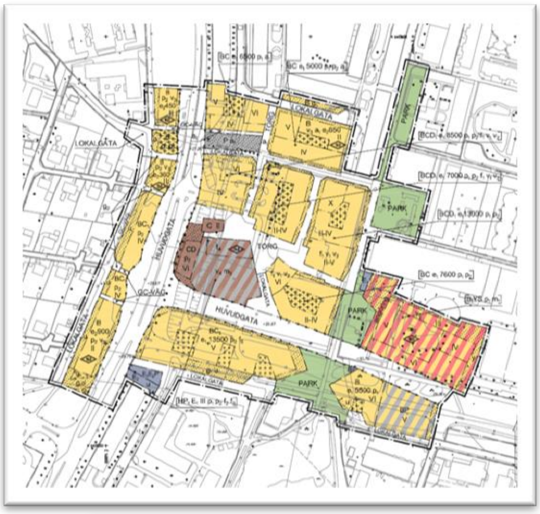

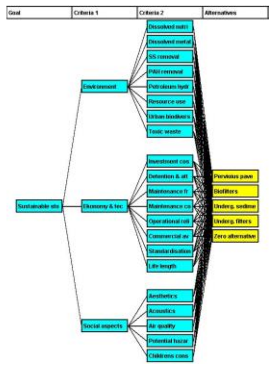

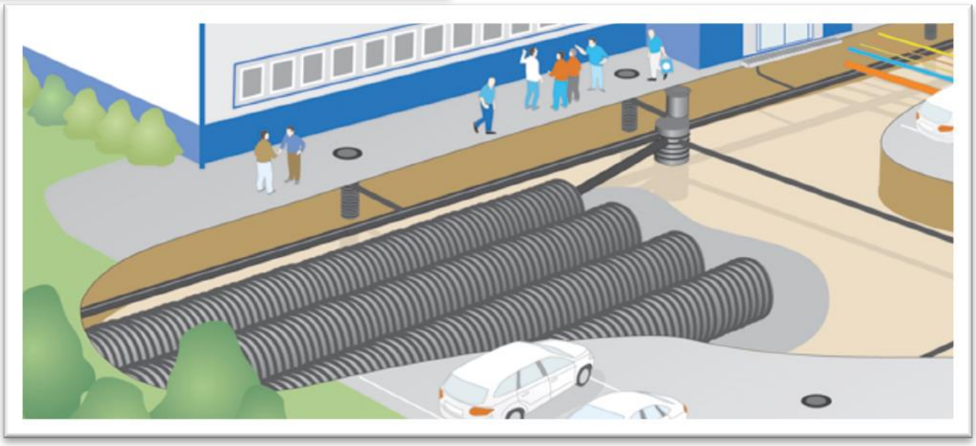

Evaluating Stormwater Management Techniques for Dense Urban Areas using Multi-Criteria Decision Analysis

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

DANIEL KANGAS

Department of Civil and Environmental Engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016
Examensarbete BOMX02-16-15

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Cover:
Zoning map of the case study area (upper left), Web-HIPRE model structure (upper right) and underground sedimentation units (bottom).

Chalmers Reproservice/Department of Civil and Environmental Engineering
Göteborg, Sweden 2016

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ABSTRACT

Stormwater problems concern both water quantity and quality, and arise from impervious surfaces and activities which cause accumulation of pollutants on such surfaces. There is a growing knowledge and concern regarding the effects of urbanisation on stormwater, and it is increasingly common to construct treatment facilities to reduce pollution of natural watercourses. There is however, a lack of clarity in the Swedish national legislation regarding stormwater, which means that municipalities have to develop both guidelines and a proper organisation to handle stormwater issues. In Gothenburg, *Miljöförvaltningen* has established guideline values for some stormwater pollutants, but there are currently uncertainties within the municipal departments regarding the responsibilities in stormwater management. The aim of this Master's thesis work was to suggest different stormwater management techniques that potentially could be implemented in a case study area and evaluate their sustainability using Multi-Criteria Decision Analysis (MCDA). Five alternatives for stormwater management in the case study area were evaluated according to 21 criteria using a compensatory MCDA model. The model, which applies semi-quantitative scoring, was developed in this project. The work included a workshop session where stakeholders and experts were gathered to conduct the scoring and weighting elements of the method. Results showed three potential top scoring alternatives depending on the weighting employed. Those were: the zero alternative with no treatment, underground sedimentation units and finally rain gardens. In order for space to be allocated for stormwater management, it has to be decided at an early stage of planning. A semi-quantitative MCDA can be conducted at an early stage in planning and provides clear and transparent decision support. The strength of the method is that it is a good communication tool which creates a basis for discussion and shows advantages and disadvantages of different alternatives.

Key words: Multi-Criteria Decision Analysis, stormwater management, stormwater quality, urban planning

Utvärdering av dagvattenhanteringslösningar för tätbebyggda områden med hjälp av multikriterieanalys

Examensarbete inom masterprogrammet Infrastructure and Environmental Engineering

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SAMMANFATTNING

Dagvattenproblematiken omfattar både vattenkvantitet och -kvalitet, och har sitt ursprung i hårdgjorda ytor samt aktiviteter som genererar föroreningar på dessa ytor. Kunskapen och oron kring urbaniseringens effekter på dagvatten växer och det blir alltmer vanligt att med hjälp av reningsanläggningar minska mängden föroreningar som når naturliga vattendrag. Dock finns oklarheter i svensk lagstiftning gällande hantering av dagvatten, vilket innebär att kommuner måste ta fram både riktlinjer och lämpliga strategier för att hantera dagvattenproblem. I Göteborg har Miljöförvaltningen satt upp riktlinjer för dagvattenföroreningar, men det råder osäkerhet bland kommunens förvaltningar kring ansvar för dagvattenhantering. Syftet med det här examensarbetet var att föreslå olika dagvattenhanteringslösningar som hade kunnat användas i ett fallstudieområde och att utvärdera deras hållbarhet med hjälp av multikriterieanalys (MKA). Fem alternativ för dagvattenhantering i området utvärderades enligt 21 kriterier genom användning av en kompenserande MKA-modell. Modellen, som använder semikvantitativ poängsättning, utvecklades i detta projekt. Arbetet innefattade en workshop där intressenter och experter samlades för att genomföra poängsättnings- och viktningselementen i metoden. Resultaten visade att beroende på vilken viktning som används, är det tre olika alternativ som fått högst poäng. Dessa tre var: ett nollalternativ utan rening, underjordiska avsättningsmagasin och slutligen regnrabatter. För att plats ska kunna avsättas för dagvattenhantering i urbana områden, krävs att detta bestäms i ett tidigt skede av planeringen. En semikvantitativ MKA kan utföras i tidiga skeden av planeringen och tillhandahåller ett tydligt och genomskådligt beslutsstöd. Styrkan i metoden är som ett kommunikationsverktyg som skapar grunder för diskussion och visar fördelar och nackdelar med olika alternativ.

Nyckelord: Multikriterieanalys, dagvattenhantering, dagvattenkvalitet, stadsplanering

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Preface

In this Master's thesis, a Multi-Criteria Decision Analysis model for evaluation of stormwater management techniques was designed. Supervision has been provided from researchers at the Division of Water Environment Technology at Chalmers University of Technology and employees at Atkins Sweden. Most of the work has been carried out at Atkins' office in Gothenburg during the spring of 2016.

I would like to thank my supervisor Karin Björklund and my examiner Ann-Margret Hvitt Strömvall at Chalmers as well as Kristina Hargelius and Audrone Persson at Atkins for feedback and help along the entire course of the project. I would like to also thank Jenny Norrman for providing splendid supervision and guidance in the field of decision support. Additional thanks to Linnea Lundberg who helped me understand the municipal organisation in Gothenburg. Finally, thanks to all workshop attendants who contributed to the results of this work, and to all helpful and delightful employees at Atkins for making me feel welcome at your office.

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Daniel Kangas

1 Introduction

Urbanisation causes an increase in the amount of impervious surfaces compared to natural land uses. This results in increasing stormwater flows, which in turn calls for development of stormwater sewer systems that are capable handling these flows (Duffy et al., 2008; Butler & Davies, 2011). Urbanisation not only affects the quantity, but also the quality of stormwater. Pollutants in stormwater originate from various sources such as vehicles, building materials and atmospheric deposition and accumulate on surfaces in the urban setting, particularly in streets and parking lots (Alm et al., 2010). Stormwater management is a growing field of research within sustainable urban development and the awareness of stormwater problems within municipal bodies has grown (Alm et al., 2010; Blecken, 2010; Butler & Davies, 2011). Municipal planners must provide strategies to deal with both quantity and quality related problems to prevent flooding and environmental damage. As with other environmental issues, municipal planners can lead the path towards a more sustainable society (Wemmel Ljung, 2015).

1.1 Background

In the city of Gothenburg on the west coast of Sweden, the municipality is working to improve the city's stormwater management. The current stormwater system in Gothenburg generally consists of underground sewers that transport stormwater from urban areas directly to receiving water bodies, without treatment (Göteborg Vatten, 2011). Guideline values set by *Miljöförvaltningen* have been introduced for pollutants in stormwater reaching receiving water bodies (Miljöförvaltningen, 2013). These guideline values call for treatment of polluted stormwater, although they cannot be reached at once because of the magnitude of the measures this transition will require. While new developments are designed with concern to stormwater quality, there are existing areas that continue to contribute to the discharge of polluted stormwater.

As the Gothenburg area develops there are ongoing reconstruction projects, for example with the purpose of making the city denser (Stadsbyggnadskontoret, 2009). These reconstruction projects present an opportunity to make changes in terms of stormwater systems. One such project is the development of the area around Selma Lagerlöfs torg, which is located in the north-east of Gothenburg, in the Backa district (Figure 1.1). There are currently development plans which involve densification of the area through construction of additional dwellings (Stadsbyggnadskontoret, 2014). Also, the services provided at Selma Lagerlöfs torg will be upgraded.

Figure 1.1 Map of Gothenburg (Source: eniro.se). The number 1 indicates the location of Selma Lagerlöfs torg.

Trafikkontoret has called for an investigation of the stormwater situation and, if needed, possible stormwater management solutions that can be applied at Selma Lagerlöfs torg in order to meet the quality guidelines. Consultants at Atkins Sweden have been assigned the task of conducting that investigation. To determine whether there should be treatment of stormwater at Selma Lagerlöfs torg after the reconstruction, a simulation has been made using the modelling software StormTac. The model is able to estimate pollutant concentrations in stormwater based on land use (StormTac, 2015). The results obtained were then compared to guideline values set by *Miljöförvaltningen* (Appendix I). This comparison showed that some expected contamination levels were exceeding guideline values for stormwater, and hence treatment of stormwater was suggested.

The task of investigating possible stormwater management solutions at Selma Lagerlöfs torg was given to Atkins after the zoning was complete, which has led to limitations in possible solutions. Previously it has been noted that sustainable stormwater management sometimes is inhibited by financial and legal aspects as well as poor understanding between municipal departments (Alm & Åström, 2014). This project explores alternative solutions that could have been implemented given the site conditions. The performance of each alternative, including the final solution designed by Atkins, is assessed using a Multi-Criteria Decision Analysis (MCDA) approach. MCDA has been frequently used for environmental problems (Munier, 2011), although it has been sparsely used for stormwater management. However, MCDA within the field of stormwater management has grown in recent years (Ellis et al., 2004; Jia et al., 2013). The intention of this study is to demonstrate the use of MCDA as a tool for decision support and to highlight the need for improved planning and communication within municipal departments in Gothenburg.

1.2 Aim

The overall aim of this study is to suggest different stormwater management techniques and evaluate their sustainability with respect to a case study area, the Selma Lagerlöfs torg site. The alternatives, including the actual design proposal, are compared according to various criteria using a Multi-Criteria Decision Analysis (MCDA) model developed in this project. The goals are (1) to review potential solutions for stormwater management in dense urban areas, (2) to demonstrate and evaluate MCDA as a tool for decision support in stormwater management and (3) to suggest improvements in the planning process within Gothenburg municipality.

1.2.1 Specific objectives

The specific objectives of this study are to:

- review viable solutions for stormwater management in dense urban areas that undergo reconstruction.
- review the current planning procedure for stormwater management within Gothenburg municipality, and briefly explore the existing problems associated with the procedure.
- investigate the preconditions and plans for design of stormwater management in the development of the case study area at Selma Lagerlöfs torg in Gothenburg.
- identify and present alternative designs of a stormwater management system at Selma Lagerlöfs torg that do not alter the functionality of the area.
- identify relevant criteria covering environmental, economic and social dimensions.
- develop and apply a MCDA model.
- gather relevant stakeholders for a workshop session in which the MCDA model is used.
- suggest needed improvements in the municipality’s planning procedure to promote the best possible and most sustainable stormwater management.

1.2.2 Research questions

Four research questions were formulated to complement the objectives by guiding the literature search and to set the goal of the MCDA application:

- Which criteria are relevant to consider in order to determine the performance of a stormwater management solution?
- What are the treatment efficiencies, initial costs of installation and maintenance requirements for different stormwater management techniques?
- Which solution would be the most sustainable and suitable for the case study area of Selma Lagerlöfs torg?

- What are the potential barriers to implementation of sustainable stormwater management, and how could those be overcome?

1.2.3 Delimitations

The stormwater system design considered for the case study area Selma Lagerlöfs torg does not include stormwater management at private properties. These privately owned properties have received specific guidelines for stormwater control within their property limits. Hence, the areas of concern for the case study are those owned by the municipality.

All stormwater management alternatives must fit within the project area. Options that involve placing stormwater management facilities (mainly end-of-pipe solutions) outside of the project area have not been considered. Furthermore, alternatives that would alter the main functionalities of the site or parts of the site have not been considered. This includes for example space consuming solutions that would require space to be taken from other uses. Therefore, only stormwater management solutions that are suitable for dense urban areas have been investigated.

2 Theory

2.1 Stormwater problems

Problems associated with stormwater originate from the replacement of natural surfaces with impervious surfaces such as asphalt (Svenskt Vatten, 2011). This decreases the amount of water that is infiltrated into the ground and increases the amount of runoff generated. This results in larger volumes stormwater and high peak flows in urban areas (Figure 2.1). Consequently, there are risks of flooding if conveyance systems are not designed to handle such flows. Flows that exhibit large fluctuations may also affect the environment near the point of discharge, where for example erosion may arise (Butler & Davies, 2011). It may be impractical or economically unfeasible to design systems for extreme rain events when there are very high peak flows, which is why systems are typically designed for events that are not the most extreme (Svenskt Vatten, 2016). Furthermore, the stormwater may be polluted by particles and substances that accumulate on the impervious surfaces. Thus there are problems associated with both the quantity and the quality of stormwater.

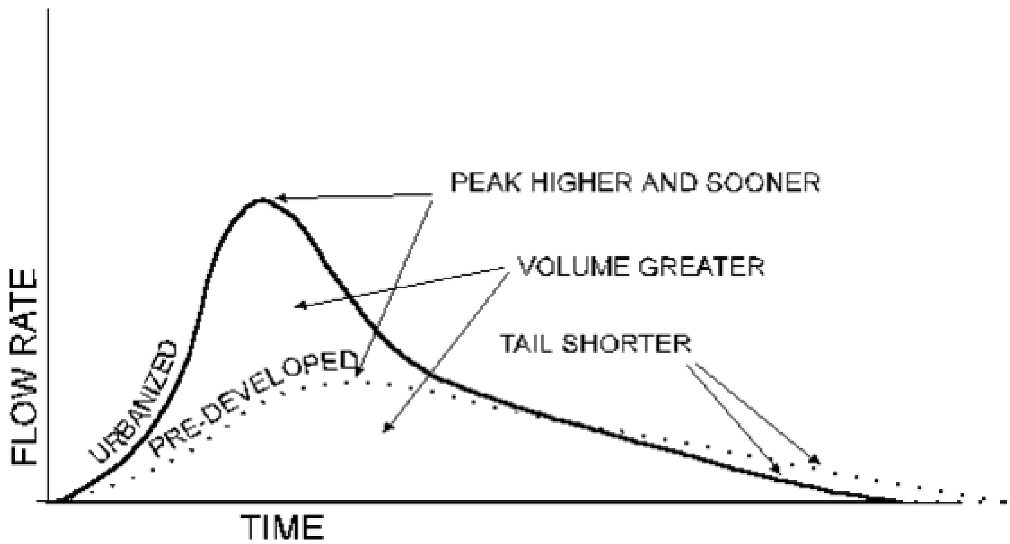


Figure 2.1 Flow rate plotted against time, for urbanized areas and pre-developed areas (Ryerson University, n.y.).

Traditional urban drainage in developed countries consists of underground pipes that convey wastewater from various sources, either directly to receiving waters or to a treatment plant before discharge to natural waters (Butler & Davies, 2011). Pipes used for conveyance may form combined or separate systems. In combined systems, both domestic sewage and stormwater are transported in the same pipes to the wastewater treatment facility. Separate systems consist of separate pipes for sewage and stormwater respectively, and the two types of pipes generally have different destinations. Sewage is led to a wastewater treatment plant, while stormwater is often led directly to receiving waters without any treatment.

Deterioration of water quality has been observed worldwide, in particular close to urban areas (WWAP, 2015). In the European Union, the Water Framework Directive (WFD) was adopted in the year 2000 (European Commission, 2015) and is part of Swedish legislation since 2004 (Havs- och vattenmyndigheten, 2014). The purpose of the directive is to ensure a good quality of water bodies and groundwater within the

European Union and to improve the quality of waters that are not considered clean. Therefore, treatment is essential for fulfilling the directive.

2.2 Stormwater pollutants

Pollutants in stormwater originate from sources such as vehicle emissions, spills, wear of vehicles, building materials and roads. There are also pollutants from animal faeces, fallen leaves and litter that end up on the ground. Types of pollutants commonly detected in stormwater include suspended solids, toxic metals, hydrocarbons and nutrients (Table 2.1) (Alm et al., 2010; Butler & Davies, 2011; Miljöförvaltningen, 2013).

Table 2.1 Summary of average and range of reported pollutant concentrations and loads in stormwater (Ellis & Mitchell, 2006). Values in brackets are range endpoints and have been rounded to two digits.

Pollutant	**Event mean concentration and range [mg/l]**		**Loads per unit area [kg/imp ha/year]**	
	Residential/ commercial	Motorways/ trunk roads	Residential/ commercial	Motorways/ trunk roads
TSS	90 (21-2600)	195 (4-5700)	487 (350-2300)	(820-6300)
BOD	9 (7-22)	24 (0.07-32)	59 (35-170)	(90-170)
COD	85 (20-370)	137 (28-170)	358 (22-700)	(180-3900)
NH4-N	0.56 (0.2-4.6)	(0.02-2.1)	1.76 (1.2-25)	(0.8-6.1)
Total N	3.2 (0.4-20)		9.9 (0.9-24)	
Total P	0.34 (0.02-4.3)		1.8 (0.5-4.9)	
Total Pb	0.14 (0.01-3.1)	0.33 (0.002-34)	0.83 (0.01-1.90)	(1.1-13)
Total Zn	0.30 (0.01-3.7)	0.41 (0.17-3.6)	1.15 (0.21-2.7)	
Total hydrocarbons	1.9 (0.04-26)	28 (2.5-400)	1.8 (0.01-43)	
PAH	0.01	(0.03-6.0)	0.002	140

As can be seen in Table 2.1 the quality of stormwater varies widely, and it is very difficult to make quick and accurate estimations of stormwater quality in a study area. Thus, computer software designed to estimate pollutant concentrations in stormwater can be very useful for quality estimations.

Pollutants may have a variety of impacts in receiving waters. Nutrients can cause eutrophication in surface waters, metals and organic pollutants are toxic to many organisms and organic matter can cause oxygen deficiencies (van der Perk, 2014). Organic pollutants are substances with the ability to bioaccumulate and they may be carcinogenic but also hold hormone-disrupting effects (Kim et al., 2013). Table 2.2 presents some environmental effects and possible origins of copper, zinc, suspended solids and PAHs respectively.

Table 2.2 Environmental effects and potential origins of Cu, Zn, TSS and PAHs.

Substance	**Environmental effects**	**Example origins**
Copper, Cu	Both dissolved and particle bound. An essential micronutrient that is mainly toxic to plants at high concentrations (van der Perk, 2014). For animals and humans, long-term exposure may damage the liver, where copper generally accumulates. Commonly causes foliar interveinal chlorosis in plants (Reichman, 2002). Chlorosis is a condition in which leafs are turning yellow due to lack of chlorophyll (Schuster, 2016).	Roofs, brakes, pipes, sheet metal, wires
Zinc, Zn	Largely dissolved, although some is particle bound. An essential micronutrient for many species and mainly toxic to plants (van der Perk, 2014). Long-term exposure to high levels of zinc may however result in for example damage to kidneys, liver and pancreas and may lead to copper deficiency. Normal symptoms for plants include stunting of root, curling and rolling of young leaves, death of leaf tips and chlorosis (Rout & Das, 2009).	Galvanised steel, tire tread, brake pads, skin care products
Suspended solids, SS/TSS	Reduce visibility and absorb light, leading to increased temperatures and decreased photosynthesis, which in turn affects the food chain and oxygen availability (StormwaterRx LLC, 2015). Fine particles may also be harmful to fish and insects by clogging respiratory systems. Furthermore, suspended solids are carriers of many organic pollutants and toxic metals (Butler & Davies, 2011; van der Peck, 2014).	Dust and particles from traffic wear, atmospheric deposition, soil erosion, construction
Polycyclic aromatic hydro-carbons, PAHs	Not very mobile, bind reasonably well to organic matter (van der Peck, 2014). Toxic effects on plants include chlorosis, inhibition of photosynthesis and decreased growth. Aquatic effects are mainly related to the more soluble compounds (i.e. the ones with lower molecular weight), although some heavier PAHs affect bottom-dwelling organisms. The PAH toxicity in aquatic animals leads to decreased individual fitness and also negatively affects reproduction. In terms of human health, especially the heavier PAHs may have carcinogenic potential and can cause hormonal disruptions (Kim et al., 2013).	Coal tar, petroleum products, creosote, roofing tar, medicines, dyes, plastics, pesticides, incineration processes

2.3 Stormwater management techniques for dense urban areas

With increased awareness of stormwater-related issues there has been a shift in stormwater management and more focus is aimed towards sustainability and environmental effects (Butler & Davies, 2011; Svenskt Vatten, 2011). Different terms are used worldwide to denote this type of more sustainable stormwater management, for example Sustainable Urban Drainage Systems (SUDS), Best Management Practice (BMP) and Low Impact Development (LID) (Fletcher et al., 2013). Promoters of sustainable stormwater management often highlight the additional environmental benefits, or ecosystem services, of so-called green infrastructure (Earth Pledge, 2005; City of Portland, 2016).

