 16_ 2019-04-08				
Stormwater	7.78	394	0.4	3.6
Effluent	7.62	329	184	92.0
Day 17_ 2019-04-10				
Stormwater	7.51	425	1.9	8.0
Effluent	6.74	332	231	93.0
Day 18_ 2019-04-12				

Bioretention Cell 2

pH	Conductivity [µS/cm]	Turbidity [FNU]	*TSS=(B-A)/C [mg/l]
7.83	322	331	218.0
7.93	482	241	156.0
7.89	528	174	96.0
7.42	518	113	54.0

Stormwater	7.56	404	1.2	8.0					
Effluent	7.48	305	186	78.0		7.82	500	84.8	44.0
Day 19_ 2019-04-15									
Stormwater	7.57	422	0.0	7.0					
Effluent	7.51	320	146	61.0		7.95	509	83.5	35.0
Day 20_ 2019-04-17									
Stormwater	7.68	373	0	3.6					
Effluent	7.62	330	185	91.6		7.89	513	92.4	42.0
Day 21_ 2019-05-02									
Stormwater	5.57	389	11.2	11.0					
Day 22_ 2019-05-03									
Stormwater	5.73	379	11.3	11.0					
Effluent	5.87	375	162	75.0		6.33	527	104	63.0
Day 23_ 2019-05-06									
Stormwater	5.95	370	2.0	4.0					
Effluent	5.93	361	164	70.0		6.32	511	102	75.0
Day 24_ 2019-05-08									
Stormwater	6.24	398	1.5	6.0					
Effluent	6.22	335	173	83.0		6.61	484	74.1	49.0
Day 25_ 2019-05-10									
Stormwater	6.43	409	3.5	5.0					
Effluent	6.41	304	148	74.0		6.83	475	72.6	43.0
Day 26_ 2019-05-13									
Stormwater	6.97	352	4.9	5.0					
Effluent	6.93	306	134	62.0		7.26	481	49.8	25.0
Day 27_ 2019-05-14									
Stormwater	6.92	410	2.3	7.0					
Effluent	6.92	310	137	64.0		7.34	468	60.3	36.0
Day 28_ 2019-05-15									

Stormwater	7.2	416	2.4	8.0				
Effluent	7.14	298	130	56.0	7.6	472	54.7	28.0
Day 29_ 2019-05-16								
Stormwater	6.83	439	0.9	5.0				
Effluent	6.84	313	112	54.0	7.36	485	43.0	25.0
Day 30_ 2019-05-17								
Stormwater	7.21	429	0.4	4.0				
Effluent 05-16	7.00	320	126	56.0	7.51	492	46.1	28.0
Effluent 05-17	6.94	321	105	58.0	7.43	495	35.8	23.0
Day 31_ 2019-05-20								
Stormwater	7.45	285	20.6	14.0				
Effluent	6.87	307	110	67.0	7.46	458	30.9	24.0
Day 32_ 2019-05-22								
Stormwater	7.82	414	12.3	11.0				
Effluent	7.03	282	148	78.0	7.34	484	32.2	25.0
Day 33_ 2019-05-23								
Effluent	6.74	292	112	61.0	7.17	459	39.6	35.0

Soil moisture and organic matter

	Depth [mm]	sample	Crucibles [g]	crucible + soil [g]	after drying (105°) [g]	water content [%]	mean	after drying (550°) [g]	organic matter [%]	mean	mean
BC1		1.4	19.5220	25.1334	24.4147	12.81		23.9875	8.73		
	0-30	1.5	13.6972	18.8970	18.2917	11.64	11.77	17.7814	11.11	10.29	
		1.6	7.9206	13.3507	12.7607	10.87		12.2264	11.04		
		1.7	7.4710	13.3937	11.7976	26.95		11.2161	13.44		
	30-100	1.8	8.1515	13.4208	12.4493	18.44	21.40	12.1830	6.20	8.67	
		1.9	6.7326	12.0472	11.0478	18.80		10.7727	6.38		
		1.10	10.1017	15.6393	14.4719	21.08		14.1474	7.43		8.23
	100-250	1.11	32.4367	37.8460	36.6647	21.84	20.78	36.3436	7.59	7.12	
		1.12	29.0545	34.4306	33.3864	19.42		33.1120	6.33		
		1.1	7.5517	13.1432	12.0607	19.36		11.8022	5.73		
	250-400	1.2	18.5876	23.7042	22.6120	21.35	20.86	22.2851	8.12	6.85	
		1.3	19.4696	25.0209	23.8060	21.88		23.5163	6.68		
BC2		2.1	17.3788	22.9088	22.2885	11.22		21.9220	7.46		
	0-30	2.2	19.3482	24.8198	24.1836	11.63	11.93	23.8234	7.45	7.73	
		2.3	19.3282	25.0657	24.3234	12.94		23.9094	8.29		
		2.4	30.9666	36.5841	35.5806	17.86		35.3828	4.29		
	30-100	2.5	12.4007	17.6921	16.8539	15.84	17.52	16.6546	4.48	4.43	
		2.6	11.7620	17.1349	16.1225	18.84		15.9248	4.53		
		2.7	11.3274	17.2651	16.0893	19.80		15.8408	5.22		5.53
	100-250	2.8	7.3675	13.2581	11.9682	21.90	20.59	11.7158	5.49	5.28	
		2.9	20.0955	25.2520	24.2168	20.08		24.0050	5.14		
		2.10	11.0935	16.4235	15.2325	22.35		15.0128	5.31		
	250-400	2.11	32.4371	37.9477	36.9482	18.14	19.60	36.7617	4.13	4.66	
		2.12	7.3645	12.7972	11.8023	18.31		11.6005	4.55		
		4.1	27.1905	33.0517	32.1255	15.80		31.8415	5.75		
Unused soil BC1		4.2	16.8663	22.1008	21.2460	16.33	15.99	20.9870	5.91	5.76	
		4.3	14.7286	20.1214	19.2678	15.83		19.0130	5.61		
		3.1	16.5982	21.9564	21.5425	7.72		21.3324	4.25		
Unused soil BC2		3.2	7.1755	12.4105	11.9146	9.47	9.08	11.7162	4.19	4.15	
		3.3	19.5251	24.9080	24.3669	10.05		24.1731	4.00		

Soil pH

	unused soil	**used soil** depth [mm]			
		0-30	30-100	100-250	250-400
BC1	4.77	5.18	5.10	5.00	4.89
BC2	6.19	6.33	6.55	6.72	6.74

TOC/DOC concentrations in stormwater, influent and effluent samples

Day	Sample name	Concentration [mg/L]
1	03-05 STORMWATER DOC	8.485
	03-05 STORMWATER TOC	5.849
2	03-06 EFFLUENT DOC	23.49
	03-06 EFFLUENT TOC	22.47
	03-06 STORMWATER DOC	5.274
	03-06 STORMWATER TOC	8.733
3	03-07 EFFLUENT DOC	30.42
	03-07 EFFLUENT TOC	29.3
4	03-13 STORMWATER DOC	9.76
	03-13 STORMWATER TOC	8.349
5	03-14 EFFLUENT DOC	29.66
	03-14 EFFLUENT TOC	32.15
	03-14 STORMWATER DOC	9.234
	03-14 STORMWATER TOC	6.46
6	03-15 EFFLUENT DOC	44.57
	03-15 EFFLUENT TOC	43.58
7	03-18 STORMWATER DOC	8.307
	03-18 STORMWATER TOC	7.133
8	03-20 EFFLUENT DOC	38.13
	03-20 EFFLUENT TOC	35.29
	03-20 STORMWATER DOC	5.902
	03-20 STORMWATER TOC	2.771
9	03-22 EFFLUENT DOC	32.64
	03-22 EFFLUENT TOC	29.2
	03-22 STORMWATER DOC	8.377
	03-22 STORMWATER TOC	5.917
10	03-25 EFFLUENT DOC	29.35
	03-25 EFFLUENT TOC	27.75
	03-25 STORMWATER DOC	6.653
	03-25 STORMWATER TOC	6.271
11	03-26 EFFLUENT DOC	26.74
	03-26 EFFLUENT TOC	33.66

