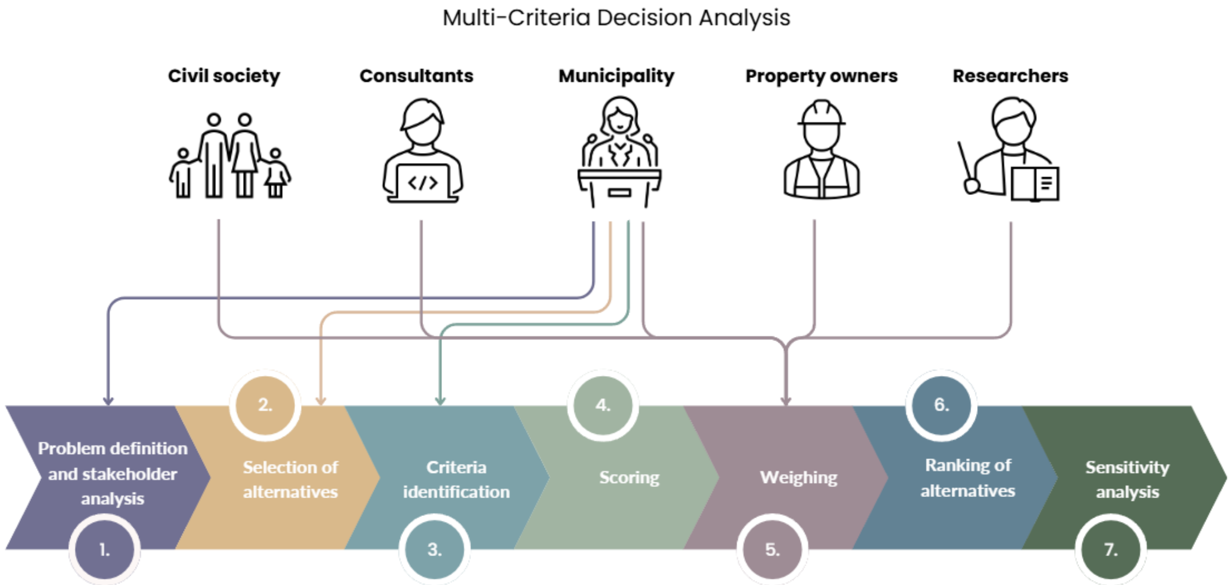

An Evaluation of Multi-Criteria Decision Analysis for Urban Stormwater Management

A Case Study of Anneberg

Master's thesis in Master Programme Infrastructure and Environmental Engineering

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DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Wind visualization constructed in Matlab showing a surface of constant wind speed along with streamlines of the flow.

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Abstract

Urban stormwater management is increasingly challenged by climate change and urbanisation, which raise flood risks and pollutant loads. This master's thesis evaluates how Multi-Criteria Decision Analysis (MCDA) can support urban stormwater management in a real-world case study: the Anneberg area of Partille Municipality, Sweden. This area is experiencing densification and has steep topography, limited space for stormwater solutions, and a downstream recipient included in the Natura 2000 network.

Five stormwater solutions were evaluated: Infiltration trench, Grass-covered infiltration trench, Rain garden, and two hybrid combinations. All alternatives meet the necessary detention volume for a 20-year rainfall event, with a duration of 10 minutes, with a 25% climate factor. A literature-based scoring, ranging from -10 to +10, was applied across ten criteria within environmental, social, economic, and technical dimensions. Stakeholder preferences were gathered through a survey with 31 respondents from four different groups, using a hierarchical direct-ranking method. These groups are personnel at Partille Municipality, researchers, consultants, and property owners.

The Grass-covered infiltration trench achieved the highest total score, followed by the hybrid solutions. The conventional infiltration trench scored 0, serving as the reference alternative, while the Rain garden was the only alternative that received a negative score due to high costs and maintenance requirements. The sensitivity analysis showed that the total score of the Grass-covered infiltration trench is robust across different stakeholder weightings, whereas the Rain garden's score varies substantially. Excluding economic and technical dimensions reversed the ranking, making the Rain garden the top-ranked alternative.

In conclusion, Multi-Criteria Decision Analysis is a powerful and transparent decision-support tool for urban stormwater management. It integrates objective performance data with stakeholder preferences, allowing trade-offs to be systematically analysed and discussed. However, the method must be carefully adapted to local conditions and priorities, and its limitations must be acknowledged, particularly the compensatory nature of the simple additive model and the risk of overemphasising the top-ranked alternative. To strengthen future applications, research should focus on validating scoring with data from installed solutions, comparing weighting methods (questionnaire vs. workshop), and developing better approaches for engaging civil society. When applied with these considerations in mind, MCDA offers a defensible framework for navigating the complex trade-offs inherent in sustainable stormwater planning.

Keywords: Case study, Green infrastructure, Infiltration trench, Multi-criteria decision analysis (MCDA), Nature-based solutions (NBS), Questionnaire, Rain garden, Stakeholder participation, Stormwater management

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This master's thesis explores the application of Multi-Criteria Decision Analysis in stormwater management decision-making, using a case study in Anneberg, Partille. The project was written during the spring semester of 2026 and is the final component of the master's programme in Infrastructure and Environmental Engineering (120 credits) at Chalmers University of Technology. The thesis was conducted at the Department of Architecture and Civil Engineering, within the Division of Water Environment Technology, and corresponds to 30 credits.

We would like to express our gratitude to our supervisors at Partille Municipality for the opportunity to conduct this research in Anneberg and for their support. We would also like to thank our supervisor at Chalmers, Baraa Khalil, for all the support, guidance, and helpful discussions. Additionally, we would like to thank our examiner, Sebastien Rauch.

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Betty Mattsson & Tintin Oharnisch Gothenburg, June 2026

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis, listed in alphabetical order:

BGI	Blue-Green Infrastructure
BOD	Biochemical Oxygen Demand
BOD5	5-Day Biochemical Oxygen Demand
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
COD	Chemical Oxygen Demand
GI	Green Infrastructure
LID	Low Impact Development
MCA	Multi-Criteria Analysis
MCDA	Multi-Criteria Decision Analysis
NAPL	Non-Aqueous Liquid
NBS	Nature Based Solutions
PAH	Polycyclic Aromatic Hydrocarbon
POP	Persistent Organic Pollutant
SAM	Simple Additive Model
SUDS	Sustainable Urban Drainage System
USWM	Urban Stormwater Management
VOC	Volatile Organic Compounds
WSUD	Water Sensitive Urban Drainage
WWTP	Wastewater Treatment Plant

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1. Introduction

Urban communities face a dual challenge from climate change and urbanisation. As of 2025, 45 % of the world's population lived in cities, and by 2050 cities are expected to account for two thirds of the population growth (United Nations Department of Economic and Social Affairs, 2025). Urbanisation, through increased asphalt, rooftops, and other impervious surfaces, decreases land permeability (Agonafir et al., 2023). Combined with rising population density and climate change, the consequences for urban stormwater management can be severe. Two main consequences are declining water quality (Müller et al., 2020) and increasing flood risks (Agonafir et al., 2023), collectively threatening environmental integrity and urban well-being.

Stormwater has historically been managed using gray infrastructure (e.g., pipes, storage tanks) (Svenskt Vatten, 2016). However, in the context of climate change and urbanisation, gray infrastructure has become inadequate to handle increasing runoff volumes and deteriorating water quality (Czemiel Berndtsson, 2010; Roy et al., 2008; Salerno et al., 2018).

Over recent decades, the perception of stormwater and drainage management has shifted significantly, from being viewed solely as a problem to being recognised as an opportunity (Fletcher et al., 2015). A promising alternative to gray infrastructure lies in Nature-Based Solutions (NBS), such as green roofs, rain gardens, and swales (Bousquet et al., 2023; Fletcher et al., 2015). These systems integrate natural processes including infiltration, evapotranspiration, conveyance, retention, and detention of stormwater. Moreover, NBS offer multifunctional benefits, such as aesthetic value, urban heat island mitigation, and biodiversity enhancement.

This underscores the need for a comprehensive method to evaluate the full range of NBS benefits when selecting the most suitable stormwater solution (Bousquet et al., 2023). Multi-Criteria Decision Analysis (MCDA) is a promising method to address this need. It integrates sustainability dimensions (social, economic, and environmental) alongside technical criteria, enabling the simultaneous evaluation of multiple objectives and the incorporation of stakeholder preferences. Therefore, this thesis aims to evaluate how MCDA can compare alternative stormwater solutions and be used to support the decision-making for the study area of Anneberg, Partille.

1.1 Aim

The aim of this thesis is to evaluate how multi-criteria decision analysis (MCDA) can support urban stormwater management decisions in urban areas, by integrating technical, environmental, social, and economic considerations in a real-world case study. To guide this aim, following research questions have been investigated in this thesis:

1. What stormwater management strategies are suitable for the study area?
2. Which evaluation criteria are relevant for comparing stormwater management

strategies in an urban context?

3. How do different stakeholders prioritise the criteria used to evaluate stormwater management?

1.2 Limitations

This master's thesis focuses on investigating stormwater, which has a 20-year return period and a climate factor of 25 %, meaning that the intensity will increase by 25 % in the future. Solutions, which manage heavy rain events such as cloudbursts, were not evaluated. The solutions evaluated in the Multi-criteria decision analysis fulfil the detention requirement, but no detailed design of the alternatives is investigated, rather schematic figures and suggestions. In a production stage, the solutions must be more detailed designed.

Regarding the weighting in the MCDA, two limitations must be acknowledged:

- Methodological choice: The weighting process was done using a survey sent by email to stakeholders. A workshop format would have allowed for interactive dialogue between stakeholders and nuanced discussions, while the survey captures isolated individual interests without people being affected by other's opinions.
- Sample size: The weighting result are based on responses from 31 respondents which is a limitation as it reflects the interests of this specific group within this specific case study area rather than providing a statistically representative view of the entire population.

The results are therefore specifically applicable for the Anneberg case and should be interpreted within the context of these participation constraints.

2. Theory

This chapter establishes the theoretical foundation necessary for understanding and analysing the challenges of urban stormwater management. The chapter is divided into four main sections, each addressing a critical component of the research.

First, Section 2.1, 2.2, and 2.3 provides a comprehensive overview of stormwater itself, covering both the quantitative aspect (runoff generation, design flow calculations, and flood risks) and the qualitative dimensions (pollutant types, sources, and environmental impacts). This dual focus is essential, as effective stormwater management must address not only the volume of water but also its capacity to degrade receiving water bodies.

Second, Section 2.4 and 2.5 introduce the concept of Urban Stormwater Management (USWM), presenting its principles, objectives, and practical applications. It highlights the shift from conventional drainage systems to nature-based solutions and multifunctionality.

Third, Section 2.6 and 2.7 examines the relevant laws and institutional frameworks that govern stormwater management, as any proposed solution must operate within existing regulatory structures.

Finally, Section 2.8 describes MCDA, a methodological framework for evaluating complex decisions involving multiple, often conflicting, objectives; a situation characteristic of sustainable stormwater planning.

2.1 Stormwater

Stormwater is precipitation and meltwater accumulated on urban surfaces (Hung et al., 2012). It poses significant challenges for both infrastructure and the environment (Czemiel Berndtsson, 2010). First, stormwater runoff stresses existing drainage systems, which can lead to urban flooding. This stress is exacerbated by two interrelated trends: climate change, which increases the frequency and intensity of heavy precipitation events, and urbanisation, which replaces permeable surfaces with impervious materials such as asphalt and rooftops, thereby reducing natural infiltration and increasing runoff volumes (Czemiel Berndtsson, 2010). Consequently, the risk of urban flooding is projected to rise. Second, stormwater acts as a major transport vector for urban pollutants, contributing significantly to the deterioration of receiving water bodies (Müller et al., 2020).

2.2 Parameters affecting stormwater quantity and flooding

Given the flood risks mentioned above, planning stormwater systems requires quantification of stormwater quantity. There are many factors that play a role in flood risks and flood characteristics. Agonafir et al. (2023) identified the following causes of urban flooding: precipitation, infrastructural factors (e.g., sewer system), topography (e.g., slope and elevation), and land features (e.g., buildings and impermeable surfaces). In the following section, these causes will be presented in more detail.

2.2.1 Calculation of stormwater design flow

The design flow of stormwater is determined by the rain intensity, catchment area, topography, surface characteristics, and the design of the buildings (Svenskt Vatten, 2016). One empirical method to calculate the peak design discharge from a specific catchment area, q_{design}, is The Rational Method (Svenskt Vatten, 2016) (Equation 2.1) and is the industry standard for hydraulic design and sizing of stormwater pipe networks in Sweden. The method is well-suited for hand calculations in catchment areas smaller than 20 hectares, while more complex calculations should be done by hydraulic computer-based models (Svenskt Vatten, 2016).

$$q_{\text{design}} = \phi \cdot i(t_r) \cdot A \cdot kf \tag{2.1}$$

Where:

- q_{design} is the design flow $[l/s]$
- ϕ is the runoff coefficient, determined by the surface characteristics $[-]$
- $i(t_r)$ is the rainfall intensity $[l/s \cdot ha]$
- A is the catchment area $[ha]$
- kf is the climate factor $[-]$
- (t_r) is the duration of the rainfall $[minutes]$

Another method to calculate stormwater design flow is the Time-Area Method, which can be used for larger, more complex catchment areas (Svenskt Vatten, 2016). In this method, the catchment area is divided into sub-catchments, allowing different runoff coefficients, flow paths and travel time within different areas. Consequently, the method effectively shows how runoff from the sub-catchment areas converges to a pipe or receiving water body (Svenskt Vatten, 2016).

2.2.2 Precipitation

The main cause of urban flooding is precipitation (Agonafir et al., 2023). While precipitation can be characterised in several ways (e.g., duration, total volume), rainfall intensity has the greatest impact. Urban drainage systems are designed for a maximum rate of stormwater, i.e., volume per time, which is an intensity-based metric. As seen in Equation 2.1, when designing drainage systems, rainfall intensity is a key input variable ($i(t_r)$).

As seen in Equation 2.2 (Swedish national standards formula), rainfall intensity, $i(t_r)$, is derived from the duration of the rainfall and the return period (Agonafir et al., 2023; Svenskt Vatten, 2016). Rainfall intensity can also be determined by using meteorological data from the specific city.

$$i(t_r) = 190 \cdot \sqrt[3]{T} \cdot \frac{\ln(t_r)}{t_r^{0.98}} + 2 \tag{2.2}$$

Where:

- $i(t_r)$ - rainfall intensity $(l/s \cdot ha)$
- (t_r) - duration of the rainfall $(minutes)$
- (T) - return period $(months)$

The return period, (T), is a statistical parameter representing the average time between rainfall events within a specific intensity and is decided by the desired level of flood protection (Svenskt Vatten, 2016).

The duration of the rainfall, t_r, is equal to the time of concentration, t_c, of the sub-catchment area, and this assumes that the whole catchment area contributes with run-off resulting in peak discharge run-off (Svenskt Vatten, 2016). t_c is the time in minutes required for the water to travel from the most distant point along the longest flow path to the point of interest.

Additionally, these rainfall-intensive storms are expected to increase in the future (Agonafir et al., 2023). Therefore, a climate factor, kf, should be included when calculating the design flow, q_{design}, as seen in Equation 2.1. The climate factor is an adaptation to the future where rain events are expected to occur more often and be more intense (Svenskt Vatten, 2016).

According to SMHI (n.d.), extreme precipitation is expected to increase by 20% by mid-century regardless of climate change, and potentially reach 40% by the end of the century. Consequently, the implementation of robust urban infrastructure is essential to manage these projected hydrological risks.

2.2.3 Topography

Slope and elevation are the two main topographic flood factors (Agonafir et al., 2023). Slope is the incline of the ground surface. This directly affects the time of concentration, t_c, mentioned. Additionally, the t_c is an important component of Manning's equation, which is used to determine water velocity and construct hydrographs (Agonafir et al., 2023), i.e., larger slope angles lead to increased velocity and water discharge.

Furthermore, the slope has an effect on flooding (Agonafir et al., 2023). An area with a greater slope has a lower mean water depth and peaks in stored run-off volumes. The contrary is true for flatter surfaces, which therefore have a higher risk of flooding.

Elevation affects flooding because low-lying areas are more prone to water accumulation (Agonafir et al., 2023). This is particularly because they are often at the bottom of slopes, where runoff converges and ponding is more likely to occur.

One reason for the increased risk is that lower elevation areas are more likely to be located at the bottom of sloped surfaces where ponding is facilitated.

2.2.4 Land features

Land features include both engineered impervious surfaces (e.g., sidewalks, roads) and man-made structures (e.g., buildings) (Agonafir et al., 2023). Impervious surfaces will hinder infiltration, thereby increasing flood risks. In Equation 2.1, the impervious surface, or the infiltration ability of the area, is represented by the run-off coefficient, ϕ. The run-off coefficient is assigned a value between $0 - 1$ (Agonafir et al., 2023; Svenskt Vatten, 2016) (0; all precipitation infiltrates, 1; all precipitation accumulates). Impervious surfaces are usually assigned a value between 0.70 and 0.95, whereas green surfaces (e.g., parks, gardens) are assigned a value between 0.05 and 0.35. The assigned value depends on specific material and conditions. During intense rainfall, the green areas can experience a lower degree of infiltration due to saturation, resulting in surface run-off (Svenskt Vatten, 2016).

Building structures contribute to urban flood risks (Agonafir et al., 2023). As for impervious surfaces, buildings prevent infiltration, which increases run-off. Additionally, it affects the path and geometry of water flow.

2.2.5 Urban drainage infrastructure

The performance of the drainage infrastructure influences the risk of flooding (Agonafir et al., 2023). There are two main types of sewer systems, combined (Salerno et al., 2018) and separate sewer systems (Thorndahl et al., 2015). In many cities, stormwater sewers are combined with sanitary sewers (Salerno et al., 2018), in so-called combined sewer systems, and conveyed to wastewater treatment plants (WWTP). This provides treatment of stormwater during small storm events, i.e., low stormwater quantity. However, when the quantity becomes too large, it would cause urban flooding (Czemiel Berndtsson, 2010) and/or exceed the capacities of the WWTP, which cause discharge of both polluted stormwater and untreated sewage into water bodies (Roy et al., 2008; Salerno et al., 2018).

There are also systems where the sanitary sewers and stormwater sewers are separated, i.e., separate sewer systems (Thorndahl et al., 2015). Usually, no treatment is provided in the separate sewers for the stormwater and the polluted water is discharged directly into nearby water bodies. Thorndahl et al. (2015) makes it clear that a total shift from combined sewer systems would be detrimental to local water bodies if no retention or treatment of pollutants takes place.

A poor performance is often due to insufficient capacity (Czemiel Berndtsson, 2010) caused by the increased demand (i.e., increasing amount of impermeable surfaces) and a delay in updating the sewer network at the same pace as cities' development (Jha et al., 2012). The Swedish sewer system was first constructed during the 19th century (Svenskt Vatten, 2016). These first sewer systems were predominantly combined. Today, 13% of the sewer systems in urban areas are combined sewer systems. Though, since the 1990s, the recommendation is to construct separate sewer systems that are designed to adequately handle a rain event with a return period of 10 years (Svenskt Vatten, 2016).

2.3 Stormwater quality

As noted in Section 2.1, stormwater acts as a major transport pathway for urban pollutants, making it a significant contributor to the degradation of receiving water bodies (Müller et al., 2020; Walsh et al., n.d.). Urban stormwater quality has been a subject of scientific concern since the mid-20th century. The following section presents the key aspects of stormwater pollutants, including their classification, environmental effects, sources, and mobilisation mechanisms.

2.3.1 Classification of stormwater pollutants

Pollutants in urban stormwater can be broadly classified into organic and inorganic groups (Rani et al., 2022). A more detailed classification is provided by Barbosa et al. (2012), who divide stormwater pollutants into six categories commonly found in urban runoff: solids, heavy metals, biodegradable organic matter, organic pollutants, pathogenic microorganisms, and nutrients. Table 2.1 presents an overview of these six categories, summarising their environmental effects, typical pollutant examples, and sources of origin.

Table 2.1: Classification of stormwater pollutants, their environmental effects and main sources of origin.

Classification	**Example of pollutant**	**Environmental effects**	**Source of origin**
Metals	Pb, Cu, Hg, Zn.	Biomagnification, bioaccumulation, toxic to aquatic ecosystems[1]	Anthropogenic activities (e.g., industrial activities, vehicle transportation), urban drainage systems (e.g., pipe material corrosion)[1][2]
Nutrients	P and N.	Eutrophication, algal bloom, oxygen depletion, fish mortality, altered species composition[1]	Anthropogenic activities (e.g., fertilizer application), atmospheric deposition, leaf litter[2][3]
Organic pollutants	VOC, PAH, NAPL, POP, microplastics	Acute and chronic toxic to organisms, persistent in nature[1]	Anthropogenic activities (e.g., vehicle transportation, industrial activities), drainage surfaces (e.g., roads)[2]
Biodegradable organic matter	BOD5 and COD.	Oxygen depletion[4]	Anthropogenic activities (e.g., sewage misconnections)[2][4]
Solids	Suspended solids, microplastics	Degradation of the biological, chemical and physical status in receiving waters, plants, and aquatic organisms[5]	Anthropogenic activities (e.g., construction work, road maintenance, littering), drainage surfaces (e.g., road wear)[2]
Pathogenic microorganisms	Bacteria, virus, fungi, parasites	Disease in plants and animals[3]	Anthropogenic activities (e.g., animal waste, sewage misconnections)[2][4]

[1] van der Perk (2014); [2] Müller et al. (2020); [3] Smith et al. (2020); [4] Björklund (2011); [5] Bilotta and Brazier (2008)

2.3.2 Environmental effects of stormwater pollutants

Research indicates that pollutants such as metals, pharmaceuticals, microplastics, nanoparticles, and personal care products negatively impact aquatic organisms, causing toxicity, endocrine disruption, and oxidative stress (Sefali et al., 2026). Two critical processes govern the fate of these pollutants in the environment: biomagnification and bioaccumulation. Biomagnification refers to the increasing concentration of a pollutant as it moves upward through the food web, while bioaccumulation describes the gradual accumulation of pollutants within a single organism over its lifetime (Sefali et al., 2026).

Metals exemplify these processes, as they can both bioaccumulate and biomagnify, are toxic to aquatic organisms (Sefali et al., 2026), and are non-biodegradable, thus persisting indefinitely in the environment (Briffa et al., 2020). Common metals found in stormwater include arsenic, cadmium, chromium, copper, lead, mercury, zinc, nickel, molybdenum, and cobalt (Rani et al., 2022).

Nutrients in stormwater primarily occur as nitrogen and phosphorus species, which adversely affect receiving water bodies by causing eutrophication (Smith et al., 2020). An important distinction lies in their chemical behaviour. Nitrogen species, such as nitrate, remain dissolved in water, making them readily bioavailable. Phosphorus, in contrast, binds to suspended solids through adsorption, which facilitates sedimentation and temporary removal from the water column (van der Perk, 2014).

Eutrophication triggers algal blooms, which subsequently lead to widespread hypoxia as the algae decompose. This process severely degrades water quality, causes fish mortality, and diminishes the socio-economic value of water bodies, impacting tourism, coastal economies, and cultural values (Smith et al., 2020). Nutrient concentrations in stormwater exhibit seasonal variability, depending on factors such as fertilizer application, atmospheric deposition, leaf litter accumulation, and rainfall intensity (Smith et al., 2020).

Organic pollutants can originate from both anthropogenic and natural sources. Their environmental impact is characterized by persistence in nature and potential for bioaccumulation (van der Perk, 2014). Many organic pollutants are hydrophobic, meaning they repel water and therefore tend to accumulate in organic tissues rather than remaining dissolved. This property, combined with their environmental persistence, causes them to bioaccumulate in aquatic organisms and biomagnify within the food web, leading to chronic toxic effects (van der Perk, 2014).

Solids affect receiving water bodies through multiple pathways. They block sunlight penetration, thereby reducing aquatic plant photosynthesis. Additionally, they act as transport vectors for other pollutants, particularly phosphorus and hydrophobic organic compounds, and can disrupt the photosynthetic functions of aquatic organisms (Bilotta & Brazier, 2008).

Pathogenic microorganisms, including bacteria, viruses, and parasites, can cause diseases in plants and animals and contaminate receiving waters, posing risks to both ecosystem and human health (Björklund, 2011).

Biodegradable organic matter, commonly measured as biochemical oxygen demand (BOD) and chemical oxygen demand (COD), exerts oxygen demand as it decomposes. This can lead to reduced oxygen levels or even anoxic conditions in receiving water bodies, which may subsequently contribute to eutrophication (Björklund, 2011).

To protect receiving water bodies from the pollutants described above, many municipalities have established site-specific guideline values. The values relevant to the case study in this thesis are presented later in Section 2.7.3.

2.3.3 Sources and mobilization of stormwater pollutants

Stormwater pollutants originate from four primary categories (Müller et al., 2020): anthropogenic activities, atmospheric deposition, drainage surfaces, and urban drainage systems. A key distinction exists between pollutant sources that are directly linked to human activities and those that are more physically static, as this influences both the type of pollutants present and their mobilization patterns.

Anthropogenic activities encompass all human actions within the urban environment, including construction work, vehicle transportation, road maintenance, industrial activities, and littering. Due to the diversity of these activities, pollutant types and concentrations vary considerably depending on local human activities, meteorological conditions, and atmospheric processes (Müller et al., 2020). Pollutants associated with anthropogenic activities include salts and heavy metals; hydrocarbons (including PAHs and BTEX); oxygen-demanding substances (BOD and COD); particulate matter (total suspended solids and microplastics); atmospheric pollutants (carbon monoxide, sulfur dioxide, and nitrogen oxides); oils; other organic contaminants; and faecal matter (Müller et al., 2020).

Sources within the remaining three categories are generally more physically static. For these, pollutant mobilization depends primarily on environmental factors, such as rainfall intensity and duration, rather than on fluctuations in anthropogenic activities (Müller et al., 2020).

Pollutants from drainage surfaces originate from roads, green areas (parks, golf courses), buildings, and construction materials. These pollutants include PAHs, metals, nutrients, microplastics, and organic compounds (Müller et al., 2020). Atmospheric deposition contributes pollutants that have been transported through the air before settling onto urban surfaces. Urban drainage systems themselves can be a source of pollution, for example, through corrosion of pipe materials, coating degradation, and misconnections where wastewater is inadvertently routed to stormwater systems. These sources release various pollutants, particularly metals (van der Perk, 2014). Once transported by stormwater, metals tend to accumulate in the sediments of receiving water bodies, where they can persist and remain bioavailable (Briffa et al., 2020).

As stormwater pollutants are mobilized during a rainfall event, their concentrations vary over the course of the runoff. The initial phase of runoff, known as the first flush, typically contains the highest concentrations of accumulated contaminants. This occurs because pollutants deposited on surfaces during dry weather are most readily available for wash-off at the beginning of a rain event (Chaudhary et al., 2022). Understanding this phenomenon is critical for both water quality monitoring and the design of effective treatment systems.

2.4 Urban stormwater management

Urban stormwater management (USWM) encompasses the planning, design, and implementation of strategies to control run-off from developed areas. As concluded, the primary goal for stormwater management is to mitigate risks associated with flooding and deterioration of water bodies (Czemiel Berndtsson, 2010; Müller et al., 2020; Walsh et al., n.d.).

Over time, USWM has evolved significantly. In the 20th century, the dominant paradigm focused on rapid conveyance and discharge, treating stormwater as a waste product to be removed as efficiently as possible (Roy et al., 2008). However, growing recognition of the limitations of this approach has spurred a shift toward strategies that mimic natural hydrological processes.

This alternative approach, referred to as Nature-Based Solutions (NBS), aims to manage water at its source, improve water quality, and provide co-benefits for urban ecosystems and communities. NBS also offer multifunctionality and ecosystem services, which are presented in detail in Section 2.5.4.

In contrast, grey infrastructure (e.g., conventional pipe systems) is designed for rapid conveyance and is often less adaptable to climate change and urbanization (Barbosa et al., 2012). Figure 2.1 visualizes the increasing integration and sophistication of USWM over time.

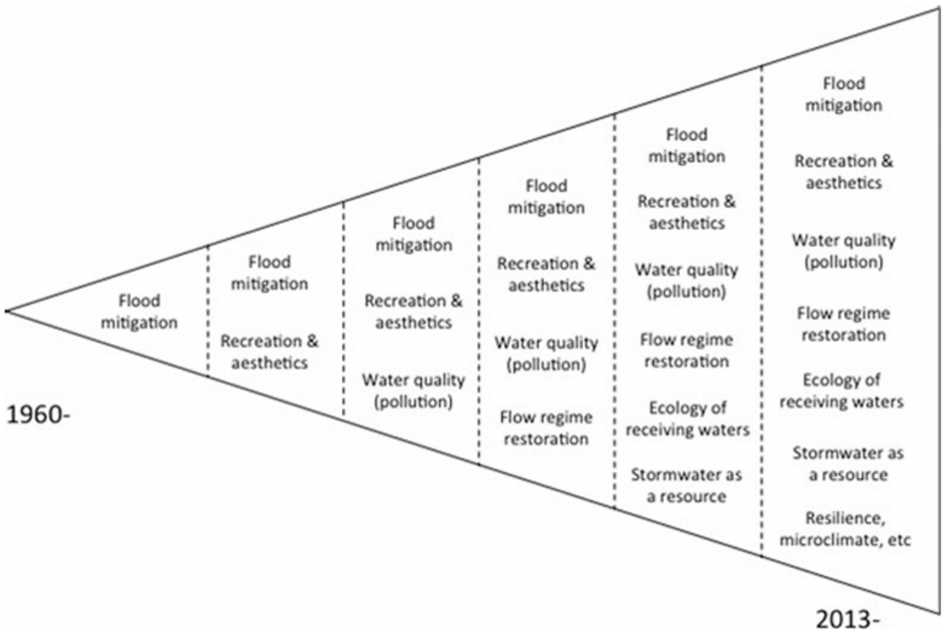

Figure 2.1: Increasing integration and sophistication of USWM over time (Fletcher et al., 2015)

2.5 Nature based solutions

A promising solution to stormwater challenges lies in NBS (Bousquet et al., 2023), also referred to as Green Infrastructure (GI) or Blue-Green Infrastructure (BGI), Low Impact Development (LID), Sustainable Urban Drainage Systems (SUDS), Water Sensitive Urban Drainage (WSUD), or Sponge city in urban climate adaptation plans (Fletcher et al., 2015). NBS are increasingly considered as a more sustainable alternative. These engineered green systems (e.g., rain gardens, green roofs, ponds, swales, urban forests, constructed wetlands) promote and enhance natural functions such as infiltration and evapotranspiration, aiding in the retention, conveyance and treatment of stormwater (Bousquet et al., 2023).

