CHALMERS
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Multi-Criteria Analysis of Sustainable Management Practices for Polluted Road Runoff

Case Study in Vitsippsbäcken, Gothenburg

Master's thesis in the Master's Programme Infrastructure and Environmental Engineering

SOFIA POLO RUIZ DE ARECHAVALETA

Department of Architecture and Civil Engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018
Examensarbete ACEX30-18-85

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Abstract

Globalization trends and climate change are affecting the way population and precipitation are being distributed. High percentage of population is expected to be moving to urban areas in the coming decades which will increase the contamination loads. Less frequent but more intense rains are expected, and therefore, the way water needs to be handeled in urban areas will be a challenge. The aim of this report is to examine the current quality of a recipient surface water-body, and to find the most effective solution for stormwater pollutant reduction and management based on a MCA (Multi-Criteria Analysis). The small stream Vitsippsbäcken was used as a case-study area and receives stormwater from a highly urbanized catchment area (43 ha), covering Sahlgrenska Hospital and parts of Guldheden. Several water quality studies have been conducted in the last 15 years by the City of Gothenburg and according to these studies the main pollutants in the area are Cu, Hg, Pb, Cr and Zn. All stormwater pollutants end up in the small stream since there is no treatment prior to discharge. There is a lack of a solution that reduces the pollution to an extent that Vitsippsbäcken can be classified as a water-body of "good status", according to the European Water Framework Directive. A complex method, based on theoretical and practical activities is followed throughout the report: review of stormwater treatment techniques, calculation of areas, flows and volumes, questionnaires, development of two models (StormTac and Web-HIPRE), sampling and analysis of laboratory results. All the information gathered in these activities is used as an input for the final MCA and the sensitivity analysis conducted in the Web-HIPRE model. Eleven stormwater techniques are reviewed divided in three groups; retention/detention, end-of-pipe, road runoff treatment techniques. Six different stakeholders are identified and the weights for the MCA are obtained through a questionnaire. Based on sampling results, Cu and Zn are defined as the target pollutants. The sampling results corroborate that Vitsippsbäcken cannot be classified as water-body of "good status". With the MCA a ranking of alternatives is obtained being the rain garden on top. The most suitable solution for Vitsippsbäcken is combining the retrofitting of existing detention pond and implementing biofiltration systems. Uncertainties are found in the MCA approach (cost) and sensitive aspects are observed in the weighting. This approach presents a subjective character since the preferences of the stakeholders are an essential part of it, but at the same time it is a useful tool that allows transparency between all parties involved and the sharing of essential information. The area is a dense urban area that needs coherent and exhaustive planning and collaboration between departments and land owners. Therefore, the jurisdiction, rights and responsibilities of each department of the City of Gothenburg and entity involved in this area need to be thoroughly defined in order to avoid any unclear situations or further conflicts. The performed analysis allows the extrapolation of data to other areas as well as to less localized areas. The exclusion criteria defined, such as area availability or flow treatment capacity allow not only local implementation restrictions but can as well be used in the city level.

Keywords: stormwater, management, treatment, sustainable, technique, StormTac, Web-HIPRE, MCA.

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Sofia Polo Ruiz de Arechavaleta, Gothenburg, June 2018

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1 Introduction

In the coming decades, the highest rates of urbanization will take place in urban centers with around 500.000 - 1.000.000 inhabitants (United Nations, 2014). This will have a direct effect on the urban density growth, traffic growth and wastewater production, among other effects. The traffic is a major cause of diffuse pollution and the increase in traffic will lead to higher emissions of particles, CO_2, hydrocarbons, metals, etc. Therefore, an early action to prevent and minimize the diffuse contamination in urban areas, much of which will end up in natural waters, is necessary.

The concentration of contaminants in road runoff varies depending on natural and human factors (Butler & Davies, 2004). The three main natural factors are geology, hydrogeology and climate. Some examples are geological background of the area, precipitation, wind direction, conductivity of the soil, etc. The most relevant human factors affecting road runoff are asphalt and pavement type, traffic intensity and mode, and euro-class of vehicles (WHO, 1996). It is important to evaluate the impact of the traffic-related contaminants and find solutions to mitigate or minimize their effects on receiving waters. The present project analyses different alternatives for stormwater treatment that can be implemented in Gothenburg (Sweden) based on performed quality assessment and specific site needs. This analysis is performed following the structure of Multi-Criteria Analysis (MCA), previously used for environmental problems (Rosén et al, 2015; Munier, 2011).

In the past 15 years, Vitsippsbäcken urban catchment (43 ha) has been subject to several studies by the City of Gothenburg to evaluate sources, pathways and levels of stormwater pollution (Göteborgs Kommun, 2007; Tegelberg & Svensson, 2011; DHI, 2016; Björgaas, 2017). Based on these reports, the main pollution sources are the copper roofs, the hospital and diffuse contamination from traffic. The main contamination pathway is the road runoff and the largest natural water input comes from a large green hilly area. According to these reports, the main pollutants found in high concentrations are Cu, Hg, Pb, Cr and Zn. Today, there is a lack of a systematic or combined solution that reduces the pollution to an extent that Vitsippsbäcken can be classified as a water-body of "good status" according to the European Water Framework Directive. Some of the pollution, especially Cu from roofs, was reduced by the stormwater facility at Sahlgrenska hospital. However, pollution remains a concern and needs to be solved. Some possible solutions have been tested, including filter installation in gully pots and weekly street sweeping. An end-of-pipe solution (Eco-vault) has as well been proposed and modelled in StormTac.

The stream Vitsippsbäcken receives stormwater and flows through the natural reserve connected to the Botanical garden. (Green, 2017). The presence of high concentrations of Cu, Hg, Pb, Cr and Zn demonstrates the need to conduct research to estimate the contribution of each of the contamination sources and to suggest treatment techniques to reduce the release of contaminants into Vitsippsbäcken. Currently there is a small detention facility situated in the stream's watershed adjacent to Sahlgrenska Hospital constructed for flooding protection reasons. The detention facility aims to retain the natural stormwater mainly from a sloped green area . Stormwater from this natural area is relatively clean and enters the stormwater pipe with high speed, which increases the flow at the discharge point and complicates the optimum management of the water.

1.1 Aim and objectives

The aim of this project is to develop and test a multi-criteria analysis approach (MCA) to find the best solutions for stormwater management. To be able to develop the MCA method, the impact of stormwater on the water quality of Vitsippsbäcken in Gothenburg is used as case study area. For this purpose, a wide review of stormwater treatment methods is performed, together with different analyses in several locations of Vitsippsbäcken to evaluate the current status of the water and to find the most suitable locations for the treatment facilities. A MCA is conducted in order to involve stakeholders and find the optimum solution for the whole catchment area, taking economic, technical, environmental and social criteria into account.

The optimum solution might be a combination of different measures, and therefore, the MCA can help to evaluate the efficiency, cost, social and environmental impact of different stormwater management measures. This study can be further used as a planning tool for the construction of a system-wide solution and is conducted in close collaboration with the Department of Sustainable Waste and Water, City of Gothenburg (Kretslopp och Vatten).

1.1.1 Hypotheses

Stormwater sampling in the main sewer of the catchment area as well as moss sampling in Vitsippsbäcken, have already been conducted by the municipality, and the levels of toxic trace metals are high (DHI, 2016). Therefore, the main hypotheses are:

1. The concentrations of heavy metals in Vitsippsbäcken downstream the existing main stormwater sewer outlet are high and therefore, do not fulfill the municipal stormwater quality guidelines.
2. After the existing stormwater outlet from the Sahlgrenska Hospital area, there are high concentrations of heavy metals in Vitsippsbäcken; hence, the treatment facility installed does not work optimally for stormwater treatment.
3. Street sweeping is an efficient alternative to reduce traffic-related pollution; in combination with the implementation of another sustainable treatment alternative, stormwater quality can be further improved

1.1.2 Research question

To set the frame of the literature review about the treatment techniques and the goal of the MCA, five research questions are proposed:

1. What is the current level of contaminants in the surface water and sediments in Vitsippsbäcken stream?
2. What are the available treatment techniques for stormwater?
3. What are the pollutant removal efficiency, costs, advantages/disadvantages and maintenance requirements for the different treatment techniques?
4. Which criteria are relevant to consider in the MCA and how can the stakeholders be involved?
5. Which is the most sustainable and suitable solution for Vitsippsbäcken catchment area?

1.1.3 Limitations

The limitations encountered during the work of this report are:

1. The volume that can be treated and bypassed in each of the units or alternatives was difficult to estimate.
2. Pollutant removal efficiencies for some of the manufactured treatment units were not available in the literature. Therefore, literature values were used from similar treatment systems.
3. The values found during sampling were compared to stormwater data from 2016. However, no recipient water data was available that would have been more optimum to compare with.
4. During the sampling events, only one sample was taken per spot, and it would have been better to take at least three in order to obtain statistical results.

2 Theory

This chapter presents the issues related to stormwater management and quality assessment. Treatment techniques that currently exist to manage stormwater quality and that would be suitable for the area are presented. The approach on how the best solution was chosen is as well described.

2.1 Water quality management in Sweden

Unsustainable development and rapid globalization have affected the quality of water bodies and availability of water resources, affecting the global economy and social health. Gradual deterioration of water quality worldwide is most apparent in urbanized areas (WWAP, 2015). Therefore, the need to adopt new measures has grown and the awareness of needed water quality improvements of the different countries within the EU has increased. In 2000, the European Union implemented the Water Framework Directive (WFD) (Directive 2000/60/EC) (European Commission, 2015) which became part of the Swedish Environmental Law in 2004 (Bergqvist, 2014). The focus of this directive is to ensure a good quality of water bodies within the European Union and has had a direct impact at city and national levels since it showed the need to implement treatment for wastewater, stormwater and other types of water to fulfill the directive.

The WFD gives an introduction and overview of key aspects providing 12 "waternotes". The Waternote #2 focuses on *Identifying and assessing surface water bodies at risk* (WISE, 2008) and sets the goal of achieving a "good status" for all European surface waters and groundwater bodies by 2015. If not reached, then it should be by 2021 or 2027. Recent studies and estimations conclude that at least 40% of the EU's surface water bodies do not meet the 2015 objective. The Vitsippsbäcken stream currently does not reach the "good status" and hence, is essential for the city of Gothenburg to address this situation.

Additionally, Sweden's Parliament has adopted the "16 Swedish Environmental Quality Objectives" (Swedish EPA, 2009). Some of these are directly related to stormwater, wastewater and recipient water quality (Appendix A). Examples of these objectives are number 3 (Natural Acidification Only), 7 (Zero Eutrophication), 8 (Flourishing Lakes and Stream), 9 (Good Quality Groundwater) and 11 (Thriving Wetlands) (Appendix A). Although these goals' horizon is 2020, none of them will be achieved considering the policies planned so far.

These environmental objectives aim to ensure a good quality of all water bodies as well as to prevent the negative impacts on them. Considering that the 2020 time span goal will not be fulfilled, future development is needed to implement new technologies or treatments that can help achieve these objectives.

2.2 Generation of Urban Runoff

Within urban areas, the replacement of natural and green spaces with impervious surfaces has increased stormwater runoff, decreased shallow and deep infiltration and decreased evapotranspiration (Figure 2.1) (EPA, 2003). In developed countries, traditionally, underground pipe-systems have been used to collect the wastewater (Butler & Davies, 2004). The percentage of sewered area (urbanized area) has a direct impact on the imperviousness of the land due to the replacement of vegetated areas with impermeable surfaces. This has a direct impact on the water concentration time, which increases, and the infiltration rate, which decreases, altering the whole hydrologic cycle and increasing the flooding risk and runoff generation (Shuster et al, 2007).

Urbanization and human activities have led to an increase in pollution loads of e.g. sediments, oils, toxic chemicals, nutrients, heavy metals, road salts, pesticides, virus and bacteria. Additionally, flows with large fluctuations can affect the environment near the point of discharge (Butler & Davies, 2004). The most visible impact within the receiving water-channels is erosion produced in the downstream areas and stream banks (Arnold & Gibbons, 1996) having consequences such as fallen vegetation, sedimentation of stream-bed material, widening of the channel, increase of temperature and influence of the stream habitat as the environment is modified (EPA, 1999).

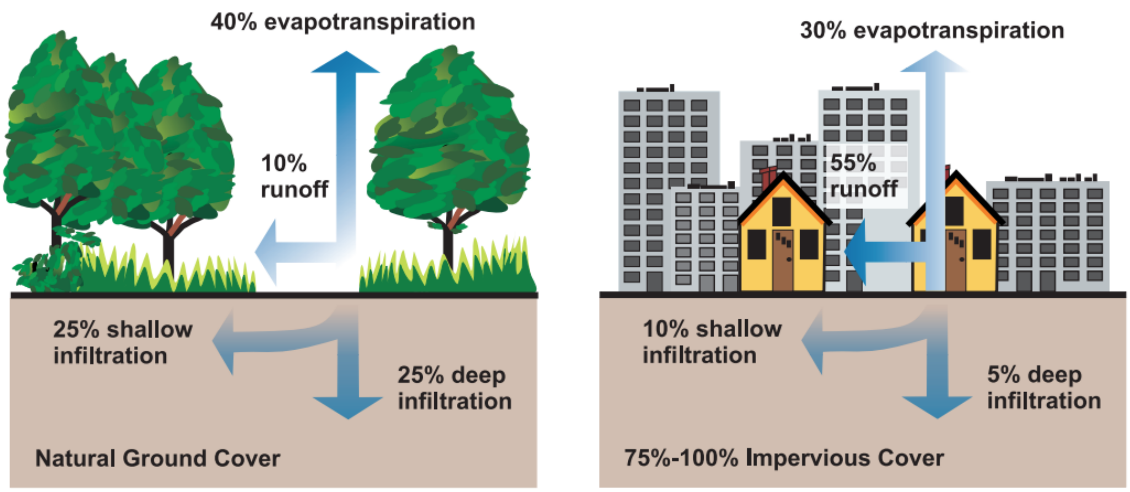

Figure 2.1. Relationship between imperviousness and surface runoff (EPA, 2003).

The traditional wastewater pipe-systems can be either combined or separated. Combined pipe-systems collect both sewage and stormwater together, in the same pipe; while separate systems collect sewage and stormwater in different pipes later discharged at different locations. Sewage water is usually discharged to a wastewater treatment plant, while stormwater is often released into receiving waters without any treatment (Butler & Davies, 2004). This fact has awakened the awareness about the quality of the receiving waters and nowadays, it is considered that locally implemented sustainable solutions are needed within the catchment areas and the discharge points to try to minimize the release of these pollutants.

In Sweden, and more precisely in the city of Gothenburg, the municipality is working to improve the stormwater management within the city. Currently, the stormwater system in the oldest areas of the city consists of combined system that transports the wasterwater to the wastewater treatment plant, Ryaverket (located on Hisingen, North Gothenburg). In the areas with separate system, the stormwater is usually discharged into receiving waters and is released with no treatment (Bergqvist, 2014).

2.3 Pollutants in urban runoff

Diffuse contamination or nonpoint source contamination refers to the release of pollutants of different origins: road runoff, industrial runoff, runoff from housing and commercial areas (SEPA, 2018). These pollutants may have a wide variety of origins and different impacts on receiving water bodies as well as on human health. The main pollutants present in stormwater runoff are nutrients, heavy metals, organic pollutants and solids. Nutrients can have natural (weathering processes of rock, decomposition of organic material, soil leaching, etc.) or anthropogenic (fertilisers, pet waste, detergents from car washing, vehicle emissions, etc.) sources (Khwanboonbumpen, 2006). In high concentrations, P and N species can lead to eutrophication and acidification of surface waters (Jiake et al, 2011). Eutrophication refers to the water enrichment by nutrients, which leads to excessive growth of algae, unbalance of organisms and water quality degradation including oxygen depletion (European Commission, 2016). Acidification refers to the change in the chemical composition of soils and surface waters, caused by the reactive products of sulphur dioxide, nitrogen dioxide and ammonia (EEA, 2016).

Heavy metals are naturally occurring persistent inorganic elements with a specific density higher than 5 g/cm^3. The most common heavy metals found in stormwater are Cu, Zn, As, Cr, Pb and Ni and their toxicity represents a threat for ecology, evolution of species, nutrition and environment (Järup, 2003). High concentrations of heavy metals in road runoff and environment often originate from anthropogenic activities such as dense traffic, vehicle tires and exhausts, road asphalt, fuel type, parking dust, etc. The main impacts on human health are gastrointestinal uptake (Pb), vomiting, vomiting of blood, low blood pressure and coma (Cu) (Järup, 2003), stomach cramps, skin irritations, vomiting, nausea and anaemia (Zn) (Lenntech B.V, 2018). Additionally, heavy metals tend to accumulate in biota (fauna and flora) and soils; and due to their toxicity, they negatively influence the activity of microrganisms and earthworms, cause alterations in plants at cellular level and interrupt the activity in soils (Lenntech B.V, 2018).

Persistent Organic Pollutants (POPs) refer to compounds that are resistant to chemical, biological and photolytic degradation in the environment. Many POPs are also bioaccumulative and lead to negative impacts on the environment and human health (Ritter et al, 2007). In 1991 the United Nations Governing Council proposed a list of 12 POPs to the UNEP (United Nations Environment Programme) which passed the filtering process defined by the Council after their definition and threats were presented. In 2001, the list was expanded through the Stockholm Convention including Polycyclic Aromatic Hydrocarbons (PAHs) which were also added to the

Water Framework Directive through the 2008/105/EC and 2013/39/EU Directives for priority substances (Abdel-Shafy and Mansour, 2016). PAHs are organic compounds generated during incomplete combustion of organic materials and their origin can be either natural (open burning, natural losses, volcanic activities or seepage of petroleum) or anthropogenic (residential heating, coal gasification, asphalt production, coke and aluminum production, motor vehicle exhaust, etc.). They contain mainly carbon and hydrogen and are composed of aromatic rings. They are the most frequently detected organic compounds in urban runoff, may have toxic effects on plants (inhibition of photosynthesis and decreased growth) and animals (decreased individual fitness and negative effects on reproduction) as well as negative effects on human health related to cancer and hormonal unbalance (Kim et al., 2013). PAHs can be dispersed through air, water, soil, humans and food (Suess, 1976) and some of them are carcinogens, mutagens, and teratogens and therefore, pose a serious threat to the health and the well-being of humans (Abdel-Shafy and Mansour, 2016).

Per- and Polyfluoroalkyl Substances (PFAS) involve a large group of fluorinated compounds which are *"neutral and anionic surface active compounds with high thermal, chemical and biological inertness"* (European Food Safety Authority, 2008). PFOS (perfluorooctane sulfonate) and PFOA (perfluorooctanoic acid) are the most produced types of PFAS and are very persistent in the environment and human body (EPA, n.d.). PFAS have been used worldwide since the 1950's in industry (aerospace, automotive, building and construction, electronics) and products (such as non-stick cookware, water-repellent clothing, stain resistant fabrics and carpets, cosmetics, firefighting foams, and other products that resist grease, water, and oil) (Agency for Toxic Substances and Disease Registry, 2018). PFOS was categorized as “moderately acute and slightly chronically toxic to aquatic organisms” by Giesy et al. (2010). On the other hand, PFOA was categorized as less toxic than PFOS for aquatic organisms (ARCADIS, 2016).

Suspended solids have different origins such as traffic (dust and particles), atmospheric deposition, soil erosion, construction (Kangas, 2016). Solids can reduce visibility and absorb light in surface waters, which can lead to increased temperatures and decreased photosynthesis and oxygen availability. Solids can carry toxic substances including metals and organic compounds and can as well clog the respiratory systems of animals and insects (Butler & Davies, 2004).

According to Bergqvist, B., (2014), there are three different urban drainage system currently in use in Gothenburg (Table 2.1). Combined and separate sewer systems with no associated water treatment discharges highlight the need to promote new regulations and treatment techniques.

Table 2.1. Urban drainage systems in Gothenburg (Bergqvist, 2014). *WWTP = Waste Water Treatment Plant.*

System Type	Treatment
Combined system (until the 50´s)	Wastewater treated in WWTP
Separate system (since the 60´s)	Wastewater treated in WWTP Stormwater discharged to dike or gutter
Duplicate system (since the 60´s)	Wastewater treated in WWTP Stormwater managed locally or discharged in dikes, gutters or pipline

The Miljöförvaltningen (Environmental Department) of the City of Gothenburg, has proposed guidelines stormwater pollutant discharge to receiving waters (Göteborg Stad, 2013). These target values (Table 2.2) serve as guidelines for water quality measures obtained in Vitsippsbäcken. The aim of these guidelines is to protect the water quality, aquatic biodiversity, watercourses and human-health. Additionally, the Swedish EPA has specific reference values for metal concentrations in sediment and moss, based on the current situation (Appendix B)(Swedish EPA, 2000b).

Table 2.2. Guideline values for discharged target emissions of pollutants to surface waters. For all metals, total concentrations are considered *(particulate+dissolved)* (Göteborg Stad, 2013).

Parameter	Target values at emission point
Arsenic (As)	15 μg/l
Chromium (Cr)	15 μg/l
Cadmium (Cd)	0.4 μg/l
Lead (Pb)	14 μg/l
Copper (Cu)	10 μg/l
Zink (Zn)	30 μg/l
Nickel (Ni)	40 μg/l
Mercury (Hg)	0.05μg/l
Oil Index	1000 μg/l
Benzo(a)pyren	0.05 μg/l
Benzene	10 μg/l
pH	6-9
TP	50 μg/l
TN	1250 μg/l
TOC	12 mg/l
SS	25 mg/l

2.4 Stormwater treatment techniques for dense urban areas

In the last years, a shift has been observed within the stormwater management field towards sustainable urban drainage techniques, in which different practices are being implemented around the world (Butler& Davies, 2014). The main focus of these, is to reduce peak flows in urban areas, to treat the water, to prevent pollution, and to provide amenity, biodiversity and/or recreation. Fletcher et al. (2014) presents a general description of the different terms for sustainable urban drainage used around the world and their classification (Figure 2.2).

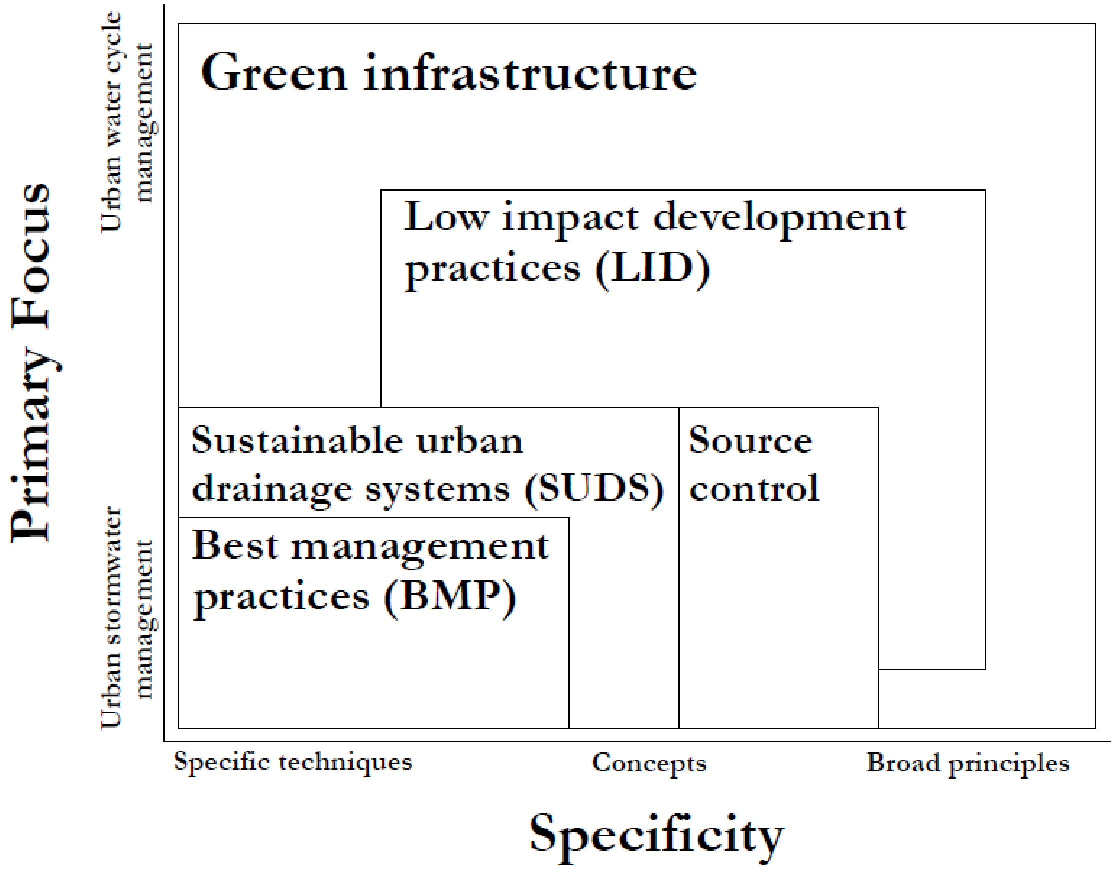

Figure 2.2. Classification of different sustainable stormwater management terminology (adapted from Fletcher et al, 2014).

The concept of green infrastructure englobes all other used terms (BMPs, LID, SUDS) since it focuses on the overall need to integrate all the infrastructure and structures within the urban areas. This concept was first used in the USA during the 1990's (Walmsley, 1995) and today, it is used interchangeably with Best Management Practices (BMPs) and Low Impact Development (LID) practices.

BMPs are structural or control systems that aim to treat contaminated stormwater and prevent pollution (Fletcher et al, 2014). The term was first described in 1972 in the draft of the Clean Water Act which was the first US law addressing water pollution (EPA, 2017). Some examples of BMPs for stormwater treatment are (1) infiltration practices (infiltration basins, infiltration trenches, pervious or porous pavements), (2) vegetated open channel practices (filtering practices, filtration basins and sand filters, media filtration units, bioretention systems) and (3) detention and retention practices (detention ponds and vaults, retention ponds, constructed wetlands) (EPA, 2005). LID practices refer to land development strategies focused on decentralized micro-scale control techniques aiming to provide source control (Ahiablame et al, 2012). It is a common term used in North America and New Zeland and was first used by Barlow et al. (1997) in a report that focused on land use planning (Fletcher et al, 2014). Some of the most popular practices of LID are rain gardens, green roofs, permeable pavement or swale systems.

This section focuses on identifying available techniques for stormwater management and quality improvement, and specifically alternatives for highly urbanized areas. The reviewed alternatives are divided into categories presented in Table 2.3.

Table 2.3. Summary of stormwater management techniques to be analyzed.

Location	**Technique**
Green area	Dry ponds Wet ponds
End-of-pipe	Underground vaults
Road runoff techniques	Biofiltration Sorption Street Sweeping

The following aspects were analyzed for all the stormwater treatment techniques: (1) description and treatment process, (2) removal efficiency, (3) maintenance and (4) advantages and disadvantages. Additionally, manufactured filtering media were analyzed as well as different manufactured units for some of the treatment techniques.

2.4.1 Dry Detention Ponds

Dry detention ponds (Figure 2.3) are usually dry basins, and their aim is to control flooding. The pond is constructed to drain stormwater within a specific period of time (Butler & Davies, 2004). In this kind of pond, sedimentation is the main pollutant removal process (Clean Water, 2001). Usually, dry ponds are used where the concentration of pollutants is expected to be low. The effectiveness of the pond is dependant on water quality, treatment volume, pond geometry, inlet location, side slope, hydraulic resident time (usually 24-48 h) and distance between inlet and outlet (Clean Water, 2001).

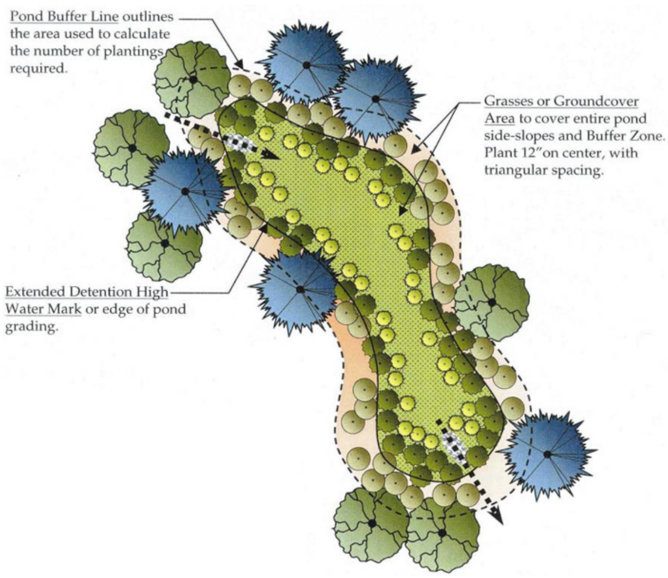

Figure 2.3. Schematic drawing of a dry detention pond (UBC, 2017).

Removal efficiencies

Based on the literature, average removal efficiencies for detention ponds are summarized in Table 2.4.

Table 2.4. Average removal efficiencies of dry ponds.

Pollutant	Removal (%)	Reference
As	22	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012)
Cr	53	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012)
Cd	33	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012)
Pb	73	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012)
Cu	29	Fraley-McNeal et al (2006)
Zn	53	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012) Fraley-McNeal et al (2006)
Ni	55	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012)
TP	23	EPA (2002) Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012) Fraley-McNeal et al (2006) Hussain et al (2006)
TN	24	Fraley-McNeal et al (2006)
TSS	50	EPA (2002) Hussain et al (2006)

Maintenance
Depending on the effectiveness and the frequency of the maintenance works, water quality might be improved in a dry pond. Some of the major problems that may occur if the wrong maintenance is conducted are: buildup of excessive sediment or debris, uncontrolled vegetate growth and obstruction of the outlet. Therefore, it is necessary to propose a thorough maintenance plan, including for example vegetation control, sediment control and optimal frequency for the maintenance works (Clean Water, 2001).

Advantages and disadvantages
The advantages and disadvantages of dry ponds, from their geometry to their efficiency are listed in Table 2.5.

Table 2.5. Advantages and disadvantages of dry ponds for stormwater management.

Advantages	**Disadvantages**
Small size and simple design*	Can become a mosquito habitat*
Lower price than wet pond*	Can decrease the property value*
Vegetative buffer capacity*	Not valid for water treatment*
Good for peak flow control**	Minimum drainage area of 2 ha
Can be effective removing suspended solids, nutrients and metals**	Less effective removing dissolved elements**

**Leber, (2015); ** EPA, (1993).*

Retrofitting an existing pond
When a dry pond is already in operation, there is the possibility to retrofit it, for example, (1) reconstructing the inlet and the outlet or reconstructing the downstream of the pond if it is located in a hilly area with (2) a meander shape (Appendix D) or with (3) terrace solutions (Appendix D). Solution 1 demands a deep reconstruction and invasive action within the pond. Therefore, if less invasive solutions are needed, alternatives 2 and 3 are optimal.

2.4.2 Wet Retention Ponds

Wet retention ponds (Figure 2.4) have a permanent volume of water which holds the stormwater for longer periods of time and allows a better settling of particles at the bottom compared to dry ponds. This kind of pond has an aesthetic positive value, recreational value and environmental benefits (Butler & Davies, 2004) and are considered one of the most effective BMPs for stormwater quality improvments (Clean Water, 2001). These ponds present high removal rates for trace metals, hydrocarbons and nutrients (Burack et al, 2008). Similar to the dry ponds, the effectiveness of the wet pond depends on several design criteria: permanent pool volume, water quality treatment volume, permanent pool depth, pond geometry, side slope, vegetatation, volume of pre-settling basin, safety bench (for maintenance access), pond configurations, distance between inlet and outlet (Clean Water, 2001).

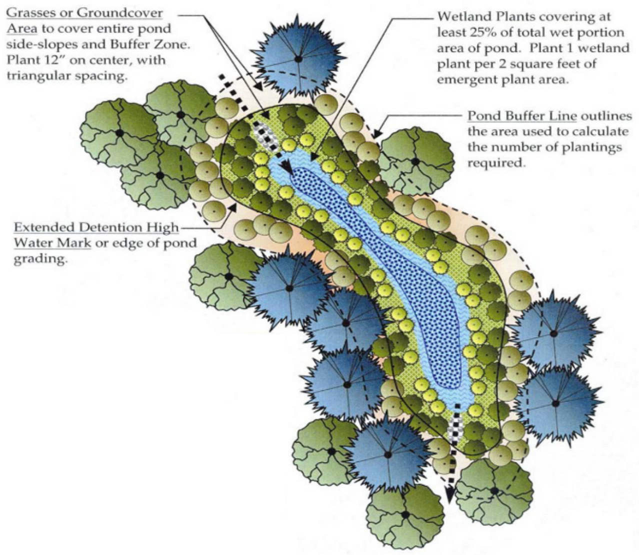

Figure 2.4. Schematic drawing of a wet detention pond (UBC, 2017).

Removal efficiencies

Based on the literature, average removal efficiencies for wet retention ponds are summarized in Table 2.6.

Table 2.6. Average removal efficiencies of wet retention ponds.