Day	Sample name	Concentration [mg/L]
	03-26 STORMWATER DOC	6.861
	03-26 STORMWATER TOC	7.139
12	03-29 Effluent DOC	24.85
	03-29 Effluent TOC	24.27
	03-29 Stormwater DOC	6.79
	03-29 Stormwater TOC	6.495
13	04-01 Effluent DOC	23.19
	04-01 Effluent TOC	5.95
	04-01 Stormwater DOC	5.44
	04-01 Stormwater TOC	24.255
14	04-03 RG1 DOC	23.045
	04-03 Effluent RG1 TOC	21.485
	04-03 Effluent RG2 DOC	18.05
	04-03 Effluent RG2 TOC	23.20
	04-03 Stormwater DOC	5.21
	04-03 Stormwater TOC	5.31
15	04-05 RG1 DOC	25.91
	04-05 Effluent RG1 TOC	28.82
	04-05 Effluent RG2 DOC	34.05
	04-05 Effluent RG2 TOC	42.05
	04-05 Stormwater DOC	4.51
	04-05 Stromwater TOC	5.21
16	04-08 RG1 DOC	14.91
	04-08 Effluent RG1 TOC	28.55
	04-08 RG2 DOC	36.73
	04-08 Effluent RG2 TOC	44.45
	04-08 STORM DOC	7.08
	04-08 Stormwater TOC	3.39
17	04-10 RG1 DOC	27.95
	04-10 Effluent RG1 TOC	28.26
	04-10 RG2 DOC	21.26
	04-10 Effluent RG2 TOC	44.41
	04-10 Stormwater DOC	5.92

Day	Sample name	Concentration [mg/L]
	04-10 Stormwater TOC	6.46
18	04-12 RG1 DOC	15.57
	04-12 RG1 TOC	13.32
	04-12 RG2 DOC	35.34
	04-12 STORM DOC	3.56
	04-12 STORM TOC	4.91
19	04-15 RG1 DOC	22.41
	04-15 RG1 TOC	23.80
	04-15 RG2 DOC	28.27
	04-15 RG2 TOC	30.95
	04-15 STORM TOC	3.53
20	04-17 RG1 DOC	23.41
	04-17 RG1 TOC	24.37
	04-17 RG2 DOC	28.34
	04-17 RG2 TOC	30.22
	04-17 SOTRM TOC	3.37
	04-17 STORM DOC	2.56
21	05-02 STORM DOC	5.86
	05-02 STORM TOC	6.55
22	05-03 RG1 DOC	30.78
	05-03 RG1 TOC	27.65
	05-03 RG2 DOC	32.54
	05-03 RG2 TOC	38.11
	05-03 STORM DOC	5.37
	05-03 STORM TOC	5.27
23	05-06 RG1 DOC	42.12
	05-06 RG1 TOC	42.35
	05-06 RG2 DOC	32.20
	05-06 RG2 TOC	36.36
	05-06 STORM DOC	5.40
	05-06 STORM TOC	4.59
24	05-08 RG1 DOC	38.37
	05-08 RG1 TOC	38.32

Day	Sample name	Concentration [mg/L]
	05-08 RG2 DOC	26.99
	05-08 RG2 TOC	14.87
	05-08 STORM DOC	3.34
	05-08 STORM TOC	4.17
25	05-10 RG1 DOC	35.36
	05-10 RG1 TOC	16.21
	05-10 RG2 DOC	24.63
	05-10 RG2 TOC	27.89
	05-10 STORM DOC	6.13
	05-10 STORM TOC	5.72
26	05-13 RG1 DOC	33.195
	05-13 RG1 TOC	29.58
	05-13 RG2 DOC	22.38
	05-13 RG2 TOC	29.32
	05-13 STORM DOC	4.163
	05-13 STORM TOC	3.1875
27	05-14 RG1 DOC	28.835
	05-14 RG1 TOC	32.54
	05-14 RG2 DOC	20.415
	05-14 RG2 TOC	24.55
	05-14 STORM DOC	5.445
	05-14 STORM TOC	5.775
28	05-15 RG1 DOC	34.605
	05-15 RG1 TOC	32.87
	05-15 RG2 DOC	24.56
	05-15 RG2 TOC	25.975
	05-15 STORM DOC	9.78
	05-15 STORM TOC	5.195
29	05-16 RG1 DOC	24.935
	05-16 RG1 TOC	30.595
	05-16 RG2 DOC	20.195
	05-16 RG2 TOC	18.265
	05-16 STORM DOC	3.397

Day	Sample name	Concentration [mg/L]
	05-16 STORM TOC	1.413
30	05-17 RG1 DOC	29.685
	05-17 RG1 TOC	29.24
	05-17 RG1/2 TOC	28.4
	05-17 RG2 DOC	20.4
	05-17 RG2 TOC	24.655
	05-17 RG2/2 DOC	15.955
	05-17 RG2/2 TOC	18.56
	05-17 STORM DOC	6.43
	05-17 STORM TOC	2.6625
31	05-20 RG1 DOC	36.005
	05-20 RG1 TOC	41.595
	05-20 RG2 DOC	60.35
	05-20 RG2 TOC	65.4
	05-20 STORM DOC	10.5
	05-20 STORM TOC	8.355
32	05-22 RG1 DOC	50.35
	05-22 RG1 TOC	48.62
	05-22 RG2 DOC	38.585
	05-22 RG2 TOC	53.65
	05-22 STORM DOC	5.565
	05-22 STORM TOC	7.01
33	05-23 RG1 DOC	57.7
	05-23 RG1 TOC	66.35
	05-23 RG2 DOC	52.95
	05-23 RG2 TOC	69.35

Organic pollutant concentrations in influent and effluent samples (BC1)

unit = µg/L	applied influent					
	non-spiked stormwater	**spiked stormwater**	**spiked stormwater**	**non-spiked stormwater**	**spiked stormwater**	**spiked stormwater**
Compound	Effluent 2019-03-06	Effluent 2019-03-15	Effluent 2019-03-20	Effluent 2019-03-22	Effluent 2019-03-25	Effluent 2019-03-26
Aliphatics >C5-C8	<10	<10	<10	<10	<10	<10
Aliphatics >C8-C10	<10	<10	<10	<10	<10	<10
Aliphatics >C10-C12	<10	<10	<10	<10	<10	<10
Aliphatics >C12-C16	<10	<10	15	<10	<10	<10
Aliphatics >C5-C16	<20	<20	15	<20	<20	<20
Aliphatics >C16-C35	<10	36	69	17	13	16
Aromatics >C8-C10	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Aromatics >C10-C16	<0.775	<0.775	<0.775	<0.775	<0.775	<0.775
Metylpyrener/metylfluorantener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Metylkrysener/metylbens(a)antracener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aromatics >C16-C35	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Toluene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Ethylbenzene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
M,p-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
O-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
∑ Xylener	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Naphthalene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Acenaphthylene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Acenaphthene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Fluorene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Phenanthrene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Anthracene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Fluoranthene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Pyrene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Benzo[a]anthracene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Chrysene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Benzo[b]fluoranthene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Benzo[k]fluoranthene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Benzo[a]pyrene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Dibenzo[a,h]anthracene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Benzo[ghi]perylene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
Indeno[1,2,3-cd]pyrene	<0.010	<0.014	<0.014	<0.010	<0.010	<0.010
PAH ∑ 16	<0.080	<0.11	<0.11	<0.080	<0.080	<0.080
∑ carcinogenic	<0.035	<0.049	<0.049	<0.035	<0.035	<0.035
∑ non-carcinocgenic	<0.045	<0.063	<0.063	<0.045	<0.045	<0.045
∑ LMW	<0.015	<0.021	<0.021	<0.015	<0.015	<0.015
∑ MMW	<0.025	<0.035	<0.035	<0.025	<0.025	<0.025
∑ HMW	<0.040	<0.056	<0.056	<0.040	<0.040	<0.040