The following section provides a more detailed explanation of rain gardens, infiltration trenches, and bioswales, as these are investigated further in this thesis.

2.5.1 Rain gardens

Rain gardens are a vegetated form of green infrastructure, designed to manage stormwater, whose compartments can be customised based on specific site characteristics and local needs (Kasprzyk et al., 2022). They restore the water balance in urban areas by creating a permeable layer which alters infiltration and retains water, after which the water is controlled via an outflow and directed to an underlying drainage system (Kasprzyk et al., 2022).

The mechanisms of removal consist of a combination of mechanical, chemical, and biological separation through plants and filter materials within the rain garden (Larm & Blecken, 2019). The filtration enables removal of dissolved and solid pollutants before the water is discharged (Larm & Blecken, 2019).

Recent studies of urban watersheds have shown that optimising the specific design elements is essential, tailoring a rain garden's design can lessen discharge flow, lower peak flow, and reduce combined sewer overflows (Z. Wu et al., 2026). Increasing the fraction of runoff directed into the system significantly reduces the discharge volume by up to 65 % , while maximising the ratio of the surface storage area to the pervious area reduces the discharge volume by up to 74.5 %, and both of these designs are proven to reduce combined sewer overflows (Z. Wu et al., 2026).

The treatment efficiency of a standardised rain garden for different stormwater pollutants is presented in Table 2.2.

Table 2.2: Treatment efficiency of a standardised rain garden [%] (VA-guiden, n.d.-b).

Parameter	**Treatment efficiency [%]**
Phosphorus (P)	65
Nitrogen (N)	40
Lead (Pb)	80
Copper (Cu)	65
Zinc (Zn)	85
Cadmium (Cd)	85
Chromium (Cr)	55
Nickel (Ni)	75
Mercury (Hg)	37
Suspended solids (S)	80
Oil index (Oil)	95
BaP	85

2.5.2 Infiltration trench

Infiltration trenches are, fully or partly, gravel-filled ditches that collect and drain water from permeable surfaces and are constructed in a linear construction (Esraz-Ul-Zannat et al., 2024). It is an open ditch in which water infiltrates through the gravel and then exfiltrates to the groundwater or is conveyed via a stormwater pipe at the bottom. This results in reduced surface run-off and temporarily storing stormwater, thereby decreasing the load of the sewer system (Larm & Blecken, 2019). They serve as a source control measure to mitigate stormwater run-off (Lewellyn et al., 2015) and are often used in urban areas where space is limited (Mueller et al., 2022).

Their hydraulic capacity declines over time due to clogging when run-off carries large amounts of suspended solids, which also shortens the trench's lifetime (Lewellyn et al., 2015). Because these trenches are often built without pre-treatment, maintenance can be challenging, and clogging might occur. Nevertheless, trenches can remove pollutants such as suspended solids (Emerson et al., 2010). If the system is installed in an area with a high groundwater level or contaminated soil, it needs to be sealed to prevent the water from becoming polluted or the existing contaminants from spreading (Larm & Blecken, 2019)

The treatment efficiency of a standardized infiltration trench for different stormwater pollutants is presented in Table 2.3.

Table 2.3: Treatment efficiency of a standardised infiltration trench [%] (VA-guiden, n.d.-a).

Parameter	**Treatment efficiency [%]**
Phosphorus (P)	60
Nitrogen (N)	55
Lead (Pb)	80
Copper (Cu)	65
Zinc (Zn)	85
Cadmium (Cd)	85
Chromium (Cr)	55
Nickel (Ni)	65
Mercury (Hg)	45
Suspended solids (S)	80
BaP	60

2.5.3 Bioswales

Bioswales are open, shallow, vegetated ditches, with a low incline where pollutant removal and detention can take place, though the main purpose is transport of stormwater (Larm & Blecken, 2019). The mechanisms of action during pollutant removal are sedimentation, infiltration, and immobilisation. Larm and Blecken, 2019 states that swales are one of the simplest stormwater management techniques that can reduce run-off or maximum flow due to the relatively low velocities within the system. While some pollutant removal occurs, Larm and Blecken states that bioswales are often not sufficient for removing pollutants to achieve good water quality. On the other hand, research has shown that bioswales can be effective in removing pollutants. J. S. Wu and Allan (2018) has shown that bioswales can have a removal rate of 33% of total phosphorous, 67% of total Nitrogen and 77% of total suspended solids and Yuan et al. (2019) has shown that the removal of metal ions is $30.95 - 97.39\%$. Regarding the peak flow reduction, studies have shown that there's an average reduction of 13% during winter, while during summer there's an average reduction of 38% (Zaqout & Andradóttir, 2021). This seasonal variation is due to cold climate conditions, where meltwater and frozen ground reduce the infiltration capacity of the system. Furthermore, lower temperatures during winter limit the evapotranspiration process that otherwise continuously restores the capacity of the swale during warmer months (Annus et al., 2024).

2.5.4 Multifunctionality of Nature Based Solutions

A key advantage of NBS over conventional grey infrastructure is their ability to deliver multiple benefits simultaneously, a property known as multifunctionality (Więckowski et al., 2026). In dense urban areas where space is limited and land-use interests conflict, multifunctional solutions allow stormwater management to coexist with recreation, biodiversity enhancement, and climate adaptation. For example, a rain garden can detain run-off, filter pollutants, provide habitat for pollinators, and offer aesthetic value – all within the same spatial footprint.

Ecosystem services are the benefits that humans obtain from nature (Pereira et al., 2023). In the context of stormwater management :

- **Provisioning services:** Water supply, biomass production
- **Regulating services:** Flood mitigation, water purification, urban heat island reduction
- **Cultural services:** Recreation, aesthetic enjoyment, education
- **Supporting services:** Nutrient cycling, habitat formation

By contrast, grey infrastructure solutions (e.g., conventional pipe systems) are typically designed for a single purpose, rapid stormwater conveyance, and offer few co-benefits (Barbosa et al., 2012). They are also less adaptable to future changes in climate or land use.

2.6 Laws and institutional framework

The Swedish Governmental report 'Vem har ansvaret?' (SOU 2017:42, 2017) stated that the responsibility of stormwater management in Sweden lacks clarity. This chapter describes the laws and regulations that regulate the responsibility of stormwater management in Sweden, which are the Planning and building act [Plan- och bygglag] (2010:900), the Swedish environmental code [Miljöbalk] (1998:808), and Public Water Services Act [Lagen om allmänna vattentjänster] (2006:412) (Boverket, 2023). See Table 2.4 for an overview of the laws and regulations, their primary legal scope, as well as their role in stormwater management. While The Public Water Services Act Lag (2006:412) om allmänna vattentjänster and The Swedish environmental code Miljöbalken (1998:808) regulate the responsibility of the stormwater within Sweden, respectively the protection of the environment, the planning and building act Plan- och bygglagen (2010:900) regulates that the stormwater is managed properly when the area is developed (Boverket, 2023).

Table 2.4: Overview of laws and regulations.

Law/regulation	Primary legal scope	Role in stormwater management
Plan och bygglagen (2010:900) [Planning and building act]	Regulation of land use, building permits and urban planning	Focuses on the suitability of land for development, ensuring safety against flooding, erosion, and climate-related risks.
Lag (2006:142) om allmänna vattentjänster [Public Water Services Act]	Defines the responsibilities of stormwater management and obligations to provide water	Gouvernance of public water and wastewater services and infrastructure
Miljöbalken (1998:808) [The Swedish Environmental Code]	Protection of human health and the environment from hazards	Stormwater is legally classified as wastewater. Regulates pollution and ensures compliance with environmental quality standards

2.6.1 Planning and building act

All municipalities shall have a comprehensive plan (Översiktsplan) that regulates the long-term development of the physical environment within the municipality. It should give guidance on future land and water use, and how the built environment should be used, developed, and preserved. Though it is not legally binding. This is regulated in Chapter 3, Sections 1-2 Planning and Building Act [Plan-och bygglagen] (2010:900).

While the comprehensive plan serves as guidance, the detailed development plan in Plan-och bygglagen (2010:900) constitutes a legally binding decision on how land and water should be used in a specific area. Municipalities should, through a detailed development plan, assess the suitability of land and water for new housing or other development that alters its current use before development. The Plan- och bygglagen (2010:900) (Chapter 2 Sections 3-5) also regulates that planning within Sweden should aim for a long-term prudent management of water and to prevent pollution of water and flooding.

Furthermore, the Plan- och bygglagen (2010:900) (Chapter 2, Section 9) states that the planning of water and land use should not negatively affect groundwater or the surrounding environment with the aim of protecting public health and safety or cause any form of nuisance. (Chapter 4, Section 5) In Plan- och bygglagen (2010:900) states that the municipality should, in a detailed development plan, determine the limits and use for public spaces, development districts, and water areas. In Plan- och bygglagen (2010:900) (Chapter 4, Sections 10 and 12), it is stated that in a detailed development plan, municipalities can decide about vegetation, topography, and elevation as well as decide how to mandate protective measures to prevent flooding, erosion, and soil contamination.

When a municipality plans to develop an area, it must announce it to the

County Administrative Board (Länsstyrelsen), which will determine if the plan will be in conflict with national interests. If not, the municipality can continue with the planning process as stated in Plan- och bygglagen (2010:900) (Chapter 5 Section 11). When the detailed development plan is adopted, it will be sent to the County Administrative Board again for approval to ensure compliance with legal requirements according to Plan- och bygglagen (2010:900) (Chapter 11, Sections 10-11).

2.6.2 The Swedish environmental code

The Swedish environmental code [Miljöbalken] (1998:808) (Chapter 1 Section 1) aims to support sustainable development while ensuring a healthy environment for both current and coming generations, and emphasises the importance of managing nature in a way that does not disrupt the nature. The law is applied so that human health and the environment are be protected against nuisances and harm, regardless of whether they are affected by pollutants or other factors. It should also be applied so that, amongst other things, water is used to promote long-term ecological, social, cultural and socio-economic sustainability.

According to Miljöbalken (1998:808) (Chapter 9, Section 2), stormwater is legally classified as wastewater. It is described as water that is diverted from an area, conveyed by a detailed development plan for the purpose of land drainage. In the same chapter (Chapter 9, Section 1), it is mentioned that discharge of wastewater is classified as 'Environmentally hazardous activities'; consequently, stormwater discharged from detailed development areas is 'Environmentally hazardous activities' and must adhere to general rules of consideration complying with Environmental Quality Standards (Chapter 5) and General Rules of Consideration (Chapter 2) (Miljöbalken (1998:808), 1998).

According to Miljöbalken (1998:808) (Chapter 5, Section 2), Environmental quality standards should determine which pollutant levels are accepted within the environment, and (Chapter 9, Section 7) further states that wastewater shall be treated or diverted so it does not create any harm for human health or the environment. Furthermore, Miljöbalken (1998:808) (Chapter 5, Section 4) states that an authority or municipality is prohibited from authorising activities that lead to increased pollutant levels or other disturbance which degrades the water quality, or if it risks the possibility for the water to reach its status or potential according to the environmental quality standards.

2.6.3 Public Water Services Act

The Public Water Services Act [Lag (2006:412) om allmänna vattentjänster] regulates the responsibility of the water and the relationship between the property owners and the municipal water and wastewater authority which is responsible for the water within the municipality.

Lag (2006:412) om allmänna vattentjänster (Section 6) states that if there's a need for water supply or sewerage in a larger context to protect the environment and human health, the municipality shall provide a public water and wastewater facility. This means that the municipality shall provide a service area to manage stormwater when a new area is developed, as stormwater is defined as wastewater in Lag (2006:412) om allmänna vattentjänster (Section 2). Section 10 and 12 states that the public water and wastewater facility must meet the requirement regarding good use of natural resources, and protect the environment and human health and should be accommodated so property owners can accommodate it so their accumulated stormwater will be led to the municipal pipes. However (Section 18) states that if the property owners don't manage their water properly, they may be denied from connecting to the municipal facility.

2.7 Stormwater regulations on a municipal level

As of 2026, a new stormwater policy and strategy have been adopted by Partille Municipality (Partille Municipality, 2026a, 2026b), updating the previous version from 2017 (Partille Municipality, 2017). The new steering documents primarily refine the technical aspects and quantification, clarify responsibilities, and strengthen integration into the planning process. The following section will be based on the newly adopted stormwater policy and strategy. The strategy and policy follow laws and regulations and industry standards in Sweden.

2.7.1 Stormwater policy

The stormwater policy (Partille Municipality, 2026a) is an overarching steering document that sets out the direction, fundamental principles, and overall objectives for stormwater management in Partille Municipality. This is visualised in Figure 2.2. Furthermore, the policy guides spatial planning, development, and management, and is to be applied by the municipality's departments, companies, and external stakeholders operating within the municipal boundaries. The policy supplements, and does not replace, existing legislation.

The policy briefly addresses stormwater management planning, the planning process, stormwater management solutions, dimensioning, environmental and recipient protection, and internal cooperation. For more in-depth guidance, the policy refers to the stormwater strategy (Partille Municipality, 2026b).

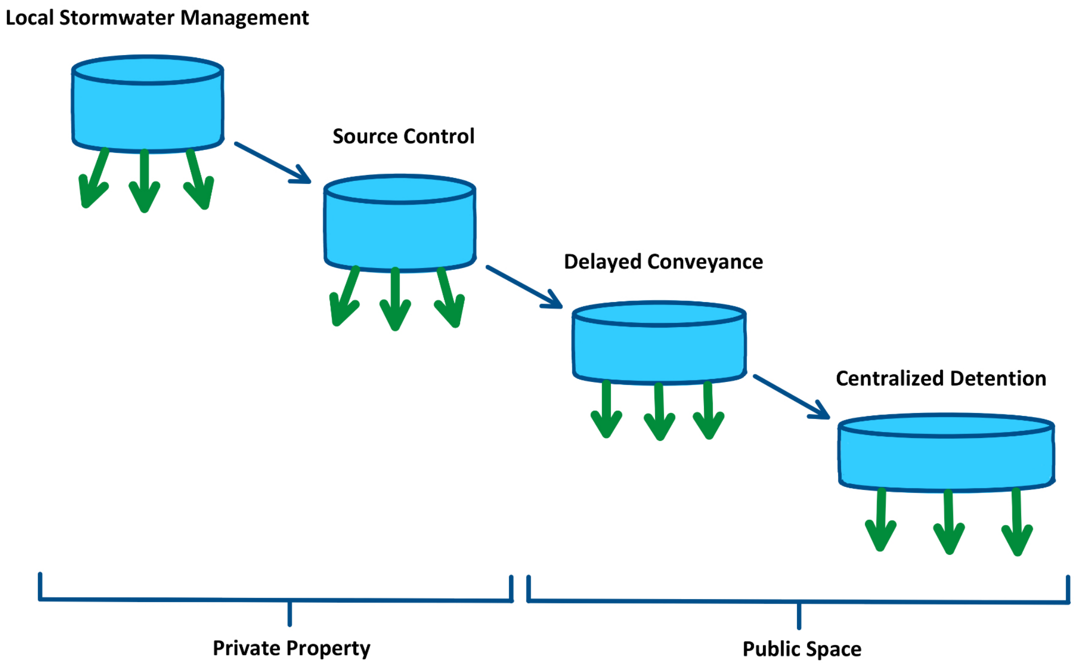

Figure 2.2: Fundamental principles and overall objectives for stormwater management in Partille Municipality (Partille Municipality, 2026a). Reworked from Swedish to English.

2.7.2 Stormwater strategy

The objective of Partille Municipality's stormwater strategy (Partille Municipality, 2026b) is to establish long-term sustainable stormwater management that preserves the natural water balance. It seeks to mitigate flood risks, safeguard water quality, and enhance ecosystem services through sustainable and climate-adapted solutions. The strategy is intended for politicians, civil servants, developers, property owners, business operators, and administrators of public spaces and water and wastewater facilities. It stipulates the terms for how stormwater management shall be executed and considered throughout the entire community building process.

The strategy specifies that cloudbursts (defined as 50 mm per hour or 1 mm per minute (SMHI, n.d.)) fall outside the scope of what the public stormwater system is designed to handle, as it would be unreasonable to dimension the system for such flows considering the financial costs and technical requirements. Instead, cloudbursts should be managed through other types of infrastructure.

When developing new areas, Partille Municipality requires that the local stormwater infrastructure is designed to manage a 20-year rainfall event for dense developments. However, the municipality emphasizes that this is not a strict limit; in areas which are prone to recurrent flooding, the system may be designed for rainfall events with longer return periods. In contrast, a 100-year rainfall is considered an extreme event, where the primary responsibility is simply to ensure that the runoff is safely routed away to prevent damage, in accordance with 2.5 from from Svenskt Vatten (2016). To account for the increased intensity and uncertainty of future precipitation, a climate factor of at least 1.25 must be applied. This means that the system must be designed to handle at least 25 % more rainfall than historical data suggests.

Table 2.5: Return periods for different types of development (Svenskt Vatten, 2016).

New combined systems	Responsibility of the water/wastewater authority		Responsibility of the municipality
	Return period for rain when pipe is full	Return period for pressure line at ground level	Return period for surface flooding with damage to buildings
Sparse residential development	2	10	> 100 years
Dense residential development	5	20	> 100 years
City center and commercial areas	10	30	> 100 years

For smaller properties, the owner is required to detain a volume of 10 mm per square meter of reduced area before discharging stormwater to the public system or a receiving water body. This should, first and foremost, be managed locally. For larger properties or development projects with a more significant impact, more comprehensive measures may be necessary. In such cases, it is essential that the volume of stormwater conveyed further does not exceed the capacity of the public stormwater network or the connection pipe. The required detention volume must be sized according to projected return periods and rainfall intensities, which could necessitate larger volumes for detention or flow attenuation. The aim is to ensure that stormwater run-off does not increase following exploitation and consequently does not lead to impaired water status, elevated pollutant load, or increased flood risk. The strategy explicitly mentions several types of stormwater solutions appropriate for Partille, including green roofs, rain gardens, permeable pavements, detention reservoirs, swales, open ditches, and underground storage facilities.

Effective stormwater management in Partille requires cross-departmental collaboration. This collaboration and early integration of stormwater issues is fundamental to minimising the risk of flooding and environmental impact. The planning department integrates stormwater issues in detailed development plans, the water and wastewater authority manages the public stormwater system, while the environmental unit oversees compliance with the Environmental Code. The street and park department maintains green structures and open stormwater solutions on public land. This organisational structure influences which stormwater solutions are feasible and who is responsible for their implementation and maintenance. The strategy supplements, and does not replace, existing legislation.

2.7.3 Guideline values

The strategy identifies several priority pollutants that must be addressed in stormwater discharges, including phosphorus, nitrogen, suspended solids, metals (lead, copper, zinc, cadmium, chromium, nickel, mercury), and organic pollutants such as oil and polycyclic aromatic hydrocarbons (PAH). These pollutants are particularly relevant when evaluating the performance of different stormwater solutions, as their removal efficiency varies between measures such as swales, rain gardens, and detention ponds.

Table 2.6 presents the minimum requirements for which pollutants and parameters must be monitored in effluent discharged to the stormwater network or directly to a recipient, along with the corresponding guideline values (Partille Municipality, 2026b). These guideline values are based on those established by Gothenburg Municipality (Miljöförvaltningen Göteborgs Stad, n.d.). The values for phosphorus and nitrogen are site-specific, and the values shown are the recommended guideline values. As a rule, the discharge of nutrients shall be limited. The strategy further emphasises that at every measure, the degree of pollution in water released to Säveån should decrease.

Table 2.6: Guideline values of pollutants in discharged stormwater (Miljöförvaltningen Göteborgs Stad, n.d.)

Pollutant	**Guideline value**
Arsenic	16 µg/L
Lead	28 µg/L
Cadmium	0.9 µg/L
Chromium	7 µg/L
Copper	10 µg/L
Mercury	0.07 µg/L
Nickel	68 µg/L
Zinc	30 µg/L
Oil index	1000 µg/L, 500 µg/L if within water protection area, 100 µg/L if close to raw water intake
Suspended solids	25 mg/L
pH	6.5–9
Phosphorous	50 µg/L
Nitrogen	1250 µg/L

2.8 Multi-criteria decision analysis

Multi-Criteria Decision Analysis (MCDA), also known as Multi-Criteria Analysis (MCA), is a structured methodological approach and set of techniques designed to handle complex decision problems characterised by multiple, often conflicting, criteria (DCLG, 2009). In the context of USWM, these criteria are typically connected to the three pillars of sustainability: social, economic, and environmental, as well as technical (Bousquet et al., 2023). The primary goal of the MCDA is to provide an ordering of alternatives, ranking them from the most preferred to the least preferred option (DCLG, 2009). MCDA is meant to provide decision support, and not an absolute truth.

The MCDA process consists of multiple, well-defined steps (DCLG, 2009), see Figure 2.3. These include: (1) problem definition and stakeholder analysis, (2) identification of alternative stormwater solutions, (3) definition of evaluation objectives and criteria, (4) scoring of alternatives against each criterion, (5) weighting of criteria to reflect their relative importance, (6) aggregation and ranking of alternatives, and lastly, (7) a sensitivity analysis to tests how robust the ranking is to changes in weights or scores.

By providing a systematic procedure to evaluate, rank, and select alternatives based on a weighted set of criteria, MCDA helps decision-makers navigate trade-offs and justify choices in a transparent and replicable manner.

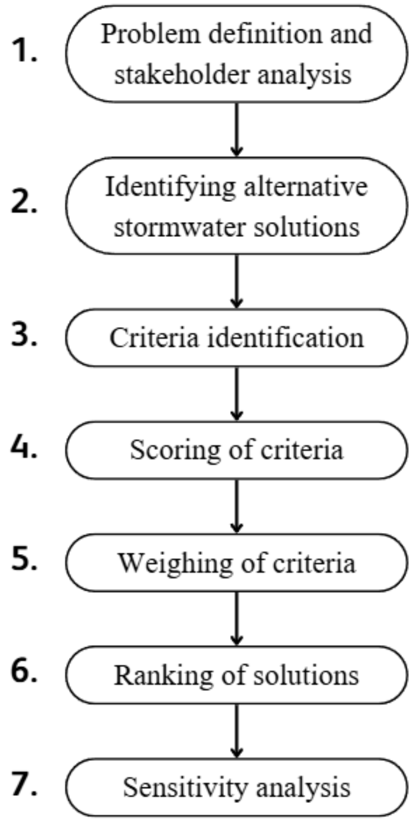

Figure 2.3: Steps in MCDA in accordance to DCLG (2009).

MCDA encompasses several methods designed to support decision-making when multiple, often conflicting, objectives must be considered. The following sections outline the core steps of a generic MCDA process, mainly drawing on the established guidance manual by DCLG (2009).

2.8.1 Problem definition

The first step in the MCDA process is problem definition. This phase involves: establishing the aim of the analysis, identifying stakeholders and other key actors, designing the socio-technical system for conducting the MCDA, and considering the context (DCLG, 2009).

Defining clear objectives at the outset provides essential guidance for the subsequent stages, ensuring the analysis remains focused and methodologically coherent (DCLG, 2009). A fundamental question to address is: 'What is the purpose of the MCDA?'

The designers of an MCDA must carefully consider which stakeholders and key players to involve, as well as the nature and extent of their participation. Key players are individuals selected to contribute valuable input and to represent all important perspectives relevant to the analysis (DCLG, 2009). Stakeholders, in contrast, are individuals or groups who have a vested interest in the outcomes of the decision but may not directly participate; their perspectives are often represented by one or more key players. It is also important to include key players who possess relevant expertise to assist the analysis, both within and outside the organisation (DCLG, 2009).

In the context of USWM, Skrydstrup et al. (2020) identified fourteen stakeholders. The stakeholders were grouped according to their role in planning, see Figure 2.4. The authors note that workshops rarely directly include *Politicians* or *Legal* representatives. This is because political objectives are already embedded in the stated goals of civil society and the municipality, while legal requirements are integrated into existing planning processes.

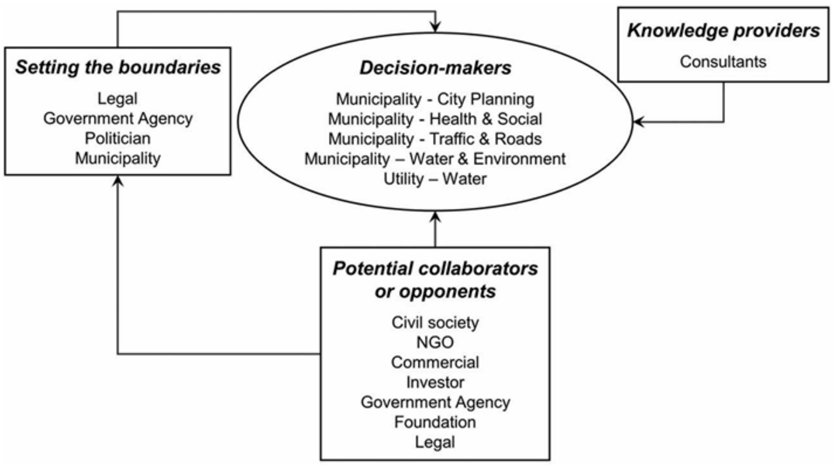

Figure 2.4: Identified stakeholders in the context of USWM (Skrydstrup et al., 2020).

Once the stakeholders and key players have been identified, the socio-technical system of the MCDA must be designed. The social aspects determine *when* (e.g., during alternative identification, criteria definition, scoring, or weighting) and *how* (e.g., through workshops, interviews, surveys, or individual exercises) stakeholders and key players will contribute to the MCDA (DCLG, 2009). To provide context for these design choices, Bousquet et al. (2023) analysed 124 papers on MCDA and NBS published between 2000 and 2022. Their analysis gathered statistics on the types of stakeholders involved *(whom)*, the phases of involvement *(when)*, and the methods of engagement *(how)*, which are summarized in Table 2.7. As seen, the percentages do not necessarily add up to 100 % since multiple stakeholders can be involved in multiple phases and ways in one study.

Table 2.7: Type of stakeholders involved, phase of involvement, and type of involvement in reviewed papers (Bousquet et al., 2023).

Type ***(whom)***	%
Research team	80
Expert(s)	10
Stakeholders (group)	18
No information	6
Involvement phase ***(when)***	**%**
Problem definition	12
Alternative definition	19
Criteria definition	20
Criteria weighing	69
No involvement	20
Involvement type ***(how)***	**%**
Survey	21
Interview	15
Workshop	32
Individual exercise	13
None/no information	19

The technical aspect focuses on the form and implementation of the MCDA model itself. A widely popular and strongly recommended strategy for gathering stakeholder and key player input is conducting workshops, though surveys and interviews are also viable options (Bousquet et al., 2023; DCLG, 2009). Effective workshops typically include a mix of key players representing the various stakeholder groups. Furthermore, an impartial facilitator, a structured modelling process, and the use of information technology for live modelling and result visualisation are key to successful workshop outcomes. However, this approach can be time-intensive, depending on the decision's complexity (DCLG, 2009).

Finally, the context of the MCDA must be considered. By comparing the current situation with the desired future state, the discrepancy becomes clear, thus defining the precise role and purpose of the MCDA (DCLG, 2009).

2.8.2 Identification of alternative stormwater solutions

The alternatives for analysis can either be identified from a pre-existing set or be developed specifically for the study (DCLG, 2009). While stakeholders can play an influential role in this identification process, both the MCDA facilitators and the relevant stakeholders must maintain a clear understanding of the overarching objectives.

When identifying and designing possible stormwater solutions, exclusion criteria or thresholds can be applied (Ellis et al., 2004). This will render some alternatives unsuitable, invalid, or unfeasible for a certain site.

Additionally, those conducting the analysis should remain open to modifying or adding options as the process unfolds and new insights emerge.

2.8.3 Criteria identification

In MCDA, the assessment focuses on the consequences of the alternatives rather than on the alternatives themselves. These consequences can be evaluated across multiple criteria or attributes (DCLG, 2009). Criteria are specific, measurable components derived from higher-level objectives, which may in turn originate from broader strategic goals.

In essence, the criteria define the specific aspects by which alternatives generate value or utility (DCLG, 2009). The process for defining these criteria depends on the starting point of the analysis. If a fixed set of alternatives is provided from the outset, a bottom-up approach is suitable. This method involves identifying criteria by analysing the key, value-relevant differences between the given options. If, however, alternatives are not predetermined, a top-down approach is employed. This strategy first establishes the fundamental objectives and overall aims of the decision-maker, subsequently deriving the criteria necessary to evaluate how well any potential alternative fulfils those objectives.

According to Bousquet et al., 2023, 60% of studies involving MCDA have less than or equal to 10 criteria. Less than 11% have more than 20 criteria. This is stated to be within recommendation, since too many criteria would reduce their individual impact on the model, as well as lead to less obvious results.

A fundamental step in structuring criteria is distinguishing between means objectives (which are instrumental) and end objectives (which are fundamental) (DCLG, 2009). This distinction can be clarified by iteratively asking, “Why is this objective important?”. An objective is considered a true “end” or fundamental objective when no further meaningful justification can be provided.

Once criteria have been identified, they could be organised hierarchically into a value tree (DCLG, 2009). This structure enables the scoring of alternatives at the level of specific criteria while allowing for the evaluation of overall performance at higher objective levels. The most important trade-offs, such as between costs and benefits, are positioned at the top of this hierarchy.

Bousquet et al. (2023) analysed which dimensions and criteria types were included in the reviewed papers as well as in what percentage of papers. As seen in Table 2.8, technical and economic criteria are less present in the studied papers. Bousquet et al. (2023) states that this could be due to a lack of knowledge of the design and the cost of NBS.

Table 2.8: Criteria type included in reviewed USWM papers (%) (Bousquet et al., 2023).