Pollutant	Removal (%)	Reference
As	30	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012)
Cr	40	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012)
Cd	50	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012)
Pb	56	Perssen et al (2009)
Cu	60	Fraley-McNeal et al (2006) Swarna Muthukrishnan, (2010)
Zn	80	Tetra Tech, Inc., (2008) Fraley-McNeal et al (2006) Swarna Muthukrishnann (2010)
Ni	37.6	Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. (2012)
Oil	70	CASQUA, (2003)
TP	43.4	EPA (2002); Tetra Tech, Inc., (2008) Burack et al (2008) Fraley-McNeal et al, (2006)
TN	43.6	Burack et al (2008); Fraley-McNeal et al (2006)
BaP	70	CASQUA, (2003)
PAH	78	CASQUA, (2003); Crabtree et al (2006)
TSS	75	EPA (2002); Tetra Tech, Inc., (2008) Burack et al (2008); Fraley-McNeal et al, (2006)

Maintenance
Maintenance is considered to be the most important factor when a wet pond is implemented (Clean Water, 2001). Maintenance should include control of invasive plants, sediment control, frequent removal of floating debris, maintenance of the aquatic flora and aesthetics of the pond and surroundings, frequent inspection and repair of embankments and inspection of inlet and outlet structures (Clean Water, 2001; Burack et al, 2008). According to EPA (2009), each maintenance activity demands a different frequency varying from twice per year (checking the permanent pool, checking erosion, looking for damages or broken signs, identifying invasive plants, etc) to every two to seven years (inspection of embankments, pipes, sediment deposition, removing accumulated sediment, etc).

Advantages and disadvantages
There are different advantages and disadvantages regarding wet ponds, from their geometry to their efficiency (Table 2.7).

Table 2.7. Advantages and disadvantages of wet ponds for stormwater management.

Advantages	**Disadvantages**
Improves water quality* (removes soluble and solid pollutants**)	Negative water quality impacts if it is not properly designed*
Can be used in residential, commercial and industrial areas**	Demands large area *, **
Can be used for recreation*	Drowning risk*, safety concerns**
Can increase property value**	Liners might be needed if groundwater level is high**
Biological treatment of runoff**	High construction cost**
Creates new habitats*	Not suitable in steep slopes***
Provides flow control*	Anaerobic conditions may occur***

* Leber (2015)
** Dublin City Council (2014)
*** Morales Torres et al (2015)

2.4.3 End-of-pipe solutions
Three end-of-pipe solutions are presented. The first is an underground vault based on sedimentation, the second is an underground vault with filtration cartridges and the third, is an underground unit focusing on bigger debris removal.

1) Underground vault: EcoVault ®
EcoVault® (Figure 2.5) is a precast concrete multi-stage system that provides separation, screening, and filtration (ESI, 2018). It is mainly constructed for treatment of debris, nutrients, suspended solids and metals. In Appendix D (Figure D.3) the standard sizes available for the EcoVault are presented, as well as information concerning the capacities of the different chambers within the vault and the different pipe sizes.

Water enters the vault through the inlet pipe (1) and passes the debris screens (2) which aim to remove trash and debris (Figure 2.5). Water then reaches the sedimentation chamber (3) and passes the first baffle wall reaching the second sedimentation tank (4). Finally, water passes the baffle buddy filter ending up inside the chamber for filtered clean water (5). The baffle buddy filter or cassette filter contains multiple media components which aim to remove cations and anions, hydrocarbons, heavy metals, VOCs (volatile rganic compounds) and nutrients. The F.O.G. Baffle Wall in the upper part (Figure 2.7) is designed to absorb incoming flow energy as well as to prevent forward movement of the floating elements (ESI, 2018).

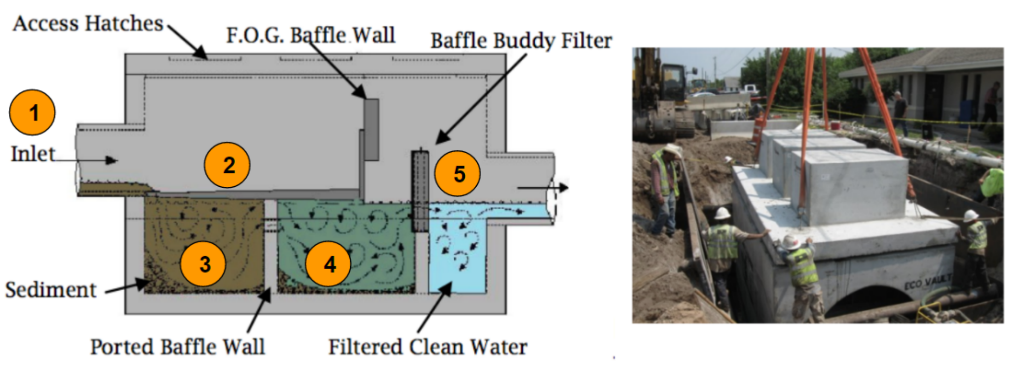

Figure 2.5. Configuration of a standard EcoVault® unit (ESI, 2018).

Maintenance
Maintenance is performed in the vault and the structure itself and the filters. The first is performed through the accessible hatches and a vacuum truck is used to remove the sediments, accumulated organic matter, and litter. Filter maintenance is to be conducted once or twice a year in order to keep the removal efficiency of the filters. The cartridges are reusable which lowers the cost of replacement. Additionally, a quarterly inspection of the vault is recommended to ensure the debris screens do not get blocked with larger organic matter (ESI, 2018). According to Lindfors et al, (2014), vacuum suction is recommended 4-12 times a year while the filter change is recommended once a year.

Advantages and disadvantages
Advantages and disadvantages of the EcoVault are summarized in Table 2.8.

Table 2.8. Advantages and disadvantages of EcoVaults for stormwater management (ESI, 2018).

Advantages	**Disadvantages**
Versatile (adaptable specific area requirements)	Frequent maintenance
Cost effective	Substantial operational requirements

Removal efficiencies
Based on the literature conducted regarding removal efficiencies of the EcoVault are summarized in Table 2.9.

Table 2.9. Average removal efficiencies of EcoVault.

Pollutant	Removal (%)	Reference
As	-15	Modeled in Stormtac (2017)
Cr	72	Lindfors et al (2014) Modeled in StormTac (2017)
Cd	74	Lindfors et al (2014) Modeled in StormTac (2017)
Pb	73.5	Lindfors et al (2014) Modeled in StormTac (2017)
Cu	70	Lindfors et al (2014) Modeled in StormTac (2017)
Zn	80	ESI, (2018) Lindfors et al (2014) Modeled in StormTac (2017)
Ni	58	Lindfors et al (2014) Modeled in StormTac (2017)
Oil	96	Modeled in Stormtac (2017)
TP	44	ESI, (2018) Lindfors et al (2014) City of Casselberry, 2015) Modeled in StormTac (2017)
TN	12	Lindfors et al (2014) Modeled in StormTac (2017)
BaP	94	Modeled in StormTac (2017)
PAH	80	Lindfors et al (2014) Modeled in StormTac (2017)
TSS	87	ESI, (2018) Lindfors et al (2014) City of Casselberry, 2015) Modeled in StormTac (2017)

2) Underground vault with filtration cartridges: StormFilter ®

Contech Engineered Solutions LLC provides devices for stormwater management and treatment, based on physical or physico-chemical techniques with different target pollutants (Bueno, 2015). StormFilter is an underground stormwater treatment facility composed of one or several concrete structures where rechargeable and media-filled cartridges are located (Contech, 2018). It is size-adjusteable and it allows parallel installation of a Combined Sewer Overflow unit (CSO) in case of overflow risk. Once the water enters the facility, it follows a seven step process described below (Contech, 2018) (Figure 2.6).

1. Stormwater enters the device.
2. Stormwater goes through cartridges, filling the center tube.
3. Water reaches the top of the tube and loat valve opens.
4. One-way check valve closes activating the siphon and polluted stomrwater goes through the filter media.

5. Filtered water discharges out of the system through the under drain.
6. Water level approaches the bottom and air rises through the scrubbing regulator breaking the watercolumn in the siphon.
7. Turbulent bubbling shakes up the filter media droping the catched sediments.

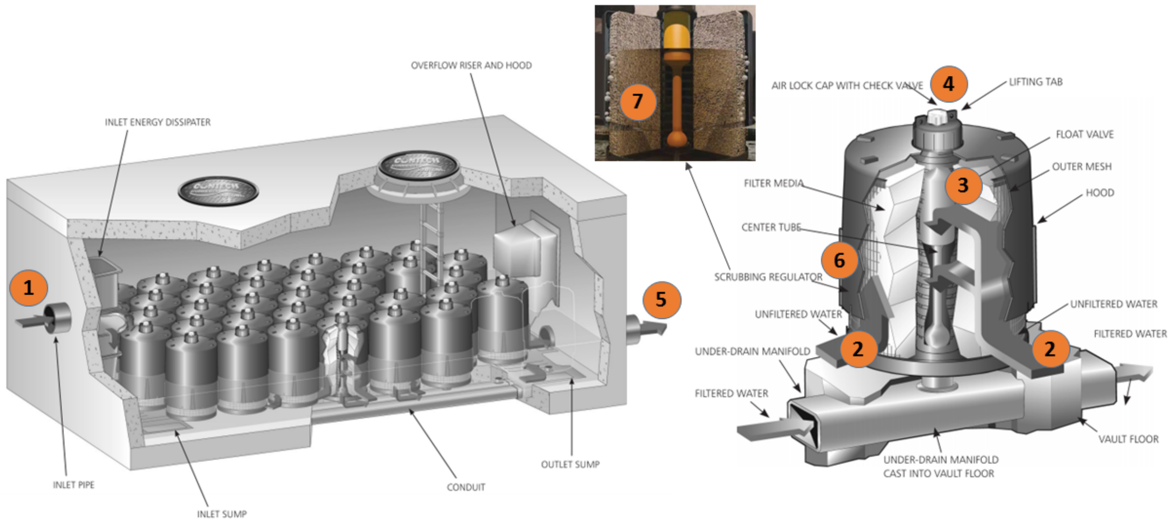

Figure 2.6. Configuration of a standard StormFilter device (Contech, 2018).

Filter media

Cartridges aim to catch particles and adsorb pollutants such as dissolved metals, hydrocarbons and nutrients. The filter media used in the cartridges can be adjusted to the needs of the specific site (Contech, 2018).

1. **PhosphoSorb ®:** Perlite based media that adsorbs dissolved-P and filters suspended phosphorus.
2. **Perlite:** Based on expanded volcanic rock. It is a porous and multi-cellular structure which is effective for removing TSS, oil, and grease.
3. **CSF® Leaf Media and Metal RX™:** A granular organic media created from deciduous leaves. It is mainly effective for removing soluble metals, TSS, oil, and for neutralizing acid rain. MetalRx on the other hand, based on a finer gradation, is used for higher levels of metal removal.
4. **Zeolite:** A naturally occurring mineral which in this case is used to remove soluble metals, ammonium, and some organics.
5. **Granular Activated Carbon:** GAC has a micro-porous structure with an extensive surface area which provides high levels of adsorption. In this case it is used to remove oil, grease and organics such as herbicides and pesticides.
6. **ZPG™:** ZPG is a Contech-proprietary mixture of zeolite, perlite, and GAC which improves the performance of perlite and targets organics, soluble metals, and other pollutants.

Removal efficiencies

Removal efficiencies of the StormFilter device, are based on the different filter media. Based on the reports from Contech (n.d.), the City of Tacoma (2008) and the City of Seattle (2012), average removal efficiencies are summarized in Table 2.10.

Table 2.10. Removal efficiencies (%) for different filter medias for StormFilter.

Compound	PhosphoSorb	CSF	Zeolite	GAC	ZPG
TSS	79	84	75.5	58.2	80
TP	73	31	-	-	30
TN	43	-	-	-	30
T Cu	79	42	44	28	25-30
T Zn	28	53	40	31	30
Diss. Cu	30	-	7	11	6
Diss. Zn	28	37	3	11	6

Jotte et al. (2017) reports higher removal rates: 94% of TSS, 78% of COD, 70% of TN, 58% of TP, 80% of PAH, 81% of Cu and Pb and 78% of Zn.

Maintenance

The device provides access to the cartridges through two wells located in the upper part of the vault (Figure 2.3) -which are big enough for human access- for all the maintenance activities such as inspection, media replacement or washing of the structure (Contech, 2018). The maintenance activities are estimated to be performed every one to three years. The cartridges used in the StormFilter unit are made with 60% recyclable material which lower the life cycle costs.

Advantages and disadvantages

The advantages and disadvantages of the StormFilter are summarized in Table 2.11.

Table 2.11. Advantages and disadvantages of StormFilters (Contech, 2018).

Advantages	Disadvantages
Effective stormwater treatment	Not all media target all pollutants
Low life-cycle cost	High surface area media cartridges
Easy maintenance	Time consuming maintenance
Customized media dependent on target pollutant(s)	Requires superficial free area for maintenance works
Flexible to meet site-specific needs	

3) Vortechs ®

Vortechs (Figure 2.7) is an underground stormwater treatment solution that catches trash, sediment, debris and hydrocarbons. The device is composed by two mechanisms: a swirl concentrator and a flow control mechanisms. It aims to create a low energy environment to catch particles down to 50μm. The vault is size-adjusteable to the site specific needs and once the water enters the facility, it follows a five step treatment process (Contech, 2018):

1. Untreated stormwater enters the swirl chamber.
2. Separation of solids and settling.
3. In the next chamber a baffle wall traps floatables and hydrocarbons.
4. The water flows below the baffle wall into the flow control chamber which has two separated flow controls (for peak and low-intensity flows).
5. Treated stormwater flows to the outlet chamber.

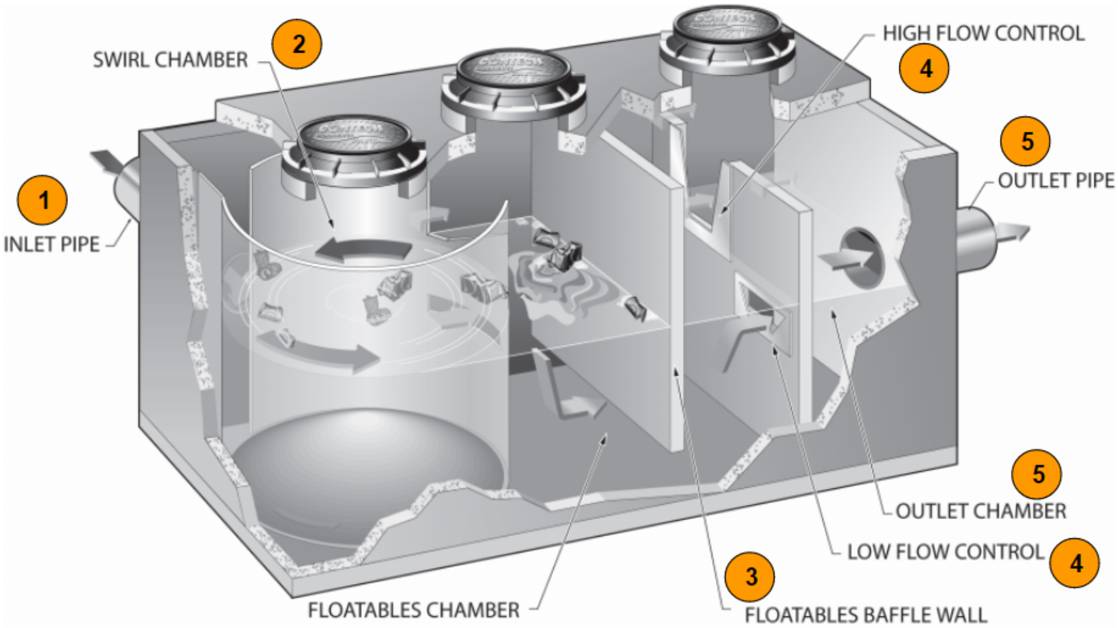

Figure 2.7. Configuration of a standard Vortechs filter device (Contech, 2017).

Removal efficiencies

This device type focuses mainly on TSS and TPH (total petroleum hydrocarbon) removal, but in some cases, heavy metal removal has also been observed. Several studies have been conducted in different areas of the US and good removal efficiencies have been observed (Table 2.12). Additionally, in a study conducted by the University of Connecticut, the system was as well effective in removing particle-bound metals and nutrients; Zn (85%), Pb (46%), Cu (56%), P (67%) and nitrate (54%).

Table 2.12. Removal (%) of TSS and TPH with Vortechs.

Location / Compound	Yarmouth, Maine (1999)	New York (2000)	New Jersey (1999 -2000)	University of Connecticut (2000 -2001)
Mean influent concentration	328 mg/L (TSS)	801 mg/L (TSS)	493 mg/L (TSS); 16 mg/L (TPH)	324 mg/L (TSS)
Mean effluent oncentration	60 mg/L	105 mg/L	35 mg/L (TSS); 5 mg/L (TPH)	73 mg/L
TSS	82%	88%	93%	77%
TPH			67%	

Maintenance
The maintenance process for the Vortechs vault can be conducted using a vacuum truck, with no need to enter the unit (Contech, 2018). Depending on the size of the unit and site-specific characteristics (such as usual flow and pollution level), the inspections should be more or less frequent. The aim of the inspections is to ensure that the device is clean and properly functioning. The system should be cleaned when the sediment depth reaches to 300 to 450 mm within the dry-weather water elevation. Additionally, the cleaning is preferable to be conducted during dry-weather periods when no flow enters the unit (Contech, 2018).

Advantages and disadvantages
The advantages and disadvantages of the Vortechs system are summarized in table 2.13 (Contech, 2018).

Table 2.13. Advantages and disadvantages of Vortechs.

Advantages	Disadvantages
Fine particle removal down to 50μm	Not much proved heavy metal removal
Easy and cost-effective installation	Large swirl chamber
Easy maintenance	Frequent inspections

2.4.4 Biofiltration

Biofiltration systems are based on soil-plant components which can be easily adapted to the specific area and can, as well, be integrated within the urban landscapes (Deletic et al., 2014). Biofilters consist of different layers (Figure 2.8) from top to bottom: (1) temporary ponding, (2) sand-based filter media, (3) coarse sand-based transition layer and (4) 2-7mm of fine aggregate. Additionally, a drainage pipe is located under the bottom layer where treated wastewater is collected and usually discharged in the closest water body or storm sewer (Payne et al. 2015). Small biofiltration systems are usually known as rain-gardens while linear systems are usually known as bio-filtration swales which provide both treatment and flow control functions (Payne et al. 2015).

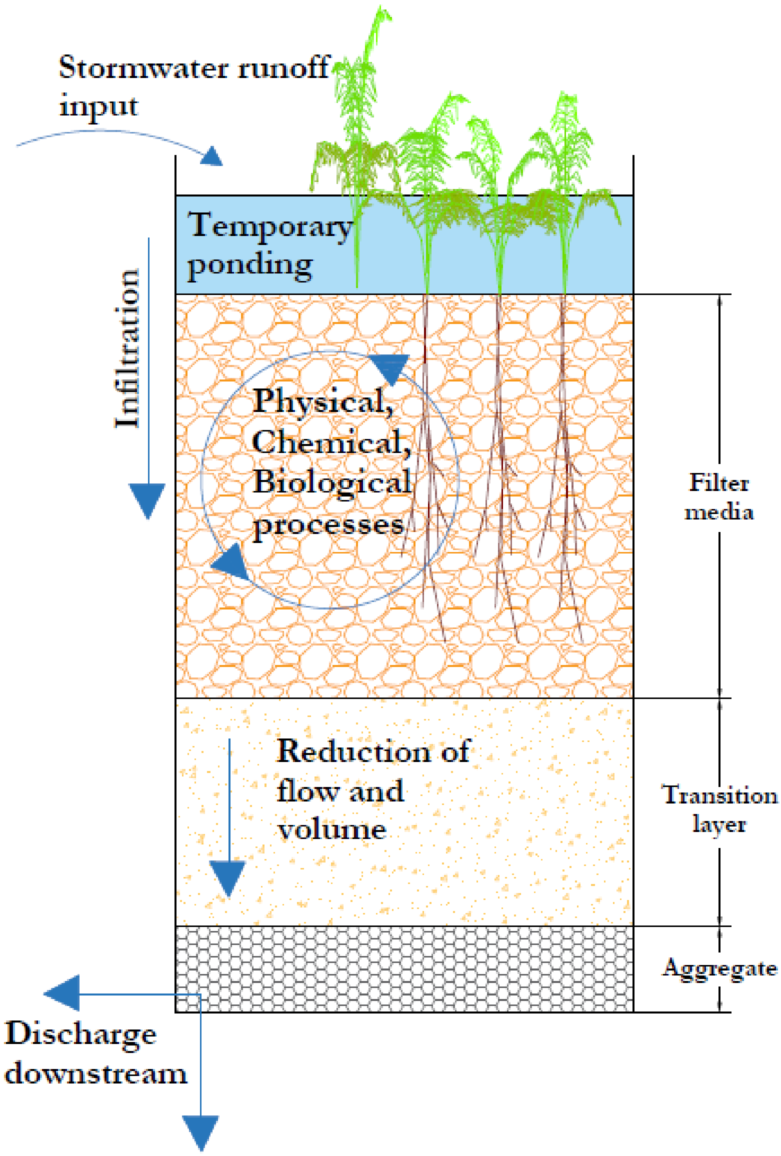

Figure 2.8. Standard biofiltration system section drawing (adapted from Payne et al. 2015).

Treatment processes

Within biofilters, water goes through physical, chemical and biological treatment processes (Payne et al. 2015).

- Physical processes: vegetation reduces the flow causing particulates to settle (through **sedimentation**). The particulates are then filtered through the soil media in a process called mechanical straining.
- Chemical processes: soil filter media are based on clay minerals and other chemically active compounds that catch dissolved pollutants through **sorption and filtering** (which is as well a physical process) mechanisms. Also, the organic content of the soil is efficient at sorbing metals, phosphate, and organic pollutants.
- Biological processes: vegetation and microbes catch nutrients and some other pollutants as their internal growing components (**microbial/plant uptake**).

Sedimentation uses gravity to remove suspended solids which have a higher density than water (Omelia, 1998). It is a process that requires long time periods depending on the volume to be treated, particle size and density, available treatment area, and ponding depth. Filtering mechanism percolate the water and separate the particles depending on particle size and pore size of filter material media (Wilén, 2017). Sorption is a physico-chemical process by which one substance becomes attached to another. The main sorption mechanisms are absorption, adsorption and ion exchange which target dissolved P, metals and many organic pollutants (Strömvall, 2017). Plant uptake captures the water and uses it for the growing process and provide transpiration.

Biofiltration materials
Different filter media can be used for biofiltration. Wang et al (2017) and Macnamara and Derry (2007) present five materials with different removal efficiency for various pollutants. While Wang et al. focus on heavy metal removal, Macnamara and Derry focus as well on nutrient removal efficiency (Table 2.14).

Table 2.14. Average removal efficiencies (%) for different biofilter media. Sandy Loam I has no aggregated materials while Sandy Loam II is sandy loam mixed with clay, silt and organic content up to an 8%. **Dissolved.*

Compound	**Sand**	**Zeolite**	**Sandy Loam I**	**Quartz Sand**	**Sandy Loam II**
Cu*	98	98	99	99	85
Pb*	99	89-98	93-100	99	70
Cd*	98	98	98	98	96
Zn*	75-98	98	99	99	85.5
TN	-	-	-	-	85
TP	-	-	-	-	68-78

A general removal capacity for biofiltration is estimated as <89% for TN, 65-78% for TP, >95% for sediments and 70-100% for heavy metals.

Among the most common sorption materials are vermiculite, perlite, zeolite, limestone or olivine (Wium-Andersen, 2012) but there are additional low-cost sorption media as well such as pine barks and sawdust (Björklund and Li, 2015). Ray et al. (2006) performed a studio based on **hardwood mulch** to remove different metals and organic compounds from urban stormwater and found high removal efficiencies: 85% Cu, 86% Cd, 68% Cr, 92% Pb, 72% Zn, 92% benzopyrene after 72 h contact with the material. **Blast furnace slag (BFS)** presents removals of 62% Zn, 66% Cu, etc. (Hossain, 2008). Hallberg and Renman (2008) performed an analysis using BFS as well through a column sorption study of BFS. The removal of dissolved Cd and Zn was more than 90%. Removal of Cu varied between 77% and 86% and Ni removal from 44% to 72%. Cr presented the lowest removal performance (6%). The total Cd was removed over 99%, total Zn was removed more than 93%, total Cu varied between 71% and 88% and total Ni varied between 40% and 69%.

Maintenance
Exhaustive maintenance of the biofilter is necessary to achieve an optimal functioning. Figure D.4 (Appendix D) illustrates typical maintenance activities. More detailed activity information is provided in each of the manufactured configurations.

Advantages and disadvantages
Regarding advantages of the bio-filters, there are some general aspects that can be highlighted (Table 2.15). The main disadvantage is that even if biofiltration systems demand relatively small area, they can be difficult to implement in dense urban areas. Additionally, poor functioning of the system can happen due to clogging of the pores (Kangas, 2016).

Table 2.15. Advantages of biofilters for stormwater management (Payne et al., 2015). **(Søberg et al, 2014).*

Advantages	**Comments**
Beneficial to the local micro-climate	Better diversity and distribution of local plant species.
Attractive landscape; can be integrated in the local urban design	Good landscape design principles, careful plant selection / maintenance needed
Flexible in design and application	Allows to apply different geometries and the use of local plants and materials
Effective pre-treatment for stormwater harvesting applications	Provides greener public spaces / reduces demand of water pumping over long distances to WWTP
Small footprint relative to their catchment	Only covers around 2% of the effective impervious catchment area
Suitable for cold weather areas*	Salt and temperature can influence the removal of TSS and some metals

Configurations
Different bio-filter types/configurations can be applied and implemented depending on the characteristics of the area (1) trees in biofiltration / bioretention, (2) rain gardens and (3) biofiltration swales.

(1) Trees in bioretention
In urban areas, trees are usually surrounded by pavements and sometimes by larger grassed areas. Therefore, these trees need planting beds or bridging structures so they can develop into attractive elements as well as sustainable elements for stormwater management systems (Stockholm Stad, 2009). Additionally, these trees need enough space to achieve good growing conditions. Trees installed as bioretention or biofiltration systems, can provide many environmental (increase infiltration and evapotranspiration, remove pollutants, etc) and community benefits (aesthetics, cleaner air, etc) (Siddam, 2014).

Tree pits aimed for stormwater management usually consist of a prefabricated concrete vault, containing engineered soil, vegetation and trees selected based on the urban conditions (Siddam, 2014). Additionally, these tree pits are designed with an under drain and connected to the existing storm sewer system. In areas where overflows are common, storage chambers can be designed attached to the precasted structure of the tree to hold the additional runoff and make it available for plant uptake or groundwater recharge. According to Siddam (2014), a standard tree pit has a high removal efficiency for P (70-75%), N (60-68%) and TSS (70-85%) and the expected life-span of the system is up to 25 years. Commercial tree pit systems developed for stormwater management are for example Filterra by Contech Engineered Solutions and Tree Pit and BioFilter by Ecosol.

Filterra Bioretention

Contech Engineered Solutions presents a defined tree pit device called "Filterra ® Bioretention" (Figure 2.9). This device aims to remove solids, nutrients, heavy metals and hydrocarbons. Runoff enters the unit throught the curb-inlet and flows through a designed filter media-mix. The pollutants captured in this filter are decomposed, volatilized and used as part of the biomass of the system´s fauna and flora. Filterra provides a ponding depth of 457mm with a treatable flow rate from 0.48 up to 2.97 L/s depending on the size of the device (Filterra, 2009; Geosyntec, 2015). Recommended filter surface area to drainage area ratio is 0.33% (Virginia Stormwatern Management, 2002).

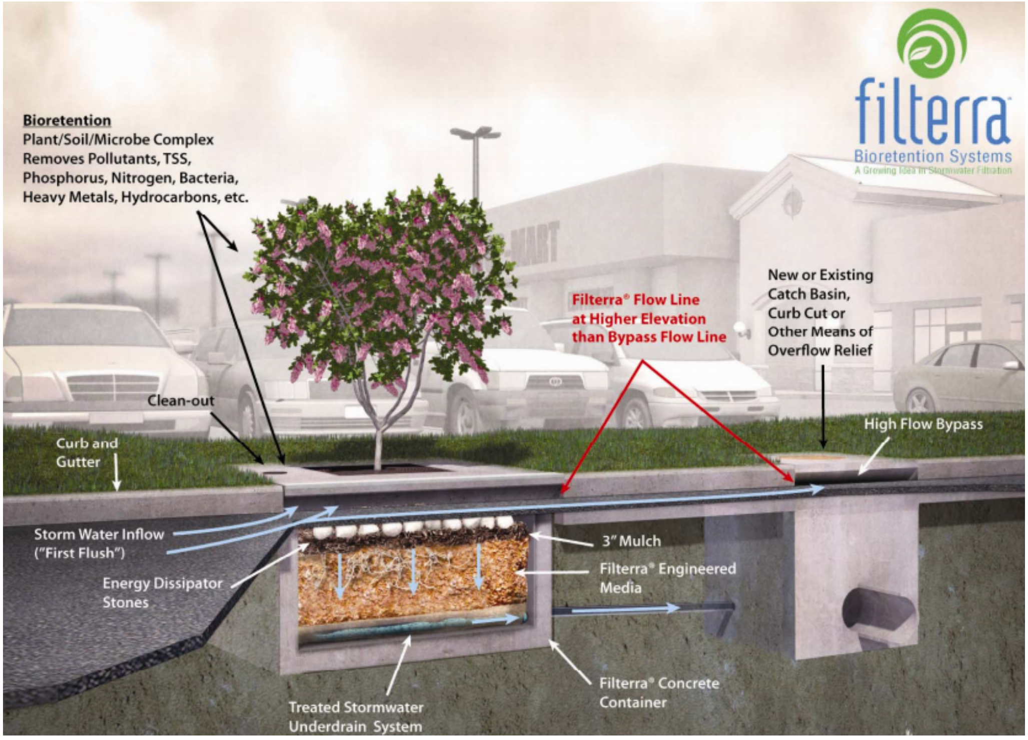

Figure 2.9. Filterra Bioretention from Contech and main parts (Contech, 2016).

Studies of the Filterra bio-filter report different removal efficiencies; in general, the highest removal rates belong to TSS and Hydrocarbons and the lowest to TN Table 2.16).

Table 2.16. Removal efficiency of Filterra Biofilter (Contech, 2016)

Pollutant	**Removal efficiency (%)**
TN	34
TP	70
TSS	86
Total Cu	55
Dissolved Cu	43
Total Zn	56
Dissolved Zn	54
Hydrocarbons	87

Usually one or two maintenance works are recommended per year based on: inspection of the filter and the surrounding area; removal of tree grate and erosion control stones; removal of debris, trash and mulch; mulch replacement; plant health evaluation and pruning or replacement as necessary; clean area around Filterra.

Tree Pit and BioFilter

Ecosol provides the Tree Pit filter and the BioFilter. They have similar treatment systems but have some differences based on their designs and configurations (Figures 2.10 & 2.11).

The tree pit is a vegetated, small filter unit that provides biological treatment through the sandy loam biofiltration media. Its compact design reduces installation costs and time, and improves environment aesthetics. With a 100 mm ponding depth it provides an estimated infiltration rate of 0.317 L/s. Once the ponding depth of 100mm is reached, the exceeding flows are bypassed downstream to the next inlet (Ecosol, 2014a). The biofilter is also a modular system a little bit bigger than the tree pit. It provides tertiary biofiltration treatment through sand and a carbon-source media and incorporates a primary treatment chamber for bigger loading capture. The maximum ponding depth of this unit is 300 mm and it supplies a treatable flow rate from 0.825 up to 3.168 L/s depending on the size of the device. The BioFilter provides an internal bypass flow capacity between 80 and 124 L/s depending on the size of the unit (Ecosol, 2014b).

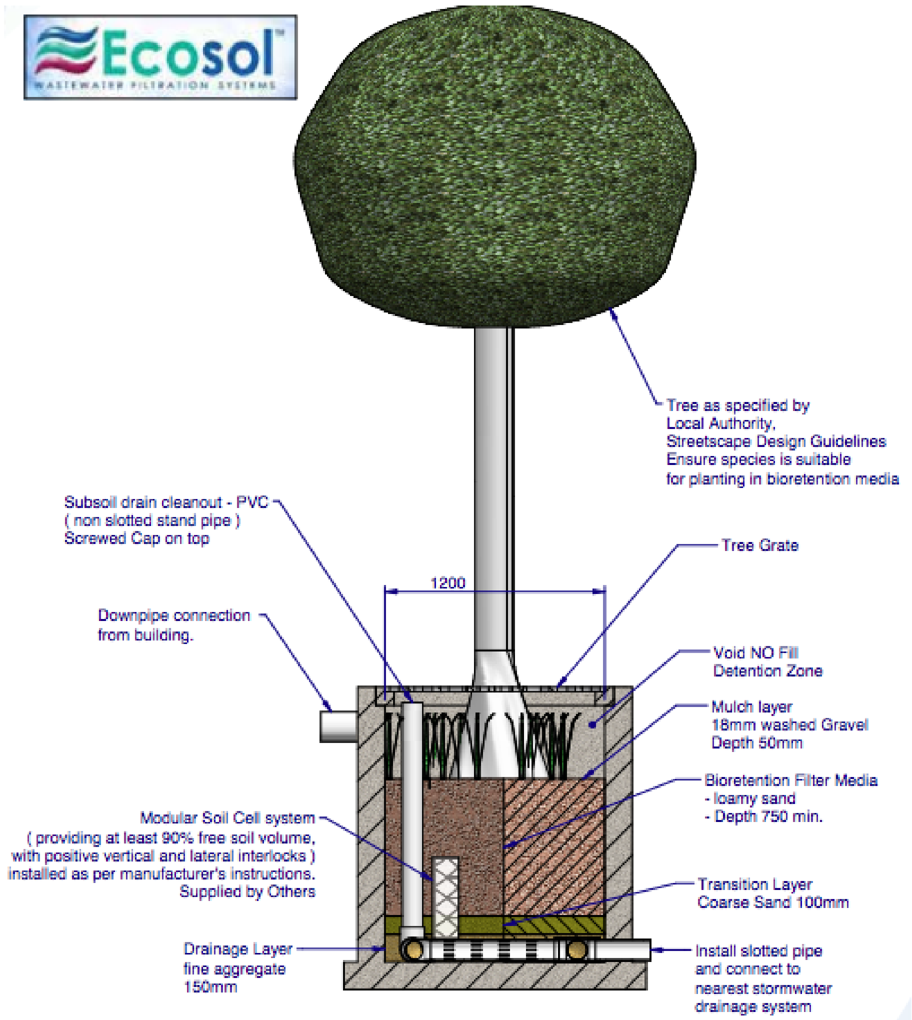

Figure 2.10. Tree Pit from Ecosol and main parts (Ecosol, 2014).