	applied influent					
	non-spiked stormwater	**spiked stormwater**	**spiked stormwater**	**spiked stormwater**	**dry period**	**spiked influent**
Compound	Effluent 2019-03-29	Effluent 2019-04-03	Effluent 2019-04-10	Effluent 2019-04-17		20190503
Aliphatics >C5-C8	<10	<10	<10	<10		265
Aliphatics >C8-C10	<10	<10	<10	<10		1690
Aliphatics >C10-C12	<10	12	16	<10		6820
Aliphatics >C12-C16	<10	11	16	<10		42000
Aliphatics >C5-C16	<20	23	32	<20		51000
Aliphatics >C16-C35	12	29	47	28		101000
Aromatics >C8-C10	<0.30	<0.30	<0.30	<0.30		18.6
Aromatics >C10-C16	<0.775	<0.775	<0.775	<0.775		11.2
Metylpyrener/metylfluorantener	<1.0	<1.0	<1.0	<1.0		<1.0
Metylkrysener/metylbens(a)antracener	<1.0	<1.0	<1.0	<1.0		<1.0
Aromatics >C16-C35	<1.0	<1.0	<1.0	<1.0		<1.0
Benzene	<0.20	<0.20	<0.20	<0.20		<0.20
Toluene	<0.20	<0.20	<0.20	<0.20		<0.20
Ethylbenzene	<0.20	<0.20	<0.20	<0.20		0.52
M,p-xylen	<0.20	<0.20	<0.20	<0.20		3.43
O-xylen	<0.20	<0.20	<0.20	<0.20		1.49
∑ Xylener	<0.20	<0.20	<0.20	<0.20		4.9
Naphthalene	<0.010	<0.014	<0.014	<0.010		2.1
Acenaphthylene	<0.010	<0.014	<0.014	<0.010		1.41
Acenaphthene	<0.010	<0.014	<0.014	<0.010		2.95
Fluorene	<0.010	<0.014	<0.014	<0.010		0.083
Phenanthrene	<0.010	<0.014	<0.014	<0.010		0.315
Anthracene	<0.010	<0.014	<0.014	<0.010		<0.014
Fluoranthene	<0.010	<0.014	<0.014	<0.010		0.039
Pyrene	<0.010	<0.014	<0.014	<0.010		0.027
Benzo[a]anthracene	<0.010	<0.014	<0.014	<0.010		<0.014
Chrysene	<0.010	<0.014	<0.014	<0.010		<0.014
Benzo[b]fluoranthene	<0.010	<0.014	<0.014	<0.010		<0.014
Benzo[k]fluoranthene	<0.010	<0.014	<0.014	<0.010		<0.014
Benzo[a]pyrene	<0.010	<0.014	<0.014	<0.010		<0.014
Dibenzo[a,h]anthracene	<0.010	<0.014	<0.014	<0.010		<0.014
Benzo[ghi]perylene	<0.010	<0.014	<0.014	<0.010		<0.014
Indeno[1,2,3-cd]pyrene	<0.010	<0.014	<0.014	<0.010		<0.014
PAH ∑ 16	<0.080	<0.11	<0.11	<0.080		6.9
∑ carcinogenic	<0.035	<0.049	<0.049	<0.035		<0.049
∑ non-carcinocgenic	<0.045	<0.063	<0.063	<0.045		6.9
∑ LMW	<0.015	<0.021	<0.021	<0.015		6.5
∑ MMW	<0.025	<0.035	<0.035	<0.025		0.46
∑ HMW	<0.040	<0.056	<0.056	<0.040		<0.056

	applied influent					
	non-spiked stormwater	**spiked stormwater**	**spiked stormwater**	**spiked stormwater**	**non-spiked stormwater**	**non-spiked influent**
Compound	Effluent 2019-05-03	Effluent 2019-05-06	Effluent 2019-05-08	Effluent 2019-05-10	Effluent 2019-05-13	20190514
Aliphatics >C5-C8	<10	<10	<10	<10	<10	<10
Aliphatics >C8-C10	<10	<10	<10	<10	<10	<10
Aliphatics >C10-C12	<10	<10	<10	<10	<10	<10
Aliphatics >C12-C16	10	13	17	16	14	<10
Aliphatics >C5-C16	10	13	17	16	14	<20
Aliphatics >C16-C35	25	39	62	60	51	11
Aromatics >C8-C10	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Aromatics >C10-C16	<0.775	<0.775	<0.775	<0.775	<0.775	<0.775
Metylpyrener/metylfluorantener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Metylkrysener/metylbens(a)antracener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aromatics >C16-C35	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Toluene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Ethylbenzene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
M,p-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
O-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
∑ Xylener	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Naphthalene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Acenaphthylene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Acenaphthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Fluorene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Phenanthrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[a]anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Chrysene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[b]fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[k]fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[a]pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Dibenzo[a,h]anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[ghi]perylene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Indeno[1,2,3-cd]pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
PAH ∑ 16	<0.080	<0.080	<0.080	<0.080	<0.080	<0.080
∑ carcinogenic	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
∑ non-carcinocgenic	<0.045	<0.045	<0.045	<0.045	<0.045	<0.045
∑ LMW	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
∑ MMW	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
∑ HMW	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040

	applied influent					
	spiked stormwater	**non-spiked stormwater**	**spiked stormwater**	**non-spiked stormwater**	**spiked stormwater**	**non-spiked Influent**
Compound	Effluent 2019-05-14	Effluent 2019-05-15	Effluent 2019-05-16	Effluent 2019-05-17	Effluent 1 2019-05-17	20190520
Aliphatics >C5-C8	<10	<10	<10	<10	<10	<10
Aliphatics >C8-C10	<10	<10	<10	<10	<10	<10
Aliphatics >C10-C12	<10	<10	<10	<10	<10	<10
Aliphatics >C12-C16	<10	<10	<10	<10	<10	<10
Aliphatics >C5-C16	19	12	<10	10	13	<10
Aliphatics >C16-C35	19	12	<20	10	13	<20
Aromatics >C8-C10	77	41	25	30	55	28
Aromatics >C10-C16	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Metylpyrener/metylfluorantener	<0.775	<0.775	<0.775	<0.775	<0.775	<0.775
Metylkrysener/metylbens(a)antracener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aromatics >C16-C35	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Toluene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Ethylbenzene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
M,p-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
O-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
∑ Xylener	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Naphthalene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Acenaphthylene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Acenaphthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Fluorene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Phenanthrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	0.016
Benzo[a]anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	0.016
Chrysene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[b]fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	0.012
Benzo[k]fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.058	<0.010
Benzo[a]pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Dibenzo[a,h]anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[ghi]perylene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Indeno[1,2,3-cd]pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
PAH ∑ 16	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
∑ carcinogenic	<0.080	<0.080	<0.080	<0.080	<0.10	0.044
∑ non-carcinocgenic	<0.035	<0.035	<0.035	<0.035	<0.059	0.012
∑ LMW	<0.045	<0.045	<0.045	<0.045	<0.045	0.032
∑ MMW	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
∑ HMW	<0.025	<0.025	<0.025	<0.025	<0.025	0.032