Dimension	Criteria type	%
Social	Esthetics	28
	Recreation	33
	Mobility	10
	Health	48
	Safety and security	46
	Connectedness	18
	Education	18
	Occupation	26
Environmental	Water quality	39
	Ressources	56
	Nature	64
Economic	Business development	25
	Low cost	34
Technical	Integration with existing infrastructures	18
	Flexibility	9
	Simple & transparent	13
	Supply safety	27

It is important that the criteria is preference independence (DCLG, 2009), meaning that the scores given to one criterion, for each alternatives, are unaffected by the score of another criteria. This is usually due to double counting (DCLG, 2009). If preference independence has not been achieved, it is usually discovered in the scoring process (i.e., if one criterion can not be scored without knowing the score on another criterion).

To ensure that relevant criteria have been identified, stakeholders and key players can be consulted (DCLG, 2009).

2.8.4 Scoring of criteria

A central challenge in MCDA scoring lies in the incomparability of different criteria (DCLG, 2009). Performance on each criterion is measured in its own distinct units (e.g., µg/L of heavy metals, cost of construction in SEK), making direct comparison and aggregation impossible. One MCDA solution is to transform these disparate measures onto a common, preferential scale (e.g., 0 to 100, 0 to 10). This involves constructing value functions or utility functions that translate the raw performance of an alternative on each criterion into a score representing its relative desirability or contribution to the overarching objective. The scores on the scale should be accompanied by a description (e.g., 0 – very bad performance, 10 – very good performance). Only after this normalisation to a unified scale of preference can the scores be meaningfully weighted and aggregated.

Another solution is the Analytic Hierarchy Process (AHP), based on pairwise comparison (DCLG, 2009; Saaty, 1987). In this process, analysts indicate their perceived performance of each alternative relative to others under a given criterion. This process is repeated for each criterion, generating pairwise comparisons across all alternatives. The outcome is a set of preference matrices, one per criterion, that capture the relative performance of the alternatives on that specific criterion.

Following the initial scoring of alternatives, a critical review is conducted to ensure preference consistency (DCLG, 2009). This step verifies that the assigned scores logically reflect the decision-makers' judgments about the relative performance of each option. Consistency is achieved when the numerical differences between scores are proportional to the perceived differences in value. For instance, a large gap in performance should correspond to a large difference in scores.

In practice, the first scoring iteration often reveals inconsistencies, as implicit preferences are made explicit through numerical scoring. By including stakeholders and key players in the scoring step, the MCDA framework facilitates this by reviewing, discussing, and iteratively refining their scores (DCLG, 2009). This is easiest conducted through workshops. The ultimate goal is to arrive at a set of scores that all key participants agree are coherent and accurate, thereby ensuring the validity and credibility of the final analysis.

2.8.5 Weighing of criteria

The weights of criteria in MCDA are used to reflect the relevance of given criteria to the final outcome (Więckowski et al., 2026) and its perceived importance among stakeholders (DCLG, 2009). The manual points out that the weights also reflect the range of performance differences among the alternatives for that criterion. Consequently, a criterion deemed 'very important' may receive a lower effective weight if all alternatives perform similarly on it. Conversely, a criterion of lesser nominal importance can become decisive if it exhibits a wide performance range, thereby having a greater impact on the final ranking. This ensures the methodology is sensitive to both stakeholder preferences and discriminative power between options.

Several methods exist for weighing criteria. One method, Direct Weighing, where stakeholders assign weights directly to each criterion (e.g., distributing 100 points, assigning a score on a scale from 0 to 10) (DCLG, 2009). As for the scoring of criteria, AHP can be used for weighing of criteria (DCLG, 2009; Velasquez & Hester, 2013). Criteria are compared in pairs to derive weights based on relative importance (Saaty, 1987), which will be used to form a preference matrix.

Another method is Swing Weighing (Bottero et al., 2024). SWING weighting anchors preference elicitation in concrete performance levels. Starting from a hypothetical worst-case scenario (all criteria at their lowest levels), the decision-maker identifies which single criterion, if improved to its best level, would most improve the overall situation. This criterion receives 100 points. The remaining criteria are then each considered in turn: improving each from worst to best is assigned a point value of less than 100, reflecting its perceived relative importance.

The process of assigning weights is not merely technical but inherently political, as it forces the question: whose preferences are prioritised? (DCLG, 2009). The manual explicitly identifies this as a fundamental issue but offers no prescriptive solution, acknowledging that the ultimate choice is contextual and political. Its primary guidance is that this dilemma must be handled explicitly rather than implicitly to ensure the MCDA process remains transparent and its assumptions open to scrutiny.

While the manual suggests that a sound, democratic aspiration is for weights to reflect the informed preferences of the public (DCLG, 2009), this ideal is frequently contested in practice by stakeholders with conflicting priorities.

2.8.6 Ranking of alternatives

The manual presents a simple additive model to derive the final ranking of alternatives. The ranking is determined directly from their total weighted scores, S_i (DCLG, 2009). To calculate S_i, the alternative's score on each criterion is multiplied by the criterion's importance weight, and these products are then summed (see Formula 2.3).

$$S_i = w_1 s_{i1} + w_2 s_{i2} + \cdots + w_n s_{in} = \sum_{j=1}^{n} w_j s_{ij} \tag{2.3}$$

where:

- S_i is the total score for alternative i,
- w_j is the weight of criterion j, and
- s_{ij} is the score of alternative i on criterion j.

The process is repeated for each alternative, and S_i is compared to establish a preference ranking. The alternative with the highest score is considered the most preferred, and the magnitude of the differences between scores provides a quantitative indication of the strength of preference between options. This model is compensatory (DCLG, 2009), meaning it is a method that combines assessments across criteria into an overall score, allowing poorer performance on some criteria to be compensated by better performance on others.

Further, there are different ways to present the results (Bousquet et al., 2023) (e.g., ranking of alternatives, master plan, equitable alternatives). Ranking of alternatives is the most common way to display MCDA results (65% of studies) (Bousquet et al., 2023).

Interpreting these results requires careful analysis (DCLG, 2009). The findings should be subjected to robustness checks (e.g., sensitivity analysis on the weights) to validate their reliability. Furthermore, the practical implications and potential impacts of implementing the top-ranked alternative(s) must be assessed before any final recommendations are made.

2.8.7 Sensitivity analysis

Sensitivity analysis offers a way to assess how uncertainty regarding input data (e.i., scores) and differing viewpoints among stakeholders (i.e., weights) may influence the final outcome of an evaluation (DCLG, 2009).

Stakeholder groups frequently diverge in their perception of both relative significance of evaluation criteria and the associated performance scores (DCLG, 2009).

However, disagreement tend to arise more often over weights than over scores. The scoring should be as objective as possible, but the performance of alternatives might be interperated differently, or perform different under different circumstances. By employing a sensitivity analysis to explore how the ranking of alternatives may vary under alternative scoring or weighting, it can show that two or three options always come out best, even if their relative order shifts. If the performance differences between these top-ranked alternatives across various weighting configurations prove to marginal, accepting the option ranked second-best may be a reasonable and defensible choice.

Sensitivity analysis may also serve as a starting point to identify how alternatives might be improved (DCLG, 2009). Beyond this, sensitivity analysis also holds potential value in helping to resolve disagreement among stakeholder groups.

The theoretical overview provides the foundation for the methodological approach adopted in this thesis. The subsequent methodology chapter will describe how these MCDA principles were operationalized in the case study of Anneberg, Part, including the specific methods selected for stakeholder engagement, criteria weighting, and alternative ranking.

3. Case study

This chapter describes the Anneberg study area and its stormwater-related characteristics. The objective is to understand the empirical foundation for the MCDA in Section 4.2. Anneberg presents a challenging decision problem: limited space for stormwater management, historical flooding, and upcoming densification that will increase run-off. The following sections describe the site's location, topography, land use, drainage infrastructure, pollutant loads, planning constraints, and the resulting detention requirement.

3.1 The study area

The case study area is situated within Partille Municipality in southwest Sweden, adjacent to the E20 highway (Figure 3.1). Anneberg is a centrally located neighbourhood south-east of Partille centrum, containing apartment buildings, a school, and a pre-school. The current land use consists of paved areas, shallow vegetation, buildings, and two larger areas with dense vegetation. The study area is approximately 7 hectares. The receiving water body is Säveån, a watercourse included in the Natura 2000 network (Naturvårdsverket, n.d.). This European network is dedicated to preserving and protecting valuable nature areas for future generations (Naturvårdsverket, 2024).

In accordance with Partille Municipality's Vision 2035, Anneberg is undergoing a densification process, transitioning into a mixed-use urban environment where natural land will be replaced by impervious surfaces (Partille Municipality, n.d.). This development aims to foster an attractive city centre and create sustainable living spaces for a growing population.

The development increases run-off volumes while reducing available space for stormwater management. The combination of a steep topography (elevation drop from 40 to 11 meters), an upstream catchment of 74 hectares, and an undersized separate sewer system makes Anneberg particularly vulnerable.

3.2 Site characteristics

This section delineates the site characteristics of the Anneberg area as they will appear after development. A description of the topography, land features, and the overall design of the urban drainage infrastructure is provided.

3.2.1 Topography

The topography was analysed using Scalgo Live (SCALGO, n.d.). The analysis shows an elevation drop from 40 m above sea level in the southern forest to 11 m above sea level in the northwest. This is a difference of 29 m over 213 m, creating a steep hydraulic gradient of 13.7%.

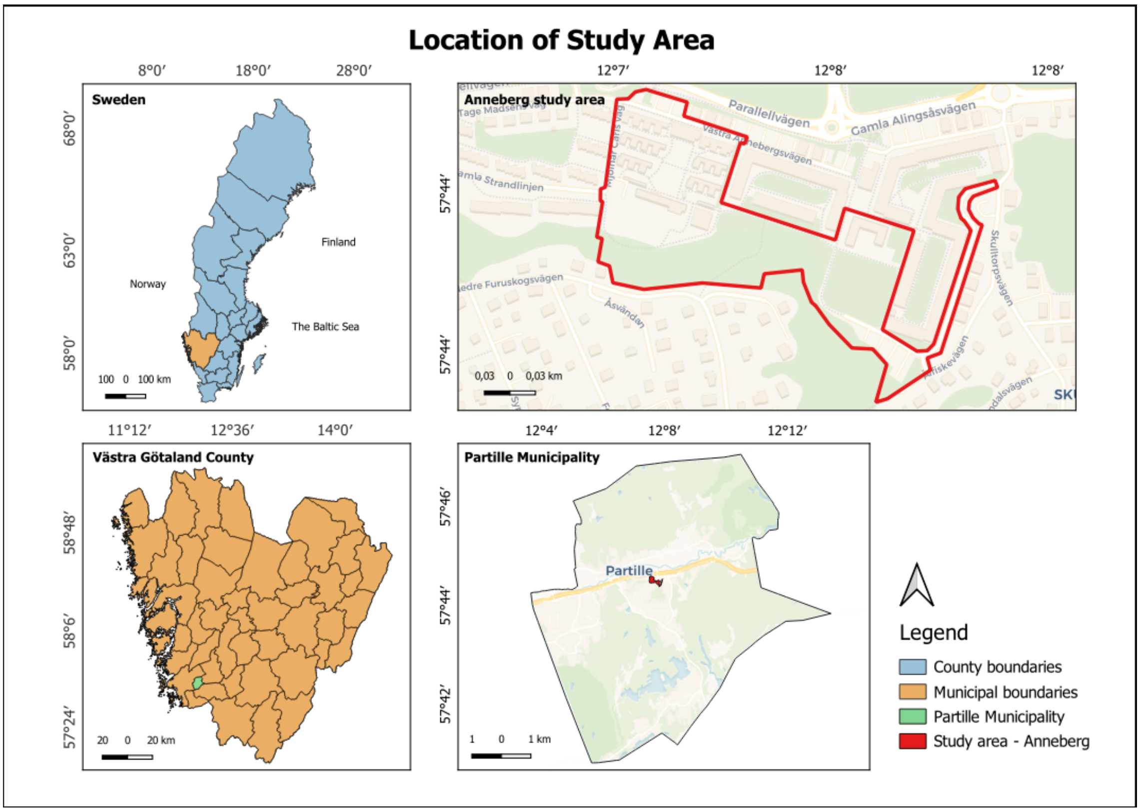

Figure 3.1: Location of study area within Sweden, the county and the municipality.

Crucially, the 7 hectare study area serves as a collection point for a 74-ha watershed (Figure 3.2). Consequently, the site must manage run-off from an area more than ten times its own size. Though, as stated in limitations (Section 1.2), this upstream water is outside this thesis scope.

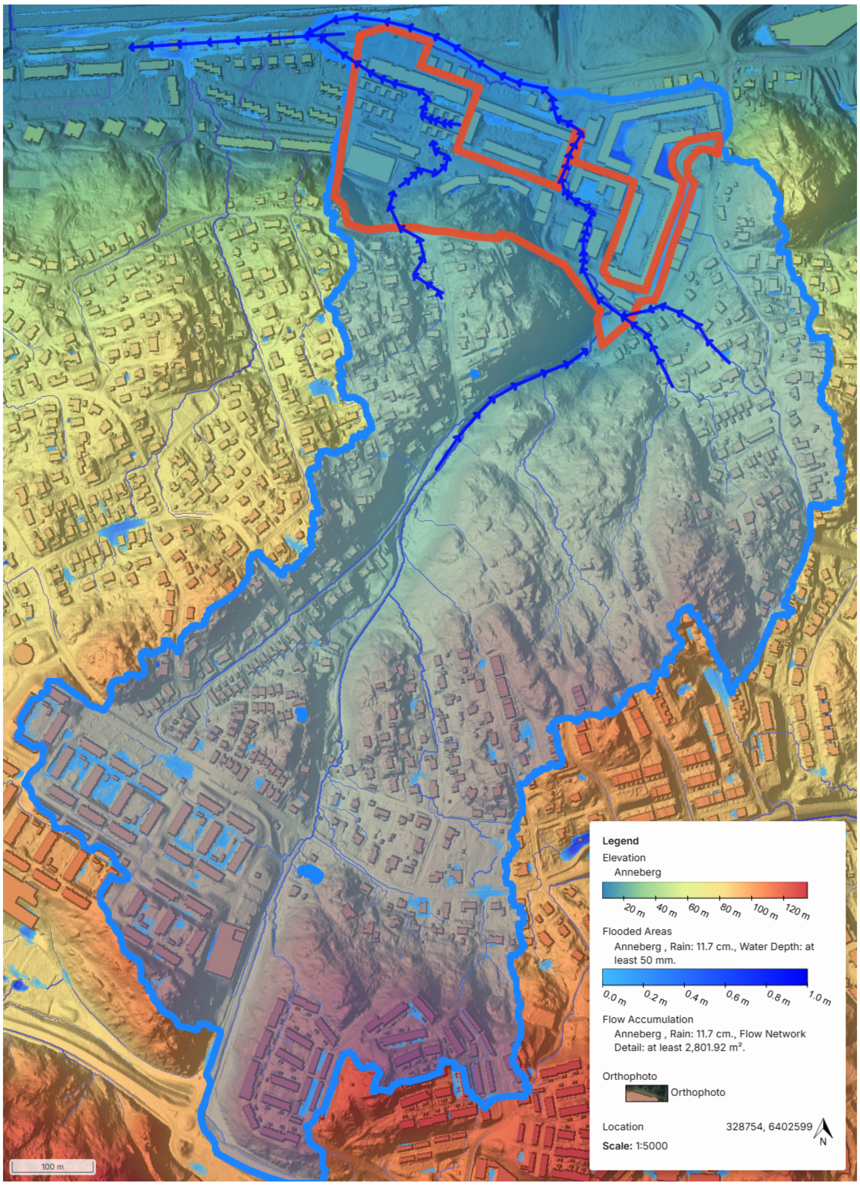

Figure 3.2: The Anneberg watershed in blue and the specific study area in red, highlighting elevation and surface water flow.

3.2.2 Land use and run-off coefficients

Figure 3.3 shows the suggested layout after development. This includes an expansion of the school (e.g., a new sports hall and football field) and pre-school, as well as the development of residential buildings. The figure includes current buildings, new buildings, vegetation cover, paved areas, and the football field.

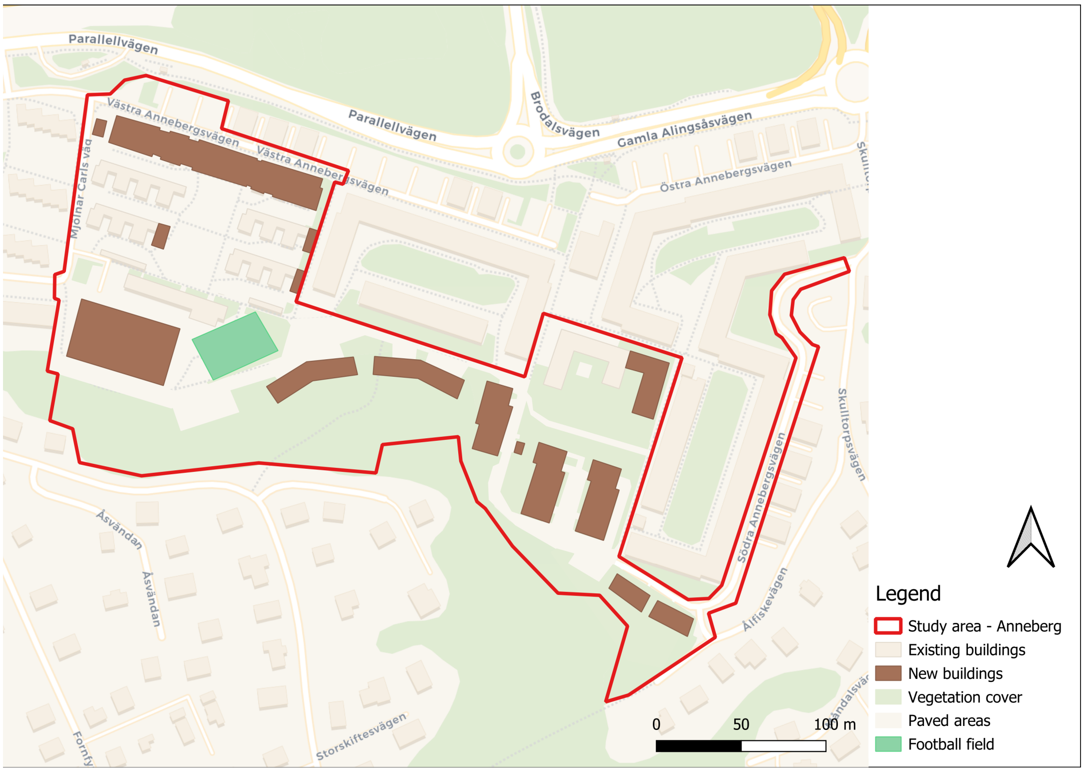

Figure 3.3: Layout of Anneberg study area after development.

Anneberg has been divided into nine sub-areas, based on land use and responsibility (Figure 3.4, Table 3.1). This is the same division as made by COWI in their stormwater and cloudburst investigation of Anneberg. When this thesis was written, the investigation was not yet finished and therefore not yet published. The investigation was made available through Partille Municipality.

Table 3.2 presents the size of each sub-area, the run-off coefficients before and after development, and the calculated reduced area. These values were given in the investigation by COWI. The suggested development will increase paved areas and reduce vegetation, which will increase the total reduced area from 2.75 ha to 2.96 ha.

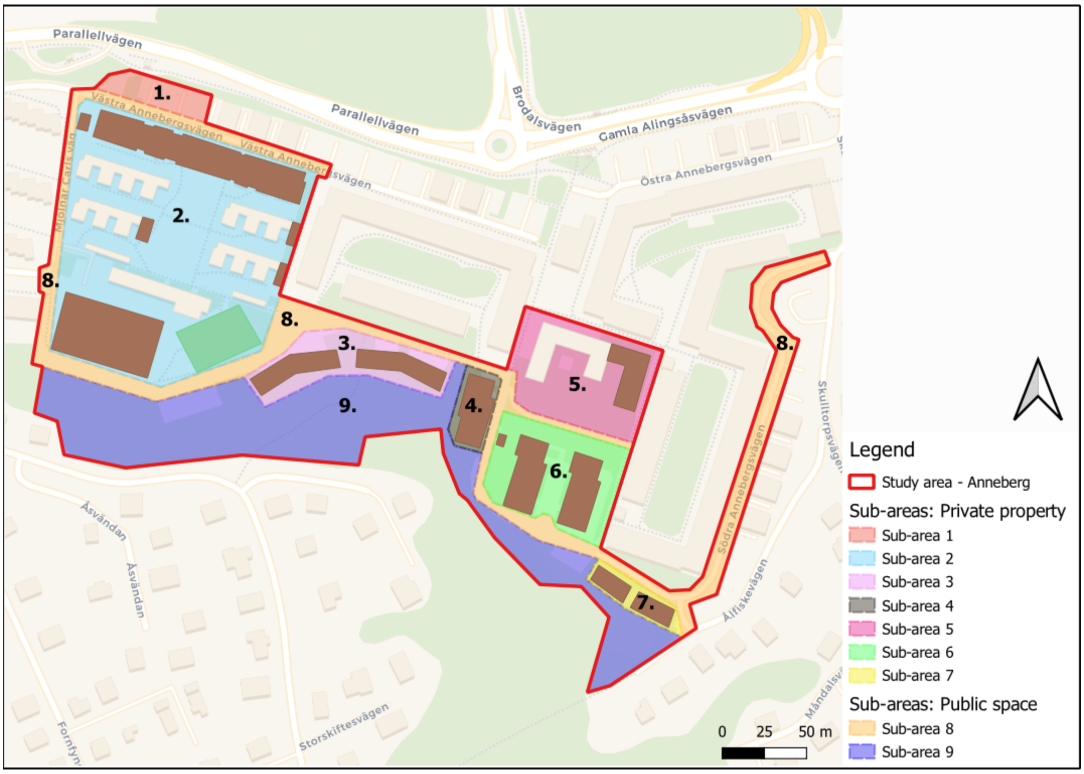

Figure 3.4: Sub-areas for Anneberg.

Table 3.1: Ownership and main use of sub-areas.

Sub-area	Ownership	Main use
1	Private property	Parking area
2	Private property	School
3	Private property	Multi-storey buildings
4	Private property	Multi-storey buildings
5	Private property	Pre-school
6	Private property	Multi storey buildings
7	Private property	Town houses
8	Public space	Local street
9	Public space	Green area

Table 3.2: Run-off coefficients and reduced area per subarea before and after development.

Subarea	Area	Before development		After development	
	$[ha]$	Runoff coefficient $[-]$	$A_{red.}$ $[ha]$	Runoff coefficient $[-]$	$A_{red.}$ $[ha]$
1	0.14	0.8	0.112	0.8	0.112
2	1.85	0.5	0.925	0.55	1.0175
3	0.36	0.3	0.108	0.5	0.18
4	0.13	0.3	0.039	0.5	0.065
5	0.41	0.5	0.205	0.5	0.205
6	0.36	0.3	0.108	0.5	0.18
7	0.18	0.8	0.144	0.5	0.09
8	0.96	0.8	0.768	0.8	0.768
9	1.13	0.3	0.339	0.3	0.339
Total $A_{red.}$:			2.748		2.957

3.2.3 Drainage infrastructure

According to the development plan, the existing stormwater system is a separate sewer system that conveys stormwater directly to Säveån through pipes. No other stormwater infrastructure exists. The current network is heavily loaded during a 2-year rain event.

To prevent overloading of the downstream system, the stormwater drainage system in the Anneberg area is designed to discharge no more than a 2-year rain event to the downstream system. This is taken into consideration when calculating the storage of the alternative stormwater solutions.

3.2.4 Pollutants

The pollutant load will increase after development (Table 3.3), as estimated by COWI in their stormwater and cloudburst investigation of Anneberg, using StormTac.

Under the Swedish Environmental Code (Miljöbalken (1998:808), 1998), municipalities cannot approve activities that increase pollutant loads or degrade water quality. Given that Säveån is a Natura 2000 site (Naturvårdsverket, n.d.) and currently does not achieve good chemical or ecological status (Vatteninformationssystem Sverige [VISS], 2026), stormwater treatment is essential. Pollutants from Anneberg may also affect downstream water bodies as the river drains to the sea.

Table 3.3: Pollutant load for land use before and after development.

Parameter	Before development [$kg/year$]	After development, without treatment [$kg/year$]
Phosphorus (P)	7.4	8.0
Nitrogen (N)	62	65
Lead (Pb)	0.39	0.40
Copper (Cu)	0.73	0.77
Zinc (Zn)	2.3	2.5
Cadmium (Cd)	0.016	0.018
Chromium (Cr)	0.32	0.37
Nickel (Ni)	0.21	0.26
Mercury (Hg)	0.0014	0.0015
Suspended solids	1900	2200
Oil index (Oil)	21	23
BaP	0.0012	0.0015

3.3 Planning constraints for stormwater solutions

The development of Anneberg is constrained by two main factors regarding stormwater measures, which are presented in this section.

3.3.1 Available space for stormwater management

According to the comprehensive plan for Anneberg, a two-meter-wide strip along the local street (sub area 8) is allocated for stormwater management, which is referred to as the Flex area. The local street is approximately 1000 meters long, giving an initial area of 2000 m^2. However, sections on the Flex area are reserved for vehicle meeting points, waste collection, and other utility functions, estimated at 80 meters in total. After deduction, the available length is 920 meters, resulting in an available area of 1840 m^2 for stormwater measures. This area is marked with blue in Figure 3.5. For a generalised visualisation of the flex area in relation to the local street, see Figure 3.6.

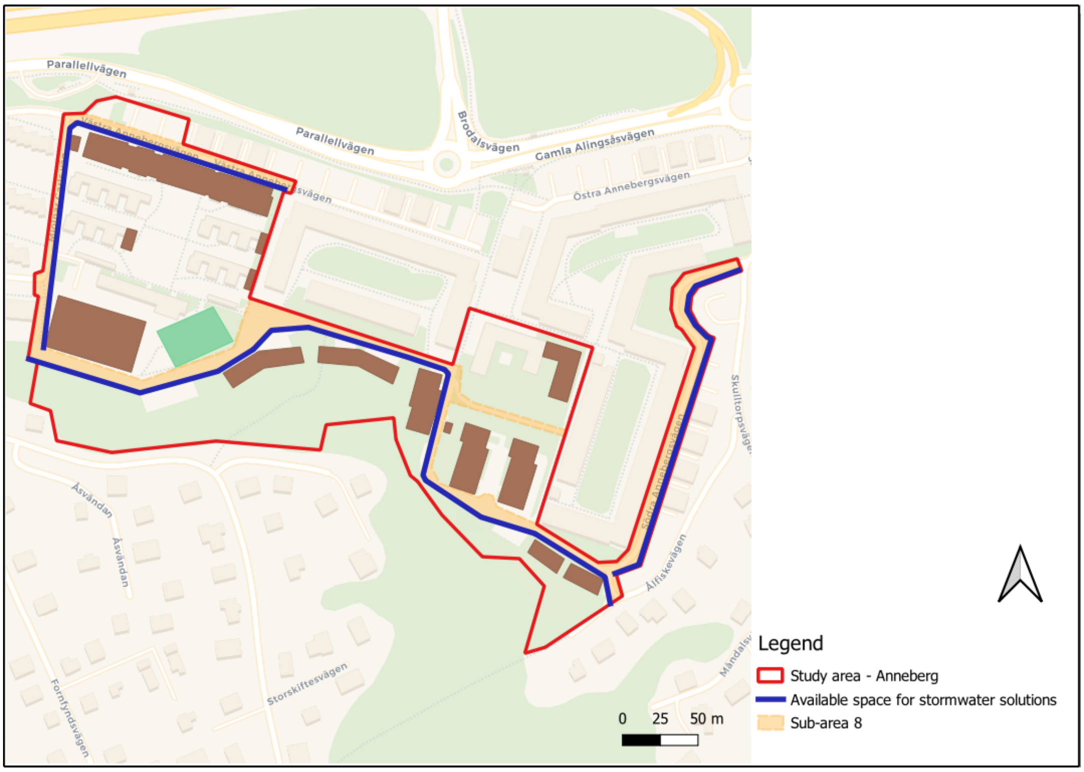

Figure 3.5: Map of the Anneberg study area, with the location of available area for stormwater management marked in blue.

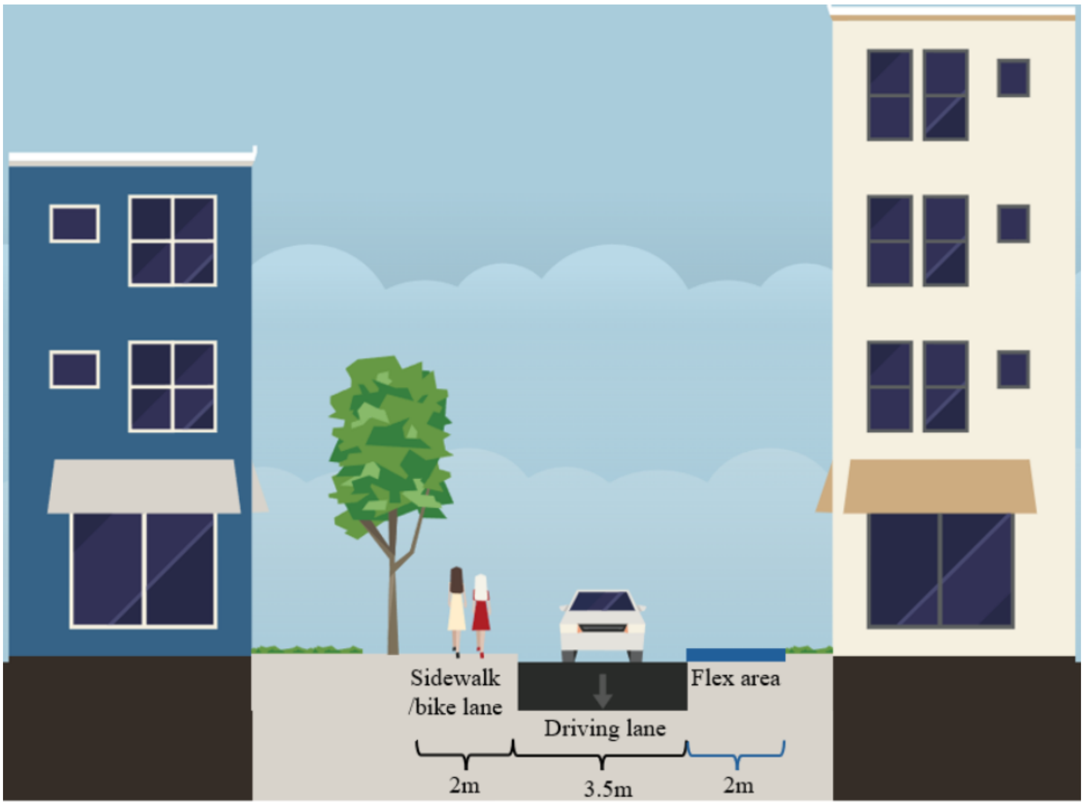

Figure 3.6: Street view of a section of the local street.