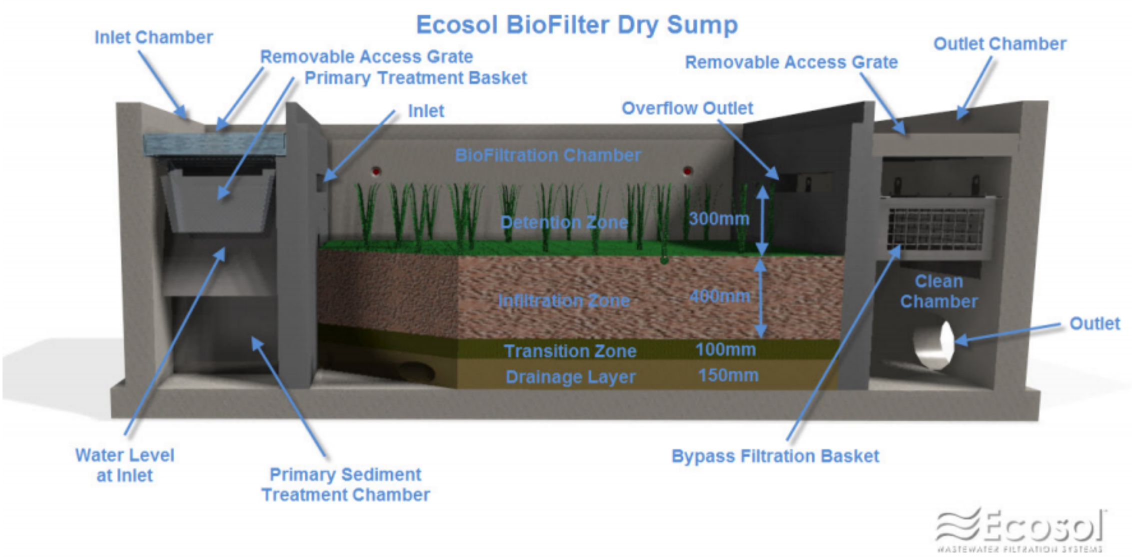

Figure 2.11. Bio Filter from Ecosol and main parts (Ecosol, 2014).

The two types of biofilters presented by Ecosol have different removal rates of pollutants (Table 2.17). The Tree Pit presents the highest removal efficiency for hydrocarbons, TSS, and P while the BioFilter presents the highest removal efficiency for heavy metals and TSS.

Table 2.17. Removal efficiency of Tree Pit (1) and Bio Filter (2) (Ecosol, 2014).

Pollutant	**Removal efficiency (1)**	**Removal efficiency (2)**
Nitrogen (TN)	45%	50%
Phosphorus (TP)	80%	65%
TSS	85%	95%
Heavy Metals	50%	90%
Hydrocarbons	93%	70%

The maintenance of the tree pit focuses on four different aspects: mulch (layer added on top of soil used for soil moisture conservation, improvement of the soil fertility and enhancing the visual appearance of the area), filter media, vegetation and structural components. The first three activities are to be done every third month or right after a rain event, while the structural component inspection should be done once per year (Ecosol, 2014a). The maintenance activities for the BioFilter focus as well on four aspects; (1) inlet primary treatment chamber, (2) tertiary treatment chamber (biofiltration), (3) outlet (overflow) chamber and (4) structural components. As for the tree pit, all the activities are to be done every third month or right after a rain event while the structural components are to be inspected once per year (Ecosol, 2014b).

(2) Rain Gardens

Rain gardens are vegetated soil filters which provide water quantity and quality control as well as enhancing the aesthetic value of the landscape. It is a rather new technology that appeared in the USA in the 1990s (Lindfors et al., 2014). Usually, the area of the rain gardens is 2–5% of the dewatered impervious area and the main processes involved in this system are evapotranspiration through the plants, sedimentation, plant uptake, sorption and microbial degradation (Strömvall, 2017). The usual ponding depth should be 400-600mm and the infiltration rate varies between 150 to 350 mm/hr (Yuan et al, 2017).

Rain gardens can be designed in different ways based on the site-specific needs usually focusing on environmental conditions, technical aspects and aesthetics (Lindfors et al., 2014). Rain gardens are usually built based on three main parts (Figure 2.12); (1) vegetation, (2) ponding area and (3) inflow and outflow structures (Basdeki et al., 2016). The vegetation is usually formed by native plants that have the capacity to survive inundations. The ponding area is a naturally or artificially constructed depression filled with soil or specific filter media, covered in the bottom with a mulch layer. The inflow-outflow structures allow water to enter and exit the facility; the outflow structures are usually pipes (Basdeki et al., 2016).

The selection of the filter media is important since the needs for the different actions demand a specific type of media. For example, stormwater detention demands high permeability media since it allows large flows of water. However, low permeability media is desired for pollutant removal (Kangas, 2016).

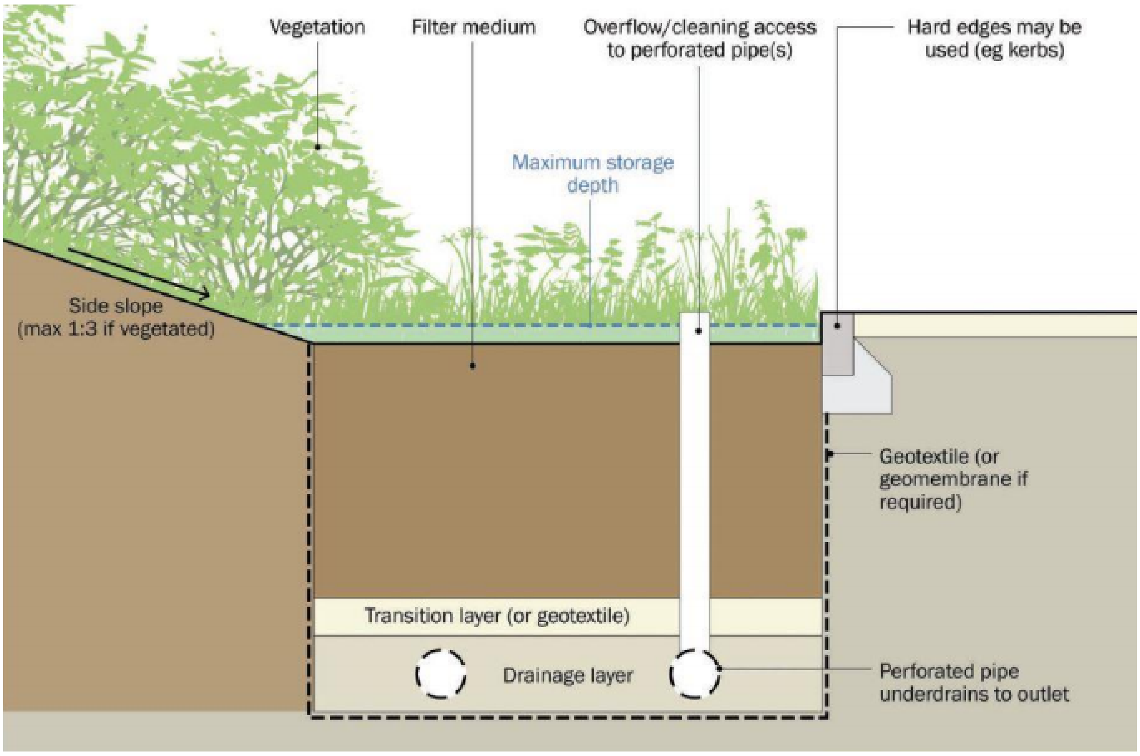

Figure 2.12. Schematic cross-section drawing of a rain garden (Kangas, 2016).

Removal Efficiency

Bioretention units have provided good results for stormwater treatment in cold climates since some of the compounds' removal efficiencies are not dependant on the temperature, such as suspended solids and phosphorus (Blecken et al., 2010a; 2010b). However, nitrogen removal is affected by the climate since nitrification and denitrification processes are slower in cold temperatures (Zou et al, 2014). Blecken (2010b) proposes the addition of a saturated zone with a carbon source to decrease the effect of cold climate. Lindfors et al., (2014) summarize the removal efficiencies of rain gardens (Table 2.18) focusing on heavy metals, nutrients and others compounds.

Table 2.18. Removal efficiency of rain gardens (Lindfors et al., 2014)

Pollutant	**P**	**N**	**Pb**	**Cu**	**Zn**	**Cd**	**Cr**	**Ni**	**Hg**	**SS**	**Oil**	**PAH**
%	60	25	80	60	90	80	25	75	50	85	60	85

Maintenance
Raingardens are designed to demand rather little maintenance. Watering of the plants in essential during the first year and occasional replacement of plants is as well necessary during the lifespan of the garden. Regarding the inlet and outlet, sediment accumulations and organic matter accumulations need to be inspected regularly and removed if necessary. Additionally, if water ponds stay longer than 48h, it means that the media is not capable of adsorbing and filtering and hence, at least the top layer needs to be changed (Center for Watershed Protection, 2015).

Advantages and disadvantages
Advantages and disadvanages of rain gardens are summarized in table 2.19.

Table 2.19. Advantages and disadvantages of raingardens (Center for Watershed Protection, 2015).

Advantages	**Disadvantages**
Good pollutant treatment	Not suitable with steep slopes
Increase of groundwater recharge	Must be sited in a location that allows overflow
Micro-scale habitat	Should not be located close to heavy tree covered areas since the roots systems can make the installation difficult
Easy maintenance	Quite frequent maintenance
Aesthetic improvement	

2.4.5 Biofiltration Swales

Biofiltration or bioretention swales are usually shallow and vegetated depressions designed with lateral slopes (Figure 2.13). They aim to capture, infiltrate and hence, improve the stormwater runoff quality. They are economically attractive but demand large space (NACTO, 2017). Swales are usually designed for residential streets along medians, roundabouts or shared spaces. Biofiltration swales involve different mechanisms for the removal of the pollutants such as interception, infiltration, settling, evaporation, filtration, absorption, transpiration, evapotranspiration, assimilation and adsorption.

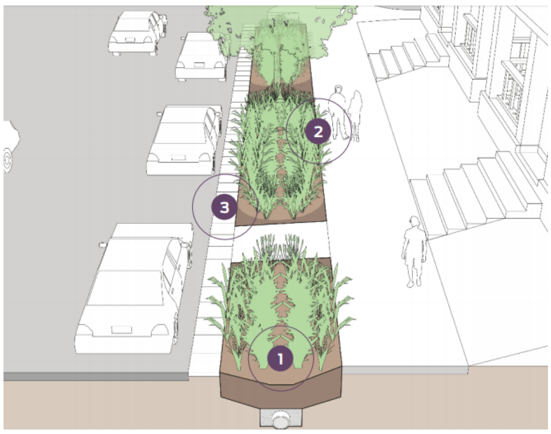

Figure 2.13. Schematic drawing of a biofiltration swale (NACTO, 2017).

Additional bio-chemical processes include nitrification, denitrification, degradation and decomposition (The Prince George's County, 2007). Usually, the area of the swales is 4–12% of the dewatered impervious area, the usual ponding depth is 100-300 mm and the infiltration rate varies between 100 to 300 mm/hr (Payne et al. 2015).

Removal Efficiency

Based on the literature, average removal efficiencies for biofiltration swales are summarized in Table 2.20.

Table 2.20. Average removal efficiencies of EcoVault.

Pollutant	**Removal (%)**	**Reference**
As	83	Geosyntec Consultants, Inc. and Wright WaterEngineers, Inc. (2012)
Cr	48	Geosyntec Consultants, Inc. and Wright WaterEngineers, Inc. (2012)
Cd	21	Geosyntec Consultants, Inc. and Wright WaterEngineers, Inc. (2012)
Pb	51	Barrettet al. (1998b);Hunt et al. (2006) Davis et al.(2006); UNHSC (2006) Ermilio and Traver (2006) Geosyntec Consultants, Inc. and Wright WaterEngineers, Inc. (2012)
Cu	62	Hunt et al. (2006);Davis et al.(2006) UNHSC (2006);Ermilio and Traver (2006)
Zn	69	Barrettet al. (1998b) Hunt et al. (2006);Davis et al.(2006) UNHSC (2006);Ermilio and Traver (2006)
Ni	68	Geosyntec Consultants, Inc. and Wright WaterEngineers, Inc. (2012
Hg	59	Modeled in StormTac (2017)
Oil	86	Little et al.(1992) Hunt et al. (2006);Davis et al.(2006) UNHSC (2006);Ermilio and Traver (2006)
TP	40	EPA (1999) Barrettet al. (1998b) Hunt et al. (2006);Davis et al.(2006) UNHSC (2006);Ermilio and Traver (2006)
TN	40	EPA (1999); Barrettet al. (1998b) Hunt et al. (2006);Davis et al. (2006) UNHSC (2006);Ermilio and Traver (2006)
BaP	85	Modeled in StormTac (2017)
PAH	85	Hellberg (2016)
TSS	70	EPA (1999);Barrettet al. (1998b) Little et al.(1992) Hunt et al. (2006);Davis et al. (2006) UNHSC (2006);Ermilio and Traver (2006)

Maintenance

Swales are to be maintained as the surrounding landscape; mowing and weeding at regular intervals (each 6 month at least) is necessary to maintain the aesthetics of the swale (Hunt et al, 2015). If erosion is observed within the swale, flow-resistant rocks can be placed along the structure. If mosquito habitat is formed, can be due to two different facts; (1) the swale is not dewatering properly or (2) sedimented debris is providing shelter for the mosquitoes. In these cases the best is to control the filtration system and to remove the debris.

Advantages and disadvantages

Advantages and disadvantages of the swales are presented in Table 2.21.

Table 2.21. Advantages and disadvantages of swales (NACTO, 2017).

Advantages	**Disadvantages**
Good pollutant treatment	Require large area
Allows the use of a large variety of plants	Debris can lock the filtration
Provide micro-scale habitat	Can create mosquito habitat
Easy maintenance	Frequent maintenance

2.4.6 Street Sweeping

Street Sweeping has been used all around the world to reduce trash, dirt, and vegetation volumes from the streets. There is ongoing development of street sweepers towards more effective and sustainable solutions e.g. PAH and metal removal (Amato et al, 2010). Currently, there are four main types of sweepers: (1) mechanical sweepers, (2) vacuum-assisted sweepers and (3) regenerative-air units and (4) sampler sweepers that allow the sweeping and the sampling at the same (dust sampler) (Figure 2.14). Vacuum-assisted sweepers and regenerative-air sweepers are better than mechanical sweepers at removing finer sediments but are only efficient in smaller areas, while mechanical sweepers are better at removing larger debris and at sweeping larger areas.

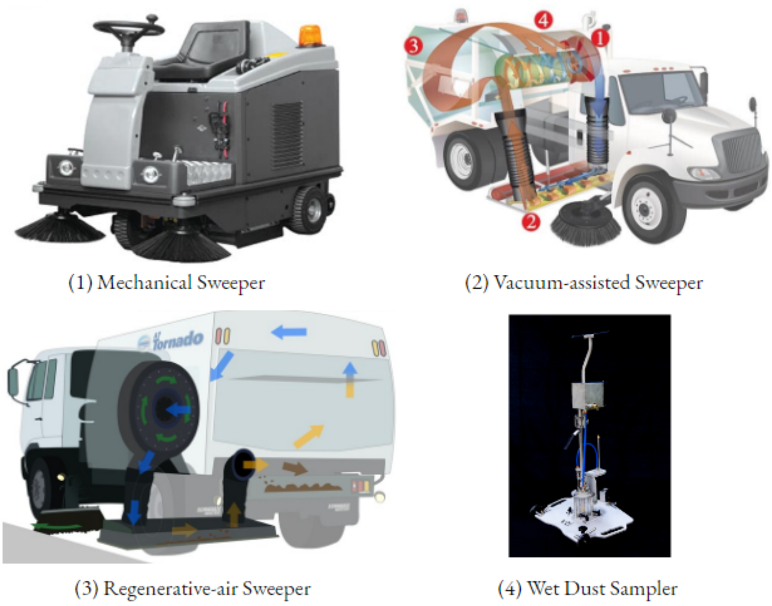

Figure 2.14. Examples of the four types of street sweepers.

Removal Efficiency
Street sweepers have proved to provide quite effective removal rates of different compounds (Table 2.22) except for Cadmium (Cd).

Table 2.22. Removal efficiency reported for a street sweeping in Gothenburg (Sustainable Waste and Water, City of Gothenburg, 2018). **Kuehl et al, (2008)*

Substance	**P**	**N**	**Pb**	**Cu**	**Zn**	**Cd**	**Cr**	**Ni**	**As**	**SS***	**Oil**
%	15.5	43	37	44	31.5	-20	17	32	37.5	21	81.3

2.4.7 Cost of the researched treatment techniques

Based on the literature, the net costs were found for the researched treatment techniques (Table 2.23). The investment cost presented in Table 2.23 represent the cost per unit without considering construction, machinery, personnel or connection to drainage system costs.

Table 2.23. Investment, maintenance and control (M&C) costs (per year and per unit) for researched treatment techniques in SEK.

Alternative	**Inv. cost**	Reference	**M&C Cost**	Reference
Dry pond	150 000	Morales Torres et al, 2015	6 000	Morales Torres et al, 2015
Wet pond	270 000	Morales Torres et al, 2015	19 000	Morales Torres et al, 2015
EcoVault	700 000	Sustainable Waste and Water, City of Gothenburg, 2018	50 000	Sustainable Waste and Water, City of Gothenburg, 2018
StormFilter	650 000	Olson et al, 2010	35 000	Olson et al, 2010
Vortechs	300 000	Olson et al, 2010	15,000	Olson et al, 2010
Filterra	130 000	Olson et al, 2010	13 000	Olson et al, 2010
Tree pit	33 000	Case study Melbourne Payne et al, 2015	1 200	Payne et al, 2015
Biofilter	150 000	Olson et al, 2010	10 000	Olson et al, 2010
Rain garden ($100m^2$)	150 000	Morales Torres et al, 2015; Zhiliang, 2012	13 000	Morales Torres et al, 2015; Zhiliang, 2012
Biofiltration swales ($200m^2$)	50 000	Morales Torres et al, 2015; Zhiliang, 2012	2 000	Morales Torres et al, 2015; Zhiliang, 2012
Street sweeping	125 000	Schilling, J.G. 2005	20 000	Sustainable Waste and Water, City of Gothenburg, 2018
Filters	300 000	Sustainable Waste and Water, City of Gothenburg, 2018	28 000	Sustainable Waste and Water, City of Gothenburg, 2018

2.5 Selection procedure for stormwater treatment technique

The MCA is a decision support tool which aims to evaluate several criteria for multiple alternatives and provide a ranking of these alternatives (DCLG, 2009). Some studies have been conducted focused on the use of MCA for the selection of urban stormwater management alternatives.

Among the studies found related to MCA for stormwater decision-making, the oldest one dates from 2004 and was written by Ellis et al. This study focuses on the development of a multi-criteria analysis methodology for evaluating and accrediting different Sustainable Urban Drainage Systems (SUDS) structures defining different performance criteria. Later, Martin et al. (2006) wrote about the application of a MCA approach to the urban storm water drainage management which allowed them to evaluate and rank different alternatives involving different decision-makers. Jia et al. (2013), Carvallo Aceves & Fuamba (2015) and Song & Chung (2017) focused on the application of the MCA framework to evaluate and rank different types of low impact development (LID) practices and best management practices (BMPs) for stormwater management. In the five papers evaluated, the conclusions reached by the researchers were similar. First, it was identified that the MCA approach involves all points of view and criteria from all entities involved and allows the sharing of information; which is crucial for providing transparency to the approach (Ellis et al., 2004; Martin et al., 2006; Jia et al., 2013; Carvallo Aceves & Fuamba, 2015 and Song & Chung, 2017). Second, the researchers also agree that the steps followed during the MCA provide a clear path for analysis and allow feedback and corrections to be done during the process.

However, the authors argue that the MCA does not consider longstanding engineering solutions as more suitable solutions and that it takes the risk on ranking higher-up alternatives that have not been implemented as much. This represents a high uncertainty since the reliability of the new systems cannot be quantified as easily as the historically most implemented options (Ellis et al., 2004; Martin et al., 2006; Jia et al., 2013). These papers as well emphasize the fact that some selected criteria during the decision-making process might have consequences during the implementation of the alternative that are usually not analyzed. For example, they discuss that the maintenance and control cost is always included in the MCA, while determining the responsible entity carrying out the maintenance activities is usually not defined. This leads to confrontation between stakeholders and neglecting the maintenance activities.

The MCA approach allows to weight each of the criteria based on the demands of the stakeholders resulting in the ranking of the most optimal and suitable solutions. The method can be conducted following eight main stages (DCLG, 2009):

1. **Define the context**
    (a) Define the aims of the MCA
    (b) Identify the decision makers and stakeholders
    (c) Design the socio-technical system
    (d) Consider the context of the appraisal (budget)
2. **Identify and describe the alternatives to be evaluated**
3. **Identify the main objectives and the criteria to be considered**
    (a) Identify the criteria in order to assess the consequences of each alternative
    (b) Define independence or interdependence of criteria
4. **'Scoring' process**
    (a) Assess the expected performance of each alternative against the criteria
    (b) Describe the consequences of the options
    (c) Score the options on the criteria
    (d) Check the consistency of the scores on each criterion
5. **'Weighting' process.** Assign weights for each of the criterion in order to reflect their importance to the decision
6. **Combine the weights and scores for each option to derive an overall value**
7. **Examine the results**
8. **Sensitivity analysis**
    (a) Perform a sensitivity analysis: how do the scores and weights affect the overall ordering of the alternatives?
    (b) What are the advantages and disadvantages of the selected alternatives?
    (c) Propose possible new alternatives with new combinations
    (d) Repeat these steps until an adequate model is obtained

2.5.1 Criteria definition

Specific site conditions may help defining MCA criteria. Objectives, primary criteria and secondary criteria are to be defined which usually are independent from each other (DCLG, 2009).

However, Kamışlı Öztürk (2006) presented a review of papers and theories defending the dependency between criteria and that in several decision making processes (Carlsson and Fuller-1995; Karwan et al-1995; Saaty-1996), criteria were interdependent. The review also presents the different models (crisp and fuzzy theories)(Carlsson and Fuller-1994; Felix-1994; Angilella et al-2004; Tzeng et al-2005) and mathematical theories (ANP *(Analytic Network Process)*) (Saaty-1996) that have been developed throughout the years presenting and defending as well the concept of interdependence.

2.5.2 Scoring

Each alternative needs to be scored with a maximum of five points based on the impact on each criteria. A linear scale can be used which is presented from the worst possible value to the best possible value (Martin et al., 2006). The description of each point can be defined differently for each of the criterion.

2.5.3 Weighting

The weighting process is necessary to ensure that the interests and requirements of the stakeholder are reflected in the process (Munier, 2011). The objectives should be ranked based on the requisites of the stakeholder (Baptista et al., 2007) and the same procedure should be followed for the criteria.

2.5.4 Final calculation

The most used MCA in the field of urban stormwater management is the linear additive model (Ellis et al., 2004), once that the scoring and weighting is completed. This model is based on equation 2.1 (DCLG, 2009).

$$S_i = \sum_{j=1}^{n} w_j \cdot s_{i,j} \tag{2.1}$$

- S_1: Total score of alternative i
- w_j: Weight of primary criteria j
- $s_{i,j}$: Score of alternative i in criteria j
- n: number of criteria

2.5.5 Sensitivity analysis

A sensitivity analysis can be conducted in the Java developed web-programm "Web-HIPRE" (HIerarchical PREference analysis on the World Wide Web) which was developed by the Finish university of Aalto. Web-HIPRE allowes to create goals, primary criteria and alternatives in a hierarchical structure and connect all parts with each other. Alternatives can be scored based on the project and each criteria can be as well weighted as desired. It also allows adapting of the scales.

2.6 Calculations

There are several parameters of certain relevance that can directly eliminate an alternative as a possible option. Those parameters are: area availability, design flows with the rational method, pipe sizing, treatable flow rate and cost of facility; presented in the Method chapter.

3 Case-study area description

This chapter presents a description of the catchment area of Vitsippsbäcken. Specifications of the area are presented and described; (1) the location, (2) climate, (3) geology and topography, (4) previous studies, (5) catchment status and (6) description of treatment facility at Sahlgrenska Hospital.

3.1 Location of Vitsippsbäcken catchment area

Vitsippsbäcken catchment area is located in the city of Gothenburg, which is the second largest city of Sweden (City of Gothenburg, 2016). Figures 3.1 and 3.2 show the location of the Vitsippsbäcken stream where the samples were taken. The two figures were obtained with the SGU tool (Sveriges Geologiska Undersökning), and are presented in different scales.

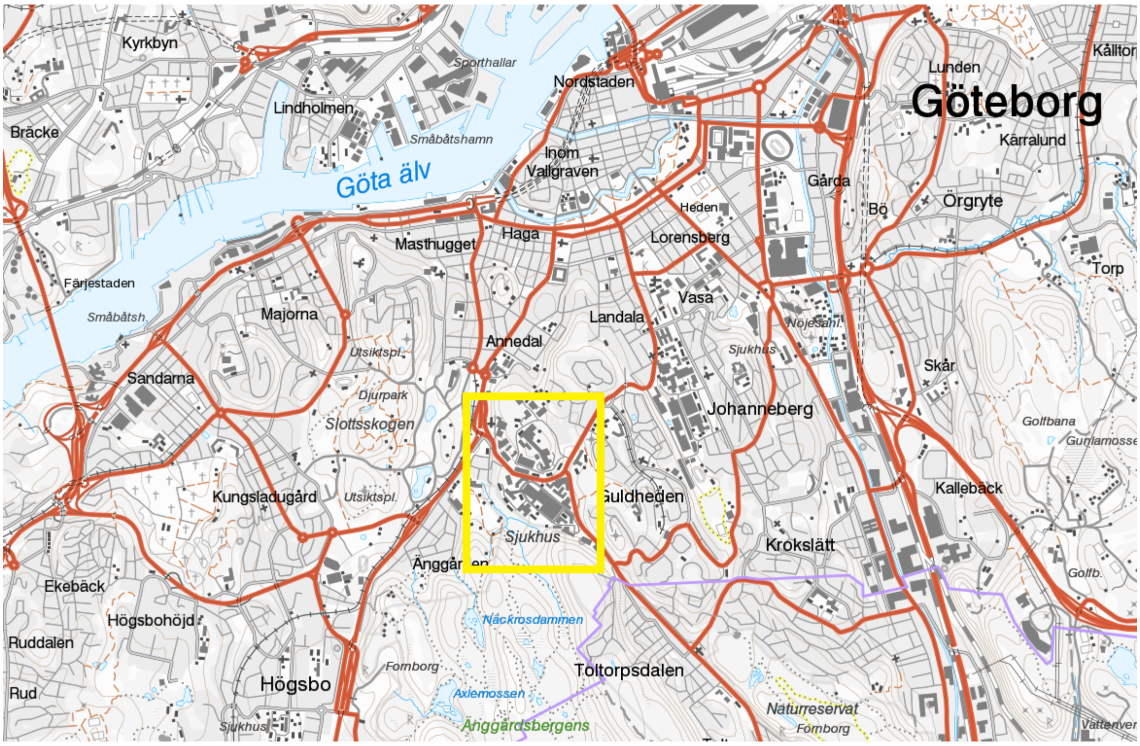

Figure 3.1. Map of Vitsippsbäcken catchment in Gothenburg. Scale 1:25000 (SGU).

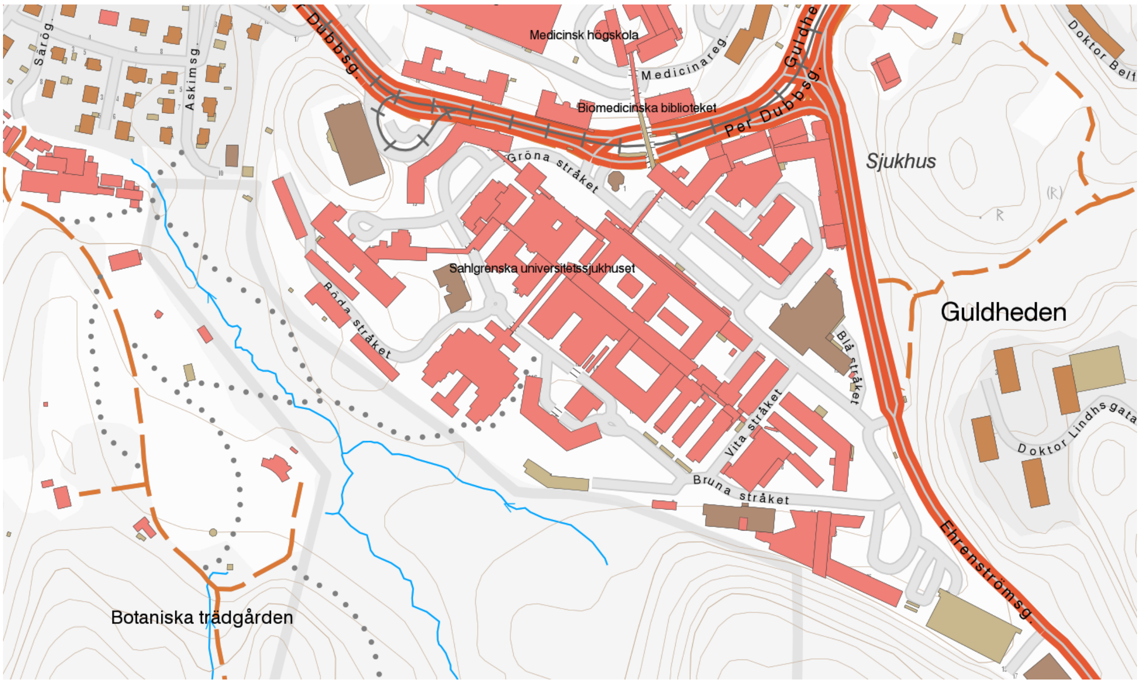

Figure 3.2. Location of Vitsippsbäcken the stream south of the Sahlgrenska hospital. Scale 1:2500 (SGU).

3.2 Climate in Gothenburg

The city of Gothenburg has a warm-summer humid continental climate where the coldest month average is below 0 °C with no notable precipitation difference between months and season (Kottek et al, 2006). The average annual precipitation is around 840 mm/year (Ljungdahl, 2015). However, according to the SMHI (2017), the precipitation in 2017 was 993 mm while the normal average precipitation registered in Gothenburg between the years 1961-90 was 758 mm (see Appendix E). The biggest precipitation events were registered in the year 2006 with an annual precipitation of 1264mm (SMHI, 2017).

3.3 Geology and topography of the case-study area

Based on SK 1983-87 (Swedish Survey of Forest Soils and Vegetation) and maps obtained from SGU, Vitsippsbäcken catchment area is located over bedrock outcrop with granitic formations together with fine-grained sediments with fairly/very shallow soil depth. The dominating soil type is lithosol and brown forest soil. Regarding the mineral composition of the soil, quartz (25-30%), feldspar (25-27%) and plagioclase (27-30%) are present. Additionally, in the green areas the mixed deciduous coniferous forest prevails. Sahlgrenska Hospital is located in a geological depression (Figure 3.3). This fact represents a high flooding risk from the surrounding hills in the North and West. Since the elevation difference between the East and West side is quite notorious, the need for a retention/detention pond seems necessary to reduce the water volume coming down the hill.

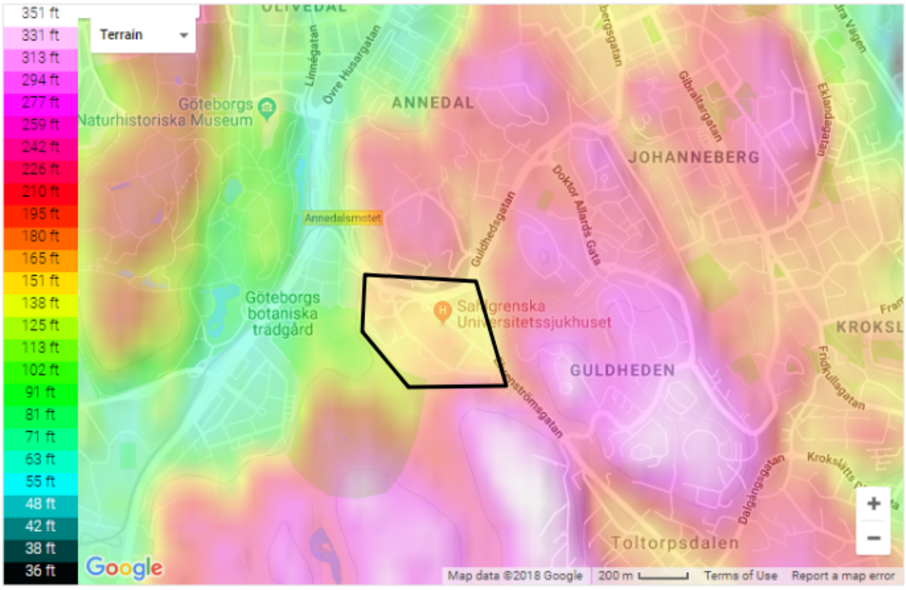

Figure 3.3. Elevations of the Vitsippsbäcken area and depression (marked in black) where the Sahlgrenska Hospital is located.