	applied influent					
	petrol spiked stormwater	**spiked influent**	**petrol spiked stormwater**	**petrol spiked stormwater**	**petrol spiked stormwater**	**non-spiked stormwater**
Compound	Effluent 2019-05-20	20190522	Effluent 1 2019-05-22	Effluent 2 2019-05-22	Effluent 3 2019-05-22	Effluent 2019-05-23
Aliphatics >C5-C8	<10	<10	<10	<10	<10	<10
Aliphatics >C8-C10	<10	2790	<10	<10	<10	<10
Aliphatics >C10-C12	<10	<1000	<10	<10	<10	<10
Aliphatics >C12-C16	<10	26	<10	<10	<10	<10
Aliphatics >C5-C16	19	43	20	18	39	29
Aliphatics >C16-C35	19	2900	20	18	39	29
Aromatics >C8-C10	83	351	35	30	135	90
Aromatics >C10-C16	3.42	7920	0.58	0.69	0.74	1.13
Metylpyrener/metylfluorantener	<0.775	85.3	<0.775	<0.775	0.075	0.05
Metylkrysener/metylbens(a)antracener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aromatics >C16-C35	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Toluene	8.3	3330	<0.20	54.9	23.3	0.6
Ethylbenzene	22.5	19500	<0.20	61	13.7	<0.20
M,p-xylen	1.03	1410	0.67	1.25	<0.20	<0.20
O-xylen	5.28	6920	<0.20	3.87	8.53	22.9
∑ Xylener	2.79	2900	1.72	4.13	7.53	14.2
Naphthalene	8.1	9800	1.7	8	16	37
Acenaphthylene	0.228	157	<0.014	<0.014	<0.014	<0.014
Acenaphthene	<0.010	0.098	<0.014	<0.014	<0.014	<0.014
Fluorene	<0.010	0.586	<0.014	<0.014	<0.014	<0.014
Phenanthrene	<0.010	1.19	<0.014	<0.014	<0.014	<0.014
Anthracene	<0.010	1.63	<0.014	<0.014	<0.014	<0.014
Fluoranthene	<0.010	0.303	<0.014	<0.014	<0.014	<0.014
Pyrene	<0.010	0.156	<0.014	<0.014	<0.014	<0.014
Benzo[a]anthracene	<0.010	0.272	<0.014	<0.014	<0.014	<0.014
Chrysene	<0.010	0.062	<0.014	<0.014	<0.014	<0.014
Benzo[b]fluoranthene	<0.010	0.045	<0.014	<0.014	<0.014	<0.014
Benzo[k]fluoranthene	<0.010	0.03	<0.014	<0.014	<0.014	<0.014
Benzo[a]pyrene	<0.010	<0.014	<0.014	<0.014	<0.014	<0.014
Dibenzo[a,h]anthracene	<0.010	0.021	<0.014	<0.014	<0.014	<0.014
Benzo[ghi]perylene	<0.010	<0.014	<0.014	<0.014	<0.014	<0.014
Indeno[1,2,3-cd]pyrene	<0.010	0.038	<0.014	<0.014	<0.014	<0.014
PAH ∑ 16	<0.010	<0.014	<0.014	<0.014	<0.014	<0.014
∑ carcinogenic	0.23	160	<0.11	<0.11	<0.11	<0.11
∑ non-carcinocgenic	<0.035	0.16	<0.049	<0.049	<0.049	<0.049
∑ LMW	0.23	160	<0.063	<0.063	<0.063	<0.063
∑ MMW	0.23	160	<0.021	<0.021	<0.021	<0.021
∑ HMW	<0.025	3.6	<0.035	<0.035	<0.035	<0.035

Organic pollutant concentrations in influent and effluent samples (BC2)

unit = µg/L	applied influent					
	non-spiked stormwater	**spiked stormwater**	**non-spiked stormwater**	**non-spiked stormwater**	**spiked stormwater**	**dry period**
Compound	First effluent 2019-04-03	Effluent 2019-04-10	Effluent 2019-04-12	Effluent 2019-04-15	Effluent 2019-04-17	
Aliphatics >C5-C8	<10	<10	<10	<10	<10	
Aliphatics >C8-C10	<10	<10	<10	<10	<10	
Aliphatics >C10-C12	15	<10	<10	<10	<10	
Aliphatics >C12-C16	10	<10	<10	<10	<10	
Aliphatics >C5-C16	25	<20	<20	<20	<20	
Aliphatics >C16-C35	35	28	21	22	24	
Aromatics >C8-C10	<0.30	<0.30	<0.30	<0.30	<0.30	
Aromatics >C10-C16	<0.775	<0.775	<0.775	<0.775	<0.775	
Metylpyrener/metylfluorantener	<1.0	<1.0	<1.0	<1.0	<1.0	
Metylkrysener/metylbens(a)antracener	<1.0	<1.0	<1.0	<1.0	<1.0	
Aromatics >C16-C35	<1.0	<1.0	<1.0	<1.0	<1.0	
Benzene	<0.20	<0.20	<0.20	<0.20	<0.20	
Toluene	<0.20	<0.20	<0.20	<0.20	<0.20	
Ethylbenzene	<0.20	<0.20	<0.20	<0.20	<0.20	
M,p-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	
O-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	
∑ Xylener	<0.20	<0.20	<0.20	<0.20	<0.20	
Naphthalene	<0.014	<0.010	<0.010	<0.010	<0.010	
Acenaphthylene	<0.014	<0.010	<0.010	<0.010	<0.010	
Acenaphthene	<0.014	<0.010	<0.010	<0.010	<0.010	
Fluorene	<0.014	<0.010	<0.010	<0.010	<0.010	
Phenanthrene	<0.014	<0.010	<0.010	<0.010	<0.010	
Anthracene	<0.014	<0.010	<0.010	<0.010	<0.010	
Fluoranthene	<0.014	<0.010	<0.010	<0.010	<0.010	
Pyrene	<0.014	<0.010	<0.010	<0.010	<0.010	
Benzo[a]anthracene	<0.014	<0.010	<0.010	<0.010	<0.010	
Chrysene	<0.014	<0.010	<0.010	<0.010	<0.010	
Benzo[b]fluoranthene	0.017	<0.010	<0.010	<0.010	<0.010	
Benzo[k]fluoranthene	<0.014	<0.010	<0.010	<0.010	<0.010	
Benzo[a]pyrene	<0.014	<0.010	<0.010	<0.010	<0.010	
Dibenzo[a,h]anthracene	<0.014	<0.010	<0.010	<0.010	<0.010	
Benzo[ghi]perylene	<0.014	<0.010	<0.010	<0.010	<0.010	
Indeno[1,2,3-cd]pyrene	<0.014	<0.010	<0.010	<0.010	<0.010	
PAH ∑ 16	0.017	<0.080	<0.080	<0.080	<0.080	
∑ carcinogenic	0.017	<0.035	<0.035	<0.035	<0.035	
∑ non-carcinocgenic	<0.063	<0.045	<0.045	<0.045	<0.045	
∑ LMW	<0.021	<0.015	<0.015	<0.015	<0.015	
∑ MMW	<0.035	<0.025	<0.025	<0.025	<0.025	
∑ HMW	0.017	<0.040	<0.040	<0.040	<0.040	

	applied influent					
	spiked influent	**non-spiked stormwater**	**spiked stormwater**	**non-spiked stormwater**	**spiked stormwater**	**non-spiked stormwater**
Compound	20190503	Effluent 2019-05-03	Effluent 2019-05-06	Effluent 2019-05-08	Effluent 2019-05-10	Effluent 2019-05-13
Aliphatics >C5-C8	265	<10	<10	<10	<10	<10
Aliphatics >C8-C10	1690	<10	<10	<10	<10	<10
Aliphatics >C10-C12	6820	<10	<10	<10	<10	<10
Aliphatics >C12-C16	42000	<10	<10	<10	<10	<10
Aliphatics >C5-C16	51000	<20	<20	<20	<20	<20
Aliphatics >C16-C35	101000	12	21	17	29	19
Aromatics >C8-C10	18.6	<0.30	<0.30	<0.30	<0.30	<0.30
Aromatics >C10-C16	11.2	<0.775	<0.775	<0.775	<0.775	<0.775
Metylpyrener/metylfluorantener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Metylkrysener/metylbens(a)antracener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aromatics >C16-C35	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Toluene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Ethylbenzene	0.52	<0.20	<0.20	<0.20	<0.20	<0.20
M,p-xylen	3.43	<0.20	<0.20	<0.20	<0.20	<0.20
O-xylen	1.49	<0.20	<0.20	<0.20	<0.20	<0.20
∑ Xylener	4.9	<0.20	<0.20	<0.20	<0.20	<0.20
Naphthalene	2.1	<0.010	<0.010	<0.010	<0.010	<0.010
Acenaphthylene	1.41	<0.010	<0.010	<0.010	<0.010	<0.010
Acenaphthene	2.95	<0.010	<0.010	<0.010	<0.010	<0.010
Fluorene	0.083	<0.010	<0.010	<0.010	<0.010	<0.010
Phenanthrene	0.315	<0.010	<0.010	<0.010	<0.010	<0.010
Anthracene	<0.014	<0.010	<0.010	<0.010	<0.010	<0.010
Fluoranthene	0.039	<0.010	<0.010	<0.010	<0.010	<0.010
Pyrene	0.027	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[a]anthracene	<0.014	<0.010	<0.010	<0.010	<0.010	<0.010
Chrysene	<0.014	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[b]fluoranthene	<0.014	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[k]fluoranthene	<0.014	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[a]pyrene	<0.014	<0.010	<0.010	<0.010	<0.010	<0.010
Dibenzo[a,h]anthracene	<0.014	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[ghi]perylene	<0.014	<0.010	<0.010	<0.010	<0.010	<0.010
Indeno[1,2,3-cd]pyrene	<0.014	<0.010	<0.010	<0.010	<0.010	<0.010
PAH ∑ 16	6.9	<0.080	<0.080	<0.080	<0.080	<0.080
∑ carcinogenic	<0.049	<0.035	<0.035	<0.035	<0.035	<0.035
∑ non-carcinocgenic	6.9	<0.045	<0.045	<0.045	<0.045	<0.045
∑ LMW	6.5	<0.015	<0.015	<0.015	<0.015	<0.015
∑ MMW	0.46	<0.025	<0.025	<0.025	<0.025	<0.025
∑ HMW	<0.056	<0.040	<0.040	<0.040	<0.040	<0.040