3.3.2 Detention requirement

This analysis focuses solely on the municipal responsibility and will therefore only handle run-off from sub-area 8 (local street) and 9 (green area) in accordance with Table 3.1. The private property owners have other regulations and requirements, as described in Section 2.6 and 2.7.

A summary of the detention calculation is given here. For further description of calculations, see Section 4.2.2. Based on the site characteristics and the regulatory requirement of a 20-year return period (10 min duration) with a 25% climate factor, the design flow from public space was calculated using the Rational Method. This resulted in the required dimensioning flow, Q_{dim}, of 397 l/s, and the allowed outflow, Q_{out}, of 148 l/s. The required detention volume was calculated to be 93 m^3. All stormwater solutions evaluated in the MCDA are designed to handle this volume.

4. Method

This chapter presents the methodology employed in this thesis. The method consists of two main components: a literature study and the multi-criteria decision analysis.

The literature study provides the theoretical framework necessary for understanding the topic and will serve as the baseline for the evaluation of the stormwater solutions. The MCDA serves as the evaluation framework, encompassing the scoring, weighting and final ranking of the solutions.

4.1 Literature study

The literature study in this thesis was conducted following a systematic approach as well as snowballing to find additional literature. A literature review is a study and an interpretation of literature within a specific subject which aims to gain new insights regarding a specific research question and the literature is analysed in a systematic approach (Bryman & Bell, 2015).

The literature search aimed to investigate how MCDA is performed in general and how it is currently applied within USWM. Furthermore, the literature was reviewed to gather knowledge on stormwater characteristics, associated pollutants and the parameters that affect flooding. The search also served to identify the laws and regulations governing the stormwater management in Sweden. Beyond providing information for Chapter 2, the literature review was also conducted to gather the data needed for scoring the criteria in the MCDA. By using established literature, the scoring could be done in a robust way. The literature was also partly used to identify the criterion.

The literature search was conducted in Scopus and Google. Scopus and Scopus AI were used to find scientific, peer-reviewed articles for the theoretical framework describing stormwater quantity and quality, as well as the current application of MCDA within USWM.

The search strategy employed various keywords related to the subject, which were varied across different searches to optimize the results. Different searches served different purposes. For example, some searches aimed to obtain specific knowledge on the removal rate of a particular pollutant by a specific nature-based solution, while others sought to understand which parameters affect stormwater quantity. Keywords included terms such as *stormwater*, *pollutants*, *metals*, *Rain Garden*, *removal*, and *urban flooding*, among others.

Scopus AI was also used as a search tool. Example prompts included "Infiltration Trenches for stormwater management". The output from Scopus AI consisted of a summary of the topic, accompanied by referenced sources. These sources were reviewed and subsequently used in writing the literature review. This approach enabled a faster and more efficient literature search.

Google was used to find information on current laws and regulations applicable to stormwater management in Sweden. The initial search was conducted on Boverket's website, where the relevant laws and regulations were outlined. This was followed by targeted Google searches for specific information regarding these laws.

Lastly, information provided by Partille Municipality was used in the literature study, which specifically describes their stormwater strategy and policy. This served as the basis for the calculations of the stormwater techniques evaluated in the MCDA, as these are steering documents for the planning within the municipality, while adhering to the institutional framework applied in Sweden. Additional information about the study area and plans for the area was also provided by Partille Municipality.

4.2 Multi criteria decision analysis

To address the decision problem in Anneberg, the conflict between the limited available urban space and the necessity of preventing urban flooding, a multi-criteria decision analysis was applied. This method allows for navigating the competing priorities, such as remediation of stormwater pollutants, a reasonable economic situation, and preserving the recreational value of the urban landscape. By systematically evaluating the stormwater solutions, the MCDA identifies the most viable strategies given Anneberg's characteristics.

4.2.1 Problem definition and stakeholder analysis

The first step of the MCDA for Anneberg was to define the core of the decision problem, which has been characterized in the case study (i.e., managing stormwater in a limited available space). This context necessitates a method that can evaluate a spectrum of solutions, ranging from Infiltration Trenches, which prioritize drainage efficiency, to Rain Gardens, which can offer multi-functional benefits. To further address the complexity of the site, the analysis also includes hybrid options that are a combination of two different solutions. By applying MCDA, it becomes possible to evaluate which solution best suits the area, based on the spatial constraints and hydraulic requirements in Anneberg.

The aim of the MCDA was to navigate the competing priorities by providing a robust evaluation of solutions for the study area of Anneberg based on the constraints. It further aims to identify which strategy provides cost-effectiveness, technical feasibility, as well as social and environmental benefits, while meeting mandatory hydraulic requirements. This shifts the focus from a solely technical drainage issue to a multidimensional planning challenge.

According to the literature, it is preferred to involve stakeholders in an MCDA and to perform a stakeholder analysis. The involvement of stakeholders enables that the competing priorities are accurately represented. Stakeholders were identified in collaboration with representatives from Partille Municipality. The stakeholders were selected based on the following inclusion criteria:

- **Direct responsibility for stormwater infrastructure** – to include those with decision-making authority and implementation capacity (e.g., municipal planners, technical departments).

- **Affected by the implementation** – to capture the perspectives of those who experience the outcomes, ensuring social and economic impacts are represented (e.g., property owners, residents).
- **Possessing technical and/or local knowledge** – to incorporate expertise on solution performance and site-specific conditions, enhancing the credibility and contextual relevance of the evaluation (e.g., consultants, local experts).

The criteria defines which stakeholders to include, but not how many. These criteria also ensure that the stakeholder group reflects the key dimensions of power, interest, and knowledge necessary for a robust and inclusive MCDA process. No politicians or legal representatives were included as stakeholders, following Skrydstrup et al. (2020): political objectives are already embedded in municipal goals, and legal requirements are integrated into planning processes.

Following the stakeholder categories identified in Bousquet et al. (2023) and Skrydstrup et al. (2020), a group consisting of municipal planners, consultants, and property owners was engaged primarily for the weighting of criteria, while the other steps were conducted by the authors.

Since all alternatives are fitted into the available space and fulfils the hydraulic requirement, the stakeholders' input was crucial to determine the relative importance of the criterion within the environmental, social, economic, and technical dimensions. This method ensures that the final result reflects the stakeholders' interests.

The division of the steps conducted by stakeholders and authors is seen in Table 4.1. The stages of scoring, ranking of alternatives, and sensitivity analysis were exclusively conducted by the authors to ensure compliance with regulations and site-specific data. By basing the scoring on literature and site-specific data, the scoring was assessed consistently based on performance, without individual bias or value-based scoring.

Throughout the MCDA process, stakeholder involvement varied depending on the stage. For the identification of alternatives and criteria, representatives from Partille Municipality were engaged through email correspondence, online meetings, and in-person discussions. In these interactions, potential solutions and evaluation criteria were presented and discussed, where the authors proposed alternatives and the municipality provided feedback and local insights.

For the weighting stage, a broader group of stakeholders was included: Partille Municipality, researchers, civil society, consultants, and property owners. To collect their preferences, a questionnaire was distributed, allowing stakeholders to express the relative importance of the different criteria. The design and implementation of this questionnaire are further described in Section 4.2.5. This involvement of the stakeholders ensures that the final result is not just a given solution but rather a reflection of the actual needs and values of those involved in Anneberg.

Table 4.1: Stakeholder involvement in the MCDA socio-technical system: Roles and participation per stage.

Stage in MCDA	Stakeholder(s)/key player(s)	How
Stakeholder analysis	Partille Municipality	Online meeting, in-person discussions, e-mail correspondence
Identification of alternative stormwater solutions	Partille Municipality	Online meeting, in-person discussions, e-mail correspondence
Criteria identification	Partille Municipality	Online meeting, in-person discussions, e-mail correspondence
Scoring of criteria	Only Authors	
Weighing of criteria	Partille Municipality, Civil Society, Consultants, Property owners, Researchers	Questionnaire
Ranking of alternatives	Only authors	
Sensitivity analysis	Only authors	

4.2.2 Selection of alternative stormwater solutions

After defining the problem and identifying relevant stakeholders, the next step was to identify potential stormwater solutions to evaluate in the MCDA. To ensure a realistic methodology, a pre-selection of feasible alternatives was conducted based on planning and space constraints within the area. The pre-selection of alternatives was made in collaboration with representatives from Partille Municipality, and supported by a literature review of stormwater solutions. This process ensured that all stormwater solutions entering the evaluation in the MCDA are feasible for the characteristics and requirements within Anneberg. Specifically, two exclusion criteria were applied:

1. **Hydraulic performance:** The solution must be able to fulfil the required detention volume within the case study area
2. **Space availability:** The physical area required by the solution to provide this detention volume must not exceed the available area, identified in Section 3.3.1.

Establishing these exclusion criteria beforehand allows the MCDA to shift from basic hydraulic capacity and technical feasibility to a nuanced analysis of criteria that provide other benefits.

After defining the exclusion criteria, the next step was to calculate the hydraulic performance by calculating the required detention volume. This calculation was limited to run-off from public space (i.e., sub-areas 8 and 9 in Figure 4.1). The focus on public space ensures that the suggested solutions are within the municipality's area of responsibility.

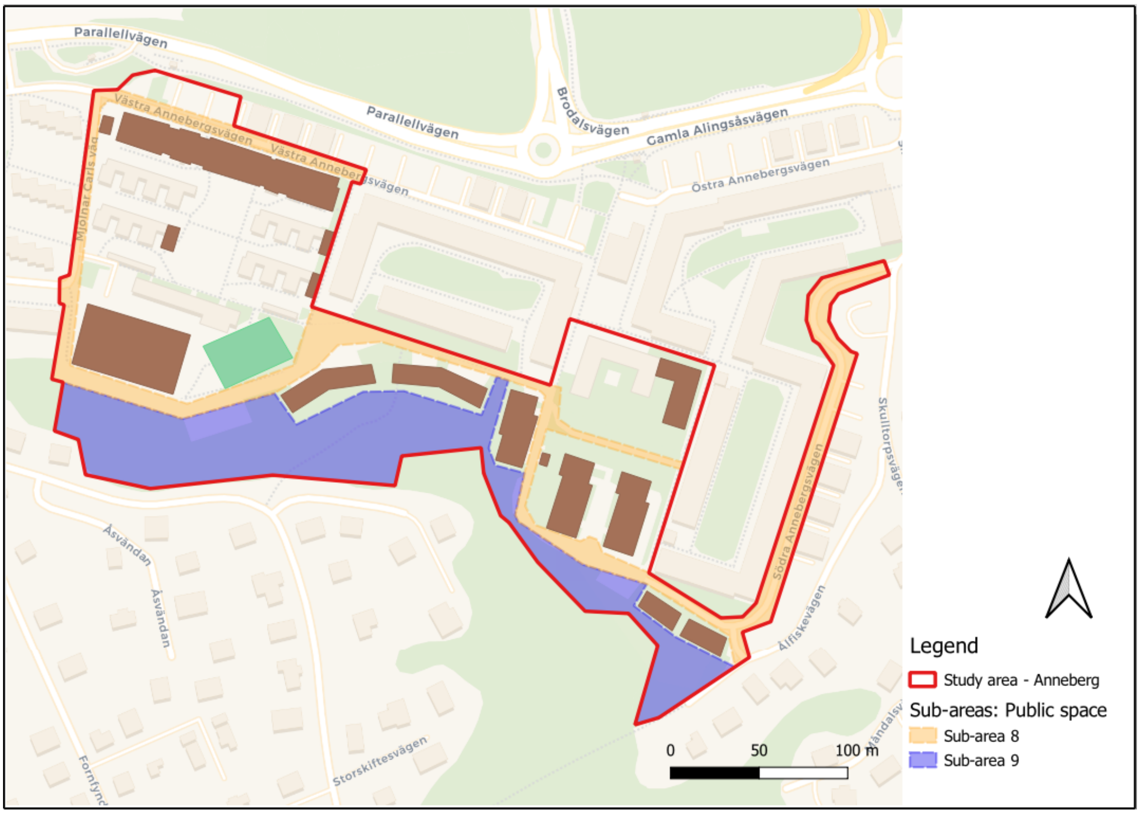

Figure 4.1: Public space in Anneberg considered for stormwater runoff calculations.

The required detention volume was calculated using a return period of 20 years and a rainfall duration of 10 minutes, according to Partille Municipality's policy. The rational method (Equation 4.1) was applied to estimate flows (Q_{dim} and Q_{out}). Despite its known limitations for complex urban catchments, the method was deemed sufficient for this comparative analysis given the study area's characteristics, as it is relatively small.

$$q_{\text{design}} = \phi \cdot i(t_r) \cdot A \cdot kf \tag{4.1}$$

Where:

- q_{design} is the design flow $[l/s]$
- ϕ is the runoff coefficient, determined by the surface characteristics $[-]$
- $i(t_r)$ is the rainfall intensity $[l/s \cdot ha]$
- A is the catchment area $[ha]$
- kf is the climate factor $[-]$
- (t_r) is the duration of the rainfall $[minutes]$

The parameters for Equation 4.1 were derived following the guidelines in Svenskt Vatten (2016) and are presented in Table 4.2. The rainfall intensity $i(t_r)$ was based on Dahlströms rainfall statistics.

Table 4.2: Input values for rational method to calculate Q_{dim} and Q_{out}.

Parameter	Q_{dim}	Q_{out}
Return period $[years]$	20	2
ϕ (Local street) $[-]$	0,8	0,8
Area (Local street) $[ha]$	0,96	0,96
ϕ (Green area) $[-]$	0,3	0,3
Area (Green area) $[ha]$	1,13	1,13
$i(t_r)$ $[l/s \cdot ha]$	286,7	134,1
(t_r) $[minutes]$	10	10
kf $[-]$	1,25	-
Resulting Q $[l/s]$	**397**	**148**

After Q_{dim} and Q_{out} have been calculated, the maximum required detention volume was calculated using 4.2 (Svenskt Vatten, 2016).This volume represents the detention requirement that each stormwater solution must fulfil.

$$V_{\text{d,max}} = 0,06 \cdot t_r \cdot (Q_{\text{dim}} - Q_{\text{out}}) - V_c \tag{4.2}$$

Where:

- $V_{\text{d,max}}$ – maximum required detention volume [m^3]
- t_r – duration of the rain event [minutes]
- Q_{dim} – dimensioning flow to the facility [l/s]
- Q_{out} – dimensioning flow out of the facility [l/s]
- V_c – equalizing effect on the required detention volume due to the inflow process, according to (Svenskt Vatten, 2016) [m^3]

The equalizing effect on the required detention volume V_c was calculated using Equation 4.3 (Svenskt Vatten, 2016), which gave a total V_{c} of 56 m^3. The input values were the same as for Q_{dim} in Table 4.2, and Q_{out} was set to the previously calculated value of 148 l/s.

$$V_{\text{c}} = 0,06 \cdot t_c \cdot Q_{\text{out}} \cdot \left(1 - \frac{Q_{\text{out}}/(\phi_d \cdot A_d)}{I \cdot f_c}\right) \tag{4.3}$$

The maximum required detention volume $V_{\text{d,max}}$ was then calculated to 93 m^3.

To calculate the required area for the stormwater facilities, Equation 4.4 (Svenskt Vatten, 2016) was used. This equation calculates the effective detention volume based on the facility's area and the thickness and porosity of its different layers.

$$V_{\text{eff}} = A_{\text{sf}} \cdot (h_1 + h_2 \cdot p_2 + h_3 \cdot p_3 + h_4 \cdot p_4 + ...)/1000 \tag{4.4}$$

Where:

- V_{eff} – effective detention volume [m^3]
- A_{sf} – surface area of the facility [m^2]
- h_1 – thickness of regulating volume layer [mm]
- h_2 – thickness of filter material layer [mm]
- h_3 – thickness of separator layer [mm]
- h_4 – thickness of macadam layer [mm] (additional layers are possible)
- p_2 – porosity of filter material [-]
- p_3 – porosity of separator layer [-]
- p_{4-6} porosity of macadam layers [-]

The design features for each solution are presented in Figure 4.2, 4.3, and 4.4. The dimensions were chosen based on recommended values (Larm & Blecken, 2019).

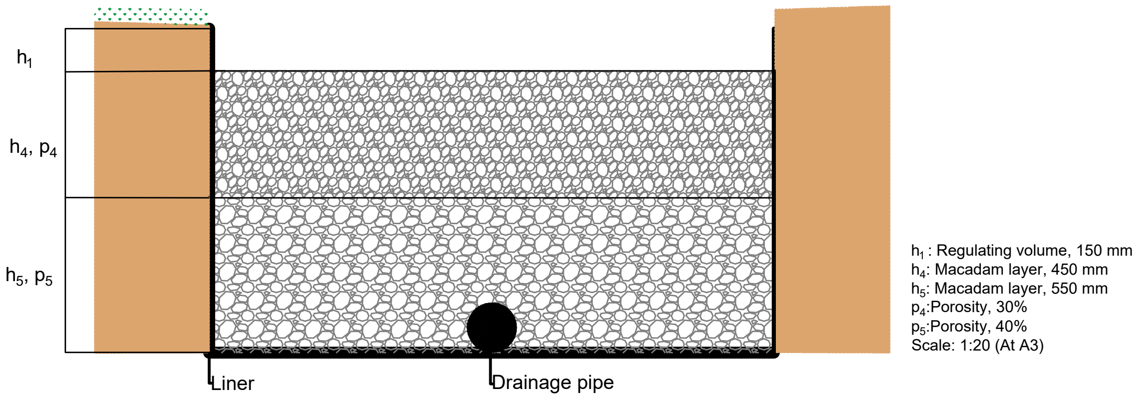

Figure 4.2: Cross-section drawing of Infiltration Trench.

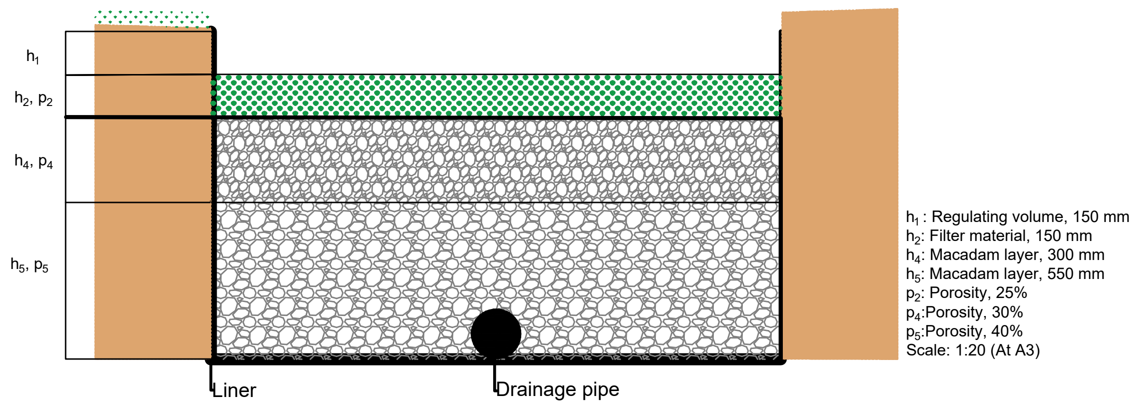

Figure 4.3: Cross-section drawing of Grass-covered Infiltration Trench.

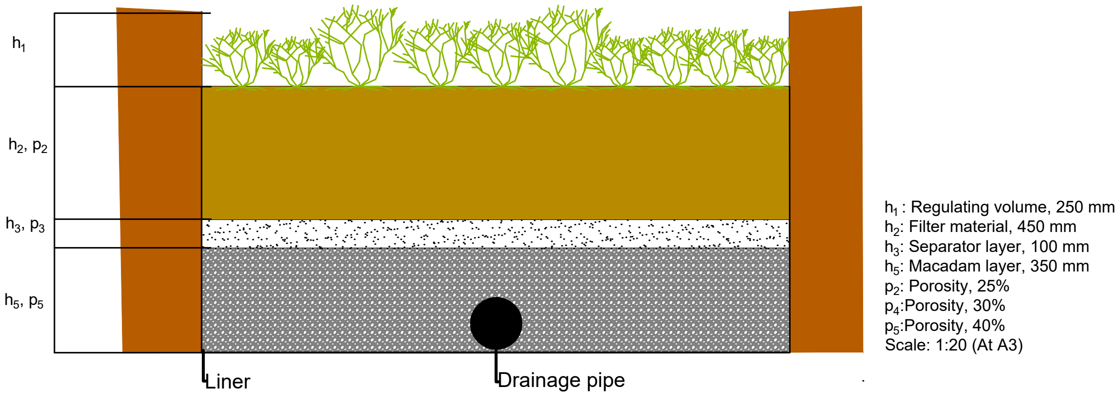

Figure 4.4: Cross-section drawing of Rain Garden.

By setting V_{eff} equal to the required detention volume of 93 m^3, the required area for each solution was calculated. This resulted in the following dimensions: Infiltration Trench 185 m^2, Grass-covered Infiltration Trench 187 m^2 and Rain Garden 192 m^2. All three solutions met the second exclusion criterion, as their required areas were well within the available area of 1840 m^2.

Bioswales were also evaluated to investigate whether it is an option that is suitable for the area by fulfilling the exclusion criteria. Bioswales differ from the other stormwater solutions in that their detention volume and flow capacity are determined by their cross-sectional geometry rather than layered storage. Given the available width of only two meters, this constraint was critical when designing the bioswales.

The required cross-sectional area and, consequently, the required length were calculated to achieve the necessary detention volume, see (Larm & Blecken, 2019) for equations. The cross-sectional design was then controlled against the flow capacity to ensure that no or minimal erosion would occur, using standard design equations for vegetated swales. However, no combination of cross-sectional geometry could simultaneously provide the required detention volume and withstand the dimensioning flow from the catchment area with the two-meter width constraint. Consequently, bioswales were excluded as an alternative for further evaluation in the MCDA.

The stormwater solutions selected for further evaluation in the MCDA were therefore: Infiltration Trench, Grass-covered Infiltration Trench, Rain Garden, and hybrid solutions combining the Rain Garden with the two different Trenches. The hybrid solutions split the required detention volume equally between two facility types. The final list of alternatives is presented in Table 4.3.

Table 4.3: Stormwater solutions and their required areas.

Solution	Description	Area
Infiltration Trench	Flow distribution: 100% to gravel ditch	185
Grass-covered Infiltration Trench	Flow distribution: 100% to grass-covered gravel ditch	187
Rain Garden	Flow distribution: 100% to rain garden	192
Infiltration Trench & Rain Garden	Flow distribution: 50% to gravel ditch, 50% to rain garden	190
Grass-covered Infiltration Trench & Rain Garden	Flow distribution: 50% to grass-covered gravel ditch, 50% to rain garden	188

4.2.3 Choosing dimensions, goals and criteria

The dimensions chosen to be incorporated in the MCDA were based on the three pillars of sustainability (environmental, social, and economic), complemented by a technical dimension. From these dimensions, goals were constructed to reflect the desired outcomes of the stormwater management system in Anneberg. These goals were then operationalized into specific criteria that could be evaluated. For example, the social dimension's goal of 'Good quality of life' was operationalized into the criteria 'Recreation and appeal' and 'Education'.

The selection criteria for inclusion were:

1. Not represented in the exclusion criteria
2. Impact on the performance
3. Relevance to the specific conditions and priorities of the study area Anneberg

Each criterion was carefully examined to ensure preference independence, meaning that the score of one criterion does not influence the score of another. This was done by qualitatively assessing whether a change in one criterion's performance could logically affect another criterion's score.

The final set of criteria consisted of ten criteria. This is in alignment with recommendations by Bousquet et al. (2023). Table 4.4 presents the full list of the chosen dimensions, goals, and criteria, including the description of each criterion and whether it will be scored qualitatively or quantitatively. The criteria include both benefits (biodiversity, pollutant remediation, and social criteria) and costs (installation cost, maintenance cost, maintenance frequency, and maintenance complexity).

Table 4.4: Criteria included in the MCDA.

Dimension	**Goal**	**Criterion**	**Description**	**Qualitative or Quantitative**
Environmental	Good chemical and ecological status in recipient	Remediation of nutrients	Nutrients remediated (P and N) [kg/year]	Quantitative
		Remediation of pollutants: metals and PAH	Metals and PAH remediated [kg/year]	Quantitative
		Remediation of suspended particles	SS remediated [kg/year]	Quantitative
	An urban ecosystem in balance	Biodiversity	Number of structural components within the stormwater solution supporting ecological niches [index score]	Quantitative
Social	Good quality of life	Recreation and appeal	How inviting the site is for people to visit	Qualitative
		Education	Possibility to provide knowledge of stormwater management	Qualitative
Economic	Reasonable economic situation	Installation cost	Cost of installation [SEK]	Quantitative
		Maintenance cost	Maintenance cost [SEK/year]	Quantitative
Technical	Maintainability	Frequency	Frequency of maintenance [times per year]	Quantitative
		Complexity	Complexity of maintenance	Qualitative

The selection of goals and criteria was based on both a literature review of MCDA applications in urban stormwater management and consultation with representatives from Partille Municipality. Through discussions and email correspondence, the municipality provided input on local priorities and contextual factors that should be reflected in the evaluation framework. See Table 4.5 for an overall rationale for the inclusion of the ten chosen criteria (i.e., why each criterion is important for stormwater management in Anneberg).

Table 4.5: Rationale for inclusion of criteria.

Criteria	**Reason to include**
Remediation of nutrients Remediation pollutants: PAHs and metals Remediation of suspended particles	Development is projected to increase pollutants, necessitating mitigation to comply with regulations and protect the recipient.
Biodiversity	Mitigates the loss of natural habitats and ecosystem services caused by increased urbanization.
Recreation and appeal	Enhances the aesthetic and functional value of the local environment, transforming infrastructure into attractive public spaces.
Education	Provides pedagogical opportunities for nearby schools and increases public awareness regarding sustainable stormwater management.
Installation cost Maintenance cost	Ensures financial responsibility and long-term sustainability by optimizing the use of public tax funds and municipal resources.
Frequency Complexity	Ensures that the solution's technical complexity and maintenance needs are compatible with the municipality's long-term operational capacity.

4.2.4 Scoring

Once the dimensions, goals, and criteria were established, each alternative stormwater solution was assigned a score based on its performance. A scale from −10 to +10 (using whole numbers only) was adopted, where the Infiltration Trench served as the reference alternative with a baseline score of 0 across all criteria. This solution was chosen as the reference due to its simple and well-established design. All other alternatives were scored relative to this baseline, ensuring that results reflect relative rather than absolute performance.

On this scale, 0 corresponds to the performance of the Infiltration Trench, −10 to the worst possible performance, and +10 to the best possible performance. To ensure consistent scoring, each scoring scale was described for every criterion (Table 4.6).

Table 4.6: Description of the scoring scale for each criterion.

	Assessment scale				
Criteria	**-10**	**-5**	**0**	**5**	**10**
Remediation of nutrients [kg/year]	Pollutant load ≥ pollutant load future land use without treatment		Equal to Reference alternative		Pollutant load = 0
Remediation of pollutants: PAHs & metals [kg/year]	Pollutant load ≥ pollutant load future land use without treatment		Equal to Reference alternative		Pollutant load = 0
Remediation of particles [kg/year]	Equal to or more than starting value		Equal to Reference alternative		Pollutant load = 0
Biodiversity	No structural heterogeneity, contains 0 components supporting ecological niches		Same as Reference alternative		Maximum structural heterogeneity, all 34 biodiversity components present
Recreation and appeal	The site becomes inaccessible or unpleasant (e.g., fencing, steep edges, bad odor)	Less inviting (e.g., harder to access, less pleasant)	Same as Reference alternative	More inviting (e.g., easier access, more pleasant)	A destination people actively seek out. Very high attractiveness.
Education	Hides all processes. No insight (e.g., all detention happen underground or in closed pipes)	Less insight and harder to understand the processes	Same as Reference alternative	Clearer process, passive understanding of function.	Perfect for study visit, clearly shows ecological connections and treatment technologies.
Installation cost [SEK]	Double (or more) as costly		Equal to Reference alternative		No cost
Maintenance cost [SEK/year]	Double (or more) as costly as Reference alternative		Equal to Reference alternative		No cost
Maintenance frequency [Times/year]	More than 12 times per year		Equal to Reference alternative		No maintenance needed
Maintenance Complexity (required equipment, knowledge and time)	Extremely complex (e.g., requires specialist expertise and advanced equipment)	More complex (e.g., might require some expertise, simple machinery)	Same as Reference alternative	Moderately simpler (e.g., less effort, less expertise)	Extremely simple (e.g., no effort, no expertise)

For criteria that were scored quantitatively, the raw performance values were normalised to the −10 to +10 scale. This is the reason why no description was assigned to the quantitative criteria for grade −5 or +5 in Table 4.6. Four different equations were used depending on (i) whether the criteria prefer a high or low raw score, and (ii) whether the alternative performed worse or better than the reference alternative (Table 4.7). See Table 4.8 for which of the quantitative criteria prefer a high or low raw score.

Table 4.7: Equations used to calculate a normalised score for each criterion.

ii \ i	**Prefer high raw score**	**Prefer low raw score**
Better than the reference alternative	$S_i = 10 \cdot \frac{P_i - R}{B - R}$	$S_i = 10 \cdot \frac{R - P_i}{R - B}$
Worse than the reference alternative	$S_i = -10 \cdot \frac{R - P_i}{R - W}$	$S_i = -10 \cdot \frac{P_i - R}{W - R}$

Where:

- S_i – Score for alternative i
- P_i – Raw performance value of alternative i
- R – Raw performance value of the reference alternative (corresponds to a score of 0).
- W – Raw performance value corresponding to a score of -10 (worst possible). Described in Table 4.6.
- B – Raw performance value corresponding to a score of $+10$ (best possible). Described in Table 4.6.