3.4 Previous studies of the stormwater quality in Vitsippsbäcken's catchment

To date, two different upstream solutions have been tested in an attempt to minimize the stormwater pollution released into the stream. Additionally, an end-of-pipe solution has been modeled in StormTac.

1. **FILTERS:** The first upstream solution was tested between 2012-2016, which resulted in the installation of 46 filters of three different types in gutter wells (Table 3.1). The aim was to treat the stormwater that is diverted to the small stream from the main roads and public land (DHI, 2016). The last measurements conducted in 2016 indicated that the filters reduced the amount of pollutants significantly. For most of the pollutants, a reduction between 40-60% was achieved except for Hg (30%), Cd (15%) and benzo(a)pyrene (10%); and the estimation of dissolved metal contents indicated that the water passing through the filters met the environmental management guidelines for all metals except for Cu.

Table 3.1. Filter types installed in the 46 gutter wells in Vitsippsbäcken catchment area.

Company	Filter Material	Quantity	Data Sheet
ENWA	Pine bark with elements of tile	23	ENWAmatic (2017)
FlexiClean	Pine bark with elements of tile	11	FlexiClean (2015)
Kenrex	Spun polypropylene	11	SSFilters (2016)

2. **STREET SWEEPING:** The second upstream solution was tested in 2017 and resulted in weekly sweeping of the main traffic roads, performed by the traffic department. Street sweeping was conducted with a conventional machine (vacuum and sweeper). Stormwater was sampled during five rain events and the results showed a significant reduction of most metals compared to measurements without street sweeping in 2016 (Sustainable Waste and Water, City of Gothenburg, 2018).
3. **MODELLING OF END-OF-PIPE SOLUTION:** As an end-of-pipe solution, an underground retention basin with filter as the EcoVault type modelled in 2018 in StormTac by the Waste and Water department, City of Gothenburg (Sustainable Waste and Water, City of Gothenburg, 2018).

Results obtained from the analysis of these three actions/studies are summarized in Table 3.2. Some of the obtained values still exceed the target values defined by the Environmental department in Gothenburg (marked in red), which suggests the need for additional measures.

Table 3.2. Measured and simulated stormwater quality data after the three different remediation actions taken until today (Sustainable Waste and Water, City of Gothenburg, 2018).

Parameter (ug/L)	Reference values (2016)	Measured mean values with street sweeping	Measured mean values with filters	Modeled end-of-pipe reduction
P	116	98	77	63
N	1540	882	610	1400
As	0.88	0.55	0.43	2.2
Pb	6.47	4.08	3.36	1.8
Cd	0.25	0.71	0.18	0.067
Cu	64	36	40	12
Cr	6.58	5,52	3,64	1,7
Ni	5.08	3,46	3.4	2
Zn	232	159	107	22
Oil index	1500	280	230	58
BaP	0.064	0.028	0.87	0.004

3.5 Vitsippsbäcken catchment's conditions

The starting point for the analysis of Vitsippsbäcken's catchment area were reports, provided by the municipality of Gothenburg, regarding the removal efficiency of previously tested alternatives i.e. filters and street sweeping; and a model built in StormTac as a base for efficiency calculations. As the main need for the area was to minimize pollutant discharges into the stream, the conducted review of the stormwater treatment techniques focused on different sub-catchments in the area (Figure 3.4). According to the model built in StormTac, the total catchment area has a surface area of 43 ha. The North sub-catchment (Norra) has a total area of 15 ha, the West sub-catchment (Västra), of 5 ha and the East (Östra) sub-catchment, of 23 ha. This means that the eastern part of the area represents the 53% of the total area followed by the northern area (35%) and the western area (12%).

Surface type/Area (m²)	Total	West	North	East
Asphalt surfaces	75590	16297	43390	15960
Buildings	58026	13362	31114	13550
Gravel surfaces	2114	0	26	2088
Natural hard surfaces	14086	28	3801	10258
Forest	51615	1749	8314	41551
Roads	43508	10399	21855	11262
Other vegetation	198614	8085	71623	118921

Asphalt surfaces
Buildings
Gravel surfaces
Natural hard surfaces (rock)
Forest
Roads
Other vegetation
Sub-catchment delimitations

Figure 3.4. Map of the Vittsppsbäcken catchment area together with the location of the proposed alternatives for stormwater management.

Each of the sub-catchments represents a percentage of the total catchment and therefore, a percentage of the total runoff generated. Based on the StormTac simulation, the total yearly flow is calculated by summing the base flow and the runoff generated by precipitation (Table 3.3). This flow helps determining the amount of units needed of each treatment alternative to treat the largest possible volume of water.

Table 3.3. Total yearly flow (L/s) estimation based on StormTac data. See Figure 3.6 for subcatchment area definition.

Area	Base flow + runoff (L/s)	Total yearly flow (L/s)
Total	2.5+2.6	**5.1**
North	0.8+1.2	**2**
West	0.29+0.33	**0.62**
East	1.4+1.1	**2.5**

The first area analyzed was the east subcatchment area where a detention pond (Figure 3.5) is currently located and collects stormwater from half of the sub-catchment (14 ha), see the area marked in yellow in Figure 3.4 (MarkTeknik AB 2007). These 14 ha encompass a large green steep area which generates surface runoff with high peak flows. This condition increases the flooding risk; however, the runoff is considered to be natural and clean without traffic pollution. Therefore, the existing detention pond is needed because of flood protection for Sahlgrenska. This small pond is connected downstream to the main pipe (AD1500) located under Ehrenströmsgatan street through a series of connected pipes of different diameters (Figure 3.6). Both the pond and the pipes were designed for a rain duration of 22 minutes with a return period of 50 years, representing a rain intensity of 267 L/s · ha. The diameter of the connecting pipe is 600 mm, hence the maximum design flow is 1450 L/s; further calculations presented in Chapter 5.

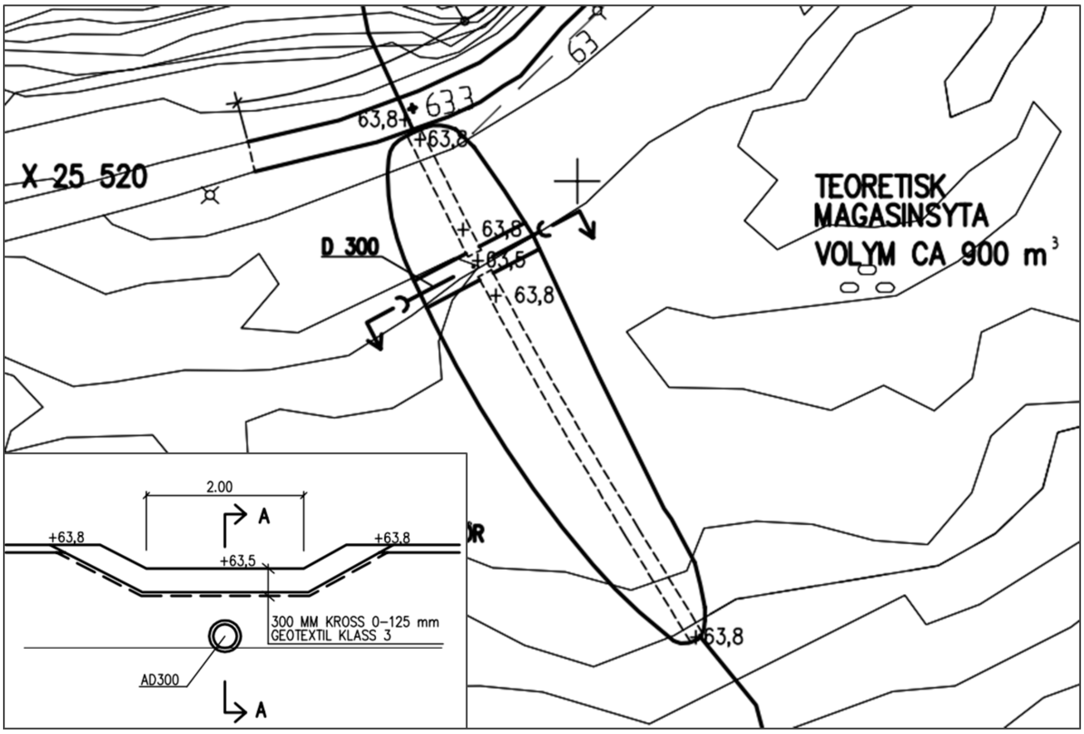

Figure 3.5. Detailed drawing of the existing detention pond (MarkTeknik AB, 2007).

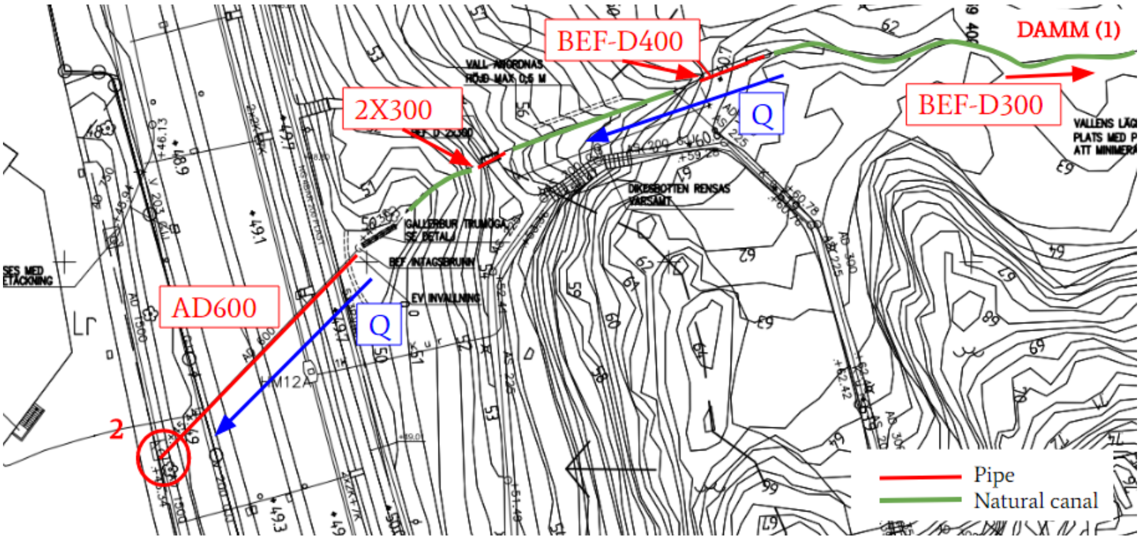

Figure 3.6. Connection pipes from the pond with the main AD1500 pipe (Mark-Teknik AB, 2007).

The existing detention facility could be retrofitted (Figure 3.7) or a new one could be implemented as either retention or detention pond aiming to retain the natural stormwater and provide a longer retention time, which would not need further treatment. Among the different alternatives, terrace solutions (1) and meanders (2) are proposed.

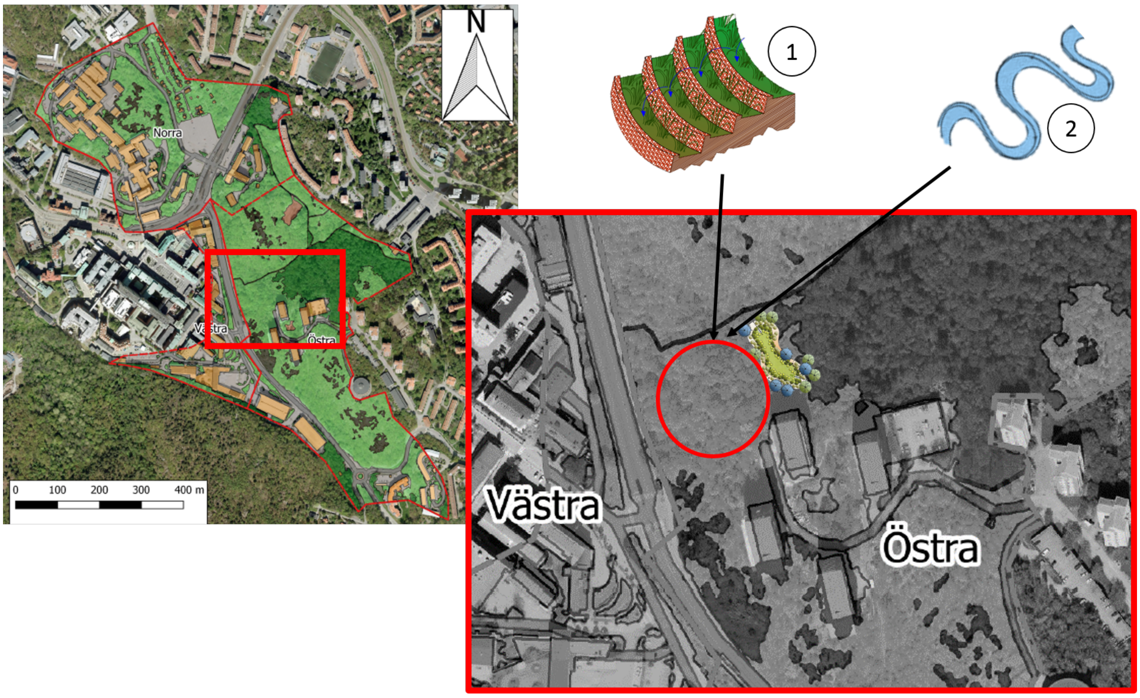

Figure 3.7. Options to retrofit the green area and the pond. (1) Terrace solution; (2) Meander solution.

The second area analyzed focuses on the discharge point where the untreated stormwater runoff reaches the stream, marked with a blue ring in Figure 3.4. An underground end-of-pipe solution would be optimal; always taking into consideration the space limitation in the area due to the land uses and land owners. Next locations focused on polluted road runoff and therefore, on road side areas. Since some filters were already implemented in the gutter wells and good results were obtained, the aim with this third location was to analyze if there is any alternative filter that would require less maintenance and could provide a higher removal efficiency. In the side areas of the road bio-filtration systems can be installed. The street sweeping would be conducted along the main roads as well.

3.6 Stormwater treatment facility at Sahlgrenska Hospital

Several of the buildings at the Sahlgrenska Hospital have copper roofs. Western properties intend to gradually reduce the cooper roof area by replacing the roof or demolishing buildings. The rainwater falling over the roofs is diverted into four different waterways; D315, D800, D1500 *(D=Diameter)* and a combined pipeline. The combined pipeline goes to Ryaverket while the other three pipelines are discharged to Vitsippsbäcken. Before the water is released to Vitsippsbäcken, it goes through a treatment facility which consists of three series-connected wells filled with a material that reduces the Cu content in the water (Figure 3.8).

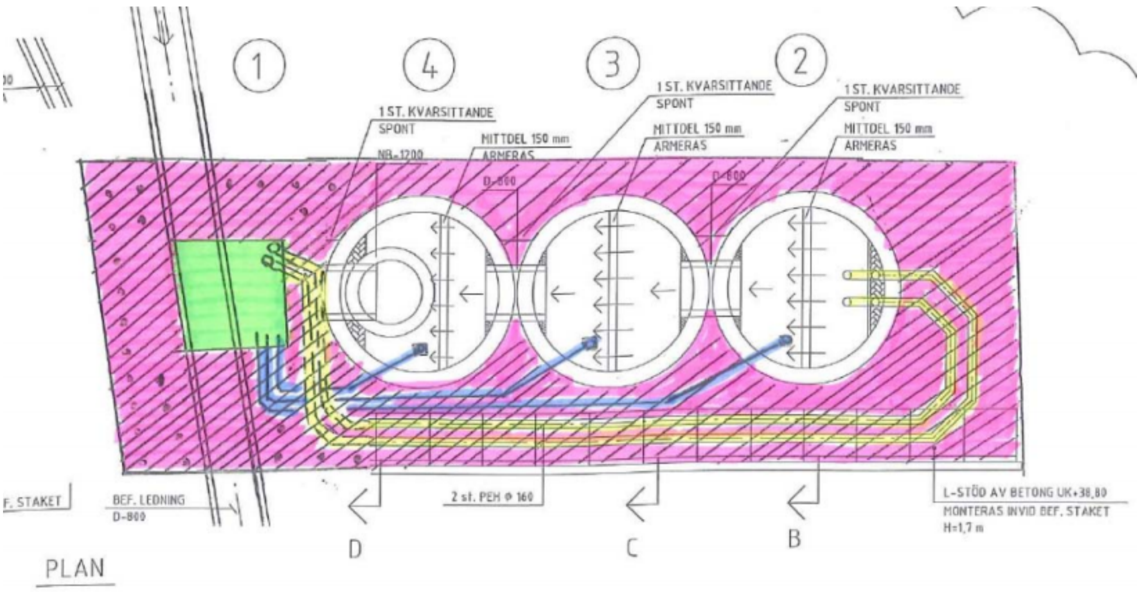

Figure 3.8. The Copper Well stormwater treatment facility at Sahlgrenska (Åf, 2017).

4 Method for treatment selection

This master's thesis work focuses on the implementation of a multi-criteria analysis (MCA) and the case study is based on the catchment area of Vittsippsbäcken aiming to find the most suitable solution for stormwater management. This was conducted through a combination of steps; (1) literature review (Chapter 2), (2) water status analysis based on sampling, (3) calculations regarding drained areas, flows, etc. (4) questionnaires with identified stakeholders (Appendix I), (5) development of models (Appendix J), and (6) implementation of the MCA, see flowchart in Figure 4.1.

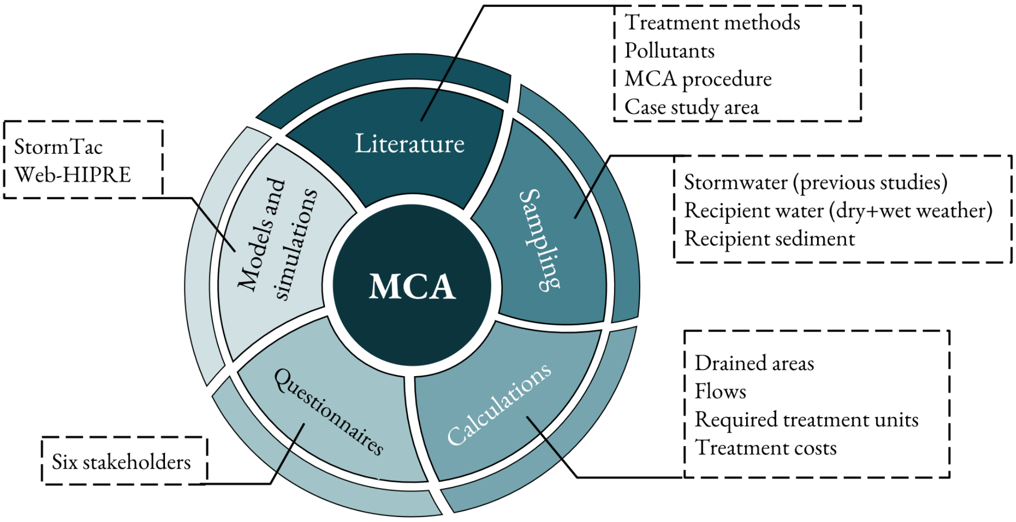

Figure 4.1. Flowchart summarizing the MCA methodology used for selection of treatment options of polluted stormwater.

4.1 Water quality analysis

In order to analyze the current status of the water in Vitsippsbäcken, three sampling events were performed, following the sampling protocols (Appendix F) and the samples were analyzed by a commercial laboratory.

4.1.1 Sampling method

Four water and sediment samples were collected each sampling day (Figure 4.2). Samples W1 and S1 (W=Water, S=Sediment) were collected just upstream from the main stormwater outlet and represent natural water inputs (coordinates 318700, 6397232). Samples W2 and S2 were collected 10 m downstream from the main outlet and upstream from the stormwater outlet from Sahlgrenska Hospital (coordinates 318638, 6397262) to analyze the contamination levels coming from Vitsippsbäcken urban catchment. Samples W3 and S3 were collected 10 m downstream from Sahlgrenska Hospital outlet (coordinates 318554, 6397286) to analyze the pollution level discharged from their treatment facility. W4 and S4 samples were collected downstream from all stormwater outlets (coordinates 318512, 6397318); this water additionally receives natural inputs.

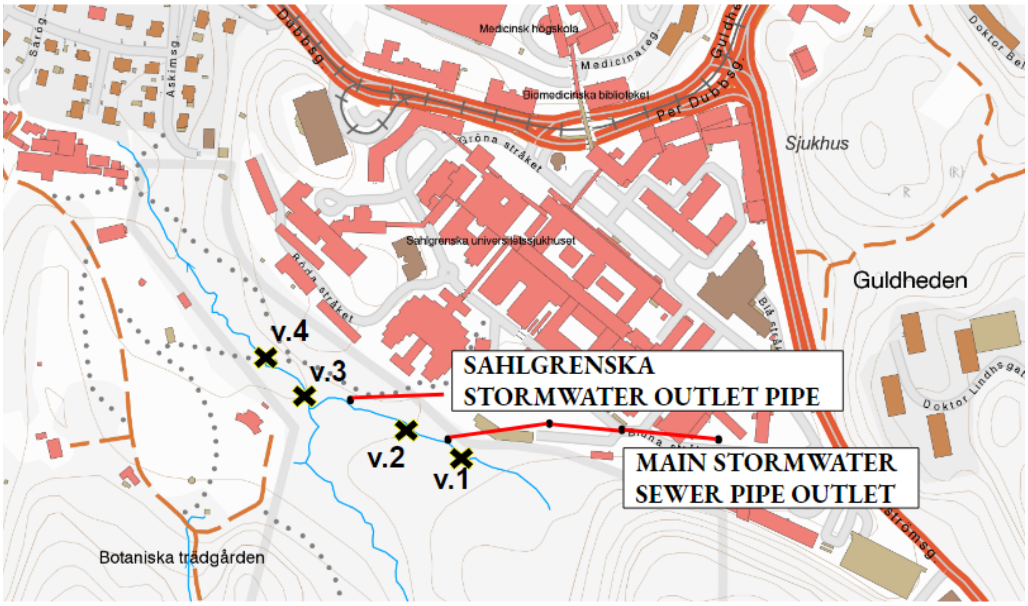

Figure 4.2. Location of sampling and stormwater discharge points. W1 and S1 were sampled at v.1; W2 and S2 at v.2; W3 nd S3 at v.3; W4 and S4 at v.4.

4.1.2 Chemical analysis

The main priority was to analyze the metal and nutrient content both in water and sediments since previous studies showed that the concentration of these pollutants in stormwater were above the target values. The table Appendix G shows the list of water and sediment quality factors that were analyzed. All the parameters shown in the table were analyzed by the commercial laboratory Synlab.

4.2 Calculations of areas, flows and costs

4.2.1 Area availability

The available area is a key factor when choosing the device or facility to be installed since the lack of area would mean that a certain alternative had to be disregarded. Most of the treatment techniques are, however, adaptable to the specific site. Hence, it is important to define the area where the treatment is to be installed and define if there is enough area for all the parallel works; e.g. construction material reception, restrooms for the workers, machinery.

4.2.2 Design flows with The Rational Method

To design the geometry of the device or facility needed, the average and peak water flows need to be considered. The combined or separated drainage system is usually estimated based on the Rational Method which is a deterministic mathematical model used to estimate stormwater flows in urban areas. (Needhidasan & Nallanathel, 2013; Pitman, 2001). Main formulas for the Rational Method are presented in Appendix B.

Runoff coefficient (Cs)

The runoff coefficient is dimensionless and correlates the amount of runoff with the total precipitation (Table B.1; Appendix B). It represents the proportion of the total precipitation that may contribute to runoff taking into consideration evapotranspiration, infiltration and absorption by vegetation (Swedish Water, 2016). The coefficient presents a higher value in areas with low infiltration rate and high runoff (such as pavements) and a lower value in permeable and vegetated areas such as forests or gardens (SWRCB, 2011). When the area is formed by several types of surfaces, the runoff coefficient can be estimated using the equation B.3 (Appendix B)(Swedish Water, 2016).

Rain intensity (i)

The intensity of the rain is defined as the amount of rain per duration of rain event [mm/h] and return time [years]. Usually, the intensity at the time of concentration (t_c) is used to calculate the peak flow (ODOT, 2014). When there is no statistic data available for the analyzed area, the rain intensity can be calculated using the equations B.5 and B.6 (Appendix B). The rain intensity can as well be estimated based on a mathematical function that aims to relate intensity of the rain with the duration of the rainfall and the frequency of occurrence, so called Intensity-Duration Curves (IDF) (Koutsoyiannis et al., 1998). The shapes of the IDF curves depend on rain return time. The formulas can be seen in the Table B.1 in Appendix B (Arnell, 1978). To calculate the intensity, t_r (rain duration) is assumed to be 30 minutes based on the StormTac model and following the standard values in Sweden, and N (return period), is assumed to be 1 year. The specific runoff coefficient is obtained in StormTac by finding the mean value of all the thirteen different land types.

Time of concentration and rain duration

The time of concentration is the time required for a drop of water to flow from the remotest part of the catchment area to the point of collection (Petterson, 2017). Concentration time is defined as the sum of the time of entry and time of flow (Equation B.7; Appendix B). The time of entry is the time a drop spends in the catchment area until it enters the stormwater sewer system. It is dependant on the distance between the gutter wells, type of catchment area and surface roughness, ground slope and rain characteristics. The time of flow is the time that a rainwater drop spends in the stormwater sewer system until the collection and is dependant on the pipe slope and the pipe size (Petterson, 2017). In the Rational Method, the rain duration is equal to the time of concentration (Tc). Usually, Tc can be calculated dividing the longest flow distance with the speed of the water which depends on the flow channeling type (Table B.3; Appendix B).

Return time

The return time refers to the occurrence expected for a particular flow. However, this does not mean that this expected flow or rain event cannot happen more than one time during the expected time span. Wern & German (2009), presented probabilities for the different rain events occurring during different time spans taking into consideration their return periods (Table B.4; Appendix B).

Climate Factor

According to the SMHI (2014) more rain and higher intensities are expected in Sweden in the future, which increases the risk of flooding in urban areas. This is the reason why Swedish Water (2016) proposed that a climate factor should be implemented in the Rational Method equation for the peak discharge calculation. It is recommended to use a climate factor of 1.25 for precipitations shorter than 60 minutes (Swedish Water, P110). For long-term rains the recommended climate factor is at least 1.2.

4.2.3 Pipe sizing

Methods to estimate the size of a pipe include the calculation formulas from Colebrook, Darcy Weisbach, Hazen Williams or Manning (Haestad Methods, Inc, 2002). The most suitable one in the present case would be Manning's formula (Equation 4.1) since it can be used for open channels and non-pressurized pipes. The existing pipe under Ehrenströmsgatan has a diameter of 1.2 m and is more or less never full; last registered in 2006 (Markteknik AB, 2007). Hence, it is assumed that the pipe acts as an open channel. The remaining formulas, such as Darcy-Weisbachs or Hazen-Williams are used to design pipes under pressure where the whole cross section area is assumed to be filled with water.

$$Q = \frac{1}{n} \cdot \frac{A^{5/3}}{P^{2/3}} \cdot \sqrt{S} \tag{4.1}$$

Where:

- n: Gauckler–Manning coefficient dependent on roughness of material (n=0.014 for concrete) [adim]
- A: Cross section of pipe [m^2]
- P: Wet perimeter [m]
- S: Slope of pipe [%]

4.2.4 Treateable flow rate

Based on the ponding-depth of the different bio-filtration systems, the infiltration rates and the pervious to impervious area ratio of the facility, it is possible to calculate the treatable flow rate in L/s (Equation 2.6).

$$Q_{treat} = [X]\frac{mm}{hr} = [X]\frac{L}{m^2 * hr} \tag{4.2}$$

4.2.5 Cost of facility

The flow is an important parameter when sizing a device or facility since it provides information on the water volume entering the unit. Therefore, this is directly related to the investment cost. The higher the flow, the bigger the size, the bigger the treatment device or the needed amount of units and the higher the cost. However, there are additional factors that have an effect on the cost of the facility summarized by Abukar Warsame (2006) (Table 4.1).

Table 4.1. Factors that have a direct impact on the capital cost of stormwater treatment facilites (Warsame, 2006). ** Large, medium or small.** Public or private.*

Factors	**Examples**
1. Project-specific factors	Project size* Project complexity Quality of materials
2. Site-specific factors	Construction cost Connection to drainage system cost Machinery cost Personell cost
3. Client and contractor-related factors	Contractor type Client type ** Procurement method Contractor-client relationship
4. Competition and market conditions	Level of competition Level of construction activity
5. Macroeconomic and political factors	Inflation and interest rate General labour market rules

4.2.6 StormTac simulation

A **StormTac** model was built and used as a tool for finding the efficiencies of the reviewed treatment techniques. The different characteristics of the area and the techniques were added to the model and the removal efficiencies were obtained as an output for each of the techniques. Different BMPs were modelled to estimate the removal efficiencies for different pollutants. The following list enumerates the modelled scenarios:

- Detention and retention ponds, and in combination with street sweeping
- Gully pot filters, and in combination with street sweeping
- Biofiltration systems: rain gardens, swales and standard tree pits
- Underground vaults, and in combination with street sweeping

4.3 MCA application

Once that all results from the water and sediment sampling were available, the most relevant pollutants to reduce were identified by comparing the current levels to the target values (Table 2.2; Göteborg Stad, 2013); those exceeding the target values were considered to be the target pollutants. Based on the review of available stormwater treatment techniques, the first scoring process was conducted taking into consideration the current situation as the baseline to which positive or negative impacts of the proposed alternatives were compared.

Thereafter, all the stakeholders were involved by answering a questionnaire (Appendix I) to conduct the weighting procedure. The questionnaire was sent to each of the identified stakeholders and with some stakeholder representatives, personal interviews took place. From the questionnaire, input data for the weighting of the objectives and criteria were obtained. This way, the MCA was performed based on the different stakeholders and their points of view.

4.3.1 Review on treatment techniques

To find the most suitable stormwater treatment technique for Vitsippsbäcken, a literature review was conducted (presented in section 2). The information gathered in this review was used as input for the MCA.

4.3.2 Stakeholders

The identified stakeholders of this project are; (1) Waste and Water department of the City of Gothenburg, (2) Environmental department of the City of Gothenburg, (3) Park and Nature department of the City of Gothenburg, (4) Traffic department of the City of Gothenburg and (5) Sahlgrenska Hospital.

The Water and Waste department is the main interested department on the assessment for this area and is the responsible for the coordination of this project. The department's main objective is to find a suitable technique or unit that could minimize the pollutant discharge in the receiving waters within the available budget (Vatten och avlopp, 2017).

The Environmental department provides guidelines and recommendations that are to be followed during and after the construction of the treatment facility or unit (Miljöförvaltningen, 2017). They have a sub-division called City-Environment which focuses more on the watercourses in general rather than in the discharged waters' quality. The Park and Nature department focuses on the protection of the nature reserves and parks, trying to avoid any artificial construction within their natural and green areas (Park- och naturförvaltningens miljö, 2017).

The traffic department is responsible for the maintenance of the roads in Gothenburg, divided in winter and summer activities, related to both the status of the surface cover and water issues (flooding, accumulation of debris, etc.) (Faith-Ell, 2005). These maintenance works aim to control and minimize the pollutants that are leached out and transported to surface or groundwater recipients (Faith-Ell, 2005). The Sahlgrenska Hospital is involved in the project since an end-of-pipe solution is proposed to be built within their land. Also, as the municipal stormwater pipes go through the hospital area, an arrangement is to be done.

4.3.3 Criteria definition

The objectives, primary criteria and secondary criteria defined for this project are presented in Table 4.2.

Table 4.2. Objectives, primary criteria and secondary criteria to be used in the MCA (Martin et al., 2006).

Objective	**Primary criteria**	**Secondary criteria**
Technical Performance	System Removal Efficiency	(1)Dissolved contaminant retention (2)Suspended contaminant retention
	System Reliability	Probability of system failure
	System Durability	Maintenance frequency
Environmental impacts	Impact on receiving waters and environment	(1)Impact on water quality (2) Impact on water volume (3)Impact on ecology and biodiversity
	Impact on discharged waters	(1)Impact on water quality (2) Impact on water volume
	Resource use	(1)Land Use (2)Availability of materials needed for construction
Economical impacts	Investment cost	(1)Land costs (2)Material cost (3)Installation cost
	Maintenance and Control cost	(1)Control need and frequency (2) Maintenance need and frequency
Societal impacts	Aesthetics	Amenity level and community benefits
	Acceptance	(1)Budget within limit (2)Society knows about it and considers it acceptable

4.3.4 Weighting process

The weighting process was conducted based on the answers obtained from the questionnaire and the interviews. Each of the stakeholders provided a percentage to each of the four objectives and ten criteria based on their preferences.

4.3.5 Scoring process

A specific score was given to each criteria based on the literature review of each alternative. The details on how the scoring was conducted for each criteria are described in Table 4.3. All the scores had a scale from 1 (worst situation) to 5 (best situation).

Table 4.3. Scoring process description for each criteria to be used in the MCA.