	applied influent					
	non-spiked influent	**spiked stormwater**	**non-spiked stormwater**	**spiked stormwater**	**non-spiked stormwater**	**spiked stormwater**
Compound	20190514	Effluent 2019-05-14	Effluent 2019-05-15	Effluent 2019-05-16	Effluent 2019-05-17	Effluent 1 2019-05-17
Aliphatics >C5-C8	<10	<10	<10	<10	<10	<10
Aliphatics >C8-C10	<10	<10	<10	<10	<10	<10
Aliphatics >C10-C12	<10	<10	<10	<10	<10	<10
Aliphatics >C12-C16	<10	<10	<10	<10	<10	<10
Aliphatics >C5-C16	<20	<20	<20	<20	<20	<20
Aliphatics >C16-C35	11	27	14	20	14	39
Aromatics >C8-C10	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Aromatics >C10-C16	<0.775	<0.775	<0.775	<0.775	<0.775	<0.775
Metylpyrener/metylfluorantener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Metylkrysener/metylbens(a)antracener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aromatics >C16-C35	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Toluene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Ethylbenzene	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
M,p-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
O-xylen	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
∑ Xylener	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Naphthalene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Acenaphthylene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Acenaphthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Fluorene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Phenanthrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[a]anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Chrysene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[b]fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.050
Benzo[k]fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[a]pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Dibenzo[a,h]anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo[ghi]perylene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Indeno[1,2,3-cd]pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
PAH ∑ 16	<0.080	<0.080	<0.080	<0.080	<0.080	<0.10
∑ carcinogenic	<0.035	<0.035	<0.035	<0.035	<0.035	<0.055
∑ non-carcinocgenic	<0.045	<0.045	<0.045	<0.045	<0.045	<0.045
∑ LMW	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
∑ MMW	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
∑ HMW	<0.040	<0.040	<0.040	<0.040	<0.040	<0.060

	applied influent					
	non-spiked Influent	**petrol spiked stormwater**	**spiked influent**	**petrol spiked stormwater**	**petrol spiked stormwater**	**petrol spiked stormwater**
Compound	20190520	Effluent 2019-05-20	20190522	Effluent 1 2019-05-22	Effluent 2 2019-05-22	Effluent 3 2019-05-22
Aliphatics >C5-C8	<10	<10	2790	<100	<100	<10
Aliphatics >C8-C10	<10	<10	<1000	<100	<100	<10
Aliphatics >C10-C12	<10	<10	26	<10	<10	<10
Aliphatics >C12-C16	<10	14	43	<10	<10	29
Aliphatics >C5-C16	<20	14	2900	<110	<110	29
Aliphatics >C16-C35	28	51	351	<10	<10	96
Aromatics >C8-C10	<0.30	11.3	7920	4.25	2.83	24.2
Aromatics >C10-C16	<0.775	<0.775	85.3	<0.775	<0.775	0.057
Metylpyrener/metylfluorantener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Metylkrysener/metylbens(a)antracener	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Aromatics >C16-C35	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Benzene	<0.20	130	3330	<2.00	75.9	228
Toluene	<0.20	278	19500	<2.00	105	467
Ethylbenzene	<0.20	14.8	1410	<2.00	3.58	28.1
M,p-xylen	<0.20	71.4	6920	8.32	11.6	133
O-xylen	<0.20	36.3	2900	<2.00	13.2	80.5
∑ Xylener	<0.20	110	9800	8.3	25	210
Naphthalene	<0.010	0.307	157	0.06	0.059	0.561
Acenaphthylene	<0.010	<0.010	0.098	<0.010	<0.010	<0.014
Acenaphthene	<0.010	<0.010	0.586	<0.010	<0.010	<0.014
Fluorene	<0.010	<0.010	1.19	<0.010	<0.010	<0.014
Phenanthrene	<0.010	<0.010	1.63	<0.010	<0.010	<0.014
Anthracene	<0.010	<0.010	0.303	<0.010	<0.010	<0.014
Fluoranthene	0.016	<0.010	0.156	<0.010	<0.010	<0.014
Pyrene	0.016	<0.010	0.272	<0.010	<0.010	<0.014
Benzo[a]anthracene	<0.010	<0.010	0.062	<0.010	<0.010	<0.014
Chrysene	0.012	<0.010	0.045	<0.010	<0.010	<0.014
Benzo[b]fluoranthene	<0.010	<0.010	0.03	<0.010	<0.010	<0.014
Benzo[k]fluoranthene	<0.010	<0.010	<0.014	<0.010	<0.010	<0.014
Benzo[a]pyrene	<0.010	<0.010	0.021	<0.010	<0.010	<0.014
Dibenzo[a,h]anthracene	<0.010	<0.010	<0.014	<0.010	<0.010	<0.014
Benzo[ghi]perylene	<0.010	<0.010	0.038	<0.010	<0.010	<0.014
Indeno[1,2,3-cd]pyrene	<0.010	<0.010	<0.014	<0.010	<0.010	<0.014
PAH ∑ 16	0.044	0.31	160	0.06	0.059	0.56
∑ carcinogenic	0.012	<0.035	0.16	<0.035	<0.035	<0.049
∑ non-carcinocgenic	0.032	0.31	160	0.06	0.059	0.56
∑ LMW	<0.015	0.31	160	0.06	0.059	0.56
∑ MMW	0.032	<0.025	3.6	<0.025	<0.025	<0.035
∑ HMW	0.012	<0.040	0.2	<0.040	<0.040	<0.056

	applied influent
	non-spiked stormwater
Compound	effluent 2019-05-23
Aliphatics >C5-C8	<10
Aliphatics >C8-C10	<10
Aliphatics >C10-C12	<10
Aliphatics >C12-C16	15
Aliphatics >C5-C16	15
Aliphatics >C16-C35	62
Aromatics >C8-C10	15.4
Aromatics >C10-C16	<0.775
Metylpyrener/metylfluorantener	<1.0
Metylkrysener/metylbens(a)antracener	<1.0
Aromatics >C16-C35	<1.0
Benzene	122
Toluene	179
Ethylbenzene	14.4
M,p-xylen	113
O-xylen	70.6
∑ Xylener	180
Naphthalene	0.225
Acenaphthylene	<0.010
Acenaphthene	<0.010
Fluorene	<0.010
Phenanthrene	<0.010
Anthracene	<0.010
Fluoranthene	<0.010
Pyrene	<0.010
Benzo[a]anthracene	<0.010
Chrysene	<0.010
Benzo[b]fluoranthene	<0.010
Benzo[k]fluoranthene	<0.010
Benzo[a]pyrene	<0.010
Dibenzo[a,h]anthracene	<0.010
Benzo[ghi]perylene	<0.010
Indeno[1,2,3-cd]pyrene	<0.010
PAH ∑ 16	0.23
∑ carcinogenic	<0.035
∑ non-carcinocgenic	0.23
∑ LMW	0.23
∑ MMW	<0.025
∑ HMW	<0.040