In order to reduce peak flows in urban areas there is need for local detention or reduction through infiltration and evapotranspiration (Svenskt Vatten, 2011), e.g. by increasing the amount of vegetated surfaces. In modern stormwater management, the drive is to achieve a more natural drainage, i.e. approaching the “pre-developed” curve in Figure 2.1, through more pervious surfaces and other ways of localised management.

Removal of stormwater pollutants is also important in designing sustainable stormwater systems. Retrofitting and reconstruction applications present particular challenges in terms of available space, although there are numerous solutions available for stormwater treatment in dense urban areas (Appendix II) and the technologies continue to develop. Removal processes that are used involve sedimentation, physical filtration, adsorption and biological treatment (Lindfors et al., 2014). Table 2.3 presents some examples of stormwater treatment technologies and short descriptions of their functionalities, advantages and disadvantages. The technologies presented in Table 2.3 are further described in the following subsections.

Table 2.3 Summary of the stormwater management techniques presented in Subsections 2.3.1-2.3.5.

Stormwater management technique	**Description**	**Advantages**	**Disadvantages**
Pervious pavements	The pavement structure allows water to be filtered through it. Commonly used for car parks.	Effective removal of suspended solids and organic pollutants.	Clogging of pores may cause poor function. Shorter life length than traditional paving.
Bioretention units (rain gardens)	Vegetated filters often placed along streets and car parks.	Effective removal of a wide range of contaminants. Provides ecosystem services.	Requires surface space. Clogging of pores may cause poor function.
Underground sedimentation units	Small to large scale tanks that provide storage and sedimentation of particulate pollutants.	Effective removal of suspended solids. Good storage potential.	No treatment of dissolved pollutants. High construction costs.
Underground filter units	Engineered filters suitable for ultra-urban settings	Effective removal of a wide range of contaminants, including potentially high performance versus dissolved pollutants.	Substantial operation and maintenance requirements.
Well-mounted filters	Engineered filters placed in gully pots, filter water before it is conveyed downstream.	Easy to install.	Unreliable performance. Substantial operation and maintenance requirements.

2.3.1 Pervious pavements

Pervious pavements are designed to allow for water to travel vertically through the surface, hence reducing runoff volumes (Figure 2.2). Pervious pavement structures are most commonly used for parking areas and light traffic streets (Booth & Leavitt, 1999; US EPA, 1999; Elmefors, 2014; Woods-Ballard et al., 2015a). There are two main types of previous pavements: porous and permeable (Woods-Ballard et al., 2015a). Porous pavements have a surface that allows infiltration across the entire area. Permeable pavements are made up of impervious elements ordered in structures that allow water to infiltrate through openings between the elements.

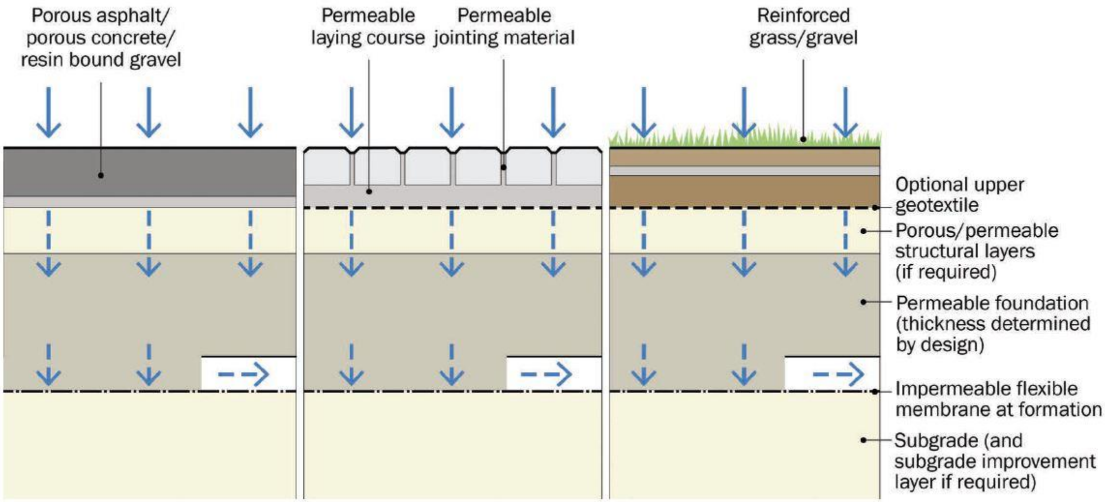


Figure 2.2 Schematic drawing of pervious pavements equipped with underdrains (Woods-Ballard et al., 2015a).

The primary pollutant removal process in pervious pavements is mechanical filtration (Elmefors, 2014). There are however also adsorption, biodegradation and sedimentation processes (Woods-Ballard et al., 2015a). Biodegradation is enhanced if there is a geotextile in the upper part of the construction since geotextiles provide good growing media for microorganisms (Elmefors, 2014). According to Scholz & Grabowiecki (2006), permeable pavements provide very good removal of suspended solids. This is supported by US FHWA (n.y.) that states a suspended solids removal of 82 – 95 % (Appendix II). Other pollutants that may be effectively removed by permeable pavements are hydrocarbons, bacteria and metals (Elmefors, 2014). Cold weather may however reduce the efficiency of microbial processes and cause reduced metal removal because of road salts that may cause acidification and therefore increased dissolved fractions.

An issue frequently associated with permeable pavements is clogging (US EPA, 1999; Scholz & Grabowiecki, 2006; Elmefors, 2014; Winston et al., 2015). It is crucial that sediment loads are not excessive and that the surfaces are properly maintained. Winston et al. (2015) found that milling of the top layer (25 mm) of porous asphalt could almost restore the original infiltration capacity (>200 mm/min) of a pavement that was laid over 20 years ago in Luleå. The authors also found that pressure washing was more effective than vacuuming the same pavement and they deem that maintenance will have reduced efficiency as the pavement ages. Furthermore, they conclude that permeable pavements can provide effective stormwater mitigation if proper maintenance routines (Appendix III) are applied, including standard street sweeping and cleaning operations such as pressure washing.

Porous asphalt has shorter life length than traditional dense asphalt due to less wear resistance. A particular source of wear in cold climates is studded tires (Stockholms Stad, 2016). Also, the increased air contact due to the porous structure of porous asphalt causes a more rapid degradation of the bitumen binder than in conventional dense asphalt (Scholz & Grabowiecki, 2006). In Sweden, there have been some tests on the use of porous asphalt mainly due to its ability to reduce traffic noise (Dahlquist, 2009; Larsson, 2010). The results have however not been satisfactory in terms of reliability, maintenance and costs. Therefore, many municipalities no longer consider this as an alternative for roads with moderate to high traffic volumes. Pervious pavements are however still common for parking areas.

Construction of pervious pavements is more expensive than conventional paving. Booth & Leavitt (1999) stated that the costs are 25–300 % higher for the pervious alternatives compared to the conventional ones. However, they also point out that the total construction costs may be lower than the conventional approach due to less need for drainage structures. US FHWA (n.y.) claim that the capital cost of installing porous pavements is low (Appendix II). It is difficult to estimate general costs because of the lack of consistency in the literature.

2.3.2 Bioretention units (rain gardens)

Bioretention units, also known as rain gardens, are vegetated soil filters used for storing and treatment of contaminated stormwater. It is a relatively new technology which appeared in the USA around 1990 (Lindfors et al., 2014). Portland in Oregon is often mentioned together with bio retention for stormwater management (Svenskt Vatten, 2011; Lindfors et al., 2014; Hjertberg, 2015). The local government in Portland is working for sustainable stormwater management through “green infrastructure” (City of Portland, 2016), which includes various bioretention solutions, such as rain gardens (Figure 2.3), and green roofs. Bioretention units are commonly used as retrofits in developed areas (Le Coustumer et al., 2009). They may be designed in many different ways, with different modifications depending on environmental conditions, technical aspects and aesthetics (Lindfors et al., 2014).

Figure 2.3 Two types of rain gardens in Portland: curb extension (left) and a so called green street (right) with small rain gardens in the pavement (Source: City of Portland, 2016).

The principles of treatment are essentially the same regardless of the type of bioretention unit. Water is treated through sedimentation, filtration, sorption and biological processes. Figure 2.4 shows a conceptual design of a typical rain garden setup.

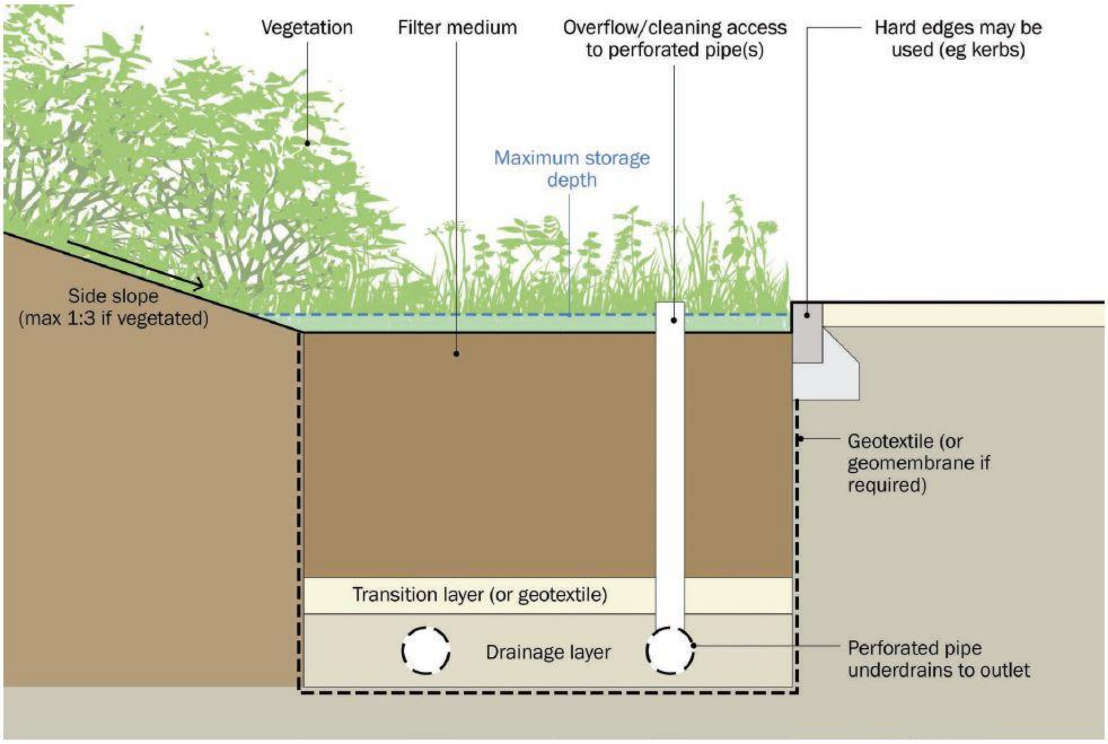


Figure 2.4 Schematic drawing of a rain garden cross-section (Woods-Ballard et al., 2015b).

Bioretention design needs to consider multiple aspects, for example when selecting filter media (Lindfors et al., 2014). In terms of stormwater detention it is preferable to have a media with high permeability, which allows for large flows of water. However, for pollutant removal it is preferable to have soil with low permeability. Those two aspects are hence conflicting. Another media aspect to consider is vegetation, which demands certain conditions in terms of water, air and nutrients. Therefore the selection of filter media is usually a compromise where aspects are weighted against each other. The dimensions of a bioretention unit usually depend on the size of the catchment area and the type of vegetation, where heavier vegetation like trees require deeper soil layers. The typical area of a rain garden is 2–5 % of the dewatered impervious area (Blecken, 2010).

In Sweden, rain gardens have been constructed in a few locations, although there are currently no available documentations on their performances. There are plans to evaluate rain gardens that have been constructed in Tyresö (LTU, 2015) and Gothenburg (Hjertberg, 2015).

Bioretention units appear to work well for treatment of stormwater in cold climates (Blecken et al., 2010a; 2010b). Removal of suspended solids is not influenced by temperature and neither is phosphorous, which is largely particle-bound in stormwater. Nitrogen removal is however limited (Table 2.4) and when nitrogen removal is essential Blecken (2010b) recommends design modifications such as a saturated zone with addition of a carbon source. Nitrification and denitrification processes are slower in cold temperatures (Zou et al, 2014). In terms of metal removal, some toxic metals are largely particle-bound in stormwater, which means that there is a correlation between the removal of suspended solids and those metals (Blecken et al., 2010a). Moreover, tests by Blecken et al. (2010a) showed more efficient removal of Cu at colder temperatures. It has also been shown that organic pollutants may be effectively removed in bioretention units (Table 2.4). Zhang et al. (2014) report removal of various organic pollutants. Among the studied pollutants are the PAHs pyrene and naphthalene, for which the two tested bioretention units exhibited removal rates in the region 85–95 %. The high removal rate is supported by tests by DiBlasi et al. (2008), who investigated removal of 16 types of PAHs and concluded that the average PAH mass load reduction of bioretention units was 87 %.

Table 2.4 Treatment efficiency for bioretention units (Lindfors et al., 2014).

Substance	**P**	**N**	**Pb**	**Cu**	**Zn**	**Cd**	**Cr**	**Ni**	**Hg**	**SS**	**Oil**	**PAH**	**BaP**
Treatment efficiency [%]	60	25	80	60	90	80	25	75	50	85	60	85	85

Maintenance needs of bioretention units (Appendix III) arise mainly from accumulation of litter and particles close to inlets (Woods-Ballard et al., 2015b). The vegetation also requires maintenance, which can be undertaken as part of urban landscape management routines.

Costs of bioretention units may vary and are site specific. According to US FHWA (n.y.) construction costs are moderate and costs of operation and maintenance are low. In Tyresö in Sweden, at a pedestrian crossing at Öringevägen, four rain gardens were constructed (Figure 2.5), two at each side of a local street with around 1 000–2 000 vehicles passing per day (Larsson et al., 2014). The cost of these rain gardens was 1 165 000 SEK (Lindfors et al. 2014). The area draining to two of the filters combined was measured to 0.19 hectares, of which around 60 % consists of road and the remaining 40 % is sidewalk.

Figure 2.5 Rain gardens at Öringevägen in Tyresö (Source: Banach et al., n.y.).

2.3.3 Underground sedimentation units

Underground sedimentation units, sometimes referred to as detention tanks, include hydrodynamic separators (Figure 2.6) and wet vaults (Figure 2.7) (Erickson et al. 2013a). Hydrodynamic separators have relatively small storage volumes and do not provide significant peak flow reduction. Wet vaults, on the other hand, may provide peak flow reduction through their large storage volumes. There are multiple wet vault designs available, including large diameter pipes, plastic cartridges and concrete vaults.

Figure 2.6 A full-scale two-chamber hydrodynamic separator (Source: Erickson et al., 2013a).

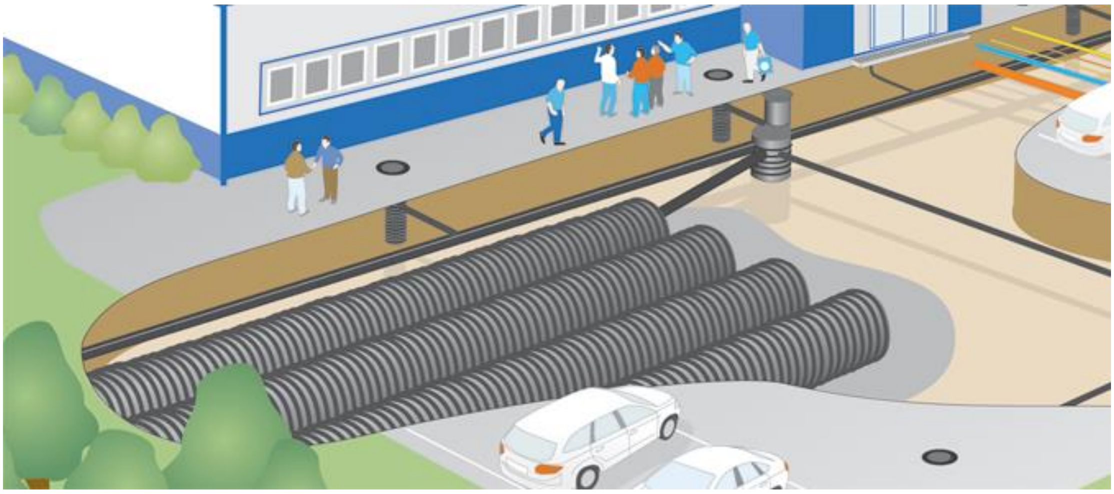


Figure 2.7 Wet vault consisting of oversized pipes (Source: Uponor).

The treatment efficiency of underground sedimentation units depends on the retention time and settling distance. A sedimentation unit at Ryska Smällen in Stockholm treats runoff from 7 400 m^2, partly from a road with an annual average daily traffic (AADT) of 71 000. The unit is roughly 110 m^3 and designed to handle the first 20 minutes of a rainfall event, retain the water in the tank for 36 hours before it is discharged through automated controls. The average removal of SS was over 80 %; Cu 67 %; Zn 65 %; and PAH 55 % (Aldheimer, 2004). Similar results were found by McIntosh (2015), who investigated pollutant removal in a wet vault with an area of 1 200 m^2 and a height of 3.4 m. The results showed around 80 % removal of suspended solids and around 70 % removal of total metals. Those removal rates are similar to those of detention ponds (Appendix II).

Maintenance of sedimentation units involves inspection and removal of sediment when necessary. In a survey presented by Erickson et al. (2013b) municipal workers stated that they inspected underground sedimentation units up to twice a year. It is however unclear whether those inspection frequencies ensured proper functioning of the devices. The sedimentation unit at Ryska Smällen in Stockholm is inspected 2–3 times per month (Aldheimer, 2004), and US FHWA (n.y.) state that detention tanks have high operation and maintenance costs.

Furthermore, US FHWA (n.y.) list detention tanks as moderate to high in capital costs. The construction cost for the sedimentation unit at Ryska Smällen in Stockholm was around 2 million SEK in 1997, and the annual operation and maintenance costs are roughly 70 000 – 75 000 SEK (Aldheimer, 2004).

2.3.4 Underground filter units

One type of underground filter units for treatment of urban stormwater is sand filters (Figure 2.8), which treat stormwater through sedimentation, mechanical filtering and sorption (SMRC, n.y.). There are also specially engineered filter units, also known as proprietary treatment systems (Woods-Ballard et al., 2015d). One such unit is the EcoVault (Figure 2.9), which utilises the same treatment processes as sand filters (Lindfors et al., 2014). EcoVault filters may be specialised for removal of specific dissolved pollutants.

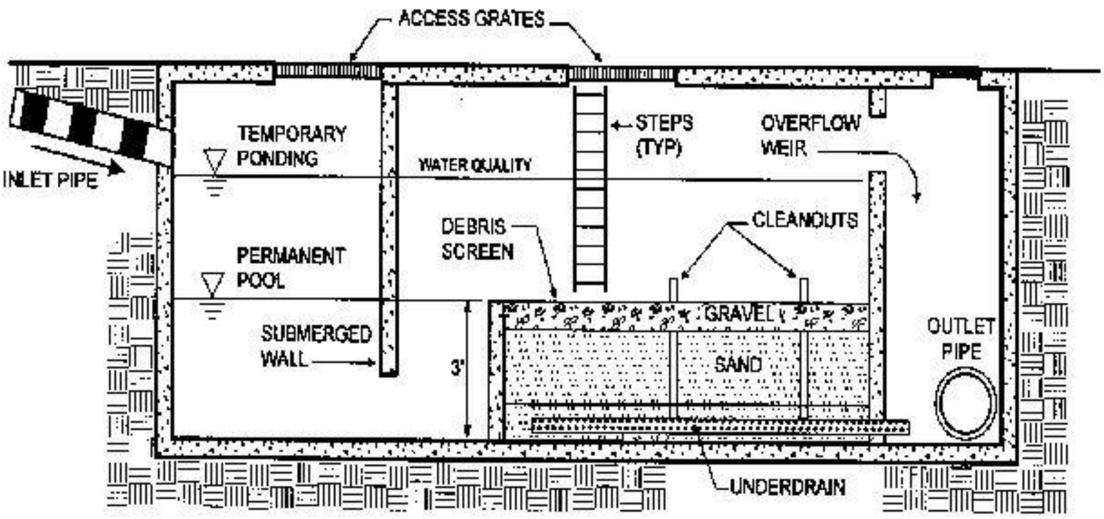


Figure 2.8 Schematic drawing of a sand filter (SMRC, n.y.).