Criteria	Score of 1	Score of 5
Removal efficiency	LOW average removal	HIGH average removal
System Reliability	When HIGH maintenance is needed	When LOW maintenance is needed
System durability	SHORT lifespan	LONG lifespan
Impact on receiving water	System providing HIGH removal and flow control	System providing LOW removal and flow control
Impact on discharged waters	HIGH removal of target pollutants	LOW removal of target pollutants
Resource use	HIGH invasion of land (or) conflicting with land ownership (and) HIGH needed amount of materials	LOW invasion of land (or) conflicting with land ownership (and) LOW needed amount of materials
Investment cost	HIGH investment cost	LOW investment cost
Maintenance and Control Cost	HIGH M&C cost	LOW M&C cost
Aesthetics	Does not provide community benefits, does not integrate in the area	Provides community benefits, integrates in the area
Acceptance	People does not know about it or does not approve it	People knows about it and approves it

4.3.6 Ranking procedure

Once the scoring and the weighting were included in the hand-made MCA model, the ranking of alternatives was obtained for each stakeholder. To do so, the percentage of the criteria i.e. the weight was multiplied with the score given to each criteria for each alternative. Subsequently, these multiplied values were summed up for each of the alternatives and divided by 100 (the total percentage given to the criteria). This resulted in a value where 5 was the highest possible value for the alternative. For each stakeholder, a different ranking of the alternatives was obtained since the resulting value that of each alternative, was based on the stakeholders' weightings.

4.3.7 Sensitivity analysis

A model was built in Web-HIPRE (Appendix J) to perform a sensitivity analysis, focusing on the sensitivity of each criteria as well as on the sensitivity of the weights given by each stakeholder.

5 Results and Discussion

5.1 Stormwater treatment technique alternatives for Vitsippsbäcken

Based on the analysis of the area, the high urban density and the low space available, each reviewed alternatives had a different feasibility potential. Therefore, the alternatives were divided in three groups depending on this potential (Table 5.1). Table 5.2 summarizes the main characteristics used later as inputs for the MCA of each alternative (in brackets, the alternative number), including removal efficiency, cost, durability and maintenance frequency.

Table 5.1. Feasibility potential of each stormwater treatment technique.

High feasibility	**Comments**
(7)Filterra	Demands low space and provides high removal. It is suitable for winter weathers.
(8)Tree Pit	Demands low space and provides high removal. It is suitable for winter weathers.
(9)BioFilter	Demands low space and provides high removal. It is suitable for winter weathers.
Moderate feasibility	**Comments**
(1)Street Sweeping	It is an ongoing solution and gives medium removal efficiency results. It depends on the traffic department
(10)Rain Garden	Demands large area. Possible conflict with Sahlgrenska
(11)Swale	Demands very large area. Possible conflict with Sahlgrenska
(5)Eco Vault	Possible conflict with Sahlgrenska
(6)StormFilter	Possible conflict with Sahlgrenska
Low feasibility	**Comments**
(2)Filters	Demands high maintenance frequency
(3)Dry Pond	A retrofiting of the existing pond is more likely
(4)Wet Pond	A retrofiting of the existing pond is more likely
Vortech	It is an underground vault that only focuses on solid pollutant removal having no removal capacity of dissolved pollutants

Filterra (7) and BioFilter (9) are manufactured small biofiltration units with two main elements; a tree and a small underground concrete structure that provides filtration, sorption, chemical and physical processes and plant uptake for pollutant removal. Tree pit (8) is a similar unit with smaller dimensions. EcoVault (5) and StormFilter (6) systems are underground concrete vaults that may preferably be located at the end-of-pipe. These treat the water through sedimentation and filtration processes. All of the stormwater treatment techniques were considered for the MCA (except Vortechs), this way presenting the ranking for all the reviewed options and providing a broad picture of the analysis.

Table 5.2. Summary of information compiled during the review of all stormwater treatment techniques used in the MCA.

	Description	Street Sweeping	Filters	Dry pond	Wet pond	Eco Vault	StormFilter	Filterra	Tree Pit	BioFilter	Rain Garden	Swales
REMOVAL EFFICIENICES (%)	Arsenic (As)	37.5	51	22	29.5	-15	36	39	39	39	75	83
	Chromium (Cr)	17	44.7	52.5	40	72	68	56	56	56	25	47.8
	Cadmium (Cd)	-20	28	33	50	74	86	38	38	38	80	20.6
	Lead (Pb)	37	48	73	56	73.5	92	77	77	77	80	50.6
	Copper (Cu)	44	37.5	29	60.3	70	81	55	50	90	60	62
	Zink (Zn)	31.5	54	53	80	80	78	56	50	90	90	69
	Nickel (Ni)	32	33	54.7	37.6	58	58	51	51	51	75	68
	Mercury (Hg)					45	0	20	20	20	50	59
	Oil Index	81.3	85		70	96	79	93	50	75	60	86.3
	TP	15.5	33.6	23	43.4	44	73	70	80	65	60	40
	TN	43	60.4	24	43.6	12	70	34	45	50	25	40
	BaP	56	-20	22	70	94	79	76	76	76	85	85
	PAH				78	80	80	92	92	92	85	85
	TSS	21		50	75	87	94	86	85	95	85	70
	Hydrocarbons							87	93	70		62
AVERAGE REMOVAL (%)		26	30	29	49	58	65	62	60	66	62	62
COSTS	Needed units	1	46	1	1	1	1	2	11	2	1	1
	Investment cost (considering number of needed units) (SEK)	125,00	300,000	150,000	270,000	700,000	650,000	260,000	363,000	300,000	150,000	50,000
	M&C cost (SEK/year)	20,000	28,000	6,000	19,000	50,000	35,000	26,000	13,200	20,000	13,000	2,000
DURABILITY	(years)	10	50	30-75	30-75	50	50	15-50	15-50	15-50	30-50	50
MAINTENANCE FREQUENCY	High freq. maint. activities (per year)	1	3-4	1-2	1-2	4-12	1	1-2	4	4	First 2 years, frequent	1-2
	Lower freq. maint. activities		And after each rain event	2-7	2-7		And after each rain event	And after each rain event	And after each rain event	And after each rain event	Almost non later	

5.2 Area, Volume and Flow Calculations

5.2.1 Available area

The area where the end-of-pipe solution was planned to be build consists of 3800 m^2 and the land is owned by the Sahlgrenska Hospital (Figure 5.1). However, according to the Swedish Constitution, the municipality has the right to use the land above the underground pipe system, if the land owner is financially compensated (Sveriges Riksdag, 2016). The available area highlighted in Figure 5.2 would be around 535 m^2 and the proposed end-of-pipe solution could be constructed underground. This way, only small areas above ground would be needed to be free for maintenance access.

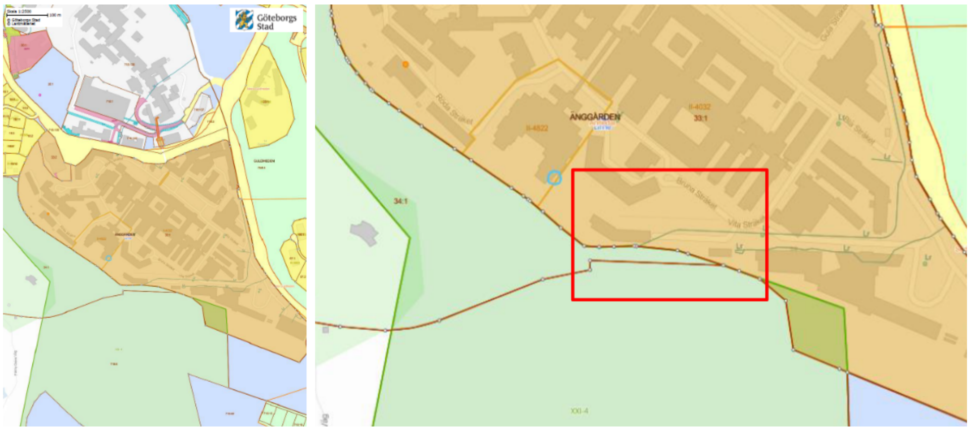

Figure 5.1. Available area for end-of-pipe installation.

Figure 5.2. Available underground area for facility installation (535 m^2).

Regarding the biofiltration systems, the available area would sum up to 1100 m^2 considering that the "Swedish Constitution 1973: 1144" would be applied as well in this case (Figure 5.3). This area would preferably be used for rain gardens, Filterra, BioFilter and tree pits.

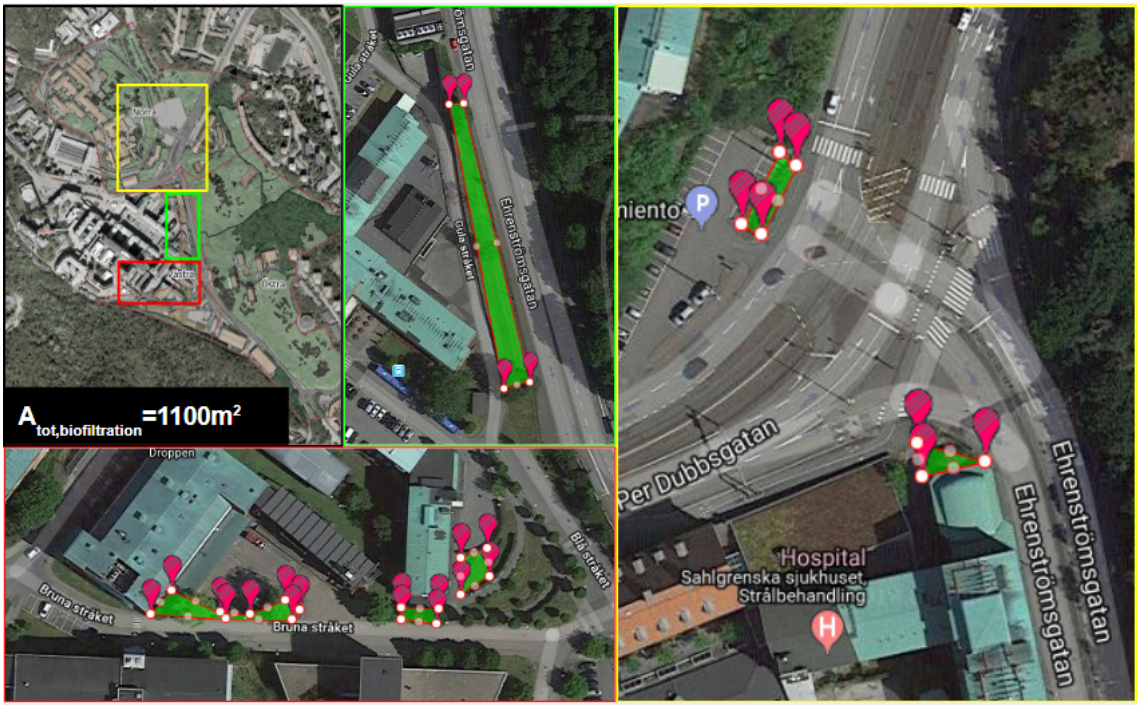

Figure 5.3. Available area for biofiltration system installation in Vitsippsbäcken catchment area.

The catchment area is so dense that the implementation of any end-of-pipe or biofiltration system might be problematic; both for the location decision and the construction process. Having several landowners makes any possible solution difficult to implement. Additionally, there are new plans for developing some Sahlgrenska Hospital's area which makes the proposed location of the biofiltration and end-of-pipe solutions very uncertain. Both rain gardens and biofiltration swales demand high surface space which is not suitable. The subdivision of rain gardens or swales throughout the area could reach up to a 1% pervious to impervious area ratio. This means that smaller biofiltration units, either rain gardens, tree pits, Filterra or BioFilter, could be more suitable than a large rain garden or swale. If the alternatives were only analyzed based on the flow that each of them can treat, all the alternatives would be suitable. All of them would be capable of treating the base-flow and runoff flow but more than one unit would be needed for some of the techniques proposed, such as tree pits, Filterra or BioFilter.

5.2.2 Design flow

Based on the Rational Method, the design flow was calculated:

$$Q = 1.25 \cdot i[L/s \cdot ha] \cdot 0.31 \cdot 43[ha] \tag{5.1}$$

The intensity was calculated as:

$$i = \left(\frac{2000}{30+9}\right) + 6 \tag{5.2}$$

$$i = 57.3 L/s \cdot ha \tag{5.3}$$

The resulting design flow was:

$$Q = 1.25 \cdot 57.3 \cdot 0.31 \cdot 43 = \mathbf{910\ L/s} \tag{5.4}$$

This result is almost the same as obtained with the StormTac model (900 L/s) and hence, both are comparable and reliable. Additionally, this value represents a one year return period rain and dividing it with the 365 days of the year, the runoff expected per day can be estimated: 910/365 = 2.5 L/s which correlates with the value obtained from StormTac for runoff, see Table 3.3.

5.2.3 Connection pipes

The pipe connecting the existing detention pond with the AD1500 pipe has a diameter of 600mm, a length of 38m and a slope of 5%. The flow coming from the 14ha hilly area represents 34% of the total flow discharged into the stream. With this information and by using Manning's equation, the maximum capacity of the pipe is calculated.

$$Q = \frac{1}{0.014} \cdot \frac{(\frac{\pi \cdot 0.6^2}{4})^{5/3}}{(2 \cdot \pi \cdot 0.3)^{2/3}} \cdot \sqrt{0.05} \tag{5.5}$$

$$Q = \mathbf{1270\ L/s} \tag{5.6}$$

Within the return period of 50 years, the design flow is higher than the capacity of the pipe; flooding may occur in these 50 years.

$$Q = 1.25 \cdot 267 \cdot 0.31 \cdot 14 = \mathbf{1450\ L/s} \tag{5.7}$$

Therefore, 180 L/s of overflow are expected. However, with a 1 year return period rain with a duration of 30 minutes, the expected flow would be 310 L/s and therefore, no overflow would be expected.

5.2.4 Treatable flow rate

The flow rate was given for commercial, manufactured units, see Contech Engineered Solutions and Ecosol in section 2.5.4. For the rain garden, a pervious to impervious area ratio of 2% was assumed, with an infiltration rate of 200 mm/h (mean). The assumed area for the rain gardens was 100 m^2. Therefore, the treatable flow rate was calculated as:

$$Q_{treat} = 200\frac{mm}{hr} = 200\frac{L}{hr \cdot m^2} = \frac{200 \cdot 100}{3600} = \mathbf{5.5\ L/s} \tag{5.8}$$

For the swale, the same calculation was done assuming a pervious to impervious area ratio 4% and a mean infiltration rate of 150 mm/hr. The assumed area for the swales was 200 m^2. The treateable flow rate is:

$$Q_{treat} = 150\frac{mm}{hr} = 150\frac{L}{hr \cdot m^2} = \frac{150 \cdot 200}{3600} = \mathbf{8.3\ L/s} \tag{5.9}$$

Based on the available area for biofiltration systems, if 1100 m^2 were considered (which represents a previous to impervious area ratio of 1%), the treatable flow rate would increase to 61 L/s for rain gardens and 45.8 L/s for swales.

5.2.5 Number of biofiltration units needed

Based on the total yearly flow and the treatable flow rate of each biofiltration system, it was estimated how many units of each type would be needed. This was calculated by dividing the total flow by the treatable flow rate, assuming that 100% of the runoff volume could be treated. The different biofiltration units were assumed to be located to treat the water coming from the North, West and 73 590 m^2 of the East sub-catchment (35%) (Figure 3.4) since the remaining runoff is collected in the pond. The total yearly flow that needs to be treated, based on StormTac simulation values is:

$$Q_{treat} = Q_{treat,norra} + Q_{treat,västra} + (Q_{treat,östra} \cdot 0.35) \tag{5.10}$$

$$Q_{treat} = 2 + 0.62 + (0.35 \cdot 2.5) = \mathbf{3.5\ L/s} \tag{5.11}$$

Table 5.3. Estimation of needed units of each biofiltration system. Assumed total treated flow: 3.5 L/s.

Treatment option	**Area per unit (m^2)**	**P/I area ratio (%)***	**Treatable Flow per unit**	**Required number of units**
Tree Pit	1.44	0.015**	0.317(L/s)	11
Biofilter	16	0.03**	2(L/s) (mean)	2
Filterra	15	0.03	1.7(L/s) (mean)	2
Rain Garden	100	0.01	5.5(L/s)	1
Swale	200	0.2	8.3(L/s)	1

**Pervous to Impervious area ratio: due to the low space available, these ratios are smaller than the recommended P/I ratio which are Tree pit: 0.13%; Filterra and Biofilter: 0.33%; Rain garden: 2%; Swale: 5%.*
***Calculated from the filter surface of Filterra since the systems are considered to be similar.*

These results reflect an increased estimated investment cost and maintenance and control cost (Table 5.4) for some of the units such Tree Pit, BioFilter and Filterra. This as well reflects that the rain garden and the swale can be smaller than the estimated.

Table 5.4. Estimation of costs of each biofiltration alternative based on the total required number of units.

Unit	Investment cost (SEK)	M&C cost (SEK)
Filterra	260 000	26 000
Tree Pit	363 000	13 200
Biofilter	300 000	20 000
Rain Garden	150 000	13 000
Swale	50 000	2 000

5.3 Sampling observations

Sampling on 2018-03-12 was performed for wet weather sampling **during snow-melt and after snow-storm** and 2018-05-04 represents wet weather sampling **after rain event**. On 2018-03-16, dry weather samples were collected. Some observations were made on site both for water and sediments (Table 5.5 and 5.6).

Table 5.5. Observations on Vitsippsbäcken recipient water during sampling events.

Sampling spot	2018-03-12	2018-03-16	2018-05-04
1 (Upstream)	Transparent	Transparent	Transparent
2 (Downstream municipality stormwater outlet)	Turbid	Transparent	Turbid greyish
3 (Downstream Sahlgrenska stormwater outlet)	Yellowish	Transparent	Turbid greyish
4 (Downstream all outlets)	Brownish	Transparent	Turbid greyish

Table 5.6. Observations on sediments from Vitsippsbäcken during sampling 2018-03-12.

Sampling spot	Sediment description
1	Loose with small gravel
2	Sandy with small gravel
3	Brown muddy
4	Black muddy

5.4 Laboratory results

5.4.1 Concentration of metals and PAHs in sediments

Cu shows the most critial results since the concentrations are higher than the target values for sediments defined by the Swedish EPA (2000) in all spots but the upstream spot (Figure 5.4). The concentrations of Zn show an accumulation from the upstream spot (v.1) to the downstream spot (v.4) in sediments, see Figure 5.4. The only non-critical metals are Cd and As; Cr and Ni show exceeding concentrations in at least two of the sampling points, see Figure 5.5. All of the PAHs show a clear accumulation in the sediments from the upstream spot (v.1) to the downstream spot (v.4) (Table 5.7).

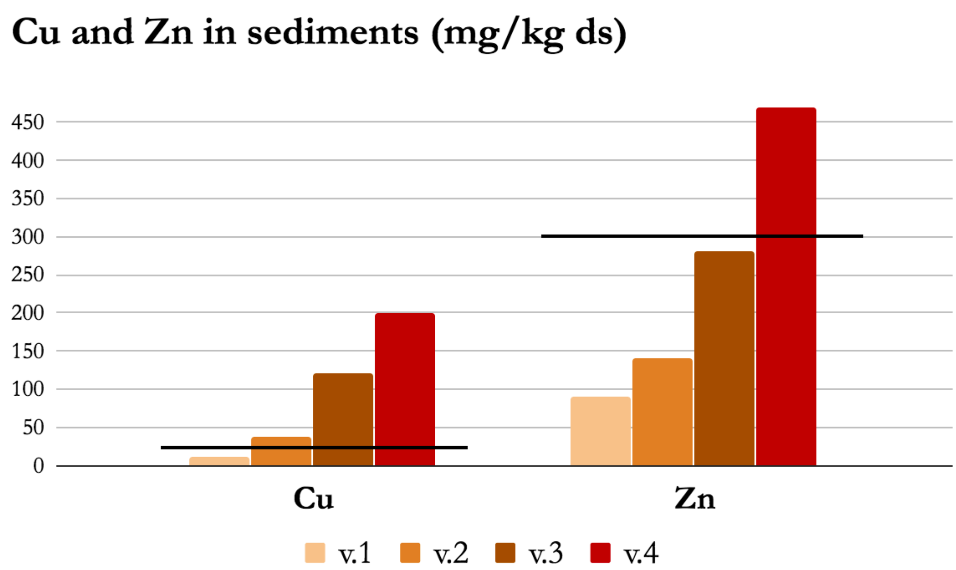

Figure 5.4. Cu and Zn concentrations in sediments along Vitsippsbäcken. The target values represent the moderately high concentrations (Swedish EPA, 2000).

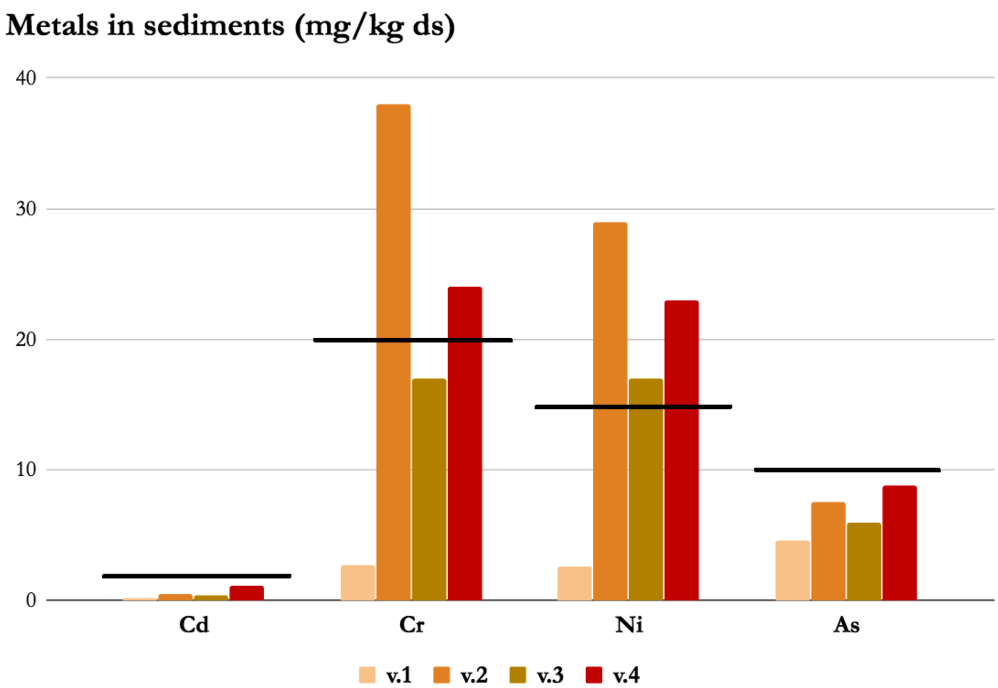

Figure 5.5. Toxic trace metal concentrations in sediments along Vitsippsbäcken. The target values represent the moderately high concentrations (Swedish EPA, 2000).

Although the organic matter in the first spot is high, PAHs concentrations are low, which could be expected since it is a background sampling point (upstream). However, in sampling spots 2, 3 and 4, it is possible to see a correlation trend between the concentrations of PAHs and organic matter (OM) (Figure 5.6); PAH concentrations increase as OM increases. Nevertheless, as only one sediment sampling event was conducted, these results are considered to be just indicators. Often, OM concentrations correlate positively with PAH concentrations because hydrophobic PAHs tend to attach to hydrophobic areas on organic particles rather than to mineral particles (Raber & Kögel-Knabner, 1997).

Table 5.7. Accumulation of PAHs in sediments. The target values are those defined by the Swedish EPA (2000a).

	Target values (Swedish EPA, 2000)								
PAHs (ug/kg TS)	**None**	**Low**	**Moderate**	**High**	**Very High**	**v.1**	**v.2**	**v.3**	**v.4**
Antrathene	0	0-2	2.0-8.0	8.0-30	> 30	10	10	35	52
Fluoranthene	0	0-20	20-80	80-270	> 270	10	20	200	330
Pyrene	0	0-12	12.0-50.0	50-200	> 200	10	20	190	320
Benz[a]anthracene	0	0-10	10.0-35.0	35-110	> 110	10	10	95	130
Krysten + Triphenylene	0	0-13	13-50	50-180	> 180	10	20	100	170
Benzo[b]fluoranthene	0	0-50	50-150	150-400	> 400	10	20	180	300
Benzo[k]fluoranthene	0	0-20	20-50	50-160	> 160	10	20	64	110
Benzo[a]pyrene	0	0-20	20-60	60-180	> 180	10	20	110	170
Benzo[ghi]perylene	0	0-30	30-100	100-350	> 350	10	20	120	200
indeno[1,2,3-cd]pyrene	0	0-50	50-170	170-600	> 600	10	20	100	160

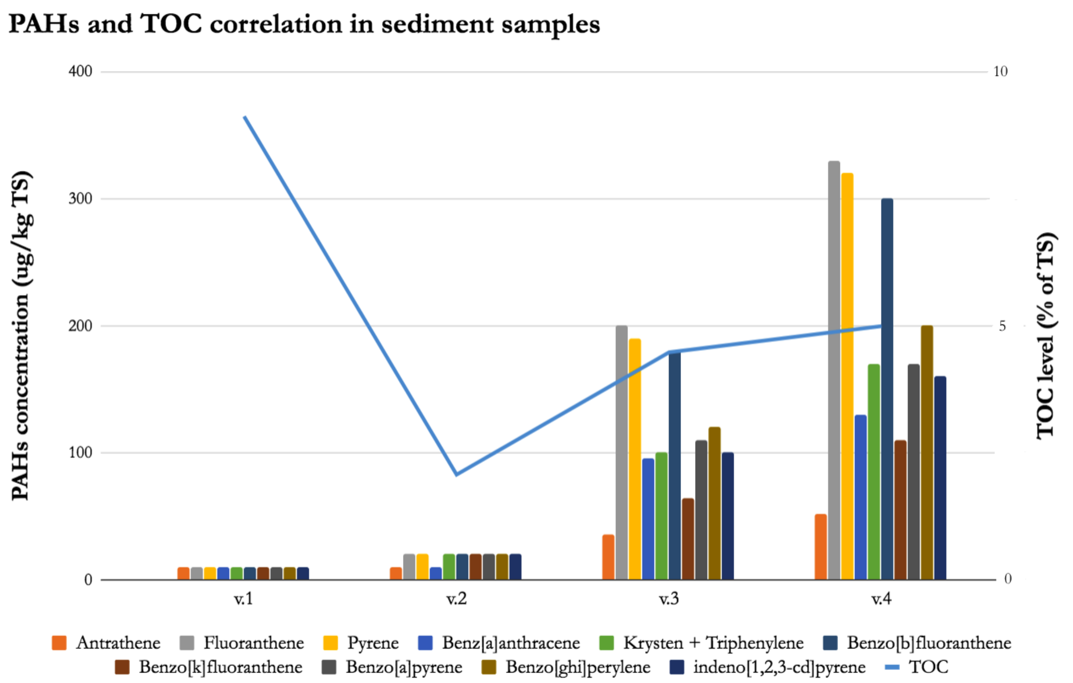

Figure 5.6. PAHs and OM correlation in the sediments along Vitsippsbäcken.

5.4.2 Concentration of pollutants in water samples

The highest metal concentrations in water samples, and therefore, the target pollutants were Cu and Zn (Figure 5.7), which was expected from previous studies (City of Gothenburg, 2016). In 2016, the measured data in the stormwater drainage-well for Cu was 64 μg/L and for Zn, 232 μg/L. It can be seen that the actual situation is better than in 2016 since the highest concentration of Cu was 59 μg/L and for Zn, 110 μg/L; probably due to dilution of stormwater in the stream. However, these values are still above the target values defined by the environmental department at the City of Gothenburg. Stormwater clearly affects the concentrations of Cu and Zn in the recipient water. Copper concentration increased up to a 3:1 average ratio during the first wet weather sampling event and to a 8:1 average ratio during the second; compared to the dry weather sampling results. Zink concentrations increased up to a 2:1 average ratio during the first wet weather sampling event and to a 4:1 average ratio during the second; compared to the dry weather sampling results. Additionally, a difference can be seen between the two wet weather sampling results. This may be due to the climatology factors. The first wet weather sample was taken during the melting of ice and right after a snow storm while the second wet weather sample was taken right after an intense rain of approximately half an hour with no snow or ice presence. Therefore, as the second sampling was performed right after a rain event, the first flush of stormwater was probably sampled which usually transports the majority of the road runoff pollutants accumulated in the roads and surrounding impervious areas. Li et al (2015) reported that 83% of the total pollution load mass was transported with the first 60% of the road runoff volume while earlier, Bertrand-Krajewski et al. (1998), reported that 80% of the pollution load mass was transported by 74% of the total volume in separate sewer systems. Both cases explain and support the high concentrations found in Vitsippsbäcken.

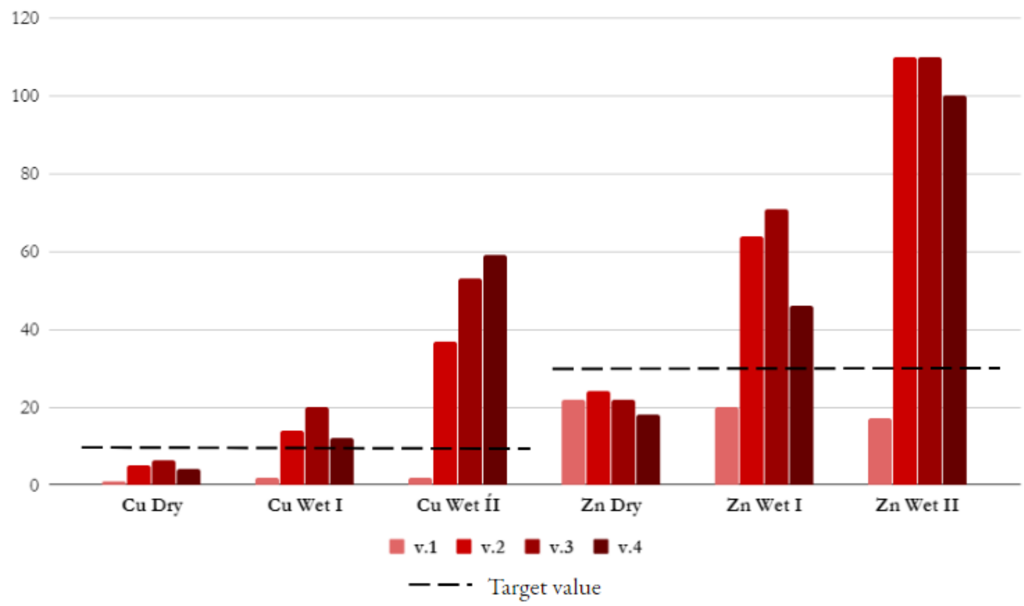

Figure 5.7. Cu and Zn in water samples along Vitsippsbäcken in dry and wet weather (μg/L).

Regarding the rest of the metals in the water, all the levels are below the target values. However, it is possible to see a correlation between the dry and wet weather sample results, where the metal concentration increases for all the cases but for Cd that remains constantly low (Figure 5.8).

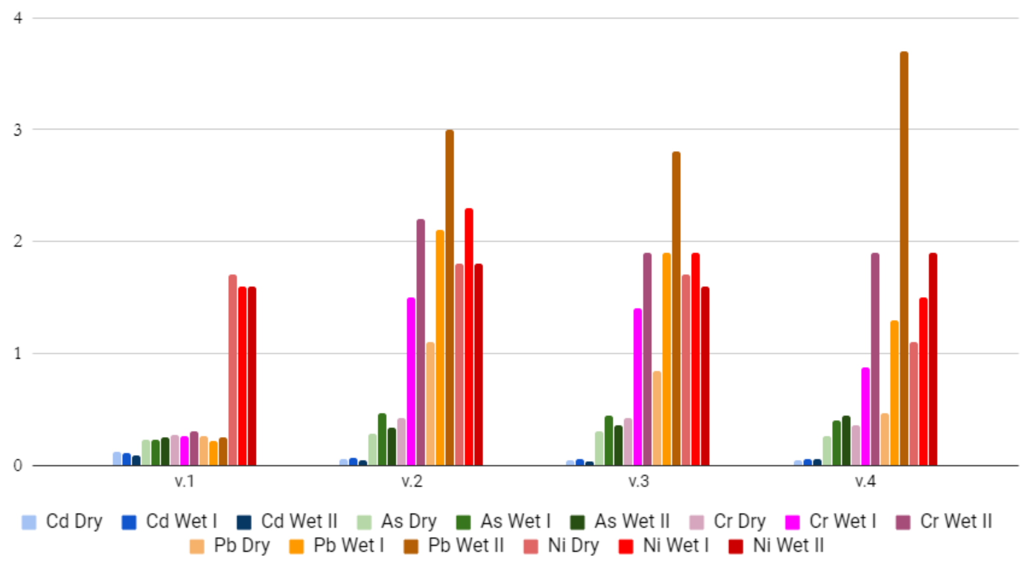

Figure 5.8. Dry and wet weather toxic trace metals concentrations in water along Vitsippsbäcken in μg/L.

The remaining measured data in the recipient water during dry and wet weather is summarized in Table 5.8. The concentrations of PFOS and PFOA were high both in dry and wet (I&II) weather when compared to the annual average (AA) limiting values. When compared to the maximum annual concentration (MAC), the values are low. Regarding PAHs, benso(ghi)perylen is the only specific compound in slightly high concentration in both dry and wet weather in the four spots. Benso(b)fluorantene and benso(k)fluorantene show slightly high values in the first spot during wet weather which might be related to natural organic matter inputs upstream that may dilute downstream or to atmospheric depositions from traffic gas emissions. Regarding nutrients, TN (total nitrogen) shows more critical concentrations than TP (total phosphorus) which is high in the second spot during the first wet weather event and in second, third and fourth spots during second wet weather sampling. The results show that high concentrations of P are being discharged from the stormwater sewage outlets. Additionally, the low pH values in the upstream spot together with the high values of TN in this same spot conclude that the upstream water may be slightly acidified due to natural inputs or humic acids present in the area, but it later stabilizes. This stabilization may occur due to the addition of Ca from the concrete pipes and stormwater itself which produces a liming effect to the water. The highest concentration obtained for Ca was 18 mg/L in spot v.2.