Table 4.8: Preference direction: high vs. low raw score for quantitative criteria.

Preferred high or low raw score	**Criteria**
High	Biodiversity
Low	Remediation of nutrients, pollutants and particles Installation cost Maintenance cost Maintenance frequency

The scoring is based on literature. Table 4.9 presents the sources and a short description for each criterion. The resulting scores are presented in Section 5.1 as part of the results, and will be used in Section 4.2.6.

The removal efficiency of the stormwater solutions in percent were derived, which later was used for scoring. First the removal efficiency of the Infiltration Trench was calculated and set

The remediation of nutrients, pollutants, and suspended solids was calculated by multiplying the pollutant loads for future land use without treatment (see Appendix C) by the treatment efficiency of each alternative. First, the removal was calculated for the Infiltration Trench, which served as the reference. Then, the removal efficiency for each alternative was calculated.

For nutrients, phosphorus and nitrogen were scored separately, and the mean of the two scores was used as the nutrient removal score. The same approach was applied to pollutant removal: each metal was scored individually, and the average of these scores was calculated. The final score for pollutant removal was then calculated as the average of the metal remediation score and the BaP remediation score.

Table 4.9: Sources used for scoring.

Criterion	Source(s)	Description of source(s)
Remediation of nutrients	StormTac (VA-guiden, n.d.-a); (VA-guiden, n.d.-b)	Remediation efficiency of P and N from Stormtac (see Table 2.2 and 2.3)
Remediation of pollutants	StormTac (VA-guiden, n.d.-a); (VA-guiden, n.d.-b)	Remediation efficiency of Pb, Cu, Zn, Cd, Cr, Ni, Hg) and PAH from Stormtac (see Table 2.2 and 2.3)
Remediation of suspended particles	StormTac (VA-guiden, n.d.-a); (VA-guiden, n.d.-b)	Remediation efficiency of suspended solids from Stormtac (see Table 2.2 and 2.3)
Biodiversity	(Monberg et al., 2018)	A framework developed by landscape architects and urban ecologists establishing an index for structural habitat heterogeneity. This index assesses the presence of structural components within a SUDS asset, serving as a proxy measure for potential biodiversity
Recreation and appeal	(Hoban & Kennedy, n.d.); (Liddle & Russo, 2025)	Investigates perception of Rain Gardens five years after implementation; investigates perception of Rain Garden before implementation
Education	(Hoban & Kennedy, n.d.); (Church, 2015)	Investigates perception of Rain Gardens five years after implementation; investigates whether visibility fosters environmental learning
Installation cost	(Andersson & Åkerman, 2016); (Adrian, n.d.)	Cost calculations for stormwater solutions; Stormwater and cloudburst investigation giving maintenance and installation costs for the solutions in (kr/m^2) and (kr/m^3)
Maintenance cost	(Andersson & Åkerman, 2016);(Adrian, n.d.)	Same sources as installation cost
Maintenance frequency	(Martini, n.d.); (Yergeau & Obropta, 2013); (Guo, 2012);(Mueller et al., 2022); (Bergman et al., 2011); (Lewellyn et al., 2015)	Maintenance and operation manual of several solutions for property owners;Care and maintenance of Rain Garden;Operation of Rain Garden;Field analysis of Infiltration Trench and recommendation for maintenance;Evaluation of Infiltration Trench after 15 years in operation;Evaluation of Infiltration Trench after 10 years in operation
Maintenance complexity	(Martini, n.d.); (Yergeau & Obropta, 2013); (Guo, 2012);(Mueller et al., 2022); (Bergman et al., 2011); (Lewellyn et al., 2015)	Same sources as maintenance frequency

4.2.5 Weighing

A questionnaire was constructed to collect stakeholders' preferences by weighting the previously identified criteria across the four dimensions. The stakeholders were identified in Section 4.2.1. A questionnaire was chosen over workshops or interviews due to logistical constraints (e.g., respondent availability, travel, and willingness to participate) and its ability to reach a larger number of stakeholders. The weights will be multiplied by the corresponding scores to produce the final ranking; without this step, all criteria would have equal influence. The final ranking is derived in Section 4.2.6.

When designing the questionnaire, the following principles were applied:

- **Contextualization:** A neutral overview of the decision situation at Anneberg will be given, ensuring all participants have a common baseline of understanding.
- **Scores:** In alignment with DCLG (2009), the performance score of each criterion will be given to the participant, since the weighting also reflects the range of performance differences among the alternatives for that criterion.
- **Clarity and Comprehension:** All descriptions of the evaluation criteria will be written in plain, accessible language, avoiding technical jargon. The fundamental differences between the criteria will be made explicit to ensure stakeholders understand what they are comparing.
- **Ease of Task:** The chosen weighting method will be selected and explained in a way that minimizes cognitive burden, making the task of assigning weights intuitive and straightforward for participants with no prior MCDA experience.
- **Procedural Validity:** The instructions will clearly articulate how the participant's input will be aggregated and used to influence the final analysis, reinforcing the value and impact of their participation.
- **Robustness of Output:** The method will be constructed to ensure the resulting weights are logically sound and provide a reliable foundation for the subsequent analysis.
- **Respondent Burden:** The questionnaire is designed to be completed in maximum five minutes to encourage participation and maintain engagement, thereby minimising the risk of respondent fatigue. This requires a careful balance between the complexity of the weighting task and the desired robustness of the output.
- **Neutrality:** All questions and descriptions will be carefully worded to avoid any form of bias or leading language that could inadvertently steer stakeholders' judgments.
- **Language:** The questionnaire will be given in both Swedish and English.
- **Anonymity:** The questionnaire's preamble will clearly state the anonymity and confidentiality of all responses, though a question of which role or type of stakeholder is answering will be included.

- **Pilot-testing:** Prior to full deployment, the questionnaire will be pilot-tested with a small group of individuals representative of the stakeholder population to validate its clarity, timing, and overall usability. Feedback from the pilot test will be used to refine the final instrument.

While these principles guided the design, any simplification of a complex weighting task involves trade-offs, and the potential for minor inconsistencies or misinterpretations cannot be entirely eliminated.

The survey employed a hierarchical weighting method. Two versions of the questionnaire were constructed:

- **Comprehensive version:** Included criteria over all four dimensions, and was distributed to Partille Municipality, consultants, and researchers/experts at Chalmers University of Technology. This version was provided in both English and Swedish. See Appendix A for the English version of the comprehensive questionnaire.
- **Abbreviated version:** Focused only on dimension weighting and was distributed to civil society and property owners. This group was expected to have less prior knowledge and less direct involvement in the decision process, making a shorter questionnaire more appropriate. See Appendix B for the abbreviated version of the questionnaire. Only a Swedish version was produced and distributed, since all stakeholders receiving this version spoke Swedish.

The comprehensive questionnaire asked respondents to first distribute 100 points among the criteria within each dimension. For example, giving 90 points to 'Aesthetic and recreation' and 10 points to 'Education' within the social dimension indicates that recreational value is considered much more important than educational value. Each criterion was presented with a brief, informative description (maximum two short sentences) to avoid overwhelming the respondents. Descriptions were formulated without value-laden language (e.g., 'Nutrients can cause overload of nutrients in aquatic environments and eutrophication' rather than 'Nutrients can cause harmful eutrophication'). When each criterion within each dimension had been allocated points, respondents were asked to distribute an additional 100 points among the four dimensions. High points for the social dimension mean that the criteria within it should have a large impact on the final ranking, and vice versa.

The distribution of 100 points (direct ranking) is an established method within MCDA (DCLG, 2009). The method was chosen since it is transparent and easily understandable for participants without prior MCDA knowledge. Respondents could not proceed if they had not distributed exactly 100 points.

The final weight for each criterion was calculated using Equation 4.5, where the criterion weight within its dimension was multiplied by the dimension weight and then divided by 100 to normalize the scale.

$$W_{\text{final},i} = \frac{W_{\text{score},i,j} \cdot W_{\text{dim},j}}{100} \tag{4.5}$$

Where:

- $W_{\text{final},i}$ – final weight for criterion i
- $W_{\text{score},i,j}$ – weight for criterion i within dimension j
- $W_{\text{dim},j}$ – weight for dimension j

The point distribution within each dimension was visualized in a pie chart that updated in real time. A separate pie chart for the dimensions showed the final weights based on Equation 4.5.

The abbreviated version, focusing only on dimensions, was designed similarly. It described what each dimension included and used neutral language. A pie chart was included, showing only the dimensions (not the criteria), since no criterion-level points had been allocated.

The questionnaire was implemented as a web-based survey using HTML, CSS, and JavaScript. The questionnaire was published via GitHub Pages, and respondent data was stored in Google Sheets using an Apps Script back-end, enabling anonymous data collection without requiring login. Although the questionnaire could be answered on multiple devices, it was designed for computers; respondents were therefore advised to use a computer to ensure user-friendliness.

A pilot study was conducted in three rounds to test the comprehensibility and technical functionality of the comprehensive questionnaire:

- **Round 1 (n=3):** The initial version included number lines for each criterion showing performance scores. Respondents misunderstood the function of the number lines and became overwhelmed.
- **Round 2 (n=2):** A revised version added an explanatory example of the number lines. This improved understanding, but the cognitive load remained high.
- **Round 3 (n=2):** The number lines were removed entirely to avoid misinterpretation and reduce cognitive load.

The third version required only minor wording adjustments. For example, 'Maintenance complexity' was perceived as counter-intuitive. Giving the criterion many points would imply that complexity is desirable. Therefore, criteria in the technical and economic dimensions were renamed to 'Lower maintenance frequency', 'Lower maintenance complexity', 'Lower construction cost', and 'Lower maintenance cost' to align with the interpretation that more points indicate a more favourable outcome. Since the changes in the third round were minor, no further testing was conducted.

The survey was anonymous, and no personal data was collected. Respondents were informed about the purpose of the study, that participation was voluntary but appreciated, and that responses would only be used for this thesis. For both versions, respondents were asked to select a role and indicate whether they had prior knowledge of stormwater and/or the Anneberg study area. None of these questions can be used to identify individual respondents.

The survey was conducted using a two-step distribution process to ensure a larger set of responses. Initially, a targeted group of 30 individuals was identified within the identified stakeholder groups. This was done to capture a diverse range of perspectives. This distribution included 8 municipal officials, 11 researchers in the field, 4 representatives from property owners, 6 consultants, and 1 representative from civil society. The questionnaire was distributed by email to all stakeholders (see Table 4.10 for an overview).

The second step involved a snowball sampling approach. The consultants and the municipal officials were asked to internally facilitate the questionnaire to colleagues with relevant expertise to increase the response rate. Two of the six contacted consultants confirmed participation and facilitated internal distribution to 16 and 10 colleagues within their departments, respectively. This expanded the total reach of the survey to 56 potential respondents. Since the survey prevents tracking of individual participation, and the other four contacted consultants did not provide a direct response to the email invitation, there is no way to determine whether these consultants distributed the questionnaire further. The municipal officials distributed the survey to 6 colleagues, making the survey reach 62 people in total.

Table 4.10: People contacted for the questionnaire.

Respondent group	**Number contacted**	**Additionally contacted**
Researchers/experts	11	-
Property owners	4	-
Municipality representatives	8	6
Consultants	6	26
Civil society	1	-
Summary	*30*	*32*

The weighting data collected from the 31 respondents were processed in Microsoft Excel to establish the final weights for the MCDA. The process followed a systematic approach.

First, each respondent was divided into a representative stakeholder group (municipality, researchers, consultants, or property owners) based on their selected role. Thereafter, each respondent's individual criterion weight was calculated using Equation 4.5 and validated to ensure the total sum of the assigned weights was equal to 100%.

Since the property owners were given a questionnaire in which only the dimensions were weighted, an assumption about the level of importance of the criteria had to be made. In this thesis, a uniform importance of the criteria within each dimension was assumed.

In addition to the weighting, the survey included an open-ended section where stakeholders could provide qualitative feedback or comments. These comments offer further insight into the rationales behind the assigned weights from the stakeholders.

To ensure the reliability and the validity of the data, the survey also included questions regarding the respondents' professional roles as well as self-assessment of their expertise within stormwater. Participants were asked a yes or no question if they had knowledge of stormwater and/or in the case study area, Anneberg.

These questions served the purpose of ensuring that the respondents had sufficient knowledge within the area and the topic. If a respondent did not have knowledge of either, their answer would be neglected.

For each respondent, the final criterion weight was calculated by multiplying the criterion's intra-dimensional weight by the weight of its corresponding dimension. Because the number of responses varied between stakeholder groups, a two-step averaging process was used to ensure equal representation. First, the mean weight for each criterion was calculated within each stakeholder group. Second, the arithmetic mean of these group averages was taken across all stakeholder groups. This approach prevents groups with more respondents (e.g., municipality officials) from dominating the final weights, giving each stakeholder group equal influence on the result.

The result from the questionnaire is presented in Section 5.2.

4.2.6 Final score and ranking

The final score for each of the five stormwater solutions was calculated using the Simple Additive Model (SAM) described in Section 2.8.6. The scores and weights used to calculate the final scores are presented in Section 5.1 and 5.2. The alternatives were then ranked by their final score; a higher rank indicates a solution that is more suitable for Anneberg based on the included criteria.

4.2.7 Sensitivity analysis

To assess the robustness of the ranking, two sensitivity analyses were performed:

1. **Stakeholder preference variation:** The final scores were recalculated using the weight sets of each stakeholder group individually (municipality, researchers, consultants, property owners) instead of the average weights.
2. **Exclusion of dimensions:** The economic and/or technical dimensions were removed from the aggregation to see how the ranking changed. This tests how decisive the cost dimensions are for the outcome.

By varying the stakeholder preferences and excluding cost dimensions, new scores and rankings were gathered and analysed.

5. Results

This chapter presents the scores assigned to each stormwater solution, the stakeholder weights obtained from the questionnaire, the final ranking of alternatives, and the results of the sensitivity analysis.

5.1 Scores

Each evaluation criterion is detailed below with its corresponding score and a comprehensive breakdown of the underlying justifications.

5.1.1 Environmental dimension

For the biodiversity, the Rain Garden most similar to the proposed design of this master thesis was given a score of 4 byMonberg et al. (2018). However, as shown in Table 5.1, the Rain Garden in this study received a raw score of 7 (which translates to a normalised score of 2). This score is assigned since the proposed design also contains two or more soil types, temporarily muddy areas and an ornamental garden in addition to those already given by the experts which are sun exposed areas, low slope and south facing slopes.

The Grass-covered Infiltration Trench was not explicitly evaluated by Monberg et al. (2018). In this study, it was assigned 3 raw points for containing sun-exposed areas, frequently mown grassland, and gravel. While it offers slightly more biotic structure than the conventional Infiltration Trench due to the grass layer, its lack of topographic variation and structural diversity keeps the score low. When the normalised proportionally against the 34-point scale, these 3 raw points correspond to a normalized value of 0, indicating that it performs as well as the reference.

The hybrid solution combining a Rain Garden and an Infiltration Trench was assigned 9 raw points. The score represents a combination of the scores assigned to the different solutions, strictly excluding overlapping features. The addition of the open gravel surface from the Trench to the diverse vegetation in the Rain Garden increases the abiotic heterogeneity, offering a new microhabitat. Based on the normalised equation, these 9 raw points round to a score of +2.

The other hybrid solution, combining Rain Gardens and Grass-covered Infiltration Trenches, was assigned a raw score of 10. The design integrates the structurally diverse components within the Rain Garden with the grass in the Infiltration Trench, which assigns the highest score within the category biodiversity. By combining the systems, the design creates valuable ecotones (natural transition zones between adjacent ecological systems) between the varying vegetation types and structures, which is known to support a wider array of insects (Monberg et al., 2018). These 10 points were normalized into a score of +3, resulting in the SUDS with the highest ecological performance of the evaluated options.

Regarding the pollutants, scores were calculated by multiplying the pollutant loads for future land use, without treatment. See Appendix C for the pollutant load after development without treatment and with treatment for the different solutions.

Table 5.1 shows the calculated, normalized scores within the environmental dimension for the stormwater solutions.

Table 5.1: Score matrix for environmental dimension.

Criteria	**Parameter**	**Score**			
		Grass-covered Infiltration Trench	**Rain Garden**	**Infiltration Trench + Rain Garden**	**Grass-covered Infiltration Trench + Rain Garden**
Remediation of nutrients	P N	0	-1	0	0
Remediation of metals	Pb Cu Zn Cd Cr Ni Hg	0	0	0	0
Remediation of PAH	BaP	0	6	3	3
Remediation of suspended solids	SS	0	0	0	0
Biodiversity	Biodiversity index	0	2	2	3

5.1.2 Social dimension

Hoban and Kennedy (n.d.) found that residents felt that the Rain Gardens improved their property value and overall value of the estate. 78 % of residents agreed or strongly agreed that Rain Gardens should be implemented in all new developments. They received comments such as 'I love the look of the Rain Gardens' and 'they are unobtrusive yet very pleasing to the eye'. Though several participants commented on the need for better maintenance (e.g., litter and weeds). At the time the survey was conducted, the Rain Gardens had not been maintained for several months. They hypothesise that there would have been a different result if the survey had taken place a month later, since maintenance was undertaken shortly after (Hoban & Kennedy, n.d.).

In Liddle and Russo (2025), the residents were asked to rate the aesthetics of Rain Gardens on three different aspects: interesting, tidy, and attractive. 84 % answered that they somewhat or strongly agree with the Rain Gardens being interesting, 73% tidy, and 87 % attractive. They were further asked what they liked about the pictures of the Rain Gardens, which 52 % answered aesthetics, 23

% improvements on existing landscape, 21 % green space, 15 % nature, and 14 % environment. Liddle and Russo (2025) concluded that 85 % considered the aesthetics of Rain Gardens would be an improvement on the current landscape. Though the Rain Gardens with a more visible gravel bed proved to be unpopular. Further, there were concerns about maintenance, including 'Rain Gardens becoming overgrown', 'untidy', 'messy', and/or 'looking neglected'.

Further, 41 % would be more inclined to walk to local facilities, 42 % think children would spend more time outside, 38 % would spend more time outside being active and 55 % would enjoy spending time outside more. Respectively, only 18 %, 18 %, 15 % and 9 % disagree or strongly disagree.

Based on the previous information, the Rain Gardens were assigned a score of 6, and the Grass-covered Infiltration Trench a score of 1. The combined solution Infiltration Trench and Rain Garden were assigned a score of 3, and the Grass-covered Infiltration Trench a score of 4. The scores are presented in Table 5.2

By design, the Rain Gardens are a visible technology that incorporates ecological processes into the design of the landscape (Church, 2015). Hoban and Kennedy (n.d.) stated that 'despite most residents not having received information about the Rain Garden, most understood their function'. The research demonstrated that the Rain Gardens are an intuitive technology. Church (2015) suggests that Rain Gardens could have the potential to influence reflection on the stormwater system. For example, one said 'observing the function of the facilities (filling and draining with water) triggered thoughts about the stormwater system'. Though an informational signage would be effective to convey the purpose of the Rain Gardens (including all benefits, such as flood reduction, biodiversity, remediation, etc.).

No further information was found regarding whether Infiltration Trenches could serve as an educational technology. Logically, observing the facilities could trigger thoughts about the stormwater system, by the same principle as for Rain Gardens.

Based on these findings, the Rain Gardens were scored a 5, since they provide a passive understanding of the technical functionality and are an intuitive technology. The Grass-covered Infiltration Trench is assumed to be as educational as the Infiltration Trench since no other educational properties could be found. It is assumed that roughly halving the area of the Rain Gardens would not have a significant effect on their educational value. The combined solutions are therefore scored a 4. The scores are presented in Table 5.2.

Table 5.2: Score matrix for aesthetics, recreation and education.

Criteria	**Score**			
	Grass-covered Infiltration Trench	**Rain Garden**	**Infiltration Trench + Rain Garden**	**Grass-covered Infiltration Trench + Rain Garden**
Aesthetics and recreation	1	6	3	4
Education	0	5	4	4

5.1.3 Economic dimension

Based on the literature, all solutions except the Grass-covered Infiltration Trench had higher installation costs than the reference alternative, resulting in negative scores.

The Grass-covered Infiltration Trench was the only solution that did not cost more to maintain than the Infiltration Trench. The Rain Garden had the highest maintenance cost, receiving a score of -5. See Table 5.3 for installation and maintenance scores.

Table 5.3: Final score matrix for installation and maintenance cost.

Criteria	Score			
	Grass-covered Infiltration Trench	**Rain Garden**	**Infiltration Trench & Rain Garden**	**Grass-covered Infiltration Trench & Rain Garden**
Installation cost	0	-10	-5	-6
Maintenance cost	0	-5	-2	-2

5.1.4 Technical dimension

Table 5.4 shows the scores for the criteria maintenance frequency where the scores indicate that all evaluated solutions were assigned a negative score indicating that the solution requires more maintenance than the Infiltration Trench. The solution which obtained the lowest score is the Rain Garden. The hybrid solutions were assigned a mean value of the individual solutions, thereby assigning them lower scores than the Rain Garden itself.

Table 5.4: Final score matrix for maintenance frequency and complexity.

Criteria	Score			
	Grass-covered Infiltration Trench	**Rain Garden**	**Infiltration Trench + Rain Garden**	**Grass-covered Infiltration Trench + Rain Garden**
Maintenance frequency	-1	-6	-3	-4
Maintenance complexity	1	-2	-1	-1

The complexity of maintenance was assigned scores as seen in Table 5.4. Comparing the Grass-covered Infiltration Trench with the regular Infiltration Trench, the grass needs frequent mowing, but clogging will occur later than for the regular Trench. This is due to the grass reducing gravel clogging. Therefore, it was assigned a score of 1, since the maintenance is somewhat simpler.

The Rain Garden received a score of –2. According to Annus et al. (2024), the occurrence of invasive species tends to increase with greater biodiversity, which in turn raises both the complexity and frequency of required maintenance.

5.1.5 Summary of scores

The scores across all criteria are summarised in Table 5.5. Because the Infiltration Trench was used as the reference alternative, it consistently receives a score of 0 and is therefore not shown in the summary table.

Table 5.5: Summary score matrix for all alternatives (excluding the Infiltration Trench) across all criteria.

Criteria	**Alternatives**			
	Grass-covered Infiltration Trench	**Rain Garden**	**Infiltration Trench + Rain Garden**	**Grass-covered Infiltration Trench + Rain Garden**
Remediation of nutrients	0	-1	0	0
Remediation of PAHs and metals	0	1	1	1
Remediation of suspended solids	0	0	0	0
Biodiversity	0	2	2	3
Recreation and appeal	1	6	3	4
Education	0	5	4	4
Installation cost	0	-10	-5	-6
Maintenance cost	0	-5	-2	-2
Frequency of maintenance	-1	-6	-3	-3
Complexity of maintenance	1	-2	-1	-1

5.2 Questionnaire

The survey was distributed to 62 individuals, with a response rate of 50 %. See Table 5.6 for the number of respondents in each stakeholder group. No response was received from Civil Society. However, it should be noted that the questionnaire was distributed to only one individual within this stakeholder group.

Table 5.6: Number of people contacted and responses.

Stakeholder group	**Number contacted**	**Number of responses**
Researchers/experts	11	7
Property owners	4	2
Municipality representatives	14	12
Consultants	32	9
Civil society	1	0
Other	-	1
Total	**62**	**31**
Response rate	*50 %*	

5.2.1 Answers: About the respondent

Nearly all respondents (94%) had prior knowledge of stormwater management. While most respondents overall (61%) were unfamiliar with Anneberg, the majority of municipality respondents (75%) were familiar with it.

Table 5.7: Knowledge about stormwater and Anneberg among stakeholders.

Stakeholders	**Knowledge about stormwater**		**Knowledge about Anneberg**	
	Yes [%]	**No [%]**	**Yes [%]**	**No [%]**
Municipality	83	17	75	25
Researchers	100	0	14	86
Consultants	100	0	11	89
Property owner	100	0	50	50
Other	100	0	0	100
Average	**94**	**6**	**39**	**61**

Five respondents gave comments on the questionnaire and the weighing of criteria. For the comments, as well as a translation of the comments to English, see Appendix D.

5.2.2 Preference of stakeholders: Weighing

The mean weighting for each stakeholder group combined is presented in Figure 5.1. The most important dimension was environment, followed by social, economic, and technical. The most important criteria were Remediation of pollutants, Recreation and appeal, and Maintenance cost. The least important criterion was Maintenance complexity.

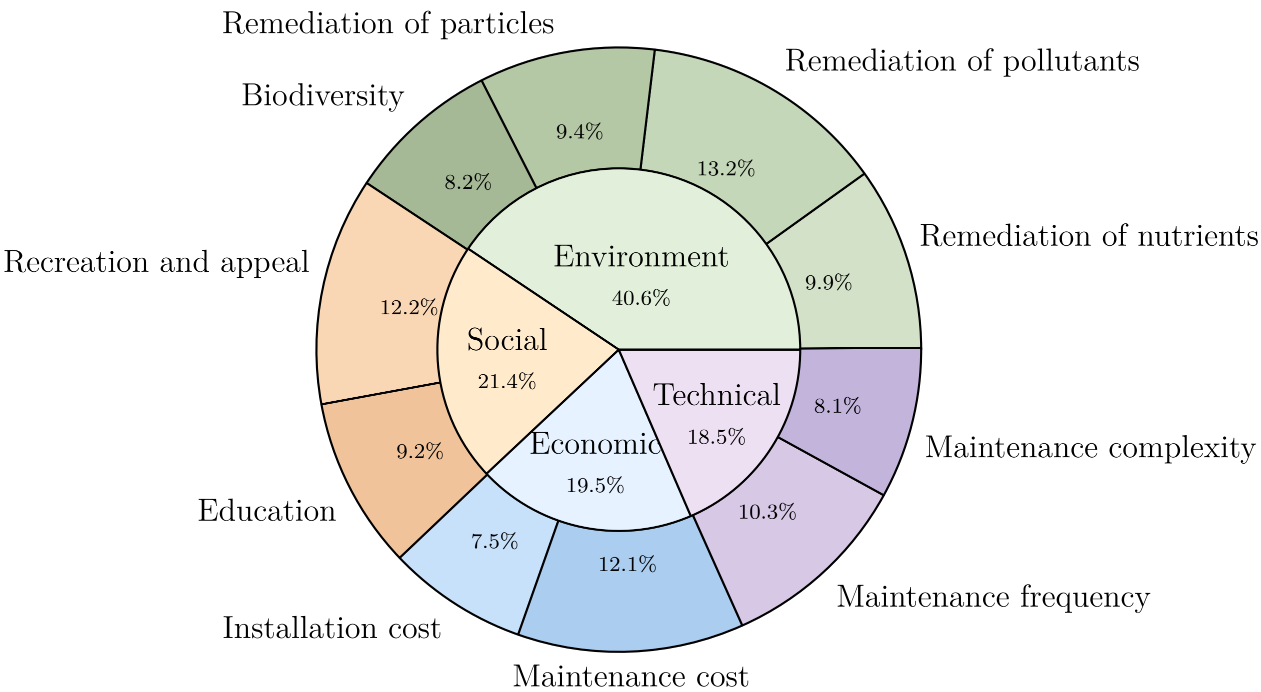

Figure 5.1: Combined weight of dimensions and criteria for all stakeholder groups.

The most important dimension for Partille municipality was the environmental, which received more than double the weight of the other dimensions. Economic and technical dimensions were weighted almost the same and were the least important dimensions. The most important criteria were Remediation of pollutants, Recreation and appeal, and Maintenance cost. The least important criterion was Installation cost. See Figure 5.2 for the weight of each dimension and criterion.

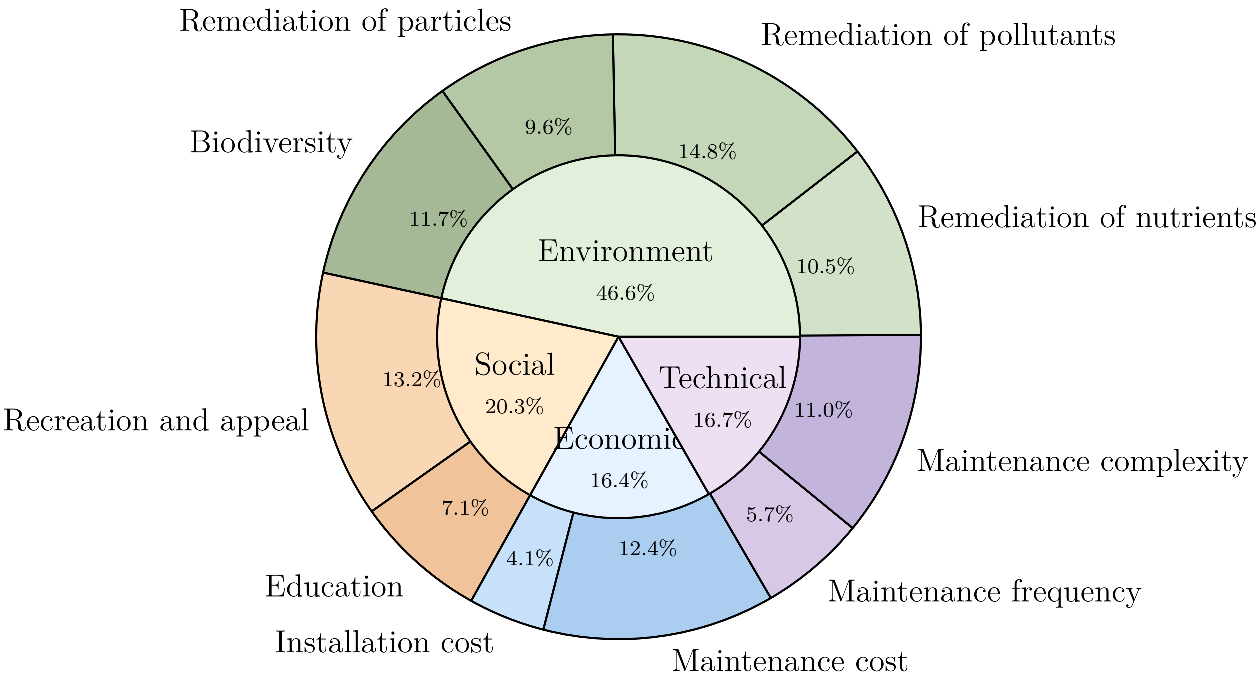

Figure 5.2: Weight of dimensions and criteria for Partille Municipality.