Organic pollutant concentrations in unused soil of BC1

Sampling date: 2019-03-05

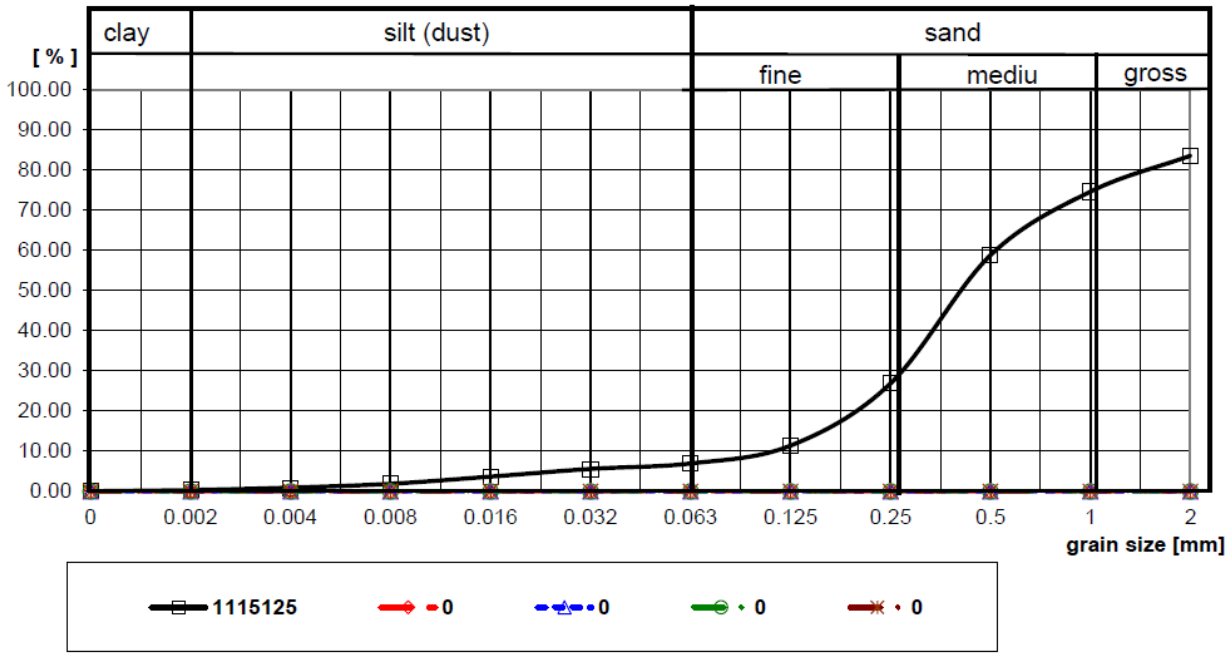
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
TS_105°C	76.7		%	1	O	JOHE
alifater >C5-C8	<10		mg/kg TS	2	J	AMLU
alifater >C8-C10	<10		mg/kg TS	2	J	NOSA
alifater >C10-C12	<20		mg/kg TS	2	J	NOSA
alifater >C12-C16	<20		mg/kg TS	2	J	NOSA
alifater >C5-C16 *	<30		mg/kg TS	2	N	AMLU
alifater >C16-C35	45		mg/kg TS	2	J	NOSA
aromater >C8-C10	<1		mg/kg TS	2	J	NOSA
aromater >C10-C16	<1		mg/kg TS	2	J	NOSA
metylpyrener/metylfluorantener *	<1		mg/kg TS	2	N	NOSA
metylkrysener/metylbens(a)antracener *	<1		mg/kg TS	2	N	NOSA
aromater >C16-C35	<1		mg/kg TS	2	J	NOSA
bensen	<0.01		mg/kg TS	2	J	AMLU
toluen	<0.05		mg/kg TS	2	J	AMLU
etylbensen	<0.05		mg/kg TS	2	J	AMLU
m,p-xylen	<0.05		mg/kg TS	2	J	AMLU
o-xylen	<0.05		mg/kg TS	2	J	AMLU
xylener, summa *	<0.05		mg/kg TS	2	N	AMLU
TEX, summa *	<0.1		mg/kg TS	2	N	AMLU
naftalen	<0.1		mg/kg TS	2	J	NOSA
acenaftylen	<0.1		mg/kg TS	2	J	NOSA
acenaften	<0.1		mg/kg TS	2	J	NOSA
fluoren	<0.1		mg/kg TS	2	J	NOSA
fenantren	<0.1		mg/kg TS	2	J	NOSA
antracen	<0.1		mg/kg TS	2	J	NOSA
fluoranten	<0.1		mg/kg TS	2	J	NOSA
pyren	<0.1		mg/kg TS	2	J	NOSA
bens(a)antracen	<0.08		mg/kg TS	2	J	NOSA
krysen	<0.08		mg/kg TS	2	J	NOSA
bens(b)fluoranten	<0.08		mg/kg TS	2	J	NOSA
bens(k)fluoranten	<0.08		mg/kg TS	2	J	NOSA
bens(a)pyren	0.33	0.089	mg/kg TS	2	J	NOSA
dibens(ah)antracen	<0.08		mg/kg TS	2	J	NOSA
benso(ghi)perylen	<0.1		mg/kg TS	2	J	NOSA
indeno(123cd)pyren	<0.08		mg/kg TS	2	J	NOSA
PAH, summa 16	<1.5		mg/kg TS	2	D	NOSA
PAH, summa cancerogena *	0.33		mg/kg TS	2	N	NOSA
PAH, summa övriga *	<0.5		mg/kg TS	2	N	NOSA
PAH, summa L *	<0.15		mg/kg TS	2	N	NOSA
PAH, summa M *	<0.25		mg/kg TS	2	N	NOSA
PAH, summa H *	0.33		mg/kg TS	2	N	NOSA
fraktion >2 mm	16.5	1.65	%	3	1	ULKA
fraktion 1-2 mm	8.95	0.89	%	3	1	ULKA
fraktion 0,5-1 mm	15.8	1.58	%	3	1	ULKA

fraktion 0,25-0,5 mm	31.9	3.19	%	3	1	ULKA
fraktion 0,125-0,25 mm	15.5	1.55	%	3	1	ULKA
fraktion 0,063-0,125 mm	4.44	0.44	%	3	1	ULKA
fraktion 0,032-0,063 mm	1.35	0.13	%	3	1	ULKA
fraktion 0,016-0,032 mm	1.92	0.19	%	3	1	ULKA
fraktion 0,008-0,016 mm	1.79	0.18	%	3	1	ULKA
fraktion 0,004-0,008 mm	0.96	0.10	%	3	1	ULKA
fraktion 0,002-0,004 mm	0.60	0.06	%	3	1	ULKA
fraktion <0,002 mm	0.30	0.03	%	3	1	ULKA
se bilaga till rapport	ja			3	1	ULKA