Total suspended solids (TSS) have a high concentration as well after the main stormwater sewage pipe in wet weather, which may be due to the discharge of road runoff particles transported by the stormwater. Additionally, higher concentrations of TSS are observed after the main sewage pipe (v.2) during the first wet weather sampling (66 mg/l) than during the second wet weather sampling (36 mg/l). This correlates with Westerlund's study performed in Sweden (Westerlund & Viklander, 2006), which showed that the concentrations during the snow/ice melting period were higher than those during the rain events.

Table 5.8. Concentrations of solids, organic matter, organic pollutants and nutrients in water samples along Vitsippsbäcken. **AA=Annual verage values*; *MAC=Maximum annual concentration.*

	MAC	DRY (2018-03-16)				WET I (2018-03-12)				WET II (2018-05-04)			
Compound	**Target values µg/l**	**v.1**	**v.2**	**v.3**	**v.4**	**v.1**	**v.2**	**v.3**	**v.4**	**v.1**	**v.2**	**v.3**	**v.4**
pH	6,0-9,0	5	7.3	7.4	7.1	5.1	7.1	7.3	7.1	5	7	7.3	7.2
TP	50	5	15	11	12	6.4	79	39	33	11	99	120	160
TN	1250	1700	900	930	710	1500	1400	1400	1200	1500	1600	1700	2100
TOC mg/l	12	7	6.4	5.9	5.6	7	10	8.2	7.1	7.9	11	11	9.1
TSS mg/l	25	2	3	2	2	2	66	22	15	<2	36	40	54
PFOS	0,00065*	0.00033	0.0062	0.0057	0.0032	0.000029	0.0041	0.0044	0.0029	0.00043	0.0056	0.012	0.005
PFOA	0,00065*	0.0003	0.0018	0.0019	0.0013	0.000046	0.0033	0.0035	0.0028	0.0003	0.0019	0.0042	0.0033
Naphthalene	130	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0.1	<0.1	<0.1	<0.1
Antrathene	0.1	<0,01	<0,01	<0,01	<0,01	0.022	<0,01	<0,01	<0,01	<0.01	<0.01	<0.01	<0.01
Fluoranthene	0.12	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0.01	<0.01	<0.01	<0.01
Benzo[a]pyrene	0.27	<0,01	<0,01	<0,01	<0,01	0.024	<0,01	<0,01	<0,01	<0.01	<0.01	<0.01	<0.01
Benzo[b]fluoranthene	0.017	<0,01	<0,01	<0,01	<0,01	0.025	<0,01	<0,01	<0,01	<0.01	<0.01	<0.06	<0.04
Benzo[k]fluoranthene	0.017	<0,01	<0,01	<0,01	<0,01	0.022	<0,01	<0,01	<0,01	<0.01	<0.01	<0.01	<0.01
Benzo[ghi]perylene	0.0082	<0,01	<0,01	<0,01	<0,01	0.02	<0,01	<0,01	<0,01	<0.01	<0.01	0.046	0.053
Benzen	50	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0.1	<0.1	<0.1	<0.1
Bis(2-ethylhexyl) phthalate	1,3*	<0,4	<0,4	<0,4	<0,4	<0,4	<0,4	<0,4	<0,4	<0.4	0.64	0.74	1
4-tert-octylphenol	0,1*	<0,01	<0,01	<0,01	<0,01	<0,01	0.02	0.02	0.01	<0.01	0.04	0.03	0.03
4-n-nonylphenol	2*	<0,03	<0,03	<0,03	<0,03	<0.03	<0,03	<0,03	<0,03	<0.03	<0.03	<0.03	<0.03

The presence of high concentration of contaminants in the sediment is assumed to be due to historical accumulation. This may be related to the lack of treatment of the stormwater coming from the whole catchment area as well as from the Sahlgrenska Hospital which until 2013 did not have any treatment facility for the copper roofs. Still today, in 2018, this facility has not been 100% calibrated and it is still not working appropriately. Cu and Zn in the recipient water show the highest levels in the last three spots which means that if a good status wants to be achieved, two actions need to be taken: (1) the stormwater treatment facility at Sahlgrenska Hospital, needs to be updated or improved and (2) the City of Gothenburg needs to provide a solution as soon as possible for the stormwater. However, it is important to mention that the guidelines presented by Miljörförvltningen are considered restrictive and difficult to achieve by several parties, including both municipal and industry stakeholders, which can lead to a "giving-up" feeling by the City of Gothenburg.

Hansson et al. (2012) defined the loads of heavy metals, nutrients and organic pollutants from different diffuse contamination sources in Sweden during 2009-2010. Table 6.1 summarizes the total loads and stormwater pollutant loads in Sweden and in Skagerrak & Kattegat region (where Gothenburg is located). These values corroborate that N, P, Zn and Cu are the most probable pollutants to be detected in high concentrations in stormwater in Sweden and Skagerrak & Kattegat region. This proves that the results obtained in Vitsippsbäcken follow the tendency, and can be classified as logic and with sense.

Table 5.9. Gross load of pollutants from diffuse sources to water, focusing on stormwater (Hansson et al., 2012).

	Total diffuse emissions in Sweden	**Stormwater as a source in Sweden**	**Stormwater as a source, Skagerrak & Kattegat region**
METALS	**(kg/year)**	**(kg/year)**	**(kg/year)**
Cd	3 900	670	250
Pb	90 000	20 000	7200
Cu	270 000	38 000	13 000
Zn	760 000	110 000	41 000
Ni	100 000	7 200	2 700
Hg	750	110	36
NUTRIENTS	**(tonnes/year)**	**(tonnes/year)**	**(kg/year)**
N	140 000	1 700	810 000
P	4 300	190	71 000
ORGANIC POLLUTANTS		**(kg/year)**	**(kg/year)**
PAH (16)		500	200

5.5 Hypothetically discharged pollutant concentrations to Vitsippsbäcken stream

Literature values of pollutant removal efficiencies of all treatment techniques are summarised in Table 5.9. In the lower part of the table are presented the hypothetical concentrations that would be discharged into the stream if the removal efficiencies of the different alternatives were applied and assuming that 100% of the volume entering the unit was treated. These values were calculated by multiplying each reference value from 2016 of each pollutant (see Table 3.2; no treatment measures were implemented then) by the removal efficiency provided by each alternative. In this way, the discharged concentration was estimated and compared with the target values defined by the environmental department (Table 2.2). Calculated discharge concentrations below the target value are highlighted in green; concentrations exceeding the target are highlighted in red. Even if treatment was assumed for 100% of the volume, this does not represent the reality. Usually, the proposed devices provide treatment of 40-70% of the total volume and the rest is usually bypassed untreated (StormTac).

As some removal efficiencies were not found in literature, the StormTac model was used to model the removal capacity provided by each of the alternatives that were possible to model. The StormTac model was already developed for the catchment area and the levels and removal efficiencies that it provided were therefore, obtained based on simplified approaches. This means that removal efficiencies assumed for some of the alternatives should be considered as indicators and not as measured values.

Three additional analyses were performed. In the first analysis, stormwater concentrations measured during the street sweeping campaign were multiplied with the removal efficiencies of each treatment technique. The discharged concentration values of Zn, Cu and TN for some of the alternatives are below the target value while Cd increases during street sweeping activities (see Table H.2; Appendix H). The second analysis was similarly conducted but sorption media was added to the biofiltration systems. Only Cd seems to be the problem in this case but the BFS can provide a 99% of removal of Cd which may solve the leaching problem. The only high concentration was TP which with the swale was not possible to reduce below the target value (see Table H.3; Appendix H). The third analysis was based on analyzing the impact of each biofiltration alternative based on the measured stormwater concentrations in 2016 when no treatment was implemented but with the addition of sorption media. All the discharged concentrations were below the target values except for TP with swales as in the previous study (see Table H.4; Appendix H).

Table 5.10. Removal efficiencies and discharged concentrations per stormwater treatment technique.

	Removal efficiencies of the different alternatives (%)											
Compound	Ref.Values (2016)	Street Sweeping	Filters	Dry pond	Wet pond	Eco Vault	StormFilter	Filterra	Tree Pit	BioFilter	Rain Garden	Swales
Arsenic (As)	0.88	37.5	51	22	29.5	-15	36	39	39	39	75	83
Chromium (Cr)	6.58	17	44.7	52.5	40	72	68	56	56	56	25	47.8
Cadmium (Cd)	0.25	-20	28	33	50	74	86	38	38	38	80	20.6
Lead (Pb)	6.47	37	48	73	56	73.5	92	77	77	77	80	50.6
Copper (Cu)	64	44	37.5	29	60.3	70	81	55	50	90	60	62
Zink (Zn)	232	31.5	54	53	80	80	78	56	50	90	90	69
Nickel (Ni)	5.08	32	33	54.7	37.6	58	58	51	51	51	75	68
Oil Index	1500	81.3	85	0	70	96	79	93	50	75	60	86.3
TP	116	15.5	33.6	23	43.4	44	73	70	80	65	60	40
TN	1540	43	60.4	24	43.6	12	70	34	45	50	25	40
BaP	0.064	56	-20	22	70	94	79	76	76	76	85	85
	Resulting concentrations assuming measured stormwater concentrations (2016) when no treatment is implemented											
Compound	Target Values (µg/l)	Street Sweeping	Filters	Dry pond	Wet pond	Eco Vault	StormFilter	Filterra	Tree Pit	BioFilter	Rain Garden	Swales
Arsenic (As)	15	0.55	0.43	0.69	0.62	1.01	0.56	0.54	0.54	0.54	0.22	0.15
Chromium (Cr)	15	5.46	3.64	3.13	3.95	1.84	2.11	2.90	2.90	2.90	4.94	3.43
Cadmium (Cd)	0.4	0.71	0.18	0.17	0.13	0.07	0.04	0.16	0.16	0.16	0.05	0.20
Lead (Pb)	14	4.08	3.36	1.75	2.85	1.71	0.52	1.49	1.49	1.49	1.29	3.20
Copper (Cu)	10	35.84	40	45.44	25.41	19.20	12.16	28.80	32.00	6.40	25.60	24.32
Zink (Zn)	30	158.92	106.72	109.04	46.40	46.40	51.04	102.08	116.00	23.20	23.20	71.92
Nickel (Ni)	40	3.45	3.40	2.30	3.17	2.13	2.13	2.49	2.49	2.49	1.27	1.63
Oil Index	1000	280.50	225	1500	450.00	60.00	315.00	105.00	750.00	375.00	600.00	205.50
TP	50	98.02	77.02	89.32	65.66	64.96	31.32	34.80	23.20	40.60	46.40	69.60
TN	1250	877.80	609.84	1170.4	868.56	1355.20	462.00	1016.40	847.00	770.00	1155.00	924.00
BaP	0.05	0.03	0.08	0.0499	0.02	0.00	0.01	0.02	0.02	0.02	0.01	0.01

5.6 MCA application

(1) Definition of the context

The aim of the conducted MCA was to find a suitable solution for stormwater management in dense urban areas. The case-study area focused on the catchment area of Vitsippsbäcken in Gothenburg.

(2) Description of alternatives

As presented in chapter two, the eleven reviewed alternatives are: (1) street sweeping *(S.S)*, (2) filters *(F)*, (3) dry pond *(D.P)*, (4) wet pond *(W.P)*, (5)EcoVault *(EV)*, (6)StormFilter *(SF)*, (7) Filterra *(F ®)*, (8) tree pit *(TP)*, (9) BioFilter *(BF)*, (10) rain garden *(RG)* and (11) biofiltration swale *(S.)*.

From a larger perspective, additional stormwater treatment techniques could be suggested, such as previous pavements which have the capacity to filter the stormwater and improve its quality, or green roofs which have the capacity to decrease the peak flow and improve the quality of the stormwater. Site-specific conditions and characteristics may help excluding alternatives.

(3) Definition of objectives and criteria

Defined in section 4.4.2. Additional objectives and criteria could be defined by involving the identified stakeholders and additional ones. This way, a scenario more adjusted to the reality could be developed.

During the interviews with some of the stakeholders, they proposed additional criteria that may be considered in a future selection process. These criteria were:

1. Who will be in charge of the maintenance and control? Proposed by Sahlgrenska and Environmental department
2. Who invests? Who pays the maintenance and control? Proposed by Sahlgrenska
3. How fast can a problem as for example clogging, flooding, etc. be solved? Who to contact? Proposed by Sahlgrenska
4. Biological values, rare species etc. Proposed by Park and Nature department and Environmental department
5. Impact on people's access to nature. Proposed by Park and Nature department

(4) Scoring

Based on the literature review, the scoring for the MCA is presented (Table 5.11). The scores from 1 to 5 were used for the hand-made MCA analysis while the scores were transformed to a 0 to 100 scale for the Web-HIPRE model. Some criteria were correlated with each other which may had an impact on the MCA outcome. The interconnection and relations defined during the scoring, had a subjective character and therefore, uncertainties in these scores is present. By involving the stakeholders within this process, more accurate and reliable scores could be achieved. Criteria which correlated with each other include:

- The higher the maintenance needs and the higher the frequency, the lower the reliability since a constant inspection is needed. If the needed maintenance is not performed, the risk for the system to fail is higher.
- The impact on discharged waters was based on the removal capacity of each alternative for each target pollutant. The target pollutants are the main concern because they present a concentration above the "target value".
- Due to property boundaries, some alternatives need to be implemented in non-municipal land, which represents the need of an agreement to be able to implement the unit.

The MCA allows to involve several points of view and provides transparency between the different stakeholders. However, the subjectivity given by each of these, makes the process vulnerable to uncertainties and sensitivities. The alternatives that have already been tested (filters, sweeping), got a lower score, because it was known how these alternatives operate and fail. Not tested alternatives, however, may be overestimated, because it is believed they can work well, based on literature. The literature-based scoring can be considered as less subjective as it is based on "optimal performance" based on laboratory or field testing in rather controlled conditions. Nevertheless, scoring based only on literature does not take local factors into account, which stakeholders could. So, it is difficult to know what the best way to do the scoring is, but it could be more adaptable and optimal for the project needs if all the stakeholders could be involved in it. The combination of literature information and knowledge from stakeholders may be the best solution for the scoring process.

Table 5.11. Scoring of stormwater treatment alternatives for the MCA.

Objective	**Alternative Criteria**	SS	F	DP	WP	EV	SF	F®	TP	BF	RG	S
Tech. Performance	Removal	1.5	2	1.5	3	3.5	5	4.5	4	5	4.5	4
	Reliability	4.5	3	5	5	2	3.5	3.5	2.5	2.5	5	4.5
	Durability	3	3.5	4	4	4	4	4	4	4	4.5	5
Cost	Investment	4.5	3.5	4.5	4	2	2	4	3.5	3.5	4.5	5
	Maint.	3	3	5	3.5	1	2	3	4	3	4	5
Environ.	Impact receiving water	1.5	2	1.5	3	4	5	4.5	4	5	4.5	4
	Impact discharged water	1.5	2	1.5	4	4.5	5	3.5	3	5	4.5	4
	Resource use	3	2	3	3	2.5	2.5	2.5	2.5	2.5	4	4
Society	Aesthetics	2	4	4	4.5	4	4	5	5	5	5	5
	Acceptance	5	4	4	4.6	3.5	3.5	4.5	4.5	4.5	5	3.5

(5) Weighting

Next, the weights given by each of the identified stakeholders to objectives (Table 5.12) and primary criteria (Table 5.13) are presented. See Figure 5.9 for the mean distribution of weights based on all stakeholders. From a larger point of view, additional stakeholders could be identified. This is based on each specific case-study and therefore, the inclusion or exclusion of stakeholders may have a direct impact on the results. The more stakeholders involved, the more accurate results can be obtained since all perspectives can be involved even if subjectivity would be present.

It is possible to observe a big fluctuation in the weights given by the different stakeholders. The most stable objective for all stakeholders is the societal objective which obtains a 10% by all of them. The technical performance, environment and cost objectives however, present a 30% of difference between some stakeholders and others. These differences are as well present in the weights given to the criteria.

Table 5.12. Weights given to the four objectives by the stakeholders during the interviews and questionnaires.

Objective/Stakeholder	E.D	C.E.D	S.H	P.N.D	W.W.D	T.D	**MEAN**
Technical Performance	20	30	45	50	20	20	30
Cost	20	10	20	20	40	20	22
Environment	50	50	25	20	30	50	38
Society	10	10	10	10	10	10	10

Table 5.13. Weights given to the ten criteria by the stakeholders during the interviews and questionnaires.

Criteria	E.D	C.E.D	S.H	P.N.D	W.W.D	T.D	**MEAN**
Removal eff.	10	20	15	30	10	10	15
Reliability	5	5	15	10	5	5	7.5
Durability	5	5	15	10	5	5	7.5
Investment Cost	10	1	10	5	30	5	10
Maint. & Control Cost	10	9	10	15	10	15	12
Impact receiving water	20	40	10	3	15	30	20
Impact discharged water	20	0	10	15	15	10	12
Resource use	10	10	5	2	0	10	6
Aesthetic	7	5	5	8	5	5	6
Acceptance	3	5	5	2	5	5	4

**E.D: Environmental Department; C.E.D: City Environment Department; S.H: Sahlgrenska Hospital; P.N.D: Park och Natur Department; W.W.D: Waste And Water Department; T.D: Traffic Department.*

The mean values of the weights (Figure 5.9) are obtained by calculating the average of the sum of all stakeholders' weights. It is possible to observe that considering all identified stakeholders, the environmental objective is the most important one, followed by the technical performance, cost and society. However, it is important to mention the relevance of the stakeholders. The more stakeholders, the higher the variations that may be found in the weights. Therefore, it is important to perform a research in the beginning of any project to identify as many stakeholders as possible.

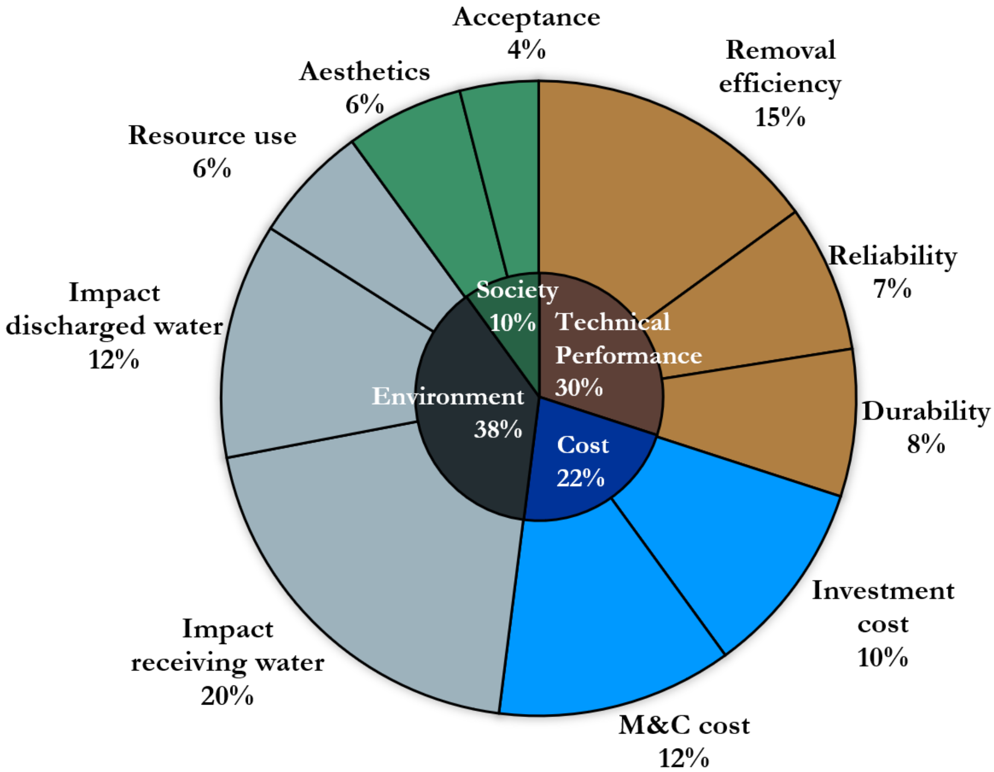

Figure 5.9. Mean weights considering all inputs from the stakeholders.

It is necessary to define the responsible entities in Vitsippsbäcken based on the different necessities (e.g. construction, maintenance, remediation). There are several landowners as well as several departments from the City of Gothenburg involved. This fact demands the development of an exhaustive plan not only to be applied in the present case but in any case in Gothenburg. The jurisdiction, responsibilities and rights of each of the involved entities need to be clarified and therefore, further investigation and time is needed in this aspect. It has been noticed that the involved stakeholders have a more positive attitude towards alternatives which require less maintenance. However, a change on this mentality is urged, not only within the City of Gothenburg but a more global scale. It is necessary to see a change in the coming years and understand that low investment costs demand high maintenance costs and vice-versa. It is necessary as well to understand that the control and maintenance activities are just an investment to increase the life-span of a unit and optimize its performance.

(6) Combination of weights and scores

Following the steps mentioned in Section 4.3 the results were obtained for each stakeholder and each alternative (Figure 5.10). The values are presented on a scale from 1-5 where 5 represents the best value (see Table H.1 in Appendix H for exact values). It is possible to see that for all stakeholders, the biofiltration systems get the highest values while the ones already implemented in the area as e.g. street sweeping and filters, get the lowest values.

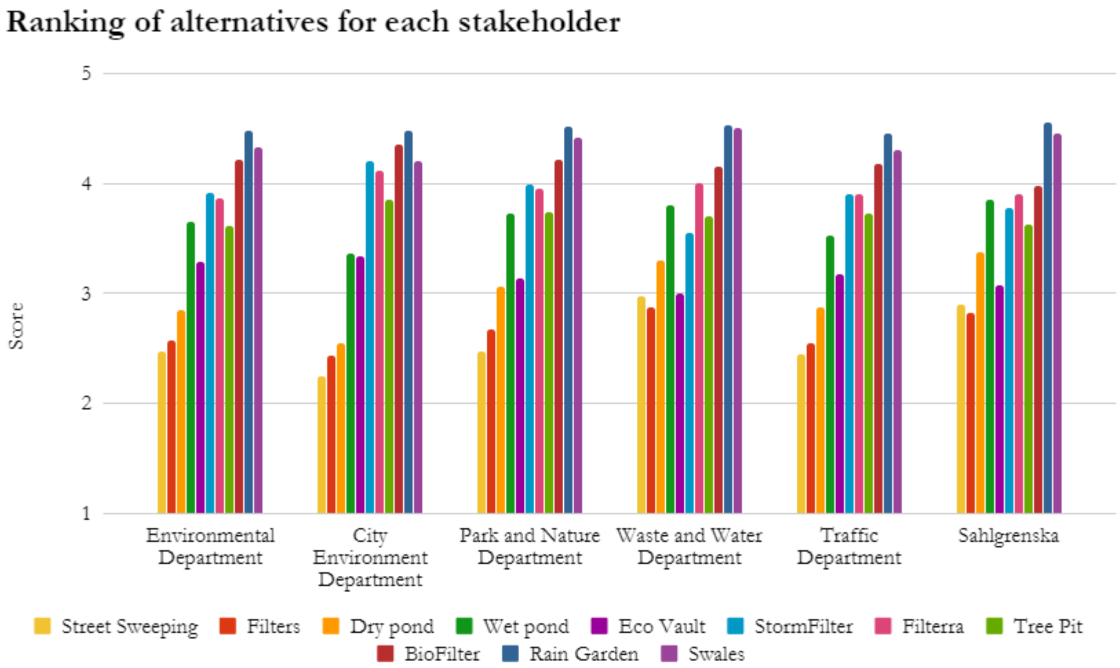

Figure 5.10. Final ranking of alternatives for treatment of stormwater for each stakeholder based on scoring and weighting process.

(7) Analysis of the results

The Web-HIPRE tool was used to create a basic model for the MCA and provides the option to perform a sensitivity analysis. The normalization and linearization of values, performed by the model, did not affect the results and both MCAs (handmade and modeled) obtained the same mean results (Figure H.1 in Appendix H). For the analysis, the mean weights were used.

Moreover, each of the ranking-columns is divided into four objectives (Figure 5.11) and in ten criteria (Figure 5.12). This composite priority result shows that the main factor contributing for the rain garden to be in the first place is the environment followed by the technical performance, the cost and the social aspects. The StormFilter and BioFilter provide a higher environmental performance than the rain garden but the higher costs have a negative impact on these two alternatives and decreases their total score. Even though EcoVault has high environmental and technical performances, it has the highest cost of all alternatives and this fact makes it fall to the 8th position.

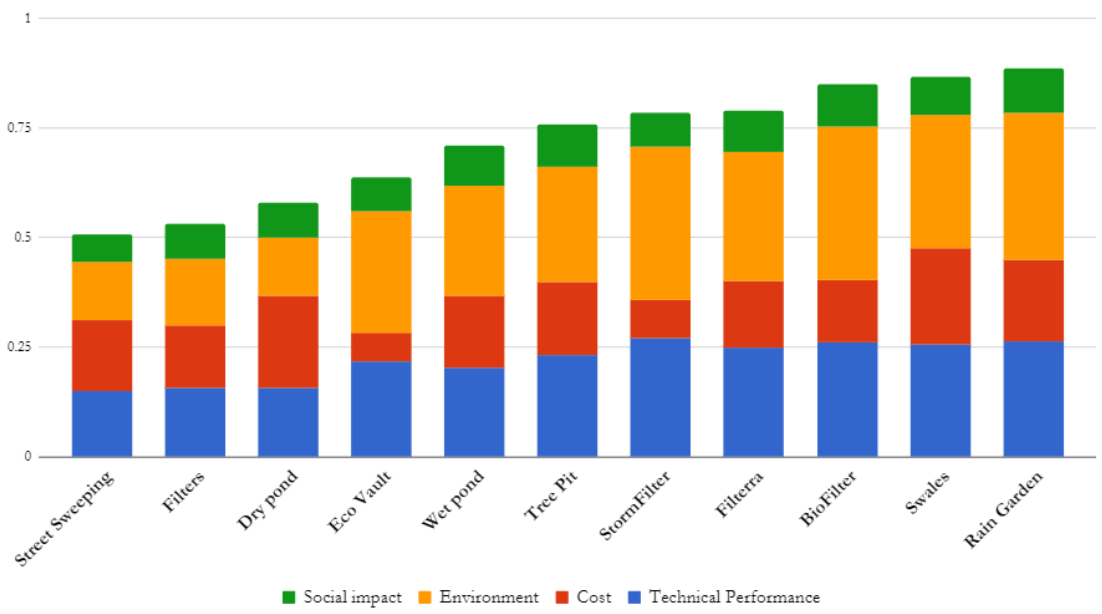

Figure 5.11. Composite priority results presenting positive impacts based on objectives.

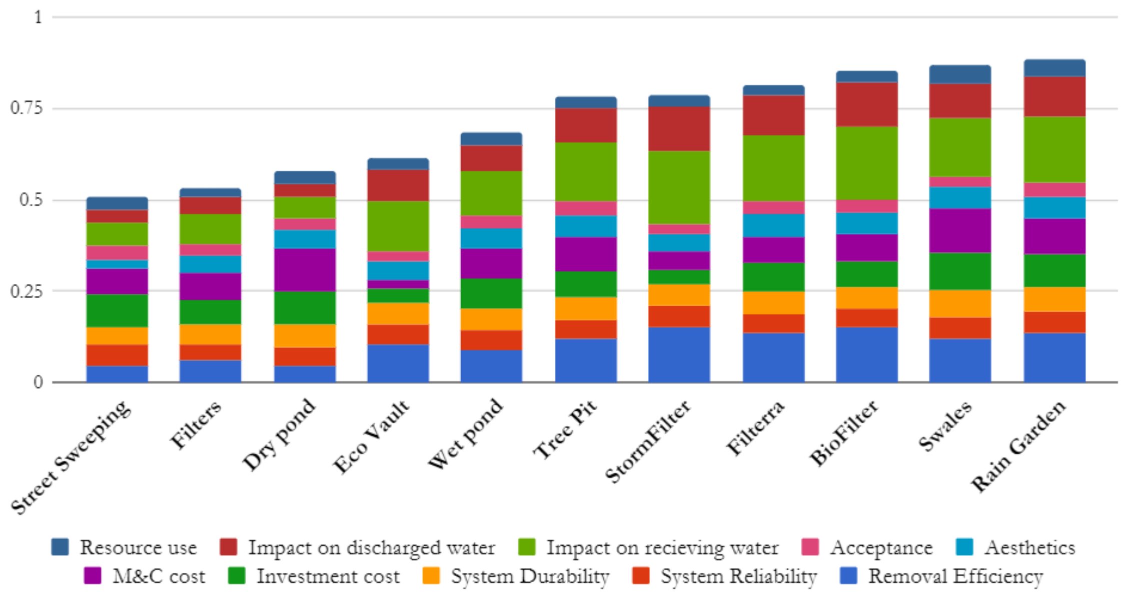

Figure 5.12. Composite priority results presenting positive impacts based on primary criteria for stormwater treatment techniques.

As seen in Figure 5.12, removal efficiency, impact on receiving waters and impact on discharged waters are the criteria having the highest contribution on the final ranking; followed by both investment cost and maintenance and control cost. Therefore, the most suitable solution seems to be a combination of alternatives. The retrofitting of the existing pond (with meander or terrace solutions) is a positive implementation since it would delay part of the volume coming into the treatment unit. In addition, this would also contribute to avoid mixing of natural water with polluted road runoff. However, a more optimal solution could be to add a parallel pipe which could redirect the natural water to avoid mixing with road runoff, as no treatment is needed of this water before discharge into the stream. This solution, however, is a less sustainable and more traditional solution that would demand the opening of trenches and the implementation of new pipes which would demand a high investment cost but a low maintenance frequency and cost. In addition to these implementations, the installation of rain gardens, considering the ranking of the MCA, seems to be the most suitable solution even if the cost parameter remains uncertain. According to CEDR (2016) and Jotte et al (2017), the most commonly applied techniques for road runoff management in Sweden are infiltration in open ditches and sedimentation ponds; and in cases where low area is available, sedimentation tanks with flocculation chemicals are usually implemented. This means that the retrofitting of the existing pond would correlate with the techniques used currently in Sweden. However, the implementation of an EcoVault would be more likely because it correlates with the stormwater managment options previously installed in Sweden rather than any biofiltration system based on CEDR (2016) and Jotte et al (2017) researches.

(8) Sensitivity analysis

Among the four objectives i.e. technical performance, cost, environment and society, the cost is the most sensitive one to changes in weights (Figure 5.13). Figure 5.13 shows a screen shot from the Web-HIPRE sensitivity analysis, showing the performance of all alternatives based on their cost. The rain garden (dotted blue line number 10) is the best performing alternative as long as approximately less than 30% of the total weight is given to cost. At that point, biofiltration swales (dotted yellow line number 11) overpass rain gardens and become the best performing alternative. Meaning that if a higher weight would be attributed to the cost of any particular decision taken by the stakeholders, the swale would be a more optimal solution than rain gardens.

The high sensitivity of the cost might be because a score from 1 to 5 was given to each alternative, even if the cost range was not so big (see Figure 5.11). This could be solved by considering the points of view of the different stakeholders and analyzing if the cost differences are big or small. This way, instead of ranging from 1 to 5, the scores could be e.g. from 2.5 to 4.5 providing smaller differences between the alternatives. When the cost of an alternative is high, it has a small contribution in the composite results and a downward tendency (negative slope, see figure 5.13) while an alternative with a lower cost has an upward tendency. Depending on the contribution to the composite result, the slope is steeper or flatter i.e. the higher the contribution, the steeper the slope.

Clearly, the swales overtake the rain gardens as soon as the weighting is slightly increased for the cost; showing the sensitivity of the whole concept of the MCA and the important role of the stakeholders. Therefore, a further and deeper investigation regarding these two alternatives is recommended to investigate more detailed information and figure out the best solution. If an easier implementation and construction process is desired, however, precast biofiltration units may be a good alternative. BioFilter, Tree Pit and Filterra in combination with sorption media, provide discharged concentration levels below the target values. Regarding the street sweeping, if the traffic department offers continuing with it, this could increase the removal of pollutants and decrease the concentration in discharged waters except for Cd.

It can be discussed if the cost must be included or not in the MCA procedure as an objective. The alternatives could be evaluated by means of the other criteria, and the budget of the project could later, in a second step, determine which BMP is implemented always taking into consideration the list of "top alternatives" obtained in the MCA. Additionally, the costs that were not considered within the investment cost can have an impact on the final cost of the alternative; the construction, machinery personnel and piping connection to the drainage system costs. Therefore, this parameter was considered as uncertain which was as well confirmed in the Web-HIPRE tool. Further investigation and literature review is recommended. Through the Web-HIPRE, it was seen how sensitive the cost was regarding both investment cost and maintenance and control cost; the smallest changes could affect the ranking of alternatives.