The most important dimension for researchers was the environment, followed by economic, technical, and social. The most important criteria were Remediation of pollutants, Maintenance cost, and Maintenance complexity. The least important criterion was installation cost. See Figure 5.3 for the weight of each dimension and criterion.

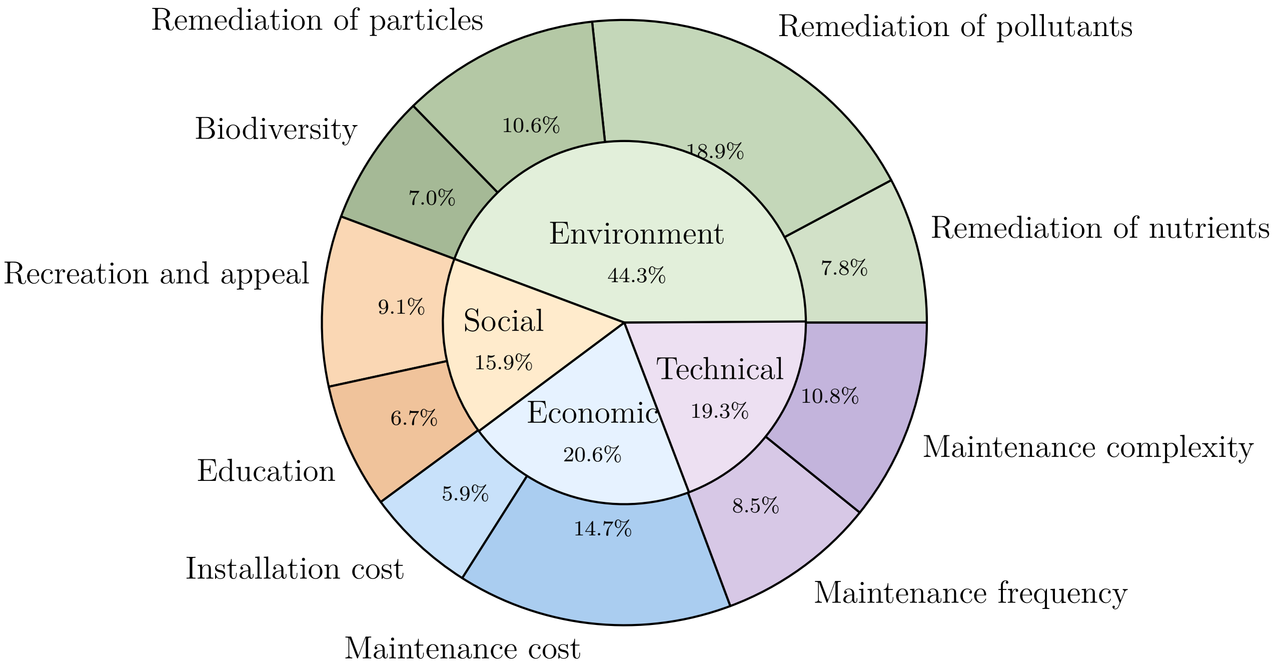

Figure 5.3: Weight of dimensions and criteria for Researchers.

The most important dimension for consultants was the environment, followed by economic, technical, and social. The most important criteria were Maintenance cost, Installation cost, and Remediation of nutrients. The least important criterion was Biodiversity. See Figure 5.4 for the weight of each dimension and criterion.

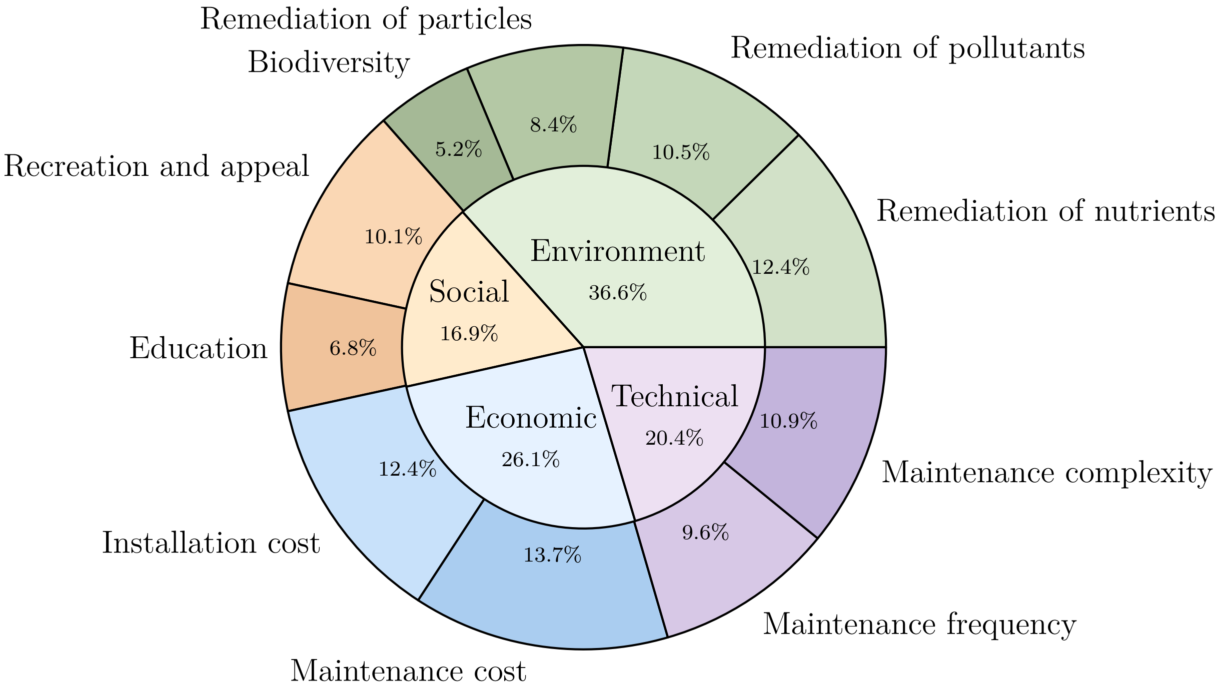

Figure 5.4: Weight of dimensions and criteria for Consultants.

The most important dimension for property owners was the environment, followed by social, technical, and economic. Since this stakeholder group only weighed the dimensions, each criterion received the same score within each dimension. See Figure 5.5 for the weight of each dimension and criterion.

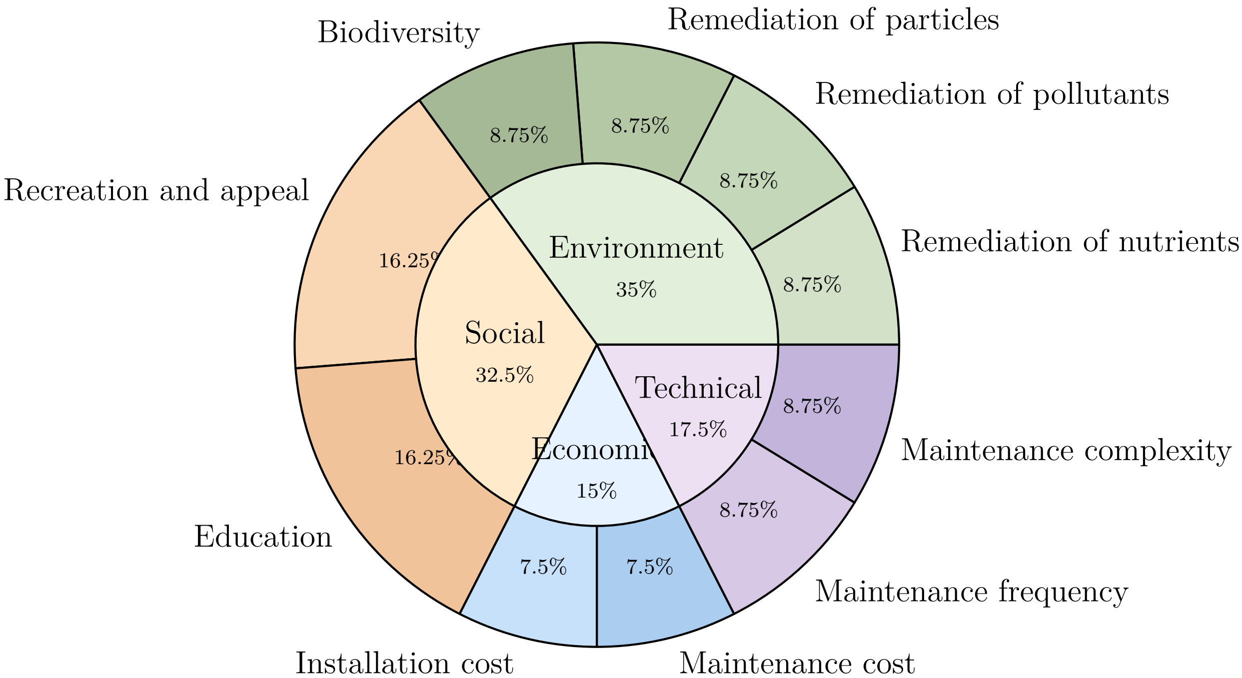

Figure 5.5: Weight of dimensions and criteria for Property owners.

5.3 Final scores and ranking of solutions

The results of the final scoring are presented in Figure 5.6. The Grass-covered Infiltration Trench achieved the highest total score (15), followed by the hybrid Grass-covered Infiltration Trench and Rain Garden (11). The Rain Garden received the lowest final score (–53).

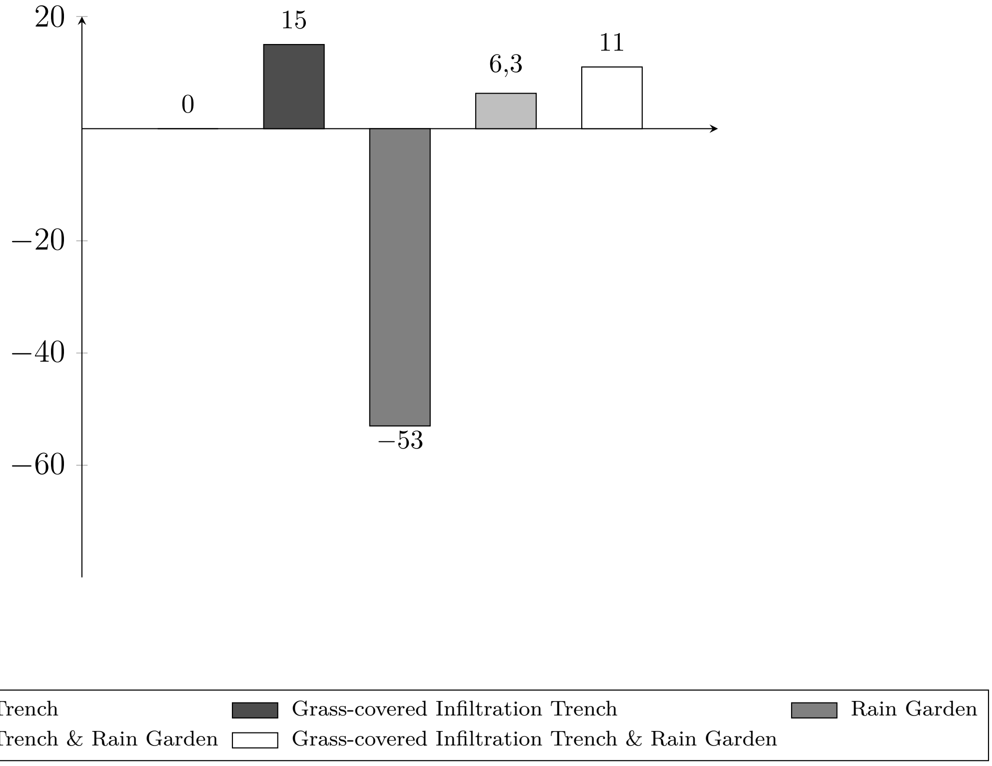

Figure 5.6: Final score of evaluated stormwater solutions.

For the final score amongst the dimensions, see Figure 5.7, 5.8, 5.9, and 5.10, which illustrate the performance within the different dimensions. It differs drastically between the dimensions; for instance, the Rain Garden scores very high within the social and environmental dimension, but performs poorly within the technical and economic dimension.

In contrast, the Grass-covered Infiltration Trench, which received a final score of 15 for all dimensions combined, maintained a consistent performance amongst all individual dimensions. While it did not perform nearly as well as the Rain Garden amongst the environmental and social dimensions, its technical feasibility and economic efficiency made it receive the highest final score.

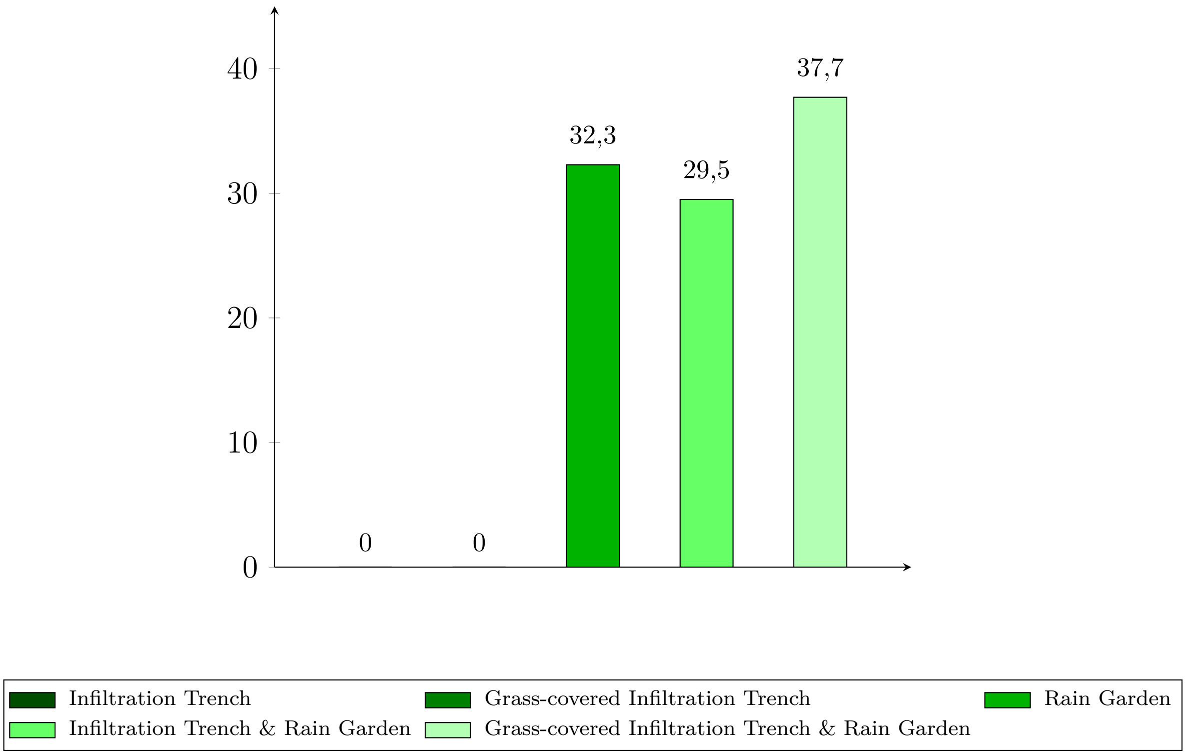

Figure 5.7: Final score within the environmental dimension.

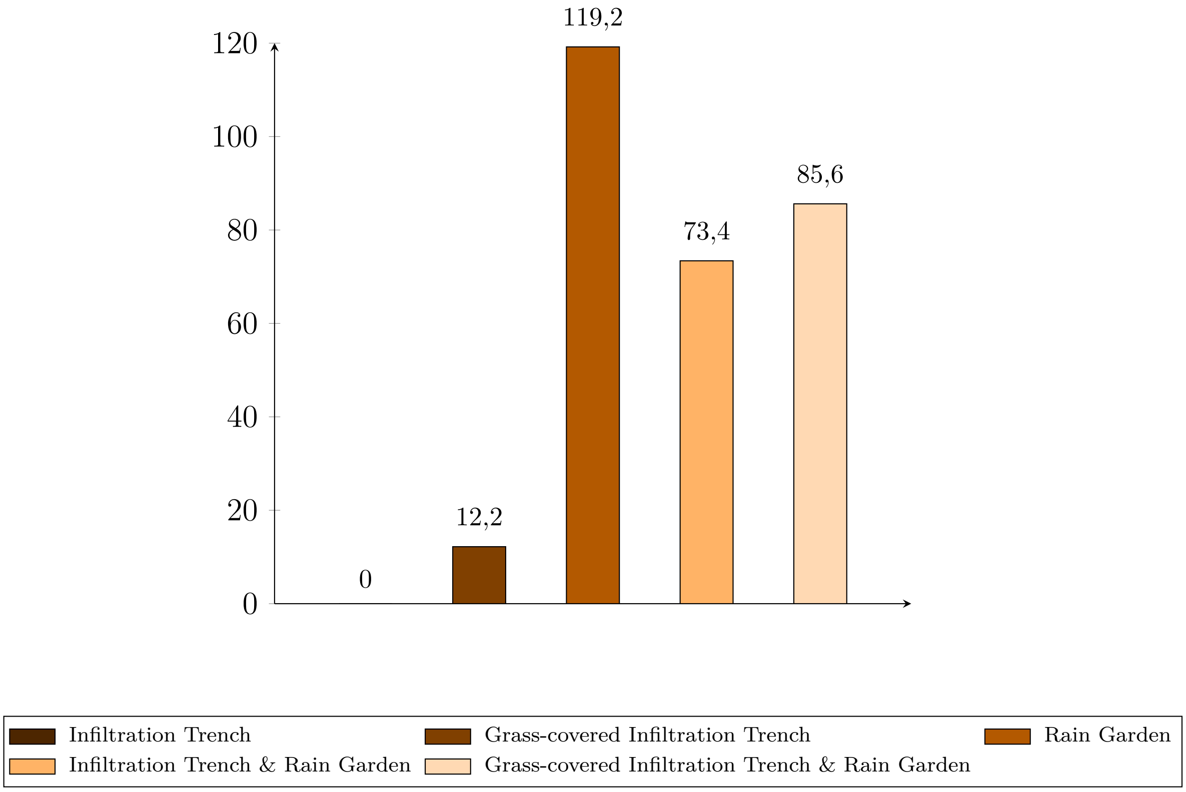

Figure 5.8: Final score within the social dimension.

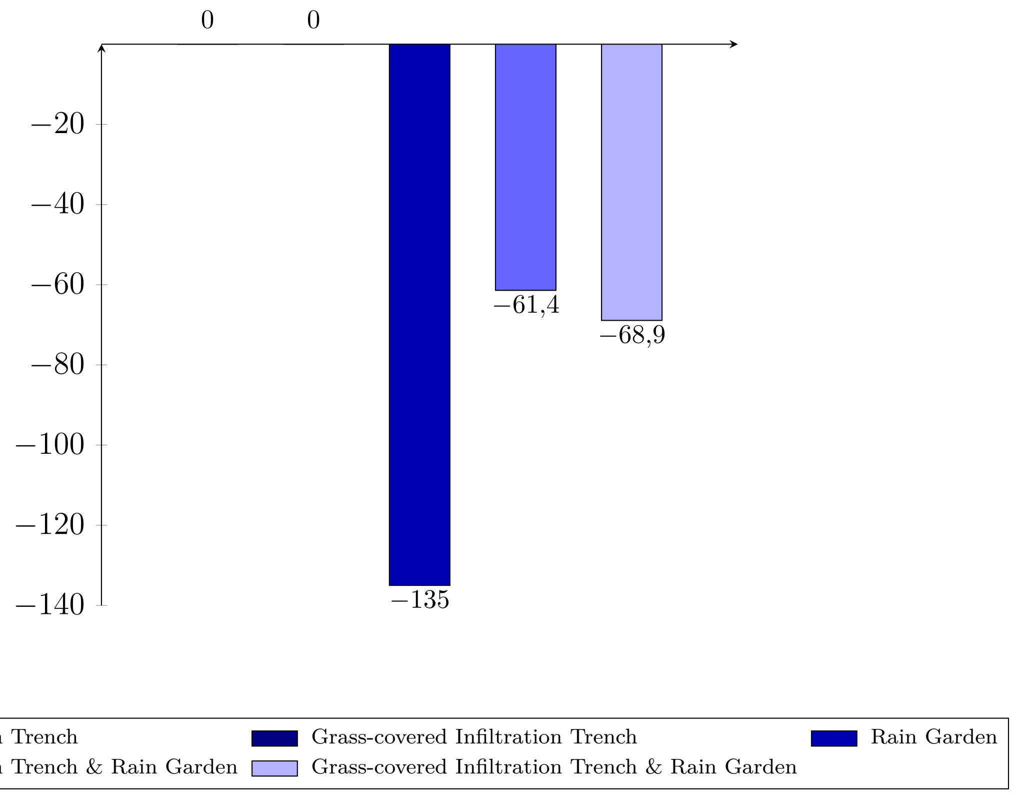

Figure 5.9: Final score ranking within economic dimension.

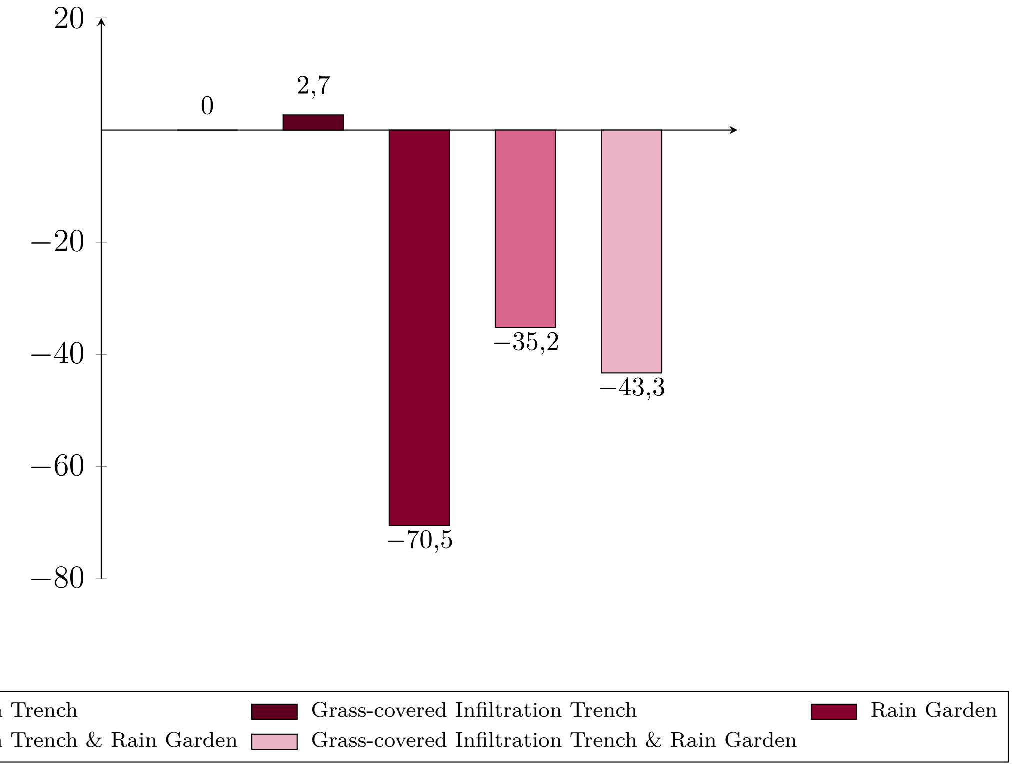

Figure 5.10: Final score ranking within technical dimension.

Based on the final scoring, the alternatives were ranked in descending order of their total scores, where rank 1 corresponds to the highest score, rank 2 to the second highest, and so forth (Table 5.8). The Grass-covered Infiltration Trench achieved the highest ranking overall and within the technical dimension. Within the economic dimension, the Grass-covered Infiltration Trench and the Infiltration Trench were tied for the highest rank. The Rain Garden received the highest ranking within the social dimension, and the Hybrid Grass-covered Infiltration Trench and Rain Garden received the highest ranking within the environmental dimension.

Table 5.8: Ranking of stormwater solutions.

Dimension(s)	**Rank**				
	Infiltration Trench	**Grass-covered Infiltration Trench**	**Rain Garden**	**Infiltration Trench & Rain Garden**	**Grass-covered Infiltration Trench & Rain Garden**
All dimensions	4	1	5	3	2
Environmental	4	4	2	3	1
Social	5	4	1	3	2
Economic	1	1	5	3	4
Technical	2	1	5	3	4

5.4 Sensitivity analysis of final ranking

In the following section, the results of the sensitivity analysis are presented. The analysis was conducted to assess how uncertainty regarding the preferences of different stakeholders, as well as the exclusion of the economic and technical dimensions (costs), influences the final scores and ranking. All weights and exclusion of dimensions were varied systematically as described in Section 4.2.7.

5.4.1 Preferences of stakeholders

The stakeholder-specific weight sets from Figure 5.2, 5.3, 5.4 and 5.5 were applied to evaluate ranking stability.

Figure 5.11 shows the final scores when only one of the stakeholder groups' weights is included. As seen, the preferences of different stakeholders affect the final scores of the stormwater solutions. The largest variation in final scores is observed for the Rain Garden, with a difference of 182.7 between its highest and lowest score. Excluding the reference alternative (Infiltration Trench), the smallest variation is seen for the Grass-covered Infiltration Trench, which has a difference of 7.1 between its highest and lowest score.

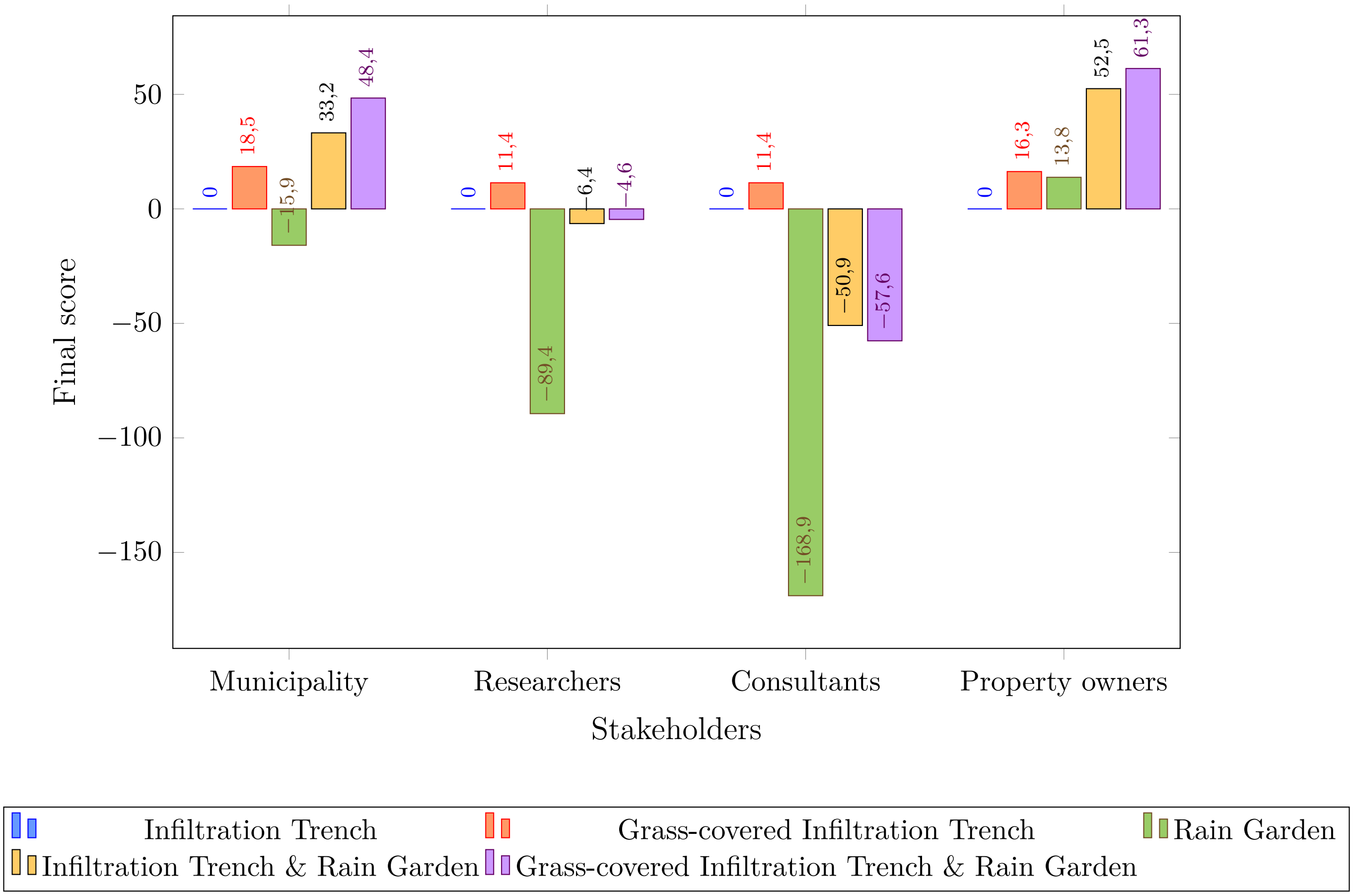

Figure 5.11: Final score of stormwater solutions by stakeholder group.

The inclusion of different stakeholder preferences also influences the final ranking. As seen in Table 5.9, the Grass-covered Infiltration Trench performs best for three out of five stakeholder groups (including the aggregated 'all stakeholder groups'). The combined alternative Grass-covered Infiltration Trench & Rain Garden performs best for two stakeholder groups. The Rain Garden ranks worst for all stakeholder groups except property owners, where the Infiltration Trench ranks worst.

Table 5.9: Ranking of stormwater solutions by stakeholder group.