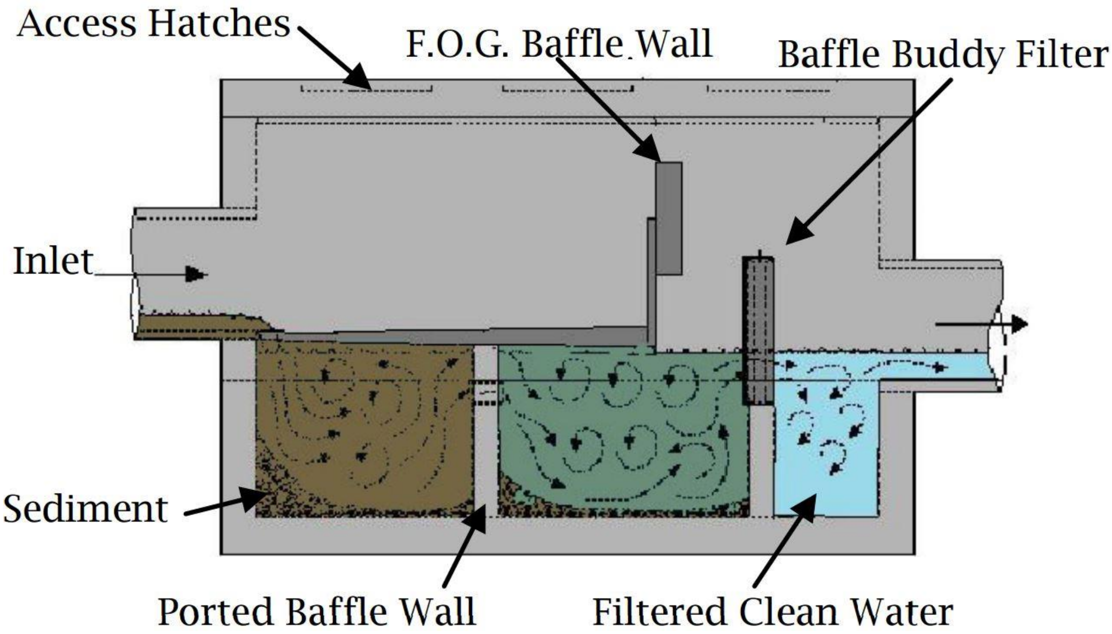


Figure 2.9 Schematic drawing of an EcoVault unit (ESI, n.y.).

Sand filters are recognised as high performance treatment units, with 70–-90 % removal of TSS and potentially high removal of metals (Appendix II). *EcoVault* has shown high removal rates for Cu (60 %), Zn (70 %) and suspended solids (Lindfors et al., 2014). However, those tests were conducted in Florida. Units installed in Sweden have not yet been fully evaluated.

Sand filters must be inspected and cleaned regularly to ensure proper functioning. The amount of maintenance needed is determined from site to site and US EPA (1999b) recommends that filters should be inspected after every storm event. They also recommend removing trash and debris at least every six months and regular recording of the dewatering times to determine when maintenance of the filter media is needed. Maintenance of the filter consists of removing the top layer of the filter media where most pollutants have accumulated and caused clogging. Woods-Ballard et al. (2015d) give some general recommendations for operation and maintenance for proprietary treatment systems (Appendix III). More specific recommendations may be provided by manufacturers. For *EcoVault*, vacuuming 4–12 times per year is recommended and the filters should be replaced at least once per year (Lindfors et al., 2014).

Sand filters have high capital costs and high operation and maintenance costs according to US FHWA (n.y.). Lindfors et al. (2014) state that *EcoVault* generally have low construction costs compared to corresponding sedimentation basins in Sweden, although the costs vary from site to site.

2.3.5 Well-mounted filters

Well-mounted filter units, such as *FlexiClean* (Figure 2.10), are fitted into gully pots to filter stormwater before it is conveyed downstream (Alm et al., 2015). It is quick and easy to install as a retrofit option (FlexiClean, n.y.). The filter media removes pollutants through mechanical filtration and adsorption.

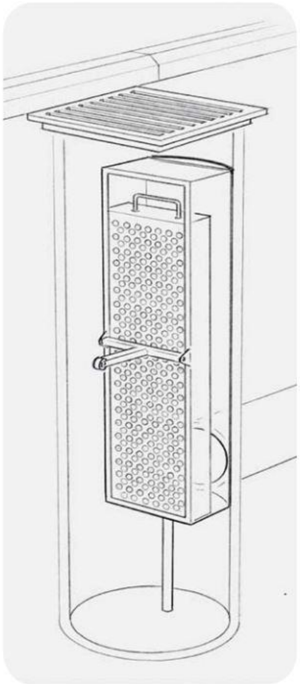


Figure 2.10 FlexiClean well-mounted filter unit (FlexiClean, n.y.).

The removal of pollutants is highly dependent on the type of filter media used. Kalmykova et al. (2008) showed that peat filters may be efficient in removing dissolved metals (over 90 % removal). Wood-based materials including bark also have potential to remove organic pollutants (Björklund & Li, 2015). However, the tests were conducted in a laboratory and Björklund & Li (2015) acknowledge that real in situ contact times between filter media and stormwater are likely lower. Thus less removal of contaminants is to be expected in real applications. Alm et al. (2015) conducted field tests on well-mounted filters in Nacka municipality in the Stockholm region. Conclusions from that study were that no treatment could be proven. In some cases the outgoing water contained more pollutants than the incoming water, which would indicate that the filter in fact acted as a source of pollutants. This was probably due to washing out of previously captured contaminants. The authors thus deem the solution to be unreliable and would not recommend using it to treat road runoff.

Maintenance of well-mounted filters consists of replacing the filter media. This should be done with intervals of 6–-12 months depending on the pollutant load (Alm et al., 2015).

2.3.6 Preventive measures

Aside from the stormwater treatment techniques presented in the previous sections, there are preventive measures that can be undertaken to address the problem of stormwater quality by managing pollutants at their source. Addressing pollution at their source has received increasing attention and is regarded as an effective way of reducing pollutants (Davis & McCuen, 2005). Non-structural measures may include changes in maintenance, such as street sweeping and gully pot cleaning, and limitation of potential polluting activities such as chemical storage and pesticide use

(Butler & Davies, 2011). Woods-Ballard et al. (2015e) set up a hierarchy for pollution prevention:

1. **Avoid** the use of materials and activities that generate pollutants.
2. **Minimise** the use of materials and activities that generate pollutants.
3. **Prevent** pollutants mixing with rainfall.
4. **Capture** pollution within the drainage system for removal, treatment or clean-up and rehabilitation (where required).

Materials causing stormwater pollution are for example copper and zinc in roofs (Davis & McCuen, 2005). Hence replacing those materials with non-polluting materials will reduce stormwater pollutant loads. Another example of pollution prevention is various methods of reducing traffic volumes, for example through congestion charges.

Effective pollution prevention strategies are those supported by multiple stakeholders (Woods-Ballard et al., 2015e). An important part of a successful strategy is education and training, since awareness among businesses and individuals can reduce unwanted and inappropriate behaviour.

2.4 Stormwater in urban planning in Sweden

2.4.1 Comprehensive plans and zonings

There are three levels of planning documentation within Swedish municipalities (Boverket, 2015a). First is the comprehensive plan, which encompasses the entire municipality and presents strategies and guidelines for the urban development. The comprehensive plan is not legally binding, which is why there are detailed plans (zonings) for smaller areas, describing how the land may be used. In between the comprehensive plan and the zonings there is a third type of plan, area regulations, which may be used for limited areas to regulate land- and water use. These are typically used for fulfilment of the comprehensive plan in areas where there is absence of zonings (Boverket, 2016a).

The comprehensive plan works as a guide for the strategic development of the entire municipality (Boverket, 2016b). It is publically available and presents the plans for future developments, for example location of new residential areas. In the plan there may for example be projections of population growth and also visions and policies set up by the municipality. These visions and policies may control what is permitted in terms of developments and the zonings should normally comply with the comprehensive plan in order to get approved.

A zoning decides how land and water may be used within a limited area, as well as what type of buildings may be constructed (Boverket, 2014). It is a legally binding set of documents including maps and descriptions of plans and implementation. As part of the zoning there are usually investigations, for example concerning stormwater management, hydrogeology and environmental impacts.

In terms of stormwater management, overall principles for urban areas may be outlined in the comprehensive plan (Boverket, 2015b). Many municipalities also have stormwater management strategies that describe how stormwater should be handled within the city or region (Svenskt Vatten, 2011). Such documents often advocate localised stormwater management, which in Sweden is generally denoted *Lokalt omhändertagande av dagvatten (LOD)*. In zonings, there are often stormwater investigations that focus on the specific development area. Such investigations normally include information on site conditions such as surfaces, slopes, soils, groundwater levels and existing stormwater infrastructure. There are also estimations of future stormwater volumes and suggestions for facilities and mitigation measures. Potential treatment methods are included in the investigation if there are such requirements or if the receiving waters are deemed sensitive or have high natural values.

2.4.2 Challenges identified in sustainable stormwater management

Even though research has shown that stormwater treatment can be achieved in various ways, there are challenges and obstacles that may inhibit the use of stormwater treatment facilities.

Several technical aspects limit the feasibility of stormwater treatment measures. One such is space requirement, which is typically a major concern in retrofitting applications where there is limited space available (Svenskt Vatten, 2011). The performance of treatment processes may also be affected by climate conditions and temperature (Bäckström & Viklander, 2000). For example, in cold weathers problems arise from de-icing agents (road salts), freezing, accumulation of pollutants in snow and reduced function of biological treatment processes. There are also large runoff volumes during the spring melting period and the area contributing to runoff may be greater due to saturation of soils and low evaporation.

Alm & Åström (2014) investigated financial and legal aspects of stormwater management within Swedish municipalities and found that the laws concerning stormwater are unclear since there is no formal definition of stormwater in Swedish jurisdiction. Different laws deal with it in different ways and it is not always clear who is responsible for the management of stormwater. According to the authors, lack of clarity and consistency may lead to confusion, poor planning and less investment. The outcome may then be increased total societal costs. As municipalities cannot rely on national laws, they often form their own strategies for stormwater management and the division of responsibilities. The authors further acknowledge that there is often poor knowledge and understanding of stormwater problematics in municipal departments other than those who are responsible for water and wastewater. Since stormwater is a matter that affects and involves different functions of city planning, there is a need for improved understanding between the municipal departments in order to reach more sustainable solutions.

2.4.3 Recommendations from research

There has been little research on the planning aspect of stormwater management in Sweden. At Luleå University of Technology in northern Sweden there is a research program called *GrönNano,* which is entirely dedicated to stormwater management (LTU, 2014). One of the five areas of interest for this research project is how to deal with planning of stormwater management.

During 2015 *GrönNano* arranged workshops in Skellefteå, Sundsvall, Gothenburg, Östersund and Luleå to promote changes in planning processes to facilitate more sustainable stormwater management (LTU, 2016). The subjects of the workshops included how to make sure stormwater issues are considered early in the planning process, how to improve collaboration across organizational boundaries and to increase the municipal departments' understanding of each other's needs. Key issues were identified in responsibility, demands, legislation and lack of comprehensive views. This is consistent with the findings of Alm & Åström (2014) presented in Subsection 2.4.2.

LTU (2016) recognize that there should be routines available or people responsible for bringing stormwater management issues into the early stages of planning. No clear recommendation is given as to which municipal department should be responsible for this, since the issues are relevant to many departments. There are however recommendations in favour of municipal stormwater management strategies as guidelines for how to handle stormwater in urban developments. Also suggested is more communication between departments, for example through regular meetings and formation of stormwater collaboration groups. Furthermore, it has been recognized that collaboration and understanding is more difficult when there are municipal-owned companies involved, since there are wide differences in interests.

2.5 MCDA as a tool in stormwater management

2.5.1 MCDA approaches

Multi-Criteria Decision Analysis (MCDA), sometimes referred to as Multi-Criteria Analysis (MCA), is a methodological framework or a decision support tool that is suitable for handling complex decision problems (DCLG, 2009; Munier, 2011). Complex decisions may involve all aspects of sustainability: environment, economy and society.

The method consists of selecting viable decision alternatives, selecting appropriate criteria for evaluation of the decision alternatives, scoring of alternatives according to each criteria and weighting of the criteria. Although these elements are more or less apparent in every type of MCDA, there are some different methodological approaches. Table 2.5 shows a summary of some commonly used versions of MCDA and shortly describes their characteristics.

Table 2.5 The characteristics of some common MCDA methods.

Methods	Characteristics
Multi-Attribute Utility Theory (MAUT), Multi-Attribute Value Theory (MAVT)	MAUT and MAVT are compensatory models (Belton & Stewart, 2002; DCLG, 2009). Compensatory means that scores are combined to a final score. Hence good performance in one criterion may compensate for poor performance in another. The two models are differentiated by the fact that MAUT can account for uncertainties. That however makes it difficult to use, which is why it is rarely used in real life applications. Linear additive models are simple versions of MAVT that may be used if criteria are preferentially independent of each other (DCLG, 2009). Preferential independence means that scores for each criterion may be assigned without knowledge of scores in other criteria.
Analytical Hierarchy Process (AHP)	AHP is a linear additive method based on pairwise comparisons (DCLG, 2009; Munier, 2011). For scoring, the analysts state how they think one alternative compares to the other in a specific criterion. This procedure is repeated so that all alternatives have preference relations to all other alternatives for all criteria. The results of this process are preference matrices, one for each criterion, that describe the relative performance of each alternative in that specific criterion. For the weighting of criteria, the same procedure of pairwise comparison is applied to the criteria, and the analysts state how important they think one criteria is compared to every other criterion. The actual scores and weights are calculated through linear algebra using the preference matrices.
Outranking methods: ELECTRE, PROMETHEE-GAIA	The outranking methods ELECTRE and PROMETHEE-GAIA utilise pairwise comparisons and also threshold values (Munier, 2011). An outranking may occur when there are enough arguments, criteria, to say that one alternative outperforms another and there is no strong objection. The thresholds are designed to determine whether alternatives are indifferent or if there is a preference towards one of the alternatives in the comparison. Also, if one alternative is vastly superior in one criterion it may not be outranked by another alternative regardless of the performance in other criteria. Hence, these outranking methods are somewhat non-compensatory (DCLG, 2009).

Few studies have been made on using MCDA for selection of urban stormwater management alternatives (Ellis et al., 2004; Martin et al., 2006; Baptista et al., 2007;

Jia et al., 2013; Bergqvist, 2014). Existing studies cover some different approaches, as can be seen in the following subsections.

2.5.2 Criteria

Criteria are often ordered in hierarchical structures, although there are different terminologies used for the different levels of goals and criteria (Ellis et al., 2004; Martin et al., 2006; Baptista et al., 2007; Jia et al., 2013; Bergqvist, 2014). Generally, objectives are divided into larger numbers of primary criteria, and even more secondary criteria. The objectives generally include environmental, economic and technical as well as social and health aspects. Ellis et al. (2004) further recommends disaggregation of secondary criteria into distinct and measurable benchmark standards for ease of comparison. Table 2.6 and Table 2.7 show some criteria used by Ellis et al. (2004) and Martin et al. (2006) respectively.

Table 2.6 Primary criteria by Ellis et al. (2004)

Category	**Primary criteria**
Technical and scientific performance	System performance (quantity and quality) System reliability System durability System flexibility and adaptability
Environmental impacts	Water volume impact Water quality impact Ecological impact Resource use Maintenance, service provision and responsibilities
Social and urban community benefits	Amenity; aesthetics, access and community benefits Public information; education and awareness Stakeholder acceptability; perception and attitude to risks and benefits
Economic costings	Health and safety risks Financial risks Affordability Life-cycle costs

Table 2.7 Objectives, primary and secondary parameters and criteria by Martin et al. (2006). Criteria in bold are BMP-specific and criteria in italic are site-specific.

Objectives	**Primary parameters**	**Secondary parameters**	**Criteria**
Technical and hydraulic (TEC)	System performance	Hydraulic control	*Return period*
			Length of antecedent dry period
			Response rate for superimposed events
		Pollution control	**Solid pollution retention**
			Dissolved pollution retention
Operation and maintenance (O&M)	System reliability	Risk management	**Probability of system failure**
	Maintenance and servicing provisions	Operation and maintenance need	**O&M needs and frequency**
Environment	Impact on receiving waters	Pollution control	**Impact on groundwater quality**
			Compliance with receiving water quality objective
		Ecological diversity	*Biological indices*
Social and urban community benefits criteria (SOC)	Amenity and aesthetics	Social inclusion and multifunctional use	**Amenity level**
	Sustainable development	Sustainable urban living	**Contribution to urban sustainable development policies**
Economic (ECO)	Life cycle	Costs	**Capital and maintenance costs**
	Accessibility	Costs for the community	*Stormwater fees*
		Long-term previsions	*Adoption and liability coverage*
	Land costs	Land take	*Land costs*

2.5.3 Scoring procedures

There are multiple ways of scoring alternatives. One is to assume a linear scale from a worst possible value to a reasonable best value, as done by Martin et al. (2006), Jia et al. (2013) and Bergqvist (2014). This is straightforward for criteria that are easily quantified, such as costs of operation (Munier, 2011). It is however not as easy for criteria of a more qualitative nature, such as aesthetics. For that, the scale is often simplified to a small number of performance intervals which may have associated subjective descriptions. For example, on a scale of 1-5 the score 5 may be accompanied by the description *very good performance*.

Another type of scoring is a simple ranking among alternatives, where the solution deemed to have the best performance in each criteria is awarded the highest rank and the other alternatives follow in a falling order**.** This approach was adopted in a French case study presented in Ellis et al. (2004).

A third type of scoring is pairwise comparison, which is the foundation of the popular Analytic Hierarchy Process (AHP) (Table 2.5) and the more advanced Analytic Network Process (ANP) (Munier, 2011). Young et al. (2010) showed how the method may be applied for selection of urban stormwater management solutions.

2.5.4 Weighting procedures

Weighting in MCDA is done to ensure that stakeholder interests are reflected in the decision process (DCLG, 2009; Munier, 2011). It is a way to balance the scores so that the criteria most valued by the stakeholders will have most effect on the final results. It is important to note that weighting of criteria may vary between different sites due to differences in stakeholder interests and site conditions (Ellis et al., 2004).

A procedure to apply weights can for example be by directly distributing percentages according to stakeholder preferences (Baptista et al., 2007). Another approach is to weigh criteria within their respective category and to weigh the categories, as done in a case study presented in Ellis et al. (2004) (Table 2.1). This weighting scheme was used for selection of alternative locations of a highway retention basin.

Table 2.8 Weighting used in French case study (Ellis et al., 2004).

Criteria	**Class (%)**	**Weight (%)**
Response to hydraulic needs	Technical Performance (30)	10
Hydraulic performance		10
Reliability		10
Visual impact	Environmental Performance (30)	15
Need for multifunctionality		10
Operational impacts		5
Immediate availability of the site	Feasibility (20)	15
Realisation constraints		5
Investment cost	Costs (20)	15
Operation and maintenance		5

Martin et al. (2006) simulated weightings according to three stakeholder viewpoints. Criteria were either regarded as *non-strategic*, meaning that they were of little importance, or *strategic*, which meant that the criterion was of importance. The methodology consisted of giving 1 % weight to the non-strategic criteria and the remaining part was distributed equally among the strategic criteria (Figure 2.11). There was no subsequent weighting of the stakeholders to reach a final decision, so the results are presented on a per-stakeholder basis (Figure 2.12).

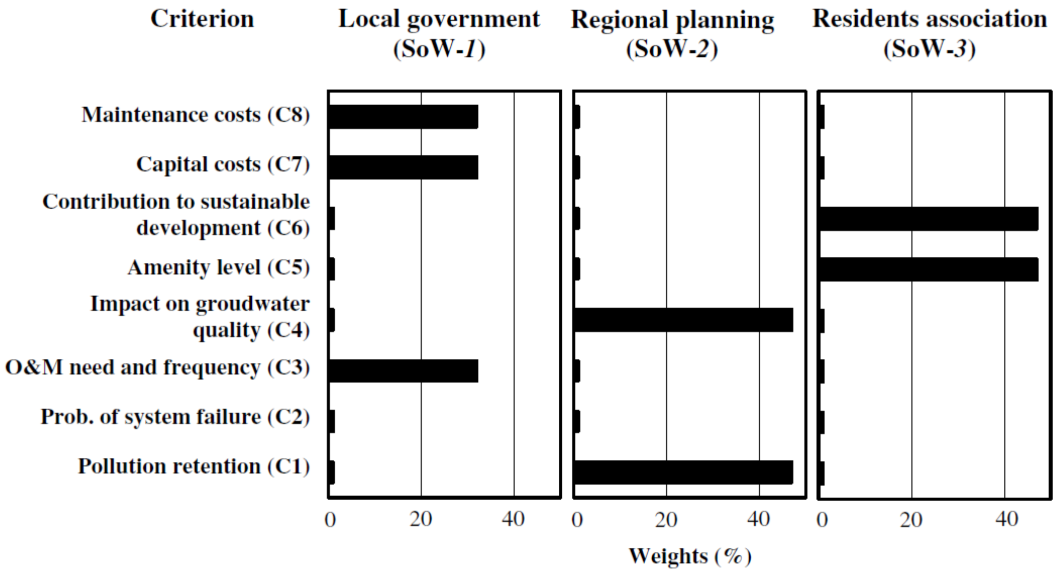


Figure 2.11 Weighting according to three theoretical stakeholders (Martin et al., 2006).

Weighting can also be done through the use of AHP (e.g. Young et al., 2010). The procedure is then the same as outlined for scoring in Subsection 2.5.3, but the pairwise comparison is done among the criteria.