Grain-size distribution curve from the filter media layer of BC1

Attachment no. 1 to the certificate of analysis for work order PR1924624

RESULTS OF GRAIN SIZE ANALYSIS



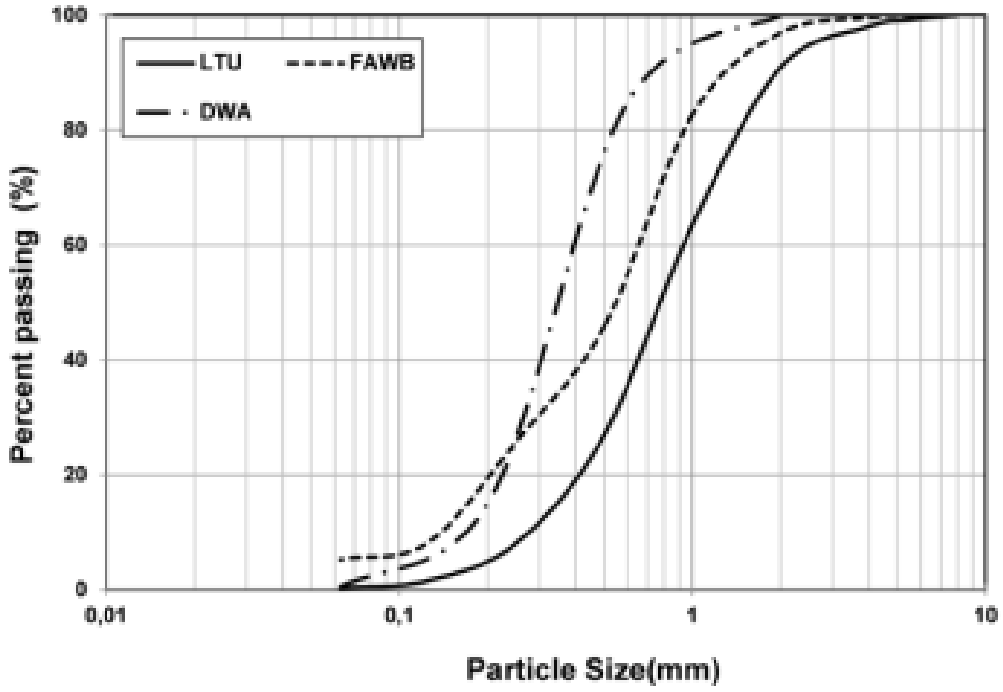
Propterties of the filter media in BC1

Göteborgs Stad
Kretslopp och vatten

Utformning av regnbäddarna vid HSB Living Lab

Regnbädd Luleå-jord (vid slänten)

1. Dräneringslager - 20cm tjockt lager krossad makadam/drängrus i fraktionen 2/6.
2. Skiljelager - 5cm lager tvättad dress sand fraktion ,2-2mm, mullfri.
3. En blandning med olika sand/jordfraktioner enligt heldraget streck i siktkurvan: 25% 0,2-0,5 mm sand, 25% 0,5-1,0 mm sand, 25% 1-2 mm sand, 10% 2-4 mm sand och 15% matjord.



4. Erosionsskydd - erosionsgrus ca 5-7cm tjockt bestående av tvättad natursten i 32/60+.

Växtval från följande lista, anpassade till LTU:s jordblandning:

- Juncus conglomeratus (Knapptåg, återfinns i Sverige både i våta, fuktiga samt torra områden),
- Juncus effusus (Veketåg), Juncus compressus (Stubbtåg vilken är vanlig på våt-fuktig mark och klarar torra perioder bra).
- Caltha palustris (Kabbleka)
- Eupatorium cannabium (Hampflockel)
- Filipendula ulmaria (Älgört)
- Geum rivale (Humleblomster)
- Iris Pseudocarpus (Gul svärdslilja)
- Lysimachia vulgaris (Videört)
- Lythrum salicaria (Fackelblomster)
- Mentah aquatica (Vattenmynta)
- Glyceria maxima (Jättegröe, den är dock invasiv)

Exempelvis väljs Knapptåg Juncus conglomeratus, Rörflen Phalaris arundinacea och Hirsstarr Carex panacea, men ni kan välja fritt de växter som ni tycker passar.

Organic pollutant concentrations in unused soil of BC2

Sampling date: 2019-03-05

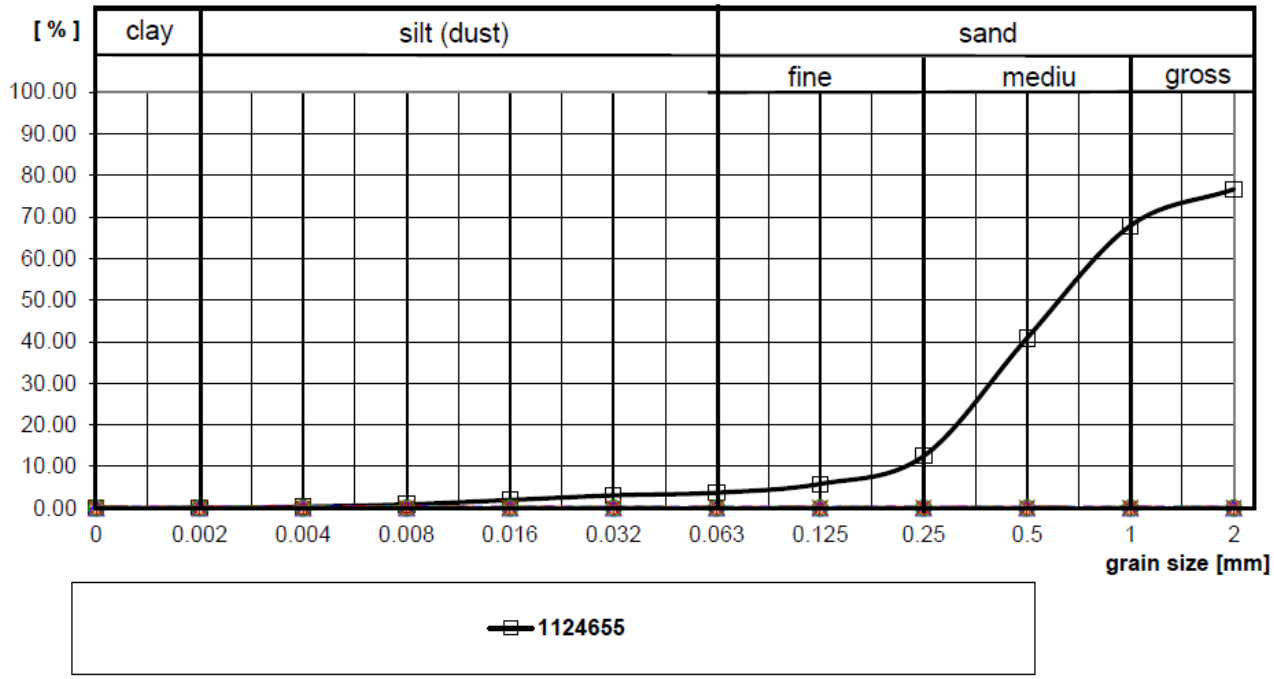
Parameter	Resultat	Osäkerhet (±)	Enhet	Metod	Utf	Sign
TS_105°C	81.3		%	1	O	SONE
alifater >C5-C8	<10		mg/kg TS	2	J	MASU
alifater >C8-C10	<10		mg/kg TS	2	J	ATJA
alifater >C10-C12	<20		mg/kg TS	2	J	ATJA
alifater >C12-C16	<20		mg/kg TS	2	J	ATJA
alifater >C5-C16 *	<30		mg/kg TS	2	N	MASU
alifater >C16-C35	<20		mg/kg TS	2	J	ATJA
aromater >C8-C10	<1		mg/kg TS	2	J	ATJA
aromater >C10-C16	<1		mg/kg TS	2	J	ATJA
metylpyrener/metylfluorantener *	<1		mg/kg TS	2	N	ATJA
metylkrysener/metylbens(a)antracener *	<1		mg/kg TS	2	N	ATJA
aromater >C16-C35	<1		mg/kg TS	2	J	ATJA
bensen	<0.01		mg/kg TS	2	J	MASU
toluen	<0.05		mg/kg TS	2	J	MASU
etylbensen	<0.05		mg/kg TS	2	J	MASU
m,p-xylen	<0.05		mg/kg TS	2	J	MASU
o-xylen	<0.05		mg/kg TS	2	J	MASU
xylener, summa *	<0.05		mg/kg TS	2	N	MASU
TEX, summa *	<0.1		mg/kg TS	2	N	MASU
naftalen	<0.1		mg/kg TS	2	J	ATJA
acenaftylen	<0.1		mg/kg TS	2	J	ATJA
acenaften	<0.1		mg/kg TS	2	J	ATJA
fluoren	<0.1		mg/kg TS	2	J	ATJA
fenantren	<0.1		mg/kg TS	2	J	ATJA
antracen	<0.1		mg/kg TS	2	J	ATJA
fluoranten	<0.1		mg/kg TS	2	J	ATJA
pyren	<0.1		mg/kg TS	2	J	ATJA
bens(a)antracen	<0.08		mg/kg TS	2	J	ATJA
krysen	<0.08		mg/kg TS	2	J	ATJA
bens(b)fluoranten	<0.08		mg/kg TS	2	J	ATJA
bens(k)fluoranten	<0.08		mg/kg TS	2	J	ATJA
bens(a)pyren	<0.08		mg/kg TS	2	J	ATJA
dibens(ah)antracen	<0.08		mg/kg TS	2	J	ATJA
benso(ghi)perylen	<0.1		mg/kg TS	2	J	ATJA
indeno(123cd)pyren	<0.08		mg/kg TS	2	J	ATJA
PAH, summa 16	<1.5		mg/kg TS	2	D	ATJA
PAH, summa cancerogena *	<0.3		mg/kg TS	2	N	ATJA
PAH, summa övriga *	<0.5		mg/kg TS	2	N	ATJA
PAH, summa L *	<0.15		mg/kg TS	2	N	ATJA
PAH, summa M *	<0.25		mg/kg TS	2	N	ATJA
PAH, summa H *	<0.3		mg/kg TS	2	N	ATJA
fraktion >2 mm	23.3	2.33	%	3	1	ULKA
fraktion 1-2 mm	8.78	0.88	%	3	1	ULKA
fraktion 0,5-1 mm	27.0	2.70	%	3	1	ULKA
fraktion 0,25-0,5 mm	28.3	2.83	%	3	1	ULKA