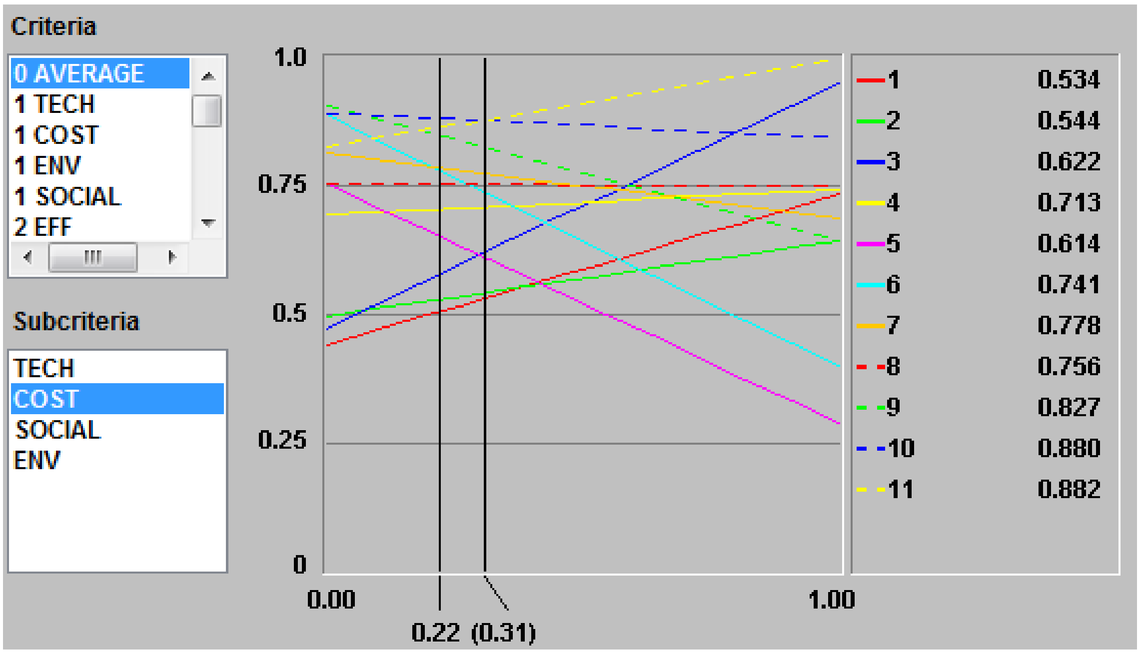

Figure 5.13. Sensitivity analysis of cost category for the mean weight (Web-HIPRE).

The social objective is not sensitive to any weight change while the environmental and the technical performance categories (Figures H.5 and H.6 in Appendix H) present certain sensitivity. The environment category is less sensitive than the cost. The weight needs to be increased from 38% to 62% for the ranking to change. However, to raise the environmental weight up till 60 % is not reasonable in this case. As for the cost, the smaller the contribution the steeper the downward slope and the higher the contribution, the steeper the upward slope.

The technical performance is less sensitive than cost and environment but it shows that if the weighting would be increased to 85%, the rain garden solution would be over-passed by the StormFilter. However, this is not reasonable in a realistic scenario.

As it was possible to see, the society objective was not sensitive. This is due to the fact that all stakeholders gave to it the lowest and most constant weights. Moreover, an additional stakeholder was considered in the beginning to be a representative of the citizens of Gothenburg. However, due to lack of time, it was impossible to distribute the questionnaires to all the groups that were estimated necessary; young people, adults, the elderly and different groups such as the Green Party (among others) or workers at Sahlgrenska Hospital.

From the composite results and sensitivity analysis, it is possible to conclude that both the weighting and scoring procedure have an important role. The weighting affects the final ranking of alternatives while the scoring affects the performance of each alternative. The higher the contribution of an objective or criteria, the better performance it gets (steeper upward slope). And the lower the contribution of an objective or criteria, the worst performance it gets (steeper downward slope). When checking the criteria only, no sensitivity was found regarding the weights in the Web-HIPRE. For all criteria, the best solution is rain garden followed by the swale and the BioFilter, which correlates with the results shown in Figure 5.11.

The MCA approach therefore, has a subjective nature related to the weighting since it is based on the point of view of a certain stakeholder or entity. In the present study, it also has subjectivity traces in the scoring process since normalization of values was done by the author based only on the literature. The implementation of this approach provides transparency between the different entities and allows at all times to share information and know what each stakeholder considers of relevance. The MCA is a tool that can be implemented in case-studies focusing on stormwater management in the decision-making process and allows the inclusion of different criteria and sub-criteria as well as many alternatives as desired. From a larger perspective, the process followed in this study can be used and applied to any site and additional input data can also be integrated. The approach has the capacity to adapt to the changes and include all kind of new data.

6 Conclusions

This master thesis was based on five research questions. Research question three is not added here since it is explicitly answered in section 5.1.

Research question 1: What is the current level of contaminants in the surface water and sediments of Vitsippsbäcken stream?

Vitsippsbäcken does not fulfill the municipal stormwater quality guidelines and cannot be classified as a "good status" surface water because:

- The levels of Cu and Zn in the recipient water after the main stormwater sewer outlet and after Sahlgrenska's stormwater outlet are higher than the target values. Nutrients, TSS, PFOS and PFOA present as well high levels.
- Heavy metal and PAHs concentrations' in sediment samples are high after both outlets.
- A historical discharge of pollutants to Vitsippsbäcken is visible.
- The existing treatment facility at Sahlgrenska Hospital does not work optimally for the removal of Cu.

Research question 2: What are the available treatment techniques for stormwater?

- The lack of available area demands considering flexible and green stormwater treatment techniques.
- Eleven stormwater treatment techniques were considered and analyzed; divided in three different groups: end-op-pipe solutions, detention/retention techniques, road runoff treatment techniques.
- The end-of-pipe solutions focus on underground tanks treating water with filtration, sorption and sedimentation processes.
- The detention/retention techniques focus on dry and wet ponds using sedimentation of stormwater particles as treatment.
- Road runoff treatment techniques are divided into biofiltration systems and street sweeping techniques.
  - Biofiltration systems focus on filtration, sorption and plant uptake. Different configurations were considered: rain gardens, biofiltration swales and manufactured tree pit units.
  - Street sweeping focuses on superficial street cleaning.

Research question 4: Which criteria are relevant to consider in the MCA and how can the stakeholders be involved?

- It was evidenced that the criteria adopted were not enough since these criteria were defined in the beginning of the MCA process based on literature review and knowledge about the area.Therefore, additional criteria were suggested to be included in further analyses: those criteria proposed by some stakeholders

(see section 5.6), construction process complexity, additional costs and treatable volume.
- The scoring and weighting could be done including all stakeholders and discussing all the doubts. Therefore, a workshop is highly recommended.
- The four objectives were properly defined (technical performance, cost, environment and social aspect) since they involve all the sustainability pillars (economy, environment and society) and include as well the technical performances of the different techniques.
- It is possible to conclude that a workshop in collaboration with all stakeholders, reaching to agreements and defining all the important parameters could help achieving a more complete MCA.

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Research question 5: Which is the most sustainable and suitable solution for Vitsipsbäcken catchment area?

- There is not a perfect solution for Vitsippsbäcken. However, if the result of the MCA is exhaustively followed, the best solution is to implement rain gardens with a total area of 100 m^2 or biofiltration swales with a total area of 200 m^2.
- The subdivision of biofiltration systems in smaller units seems more suitable for the area than a large and unique biofiltration system.
- The manufactured tree biofiltration systems, in combination with sorption media, can as well provide discharged values below the target values.
- The retrofitting of the existing detention pond would also be a positive implementation since it catches stormwater from 14 ha (34 % of the total cathment area). It would delay the arrival of high volumes of stormwater to the discharging point and it would also avoid the mixing of relatively clean rainwater with polluted road runoff. A more optimal -but more traditional and invasive- solution for this water would be to add a parallel pipe and discharge the natural water directly into the stream since it does not need any treatment.
- Street sweeping in combination with end-of-pipe solutions may as well be a solution if the biggest interest for the City of Gothenburg is to obtain acceptable results with low maintenance activities.
- The StormFilter vault in combination with street sweeping can provide discharged concentrations below the target values but would demand a large investment cost. The EcoVault can as well perform similarly but Cu and TP would not be totally treated.

Future research

The methodology followed throughout the report presents a high complexity since several theoretical and practical activities were performed. The review on stormwater treatment techniques provided enough information to conduct the scoring of the MCA even if some parameters such cost remain uncertain. Further investigation of costs is therefore, necessary. The performed calculations gave an insight and understanding of the models and allowed to understand the behaviour of water within the catchment area. The sampling events in combination with the laboratory results provided enough information to define the current status of the recipient water and sediments; and allowed to define the target pollutants for the analysis. The questionnaires provided the perspectives of each of the stakeholders even if it was in a superficial extent. It is recommended to perform a workshop and reach to common scores and weights for the MCA. The models used provided additional aid for a better understanding of the alternatives reviewed and their potential. StormTac model allowed to find modelled removal efficiencies for those alternatives that were difficult to find information in the literature. The Web-HIPRE model was used as a tool for a better understanding of the impacts of the objectives, criteria and stakeholders in the MCA which was an essential part of the sensitivity analysis. Finally, the MCA approach allowed to include and relate all the information gathered in the above mentioned steps and find a possible solution for the situation in Vitsippsväcken.

As a continuation to the study, it would be very valuable to investigate the biofilters with different sorption materials and further test the potential in the given conditions. A pilot test is highly recommended. Further investigations of rain gardens and swales is recommended in order to elucidate which one is a better solution for the site conditions. Investigation regarding the best pond retrofitting solution is recommended focusing, mainly, on cost. Analyses of microplastics in the recipient waters are as well proposed since it is a growing concern at a global scale.

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A Swedish Environmental Objectives

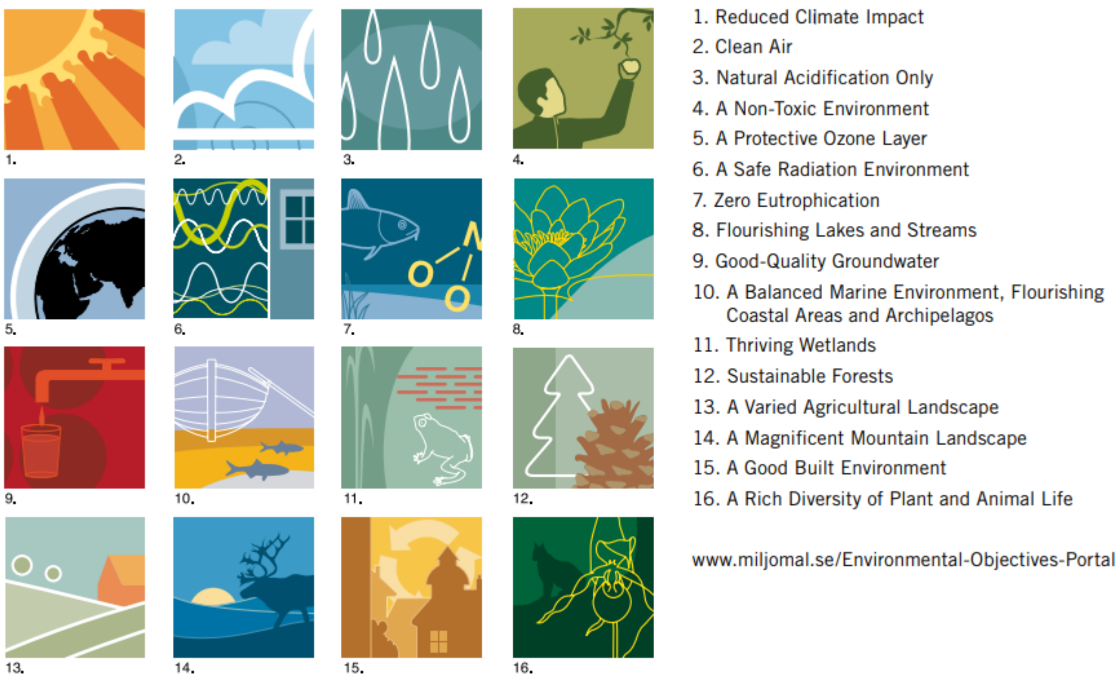


Figure A.1. 16 Environmental Quality Objectives in Sweden (Swedish EPA, 2009).

Table A.1. Description of the five environmental objectives related to water.

Objective	Goal defined in the Swedish EPA
3. Natural Acidification only (Swedish EPA, 2016a)	*"The acidifying effects of deposition and land use must not exceed the limits that can be tolerated by soil and water. In addition, deposition of acidifying substances must not increase the rate of corrosion of technical materials located in the ground, water main systems, archaeological objects and rock carvings".*
7. Zero eutrophication (Swedish EPA, 2016b)	*"Nutrient levels in soil and water must not be such that they adversely affect human health, the conditions for biological diversity or the possibility of varied use of land and water".*
8. Flourishing Lakes and Streams (Swedish EPA, 2016c)	*"Lakes and watercourses must be ecologically sustainable and their variety of habitats must be preserved. Natural productive capacity, biological diversity, cultural heritage assets and the ecological and water-conserving function of the landscape must be preserved, at the same time as recreational assets are safeguarded".*
9. Good-Quality Groundwater (Swedish EPA, 2016d)	*"Groundwater must provide a safe and sustainable supply of drinking water and contribute to viable habitats for flora and fauna in lakes and watercourses".*
11. Thriving Wetlands (Swedish EPA, 2016e)	*"The ecological and water-conserving function of wetlands in the landscape must be maintained and valuable wetlands preserved for the future".*

B Metal concentrations

Figure B.1. Metals in sediment (mg/kg ds).

CURRENT CONDITIONS: metals in sediment (mg/kg ds)

Class	Description	Cu	Zn	Cd	Pb	Hg
1	Very low concentrations	≤ 15	≤ 150	≤ 0.8	≤ 50	≤ 0.15
2	Low concentrations	15 – 25	150 – 300	0.8 – 2	50 – 150	0.15 – 0.3
3	Moderate high conc.	25 – 100	300 – 1000	2 – 7	150 – 400	0.3 – 1.0
4	High concentrations	100 – 500	1000 – 5000	7 – 35	400 – 2000	1.0 – 5
5	Very high conc.	> 500	> 5000	> 35	> 2000	> 5

Class	Description	Cr	Ni	As
1	Very low concentrations	≤ 10	≤ 5	≤ 5
2	Low concentrations	10 – 20	5 – 15	5 – 10
3	Moderate high conc.	20 – 100	15 – 50	10 – 30
4	High concentrations	100 – 500	50 – 250	30 – 150
5	Very high conc.	> 500	> 250	> 150

Figure B.2. Metals in moss (mg/kg ds).

CURRENT CONDITIONS: metals in aquatic moss (mg/kg ds)

Class	Description	Cu	Zn	Cd	Pb	Hg
1	Very low concentrations	≤ 7	≤ 60	≤ 0.3	≤ 3	≤ 0.04
2	Low concentrations	7 – 15	60 – 160	0.3 – 1.0	3 – 10	0.04 – 0.1
3	Moderate high conc.	15 – 50	160 – 500	1.0 – 2.5	10 – 30	0.1 – 0.3
4	High concentrations	50 – 250	500 – 2500	2.5 – 15	30 – 150	0.3 – 1.5
5	Very high conc.	> 250	> 2500	> 15	> 150	> 1.5

Class	Description	Cr	Ni	Co	As
1	Very low concentrations	≤ 1.5	≤ 4	≤ 2	≤ 0.5
2	Low concentrations	1.5 – 3.5	4 – 10	2 – 10	0.5 – 3
3	Moderate high conc.	3.5 – 10	10 – 30	10 – 30	3 – 8
4	High concentrations	10 – 50	30 – 150	30 – 150	8 – 40
5	Very high conc.	> 50	> 150	> 150	> 40

The five classes are defined as follows.

- **Class 1:** No risk of biological effect or very slight risk.
- **Class 2:** Slight risk of biological effects.
- **Class 3:** Effects on the reproduction or survival of species or groups of species may occur.

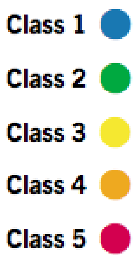
- **Class 4 and 5:** Growing risk of biological effects. The general rule says that the greatest the deviation from the reference value is, the risk of effects increases.

The reference values ideally refer to the natural state of a water body, sediment, moss or fauna which has not been affected by any human activity. The deviations from the reference values allow to estimate the extent of the impact of human activities in the water bodies by calculating the deviation of the measured value from the reference value (Equation 2.1). The extent of this deviation is classified in a five-level scale which are the classes specified above (Swedish EPA, 2000).

$$Deviation = \frac{Measured\ \ Value}{Reference\ \ Value} \tag{B.1}$$

When using the Swedish Environmental Quality Criteria, the data used and any adjustments made to reference values needs to be presented. Additionally, colour coding of classes 1 to 5 should be used (Figure 2.10).

Figure B.3. Colour coding for result classification (Swedish EPA, 2000).



C Rational Method

C.1 Main formula

$$Q = C \cdot i \cdot A \quad (C.1)$$

$$Q = Cs \cdot i \cdot As \cdot f_c \quad (C.2)$$

Where:

- Q: Flow or Peak Discharge (L/s)
- C: Runoff coefficient (adim)
- i: Rain intensity (L/*ha)
- A: Area (m^2
- f_c: Climate factor. 1.25 in Sweden (P110, Swedish Water, 2016).

C.2 Runoff coefficient

$$Cs = \frac{C_1 \cdot A_1 + C_2 + A_2 + ... + C_n \cdot A_n}{(A_1 + A_2 + ... + A_n} \quad (C.3)$$

Table C.1. Runoff Coefficients. Swedish Regulation (P90) (Petterson, 2017).

Area Type	**Runoff Coeff. (C)**
Roof	0.9
Concrete or Asphalt	0.8
Stone Surface	0.7
Gravel / Dirt roads	0.4
Rock	0.3
Gravel pitch	0.2
Park with vegetation	0.1
Cultivated surface	0-0.1
Forest land, wooded	0-0.1
Closed architecture style, no vegetation	0.7 (Flat) - 0.9 (Hilly)
Closed architecture style, with vegetation	0.5 (Flat) - 0.7 (Hilly)
Open architecture style (apartment blocks)	0.4 (Flat) - 0.6 (Hilly)
Link-attached houses (terrace houses)	0.4 (Flat) - 0.6 (Hilly)
Detached houses, sites < 1000 m2	0.25 (Flat) - 0.35 (Hilly)
Detached houses, sites > 1000 m2	0.15 (Flat) - 0.25 (Hilly)

C.3 Rain intensity

$$i(t_r) = \Big(190 \cdot \sqrt[3]{T} \cdot \frac{ln(t_r)}{t_r^0.98}\Big) + 2 \tag{C.4}$$

Where:

- i(t_r): Rain intensity (L/s · ha)
- t_r: Rain duration (min)
- T: Return time (months)

Mathematical function. Formulas and Intensity-Duration Courves (IDF).

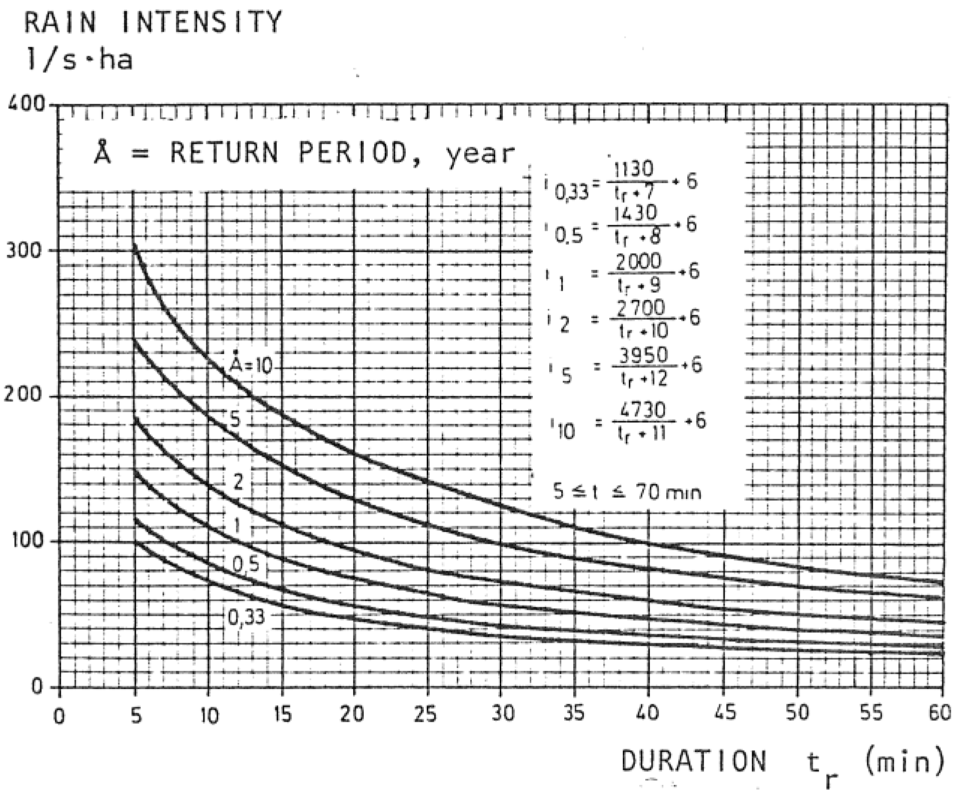
$$i = \frac{750}{D+10} \qquad 5 \leq D \leq 20min \tag{C.5}$$

$$i = \frac{1000}{D+20} \qquad 20 \leq D \leq 100min \tag{C.6}$$

Where:

- i: rain intensity (L/s · ha)
- D: Rain duration (min)

Table C.2. Intensity - Duration - Frequency (IDF) curves for Gothenburg (Arnell, 1978). t_c is equal to D.



C.4 Time of Concentration and Rain Duration

$$t_c = t_e + t_f \tag{C.7}$$

Table C.3. Flow speed for different flow channeling types

Type of material	Velocity (m/s)
Normal pipe	1.5
Bigger pipe	1
Ditch and gutter well	0.5
Ground	0.1

C.5 Return Time

Table C.4. Recurrence of events. Probability and risk for a certain return time rain to happen during a certain period of time.

Life Span / Return Period [years]	1	2	5	10	20	50	100
1	63%	87%	99%	100%	100%	100%	100%
2	39%	63%	92%	99%	100%	100%	100%
5	18%	33%	63%	86%	98%	100%	100%
10	10%	18%	39%	63%	86%	99%	100%
20	5%	10%	22%	39%	63%	92%	99%
50	2%	4%	10%	18%	33%	63%	86%
100	1%	2%	5%	10%	18%	39%	63%

D Information of alternatives

1. Retrofiting of detention pong

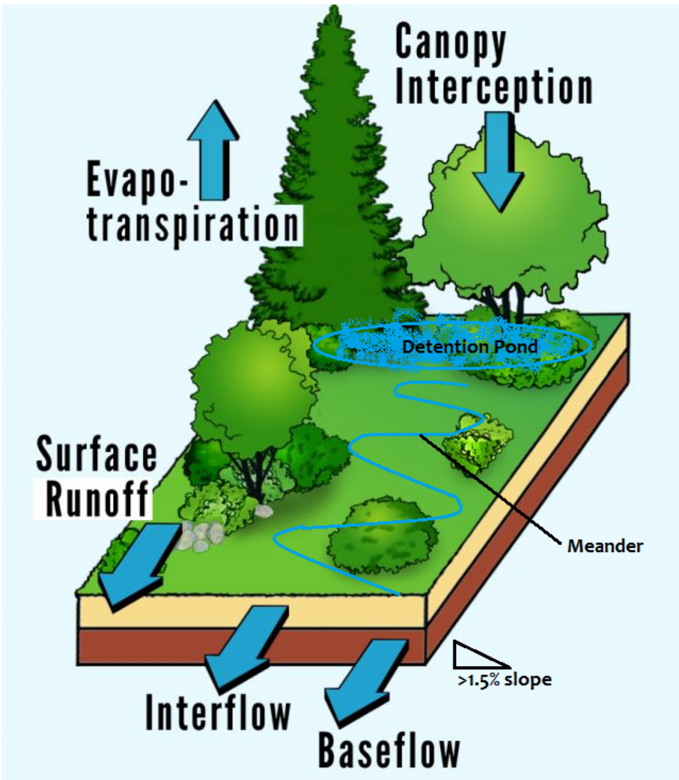


Figure D.1. Schematic drawing of meander solution.

Figure D.2. Schematic drawing of terrace solution).

2. EcoVault

Figure D.3. Standarized sizes for EcoVault (ESI, 2018).

EcoVault® Sizing					
Model Size LxW (ft x ft)	Typical Pipe Size (in)	80% TSS Removal Efficiency Flow (cfs)	Screen Storage Capacity (cf)	Sediment Chamber Capacity (cf)	Total Contaminant Capacity (cf)
5 x 11	12 - 30	15	87	150	237
6 x 12	18 - 36	24	144	201	345
8 x 14	30 - 54	32	324	321	645
8 x 16	36 - 54	40	360	369	729
10 x 16	42 - 66	45	550	465	1015
12 x 20	54 - 72	55	1008	945	1953

3. Removal efficiency of PhosphoSorb

Table D.1. Field evaluation results with PhosphoSorb (Contech, n.d).

	Parameter	Sample population (n)	Average Influent (mg/L)	Average Effluent (mg/L)	Average Removal (%)	Aggregate Pollutant Load Reduction [1] (%)
Solids	TSS	17	380	40	88	89
	SSC<500 µm	15	325	40	87	89
	Silt and Clay[2]	16	153	32	78	82
Nutrients	Total Phosphorus	17	0.33	0.07	73	82
	Total Nitrogen	17	1.14	0.57	43	50
Metals	Total Zinc	15	0.129	0.024	78	81
	Dissolved Zinc	7	0.016	0.01	28	32
	Total Copper	15	0.026	0.005	79	82
	Dissolved Copper	7	0.004	0.003	30	28
	Total Aluminum	16	5.85	1.08	83	83
	Total Lead	15	0.009	0.003	64	70

[1] Treatment Efficiency Calculation, Method #2 (TAPE, 2008)
[2] Suspended Solids less than 62.5 microns

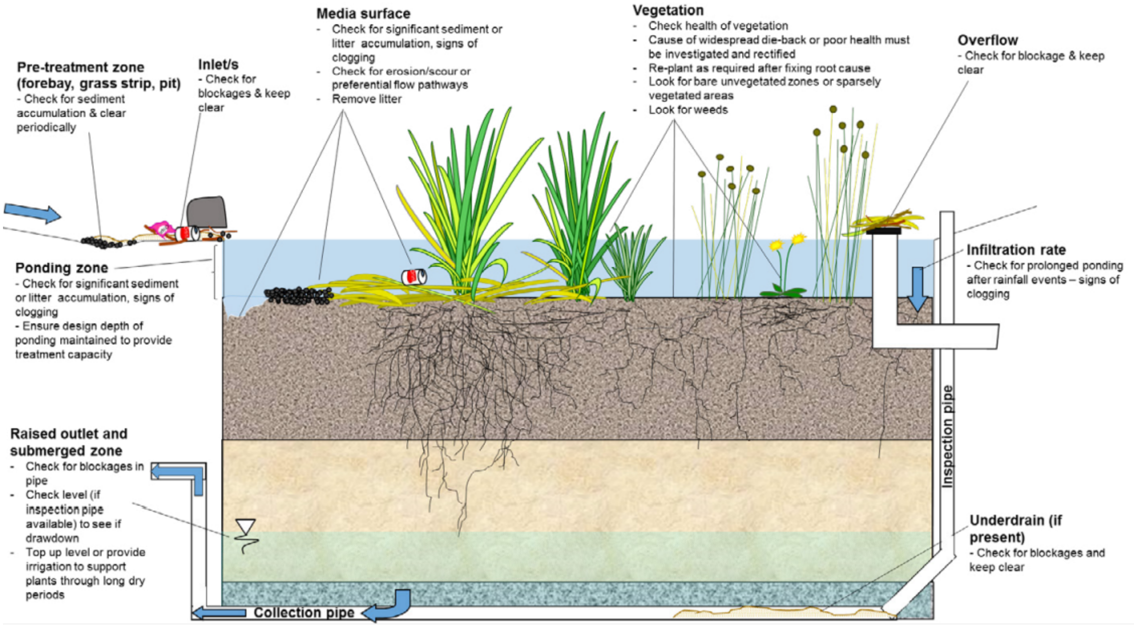


Figure D.4. Reccommended biofiltration maintenance activities (Payne et al, 2015).

E Information about Sweden

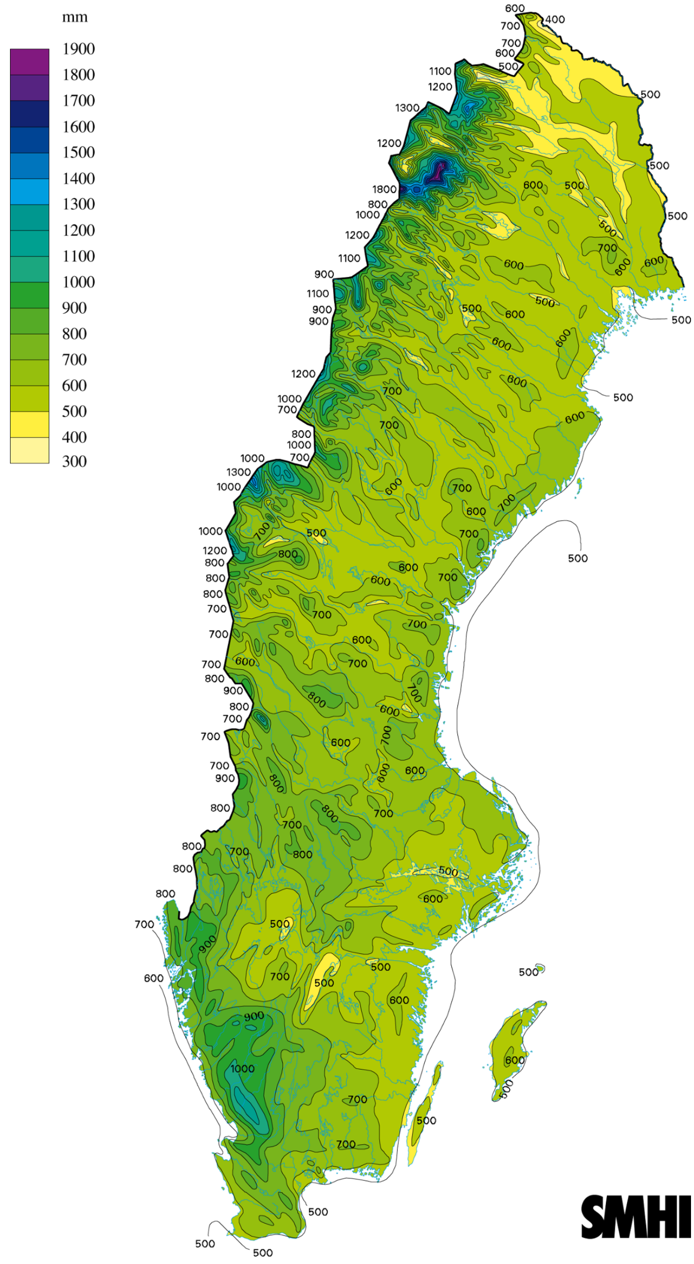


Figure E.1. Precipitation data from SMHI. Measured yearly average, average 1961-1990 (SMHI).

Preliminär statistik

SMHI – 2017

NEDERBÖRD, SOLSKEN OCH STRÅLNING – **ÅRET 2017**

Station	Startår för stationer som börjat efter 1901	Nederbörd, mm						Antal nederbördsdagar
		2017	Normal 1961-90	Största sedan 1901	År	Minsta sedan 1901	År	
Naimakka	1944	476	391	616	2004	278	1968	195
Karesuando	1879	471	386	667	2004	202	1910	205
Katterjåkk	1904	869	844	1537	1975	561	1944	216
Kiruna-Esrange	1898	657	500	755	1935	214	1901	180
Abisko	1913	394	304	475	1983	189	1976	177
Nikkaluokta	1950	656	480	704	1998	247	1994	197
Ritsem	1981	526	460	726	1989	372	1984	211
Gällivare	1897	714	490	999	1935	312	1901	208
Kvikkjokk-Årrenjarka	1889	646	560	840	1998	310	1901	169
Jokkmokk	1860	714	509	892	2011	275	1901	157
Arjeplog-Myrheden	1945	565	554	800	2011	345	1994	195
Arvidsjaur	1996	465	508	932	2000	392	2014	192
Hemavan	1886	927	748	1195	2011	487	1902	222
Sorsele	1969	*	566	888	2000	428	1976	*
Gunnarn	1860	507	528	862	2000	323	1908	194
Lycksele	1945	529	443	856	1954	385	2014	194
Vilhelmina	1996	512	493	752	2000	395	2002	188
Pajala	1940	503	432	791	1998	319	1941	204
Överkalix-Svartbyn	1962	571	450	781	2015	401	1980	198
Haparanda	1859	602	532	932	1935	353	1956	208
Luleå-Bergnäset	1944	705	506	824	2015	325	1946	162
Piteå	1859	814	539	975	2012	291	1915	173
Bjuröklubb	1879	615	503	760	1967	321	1906	195
Vindeln-Sunnansjönäs	1945	746	591	823	1998	384	1946	190
Umeå-Röbäcksdalen	1860	476	591	1024	2000	401	1922	137
Holmön	1879	697	566	787	1998	196	1901	187
Gäddede	1905	679	746	1106	1998	443	1912	226
Storlien-Storvallen	1899	725	746	1380	1962	576	1968	242
Höglekardalen	1962	676	801	1185	2000	482	1972	226
Östersund-Tullus	1860	469	543	819	1998	298	1911	188
Hoting	1996	661	518	772	2000	451	2002	203
Junsele	1884	556	522	764	2000	334	1901	189
Forse	1901	552	538	838	2000	335	1901	160
Skagsudde	1964	524	426	706	2000	280	1975	159
Härnösand	1858	785	703	1048	2000	437	1942	159
Torpshammar	1931	501	490	790	2000	346	1942	206
Stordalen-Midlanda	1943	692	569	847	2000	349	1947	167
Brämön	1995	538	471	784	2000	384	2004	168
Ljusnedal	1908	593	503	736	2011	335	1968	199
Hedeviken	1937	550	504	740	2000	361	1968	186
Sveg	1875	510	536	845	1966	302	1908	199
Delsbo	1878	487	483	796	1985	282	1901	175
Hudiksvall	1934	789	636	946	1966	412	1975	149
Edsbyn	1941	*	571	952	2000	397	1947	*
Åmot	1951	651	541	830	1981	411	2013	185
Gävle-Åbyggeby	1858	727	642	887	1981	262	1901	174
Särna	1879	594	601	855	1924	311	1908	179
Ulvsjö	1918	691	732	1150	1950	532	1947	200
Mora	1924	547	546	888	2000	338	1947	184
Malung	1879	633	730	1080	2000	357	1911	192
Falun	1860	537	617	844	1966	331	1901	164
Östmark	1942	795	878	1352	2000	572	1947	175
Gustavsfors	1917	720	671	918	2000	421	1978	199
Arvika	1945	597	594	964	2000	322	1947	194
Karlstad-Väse	1858	685	640	1003	2000	299	1947	175
Blomskog	1964	644	677	1114	2000	550	1976	199
Ställdalen	1967	815	731	944	2006	581	1976	195
Västerås	1860	573	539	724	2006	270	1947	158
Örebro	1860	663	625	950	2000	365	1933	181
Örskär	1881	500	432	716	1981	219	1933	163
Films Kyrkby	1982	602	564	826	2012	481	1996	173
Uppsala	1739	550	544	715	1981	358	1901	164
Svenska Högarna	1879	506	447	672	1960	286	1933	171
Stockholm	1785	557	539	801	1960	357	1901	166
Landsort	1879	538	433	678	1960	290	1969	148
Norrköping	1944	549	507	708	2000	269	1947	183
Linköping	1860	573	570	734	2010	326	1914	184
Harstena	1942	461	485	845	1960	351	1975	165
Skara	1860	523	564	854	2011	344	1933	162
Skövde	1931	616	652	897	2007	433	1933	188
Vänersborg	1860	708	709	1164	2000	449	1901	190
Ulricehamn	1892	912	846	1198	1990	546	1941	216
Borås	1884	1081	975	1380	2011	562	1941	210
Nordkoster	1967	647	627	1046	1988	506	2010	177
Måseskär	1883	573	580	807	1950	284	1947	177
Göteborg	1859	993	758	1264	2006	421	1922	207
Vinga	1881	602	572	933	1967	350	1947	188
Varberg	1879	1016	738	1142	1999	376	1947	177
Torup	1972	1255	1166	1472	2008	856	1996	245
Halmstad	1860	1052	796	1176	1998	450	1976	182
Jönköping-Mullsjö	1860	819	676	1027	1998	354	1955	202
Gladhammar	1859	595	601	926	2000	356	1971	177
Målilla	1946	453	484	766	1958	407	1964	159
Kalmar	1860	455	484	782	1960	296	1921	134
Växjö	1860	719	618	961	1945	459	1947	213
Ljungby	1879	909	766	1061	1988	518	1947	199
Ölands norra udde	1879	458	421	708	1960	252	1921	164
Ölands södra udde	1881	536	400	652	1944	237	1918	178
Gotska Sandön	1879	502	493	815	1974	349	1975	183
Visby	1860	619	513	718	1912	348	1975	164
Hoburg	1879	579	496	711	1960	263	1938	164
Ronneby-Bredåkra	1881	740	631	831	1994	366	1938	182
Karlshamn	1859	750	563	850	2007	411	1953	180
Hanö	1881	604	496	719	2007	263	1921	185
Osby	1923	1007	712	1037	2007	432	1947	203
Kristianstad	1880	*	511	811	1999	375	1953	*
Helsingborg	1931	889	737	993	2007	382	1976	206
Lund	1748	795	666	845	2006	422	1947	198
Malmö	1917	766	602	883	2014	375	1947	206
Falsterbo	1880	581	491	838	1960	318	1902	192

*data saknas

Station	Instrument	Startår	Solskenstid, timmar					
			2017	Normal 1961-90	Största sedan startår	År	Minsta sedan startår	År
Katterjåkk	a	1972	1347	1138	1476	2014	825	1983
Abisko	a	1913	1448	1338	1756	1969	916	1983
Tarfala	c	2007	1107	1057	1198	2016	903	2011
Kiruna	c	1958	1486	1484	1838	1969	1190	1983
Luleå	c	1957	1774	1771	2138	1976	1438'	1998
Umeå	c	1969	1715	1782	2152	1994	1499	1998
Storlien-Visjövalen	c	1953	1319	1280	1648	1969	871	1983
Östersund	c	1957	1438	1536	1862	1969	1208	1983
Borlänge	c	1987	1707	1660	2050	2013	1404	1998
Uppsala-Ultuna	a	1963	1895	1698	2163	2013	1372	1998
Karlstad	c	1950	1804	1801	2210	2013	1456	1998
Svenska Högarna	c	2007	2095	1916	2333	2011	1978	2010
Stockholm	c	1908	1867	1821	2193	1959	1378	1912
Norrköping	c	1955	1796	1765	2125	2013	1402	1998
Nordkoster	c	2006	2009	1992	2232	2013	1985	2007
Göteborg	c	1983	1618	1631	1948	1997	1321	1998
Visby	c	1952	2060'	1882	2312	2011	1666	1985
Hoburg	c	1985	2163	1880	2343	2015	1667	1998
Växjö	c	1983	1453	1440	1781	2013	1181	1998
Karlskrona	c	2009	2041		2270	2016	1071'	2009
Lund	c	1983	1577	1592	1982	2005	1363	1998
Falsterbo	a	2002	1720	1714	2038	2005	1690	2010

Solskenstiden definieras som den tid då den direkta solstrålningen överstiger 120 W/m². Instrument a: Campbell-Stokes heliograf och c: kontrastsensor.

[1] Startår 1930 för maj - september, övriga 1965.

Station	Startår	Globalstrålning, kWh/m²					
		2017	Normal 1961-90	Största sedan startår	År	Minsta sedan startår	År
Tarfala	2007	871.2	854.4	887.0	2008	763.6	2011
Kiruna	1958	799.9	816.6	927.1	1963	708.1	1983
Luleå	1961	884.0	875.6	994.2	1976	767.4'	1998
Umeå	1959	886.7	938.2	1124.2	1969	793.8	1962
Storlien-Visjövalen	2013	851.3		909.0	2014	827.6	2015
Östersund	1957	862.1	932.7	1110.7	1969	786.0	1983
Borlänge	1987	942.8	953.0	1024.1	2013	833.5	1998
Karlstad	1957	997.4	1010.7	1217.5	1968	869.6'	1998
Svenska Högarna	2007	1074.1	1042.1	1114.3	2016	1046.1	2012
Stockholm	1922	990.6	969.5	1177.6	1944	820.9	1923
Norrköping	1975	1009.4	974.9	1077.1	2013	876.5	1998
Nordkoster	2010	1034.9		1090.4	2015	1029.9	2011
Göteborg	1983	972.6	957.9	1043.8	2013	846.5	1987
Visby	1958	1089.1'	1066.9	1208.3	1968	976.6	1998
Hoburg	2013	1147.9		1198.7	2016	1145.7	2014
Växjö	1983	935.1	911.6	1043.5	2013	824.2	1987
Lund	1983	925.9	972.9	1095.3	2008	895.8	1987

Station	Startår	Långvågsstrålning, kWh/m²					
		2017		Största sedan startår	År	Minsta sedan startår	År
Tarfala	2007	2247.2'		2385.4	2011	2231.2'	2010
Kiruna	2007	2380.8		2434.1	2011	2289.4	2010
Umeå	2016	2565.5		2225.8'	2016	2225.8'	2016
Svenska Högarna	2007	2629.9		2674.9	2014	2595.5	2013
Norrköping	2007	2716.5		2757.8	2014	2634.3	2010
Visby	2007	2673.5'		2704.4	2014	2643.9	2013
Växjö	2016	2739.8		2700.3'	2016	2700.3'	2016

Förklaring till tabellerna

Om årets högsta resp lägsta temperatur inträffat under två eller flera dygn, anges i tabellen det sista av dessa dygn.

Frostdag:

Frostdag är dygn (från kl 19 till kl 19) då minimitemperaturen är under 0.0°C.

Högsommardag:

Högsommardag är dygn (från kl 19 till kl 19) då maximitemperaturen är minst 25.0°C.

Nederbördsdagar:

Antal dygn (från kl 07 till kl 07) med nederbörd ⩾ 0.1 mm.

' Interpolerat värde.

Alla tider avser svensk normaltid. Svensk sommartid = svensk normaltid plus 1 timme.

F Sampling Protocols

As the sampling is to be based on surface water, the US EPA (2013) guidelines are to be followed. This guideline aims to describe general and specific procedures and methods to consider when sampling surface waters. The main general precautions are summarized as:

1. Safety
   (a) Follow SESD Safety, Health and Environmental Management Program (SHEMP) Procedures and Policy Manual.
   (b) Follow Health and Safety Plans (HASP) for guidelines on safety precautions.

2. Procedural Precautions when collecting surface water samples (adapted from the guideline)
   (a) Take special care to not contaminate the samples. Samples shall be custody sealed during long-term storage or shipment.
   (b) Collected samples are to be in the custody of the sampler until they are given up to another party. If samples are transported by the sampler, they will remain under his/her custody or be secured until they are relinquished.
   (c) Documentation of field sampling is to be done in a bound logbook.
   (d) Chain-of-custody documents shall be filled out and remain with the samples until custody is transferred.

3. Special Precautions for Surface Water Sampling
   (a) A clean pair of new, non-powdered, disposable gloves will be worn each time a different location is sampled and the gloves should be donned immediately prior to sampling.
   (b) Sample containers for samples suspected of containing high concentrations of contaminants shall be stored separately.
   (c) All background or control samples shall be collected and placed in separate ice chests or shipping containers. Sample collection activities shall proceed progressively from the least suspected contaminated area to the most suspected contaminated area.
   (d) If possible, one member of the field sampling team should take all the notes and photographs, fill out tags, etc., while the other members collect the samples.
   (e) Samplers must use new, verified and certified-clean disposable or non-disposable equipment.

4. Sample Handling and Preservation Requirements
   (a) For water sampling, we can use a telescopic grab sampler where sample bottles (plastic/glass) can be used and filled directly, without decanting/pouring in to other container.

(b) Surface water samples will typically be collected either by directly filling the container from the surface water body being sampled or by decanting the water from a collection device such as a stainless steel scoop or other device.
(c) During sample collection, if transferring the sample from a collection device, make sure that the device does not come in contact with the sample containers.
(d) Place the sample into appropriate, labeled containers.
(e) All samples requiring preservation must be preserved as soon as practically possible, ideally immediately at the time of sample collection. For all chemical preservatives, SESD will use the appropriate chemical preservative generally stored in an individual single-use vial as described in the SESD Operating Procedure for Field Sampling Quality Control (SESDPROC-011).
(f) All samples preserved using a pH adjustment (except VOCs) must be checked, using pH strips, to ensure that they were adequately preserved. Which is only valid for metals.

Different techniques and equipment exist for surface water sampling, however, the physical location of the person responsible to conduct the sampling may define the equipment to be used. Direct dipping of the sample container into the stream is the desirable technique, however, collecting samples this way is possible when sampling from accessible locations is possible. this technique could be used in some of the sampling points selected, but in most of the locations, the water stream is not that accessible. For each of the different compounds to be analyzed, different types of bottles are to be used as will be described in the next section. However, the use of scoops is the most commonly used technique to reach water with difficult accessibility. Therefore, other techniques are required (US EPA, 2013). The main ones identified as usable for the present project are:

- Dipping Using Sample Container: The sample may be collected directly with the sample container when the water is accessible. The sampler should face upstream and collect the sample without disturbing the bottom sediment. The surface water sample should always be collected prior to the collection of a sediment sample at the same location.
- Scoops (normally used): Stainless steel scoops provide a means of collecting surface water samples from surface water bodies that are too deep to access by wading. They have a limited reach of about eight feet and, if samples from distances too far to access using this method are needed, a mobile platform, such as a boat, may be required. The scoop may be used directly to collect and transfer a surface water sample to the sample container, or it may be attached to an extension in order to access the selected sampling location.

G Laboratory analysis

Vitsippsbäcken: Sampling in 4 different spots. Compounds to analyze.		
	Sediment	Recipient water
Susp		
Ca		
Mg		
pH		
Turbidiy		
Conductivity		
pH		
TOC		
DOC		
tot-P		
tot-N		
Arsenik-tot		
Arsenik-löst		
Cu-löst		
Cu-tot		
Zn-löst		
Zn-tot		
Bly-löst		
Bly-tot		
Kadmium-löst		
Kadmium-tot		
Krom-löst		
Krom-tot		
Nickel-löst		
Nickel-tot		
Hg-löst		
Hg-tot		
PAH16L		
Bensen		
DEHP		
Oktyl- och nonylfenol		
Oljeindex		
PFOS		

Figure G.1. Analyzed compounds by Alcontrol both for sediments and recipient waters.

H Results

Table H.1. Points per alternative for each of the stakeholders based on the scoring and the weighting presented before.

Alternative #	1	2	3	4	5	6
Stakeholder / Alternative Name	**Street Sweeping**	**Filters**	**Dry pond**	**Wet pond**	**Eco Vault**	**StormFilter**
Environmental Department	2.47	2.58	2.85	3.65	3.29	3.91
City Environment Department	2.24	2.43	2.55	3.36	3.34	4.20
Park and Nature Department	2.47	2.68	3.06	3.73	3.14	3.99
Waste and Water Department	2.98	2.88	3.30	3.80	3.00	3.55
Traffic Department	2.45	2.55	2.88	3.53	3.18	3.90
Sahlgrenska	2.90	2.83	3.38	3.85	3.08	3.78
	7	**8**	**9**	**10**	**11**	
Stakeholder / Alternative Name	**Filterra**	**Tree Pit**	**BioFilter**	**Rain Garden**	**Swales**	
Environmental Department	3.86	3.61	4.21	4.475	4.33	
City Environment Department	4.11	3.845	4.355	4.48	4.2	
Park and Nature Department	3.95	3.735	4.215	4.515	4.42	
Waste and Water Department	4	3.7	4.15	4.525	4.5	
Traffic Department	3.9	3.725	4.175	4.45	4.3	
Sahlgrenska	3.9	3.625	3.975	4.55	4.45	

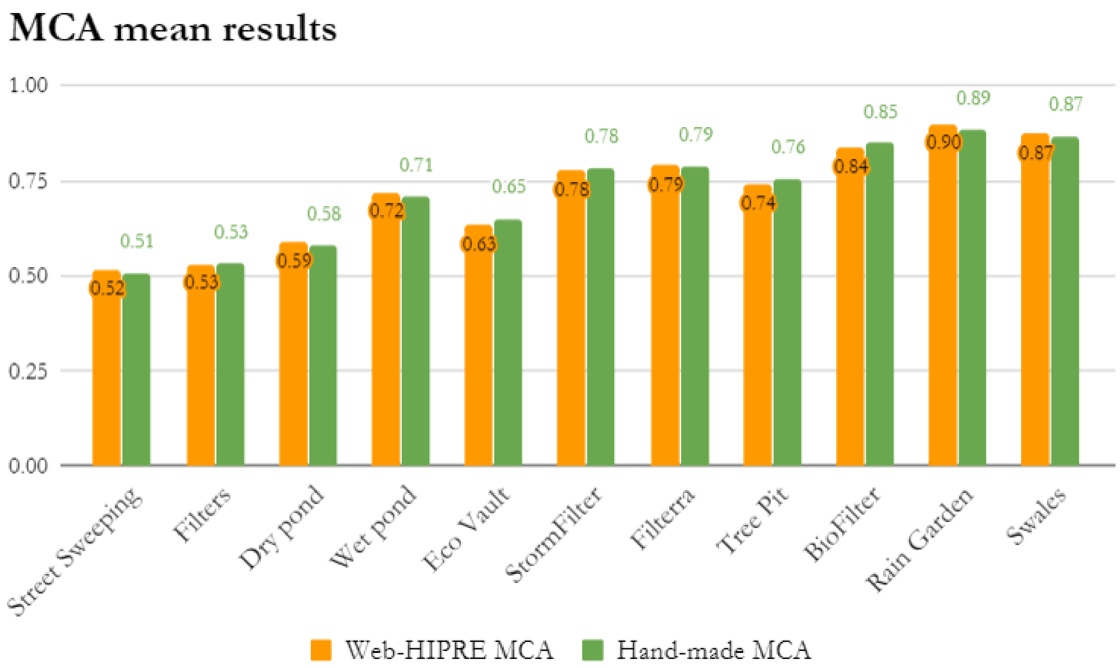


Figure H.1. Ranking of alternatives obtained both in the hand-made MCA and Web-HIPRE model.

Table H.2. Discharged concentration levels with street sweeping concentrations as reference values.

	Removal efficiencies of the different alternatives with street sweeping as reference values (%)										
Compound	**Ref.Values with street seeping**	**Filters**	**Dry pond**	**Wet pond**	**Eco Vault**	**StormFilter**	**Filterra**	**Tree Pit**	**BioFilter**	**Rain Garden**	**Swales**
Arsenic (As)	0.55	51	22	29.5	-15	36	39	39	39	75	83
Chromium (Cr)	5.4614	44.7	52.5	40	72	68	56	56	56	25	47.8
Cadmium (Cd)	0.71	28	33	50	74	86	38	38	38	80	20.6
Lead (Pb)	4.0761	48	73	56	73.5	92	77	77	77	80	50.6
Copper (Cu)	35.84	37.5	29	60.3	70	81	55	50	90	60	62
Zink (Zn)	158.92	54	53	80	80	78	56	50	90	90	69
Nickel (Ni)	3.4544	33	54.7	37.6	58	58	51	51	51	75	68
Oil Index	280.5	85	0	70	96	79	93	50	75	60	86.3
TP	98.02	33.6	23	43.4	44	73	70	80	65	60	40
TN	877.8	60.4	24	43.6	12	70	34	45	50	25	40
BaP	0.02816	-20	22	70	94	79	76	76	76	85	85
Compound	**Target Values (µg/l)**	**Filters**	**Dry pond**	**Wet pond**	**Eco Vault**	**StormFilter**	**Filterra**	**Tree Pit**	**BioFilter**	**Rain Garden**	**Swales**
Arsenic (As)	15	0.27	0.43	0.39	0.63	0.35	0.34	0.34	0.34	0.14	0.09
Chromium (Cr)	15	3.02	2.59	3.28	1.53	1.75	2.40	2.40	2.40	4.10	2.85
Cadmium (Cd)	0.4	0.51	0.48	0.36	0.18	0.10	0.44	0.44	0.44	0.14	0.56
Lead (Pb)	14	2.12	1.10	1.79	1.08	0.33	0.94	0.94	0.94	0.82	2.01
Copper (Cu)	10	22.40	25.45	14.23	10.75	6.81	16.13	17.92	3.58	14.34	13.62
Zink (Zn)	30	73.10	74.69	31.78	31.78	34.96	69.92	79.46	15.89	15.89	49.27
Nickel (Ni)	40	2.31	1.56	2.16	1.45	1.45	1.69	1.69	1.69	0.86	1.11
Oil Index	1000	42.08	280.50	84.15	11.22	58.91	19.64	140.25	70.13	112.20	38.43
TP	50	65.09	75.48	55.48	54.89	26.47	29.41	19.60	34.31	39.21	58.81
TN	1250	347.61	667.13	495.08	772.46	263.34	579.35	482.79	438.90	658.35	526.68
BaP	0.05	0.03	0.02	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00

Table H.3. Discharged concentration levels with street sweeping concentrations as reference values and addition of sorption media (BFS) to biofiltration systems.

Compound	Reference value with street sweeping	Target value	Rain Garden+BFS	Discharge d value	Swale + BFS	Discharged value	Tree Pit + BFS	Discharged value	BioFilter + BFS	Discharged value	Filterra + BFS	Discharged value
Arsenic (As)	0.55	15	75	0.14	83	0.09	39	0.34	39	0.34	39	0.34
Chromium (Cr)	5.46	15	25	4.10	47.8	2.85	56	2.40	56	2.40	56	2.40
Cadmium (Cd)	0.71	0.4	80	0.14	20.6	0.56	38	0.44	38	0.44	38	0.44
Lead (Pb)	4.08	14	80	0.82	50.6	2.01	77	0.94	77	0.94	77	0.94
Copper (Cu)	35.84	10	88	4.30	88	4.30	88	4.30	88	4.30	88	4.30
Zink (Zn)	158.92	30	93	11.12	93	11.12	93	11.12	93	11.12	93	11.12
Nickel (Ni)	3.45	40	75	0.86	68	1.11	51	1.69	51	1.69	51	1.69
Oil Index	280.50	1000	60	112.20	86.3	38.43	50	140.25	75	70.13	93	19.64
TP	98.02	50	60	39.21	40	58.81	80	19.60	65	34.31	70	29.41
TN	877.80	1250	25	658.35	40	526.68	45	482.79	50	438.90	34	579.35
BaP	0.03	0.05	85	0.00	85	0.00	76	0.01	76	0.01	76	0.01

Table H.4. Discharged concentration levels with 2016 reference values when no measure was being implemented and addition of sorption media (BFS) to biofiltration systems.

	Removal efficiencies of the different alternatives (%)					
Compound	Ref.Values (2016)	Filterra	Tree Pit	BioFilter	Rain Garden	Swales
Arsenic (As)	0.88	39	39	39	75	83
Chromium (Cr)	6.58	56	56	56	25	47.8
Cadmium (Cd)	0.25	38	38	38	80	20.6
Lead (Pb)	6.47	77	77	77	80	50.6
Copper (Cu)	64	88	88	88	88	88
Zink (Zn)	232	93	93	93	93	93
Nickel (Ni)	5.08	51	51	51	75	68
Oil Index	1500	93	50	75	60	86.3
TP	116	70	80	65	60	40
TN	1540	34	45	50	25	40
BaP	0.064	76	76	76	85	85
Compound	Target Values (μg/l)	Filterra	Tree Pit	BioFilter	Rain Garden	Swales
Arsenic (As)	15	0.54	0.54	0.54	0.22	0.15
Chromium (Cr)	15	2.90	2.90	2.90	4.94	3.43
Cadmium (Cd)	0.4	0.16	0.16	0.16	0.05	0.20
Lead (Pb)	14	1.49	1.49	1.49	1.29	3.20
Copper (Cu)	10	7.68	7.68	7.68	7.68	7.68
Zink (Zn)	30	16.24	16.24	16.24	16.24	16.24
Nickel (Ni)	40	2.49	2.49	2.49	1.27	1.63
Oil Index	1000	105.00	750.00	375.00	600.00	205.50
TP	50	34.80	23.20	40.60	46.40	69.60
TN	1250	1016.40	847.00	770.00	1155.00	924.00
BaP	0.05	0.02	0.02	0.02	0.01	0.01

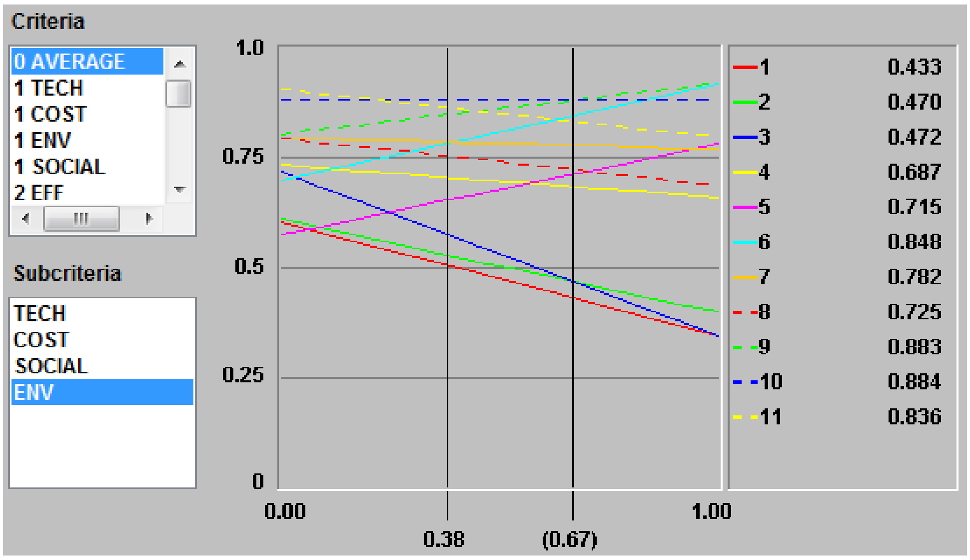


Figure H.2. Sensitivity analysis of environmental category for the mean weight (Web-HIPRE).

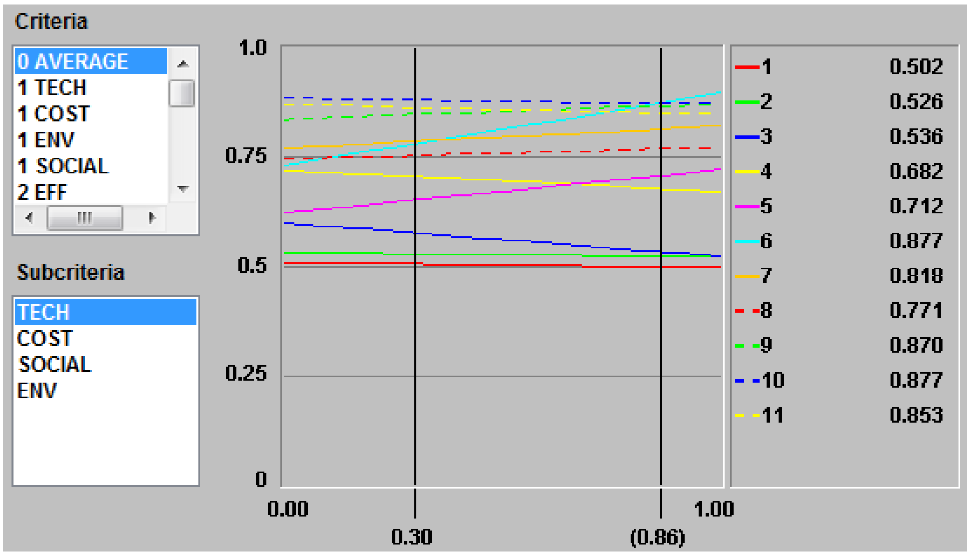


Figure H.3. Sensitivity analysis of technical performance category for the mean weight (Web-HIPRE).

I Questionnaire for stakeholders

Which organization do you work for? *Mark with an X*	
Waste and Water department	
Environmental department	
Nature and Park department	
Traffic department	
Sahlgrenska hospital	
Local population	

Name (voluntary)

The receiving water Vitsippsbäcken does not reach the classification "good water status" according to the EU Directive 2000/60/EC. Do you think that finding a stormwater treatment technique should be a priority for this area? *Mark with a X*

YES	
NO	

When selecting an adequate stormwater treatment technique, there are different objectives that should be fulfilled. Which are the most important criteria in your opinion? *Follow the example to rank the four objectives and the primary criteria. For the objectives, you must give a percentage that sums up to 100%. For the primary criteria, you must give a percentage that sums up to the percentage given to the related objective.*

Objectives	Example	Your weight 1	Primary criteria	Example	Your weight 2
1. Technical performance	30%		Pollutant removal efficiency	20%	
			System reliability	5%	
			System durability/life-time	5%	
2. Cost	40%		Investment cost	20%	
			Operation and maintenance	20%	
3.-Environment	20%		Impact on receiving water	9%	
			Impact on discharged waters	9%	
			Resource use (Energy,Materials)	2%	
4. Society	10%		Aesthetic	3%	
			Acceptance (Is people aware?)	7%	
		∑=100%			∑=100%

Would you consider additional criteria? *Mark with a X*			
YES		NO	
If yes, which ones?			

1.
2.
3.
4.

Do you think that MCDA is a good tool for decision-making in storm-water management? *Mark with a X*			
YES		NO	
Why?			

J Models

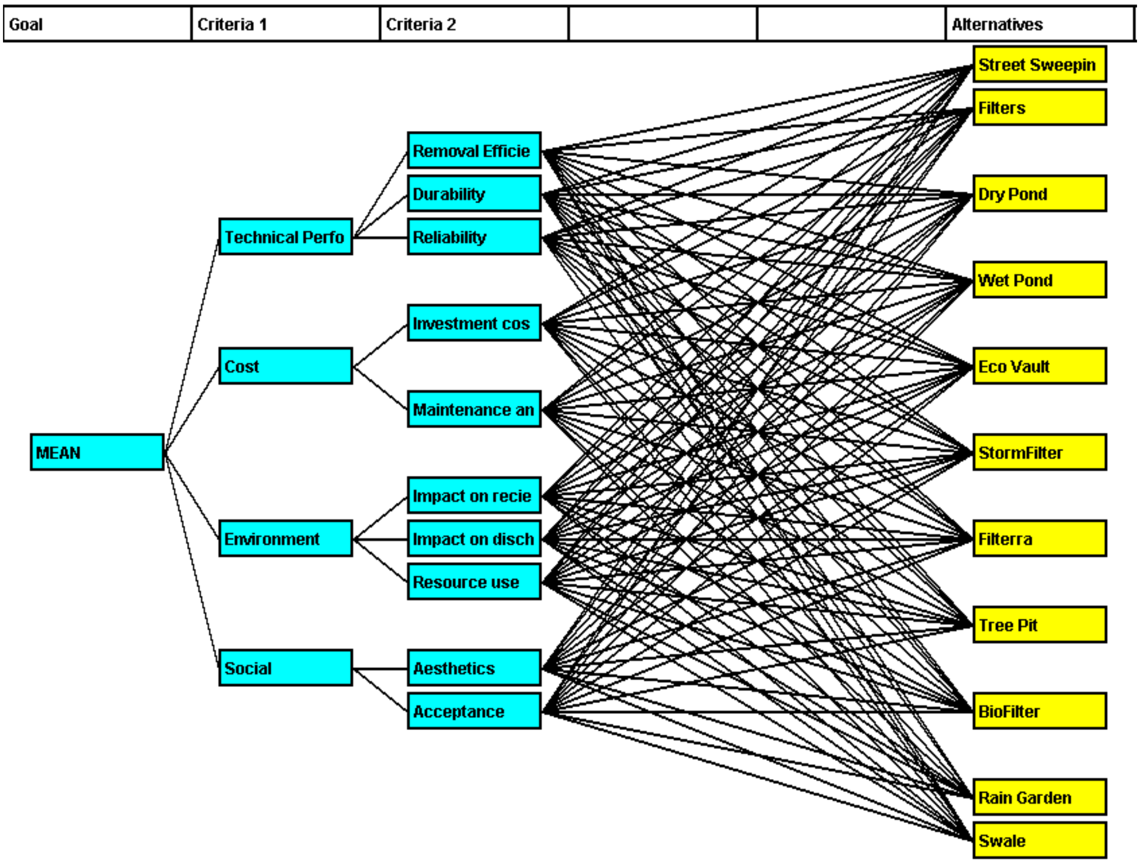


Figure J.1. Schematic layout of the Web-HIPRE model.

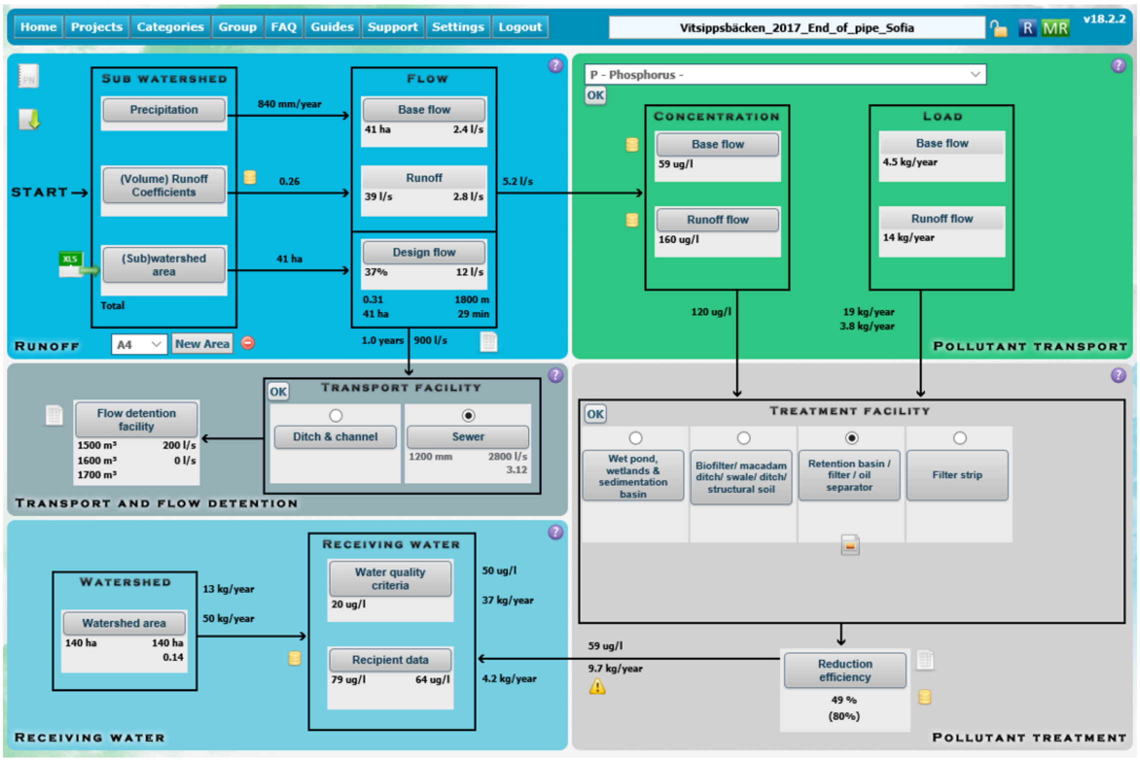


Figure J.2. Schematic layout of the StormTac model.