Stakeholder group(s)	Rank				
	Infiltration Trench	Grass-covered Infiltration Trench	Rain Garden	Infiltration Trench & Rain Garden	Grass-covered Infiltration Trench & Rain Garden
All stakeholder groups	4	1	5	3	2
Municipality	4	3	5	2	1
Researchers	2	1	5	4	3
Consultants	2	1	5	3	4
Property owners	5	3	4	2	1

5.4.2 Exclusion of dimensions

To isolate the contribution of cost dimensions, these dimensions were sequentially set to zero weight while keeping all other weights the same as for all stakeholders.

When the economic and technical dimensions are excluded, the scores change substantially. Notably, all alternatives perform better than the reference alternative, i.e., they have a positive final score. The score for the Grass-covered Infiltration Trench changes little when the economic and/or technical dimension are excluded. In contrast, the two combined alternatives and the Rain Garden show considerable changes.

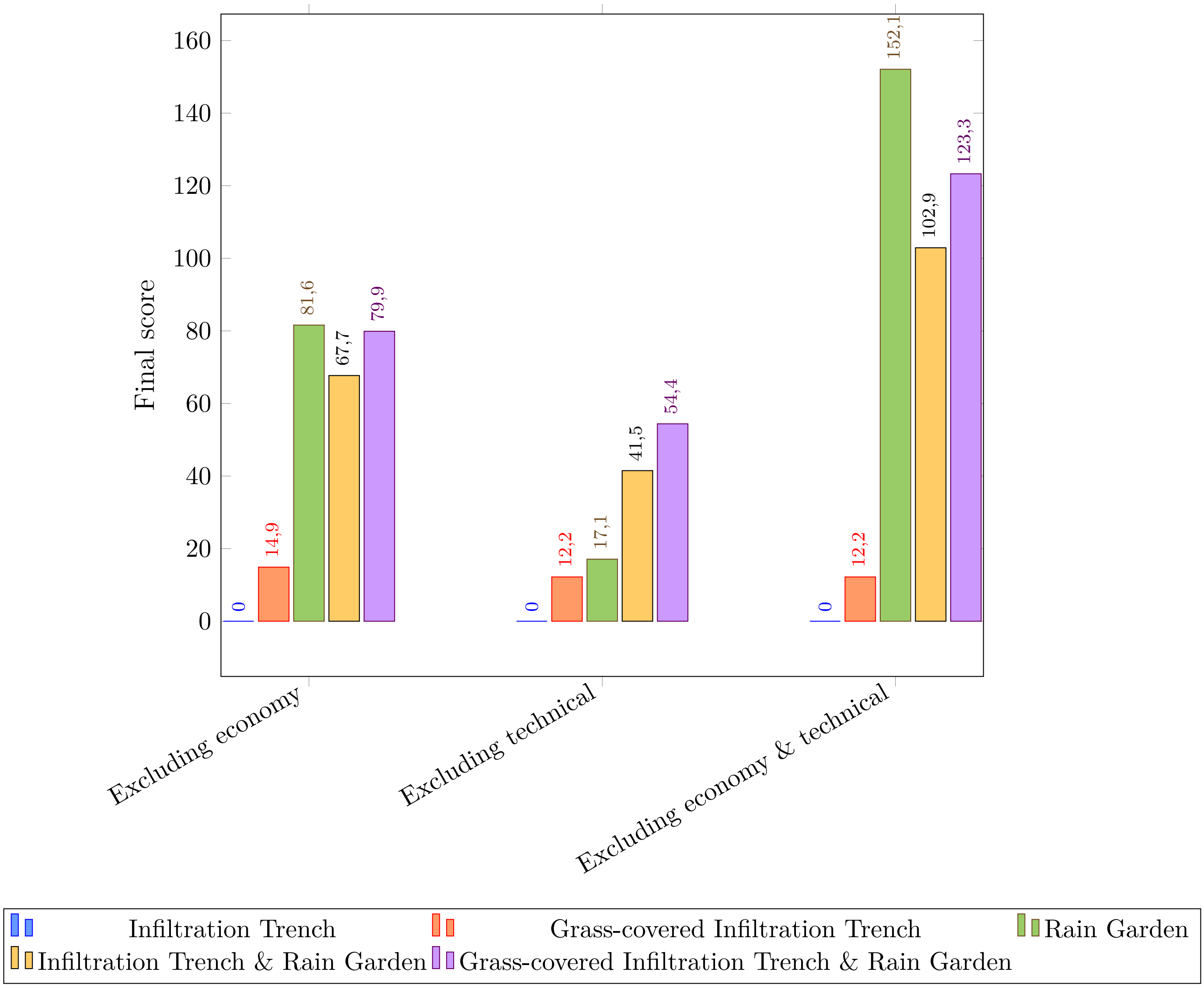

Figure 5.12: Final scores when excluding economic and/or technical dimensions.

When the economic and/or technical dimension is excluded, the ranking changes (Table 5.10). The Rain Garden and the hybrid solution Grass-covered Infiltration Trench & Rain Garden become the highest-ranking alternatives, while the Infiltration Trench and the Grass-covered Infiltration Trench become the lowest-ranking ones.

Table 5.10: Ranking of stormwater solutions when excluding economic and technical dimensions.

Exclusion of cost dimension(s)	**Rank**				
	Infiltration Trench	**Grass-covered Infiltration Trench**	**Rain Garden**	**Infiltration Trench & Rain Garden**	**Grass-covered Infiltration Trench & Rain Garden**
All dimensions	4	1	5	3	2
Excluding economy	5	4	1	3	2
Excluding technical	5	4	3	2	1
Excluding economy & technical	5	4	1	3	2

In summary, the ranking is relatively stable for top-performing solutions under stakeholder variation but changes substantially when economic and technical criteria are excluded.

6. Discussion

In this chapter, the calculated criteria scores, the stakeholder weights, as well as the final ranking and the sensitivity analysis are interpreted and discussed. This discussion contextualises the findings in relation to the specific constraints of the Anneberg case study, relevant theory within the field, and the broader application of MCDA as a decision-support tool.

6.1 The selection and definition of criteria

The selection and definition of the criteria directly affect the outcome of the MCDA and influence the final ranking. Excluding or not properly defining a criterion can favour one type of solution over another (Copăcean et al., 2026). To contextualise the scoring and validate the result of this study, the result can be compared to a similar study conducted by Thorsson et al. (2025) in the Gothenburg region. The report emphasises that the relevance and weight of the stormwater criteria are context-dependent, shifting based on local priorities. Comparing the chosen criteria with Thorsson et al. (2025) shows that many criteria are similar: pollutant removal, recreational value, installation cost, and maintenance cost. This alignment strengthens the selection of criteria in this thesis, reflecting priorities in the region. In addition, most criteria used in this thesis align with those identified in the comprehensive review by Bousquet et al. (2023).

A critical reflection in the analysis is whether the final ranking would differ if the criteria were either defined differently, or other criteria were chosen (Copăcean et al., 2026). In this thesis, the environmental dimension focuses strictly on quantifiable pollutant removal alongside a biodiversity index. If the criteria had been different, for example, 'Carbon footprint during construction', the ranking may have shifted to favour the Rain Garden. The standard Infiltration Trench would have been disadvantaged in this category due to the high emissions that occur when extracting and transporting gravel. Conversely, the Rain Garden would have gained a significant advantage in this criterion, due to less gravel.

6.2 The scoring and model assumptions

A limitation of this thesis when scoring the criteria within the environmental dimension is treating it as static. As highlighted in Copăcean et al. (2026), failing to account for dynamic factors, such as long-term maintenance and climate adaptation, can lead to underestimation or misrepresentation of the dynamics of the systems over time. For example, regarding biodiversity, the framework developed by Monberg et al. (2018) assigned high scores to the Rain Garden based on its initial structural variety, but this framework does not account for long-term variables and assumes that nature is static. In reality, biodiversity is a dynamic process strongly dependent on long-term variables such as maintenance and climate adaptation, factors that are hard to capture fully in an MCDA (Copăcean et al., 2026).

Another limitation in the scoring lies in the bio-SUDS index and its additive scoring system used in the biodiversity criteria. Since the framework relies on presence or absence of a total of 45 structural components, without applying weighted values to reflect their relative importance to biodiversity, the index might be misleading (Monberg et al., 2018). For example, a vegetated cover might contribute more to biodiversity than a gravel bed. On the other hand, both in this thesis and in Monberg et al. (2018), both components receive one point in the bio-SUDS index. Furthermore, the literature highlights that while introducing several structural components may create diverse microhabitats, it also can simultaneously cause habitat fragmentation for certain mobile species (Monberg et al., 2018). The method of giving a high index score is given by adding diverse materials which reflects a theoretical rather than a functional performance. Lastly, while the hybrid solutions scored higher due to more components, their actual contribution depends on how these structures align with the needs of local target species in Anneberg rather than the number of components.

For the hybrid solutions, the scoring was divided 50/50 for the pollutant load. While this simplified assumption was chosen, it represents a significant oversimplification of hydraulics and pollutant remediation. In a physical hybrid solution of techniques an equal split in pollutant remediation will not reflect the reality. Instead, urban run-off is highly characterised by the first flush phenomenon, meaning that a high fraction of the pollutant load is delivered during the initial portion of a Rainfall event (Chaudhary et al., 2022). Consequently, the hydrological mechanisms dictate that the primary facility captures the first flush, performing most of the remediation work. This renders the secondary system largely redundant for water quality treatment, even though it remains hydraulically necessary for volume control and delay. This split version of 50/50 might provide a poor representation of the actual system dynamics.

Another limitation of the study might be the scoring scale of the economic dimension. As seen in Section 5, all evaluated solutions except the Grass-covered Infiltration Trench were estimated to be more costly than the standard Infiltration Trench, thereby given negative scores. The major limitation of this approach is that it fails to show the true financial scale. In reality, if some of these solutions are up to three times more expensive than the reference alternative, it will still achieve -10 points. However, because the scale is stated 'Twice or more as costly' equals -10, the more expensive solutions will be assigned -10. This flattens the economic variance between the alternatives. To create a scale more aligned with reality, future projects should align the economic dimension with the actual budgets of the development projects. Instead of using a scale based on the reference alternative, a more reasonable approach could be to evaluate solutions based on the specific total budget allocated for the case study area, Anneberg. For example, if an Infiltration Trench costs 1 000 SEK, and a Rain Garden costs 2 000 SEK, the Rain Garden will receive -10 points, while in reality these numbers are low within a development project budget.

A factor that may have influenced the scoring is the objectivity of the assessment. The qualitative criteria are subject to the greatest uncertainty, as they were scored by the authors based on the literature. While this approach was intended to minimise bias, most scores could reasonably be argued to be higher or lower than the assigned value. Depending on which criterion is adjusted, the ranking may change.

A limitation of the economic criteria is that they focus only on costs (installation and maintenance) and do not consider the economic benefits of different solutions. For example, the Rain Garden provides aesthetic and recreational benefits that could increase property values, while the Infiltration Trench does not. A full cost-benefit analysis would be needed to capture these differences, but such an analysis was beyond the scope of this thesis. However, including economic benefits would introduce challenges regarding the independence of the criteria. For instance, aesthetic value would then be counted both in the social dimension (recreation and appeal) and in the economic dimension (increased property values), leading to double-counting and violating the preference independence assumption.

6.3 The performance and feasibility of solutions

In the overall assessment, the Rain Garden received the lowest ranking, while the Grass-covered Infiltration Trench received the highest ranking of all evaluated solutions. The underlying reason for these low total scores is that NBS, such as Rain Gardens, require significant initial investment and specialised maintenance to maintain ecological benefits and their hydraulic performance, as shown in Section 5. This result is similar to recent studies conducted by Thorsson et al. (2025) where a framework for the integrated assessment of NBS was presented to evaluate multifunctionality potential in relation to construction and maintenance cost. Their findings reveal that simpler solutions, such as ditches and permeable pavements, have lower costs.

In contrast, the Rain Garden performed best in the social criteria. The MCDA reveals high social performance because of it being high visibility, aesthetically pleasing, and structurally diverse. This outcome is also supported by the literature. For instance, Pereira et al. (2023) highlights that Rain Gardens, amongst others, similar solutions, are delivering ecosystem services and social values. Furthermore, Eckert (2025) highlights that the social value of an NBS lies in its visual intuitiveness and usability, noting that these solutions must be aesthetically appealing for citizens to appreciate and interact with them. Thus, while the Rain Garden's structural complexity is contributing to social values and biodiversity, that same complexity is exactly what minimises its economic feasibility, which might be one reason why it achieved the lowest total ranking.

6.4 The survey, weighting and pilot testing

The weighting process was conducted in a survey with respondents from four different stakeholder groups. To ensure the clarity of the survey, an iterative three-step pilot-testing was conducted, involving 7 participants.

The main challenge identified during pilot testing was the high cognitive load and confusion caused by the numbered line. From the user's perspective, the numbered line was more confusing than helpful. Therefore, the test participants did not take the numbered lines into account when performing the weighting. Since this confusion threatened data quality, the decision was made to remove the numbered lines. While this adjustment made the survey significantly more accessible, it introduces an important methodological limitation. According to the MCDA manual, established by DCLG (2009), using a structured, explicit scoring scale is highly recommended. The manual emphasised that formal interval scales are necessary to ensure that the mathematical differences between choices remain meaningful and consistent. By removing the numerical scale to maximise user-friendliness, the model sacrificed a degree of reliability and transparency.

A significant limitation of the final survey was the total anonymity of the respondents and the survey. On one hand, anonymity was crucial as it encouraged responses to provide honest answers. On the other hand, this anonymity introduces a limitation because it hides the respondents' specific work experience and backgrounds, as well as differences within the stakeholder groups, as they only had the option of choosing between 5 stakeholder groups. Instead, the municipality could have been further divided into, e.g., 'Planning unit' and 'Water unit'. Because the survey is anonymous, the MCDA is forced to lump all stakeholder groups into a single average during the ranking, meaning we cannot see if there was deep disagreement or different perspectives within the group, linked to personal experience, knowledge, or role.

In contrast, the consultants and the property owners demonstrated interest-driven priorities. The consultants prioritised the environmental dimension highest, but lower than each individual economic criteria. This economic focus is highly supported by literature. As Chelli et al. (2025) highlights, maintenance costs are crucial for sustaining the long-term benefits of NBS, noting that the high operational and management expenses required by certain green solutions must be carefully considered in economic evaluations. The consultants were assigning the lowest score to biodiversity, which accurately mirrors real-world NBS implementations in the industry. An evaluation of 23 BGI projects across the Baltic Sea Region revealed that practitioners systematically prioritize quantifiable objectives such as flood risk mitigation and water quality as primary goals, while qualitative criteria like biodiversity are often secondary co-benefits due to a lack of standardised assessment methods (Annus et al., 2024). On the other hand, consultants might juts perceive the social criteria as less important for stormwater management than the other dimensions.

The property owners prioritised the social dimension, i.e., recreational values and aesthetics, which is a significant exception in the result. This social preference aligns with Eckert (2025), whose review of urban NBS planning found that the public prefers recreational and aesthetic services over regulating ecosystem services. Furthermore, as noted by Eckert (2025), NBS must inherently be aesthetically pleasing for citizens to appreciate and interact with them.

Ultimately, this reveals the core value of the MCDA. By utilising a targeted questionnaire to get stakeholder weights, the analysis captured the conflicting realities between the groups. As highlighted in Bousquet et al. (2023), the strength of involving different stakeholder groups in an MCDA is its ability to integrate different knowledge and experience, thereby preventing the evaluation from being dominated by a single group.

6.5 The sensitivity analysis

The sensitivity analysis revealed that the Grass-covered Infiltration Trench is robust to changes in stakeholder preferences, with a score variation of only 7.1 points across weighting scenarios. This stability suggests that regardless of whether municipal, researchers, consultants, or property owners' priorities dominate, the Grass-covered Infiltration Trench performs consistently well. In contrast, the Rain Garden's score varied by 182.7 points, from strongly negative under consultants weights to moderately positive under researchers weights. This indicates that the acceptability of the Rain Garden depends critically on whose preferences are considered. This finding has practical implications: if the decision process is likely to involve multiple stakeholders with conflicting priorities, the alternatives with low score variation (e.g., the Grass-covered Infiltration Trench), given in the scoring process, represent a safer consensus choice than the alternatives with large score variation (e.g., the Rain Garden). Even if the alternative with large variations might be preferred by a single stakeholder group alone.

When economic and technical dimensions were excluded from the analysis, the ranking changed notably. The Rain Garden became the top-ranked solution, and the Infiltration Trench became the lowest-ranked. This result demonstrates that the economic and technical criteria were decisive in the original ranking. These criteria did not merely adjust the scores but fundamentally determined which solutions were considered viable. The findings also illustrate a potential vulnerability of MCDA: the inclusion or exclusion of dimensions and/or criteria (which is a methodological choice made by the performers of the MCDA) can reverse conclusions. Bousquet et al. (2023) note that technical and economic criteria are less frequently included in MCDA for NBS evaluations than environmental and social criteria, potentially due to a lack of cost data or design knowledge. The sensitivity analysis suggests that excluding these dimensions would produce systematically different recommendations, raising concerns about studies that exclude economic or technical considerations. Similar to Åström et al. (2025), this thesis shows that new and advanced stormwater solutions, which often have high installation and maintenance costs, dragged down the ranking. Proving economic feasibility remains a critical bottleneck.

The sensitivity analysis could have been extended to examine the impact of uncertainty in the scoring values themselves. For example, a Monte Carlo simulation could have been performed where each criterion score was varied across a plausible range (e.g., using a three-point estimate with low, most likely, and high values) to test the robustness of the ranking. This would reveal whether the top-ranked alternatives are stable under plausible variations in scoring, or whether the ranking is sensitive to the specific assumptions made in the literature-based scoring. This was not conducted due to time constraints but represents a valuable direction for future research.

6.6 Context-specificity and applicability of the findings

A further consideration is the context-dependence of this study's findings. The scoring, weighting, and ranking presented here are specific to the Anneberg case study and the assumptions made regarding the 20-year rainfall event with a 25% climate factor. The scores for education, biodiversity, and maintenance, for instance, are based on literature values and are likely to be relatively transferable across sites, as they reflect the technical performance of the solutions themselves. In contrast, the stakeholder weights are inherently context-specific, reflecting the priorities of the particular groups involved in this study. Replication in another municipality or with a different stakeholder composition would likely yield different results. This highlights an important limitation of MCDA: while the method is transparent and structured, its outputs are not universally applicable and must be recalibrated for each new context.

Additionally, this study did not evaluate cloudburst events. According to Partille Municipality (2026b), such events are managed through other types of infrastructure, and the public stormwater system is not dimensioned to handle them due to financial and technical constraints. However, the comprehensive plan for Anneberg designates the football field as a multifunctional space that can serve as an overflow area during extreme rainfall events. This cloudburst management strategy is an important complement to the detention solutions evaluated in this thesis. While the MCDA results provide guidance for managing smaller, more frequent rainfall events, the football field's multifunctional role addresses the larger, less frequent cloudburst events that fall outside the scope of this analysis. Both strategies should be considered together in the final planning for Anneberg.

6.7 Evaluation of MCDA for stormwater management

This thesis demonstrates that MCDA is a successful tool for navigating decision conflicts in USWM, but its success depends on how it is implemented. The method's primary strength is its ability to make trade-offs explicit and transparent. By implementing the quantification of scores and weights, MCDA reveals assumptions that might otherwise remain hidden in intuitive decision-making. For example, the analysis showed that the Rain Garden's environmental advantages were outweighed by its economic and technical disadvantages. By highlighting this conclusion, it can be examined, debated, and potentially revised if stakeholders disagree with the scoring or weighting. This aligns with Åström et al. (2025) who emphasise that the primary strength of MCDA is not to generate decisions but rather to facilitate knowledge transfer and create a shared understanding of necessary compromises.

However, several limitations of MCDA must be considered. First, the compensatory nature of the simple additive model means that poor performance on one criterion can be fully compensated by good performance on another. This assumes that stakeholders are willing to accept unlimited substitution, which means that low maintenance costs could theoretically compensate for a zero pollutant removal. In practice, decision makers often have minimum acceptable thresholds that are non-negotiable. This is made clear by this comment from the questionnaire: 'When choosing weighting, I assume there is a basic level of treatment that all options achieve'. The exclusion criteria used in this thesis (hydraulic performance and space availability) served this function for technical requirements, but no such thresholds were applied to the environmental, social, or economic dimensions. For future MCDA applications, where the simple additive model is used, additional exclusion criteria should be incorporated for all criteria where minimum standards exist. These could, for example, be a maximum installation cost or a minimum of remediation.

Second, the MCDA gives a single final ranking, implying that one solution is objectively best given the weights. However, the closeness of scores between the top-ranked Grass-covered Infiltration Trench (score 15) and the second-ranked Grass-covered Infiltration Trench & Rain Garden (score 11) suggests that these solutions are not clearly differentiated in terms of performance. DCLG (2009) recommends that when score differences are small, decision-makers should consider multiple top alternatives rather than just the one top-ranked solution. The sensitivity analysis supports this interpretation, as the ranking of second through fourth positions shifted under different weighing scenarios.

Third, the MCDA process was resource-intensive, requiring a literature review for scoring, survey design and distribution for weighing, and analytical effort for normalisation and sensitivity analysis. For municipal practitioners, with limited time and budget, a simplified and/or standardised MCDA would be preferred. For example, instead of performing new, extensive weighing processes for each new MCDA, some of the results could potentially be reused. Especially the researchers and consultants, since their weighting was mostly based on their knowledge about stormwater (Knowledge stormwater: 100%, Table 5.7) rather than Anneberg (Knowledge Anneberg: 11%, Table 5.7). Another suggestion would be a database where the performance of different stormwater solutions was gathered, both from previous literature reviews and documented data within the municipality or organisation. This would limit the time and resources needed for the literature review. The challenge is to balance methodological rigour with practical usability.

6.8 Further research

Several directions for future research emerge from this thesis. First, studies on installed stormwater solutions are needed to validate the assumptions made in scoring. For example, longitudinal studies to investigate maintenance frequency and complexity. Another example would be a comprehensive study of installation and maintenance costs for different solutions. The scores used in this thesis for the technical and economic dimensions are based on limited sources. Therefore, these values might not be representative of Swedish conditions or good for generalisation. The more reliable the scores are, the more reliable the MCDA becomes. Additionally, studies following the installation and life-cycle of the solutions in Anneberg would provide empirical data that could refine the scoring for future projects.

Secondly, the methodological finding that providing performance information (in this thesis, through a numbered line) during weighing confuses respondents suggests a need for research on effective stakeholder engagement for MCDA. Interactive visualisation tools, facilitated workshops, etc., may better support informed weighting than surveys alone. This corresponds with the recommendation from DCLG (2009), which suggests performing a workshop. Though a workshop takes a lot of time and coordination, which might lead to fewer participants and more workload on the performers of the MCDA. Therefore, a re-usable questionnaire might still be favourable. This thesis revealed conflicting priorities between stakeholder groups. In contrast, Åström et al. (2025), who conducted a workshop, found no distinct differences between stakeholders, suggesting that the workshop format inherently drives groups toward consensus. This raises the question: would a workshop have altered the average weights in this thesis, and potentially changed the final ranking? To determine the robustness of questionnaire-based weighting, future research should directly compare weights obtained from questionnaires with those derived from workshops.

Third, research on how to meaningfully engage civil society and property owners in technical MCDA processes, without overwhelming them or reducing participation due to complexity, is needed for democratically legitimate stormwater planning. In this thesis, no responses were received from civil society (one was sent), and two were received from property owners (four were sent). By engaging property owners and civil society, there could be a greater acceptance among the stakeholders who will actually be affected by the solutions, by having an influence on the decision process.

Lastly, further investigation into the most suitable solution for Anneberg is warranted. The Grass-covered Infiltration Trench ranked first, with the hybrid alternative (Grass-covered Trench & Rain Garden) a close second. This hybrid solution consists of 50% Grass-covered Trench and 50% Rain Garden. If these proportions were adjusted (e.g., to 70% Grass-covered Trench and 30% Rain Garden) the solution might retain some of the Rain Garden's benefits while reducing costs, potentially making it even more suitable for Anneberg. Investigating the optimal proportion of each solution type to maximise the total score would therefore be a valuable direction for future research.

7. Conclusion

This thesis aimed to evaluate how multi-criteria decision analysis (MCDA) can support urban stormwater management decisions by integrating technical, environmental, social, and economic considerations in a real-world case study. To answer the first research question, 'which solutions are suitable for the area', there are five possible stormwater management strategies for the area: Infiltration Trench, Grass-covered Infiltration Trench, Rain Garden, and hybrid versions of the latter two. The MCDA revealed that the Grass-covered Infiltration Trench achieved the highest ranking, implying that it's the most suitable strategy for the study area following the analysis strictly. Though, the hybrid solution of Grass-covered Infiltration Trench & Rain Garden came a close second. The Rain Garden is the least suitable according to the ranking, which achieved a negative final score due to its poor performance in the technical and economic dimension, despite its high performance within the social dimension.

Addressing the second research question, 'what evaluation criteria are relevant for comparing stormwater management strategies in an urban context', this study confirms that a combination of qualitative and quantitative criteria across all sustainability dimensions and technical dimensions is necessary for a comprehensive assessment. According to the analysis, all evaluated criteria are relevant for the case study area of Anneberg, as they were all assigned weights by industry professionals. The thesis also showed that the criteria are relevant for this specific case. The sensitivity analysis proved the absolute relevance of the economic and technical criteria; when these were excluded, the final ranking was changed, making the previously lowest-ranked alternative, the Rain Garden, top-ranked. This highlights that excluding criteria or dimensions from the evaluation can lead to different and potentially unfeasible recommendations.

To answer the third research question, 'how different stakeholders prioritise the criteria used to evaluate stormwater management', the analysis revealed clear differences between the groups. All stakeholder groups prioritised the environmental dimension highest, but the researchers and the municipality prioritised it much higher than the other groups. In contrast, the consultants prioritised the economic and technical criteria higher than the other stakeholder groups. Property owners uniquely assigned a much higher weight to the social dimension than the other groups. Capturing these conflicting interests is a part of the core of the MCDA, and its strength lies in acting as a transparent platform that forces participants to define their priorities and create a shared understanding, not create a single correct decision.

In conclusion, Multi-Criteria Decision Analysis is a powerful and transparent decision-support tool for urban stormwater management. It integrates objective performance data with stakeholder preferences, allowing trade-offs to be systematically analysed and discussed. However, the method must be carefully adapted to local conditions and priorities, and its limitations must be acknowledged, particularly the compensatory nature of the simple additive model and the risk of overemphasising the top-ranked alternative. To strengthen future applications, research should focus on validating scoring with data from installed solutions, comparing weighting methods (questionnaire vs. workshop), and developing better approaches for engaging civil society. When applied with these considerations in mind, MCDA offers a defensible framework for navigating the complex trade-offs inherent in sustainable stormwater planning.

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A. Comprehensive questionnaire

For an overview of the comprehensive questionnaire layout, see Figure A.1. An example pie chart for the environmental dimensions can also be seen. The same principle for each dimension's pie chart is applied. Figure A.2, A.3, A.4, and A.5 show the description of each of the four dimensions, as well as the criteria included in the dimensions.

The weighing between dimensions can be seen in Figure A.6. An example pie chart generated in this step can be seen in Figure A.7. Lastly, the 'About you' section of the questionnaire is seen in Figure A.8.

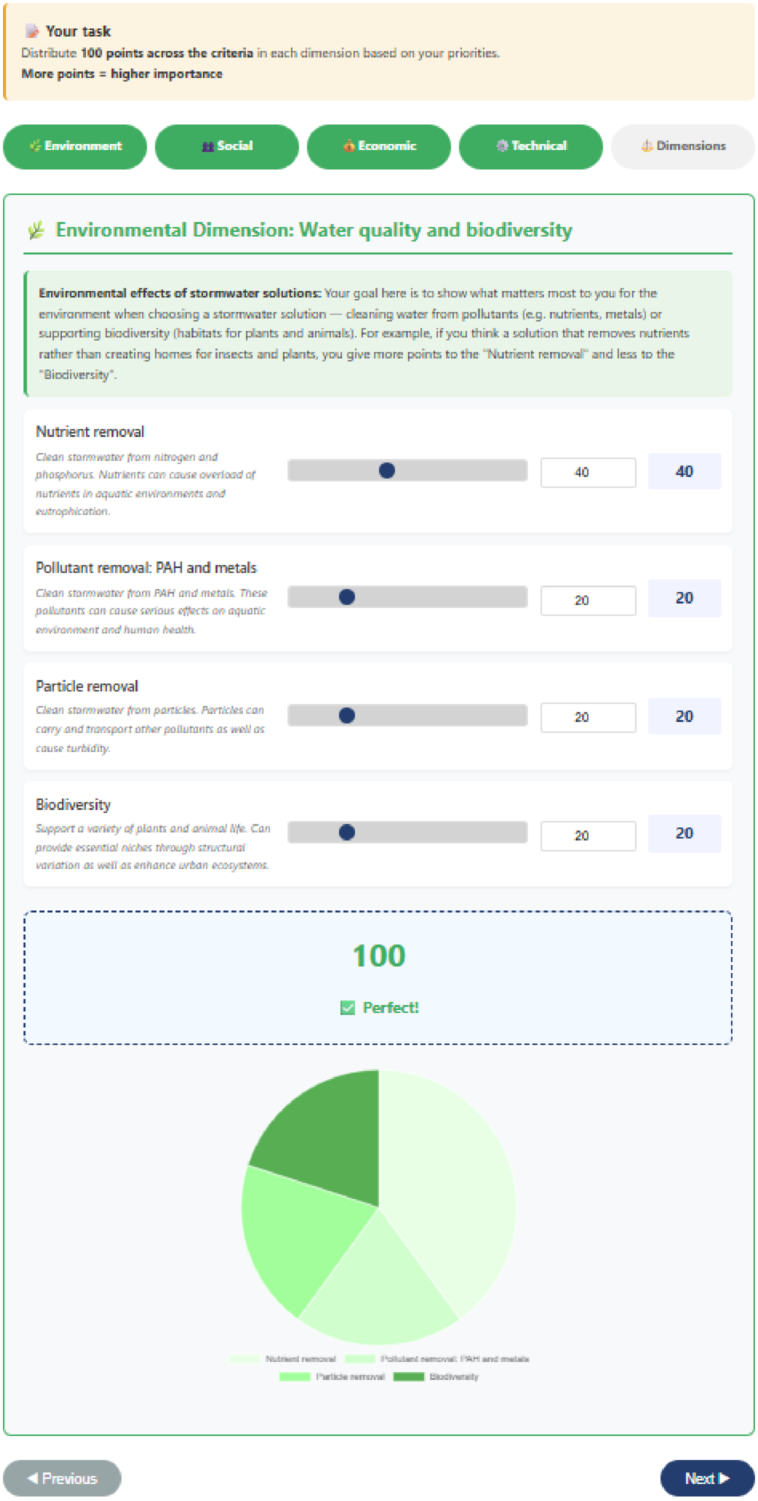

Figure A.1: Overview of the questionnaire.