2.5.5 Final evaluations

When scoring and weighting are completed, the results are meant to show an order of preference for the alternatives. This is usually done by a linear additive model (DCLG, 2009), or weighted summation, as shown in Equation 2.1.

$$S_i = \sum_{j=1}^{n} w_j s_{ij} \qquad (2.1)$$

$S_i = total\ score\ of\ alternative\ i$
$w_j = weight\ of\ criterion\ j$
$s_{ij} = score\ of\ alternative\ i\ in\ criterion\ j$
$n = number\ of\ criteria$

The linear additive model is used in most MCDAs conducted in the field of urban stormwater management (Ellis et al., 2004; Jia et al., 2013; Bergqvist, 2014). Baptista et al. (2007) however, used a different type of evaluation based on two indicators, one global performance indicator and one cost indicator. Both indicators were calculated as comparative measures based on average performance of the different alternatives. The equations used by Baptista et al. (2007) are shown in Equations 2.2 and 2.3.

$$I_p = \frac{\sum_{i=1}^{n} I_i w_i}{\sum_{j=1}^{j=m} \left(\sum_{i=1}^{n} I_i w_i\right)_j / m} \qquad (2.2)$$

$I_p = global\ performance\ indicator$
$I_i = the\ performance\ indicator\ for\ the\ scenario\ i$
$w_i = the\ weight\ of\ the\ indicator\ i$

$n = number\ of\ performance\ indicators$
$m = number\ of\ scenarios\ (alternatives)$

$$I_c = \frac{\bar{C}}{C_i} \quad (2.3)$$

$I_c = cost\ indicator\ for\ the\ alternative\ i$
$\bar{C} = average\ global\ cost\ (NPV)\ of\ the\ different\ alternatives$
$C_i = global\ cost\ (NPV)\ of\ the\ alternative\ i$

After calculation of the global performance indicators and the cost indicators using the equations above, there is an opportunity for a performance-cost analysis (Baptista et al., 2007). This is similar to Cost-Benefit Analysis (CBA), which is another methodology that is frequently applied in environmental management (Gamper et al., 2006; Lai et al., 2008).

Martin et al. (2006) used the ELECTRE III outranking method for evaluation. The results were presented in the form of flowcharts (Figure 2.12) representing indifference and preference relations according to the three different stakeholders simulated.

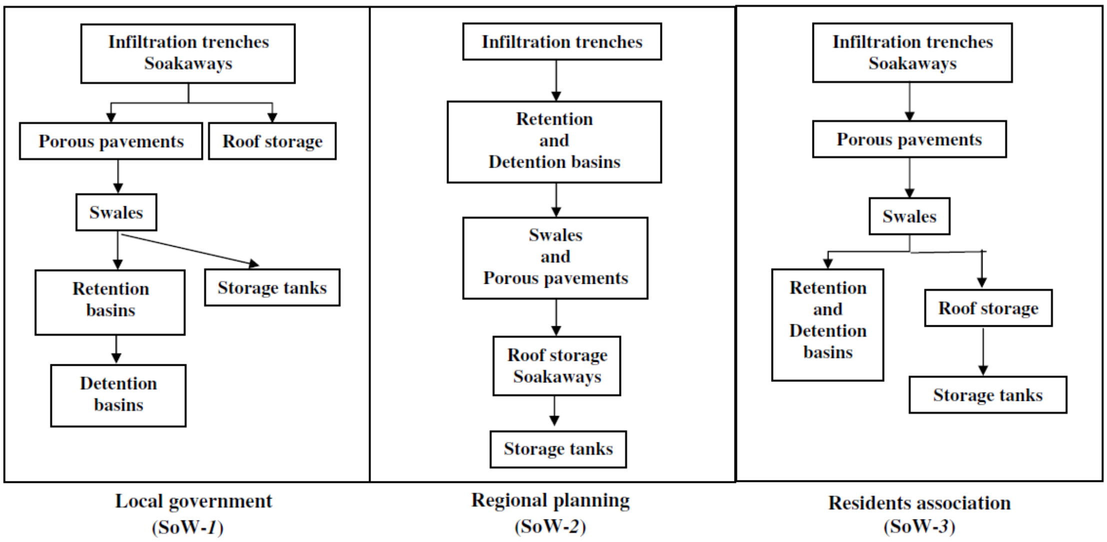


Figure 2.12 Outranking relations for three simulated stakeholders (Martin et al., 2006).

3 Method

This master's thesis work was conducted through the use of a Multi-Criteria Decision Analysis methodology (Section 3.2) applied to a case study area (Section 3.1). The framework and interrelations of the different elements of the methodology is visualised in a flowchart (Figure 3.1).

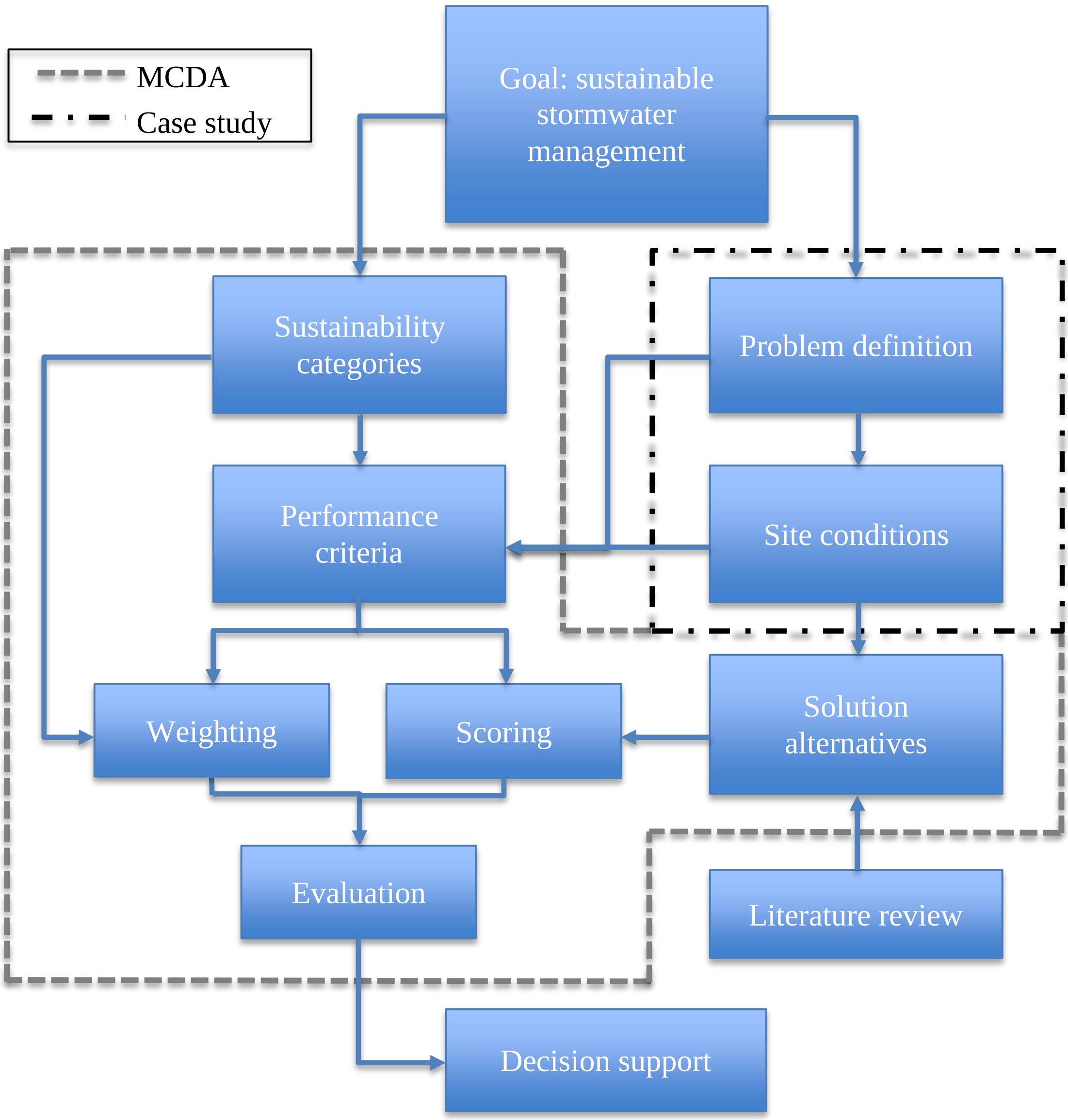


Figure 3.1 Flowchart depicting the overall methodology employed.

3.1 Case study

The starting point for the case study of Selma Lagerlöfs torg were documents regarding its future development (Stadsbyggnadskontoret, 2014), a stormwater investigation concerning the area (Ramböll, 2013) as well as a StormTac stormwater modelling (Atkins Sweden, 2016). Additional information on future development of the site was obtained from employees at Atkins.

Supplementary information about the municipal departments in Gothenburg and the planning process with regard to stormwater was collected from the municipal webpage *goteborg.se* and from employees at the municipality.

3.2 Multi-Criteria Decision Analysis (MCDA)

The MCDA methodology employed is a simple version of Multi-Attribute Value Theory (Subsection 2.5.1), weighted summation. Feasible stormwater management alternatives were decided by the author based mainly on local conditions and literature. Criteria were decided based on literature, experience and input from experts and stakeholders through questionnaires. Furthermore, the scoring and weighting of criteria were conducted in a workshop session with stakeholders and experts who were divided into groups (Table 3.1). The model used for calculations, presentation of the results and sensitivity analysis was created using the decision support software *Web-HIPRE*.

Table 3.1 Group division used in the workshop session.

Work group	**Number of attendants**	**Present organisations**
Environment	5	*Atkins, Chalmers, Kretslopp och vatten, Miljöförvaltningen*
Economy and technology	6	*Atkins, Chalmers, Kretslopp och vatten, SP – Sveriges Tekniska Forskningsinstitut, Trafikkontoret*
Social aspects and health	4	*Atkins, Chalmers, Miljöförvaltningen, Trafikkontoret*

3.2.1 Stormwater management alternatives

The stormwater management techniques outlined in Section 2.3 were found in literature on techniques that could be applied in highly urbanized areas, because it was stated from the start of the project that space-requiring solutions were unfeasible. It was also known that the in-situ soils are of low permeability. Therefore, no solutions relying on infiltration to the ground were included in the study. Feasibility judgement and potential placements for the techniques were done by combining literature on performance and information from the case study.

3.2.2 Criteria

The criteria used for evaluation in this work are solely related to the stormwater management techniques and no criteria are related to the site conditions. A similar method was employed by Martin et al. (2006) who listed both technique-specific criteria and site-specific criteria (Table 2.7), although only the technique-specific criteria were used in the evaluation.

The criteria were grouped in three different categories: environment, economy and technology and social aspects and health. Similar categorisation has been used in previous studies (e.g. Ellis et al., 2004; Martin et al., 2006), and this simplifies identification of criteria and weighting.

Some criteria for assessment of the performance of stormwater solutions were obtained from literature research. Moreover, questionnaires were handed out to stakeholders and experts in the field of stormwater management to add more relevant criteria to the model.

3.2.3 The Web-HIPRE software

Web-HIPRE (HIerarchical PREference analysis on the World Wide Web) is a web-based Java application developed at Aalto University in Finland. It is based on the HIPRE 3+ software for decision support and features implementations of MAVT through weighted summation and AHP (Mustajoki & Hämäläinen, 2000). With Web-HIPRE, the user creates goals, criteria and alternatives in a hierarchical structure (Appendix IV). Alternatives may then be scored in each criterion and the criteria may be weighted using one of the available weighting methods (Table 3.2).

Table 3.2 Weighting methods available in Web-HIPRE.

Weighting method	**Description**
Direct	The user directly inserts weights to each attribute. Normalisation is done to make sure the total sum of weight add up to 1.
SMART	10 points are assigned to the least important attribute. Then points (>10) are given to the other attributes to reflect their relative importance to the least important. Weights are calculated by normalisation.
SWING	100 points are assigned to the most important attribute. Then points (<100) are given to the other attributes to reflect their relative importance to the most important. Weights are calculated by normalisation.
SMARTER	Attributes are ranked in order of importance, 1 being the most important. The weight of the *k*th attribute is calculated as (Edwards & Barron, 1994): $w_k = \frac{1}{n} * \sum_{i=k}^{n} \frac{1}{i}$ where n is the number of attributes.
AHP	Attributes are compared in pairs to form a preference matrix. Weights are calculated through linear algebra.

3.2.4 Scoring

Scoring was done using pre-defined global scales, where each value on the scale had an associated description (Appendix V). A scale of integers 0 – 3 was used for most criteria, although for some criteria somewhat wider scales were developed. Hence, it may be regarded as semi-quantitative. The scores were all normalised in *Web-HIPRE* to a scale of 0 – 1. For criteria with scoring scales where higher values represented “worse performance”, the normalised scales were flipped so that, in all normalised scales, a higher value represents better performance. The purpose of using a scale with few available values is to simplify the scoring process. Wide ranges could make it difficult for users to decide on a specific score that represents the performance of an alternative.

3.2.5 Weighting

The weighting was performed using the SWING method (Table 3.2), because it is regarded as relatively simple, and it was expected that people are more likely to have a favourite among the criteria rather than a least favoured one. The weighting of criteria within each category was done in specialised groups (Table 3.1) and the weighting of categories was done together with all groups.

3.2.6 Evaluation

The evaluation was done through weighted summation (Equation 2.1). The final results may be significantly influenced by the weighting, which is also subjective and may vary widely depending on the group conducting the weighting. A sensitivity analysis was conducted to help understand how the results were impacted by the weighting and how the results may differ if another weighting was used.

3.3 Synthesis to improve planning

After the results of the MCDA were obtained there was a discussion with stakeholders and experts to identify challenges and obstacles in implementing sustainable solutions. Attendants at the workshop were asked to make suggestions on how the planning procedure could be changed in order to promote sustainable stormwater management.

The following questions served as a basis for the discussion:

- What are the challenges in stormwater management?
- What changes in planning are needed to approach sustainability?
- At which stage of the planning process is there need for more focus on stormwater management?
- Who should be responsible for what?
- Can MCDA be a tool for stormwater management in planning processes?
    - When could it be applied?
    - Who should be responsible?

3.4 Limitations

3.4.1 Case study

The StormTac simulation, performed by Atkins Sweden for Selma Lagerlöfs torg, provides data for pollutant levels and is a simplification of reality. Therefore the numbers are not to be taken for measured values and serve only as an indication of possible future pollutant levels in this study. It is however useful since it is impossible to have measured values prior to construction.

3.4.2 MCDA

MCDA methods contain elements that are subjective in their nature (DCLG, 2009). This is mostly associated with the weighting, although it may also apply to some cases of scoring where individual experiences may influence the analyst’s judgement of performance. Therefore, different analysts may come to different results, hence affecting the repeatability and reliability of the results. Further shortcomings of MCDA include for example double counting and under-counting (Table 3.3).

Table 3.3 Shortcomings of MCDA methods (Lai et al., 2008).

Shortcomings	Issues
Preferential independency	Preference of criteria is assumed to be independent of each other.
Double counting and under-counting	Over-estimate or under-estimate certain aspects when the chosen criteria are either redundant or not comprehensive.
Transparency of MCDA methods and results	Complex MCDA methods can be perceived by non-expert as “black-box” approaches.

The scoring scale used for most criteria in this work, integers 0 – 3, consists of few possible scores. While this provides a relatively simple scoring of alternatives, the rough scale may marginalise small differences. This may lead to less differentiation between alternatives in the evaluation.

The model outlined is suitable for decision support early in planning procedures due to its roughness and simplicity. In cases which are clearly defined in terms of land uses and sizes, such as in retrofitting applications or late stages in urban planning, quantitative scoring could be employed through hydrodynamic and economic modelling of alternatives as suggested by Aceves & Fuamba (2016). However, that requires additional time and effort.

4 Case Study: Gothenburg

4.1 Municipal departments and stormwater in urban planning

The different municipal departments involved in development projects in Gothenburg and their respective responsibilities are (Göteborgs Stad, n.y.):

- *Fastighetskontoret* – Owns and administers land, responsible for providing good conditions for residents as well as industries by offering opportunities for land exploitation.
- *Kretslopp och vatten* – Responsible for drinking water treatment and distribution, sewer management and waste disposal.
- *Miljöförvaltningen* – Work with environmental issues. The department reviews the city's performance in terms of human and environmental health.
- *Park- och naturförvaltningen* – Caretaker of the city parks, squares, nature reserves and plantations.
- *Stadsbyggnadskontoret* – The city planning office, responsible for the comprehensive plan and zonings. The department approves or rejects building permits (i.e. they decide on what is built and not).
- *Trafikkontoret* – Responsible for municipal roads and tram tracks.

4.1.1 Comprehensive plan

Stadsbyggnadskontoret has the overall responsibility of the contents in the comprehensive plan. In matters concerning stormwater however, there are more departments involved (Kretsloppskontoret, 2010). Technical solutions fall under the responsibility of *Kretslopp och vatten*. Economic aspects, i.e. construction and operation divided between municipality and property owners, demand efforts from *Kretslopp och vatten, Fastighetskontoret, Park och natur* as well as *Trafikkontoret.* Ecological aspects of stormwater management and its consequences are evaluated by *Miljöförvaltningen* and *Park och natur* in collaboration. Finally, *Park och natur* are responsible for social and aesthetical aspects of stormwater management.

In the comprehensive plan, there should be classifications of receiving waters based on their values and vulnerabilities (Kretsloppskontoret, 2010). There should also be descriptions of drainage areas for each recipient, an overview of geological conditions, information about conservation areas and policies. Moreover, there should be identification of areas that are potentially exposed to problems such as flooding. Guideline principles for stormwater management within the municipality should be present in the comprehensive plan, and there should also be mapping of suitable locations for stormwater facilities on public land.

The comprehensive plan should include (Kretsloppskontoret, 2010):

- Classification of receiving waters, based on their ecological values and vulnerabilities.
- Description of drainage areas for each recipient, an overview of geological conditions, information about conservation areas and policies.

- Identification of areas that are potentially exposed to problems such as flooding.
- Guideline principles for stormwater management within the municipality.
- Mapping of suitable locations for stormwater facilities on public grounds.

4.1.2 Zonings

Every department of the city of Gothenburg has the opportunity to affect the zoning in all stages of the planning process and it is important that everyone at an early stage is provided the opportunity to give their view of new developments (Kretsloppskontoret, 2010). It is the responsibility of *Stadsbyggnadskontoret* to contact each department at an early stage of the planning process. Contents in the zoning are for example drinking water supply, sewage management, stormwater management and preservation of nature. Stormwater management is handled in a stormwater investigation, which is paid for and ordered by *Stadsbyggnadskontoret*, although *Kretslopp och vatten* are involved in deciding the content of that investigation.

4.1.3 Issues in stormwater planning

Even though some responsibilities are outlined in guidelines for stormwater management in Gothenburg, the departments remain unsure of their respective responsibilities[1]. This can lead to stormwater management often being overlooked. Furthermore, there are no restrictions on stormwater flows from public surfaces, while there are restrictions for private properties. Combined with the relatively new guideline values for pollutants, this has led to confusion within the departments on how to handle stormwater management, especially at public places. There is however an ongoing investigation within the municipality to clearly define the responsibilities of different departments.

4.2 Guideline values for stormwater

Miljöförvaltningen has set up guidelines for discharge of polluted water to stormwater systems and receiving waters in Gothenburg municipality (Miljöförvaltningen, 2013). The purpose of the guidelines is to protect watercourses and aquatic organisms, to contribute to good status of waters as well as to minimize the risk to human health. Furthermore, it is stated that it is the responsibility of every organisation to minimize their environmental impacts and that discharge of pollutants shall be controlled at the source.

The guideline values set up by *Miljöförvaltningen* in September 2013 (Table 4.1) apply to water discharged to stormwater systems as well as water discharged directly to receiving waters. A remark regarding the guideline values is that they may be difficult to achieve[2]. *Miljöförvaltningen* themselves mention that the guidelines may be considered stringent, although that is intended (Miljöförvaltningen, 2013).

[1] Linnea Lundberg (Project Engineer, Kretslopp och vatten) interviewed 2016-03-15.
[2] Kristina Hargelius (Project Manager, Environment, Atkins Sweden) at a meeting 2016-01-26

Table 4.1 Stormwater guideline values for the city of Gothenburg (Miljöförvaltningen, 2013).

Substance/parameter	Guideline at point of discharge [µg/l]
Arsenic (As)	15
Chromium (Cr)	15
Cadmium (Cd)	0.4
Lead (Pb)	14
Copper (Cu)	10
Zinc (Zn)	30
Nickel (Ni)	40
Mercury (Hg)	0.05
Polychlorinated biphenyls (PCB)	0.014
Tributyl tin (TBT)	0.001
Oil index	1 000
Benzo(a)pyrene (BaP)	0.05
Methyl tert-butyl ether (MTBE)	500
Benzene	10
pH	6-9
Total Phosphorous (P)	50
Total Nitrogen (N)	1 250
Total Organic Carbon (TOC)	12 000
Suspended Solids (SS)	25 000
Particles	At least 90 % separation of particles > 0.1 mm if particles originate from washing processes outdoors or equivalent.
Flow	The flow to the recipient at point of discharge must not be more than 1/10 of the recipients flow at the time.

4.3 Selma Lagerlöfs torg

Before its development from the middle to late 20th century, the district Backa was largely agricultural land (Stadsbyggnadskontoret, 2008). According to Stadsbyggnadskontoret (2014), there are current shortcomings in declining trade, insecurity, fewer residents per dwelling and a small variation in the supply of dwellings. The development plans for Selma Lagerlöfs torg (Figure 4.1) concern an area of roughly 9.45 hectares and involve densification of the area through construction of more dwellings and increase of the services provided at the service centre (Figure 4.2). Also, the main streets Litteraturgatan and Backadalen that are now considered as barriers will be reconstructed so that they are classified as city streets, which have a lower speed limit and promote more interaction with pedestrians and cyclists. As part of the reconstruction, the western part of the road Backadalen will be moved north to allow for construction of additional buildings to the south of the street.