fraktion 0,125-0,25 mm	6.68	0.67	%	3	1	ULKA
fraktion 0,063-0,125 mm	2.11	0.21	%	3	1	ULKA
fraktion 0,032-0,063 mm	0.65	0.06	%	3	1	ULKA
fraktion 0,016-0,032 mm	1.11	0.11	%	3	1	ULKA
fraktion 0,008-0,016 mm	1.06	0.11	%	3	1	ULKA
fraktion 0,004-0,008 mm	0.53	0.05	%	3	1	ULKA
fraktion 0,002-0,004 mm	0.31	0.03	%	3	1	ULKA
fraktion <0,002 mm	0.04	0.004	%	3	1	ULKA
se bilaga till rapport	ja			3	1	ULKA

Grain-size distribution curve from the filter media layer of BC2

Attachment no. 1 to the certificate of analysis for work order PR1934604

RESULTS OF GRAIN SIZE ANALYSIS



Properties of the filter media in BC2

Bara Mineraler AB är marknadsledande i Europa inom förädling av platålera och pimpsten för inblandning i odlingssubstrat för yrkes- mässig odling och anläggning. Med lera som bas, producerar vi också växtvårdande produkter för hortikultur. Bara Mineraler AB är ett innovativt kunskapsföretag med kontinuerlig produktutveckling.
Vi marknadsför och säljer produkterna, i Sverige och övriga Europa, direkt och via återförsäljare.

Bara Mineraler AB | Malmövägen 503, 233 64 Bara | Tel. 040 – 54 22 10 | info@baramineraler.se | www.baramineraler.se

Hekla® Regnbädd

Produkten är ett aktivt substrat baserat på pimpsten, grönkompost och sand som kombinerar gröna miljöer med dagvattenhantering. Dagvatten som leds in över ytan infiltreras snabbt ner i bädden för att sedan absorberas i substratet. Pimpstenens egenskaper bidrar till ett utmärkt odlingssubstrat samtidigt som det är ett effektivt magasin för att buffra och fördröja dagvatten. Växtligheten bidrar samtidigt till att förbruka dagvatten.

RÅVARA Produkten är en blandning av Hekla® Pimpsten (2-8 mm), grönkompost och sand. Finns med tillsats av biokol som tillval.

ANVÄNDNING Produkten är främst avsedd att användas till regnbäddar/biofilter/”rain gardens”.

TILLVERKNING Råvarorna blandas till en homogen blandning. Inblandningen av pimpsten utgör ca 40 volym- procent.

EMBALLAGE Hekla® Regnbädd finns att tillgå som lösvara (ca 900 kg/m^3). Produkten kan också fås förpackad i 1000 liters storsäck och då är vikten per pallast ca 925 kg.

FYSIKALISKA EGENSKAPER

Bulkdensitet, fuktig:	**ca 900 kg/m^3**
Bulkdensitet vid fältkapacitet:	**ca 1400 kg/m^3**
Porvolym, total:	**60 %**
Vattenhållande porvolym vid –30 cm tryck:	**50 %**
Luftfylld porvolym vid –30 cm tryck:	**10 %**

VÄXTNÄRINGSANALYS (typiska värden)

Element	Enhet	Halt
pH		6,5-7,9

KEMISK SAMMANSÄTTNING (typiska värden)

Element	Enhet	Halt
Organiskt	% vikt	4-7

Organic pollutant concentrations in used filter media of BC1 and BC2

TS_105°C unit = mg/kg TS	**BC1 0-3 cm 20190523**	**BC1 3-10 cm 20190523**	**SOIL 10-25 cm 20190523**	**BC1 25-40 cm 20190523**	**BC2 0-3 cm 20190523**	**BC2 3-10 cm 20190523**	**BC2 10-25 cm 20190523**	**BC2 25-40 cm 20190523**
Compound	85.1	80.5	79.9	78.5	85.7	82.2	75.5	75
alifater >C5-C8	<10	<10	<10	<10	14	<10	<10	<10
alifater >C8-C10	<10	<10	<10	<10	35	<10	<10	<10
alifater >C10-C12	230	73	33	<20	350	<20	<20	<20
alifater >C12-C16	5400	1000	380	250	5600	370	78	150
alifater >C5-C16	5600	1100	410	250	6000	370	78	150
alifater >C16-C35	15000	2400	960	690	15000	1100	240	500
aromater >C8-C10	180	6	<1	<1	370	10	1.4	4.3
aromater >C10-C16	3.7	<1	<1	<1	5.7	<1	<1	<1
metylpyrener	<1	<1	<1	<1	<1	<1	<1	<1
metylkrysener	<1	<1	<1	<1	<1	<1	<1	<1
aromater >C16-C35	<1	<1	<1	<1	<1	<1	<1	<1
bensen	0.097	0.01	<0.01	<0.01	0.21	0.085	<0.01	0.023
toluen	18	1	<0.05	<0.05	39	0.95	0.062	0.13
etylbensen	16	0.52	<0.05	<0.05	20	0.18	<0.05	<0.05
m,p-xylen	82	3	<0.05	<0.05	86	1.7	<0.05	0.11
o-xylen	42	1.8	<0.05	0.06	44	1.3	<0.05	0.07
xylener, summa	120	4.8	<0.05	0.06	130	3	<0.05	0.18
TEX, summa	160	6.3	<0.1	0.06	190	4.1	0.062	0.31
naftalen	6.1	0.29	<0.1	<0.1	7.5	0.21	<0.1	0.14
acenaftylen	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
acenaften	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
fluoren	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
fenantren	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
antracen	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
fluoranten	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
pyren	<0.1	<0.1	<0.1	<0.1	0.13	<0.1	<0.1	<0.1
bens(a)antracen	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
krysen	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
bens(b)fluoranten	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
bens(k)fluoranten	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
bens(a)pyren	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
dibens(ah)antracen	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
benso(ghi)perylen	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
indeno(123cd)pyren	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08
PAH, summa 16	6.1	<1.5	<1.5	<1.5	7.6	<1.5	<1.5	<1.5
PAH, summa cancerogena	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
PAH, summa övriga	6.1	0.29	<0.5	<0.5	7.6	0.21	<0.5	0.14
PAH, summa L	6.1	0.29	<0.15	<0.15	7.5	0.21	<0.15	0.14
PAH, summa M	<0.25	<0.25	<0.25	<0.25	0.13	<0.25	<0.25	<0.25
PAH, summa H	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3