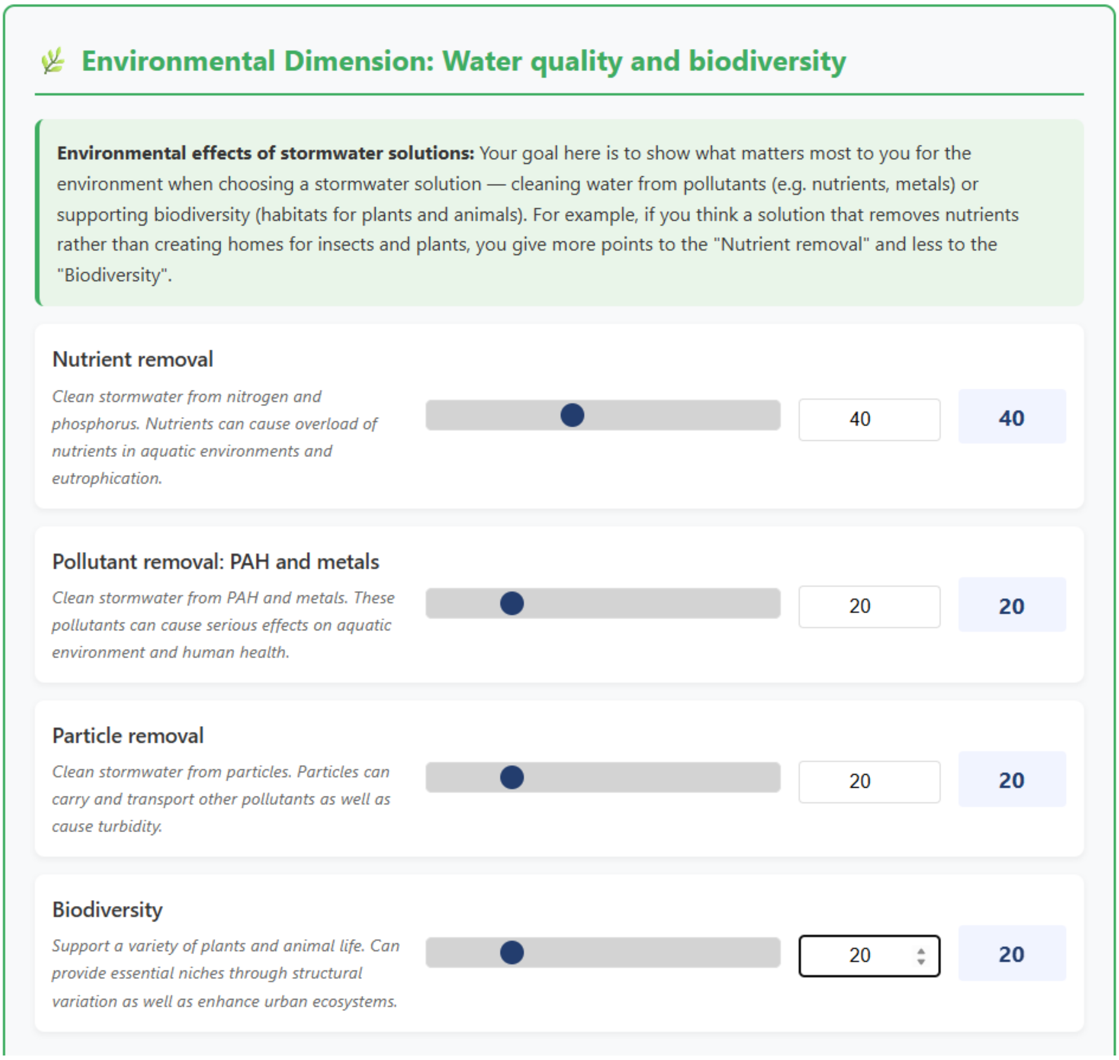

Figure A.2: Environmental dimension, including description of dimension, criteria, and description of criteria.

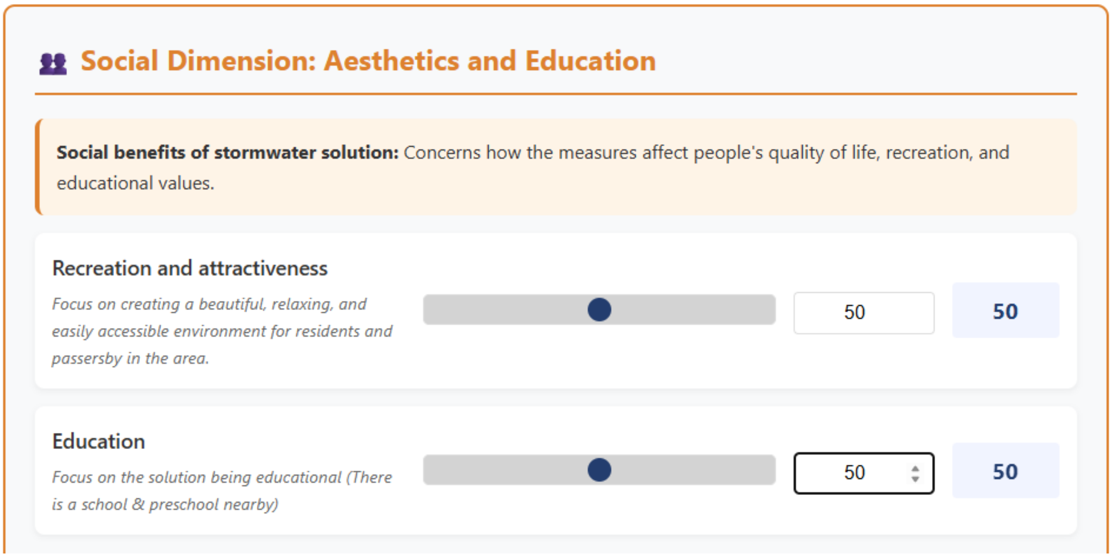

Figure A.3: Social dimension, including description of dimension, criteria, and description of criteria.

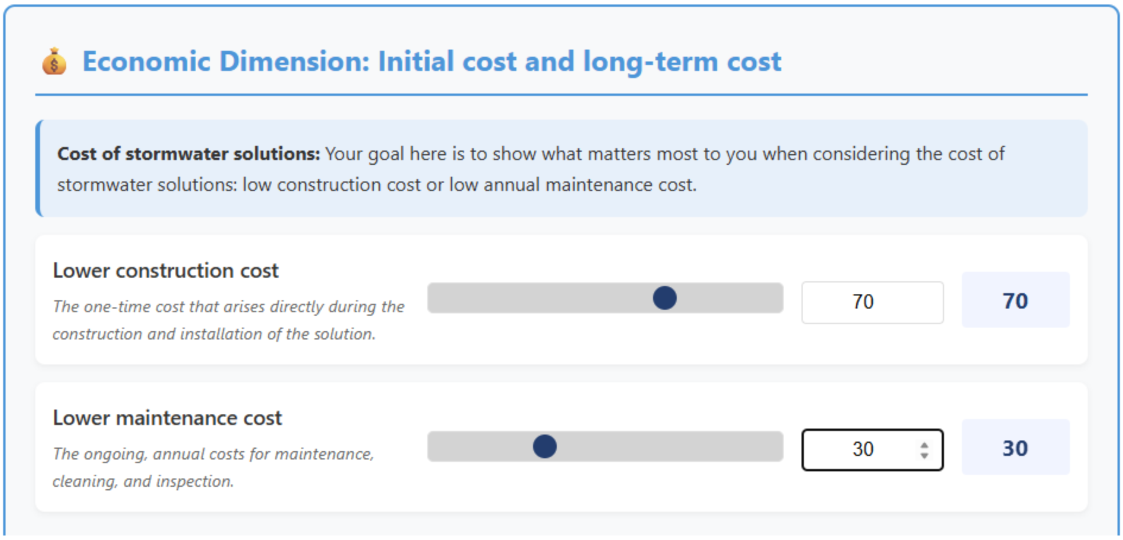

Figure A.4: Economic dimension, including description of dimension, criteria, and description of criteria.

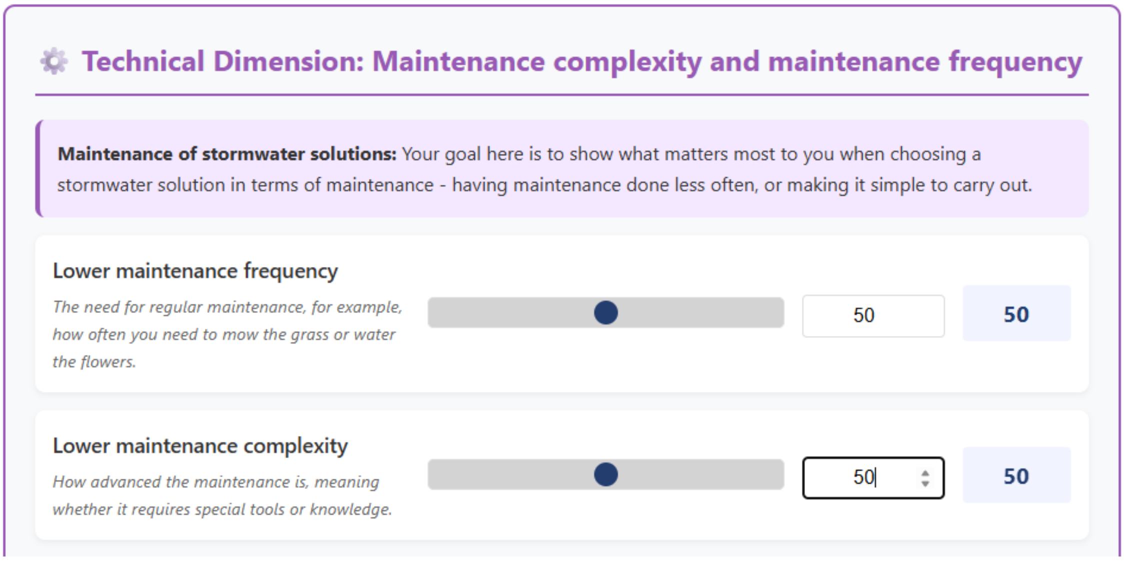

Figure A.5: Technical dimension, including description of dimension, criteria, and description of criteria.

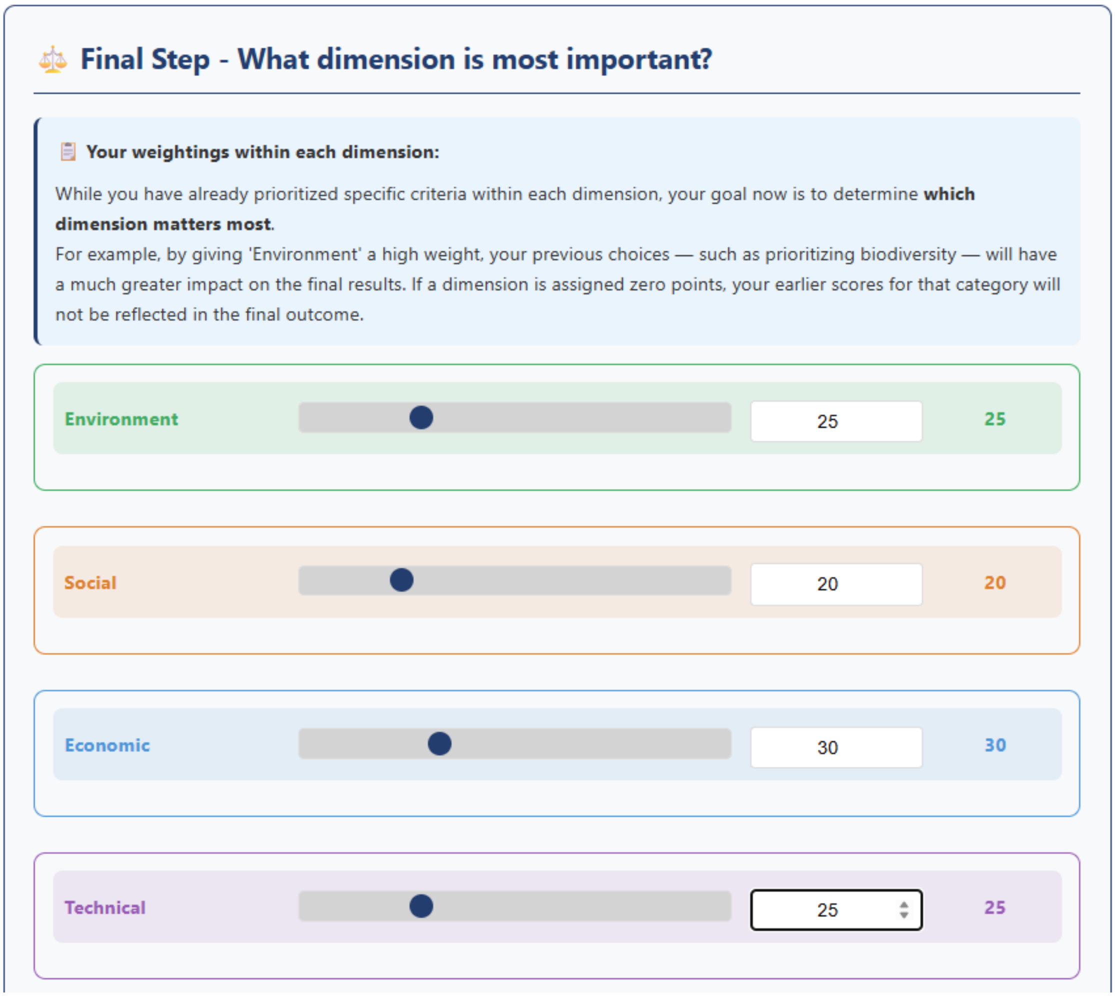

Figure A.6: Distribution of points between the criteria.

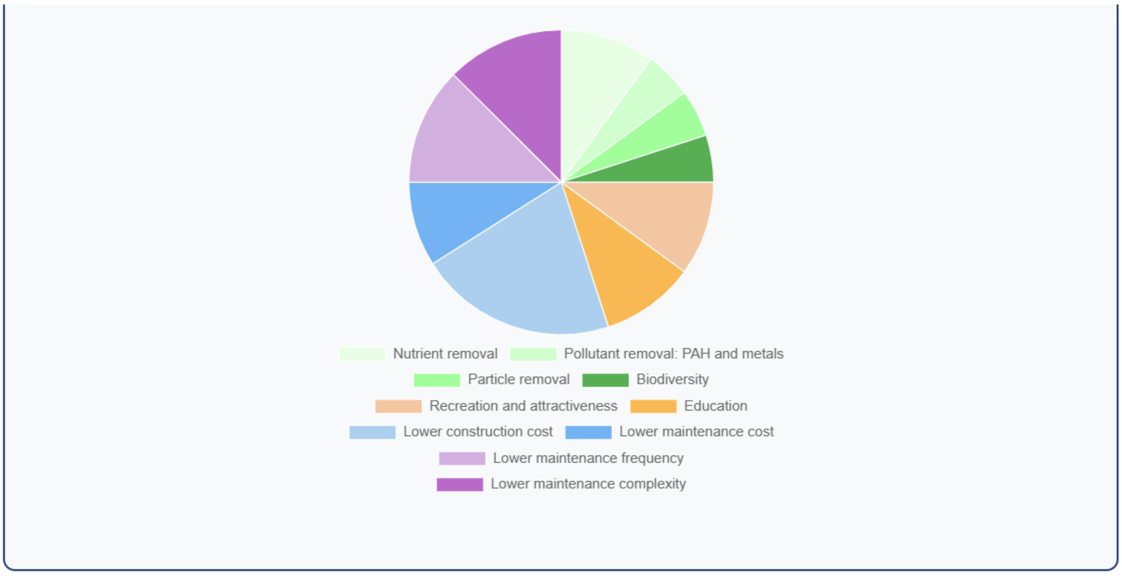

Figure A.7: An example pie chart, generated in the final step.

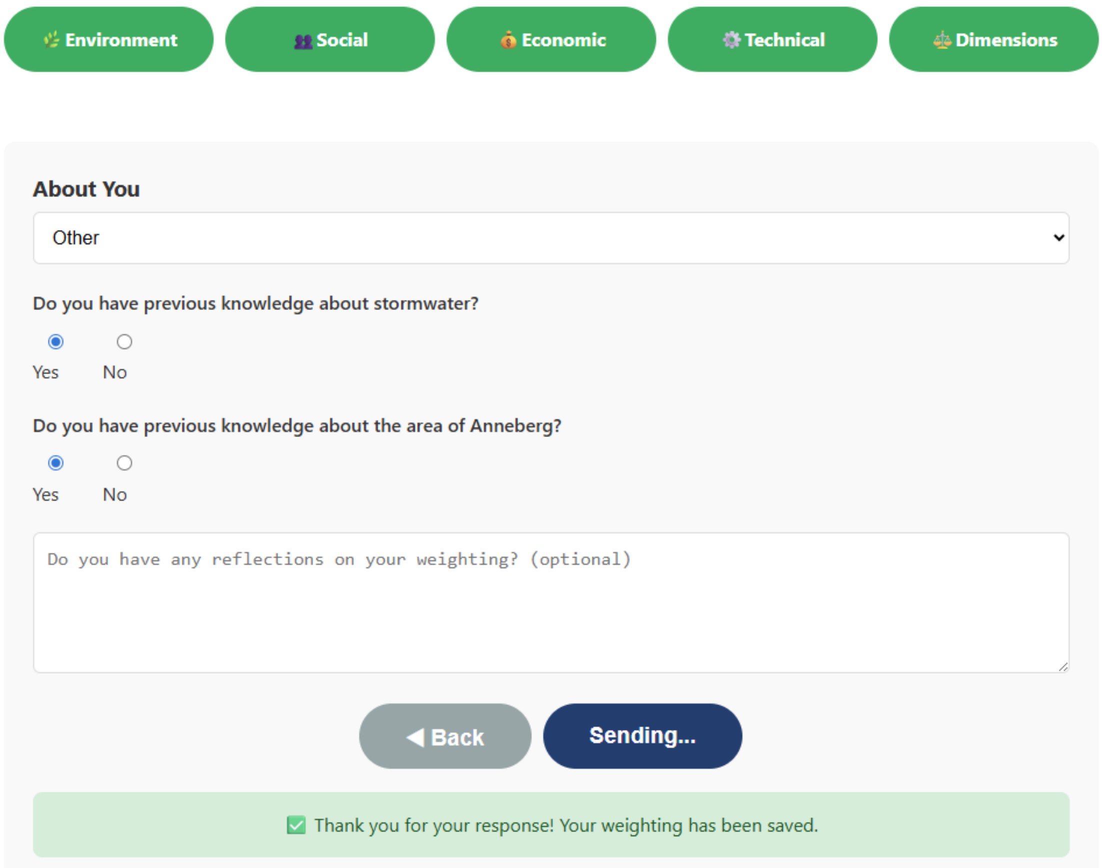

Figure A.8: Questions about the respondent, including which stakeholder and previous knowledge about stormwater and/or Anneberg. Additionally, a comment could be added.

B. Abbreviated Questionnaire

The descriptions of the abbreviated questionnaire and dimensions are seen in Figure B.1 and B.2. An example pie chart generated from this questionnaire is shown in Figure B.3.

Figure B.1: First page of the abbreviated questionnaire.

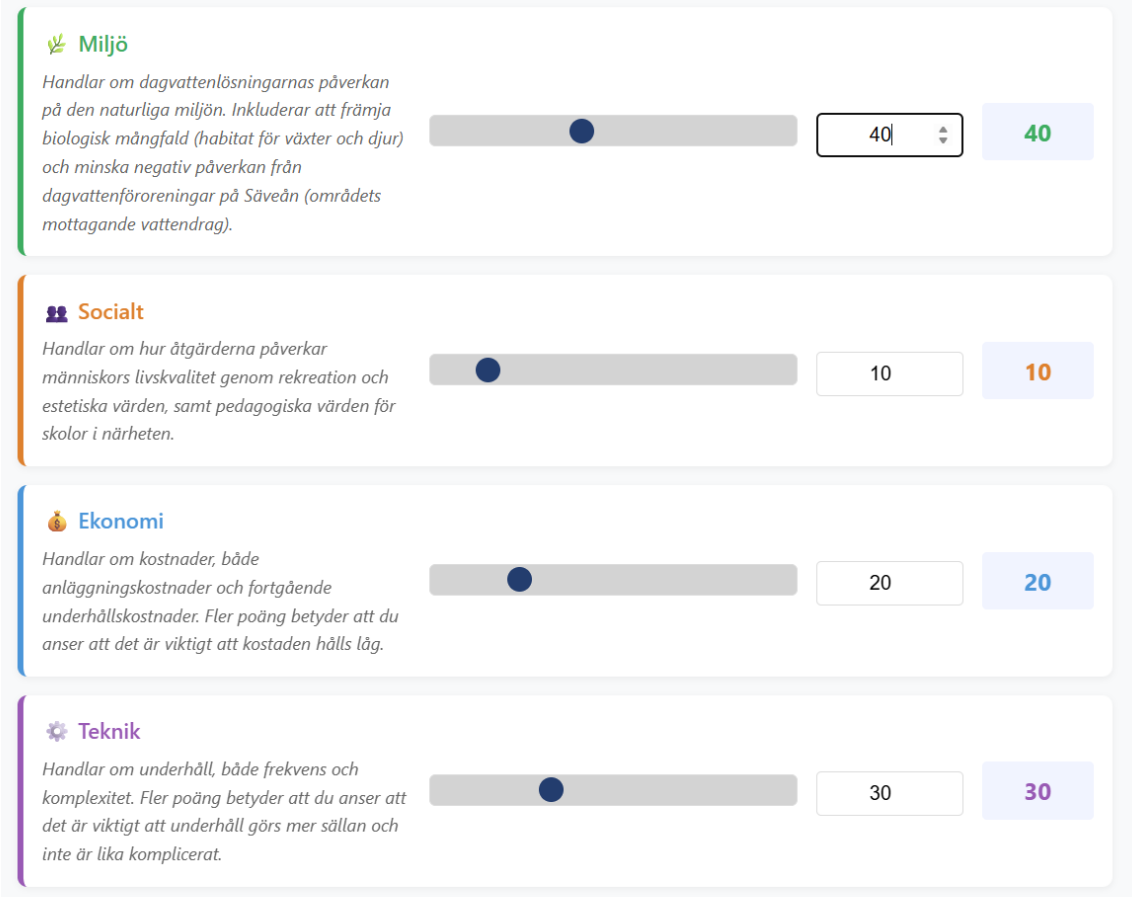

Figure B.2: Scoring dimensions abbreviated questionnaire.

Figure B.3: An example pie chart, generated in the abbreviated questionnaire.

C. Calculated Pollutant Load After Development, with and without Treatment

The calculated pollutant loads and scores for stormwater solutions can be seen in Table C.1.

Table C.1: Calculated pollutant loads and scores for different stormwater solutions.

Parameter	After development, without treatment [kg/year]	After development, with infiltration trench [kg/year]	After development, with rain garden [kg/year]	Calculated score for rain garden, pollutant
Phosphorus (P)	8,0	3,2	2,8	1,25
Nitrogen (N)	65	29	39	-2,73
Lead (Pb)	0,40	0,080	0,080	0,00
Copper (Cu)	0,77	0,27	0,27	0,00
Zinc (Zn)	2,5	0,375	0,375	0,00
Cadmium (Cd)	0,018	0,0027	0,0027	0,00
Chromium (Cr)	0,37	0,17	0,17	0,00
Nickel (Ni)	0,26	0,091	0,065	2,86
Mercury (Hg)	0,0015	0,00083	0.00095	-1,78
Suspended solids	2200	440	440	0,00
BaP	0,0015	0,00060	0,00023	6,25

D. Answers from Questionnaire

Respondents to both the comprehensive and abbreviated questionnaires could give comments, which are presented in Table D.1. The comments were originally given in Swedish, but have also been translated into English.

The individual weights given by the respondents, as well as the weighted average of criteria and dimensions for each stakeholder group, are shown in Figure D.1.

Table D.1: Stakeholder comments on questionnaire and weighting criteria.

Stakeholder	Comment (original)	Comment (English translation)
Consultant	Vid val av viktning förutsätter jag att det finns en grundnivå gällande rening som alla alternativ når upp till.	When choosing weighting, I assume there is a basic level of treatment that all options achieve.
Consultant	Min viktning är generell för dagvattenhantering. Varje projekt och utredningsområde är unikt med olika förutsättningar och krav.	My weighting is general for stormwater management. Each project and investigation area is unique with different conditions and requirements.
Municipality	Svårt att välja när man inte har mer fakta. Tex rena bort PAH och metaller är ju jättebra men ganska svårt och dyrt skulle jag gissa. Är det då värt att lägga massa pengar på det om det ger liten effekt jämfört med annat	Difficult to choose when you don't have more facts. For example, removing PAH and metals is great but quite difficult and expensive, I would guess. Is it worth spending a lot of money on it if it has little effect compared to other things
Municipality	Efter att ha arbetet inom kommunal verksamhet under några åt så vet jag att önskemålet från skattebetalare är att man ska lägga så lite pengar som möjligt, men att man vill ha så mycket av en liten budget som möjligt. Det är en svår balansgång och det finns många intressen att se till (både faktiska och känslomässiga). För att arbeta hållbart behöver vi inte bara se till dagens resurser, utan också tänka oss vilka resurser vi har om 10 år eller till och med 40 år. Om vi applicerar en större budget idag där man tar in fler intressen, ex miljö och socialt, kan vi då se besparingar över tid? är dessa besparingar miljömässigt hållbara och kommer det innebära en enkel druft som ger anläggningen en längre livskvalité?	After working in municipal operations for a few years, I know that the taxpayers' wish is to spend as little money as possible, but to get as much as possible from a small budget. It is a difficult balancing act and there are many interests to consider (both factual and emotional). To work sustainably, we need to not only look at today's resources, but also think about what resources we will have in 10 years or even 40 years. If we apply a larger budget today that includes more interests, e.g., environmental and social, can we see savings over time? Are these savings environmentally sustainable and will they mean easy operation that gives the facility a longer quality of life?
Property owner	Jag arbetar med hållbarhet och vet hur viktig vattenfrågan är	I work with sustainability and know how important the water issue is

	Environment				Social		Economic		Technical	
Stakeholder	**Nutrients**	**Pollutants**	**Particles**	**Biodiversity**	**Recreation**	**Education**	**Installation cost**	**Maintenance cost**	**Frequency**	**Complexity**
Municipality	18	15	15	12	14	6	4	6	5	5
	8	8	8	16	25,5	4,5	3	12	4,5	10,5
	15	15	7,5	12,5	9,75	5,25	10	10	3	12
	7,8	30,6	6,6	15	15,4	4,6	1,2	8,8	7,5	2,5
	6	9	6	9	18	12	10	15	6	9
	2,61	8,99	7,25	10,15	9,6	14,4	8	24	7,65	7,35
	21	28	10,5	10,5	14	6	1,95	3,05	2	3
	8,4	9,9	8,1	3,6	15	15	3	7	21	9
	15	15	12,5	7,5	13	7	3	12	1,5	13,5
	0	27,5	2,5	20	0	0	0	25	5	20
	18	6	27	9	10,5	4,5	4,5	5,5	5,25	9,75
	6	4,5	4,5	15	14	6	0	20	0	30
Average criteria weight	**10,5**	**14,8**	**9,6**	**11,7**	**13,2**	**7,1**	**4,1**	**12,4**	**5,7**	**11,0**
Average dimension weight	46,6				20,3		16,4		16,7	
Researchers	7	31,5	14	17,5	7	3	1	9	0	10
	2,4	25,2	3,2	9,2	8	8	6,27	12,73	9,25	15,75
	7,5	30	7,5	5	12	8	5	5	10	10
	5	10	30	5	8	12	6	14	3	7
	18	18	2	2	9	6	9	21	10,5	4,5
	9	7,5	6	7,5	15	5	7,5	17,5	7,5	17,5
	5,4	10,2	11,7	2,7	5	5	6,3	23,7	19,5	10,5
Average criteria weight	**7,8**	**18,9**	**10,6**	**7,0**	**9,1**	**6,7**	**5,9**	**14,7**	**8,5**	**10,8**
Average dimension weight	44,3				15,9		20,6		19,3	
Consultants	7,7	7,7	5,6	14	21	14	10	10	4	6
	7,5	9	6	7,5	15	10	12,5	12,5	14	6
	3	2	4	1	12	18	9	21	18	12
	10,5	10,5	10,5	3,5	5,25	1,75	32,5	17,5	2,8	5,2
	39,22	21,46	13,32	0	0	0	0	0	3,38	22,62
	11,2	11,2	11,2	6,4	5	5	18	12	12	8
	9	9	9	3	9,5	0,5	15	15	15	15
	6,25	6,25	6,25	6,25	17,5	7,5	7,5	17,5	12,5	12,5
	17,5	17,5	10	5	6	4	7,5	17,5	4,5	10,5
Average criteria weight	**12,4**	**10,5**	**8,4**	**5,2**	**10,1**	**6,8**	**12,4**	**13,7**	**9,6**	**10,9**
Average dimension weight	36,6				16,9		26,1		20,4	
Property owners	7,5	7,5	7,5	7,5	15	15	10	10	10	10
	10	10	10	10	17,5	17,5	5	5	7,5	7,5
Average criteria weight	**8,75**	**8,75**	**8,75**	**8,75**	**16,25**	**16,25**	**7,5**	**7,5**	**8,75**	**8,75**
Average dimension weight	35				32,5		15		17,5	

Figure D.1: Answers from questionnaire as well as average criteria and dimension weight, divided into stakeholder groups.

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