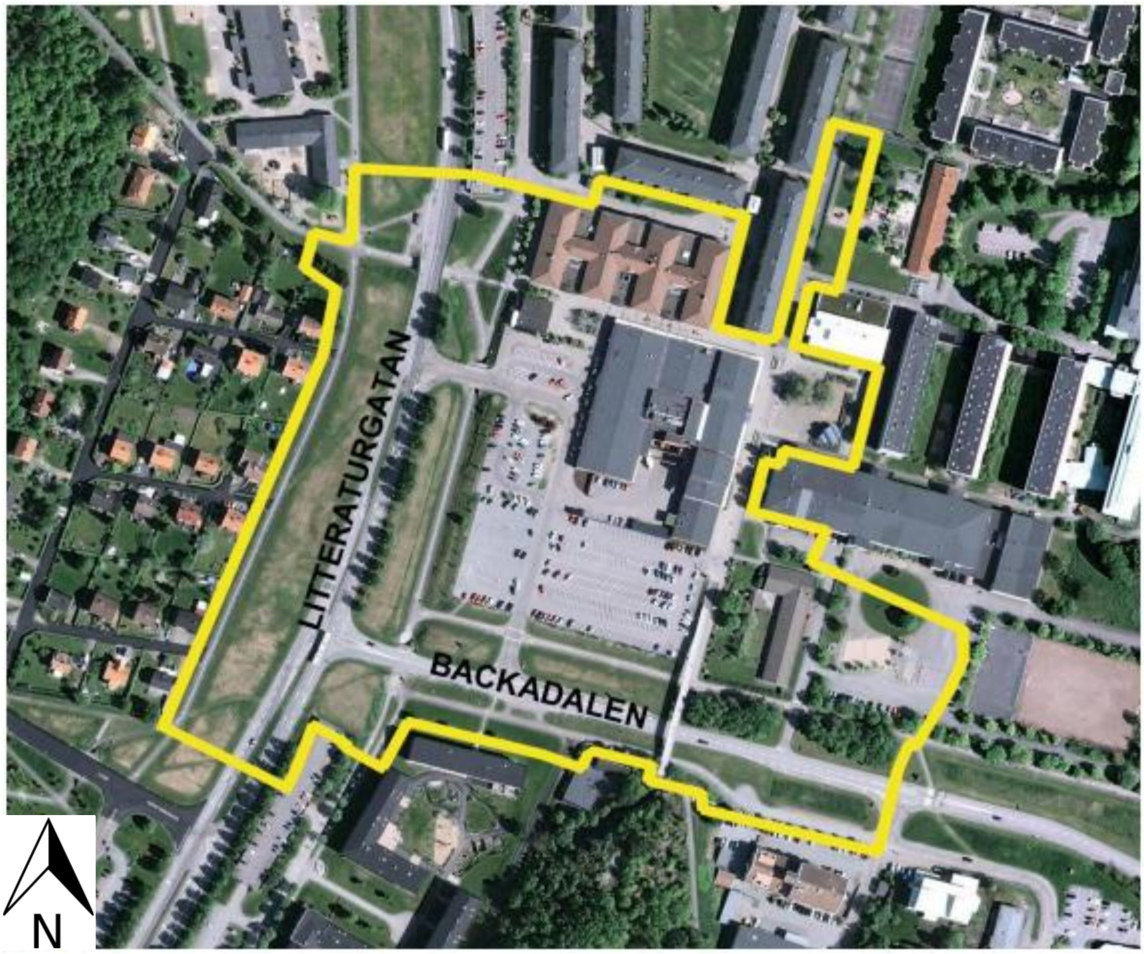


Figure 4.1 Selma Lagerlöfs torg (Stadsbyggnadskontoret, 2014). The yellow line indicates the extent of the zoning.

Figure 4.2 Zoning map for the studied area at Selma Lagerlöfs torg (Stadsbyggnadskontoret, 2014). Yellow = private properties, brown = trade/commercial properties, grey = parking areas, red = municipal properties.

4.3.1 Site geology

The area is relatively flat with a gentle slope towards the north along Litteraturgatan and east along the eastern part of Backadalen. According to Sweco (2012) the top soil (to a depth of about 1.5–3.5 meters) consists of filled materials (sand, sandy clay or gravelly sand) underneath impermeable surfaces, and dry crust clay underneath other surfaces. Below the top layer is 20–40 meters of silty clay, underneath which there is a layer of unknown thickness consisting of friction materials. The in situ natural soils are not suitable for infiltration and the groundwater level is roughly 1.5–2 meters below the surface (Ramböll, 2013).

Groundwater and soil samples in the area have shown signs of contamination[3]. This contamination is assumed not to have an impact on the stormwater quality in the area because there will be little contact between the soils and stormwater, and the soils will also be decontaminated.

[3] Kristina Hargelius (Project Manager, Environment, Atkins Sweden) at a meeting 2016-01-21.

4.3.2 StormTac simulation

StormTac is a stormwater and recipient software model used as a tool for action planning in urban water management (StormTac, 2015). It is useful for predicting both quantity and quality aspects within catchment areas and can integrate processes of runoff, transport, recipient, treatment and flow detention.

For Selma Lagerlöfs torg, StormTac (StormTac WEB v. 15.3.2) was used to estimate future pollutant concentrations and loads (Atkins Sweden, 2016). The StormTac modelling was performed for post development and a total area of 3.97 hectares (Figure 4.3), the remaining area will consist of properties that follow other stormwater regulations. More information and the results from the simulation can be found in Appendix I.

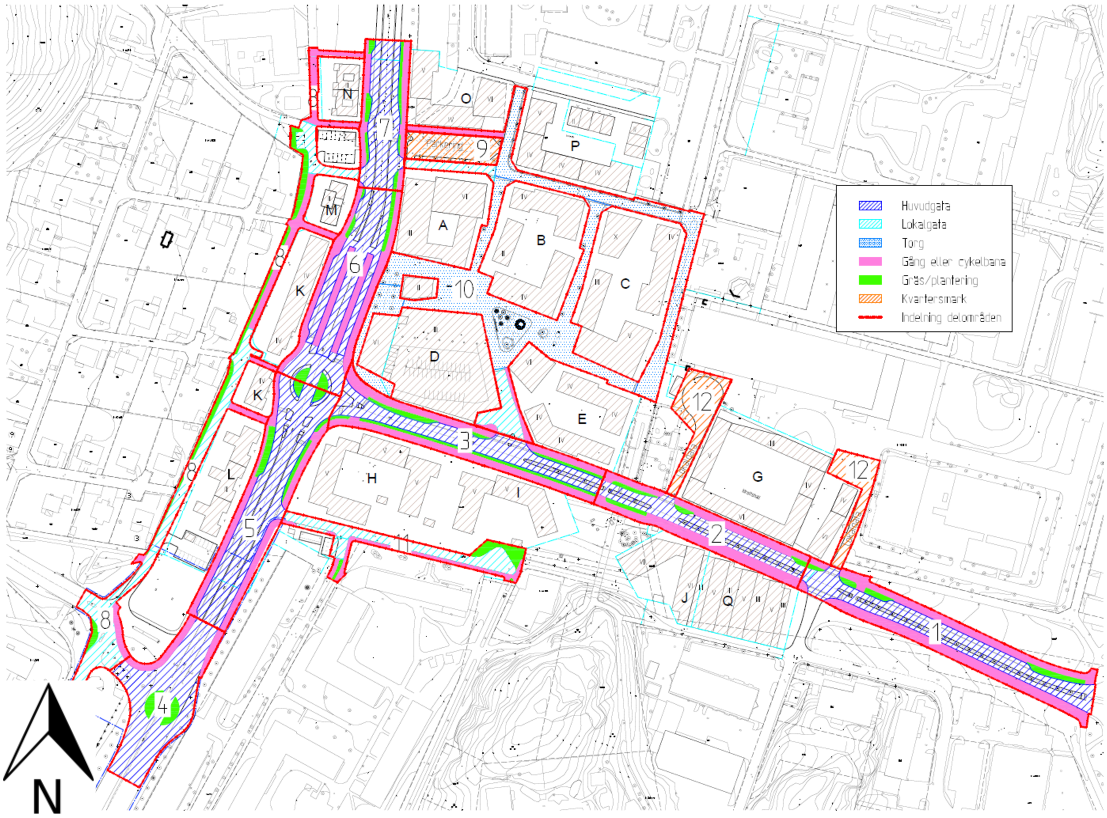


Figure 4.3 Extent of the StormTac simulation performed for Selma Lagerlöfs torg (Atkins Sweden, 2016).

The simulation showed that stormwater levels of nitrogen, phosphorous, copper, zinc, mercury, suspended solids, tributyltin (TBT), total organic carbon (TOC) and polychlorinated biphenyls (PCBs) may exceed guideline values in many of the sub-areas. In sub-area 9, which is planned to be a parking lot, the guideline values were predicted to be exceeded also for lead, cadmium, chromium and benzo(a)pyrene (BaP). These indications are based on standard values and do not include specific local pollutant sources.

4.3.3 Existing stormwater infrastructure

The current sewage system in the case study area is a separated system (Figure 4.4). Most of the area is drained by pipes towards the north, while the eastern part along

Backadalen drains towards the east. A large culvert crosses the area from the southwest to the northeast.

Figure 4.4 *Existing water, sewage and stormwater pipes at Selma Lagerlöfs torg (Ramböll, 2013). Blue lines indicate water pipes, red lines represent sewage pipes and green lines are stormwater pipes.*

The stormwater system has its outlet to Göta Älv approximately one kilometre north of the area, and the last 700 meters consist mainly of an open ditch (Ramböll, 2013).

4.3.4 Design proposal by Atkins

The design proposal by Atkins consists of four underground sedimentation units (Figure 4.5). The units are oversized pipes with a combined volume of 217 m^3 (Table 4.2). Treatment of stormwater from less polluted areas was deemed unnecessary, so runoff from the sub-areas 8, 10, 11 and 12 does not pass through any sedimentation unit. Detention and attenuation is deemed secondary because there are no such requirements. The sub-area 9 included in the StormTac simulation was excluded from the proposal since it has become clear that the area will consist of a privately owned parking lot, and hence not included in the task given to Atkins.

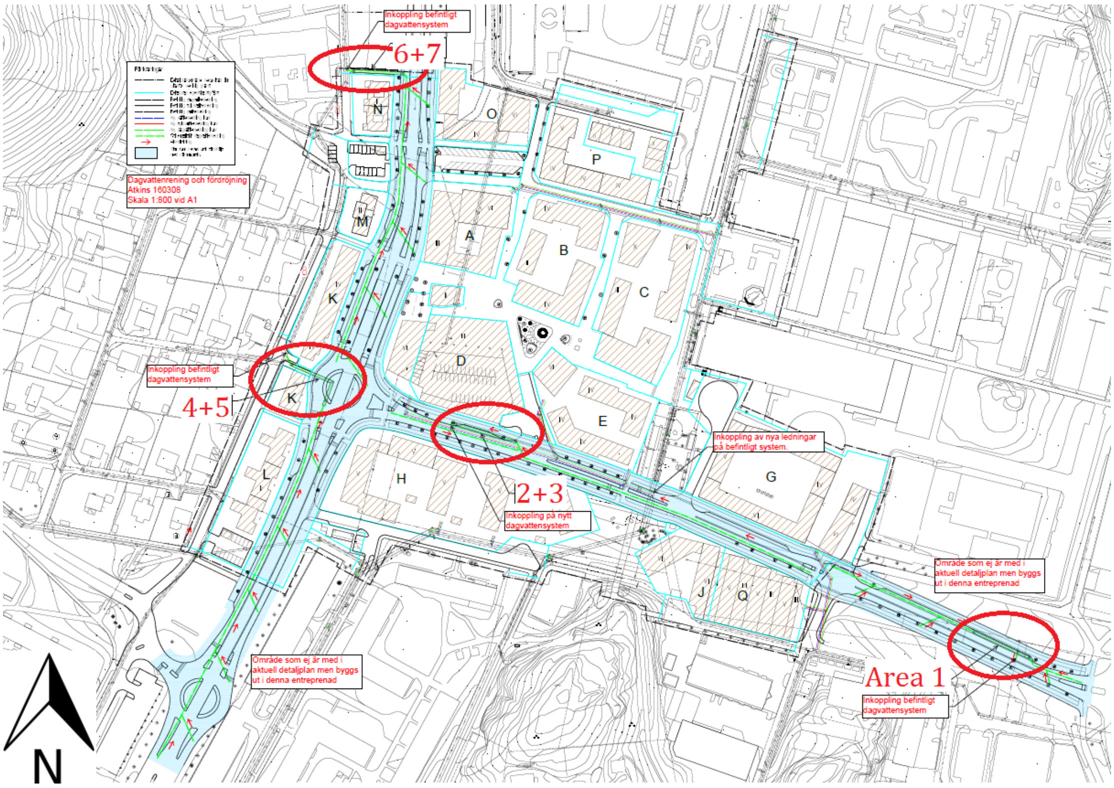


Figure 4.5 Stormwater management proposal by Atkins. Red ovals point out the locations of the storage units.

Table 4.2 Surfaces and storage volumes according to the proposal by Atkins.

Sub-area	**Main street**	**Local street**	**Vegetated surface**	**Pedestrian and bicycle path**	**City square**	**Total area**	**Storage volume**
				[m^2]			[m^3]
1	1975	-	209	1867	-	4051	38
2+3	2872	-	638	2554	-	6064	54
4+5	5391	-	586	1346	-	7323	68
6+7	3837	-	441	1917	-	6195	57
8	-	2274	598	1179	-	4052	-
10	-	808	-	301	6629	7738	-
11	-	1031	219	361	-	1611	-
12	-	1804	-	-	-	1804	-
Total							217

5 Results

5.1 Stormwater management alternatives at Selma Lagerlöfs torg

Judgement on the feasibility of techniques outlined in Section 2.3 led to elimination of well-mounted filters in the analysis. These were omitted because employees at *Kretslopp och vatten* have stated that they do not wish to use that sort of technique. They regard the technique unfeasible due to low reliability, high costs and high maintenance. This is also supported by the results of the study by Alm et al. (2015). Thus there are five alternatives (Table 5.1), including a zero alternative with a conventional stormwater pipe network.

Table 5.1 Stormwater management alternatives considered for the case study area Selma Lagerlöfs torg.

Alternative	**Description and theoretical location**
1. Pervious pavement (PP)	Porous asphalt pavement on the streets.
2. Bioretention units/rain gardens (RG)	Rain gardens along the main streets, replacing grass and trees.
3. Underground sedimentation units (US)	Detention pipes at four locations, proposal by Atkins (Section 4.3.4).
4. Underground filter units (UF)	Filter units (*EcoVault* or similar) at the same locations as underground sedimentation units proposed by Atkins. Possibly three units instead of Atkins' four (4+5 and 6+7 combined to one unit).
5. Zero alternative (Z)	Conventional pipe network, no stormwater treatment.

5.2 Criteria

The literature search and questionnaires resulted in a total of 21 criteria distributed among the three categories (Table 5.2).

Table 5.2 Criteria used for evaluation of stormwater management techniques.

Category	Criterion
Environment	Removal of dissolved nutrients Removal of dissolved metals Removal of suspended solids Removal of PAHs Removal of petroleum hydrocarbons Resource use (including energy) Influence on urban biodiversity Handling of contaminated waste
Economy and technology	Investment cost Detention and attenuation Maintenance frequency Maintenance complexity Operational reliability Commercial availability Standardisation potential Life length
Social aspects and health	Aesthetics Acoustics Air quality Potential hazards Children’s consequence

5.3 Scoring and weighting

This section presents the scoring and weighting employed by the environment work group (Table 5.3), the economy and technology work group (Table 5.4) and the social aspects and health work group (Table 5.5).

Table 5.3 Scoring and weighting by the environment work group.

Criterion	Scoring scale	Alternative					SWING weight
		1 PP	2 RG	3 US	4 UF	5 Z	
Removal of dissolved nutrients	0 = insignificant 1 = low 2 = moderate 3 = high	2	3	1	1	0	20
Removal of dissolved metals		1	2	1	2	0	80
Removal of suspended solids		3	3	2	3	1	100
Removal of PAHs		1.5	2	2	2	1	90
Removal of petroleum hydrocarbons		1.5	2	2	2	1	90
Resource use (energy, limited resources)		1	1	1.5	2	0	60
Influence on urban biodiversity	0 = very negative effect 1 = negative effect 2 = no effect 3 = positive effect 4 = very positive effect	2.5	4	2	2	2	100
Origin of contaminated waste	0 = no toxic waste 1 = low amounts 2 = moderate amounts 3 = high amounts	3	2	1	2	0.5	80

The environment work group was the only group who used non-integers for scoring. These intermediate values were used when the group could not reach a decision between two scores. It indicates that some scoring scales may have had insufficient grading. Moreover, there was a misconception regarding scoring of resource use. The group set scores according to a scale where 3 was considered best, although the intention was that the scale should be interpreted so that 3 symbolised high resource use. This was corrected afterwards by the author by translating the highest scores to the lowest and vice-versa.

Table 5.4 Scoring and weighting by the economy and technology work group.

Criterion	**Scoring scale**	**Alternative**					**SWING weight**
		1 PP	**2 RG**	**3 US**	**4 UF**	**5 Z**	
Investment costs	0 = very low 1 = low 2 = moderate 3 = high 4 = very high	2	3	3	4	0	90
Detention and attenuation	0 = no effect 1 = slight effect 2 = adequate effect 3 = good effect	3	3	3	1	0	0
Maintenance frequency	0 = very low 1 = low 2 = moderate 3 = high	1	3	1	3	0	90
Maintenance complexity		3	2	1	2	0	100
Operational reliability (ability to maintain function in changing conditions and under stress)	0 = low 1 = moderate 2 = high 3 = very high	3	1	3	1	3	80
Commercial availability	0 = hardly any market 1 = limited market 2 = easily available	2	1	2	0	2	50
Standardisation potential	0 = non-existent, unique design every time 1 = low 2 = moderate 3 = high	3	1	3	3	3	40
Life length	0 = short 1 = medium 2 = long 3 = very long	2	2	3	3	3	65

The economy and technology working group gave the criterion detention and attenuation a weight of 0, which means that the criterion has no effect on the results. The motivation behind this was that there are no needs for reduction of flows due to the current overcapacity of the stormwater system. Furthermore they stated that if there is a requirement for detention and attenuation it would be a precondition in the selection of solution alternatives rather than a criterion for weighting and scoring. The group also had comments regarding the costs of alternatives and they would like to see life-cycle costs as a criterion. This life cycle cost criterion could then replace investment costs, maintenance frequency and life length.

Table 5.5 Scoring and weighting by the social aspects and health work group.

Criterion	**Scoring scale**	**Alternative**					**SWING weight**
		1 PP	**2 RG**	**3 US**	**4 UF**	**5 Z**	
Aesthetics	0 = very negative effect 1 = negative effect 2 = no effect 3 = positive effect 4 = very positive effect	2	3	2	2	2	100
Acoustics		2	2	2	2	2	40
Air quality		2	3	2	2	2	40
Children's consequence		2	3	2	2	2	100
Potential hazards		2	1	2	2	2	100

The scores set by the social aspects and health work group exhibit small differences. In fact the only alternative that was deemed to have effects on any criteria was rain gardens. This is due to this technique being the only one that is directly visible and apparent to the public. However, the group took the current plans into account, which included the plantation of trees. Had there not been trees planned, the effects would have been greater of the rain gardens. Moreover it can be seen that acoustics did not contribute to any differentiation between the alternatives. Therefore, it can be considered unnecessary for the comparison. The group stated that pervious pavements do have an effect on reducing traffic noise, although it declines rapidly after the first year and will hence have insignificant effect during the course of the pavement lifetime. They also deemed that significant amounts of vegetation is required to achieve noise reduction and that neither rain gardens nor rows of trees and grass is sufficient to have noticeable effect.

Participants at the workshop agreed that environment was the most important category (Table 5.6), since the main purpose of stormwater treatment is to preserve the natural environment. Economy and technology was also given a relatively high weight of 80, with the motivation that the function and economic viability are key parameters and a very expensive solution will not be used regardless of the environmental benefits. Social aspects and health was given a relatively low weight of 20. It was agreed that stormwater management in this case is not greatly affecting the criteria in this category, due to the limited footprint of the solution alternatives. There are other elements of the urban environment that have much larger effect on these aspects.

Table 5.6 Weighting of categories agreed upon in the workshop session.

Category	**SWING weight**	**Resulting weight**
Environment	100	0.5
Economy and technology	80	0.4
Social aspects and health	20	0.1

After deciding on the weighting, the attendants at the workshop were asked whether they thought the weighting employed would in fact represent the weights used by a decision maker in a real situation. The general opinion was then that the decision maker would probably select economy and technology as the most important category.

5.4 MCDA outcome

The analysis of composite priorities showed that, with the scoring and weighting employed, the zero alternative received the highest score (Figure 5.1). This is due to its high performance in economy and technology. Rain gardens had the highest weighted scores in the environment category and slightly higher in the social aspects and health category, although it falls short of other alternatives in economy and technology. The best performing stormwater treatment solution in this analysis is the underground sedimentation units.

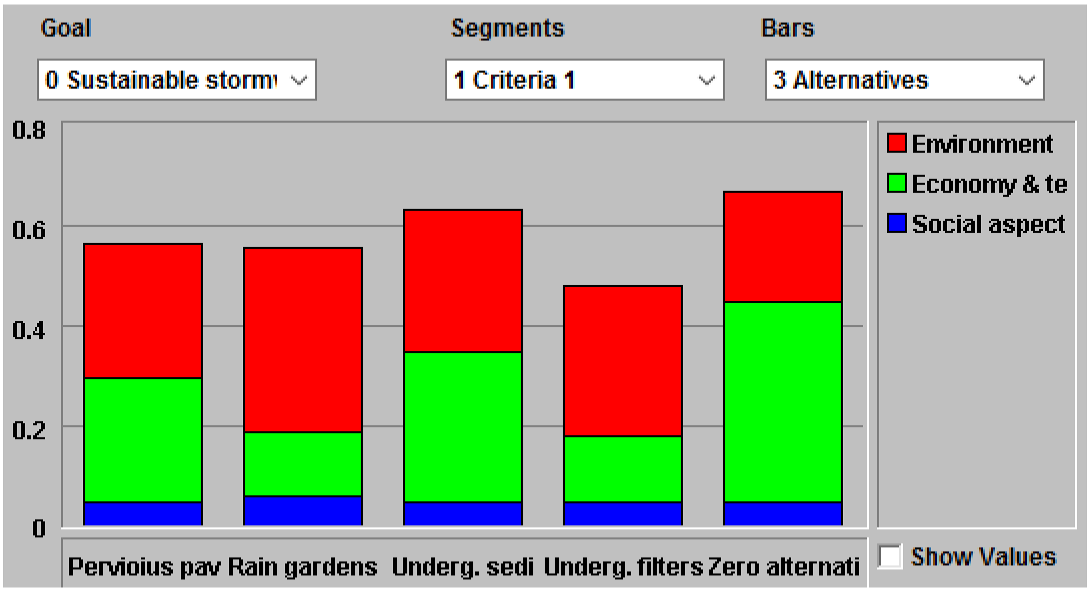


Figure 5.1 Composite priorities calculated in Web-HIPRE.

5.5 Sensitivity analysis

The sensitivity analysis of the environment category weighting (Figure 5.2) showed that there are three potential top alternatives (assuming a constant relation of economy and technology to social aspects and health of 4:1). The zero alternative is the best performing alternative until more than 60 % of the total weight is attributed to environment, where then underground sedimentation units have higher values. When the environment weight is set to more than 65 %, rain gardens constitute the best performing alternative. If there are demands for some kind of stormwater treatment (i.e. zero alternative not considered an option), underground sedimentation units will outperform the other alternatives over most of the weighting spectrum. A sensitivity analysis for the economy category is essentially a mirror image of Figure 5.2. Changing the weight of the social aspects and health category does not significantly impact the final results because scores are very similar among the different alternatives.

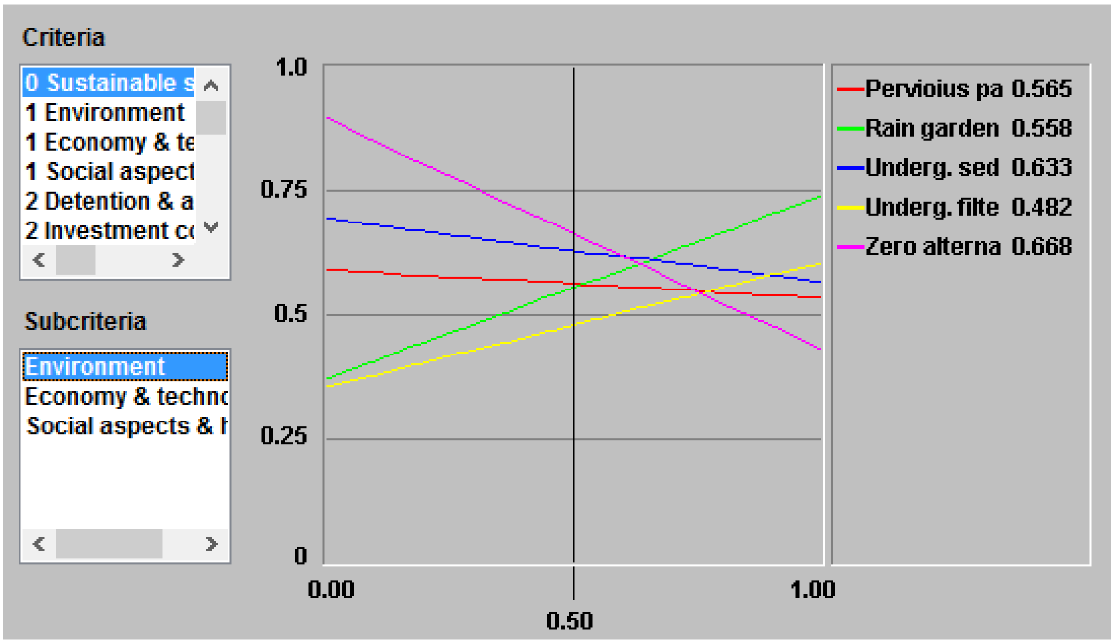


Figure 5.2 Sensitivity analysis of the environment category, in Web-HIPRE.

Weighting of criteria within categories also has significant effects on the final results. For example, having a higher weight on detention and attenuation (current weight 0) in the economy and technology category would have increased the scores of all treatment solutions, especially pervious pavements, rain gardens and underground sedimentation units, compared to the zero alternative (Table 5.4).

5.6 Workshop synthesis discussion

According to the workshop participants'' experiences, *Stadsbyggnadskontoret* often states that there are many aspects to consider in planning, and that stormwater therefore is often assessed in later stages of the process. A consequence is that surfaces that would have been suitable for stormwater management are no longer available since their use has been defined for other purposes. Even when consideration is dedicated to stormwater management at early stages of planning there is sometimes lack of follow-up to ensure that it is still considered when plans are finalized. There may also be changes in plans, often towards densification since the local politicians generally consider dwellings to be the utmost priority. It is important to comply with political decisions, as politicians are the decision makers, although it is very important to provide them with clear and informative decision aid including potential consequences that certain decisions may have.

Another problem that was discussed during the workshop was the limited information of the various performances of stormwater management techniques. This lack of information presents uncertainties, which makes decision makers more reluctant to invest in those techniques. Furthermore, projects have to be large enough to allow for substantial investigations. On the other hand, large projects may cause decision makers to be even more reluctant to try new technologies. It is therefore important that constructed solutions are monitored and evaluated to add to the current knowledge and simplify future judgement. Also international experiences should be searched for. This applies to for example rain gardens.

An attendant with knowledge of the study area explained that there are vibration problems due to the clay, and that this has to be considered in the feasibility study of alternatives. Heavy traffic could cause damage to properties and it may be inappropriate to place additional structures in the ground under or adjacent to the roads.

It was concluded that the issue of responsibility within the municipality is not easily resolved, since stormwater does not fall inside departmental borders. The same problems are apparent in other parts of Sweden, for example in Stockholm. Communication and understanding is key to succeed in this matter.

Overall, the workshop attendees deemed the MCDA-model to be a good tool for communication. Different stakeholders (municipal departments) have different views on weighting. Knowing this, and discussing it in a workshop session is good for mutual understanding and collaboration. Applied at an early stage of planning it may help to reach an informed decision while there is still time to have space set aside for stormwater management. When MCDA is used there should be representatives from all the involved municipal departments, politicians, residents, local environmental organisations and other potential actors.

5.7 Summary of workshop evaluations

Fourteen out of the fifteen workshop attendants filled in the evaluation, and the responses indicated that the workshop was well appreciated. All respondents answered that their overall impression of the workshop was good or very good and everyone also said that they learned something relevant for their professional careers. According to comments, the learning arose from the discussion with other attendants and that those discussions broadened views and highlighted the need for communication.

Some attendants regarded the scoring and weighting elements as difficult. Others said that even though they thought that instructions were clear, it was difficult to conduct the work due to the many aspects to consider when scoring and weighting. One respondent stated that the criteria were not well defined and therefore open and rather general, which made it difficult to conduct the scoring. It would indeed be preferable to have quantitative scores for criteria, for example determined through modelling. In early stages of planning however, there may not be enough information for proper modelling, which is also time consuming. Therefore it is difficult to have truly quantitative criteria at an early stage. There was also a comment that it is preferable to conduct the weighting prior to the scoring, because otherwise the weighting may be impacted by the scores. Also, many attendants of the workshop session stated that it would be highly relevant to have some representatives from *Stadsbyggnadskontoret* present. Others also mentioned the other municipal departments *Park och natur* and *Fastighetskontoret* as well as local politicians.

Most respondents said that multi-criteria decision analysis seems like a good tool for dealing with the complicated stormwater management problem. They pointed out strengths of the method as a communication tool. Concerns from the respondents were aimed towards the subjectivity of the results, the importance of gathering relevant and different stakeholders and experts, and that using MCDA as a tool might be time consuming in an already time-strained planning process. Moreover, transparency is important and results should be treated as decision support, not a decision. Showing the impact of different weights through sensitivity analysis was appreciated by the workshop attendants. There were comments in the evaluation stating that they would have liked more focus on the weighting since it had a very large impact on the results.

6 Discussion

There is confusion among the municipal departments in Gothenburg regarding responsibilities related to stormwater management. Water issues do not follow jurisdictional boundaries and departments are reluctant to undertake more responsibilities than necessary. Therefore, an internal investigation at the municipality has been initiated to clearly define the responsibilities of each municipal department. Similar problems appear in other regions in Sweden as well, and there is lack of clarity in national legislation (Section 2.4.2). Thus there is a need for improvement in national legislation, to guide municipalities that are struggling with these issues.

Multi-Criteria Decision Analysis (MCDA) provides a structured decision support tool that allow for comparison of multiple alternatives according to many criteria. It is very important to gather relevant stakeholders and experts for workshop sessions, or other ways of conducting MCDA. Some stakeholders may however be reluctant to participate due to lack of interest, which does not facilitate good communication. Input from all concerned parties is relevant in order to reach understanding and acceptance. It is important to keep in mind that the weighting is subjective and represents the opinions of the attendants. Hence the results would probably not be the same in another stakeholder and expert constellation. This is important to consider and communicate to decision makers so that they do not interpret the results as if there is one “best” solution. As one workshop attendant stated in the evaluation, it could be preferable to conduct the weighting prior to the scoring to avoid bias caused by the fact that attendants know the scores. If attendants know the scores, they may for example put a low weight on a criterion if there are small differences in performance between alternatives in that criterion.

As shown in the sensitivity analysis, the weighting of categories can have large effect on the outcome of the results. Results showed that depending on the weighting of the three categories, three alternatives (the zero alternative, underground sedimentation units and rain gardens) could be regarded as the top scoring alternative. For any stormwater treatment alternative to outperform the zero alternative, a high weight must be attributed to the environment. Most likely the economy and technology will be regarded as the most important category in real decision making, as stated by the attendants of the workshop. Therefore it is important to have environmental regulations to ensure protection of the natural environment. If there are demands for stormwater treatment, the zero alternative is not a viable option.

The guideline values for stormwater pollutants in Gothenburg set up by *Miljöförvaltningen* are not legally binding. They are however difficult to achieve. A potential consequence of having guidelines that are hard to comply with is that people may give up trying and that no stormwater treatment solutions are implemented on the grounds that the pollution reduction is not sufficient. In some cases, strict guidelines are appropriate, especially when receiving waters are sensitive to pollution, but the guidelines developed for Gothenburg do not include any differentiation based on the sensitivity of receiving waters. Such an addition in combination with data on the sensitivities of watercourses could facilitate proper allocation of treatment where they provide the greatest benefit.

Although preventive measures were not included in the analysis, they are very important in sustainable stormwater management and can have a significant effect on stormwater quality. Further research on the use of MCDA in stormwater management could include alternatives consisting of preventive measures. Moreover, combinations of different techniques could be investigated. An MCDA may also provide support in designing suitable combinations since the strengths and weaknesses of each technique are identified in the analysis. Thus techniques which complement each other can be identified.

The treatment techniques used for the MCDA in this work are all designed to be suitable for dense urban areas. Hence the alternatives are not similar to those investigated in previous studies, for example Martin et al. (2006), which is more focused towards best management practices (Figure 2.12). Porous pavements and storage tanks are however present both in this study and in Martin et al. (2006). Interestingly, porous pavements are ranked higher than storage tanks in the final evaluation for all three weightings simulated by Martin et al., although in this work the results indicate the opposite. Both the criteria and the weighting schemes used in the two studies are entirely different, which may explain the differences. Also the scoring may differ, since it is based on the experience of workshop attendants. These differences in results further show that results of MCDA are variable and depending on the users. It is important to always regard results of MCDA as decision support rather than a decision in itself.

In this work it was found that a couple of criteria had no effects on differentiating the alternatives in the final results. The criterion ”detention and attenuation” had no effect because its weight was set to zero and acoustics had no effect because all alternatives were given the same score. Furthermore, the scores for removal of PAHs and petroleum hydrocarbons are identical, which could indicate that they are treated in the same way. Hence they could potentially be aggregated into one criterion, removal of organic contaminants. There may be overlaps also in other criteria, although it has not been thoroughly studied in this work. Aggregating investment cost, maintenance frequency and lifetime into a life-cycle cost, as proposed by the economy and technology work group, could further facilitate the understanding of the advantages and disadvantages of different alternatives.

From some comments in the workshop evaluation it was apparent that the semi-quantitative scoring and the weighting elements were regarded as difficult. This indicates that further clarification of the criteria and their respective scales would be useful. All difficulties can however not be removed because of different interpretations and experiences among the attendants. This is also positive since it creates a platform for discussion. When details of a project area are well defined, quantitative scoring could be utilised through modelling and other calculations. This would however be more time consuming, which is already a concern about the use of MCDA as a tool in planning since the planning process is time-strained. Therefore, qualitative or semi-quantitative scoring may be suitable for early stages of planning, when there is limited information about a project area. This has also been noted by Norrman et al. (2016).

The information about the case study area in this work was obtained mainly from a previously conducted stormwater investigation and other zoning documents. Since that information is available at such an early stage, the use of a qualitative MCDA for evaluation of stormwater management alternatives could potentially be incorporated into stormwater investigations in zonings. At that stage of planning there is still time to allocate space for stormwater management. When space can be utilised for stormwater management, it is important to include this space usage as a criterion in the MCDA model. A stormwater investigation should preferably include both public space and private properties and it would provide the decision makers with a solid base for an informed decision of technical solutions at a project area. There could however also be stormwater management options outside of a project area, which was not considered in this work. This larger scale of stormwater infrastructure may be handled in comprehensive plans or municipal stormwater strategies. At that level of planning entire drainage areas could be investigated to find strategic locations for large stormwater facilities such as ponds, and also to determine vulnerable areas and other areas of particular concern.

7 Conclusions

Multi-Criteria Decision Analysis with semi-quantitative or qualitative scoring could potentially be utilised in stormwater investigations as part of zonings. Information required to conduct an analysis like the one in this work is obtainable in the early stage of the planning process. The scoring and weighting employed in the MCDA resulted in the zero alternative being the highest scoring alternative, despite the fact that it is not legally feasible. The high total score was due to its (not surprisingly) high performance in the economy and technology category, i.e. due to the low investment and maintenance costs. Among the treatment techniques, the underground sedimentation units had the highest score. MCDA results should not be followed blindly as they are merely for decision support, but they may provide good indications of the advantages and disadvantages of different alternatives. For example, rain gardens have relatively high performance in the environmental criteria compared to other stormwater management techniques suitable for dense urban areas. In terms of economy and technology, underground sedimentation units perform well. It is important to point out that the results in this study are case-specific.

It may be preferable to conduct the weighting prior to the scoring to avoid unnecessary bias that could arise when attendants know the outcome of the scoring. Criteria should be determined on a project-specific basis and be based on well-defined goals. Although not relevant in this work, space consumed for stormwater management alternatives is an essential criterion to consider.

The strength of using MCDA at an early stage of stormwater management in planning is that it creates good grounds for discussion and it allows exchange of information and knowledge between stakeholders. Discussing solutions at an early stage is essential if space is to be allocated for stormwater management. It is also important to note that solutions may also be present outside of actual project areas. Hence, as part of comprehensive plans or stormwater management strategies, there should be strategic analyses on drainage area-wide scales to determine potential sustainable stormwater infrastructure options.

8 References

Aceves, M. C., Fuamba, M. (2016). Methodology for Selecting Best Management Practices Integrating Multiple Stakeholders and Criteria. Part 1: Methodology. *Water (2016) vol. 8, issue 2, article 55*. Basel: MDPI AG.

Aldheimer, G. (2004). *Dagvatten – Avsättningsmagasin Ryska Smällen.* Stockholm: Stockholm Vatten. Report 11-2004

Alm, H., Åström, A. (2014). *Kommunal dagvattenhantering – juridiska och finansiella aspekter.* Stockholm: Svenskt Vatten AB. Report 2014-07

Alm, H., Banach, A., Larm, T. (2010). *Förekomst och rening av prioriterade ämnen, metaller samt vissa övriga ämnen i dagvatten.* Stockholm: Svenskt Vatten AB. Report 2010-06

Atkins Sweden (2016). *PM dagvattenföroreningar – Selma Lagerlöfs torg*.

Banach, A. et al. (n.y.). *Gestaltning av dagvatten – Exempel och framgångsfaktorer*. Stockholm: SWECO.

Baptista, M. et al. (2007). Multicriteria evaluation for urban storm drainage. *First SWITCH Scientific Meeting; 9-10 Jan, 2007, Birmingham.*

Belton, V., Stewart, T. J. (2002). Problem Structuring. *Multiple Criteria Decision Analysis: An Integrated Approach, pp. 35-78.* Dordrecht: Springer Science + Business Media B.V.

Bergqvist, N. (2014). *Environmental assessment and sustainable stormwater planning with regard to climate change through multi-criteria analysis (MCA) – Case study Guldheden.* Göteborg: Chalmers University of Technology. (Master's thesis at the Department of Civil and Environmental Engineering. Division of GeoEngineering)

Björklund, K., Li, L. (2015). Evaluation of low-cost materials for sorption of hydrophobic pollutants in stormwater. *Journal of Environmental Management 159 (2015), pp. 106-114*. Amsterdam: Elsevier Ltd.

Blecken, G.-T. (2010). *Biofiltration Technologies for Stormwater Quality Treatment*. Luleå: Universitetstryckeriet.

Blecken, G.-T., Marsalek, J., Viklander, M. (2010a). Laboratory Study of Stormwater Biofiltration in Low Temperatures: Total and Dissolved Metal Removals and Fates. *Water, Air & Soil Pollution (2011) 219, pp. 303-317.* Dordrecht: Springer Science + Business Media B. V.

Blecken, G.-T., Zinger, Y., Deletic, A., Fletcher, T. D., Hedström, A., Viklander, M. (2010b). Laboratory study on stormwater biofiltration: Nutrient and sediment removal in cold temperatures. *Journal of Hydrology 394 (2010), pp. 507-514.* Amsterdam: Elsevier B. V.

Booth, D., Leavitt, J. (1999). Field Evaluation of Permeable Pavement Systems for Improved Stormwater Management. *Journal of the American Planning Association, Vol. 65, No. 3, pp. 314-325.* Chicago: American Planning Association.

Boverket (2014). Vad är en detaljplan. *PBL Kunskapsbanken: Detaljplan – Detaljplaneinstrumentet.* http://www.boverket.se/sv/PBL-kunskapsbanken/detaljplan/detaljplaneinstrumentet/vad-ar-detaljplan1/ (2016-04-01)

Boverket (2015a). Kommunal fysisk planering. *Boverket: Samhällsplanering – Kommunal planering*. http://www.boverket.se/sv/samhallsplanering/kommunal-planering/ (2016-04-01)

Boverket (2015b). Dagvatten i den översiktliga planeringen. *PBL Kunskapsbanken: Temadelar detaljplan – Dagvatten i detaljplan*. http://www.boverket.se/sv/PBL-kunskapsbanken/detaljplan/temadelar-detaljplan/dagvatten-i-detaljplan/dagvatten-i-den-oversiktliga-planeringen/ (2016-04-01)

Boverket (2016a). Områdesbestämmelser reglerar markanvändningen i kommunen. *Boverket: Samhällsplanering – Kommunal planering*. http://www.boverket.se/sv/samhallsplanering/kommunal-planering/omradesbestammelser/ (2016-04-01)

Boverket (2016b). Översiktsplanen. *PBL Kunskapsbanken: Översiktsplan* . http://www.boverket.se/sv/PBL-kunskapsbanken/oversiktsplan/oversiktsplanens-funktion/ (2016-04-01)

Butler, D., Davies, J. W. (2011). *Urban drainage, 3rd edition*. Abingdon: Spon press.

Bäckström, M., Viklander, M. (2000) Integrated stormwater management in cold climates. *Journal of Environmental Science and Health, Part A, 35:8, pp. 1237-1249*. Abingdon: Taylor & Francis Group.

Chislock, M. F., Doster, E., Zitomer, R. A. & Wilson, A. E. (2013) Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems. *Nature Education Knowledge* 4(4):10

City of Portland (2016). Sustainable Stormwater Management. *The City of Portland, Oregon – Environmental Services: working for clean rivers*. https://www.portlandoregon.gov/bes/34598 (2016-04-28)

Dahlquist, H. (2009). Tyst asfalt fungerar dåligt. *NyTeknik.* http://www.nyteknik.se/bygg/tyst-asfalt-fungerar-daligt-6410290 (2016-04-27)

Davis, A. P., McCuen, R. H. (2005). Low impact development. *Stormwater management for smart growth, pp. 337-358*. New York: Springer Science + Business Media.

DCLG, UK Department for Communities and Local Government (2009). *Multi-criteria analysis: a manual.* Wetherby: Communities and Local Government Publications.

DiBlasi, C. J. et al. (2008). Removal and Fate of Polycyclic Aromatic Hydrocarbon Pollutants in an Urban Stormater Bioretention Facility. *Environmental Science & Technology 43 (2009), pp. 494-502.* Washington: ACS Publications.

Duffy, A. et al. (2008). A cost comparison of traditional drainage and SUDS in Scotland. *Water Science Technology, 57 (9), pp. 1451-1459.* London: IWA Publishing.

Earth Pledge (2005). *Green Roofs – Ecological Design and Construction*. Atglen: Schiffer Publishing Ltd.

Edwards, W., Barron, F. H. (1994). SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement. *Organizational behaviour and human decision processes 60 (1994), pp. 306-325.* Amsterdam: Academic Press Inc.

ESI, EcoSense International (n.y.). *EcoVault brochure.* Available at: http://ecosenseint.com/wp-content/uploads/2015/07/EcoVault_Brochure1.pdf (2016-04-28)

Ellis, J. B. et al. (2004). Multicriteria decision approaches to support sustainable drainage options for the treatment of highway and urban runoff. *Science of the Total Environment -334 – 335 (2004), pp. 251-260.* Amsterdam: Elsevier B.V.

Ellis, J. B., Mitchell, G. (2006). Urban diffuse pollution: key data information approaches for the Water Framework Directive. *Water and Environment Journal 20 (2006), pp. 19-26.* London: CIWEM.

Elmefors, E. (2014). Dagvattenrening I mark och dränerande hårdgjorda system. *Grågröna systemlösningar för hållbara städer.* Stockholm: Vinnova.

Erickson, A. J. et al. (2010). Maintenance for Stormwater Treatment Practices. *Journal of Contemporary Water Research & Education 146 (2010), pp. 75-82.*

Erickson, A. J., Weiss, P. T., Gulliver, J. S. (2013a). Stormwater treatment practices. *Optimizing Stormwater Treatment Practices: A Handbook of Assessment and Maintenance, pp. 35-52*. New York: Springer Science+Business Media.

Erickson, A. J., Weiss, P. T., Gulliver, J. S. (2013b). Maintenance of stormwater treatment practices. *Optimizing Stormwater Treatment Practices: A Handbook of Assessment and Maintenance, pp. 265-283*. New York: Springer Science+Business Media.

European Comission (2015). Introduction to the new EU Water Framework Directive. *European Comission – Environment*. http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm (2016-02-18)

Fletcher, T. D. et al. (2013). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal (2015) Vol. 12, No. 7, pp. 525-542.* Boca Raton: Taylor & Francis.

FlexiClean (n.y.). *FlexiClean Folder*. Downloaded from http://flexiclean.eu/flexiclean/SV/84/broschyrer-och-info (2016-04-28)

Gamper, C. D., Thöni, M., Weck-Hannemann, H. (2006). A conceptual approach to the use of Cost Benefit and Multi Criteria Analysis in natural hazard management. *Natural Hazards and Earth System Sciences 6 (2006), pp. 293-302.* Göttingen: Copernicus Publications.

Göteborg Vatten (2011). *Åtgärdsplan Avloppsavledning 2010 – Handlingsplan för Göteborgs avloppsavledning*. Göteborg: Göteborgs Stad.

Göteborgs Stad (n.y.). Fackförvaltningar. *Göteborgs Stad – Kommun & Politik*. http://goteborg.se/wps/portal/invanare/kommun-o-politik/kommunens-organisation/forvaltningar/fackforvaltningar (2016-02-24)

Havs- och vattenmyndigheten (2014). Ramdirektivet för vatten – utgångspunkt för svensk vattenförvaltning. *Havs- och vattenmyndigheten – Miljömål och direktiv*. https://www.havochvatten.se/hav/samordning--fakta/miljomal--direktiv/vattendirektivet.html (2016-02-22)

Hjertberg, L. (2015). Regnrabatt renar dubbelt så bra. *Vårt Göteborg – Göteborgs Stads nyhetstidning.* http://www.vartgoteborg.se/prod/sk/vargotnu.nsf/1/miljo_o_kretslopp,regnrabatt_renar_dubbelt_sa_bra (2016-01-26)

Jia, H. et al. (2013). Development of a multi-criteria index ranking system for urban runoff best management practices (BMPs) selection. *Environmental Monitoring Assessment 185 (2013), pp. 7915-7933.* Dordrecht: Springer Science+Business Media.

Kalmykova, Y. et al. (2008). Peat filter performance under changing environmental conditions. *Journal of Hazardous Materials 166 (2009), pp. 389-393.* Amsterdam: Elsevier B.V.

Kim, K-H. et al. (2013). A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects. *Environment International 60 (2013), pp. 71-80.* Amsterdam: Elsevier Ltd.

Kretsloppskontoret (2010). *Dagvatten, så här gör vi! – Handbok för kommunal planering och förvaltning.* Göteborg: Göteborgs Stad.

Lai, E., Lundie, S., Ashbolt, N. J. (2008). Review of multi-criteria decision aid for integrated sustainability assessment of urban water systems. *Urban Water Journal vol. 5, No. 4, December 2008, pp. 315-327.* Abingdon: Taylor & Francis.

Larsson, K. (2010). Satsning på tyst asfalt bromsas trots miljövinst. *Expressen.* http://www.expressen.se/nyheter/dokument/satsning-pa-tyst-asfalt-bromsas-trots-miljovinst/ (2016-04-27)

Larsson, M et al. (2014). Modellering av vattenflöden och föroreningsbelastning för grågröna dagvattenlösningar. *Grågröna systemlösningar för hållbara städer.* Stockholm: Vinnova. Report 2012-01271

Le Coustumer, S. et al. (2009). Hydraulic performance of biofilter systems for stormwater management: Influences of design and operation. *Journal of Hydrology 376 (2009), pp. 16-23.* Amsterdam: Elsevier B.V.

Lindfors, T., Bodin-Sköld, H., Larm, T. (2014). Inventering av dagvattenlösningar för urbana miljöer. *Grågröna systemlösningar för hållbara städer.* Stockholm: Vinnova.

LTU, Luleå tekniska universitet (2014). Projektområden. *Forskning: GrönNano*. http://www.ltu.se/research/subjects/VA-teknik/GreenNano/Projektorganisation (2016-04-06)

LTU, Luleå tekniska universitet (2015). Undersökning av Sveriges första biofilter. *Forskning: GrönNano – Nyheter och aktuellt.* http://www.ltu.se/research/subjects/VA-teknik/GreenNano/Nyheter/Undersokning-av-Sveriges-forsta-biofilter-1.144509 (2016-02-15)

LTU, Luleå tekniska universitet (2016). Resultat från kommunworkshopar om förändrad planeringsprocess. *Forskning: GrönNano – Nyheter och aktuellt.* http://www.ltu.se/research/subjects/VA-teknik/GreenNano/Nyheter/Resultat-fran-kommunworkshopar-om-forandrad-planeringsprocess-1.148722 (2016-04-06)

Martin, C., Ruperd, Y., Legret, M. (2006). Urban stormwater drainage management: The development of a multicriteria decision aid approach for best management practices. *European Journal of Operational Research 181 (2007), pp. 338-349.* Amsterdam: Elsevier B.V.

McIntosh, N. D. (2015). *A Study of Underground Stormwater Detention Chambers and the Creation of the Model for Underground Detention of Sediment*. Ann Arbor: ProQuest LLC.

Miljöförvaltningen (2013). *Miljöförvaltningens riktlinjer och riktvärden för utsläpp av förorenat vatten till recipient och dagvatten*. R 2013: 10. ISBN nr: 1401-2448. Göteborg: Göteborgs Stad.

Munier, N. (2011). *A Strategy for Using Multicritera Analysis in Decision-Making – A guide for Simple and Complex Environmental Projects.* Dordrecht: Springer Science+Business Media B.V.

Mustajoki, J., Hämäläinen, R. P. (2000). Web-HIPRE: Global decision support by value tree and AHP analysis. *INFOR vol. 38, no 3(2000), pp. 208-220.* Toronto: Canadian Operational Research Society.

Norrman, J. et al. (2016). Integration of the subsurface and the surface sectors for a more holistic approach for sustainable redevelopment of urban brownfields. *Science of the Total Environment (2016) [Article in press].* Amsterdam: Elsevier B.V.

Ramböll (2013). Dagvattenutredning. *Detaljplan för område vid Selma Lagerlöfs Torg – etapp 1, inom stadsdelen Backa i Göteborg*.

Reichman, S. M. (2002). *The Responses of Plants to Metal Toxicity: A review focusing on Copper, Manganese and Zinc.* Melbourne: Australian Minerals & Energy Environment Foundation.

Rout, G. R., Das, P. (2009). Effect of Metal Toxicity on Plant Growth and Metabolism: I. Zinc. *Sustainable Agriculture, pp. 873-884*. Dordrecht: Springer Science+Business Media B. V.

Ryerson University (n.y.). Runoff Characteristics. *Stormwater Management.* http://www.civil.ryerson.ca/Stormwater/menu_1/index.htm#top (2016-04-28)

Scholz, M., Grabowiecki, P. (2006). Review of permeable pavement systems. *Building and Environment 42 (2007), pp. 3830-3836.* Amsterdam: Elsevier Ltd.

Schuster, J. (2016). Chlorosis. *University of Illinois Extension - Focus on Plant Problems.* http://extension.illinois.edu/focus/index.cfm?problem=chlorosis (2016-03-18)

SMRC, Stormwater Manager's Resource Center (n.y.). Stormwater Management Fact Sheet: Sand and Organic Filter. *The Stormwater Manager's Resource Center*. http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Filtering%20Practice/Sand%20and%20Organic%20Filter%20Strip.htm (2016-04-26)

Stadsbyggnadskontoret (2008). *(20) Backa – beskrivning av stadsdelen*. Göteborg: Göteborgs Stad.

Stadsbyggnadskontoret (2009). *Översiktsplan för Göteborg – Del 1: Utgångspunkter och strategier.* Göteborg: Göteborgs Stad.

Stadsbyggnadskontoret (2014). *Detaljplan för område vid Selma Lagerlöfs torg, etapp 1 inom stadsdelen Backa i Göteborg*. Göteborg: Göteborgs Stad.

Stockholms Stad (2016). Buller från trafiken. *Stockholms Stad: Trafik & Stadsplanering.* http://www.stockholm.se/TrafikStadsplanering/Trafik-och-resor-/Trafik-och-miljo/Trafikbuller/?kontakt= (2016-04-27)

StormTac (2015). About the model. *StormTac Storm water solutions*. http://www.stormtac.com/Model.php (2016-01-21)

StormwaterRx LLC (2015). Total Suspended Solids or Suspended Solids. *Resources – Industrial Pollutants.* http://www.stormwaterx.com/Resources/IndustrialPollutants/TSS.aspx (2016-03-18)

Svenskt Vatten (2011). *P105: Hållbar dag- och dränvattenhantering – råd vid planering och utförande*. Stockholm: Svenskt Vatten AB.

Svenskt Vatten (2016). *P110: Avledning av dag-, drän- och spillvatten – Del 1 – Policy och funktionskrav för samhällens avvattning.* Stockholm: Svenskt Vatten AB.

US EPA, United States Environmental Protection Agency (1999a). *Storm Water Technology Fact Sheet – Porous Pavement.* Washington: US EPA Office of Water. EPA 832-F-99-023.

US EPA, United States Environmental Protection Agency (1999b). *Storm Water Technology Fact Sheet – Sand Filters.* Washington: US EPA Office of Water. EPA 832-F-99-007.

US FHWA, United States Federal Highway Administration (n.y.). Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring. *Environmental Review Toolkit: Water, Wetlands, and Wildlife – Storm Water Management.* https://www.environment.fhwa.dot.gov/ecosystems/ultraurb/uubmp3p1.asp (2016-02-29)

Van der Peck, M. (2014). *Soil and water contamination*. 2nd Edition. Leiden: CRC Press.

Wemmel Ljung, S. (2015). Kommunerna är vårt hopp. *Stadsbyggnad 6 (2015): Tema klimat och vatten, pp. 6-9*. Stockholm: Svenska Kommunaltekniska Föreningen.

Winston, R. J. et al. (2015). Maintenance measures for preservation and recovery of permeable pavement surface infiltration rate – The effects of street sweeping, vacuum cleaning, high pressure washing, and milling. *Journal of Environmental Management 169 (2016), pp. 132-144.* Amsterdam: Elsevier Ltd.

Woods-Ballard, B. et al. (2015a). Pervious pavements. *The SuDS Manual, pp. 386-435*. London: CIRIA.

Woods-Ballard, B. et al. (2015b). Bioretention systems. *The SuDS Manual, pp. 332-359.* London: CIRIA.

Woods-Ballard, B. et al. (2015c). Attenuation storage tanks. *The SuDS Manual, pp. 436-471.* London: CIRIA.

Woods-Ballard, B. et al. (2015d). Proprietary treatment systems. *The SuDS Manual, pp. 270-289.* London: CIRIA.¨

Woods-Ballard, B. et al. (2015e). Pollution prevention strategies. *The SuDS Manual, pp. 596-603.* London: CIRIA.

WWAP, United Nations World Water Assessment Programme (2015). *The United Nations Water Development Report 2015: Water for a Sustainable World*. Paris: UNESCO.

Young, K. D. et al. (2010). Application of the Analytic Hierarchy Process for Selecting and Modeling Stormwater Best Management Practices. *Journal of*

Contemporary Water Research & Education 146 (2010), pp. 50-63. Carbondale: Universities Council on Water Resources.

Zhang, K. et al. (2014). The validation of stormwater biofilters for micropollutant removal using in situ challenge tests. *Ecological Enginnering 67 (2014), pp. 1-10.* Amsterdam: Elsevier B. V.

Zou, S., Yao, S., Ni, J. (2014). High-efficient nitrogen removal by coupling enriched autotrophic-nitrification and aerobic-denitrification consortiums at cold temperature. *Bioresource Technology 161 (2014), pp. 288-296.* Amsterdam: Elsevier Ltd.

Appendix I – StormTac simulation results

The following text describes the StormTac simulation performed by Atkins for Selma Lagerlöfs torg. It is a direct translation of PM – Dagvattenföroreningar Selma, originally written by Atkins.

The program used was StormTac WEB v. 15.3.2.

For the calculations at Selma Lagerlöfs torg a yearly average downpour of 761 mm/year measured in Gothenburg between the years 1961 and 1990 was used. This downpour was adjusted to 837 mm/year using a correction factor of 1.1 to account for measuring errors. The adjusted downpour along with estimated runoff coefficients and the land use of the area form the basis of the calculations.

Pollutant levels and loads were calculated for the following contaminants: phosphorous (P), nitrogen (N), lead (Pb), copper (Cu), zinc (Zn), cadmium (Cd), chromium (Cr), nickel (Ni), mercury (Hg), suspended solids (SS), oil, benzo(a)pyrene (BaP), arsenic (As), polychlorinated biphenyls (PCB), tributyltin (TBT), benzene and total organic carbon (TOC). The calculated pollutant levels were compared with the guideline values set up by Miljöförvaltningen.

There are guideline values also for the pollutant methyl *tert*-buthyl ether (MTBE), although that specific pollutant cannot yet be modelled using the StormTac software and was therefore not included.

The land use after exploitation was estimated from the zoning.

The extent of stormwater treatment measures within the area can vary depending on the land use. The starting-point is site-specific treatment. Not all surfaces give rise to treatment needs, for example squares and local streets. Judgement shall be based on pollutant loads. Twelve different sub-areas have therefore been identified and analysed. The division in areas is based on land use and technical and practical feasibility.

The amounts of traffic for the local streets as well as the main street were estimated from measured average annual daily traffic (AADT).

StormTac calculations show that the guidelines are exceeded for phosphorous, nitrogen, lead, copper, zinc, chromium and suspended solids in most of the twelve sub-areas.

Sub-area 10 composes 19 % of the total area and consists of vegetated areas, paved areas for walking and biking and city square. Therefore the stormwater is less contaminated, especially in terms of phosphorous, lead, zinc, mercury and suspended solids. This is the only area where Hg and SS are below guideline values.

Sub-area 9, which consists of a smaller parking lot, has the lowest nitrogen level. This is the only area where the nitrogen level is below guideline values.

Stormwater from sub-areas with local streets is less polluted than that from areas with main streets in terms of phosphorous and zinc, although the guidelines are exceeded in all sub-areas.

Characterization of the different sub-areas in the StormTac simulation. The values presented in this table were used as input to the model.

Sub-area	**Type of surface**	**Area (ha)**	**Runoff coefficient, Φ**	**AADT**
	Main street	0.1975	0.85	8900
1	Pedestrian and bike path	0.1867	0.85	
	Grass/vegetation	0.0209	0.10	
	Main street	0.1222	0.85	8000
2	Pedestrian and bike path	0.1268	0.85	
	Grass/vegetation	0.0095	0.10	
	Main street	0.1650	0.85	7815
3	Pedestrian and bike path	0.1285	0.85	
	Grass/vegetation	0.0543	0.10	
	Main street	0.2563	0.85	9900
4	Pedestrian and bike path	0.0318	0.85	
	Grass/vegetation	0.0168	0.10	
	Main street	0.2828	0.85	9900
5	Pedestrian and bike path	0.1027	0.85	
	Grass/vegetation	0.0418	0.10	
	Main street	0.2332	0.85	8400
6	Pedestrian and bike path	0.1393	0.85	
	Grass/vegetation	0.0190	0.10	
	Main street	0.1505	0.85	8400
7	Pedestrian and bike path	0.0524	0.85	
	Grass/vegetation	0.0252	0.10	
	Local street	0.2274	0.85	1000
8	Pedestrian and bike path	0.1179	0.85	
	Grass/vegetation	0.0598	0.10	
9	Parking	0.0877	0.85	1000
	Local street	0.0808	0.85	1000
10	City square	0.6629	0.85	
	Pedestrian and bike path	0.0301	0.10	
	Local street	0.1031	0.85	1000
11	Pedestrian and bike path	0.0361	0.85	
	Grass/vegetation	0.0219	0.10	
12	Local street	0.1804	0.85	1000

ATKINS

Estimated pollutants in stormwater after exploitation
at Selma Lagerlöfs torg

Substance/parameter	Guideline	Sub-area 1	2	3	4	5	6	7	8	9	10	11	12
	Pollutant concentration, µg/l												
P	**50**	150	150	140	160	160	150	150	130	110	87	130	130
N	**1250**	2100	2000	2000	2100	2100	2100	2100	2000	1200	1800	2100	2200
Pb	**14**	6,7	6,1	6,3	9,9	9,7	6,9	7,8	3,4	35	2,7	3,4	3,6
Cu	**10**	28	26	26	33	32	28	29	20	40	16	20	21
Zn	**30**	87	74	79	130	130	88	100	35	160	31	36	40
Cd	**0,4**	0,29	0,29	0,28	0,3	0,3	0,29	0,29	0,25	0,61	0,18	0,25	0,26
Cr	**15**	8,4	7,8	7,7	9,7	9,4	8,2	8,5	6,3	16	3,7	6,4	6,8
Ni	**40**	5,5	5	5	6,7	6,6	5,4	5,7	3,7	4,8	2,3	3,8	4
Hg	**0,05**	0,073	0,072	0,069	0,072	0,07	0,072	0,07	0,069	0,1	0,045	0,07	0,073
SS	**25000**	44000	39000	44000	70000	69000	47000	57000	41000	190000	13000	44000	61000
Oil index	**1000**	720	710	680	730	710	710	700	670	840	400	680	710
BaP	**0,05**	0,013	0,013	0,012	0,017	0,016	0,013	0,014	0,0092	0,062	0,0091	0,0093	0,01
Benzene	**10**	3,7	3,7	3,5	3,6	3,5	3,6	3,6	3,5	1,5	0,59	3,5	3,6
TBT	**0,001**	0,0016	0,0015	0,0015	0,0015	0,0015	0,0015	0,0015	0,0015	0,11	0,0018	0,0015	0,0015
As	**15**	2,6	2,4	2,4	2,3	2,3	2,4	2,4	2,4	2,2	2,6	2,4	2,2
TOC	**12000**	20000	20000	19000	20000	20000	20000	20000	19000	18000	18000	19000	19000
PCB28	**0.014***	0,021	0,021	0,02	0,021	0,02	0,021	0,02	0,02	0,021	0,021	0,02	0,021
PCB101		0,0094	0,0094	0,0091	0,0094	0,0092	0,0094	0,0092	0,0091	0,0098	0,0091	0,0092	0,0095
PCB138		0,002	0,002	0,0019	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002	0,002
PCB153		0,0019	0,0019	0,0018	0,0019	0,0018	0,0019	0,0018	0,0018	0,0021	0,0019	0,0018	0,0019
PCB180		0,002	0,002	0,0019	0,002	0,0019	0,002	0,0019	0,0019	0,0023	0,002	0,0019	0,002
		Land use, m^2											
Main street (AADT 9900)		1975			2563	2828							
Main street (AADT 8900)													
Main street (AADT 8400)							2332	1505					
Main street (AADT 8000)			1222	1650									
Main street (AADT 1000)									2274		808	1031	1804
Grass/vegetation		209	95	543	168	418	190	252	598			219	
BW-pavement		1867	1268	1285	318	1027	1393	524	1179		301	361	
Parking										877			
City square											6629		
Total land use		**4051**	**2585**	**3479**	**3049**	**4274**	**3915**	**2281**	**4052**	**877**	**7738**	**1611**	**1804**

* Total PCB

ATKINS

Estimated pollutants in stormwater after exploitation
at Selma Lagerlöfs torg

Substance/parameter	Sub-area											
	1	2	3	4	5	6	7	8	9	10	11	12
	Pollutant load, kg/year											
P	0,46	0,29	0,36	0,37	0,4	0,4	0,24	0,38	0,079	0,53	0,15	0,18
N	6,6	4	5	5	5,4	5,5	3,4	5,9	0,81	11	2,4	3,1
Pb	0,021	0,012	0,016	0,023	0,025	0,019	0,013	0,0098	0,024	0,016	0,0039	0,005
Cu	0,086	0,052	0,065	0,076	0,082	0,074	0,047	0,059	0,028	0,098	0,023	0,03
Zn	0,27	0,15	0,2	0,31	0,33	0,24	0,17	0,1	0,11	0,19	0,041	0,056
Cd	0,00089	0,00056	0,00069	0,0007	0,00076	0,00078	0,00047	0,00073	0,00043	0,0011	0,00029	0,00036
Cr	0,026	0,015	0,019	0,022	0,024	0,022	0,014	0,018	0,011	0,023	0,0073	0,0095
Ni	0,017	0,0099	0,012	0,016	0,017	0,015	0,0093	0,011	0,0033	0,014	0,0043	0,0056
Hg	0,00023	0,00014	0,00017	0,00017	0,00018	0,00019	0,00011	0,0002	0,00007	0,00027	0,00008	0,0001
SS	130	78	110	160	180	130	93	120	130	80	50	85
Oil index	2,2	1,4	1,7	1,7	1,8	1,9	1,1	1,9	0,59	2,4	0,78	1
BaP	0,000041	0,000025	0,000031	0,000039	0,000042	0,000036	0,000023	0,000027	0,000044	0,000055	0,000011	0,000014
Benzene	0,011	0,0072	0,0088	0,0083	0,009	0,0098	0,0058	0,01	0,0011	0,0036	0,0041	0,0051
TBT	0,0000048	0,000003	0,0000037	0,0000034	0,0000038	0,0000041	0,0000024	0,0000043	0,000078	0,000011	0,0000017	0,000002
As	0,0079	0,0047	0,0061	0,0053	0,0059	0,0064	0,0038	0,007	0,0015	0,016	0,0027	0,0031
TOC	62	39	48	47	51	54	32	54	13	110	21	27
PCB28	0,000064	0,000041	0,00005	0,000048	0,000052	0,000056	0,000033	0,000058	0,000015	0,00013	0,000023	0,000029
PCB101	0,000029	0,000019	0,000023	0,000022	0,000023	0,000025	0,000015	0,000026	0,0000068	0,000055	0,000011	0,000013
PCB138	0,0000062	0,000004	0,0000049	0,0000046	0,000005	0,000005	0,0000032	0,0000056	0,0000014	0,000012	0,0000022	0,0000028
PCB153	0,0000058	0,0000037	0,0000045	0,0000043	0,0000046	0,000005	0,000003	0,0000052	0,0000015	0,000011	0,0000021	0,0000026
PCB180	0,0000062	0,0000039	0,0000048	0,0000046	0,0000049	0,0000054	0,0000032	0,0000056	0,0000016	0,000012	0,0000022	0,0000028
	Land use, m^2											
Total land use	**4051**	**2585**	**3479**	**3049**	**4274**	**3915**	**2281**	**4052**	**877**	**7738**	**1611**	**1804**

Appendix II – Stormwater Management Alternatives for Ultra-Urban Settings According to US FHWA

Site considerations

BMP	Area Typically Served (ha)	Area Required for BMP[7]	In Situ Soils	Minimum Head Requirement[1] (m)	Configuration	Climate a Significant Factor?[2]
Structural BMPs						
Infiltration Trench	0.8-1.6	2-4%	dependent	0.9-2.4	off-line/on-line	Yes
Infiltration Basin	0.8-8.0	2-4%	dependent	0.9-1.2	off-line	Yes
Bioretention	0.4-20.0	4-10%	independent[3]	0.6-1.2	off-line/on-line	Yes
Detention Ponds	0.8 min	10-20%	independent	0.9-1.8	on-line	No
Wetlands	0.4 min	10%	dependent	0.3-2.4	off-line/on-line	Yes
Detention Tanks[4]	0.4-0.8	0.5-1%	independent	1.5-2.4	off-line	No
Underground Sand Filters	0.8-2.0	2-3%	independent	0.3-2.4	off-line	No
Surface Sand Filters	0.8-2.0	2-3%	independent	1.5-2.4	off-line	Yes
Organic Media Filters	0.8-2.0	2-3%	independent	1.5-2.4	off-line	Yes
Vegetated Swales	0.8-1.6	10-20%	dependent	0.6-1.8	on-line	Yes
Vegetated Filter Strips	< 2	25%[5]	dependent	negligible	on-line	Yes
Oil-Grit Separators	0.4-0.8	< 1%	independent	0.9-1.8	on-line	No
Catch Basin Inserts	< 0.4	None	independent	0.3-0.6	on-line	None
Manufactured Systems	0.4-4	None	independent	1.2	on-line	None
Porous Pavements	0.8-1.6	NA	dependent	NA	NA	Yes
Nonstructural BMPs						
Streetsweeping	NA	NA	independent	NA	NA	No
New and Innovative Practices						
Alum Injection	20-80	< 1%	independent	0	on-line	No
MCTT	0.1-1.0	0.5-1.5	independent	1.2-1.8	off-line	Yes
Biofilters (e.g., StormTreat System)	0.8-2.0	2%	independent	1.2-1.8	off-line	Yes
Vegetated Rock Filters	0.8-2.0	3-5%[6]	independent	0.6-1.2	off-line	Yes

NA = Not Applicable or Not Available
Adapted from Claytor and Schueler, 1996; Young et al., 1996; and others.

1. Either the depth of water in the typical design or the total drop in water level for flow-through designs.
2. Climate issues to consider include prolonged drought and freeze periods.
3. When equipped with an underdrain system.
4. Based on storage of 12.7 mm (0.5 in) of runoff per acre of imperviousness.
5. Minimum recommended for best treatment efficiency.
6. Does not include pretreatment/equalization units required for the design.
7. Expressed as a percent of the total drainage area, can be modified to accommodate ultra-urban conditions.

Management considerations

BMP	Capital Costs	O&M Costs	Maintenance	Training[1]	Effective Life[2]
Structural BMPs					
Infiltration Trench	Moderate to High	Moderate	Sediment/debris removal	Moderate	10-15 years
Infiltration Basin	Moderate	Moderate	Mowing	Low	5-10 years before deep tilling required
Bioretention	Moderate	Low	Mowing/plant replacement	Low	5-20 years[3]
Detention Ponds	Moderate	Low	Annual inspection	Low	20-50 years
Wetlands	Moderate to High	Moderate	Annual inspection/plant replacement	Low	20-50 years
Detention Tanks	Moderate to High	High	Frequent cleanout	Moderate	50-100
Underground Sand Filters	High	High	Annual media removal	Moderate	5-20 years
Surface Sand Filters	Moderate	Moderate	Biannual media cleanout	Low	5-20 years
Organic Media Filters	High	High	Annual media removal	Low	5-20 years
Vegetated Swales	Low	Low	Mowing	Low	5-20 years
Vegetated Filter Strips	Low	Low	Mowing	Low	20-50 years
Oil-Grit Separators	Moderate	High	Frequent cleanout	Moderate	50-100 years
Catch Basin Inserts	Low	Moderate to High	Frequent cleanout	Low	10-20 years
Manufactured Systems	Moderate	Moderate	Periodic cleanout	Low	50-100 years
Porous Pavements	Low	Moderate	Semi-annual vacuum cleaning	Low	15-20 years
Nonstructural BMPs					
Streetsweeping	Moderate	NA	NA	Low	4-8 years
New and Innovative Practices					
Alum Injection	Moderate	Moderate	Periodic chemical resupply	Low	5-20 years[4]
MCTT	High	High	Sand filter cleaning & replacement of oil absorbent material	Low	5-20 years[4]
Biofilters (e.g., StormTreat System)	Moderate	Moderate	Regular cleanout of accumulated sediment/floatables	Low	5-20 years[4]
Vegetated Rock Filters	High	High	Regular inspection and cleanout	Low	5-20 years

NA = Not Applicable or Not Available
Adapted from Young et al., 1996; Claytor and Schueler, 1996; USEPA, 1993; and others.

1. In confined space entry is required, then training is placed at a moderate level; otherwise, training requirements are low.
2. Assumes regular maintenance, occasional removal of accumulated materials, and removal of any clogged media.
3. As a relatively new BMP, the effective life is uncertain. It is reasonable to assume an effective life at least as long as a vegetated swale.
4. Estimated based on best professional judgement.

Removal efficiencies

BMP	TSS	TP	TN	NO_3	Metals	Bacteria	Oil & Grease	TPH	References
Structural BMPs									
Infiltration Trench[1]	75-99	50-75	45-70	NA	75-99	75-98	NA	75	Young et al. (1996)
Infiltration Basin[1]	75-99	50-70	45-70	NA	50-90	75-98	NA	75	Young et al. (1996)
Bioretention[1]	75	50	50	NA	75-80	NA	NA	75	Prince George's County (1993)
Detention Ponds[4]	46-98	20-94	28-50	24-60	24-89	NA	NA	NA	City of Austin (1990); City of Austin (1995); Harper & Herr (1993); Gain (1996); Martin & Smoot (1986);Young et al. (1996); Yu & Benelmouffok (1988); Yu et al. (1993 & 1994)
Wetlands	65	25	20	NA	35-65	NA	NA	NA	USEPA (1993)
Detention Tanks	NA	NA	NA	NA	NA	NA	NA	NA	
Underground Sand Filters	70-90	43-70	30-50	NA	22-91	NA	NA	NA	Bell et al. (1995); Horner & Horner(1995); Young et al. (1996)
Surface Sand Filters	75-92	27-80	27-71	0-23	33-91	NA	NA	NA	City of Austin (1990); Welborn & Veenhuis (1987)
Organic Media Filters	90-95	49	55	NA	48-90	90	90	90	Claytor and Schueler (1996); Stewart (1992); Stormwater Management (1994)
Vegetated Swales	30-90	20-85	0-50	NA	0-90	NA	75	NA	City of Austin (1995); Claytor and Schueler (1996); Kahn et al. (1992); Yousef et al. (1985); Yu & Kaighn (1995); Yu et al. (1993 & 1994)
Vegetated Filter Strips	27-70	20-40	20-40	NA	2-80	NA	NA	NA	Yu and Kaighn (1992); Young et al. (1996)
Oil-Grit Separators	20-40	< 10	< 10	NA	< 10	NA	50-80	NA	Young et al. (1996)
Catch Basin Inserts	NA	NA	NA	NA	NA	NA	up to 90	NA	King County (1995)
Manufactured Systems	NA	NA	NA	NA	NA	NA	up to 96	NA	Bryant et al. (1995)
Porous Pavements	82-95	60-71	80-85	NA	33-99	NA	NA	NA	MWCOG (1983); Hogland et al. (1987); Young et al. (1996)
Nonstructural BMPs									
Streetsweeping[2]	55-93	40-74	42-77	NA	35-85	NA	NA	NA	NVPDC (1992)
New and Innovative Practices									
Alum Injection	NA	89	78	14	NA	NA	NA	NA	Harper (1990)3
MCTT	83	NA	NA	14	95	NA	NA	NA	Pitt (1996)
Biofilters (e.g., StormTreat System)	95	89	NA	NA	65-98	83	NA	NA	Allard et al. (1996)
Vegetated Rock Filters	95	82	75	NA	21-80	78	NA	NA	DRMP (1995)

NA = Not Applicable or Not Available. Removal efficiencies may be based on either mass balance or average concentration calculations. The values may originate from evaluation of multiple events or from long-term monitoring. Ranges are provided wherever possible.

1. Based on capture of 12.7 mm (0.5 in) of runoff volume. Effectiveness directly related to volume of captured runoff.
2. Typical values; actual performance strongly related to the type of equipment, cleaning frequency, and number of passes.
3. Study examined improvement in water quality within the lake receiving alum-treated stormwater runoff.
4. Included are results for three different types of ponds: extended detention wet pond, wet pond, and extended detention dry pond.

Appendix III – Maintenance of Pervious Pavements, Bioretention units and Proprietary Treatment Systems

Recommended operation and maintenance routines for pervious pavements (Woods-Ballard et al., 2015a).

Maintenance schedule	Required action	Typical frequency
Regular maintenance	Brushing and vacuuming (standard cosmetic sweep over whole surface)	Once a year, after autumn leaf fall, or reduced frequency as required, based on site-specific observations of clogging or manufacturer's recommendations – pay particular attention to areas where water runs onto pervious surfaces from adjacent impermeable surfaces as this area is most likely to collect the most sediment
Occasional maintenance	Stabilise and mow contributing and adjacent areas	As required
	Removal of weeds or management using glyphospate applied directly into the weeds by an applicator rather than spraying	As required – once per year on less frequently used pavements
Remedial actions	Remediate any landscaping which, through vegetation maintenance or soil slip, has been raised to within 50 mm of the level of the paving	As required
	Remedial work to any depressions, rutting and cracked or broken blocks considered detrimental to the structural performance or a hazard to users, and replace lost jointing materials	As required
	Rehabilitation of surface and upper substructure by remedial sweeping	Every 10 to 15 years or as required (if infiltration performance is reduced due to significant clogging)
Monitoring	Initial inspection	Monthly for three months after installation
	Inspect for evidence of poor operation and/or weed growth – if required, take remedial action	Three-monthly, 48 h after large storms in first six months
	Inspect silt accumulation rates and establish appropriate brushing frequencies	Annually
	Monitor inspection chambers	Annually

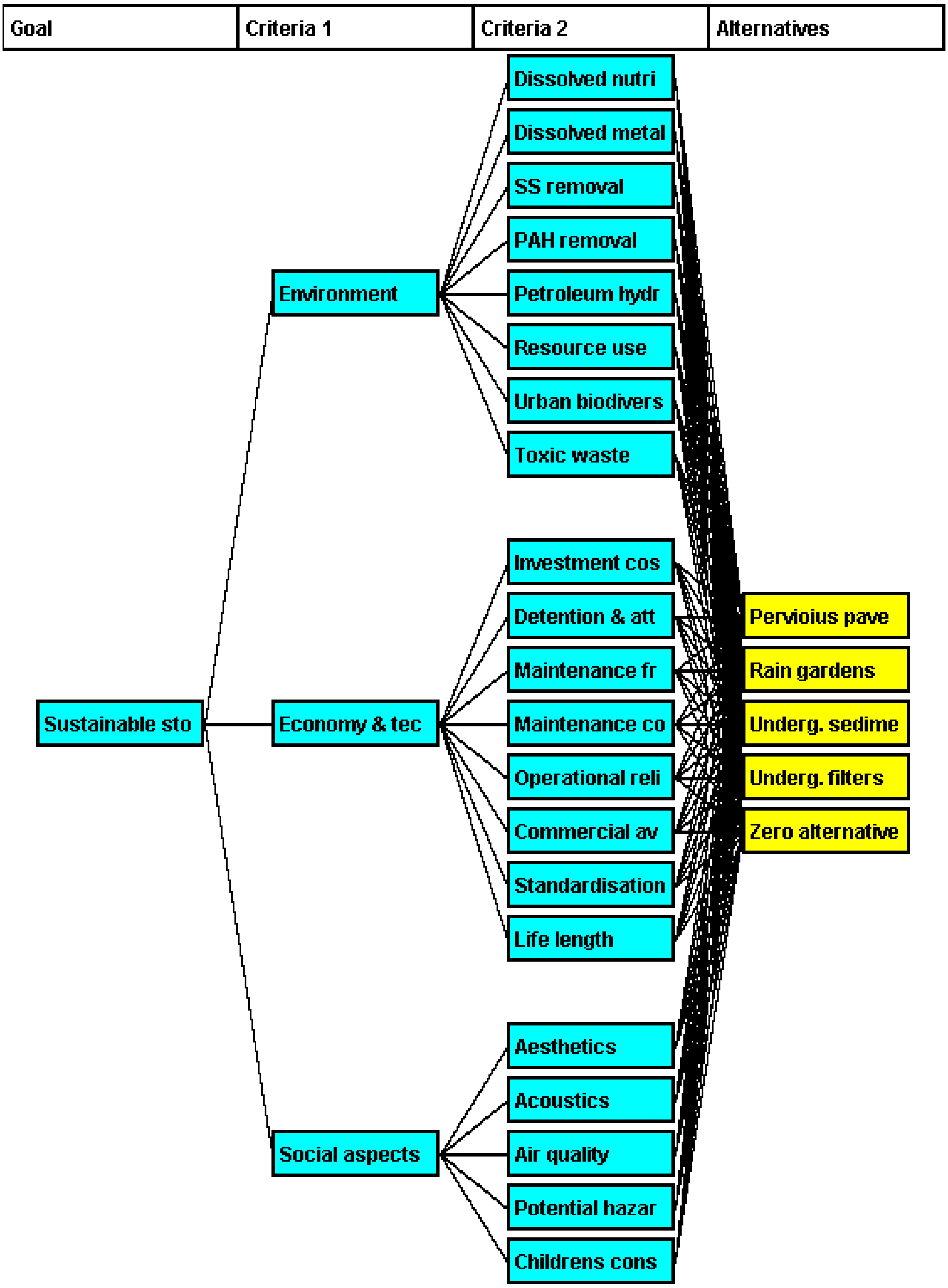
Recommended operation and maintenance routines for bioretention units (Woods-Ballard et al., 2015b).

Maintenance schedule	**Required action**	**Typical frequency**
Regular inspections	Inspect infiltration surfaces for silting and ponding, record de-watering time of the facility and assess standing water levels in underdrain (of appropriate) to determine if maintenance is necessary	Quarterly
	Check operation of underdrains by inspection of flows after rain	Annually
	Assess plants for disease infection, poor growth, invasive species etc. and replace as necessary	Quarterly
	Inspect inlets and outlets for blockage	Quarterly
Regular maintenance	Remove litter and surface debris and weeds	Quarterly (or more frequently for tidiness or aesthetic reasons)
	Replace any plants, to maintain planting density	As required
	Remove sediment, litter and debris build-up from around inlets or from forebays	Quarterly to biannually
Occasional maintenance	Infill any holes or scour in the filter medium, improve erosion protection if required	As required
	Repair minor accumulations of silt by raking away surface mulch, scarifying surface of medium and replacing mulch	As required
Remedial actions	Remove and replace filter medium and vegetation above	As required but likely to be more than 20 years

Operation and maintenance requirements for a proprietary treatment system (e.g. underground filter units) (Woods-Ballard et al., 2015d).

Maintenance schedule	**Required action**	**Typical frequency**
Routine maintenance	Remove litter and debris and inspect for sediment, oil and grease accumulation	Six monthly
	Change the filter media	As recommended by manufacturer
	Remove sediment, oil, grease and floatables	As necessary – indicated by system inspections of immediately following significant spill
Remedial actions	Replace malfunctioning parts or structures	As required
Monitoring	Inspect for evidence of poor operation	Six monthly
	Inspect filter media and establish appropriate replacement frequencies	Six monthly
	Inspect sediment accumulation rates and establish appropriate removal frequencies	Monthly during first half year of operation, then every six months

Appendix IV – Web-HIPRE model structure



Appendix V – Forms for scoring and weighting

Alternative 1: Pervious pavements
Alternative 2: Bioretention units
Alternative 3: Underground sedimentation units
Alternative 4: Underground filter units
Alternative 5: Zero alternative, conventional pipes

Environmental criteria

Criterion	**Scoring scale**	**Alternative**					**Weight**
		1	**2**	**3**	**4**	**5**	
Removal of dissolved nutrients	0 = insignificant 1 = low 2 = moderate 3 = high						
Removal of dissolved metals							
Removal of suspended solids							
Removal of PAHs							
Removal of petroleum hydrocarbons							
Resource use (energy, limited resources)							
Influence on urban biodiversity	0 = very negative effect 1 = negative effect 2 = no effect 3 = positive effect 4 = very positive effect						
Origin of contaminated waste	0 = no toxic waste 1 = low amounts 2 = moderate amounts 3 = high amounts						

Economic and technical criteria

Criterion	Scoring scale	Alternative					Weight
		1	2	3	4	5	
Investment costs	0 = very low 1 = low 2 = moderately low 3 = moderately high 4 = high 5 = very high						
Detention and attenuation	0 = no effect 1 = slight effect 2 = adequate effect 3 = good effect						
Maintenance frequency	0 = very low 1 = low 2 = moderate 3 = high						
Maintenance complexity							
Operational reliability (ability to maintain function in changing conditions and under stress)	0 = low 1 = moderate 2 = high 3 = very high						
Commercial availability	0 = hardly any market 1 = limited market 2 = easily available						
Standardisation potential	0 = non-existent, unique design every time 1 = low 2 = moderate 3 = high						
Life length	0 = short 1 = medium 2 = long 3 = very long						

Social and health criteria

Criterion	**Scoring scale**	**Alternative**					**Weight**
		1	**2**	**3**	**4**	**5**	
Aesthetics	0 = very negative effect 1 = negative effect 2 = no effect 3 = positive effect 4 = very positive effect						
Acoustics							
Air quality							
Children's consequence							
Potential hazards							

Appendix VI – Workshop evaluation form

Name (voluntary):
Organisation:

Was any element difficult or unclear? If yes, what?
Yes ☐ No ☐
Comment:

Was there any competence missing here today? If yes, what?
Yes ☐ No ☐
Comment:

Do you think that anything was devoted insufficient time or attention? If yes, what?
Yes ☐ No ☐
Comment:

Do you think that anything was devoted too much time or attention? If yes, what?
Yes ☐ No ☐
Comment:

Do you think that Multi-Criteria Decision Analysis seems to be a good tool for handling stormwater problems?
Yes ☐ No ☐
Comment:

Have you learned anything that you think may be useful in your professional career?
Yes ☐ No ☐
Comment:

What is your overall impression of the workshop? If poor/very poor, what could have been improved?

Very poor ○ ○ ○ ○ ○ ○ Very good
Comment:

Additional comments: