Norwegian University
of Life Sciences

Master's Thesis 2021 30 ECTS
Faculty of Science and Technology

A Multicriteria Analysis Method for Comparison and Selection of Stormwater Management Concepts

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Water is the driving force of all nature.

Leonardo da Vinci (1452–1519)

Acknowledgements

This master's thesis marks the end of my five-year-long education in Water and Environmental Engineering at the Norwegian University of Life Sciences (NMBU). This has been the most thrilling time of my life thus far. I am genuinely appreciative of everyone I have had the opportunity to acquaint and spend this time with.

I would like to thank those involved with my thesis. The opportunity to write this thesis arose through a summer student position in the Unit for Thematic Maps (GPT) of Agency for Planning and Building Services, City of Oslo, in 2020. I extend my sincerest appreciation to everyone at GPT and Julia Kvitsjøen, chief engineer and Ph.D. Candidate in Agency for Water and Wastewater Services, City of Oslo, for a warm and welcoming work environment, which made for a truly wonderful experience. I would like to give my genuine gratitude to Julia Kvitsjøen for her enthusiastic support and guidance, critical judgment, and knowledgeable remarks through the development of this thesis. Her positive involvement has truly been invaluable. I would also like to thank my supervisors from NMBU, my supervisor Ulf Rydningen and co-supervisor Kim Aleksander Haukland Paus, for their supportive and guiding involvement through the progress of this thesis.

I would like to thank my family for their continuous and unconditional love and support, and for providing me with great opportunities in life. I would also like to thank the people I have had the pleasure of getting to know during my time at NMBU. You have all made these past five years truly memorable. I want to express my heartfelt gratefulness in particular to those with whom I have shared a roof all this time, for being the best friends a man could hope for.

Ås, May, 2021

Bjørn Halvor Morholmen

Summary

The increasing frequency of high-intensity rainfall, a growing expanse of impermeable surfaces, and a hard-pressed sewer system expedites the necessity of sustainable stormwater management (SWM) solutions. However, optimal integration of SWM systems begins in the planning phase of site development processes. This thesis explores and demonstrates the use of a multicriteria analysis (MCA) method for comparing conceptually different SWM concepts within a minimal decision environment. The MCA method provides an opportunity to compare concepts for SWM early in a planning phase. Based on the results, the user may be able to discern better which concepts to pursue and which to discard to avoid fruitless spending of resources. The MCA is entirely built in Microsoft Excel, relying mainly on simple additive weighting (SAW) with a combination of weighted arithmetic means and min-max normalization. Factors of consideration pertaining to the management of stormwater have been discussed, and a list of 37 criteria across nine categories has been suggested. As part of this thesis, a case area has been studied, and five conceptually different concepts have been drafted for the case area. The concepts have been evaluated with the MCA, and the results, together with a limited sensitivity analysis, have been presented and discussed. Through the trials of the MCA method, possible weaknesses of the model were revealed. Limitations to the information available in the decision environment may be compensated with guesswork and conjectures. The phrasing of the criteria may limit the results of each category to an unnecessarily compressed range, which may reduce the accuracy of the model. Furthermore, although this falls outside the scope of the thesis, guidance is lacking on the evaluation of individual criteria and on assigning weights to criteria. Resolving these issues will substantially increase the reliability of the MCA model. While the MCA method of this thesis is insufficient on its own to provide clear-cut guidance and definitive results as to which concept is best suited to the conditions, goals, and interests of the site it is applied for, it can still provide some insight as to the strengths and weaknesses of concepts and how the importance of individual criteria and categories affects the final results. With further development and supporting manuals, this can be a helpful tool in the decision-making processes of SWM planning.

Sammendrag

Klimaendringer og mer intens nedbør, voksende bysentre med tette flater og et avløpssystem under press gjør det i økende grad nødvendig med smartere og mer bærekraftig overvannshåndtering. For å sikre gode løsninger og god implementering må arbeidet begynne i planleggingsfasen av byggeprosjekter. Denne masteroppgaven utforsker og demonstrerer en enkel multikriterieanalyse-metode for sammenlikning av konseptuelt ulike overvannsløsninger ved en tidlig plalegginsfase med begrenset tilgjengelig informasjon. Basert på resultatene kan brukeren være istand til å vurdere hvilke konsepter som kan være aktuelle i videre prosesser og hvilke som kan forkastes for å unngå unødvendig bruk av ressurser. Metoden er fullstendig utviklet i Microsoft Excel og er i hovedsak basert på "simple additive weighting" (SAW) med en kombinasjon av vektede aritmetiske gjennomsnitt og min-maks-normalisering. I masteroppgaven diskuters også ulike faktorer av betydning for overvanns-håndtering. En liste bestående av 37 kriterier under ni kategorier er foreslått til bruk i multikriterieanalyse. I masteroppgaven er også fem konsepter grovt utarbeidet for et case-område. Konseptene er blitt vurdert i MCDM-metoden. Resultatene, sammen med resultatene av en begrenset sensitivitetsanalyse, er presentert og diskutert. Testing av metoden avdekket mulige svakheter. Begrenset informasjon medfører økt grad av synsing og følgelig dårligere presisjon. Ordleggingen av kriteriene kan medføre en tettere gruppering av resultatene fra hver kategori; noe som kan gi dårligere presisjon. Metoden mangler veiledning for vurdering av kriteriene og for bestemmelse av riktig vekting selv om dette faller utenfor oppgavens rammer. Selv om MCDM-metoden som er lagt fram i denne masteroppgaven ikke er tilstrekkelig på egenhånd til å gi definitive svar på hvilke konsepter som er best egnet til områdets forhold og interesser, kan den likevel gi innsikt i konseptenes fordeler og svakheter og hvordan vektingen av ulike kriterier former de endelige resultatene. Med videre utvikling og veiledning i bruk av metoden kan dette bli et nyttig verktøy i beslutningstaknings-prosesser innen overvannshåndtering.

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List of Acronyms

CS	Combined Sewer
GI	Green Infrastructure
MCA	Multicriteria Analysis
MCDM	Multicriteria Decision Making
SAW	Simple Additive Weighting
SWM	Stormwater Management
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

1. Introduction

Since the industrial revolution, human activity, particularly the burning of fossil fuels, has contributed to an unnatural increase in the amount of carbon dioxide present in the atmosphere. As of 2019, the global average concentration of carbon dioxide in the atmosphere was 409.8 ± 0.1 parts per million, more significant than at any point in the last 800,000 years. Furthermore, the increase in the concentration of CO_2 in the atmosphere is accelerating (Lindsey, 2020). As carbon dioxide and other greenhouse gasses warm the Earth's surface, more evaporation will occur. Additionally, as the air becomes warmer, heated by the Earth's oceans and landmasses, its saturation point increases. As such, the air can hold more moisture, leading to greater precipitation events when the moisture condensates as the air cools down (NASA, 2021). According to Hanssen-Bauer et al. (2017, p. 8), by the end of the century, Norway should expect an increase in annual temperature of about 4.5°C and an increase in annual precipitation by about 18%. Torrential rain will become more frequent and increase in intensity, as is the case with subsequential urban pluvial floods. E.g., Hanssen-Bauer et al. (2017, p. 12) reports that preliminary analysis indicates an increase in the intensity of 30% for rainfall with a duration of 3 h and return period of 5 years. Regardless of the extent to which we, as a global community, should succeed in lowering our collective greenhouse gas emissions, temperatures are expected to increase, and associated climate changes will follow (Flæte et al., 2010).

In conjunction with high-intensity rainfall occurring more frequently, urbanization also complicates urban stormwater management (SWM). This loss of permeable surfaces within urban landscapes is often referred to as "urban creep" (Wright et al., 2011). As cities grow in conjunction with impermeable surfaces, so does the runoff. In 2019, Oslo municipality experienced 32% of Norway's total population growth that year (City of Oslo, 2021). The population of Oslo municipality was 697,549 as of Q3 2020 and is expected to reach a population of 800,540 by 2050, according to SSB (2021); an increase of almost 15%. Urbanization leads to an increased area of impervious surfaces and decreased vegetation. This causes more runoff, in addition to a more sudden runoff curve with a higher peak (ref. Figure 1.1), as less infiltration, interception, and evapotranspiration is achieved (Western Australia Department of Water and Environmental Regulation, 2017). In such a setting, one would face the challenge of managing a higher amount of runoff within a more restricted, urban landscape.

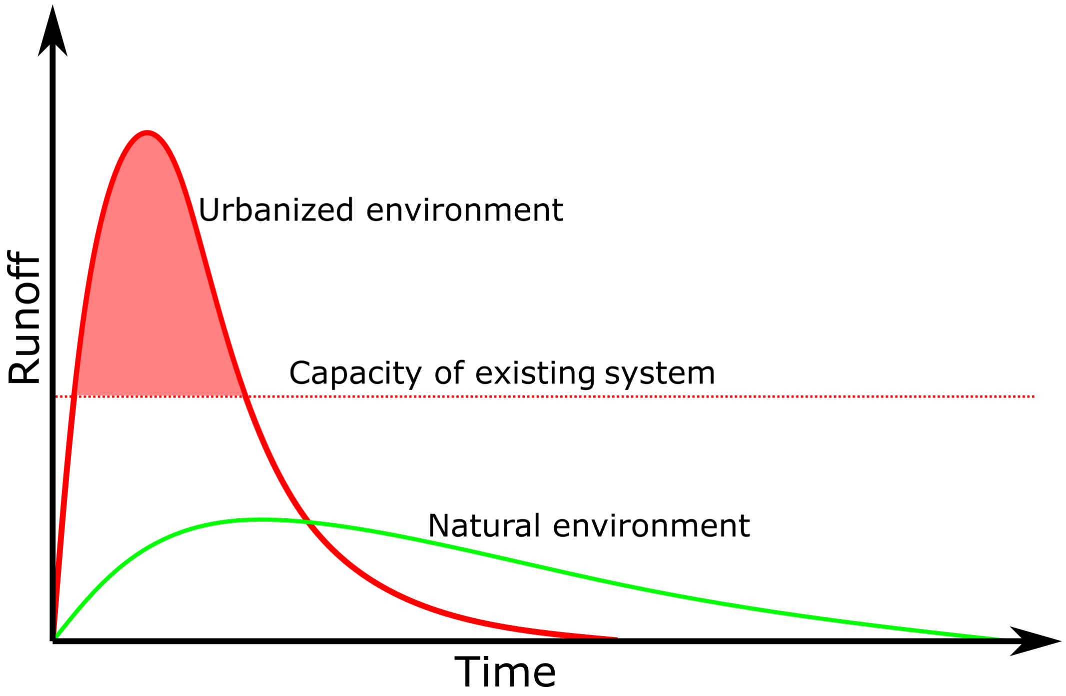


Figure 1.1: In an urbanized environment, more rainfall will run off from impervious surfaces, and peak runoff will occur earlier than in a natural environment. This leaves urbanized areas at risk of being incapable of directing rainwater to a recipient in a safe manner should the flow of stormwater exceed the capacity of their existing SWM system. The illustration is inspired by Paus (2018).

Torrential rain of relatively short duration and high intensity poses the greatest risk to people, buildings, and infrastructure. Based on the increasing frequency of such precipitation events, *Norges Offentlige Utredninger 2015: 16* (Skaaraas et al., 2015, p. 43) estimates the present value of flood-related damages over the next 40 years (counting from 2015) to between 45 and 100 billion NOK. If predicted changes to the climate are overlooked, the present value is estimated to 45 ± 15 billion NOK. In other words, changes to the climate and the ensuing ramifications may, according to the NOU, cost as much as 70 billion NOK in rainfall and pluvial flood-related damages over the next 40 years following its publication.

In 2011, Copenhagen of Denmark experienced a cloudburst of extreme proportions. 150 mm fell on the city over the course of 2 h. The number of reported damages reached 90,644 and the total cost approximated 10 billion NOK (Ritzau and Jakobsen, 2012; Langeland et al., 2017). As Langeland et al. mention, Norway will be subjected to a major cloudburst sooner or later. The Norwegian Directorate for Civil Security and Emergency Preparedness (DSB, 2016, p. 24) points out that climatically, the cloudburst that hit Copenhagen could occur along the Oslofjord as well. Furthermore, DSB consider it very likely that about half of the 20 vulnerable cities along the Oslofjord and Skagerak will experience a cloudburst of 100-110 mm in a time span of 2 h within the next 50 years as of 2016. In the aftermath of the Copenhagen cloudburst of 2011, the city has planned around 300 projects for a sum of around 11 billion NOK that will be completed over the next couple of decades (Langeland et al., 2017).

Historically, Norwegian cities have primarily relied upon sewer systems for SWM since their construction in the mid 1800s. Oslo's first sewage plan was established in 1844. At that time, sewage pipes conveying stormwater were viewed as an advantage due to the additional flushing of the pipes (Skaaraas et al., 2015, p. 49). Almost a century later, in 1978, Statens forurensningstilsyn (today The Norwegian Environment Agency) published guidelines for SWM (SFT, 1978). Here, facilitating for the stormwater to follow its natural runoff pattern is established as a premise for efficient SWM, as opposed to transportation through pipes. Today, the principles of the "three-part strategy" permeates much of the planning and implementation of on-site SWM, as exemplified by, among other official sources, "Oslo Street Norm" (Bymiljøetaten, 2020, p. 138): "The three-part strategy is the most important principle underlying stormwater management." The three-part strategy was, to the author's knowledge, first publicized in Norway by Lindholm et al. (2008). Similar strategies are also employed internationally (E.g. SuDS Wales (2021)). Paus proposes a preceding step to the "three-part strategy"; a "Step 0" to represent the need for thorough planning. Experiences indicate that SWM seldom functions as intended by the "three-part strategy" unless the required prerequisites are incorporated in an early stage of planning (Paus, 2018, p. 68). As the planning phase progresses in an area development scenario, the possibilities for an ideal integration of SWM diminish. Past a certain point, an ideal solution may no longer exist among the remaining options. The same can be said for an already developed area. Therefore, to obtain the best solution for long-term operations, SWM should be included early in the planning phase. A simple illustration of the "three-part strategy", including planning stage, is shown in Figure 1.2.

When planning for SWM, one might find oneself in a situation where two or more conceptually different alternatives are admissible. Making the best possible selection among them may pose a challenge, given the plethora of considerations one should account for. Because this decision-making process is conducted early in the project's planning phase, detailed information may be destitute and too insufficient for a clear-cut selection between alternative concepts. As such, the decision process may rely too heavily on conjectures. For better decision-making, the use of conjectures and guesswork are best kept to a minimum, although, where more detailed information does not exist or is realistically unobtainable, it cannot be wholly avoided. In situations such as these, a standardized framework for evaluating various aspects of different alternatives, be they vague or specific, may still yield some common basis for comparison.

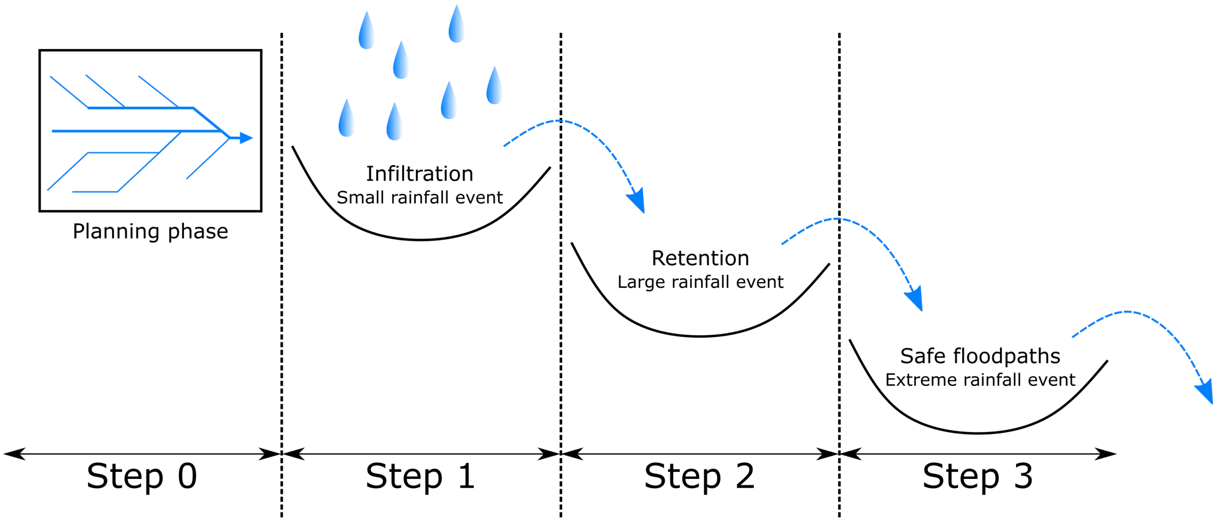


Figure 1.2: A simple illustration of the three-part strategy based on Lindholm et al. (2008, p. 8) and Paus (2018, p. 67). The figure includes a preceding planning phase, as proposed by Paus. The limits for step 1-3 must be adapted to the local conditions (Ødegaard et al., 2014, p. 353).

1.1 Scope, limitations, and research question

This study aims to develop a multicriteria analysis (MCA) method for the comparison of different conceptual designs for SWM, focusing on methods for retention and safe flood paths. That is to say, the study will pertain to "Step 0" of the "three-part strategy" (ref. fig. 1.2), in an early planning stage. This is a response to and continuation of the groundwork done by the City of Oslo and Sweco Norge AS (2021), which is introduced in Chapter 2.1. The intent for this tool is for it to be of help when evaluating the alternatives' strengths and weaknesses associated with different criteria. It should provide a framework for systematic evaluation to achieve an impartial comparison with the limited information available at the early planning stage the method is intended for while keeping conjectures at a minimum. Focus is put towards making the tool easy to learn and use while also providing valuable insight.

This thesis will also attempt to develop further the set of criteria provided by the City of Oslo and Sweco Norge AS (2021), to be used in the MCA method. However, developing a ruleset for assigning weights to the parameters is not a focus of this study, nor is it a priority to develop guidelines for how each criterion should ideally be evaluated.

The MCA method will be demonstrated for a case area. Five conceptually different SWM designs will be compared. These concepts are limited to the five primary SWM structures described in *Structures in integrated stormwater systems* (City of Oslo and Sweco Norge AS, 2021) (ref. Chapter 2.1 and fig. 2.1). The concepts being compared are not so much intended to be good solutions for the case area as they are meant to demonstrate the MCA.

Lastly, a sensitivity analysis will be performed for the MCA, using the inputs and results from the demonstration as a starting point.

The goals of the thesis are summarized below:

1. Develop a MCA method for SWM concepts
2. Produce a list of criteria to be used in said method
3. Test the method with concepts for case area
4. Perform a simple sensitivity analysis

2. Background

2.1 Structures in integrated stormwater systems

In 2020, Sweco was hired by the City of Oslo to assist them in collecting rudimentary data for the project “Thematic map for stormwater and urban flooding. Act 4 of the action plan for SWM”, from here on referred to as T4 (City of Oslo, 2016). The resulting report was titled *Structures in integrated stormwater systems* (City of Oslo and Sweco Norge AS, 2021). The data available in this report that are of relevance to this study is discussed in this chapter. The city of Oslo has defined a SWM system consisting of two main categories: flood diversion systems and retention systems. Flood diversion systems are further divided into: 1) normally dry floodpaths, 2) floodpath in stream/channel and 3) stormwater drainage pipes. Stormwater retention systems contain: 1) flooding area, and 2) retention magazines. This is illustrated in Figure 2.1 below. The main delivery of T4 is a principle map-based strategy for a comprehensive SWM system centered around the aforementioned SWM structures. The primary objective of the City of Oslo and Sweco Norge AS (2021) was to compile a data basis for the purpose of identifying socio-economically beneficial levels of climate adaptation to which principle SWM systems should be dimensioned. To this end, the report has identified parameters and criteria for use in a later stage MCA to assess the suitability of different SWM systems in varying urban environments from a technical perspective. The report describes the five SWM structures against the backdrop of this list of criteria. No further elaboration is given in the report as to how these criteria should be evaluated or weighted. The report does, however, include data sheets containing relevant information pertaining to each of the five SWM structure types that are part of T4 (ref. Figure 2.1). The data sheets hold information on which functions the SWM structures serve, technical specifications and practical information and what conditions in an area could give preference to a specific structure. How well they respond to the suggested list of criteria is also discussed, and the results are presented in a stoplight model. The criteria and their categories will be further elaborated on under Chapter 3.2.

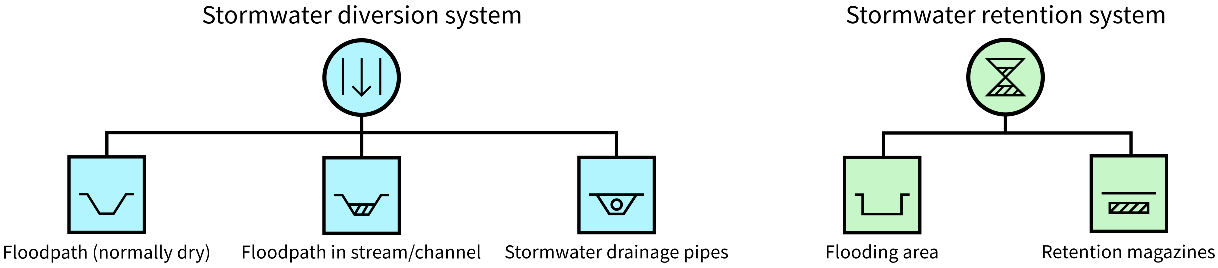


Figure 2.1: The figure shows the lineup and categorization of the SWM structures reviewed in Sweco's report on behalf of the City of Oslo. As part of the application, Sweco designed pictographs and infographics. This figure is an imitation of Sweco's design. (City of Oslo and Sweco Norge AS, 2021)

2.2 Multi-Criteria Decision Making

Multi-criteria decision making (MCDM) gained ground as a family of tools designed to address the complexity of identifying the most optimal solution from the information, alternatives, values, and preferences constituting the decision environment, with often conflicting objectives and different groups of decision-makers involved in the process (Mateo, 2012, p. 7). As noted by Velasquez and Hester (2013) in "An analysis of multi-criteria decision making methods", MCA has become very popular in a wide range of fields over the last several decades. New methods have been developed, and old ones have seen improvements. Methods are also being combined in order to balance out the weaknesses some might have when used independently.

In this study, MCDM method will refer to the specific technique used for decision making. MCA will refer to the analysis tool itself or the act of performing an analysis where multiple criteria are considered.

Velasquez and Hester have conducted an exhaustive literature review to determine some of the most popular MCDM methods and what use the different methods most commonly have seen. The methods that were identified were: 1) Multi-Attribute Utility Theory; 2) Analytic Hierarchy Process; 3) Fuzzy Set Theory; 4) Case-based Reasoning; 5) Data Envelopment Analysis; 6) Simple Multi-Attribute Rating Technique; 7) Goal Programming; 8) ELECTRE; 9) PROMETHEE; 10) Simple Additive Weighting, and 11) Technique for Order of Preference by Similarity to Ideal Solution (Velasquez and Hester, 2013). Many of these methods are quite complex and will often be required purpose-built for each application, while, naturally, their distinctive features and core elements remain the same. The more complex and specialized a method is, the less versatile it becomes.

A key focus for this study is the versatility and ease of use of the MCA method. In the authors' own investigation leading up to this study, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was frequently applied either independently or in combination with other methods, such as Simple Additive Weighting (SAW) and Fuzzy Set Theory in applications that pertain to water management, either drinking water reserves or stormwater (e.g., Shariat et al., 2019; Gogate et al., 2017; Tahmasebi Birgani and Yazdandoost, 2018; Ahmadisharaf et al., 2016; Qin et al., 2008). In the words of Qin et al.: "[TOPSIS] is an approach to identify an alternative which is closest to the ideal solution and farthest to the negative ideal solution in a multi-dimensional computing space." (Qin et al., 2008, p. 2166). TOPSIS is one of the more straightforward and versatile methods and can easily be used on its own or in combination with Fuzzy Set Theory, as demonstrated by Papathanasiou and Ploskas (2018). Papathanasiou and Ploskas have provided solid documentation of the TOPSIS method in addition to a python script both with and without the use of fuzzy numbers. However, a drawback with TOPSIS for the particular application of this study is the requirement of being able to define an ideal and anti-ideal solution. That might not always be feasible, especially when considering the need for this method to be applicable to a variety of situations and conditions. For a more specific need where an ideal solution is more clear-cut and easily definable, basing a multi-criteria analysis method around TOPSIS could be a good decision.

Another viable option is SAW, arguably the simplest among the methods reviewed by Velasquez and Hester (2013). Podvezko (2011, p. 135) refers to SAW as "the oldest, most widely known and practically used method". Its functioning can be described as follows: "A value function is established based on a simple addition of scores that represent the goal achievement under each criterion, multiplied by the particular weights. (...) The higher the weighted sum of the utility values, the better the alternative." (Qin et al., 2008, p. 2166). Its simplicity makes it intuitive for the user, and it removes the need for advanced software. It can, for instance, be built in data spreadsheets such as Microsoft Excel. For the purpose of this study, this is a major advantage, as Excel provides an easier user interface and is more transparent as opposed to custom software running on, for example, Python or Matlab. Nevertheless, SAW is not without its disadvantages. Some methods, such as AHP, can estimate criteria weights on their own (Velasquez and Hester, 2013, p. 58). This can also be achieved when methods are combined. In contrast, when using a method such as SAW, accuracy in assigning weights to criteria is required of the decision-maker. Furthermore, it is necessary to maintain consistency of judgment when assigning weights, or the basis for comparison becomes skewed.

Based on the considerations presented and literature cited in this section, the author considers the principles of SAW to be an appropriate starting-point for the MCA method of this study. It strikes an amicable balance between functionality, versatility, and ease of use.

3. Methods

3.1 MCA method

The MCA method is built around the approach of allowing the user to rate up to five different concepts for SWM systems' performance within various categories and comparing their scores. Microsoft Excel was selected as the environment for the MCA. The MCA method draws inspiration from the report of a tool called FloodMan, developed by Sweco Environment AB et al. (2018). This report describes a tool used for socio-economic analyses and evaluations for suitable strategies for adapting the city of Gothenburg to the climatic conditions expected in both the near and far future, also using Excel. It uses an MCDM method called SCORE, built for assessing the sustainability of contaminated land remediation (Rosén et al., 2015). The report emphasizes that the model is simplified and that more precise and comprehensive analyses should be conducted in more detailed stages of planning. It is only meant as a support tool for planning processes. This is the case with the MCA of this thesis as well.

The structure of the MCA of this study is inspired by the City of Oslo and Sweco Norge AS (2021) and the categories and subsequent criteria therein. By categorizing the criteria used in the MCA, both category and individual criteria can be weighted separately. However, as there is no reference to compare the results with, as there is in FloodMan, the results can only be compared to one another.

Whereas FloodMan, to the author's knowledge, does not utilize normalization, this is necessary for the MCA of this study when addressing the concepts' total score across all categories. The general formula for normalization used in this study is often referred to as rescaling or min-max normalization and is given below (Loukas, 2020):

$$z_i = \frac{x_i - min(x)}{max(x) - min(x)} \tag{3.1}$$

where $x = (x_1, ..., x_n)$ and z_i is the i^{th} normalized data. In other words, the formula converts the spread of data entries x_i of vector x to the range $[0, 1]$, while keeping the relative distance between data entries unchanged from x to z.

The score for any given combination of criterion and concept is limited to the same range of values. A concept's score from a given category is its weighted arithmetic mean. Consequentially, the results from all categories are constrained to the same range. However, simply comparing the sum of the concepts' score from each category would fail to address the intrinsic incommensurability of the criteria, which, by the MCA method's design, is overlooked with the use of linguistic variables on an arbitrary scale as scores. This issue is circumvented by normalizing the concepts' scores from each category and allowing the user to assign weights to the categories to specify their varying importance. In this process, it is essential that the slots of unused concepts are disregarded. This is achieved by a series of if-statements. Similar if-statements also ensures the correct representation of concepts in the diagrams on the "Results"-sheet.

Below are simplified flowcharts describing the procedure for using the MCA method (ref. fig. 3.1) and the workings of the MCA method (ref. fig. 3.2).

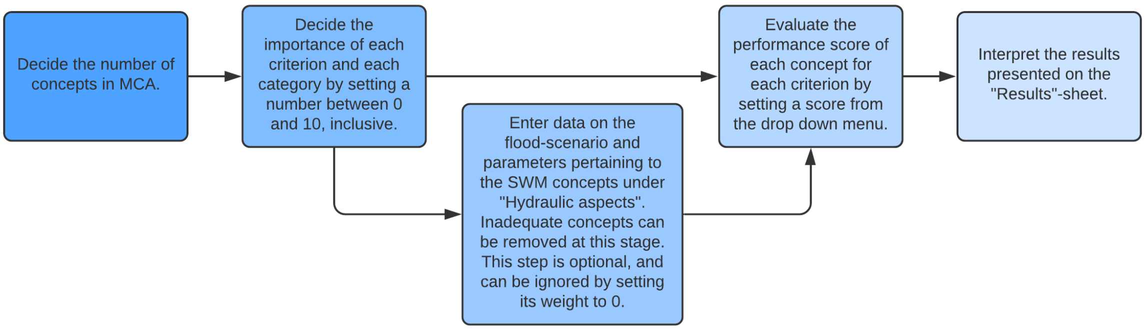


Figure 3.1: A flowchart describing the procedure for using the MCA method.

The structure of the MCA method is divided into different sheets. The "Results"-sheet has already been mentioned. The first sheet is the "Frontpage" containing general information regarding the Excel document, navigation, and a dropdown menu where the number of concepts being evaluated is selected, ranging from 2 to 5. The next sheet is "Results". This is where, as the name implies, the results are presented. It contains a variety of diagrams. The first diagram displays the concepts' combined scores in all categories. There is a series of diagrams displaying the concepts' performance per category and a diagram per concept displaying its performance in every category. The next nine sheets are where the rating and weighting are done; one sheet for every category. Here, a criterion is presented in the leftmost column. To the right of the criterion, a dropdown menu allows the user to select an appropriate weight for the respective criterion. There is then a set of dropdown

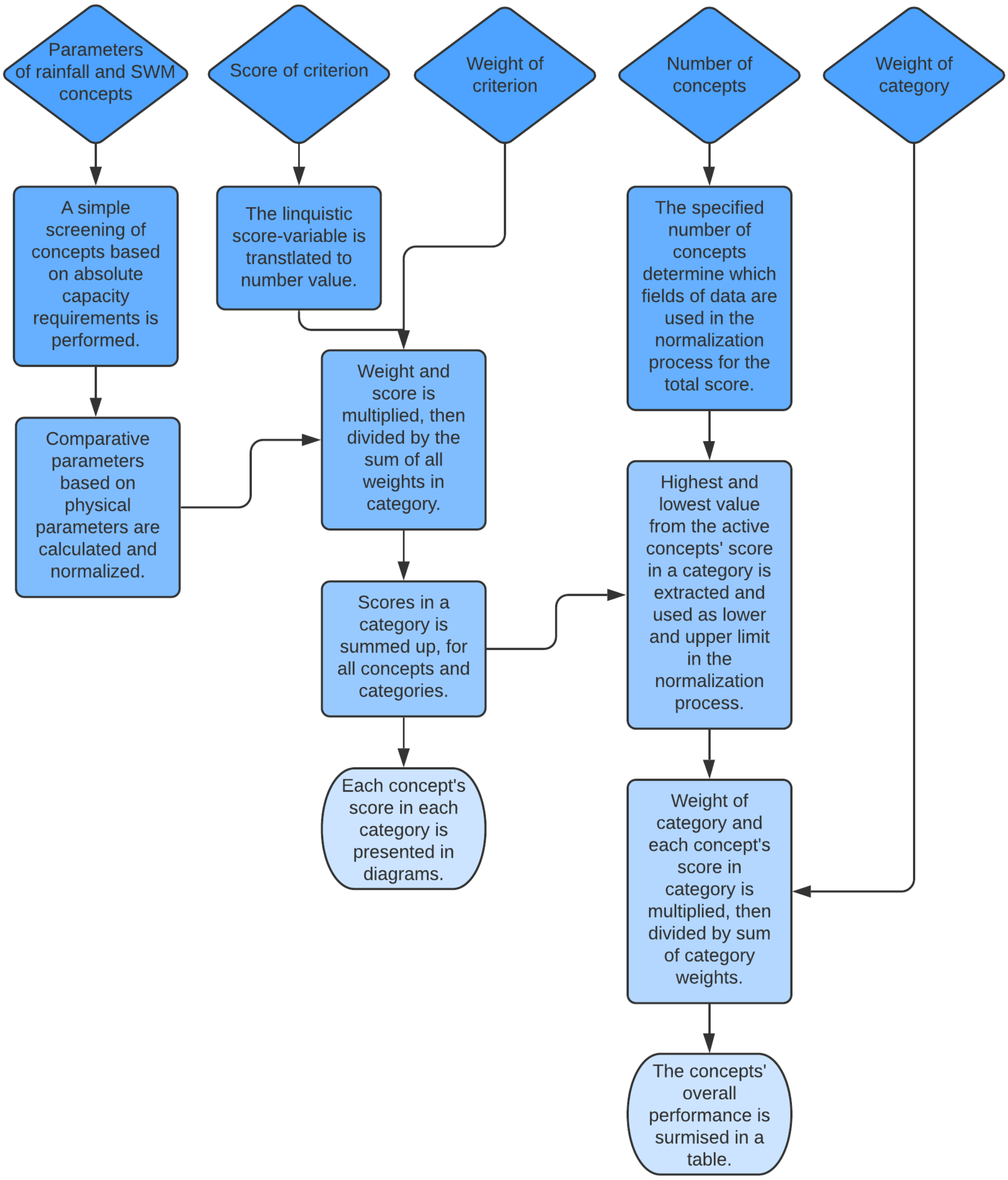


Figure 3.2: A flowchart describing various steps in the workings of the MCA method in a simplified manner.

menus, one for each concept, where each concepts' score for the given criterion is selected. This pattern repeats for every criterion and for every category sheet, with the exception of "Hydraulic aspects".

The "Hydraulic aspects" sheet consists of two parts. One is the typical structure of the sheets as described in the above paragraph, with criteria, weights, and a score. The other is a segment labeled "Physical parameters", which takes input regarding the design flood and physical properties of the concepts such as area, detention capacity, length, stormwater diversion capacity, and drainage to CS. A set of parameters is calculated from this user input. The parameters are discussed in further detail under Chapter 3.2.1. These parameters are normalized (equation 3.1), multiplied with their own set of weights, and divided by the sum of weights. Each segment contains a user-defined weight used in the calculation of the final score from the "Hydraulic aspects" sheet. The user can select the importance of each segment of the "Hydraulic aspects" sheet by shifting these weights, making either segment entirely omittable by setting the weight to zero. Another important function of the "Hydraulic aspects" segment is to filter out impassable concepts at an early stage. Each concept should be able to properly handle the design flood while staying within the limits of allowable discharge to recipient and CS. If the limits are exceeded or stormwater is left unmanaged, the corresponding cells of the "Physical parameters" segment light up in the color red. The concepts failing the requirements can then be discarded, and one can avoid spending resources exploring and inapt concept in the early planning stages.

The next sheet of the document, "Weighting of categories", is, as the name implies, where the weight of each category is set. This only affects the diagram showing the overall score of each concept. The weight distribution among the nine categories is displayed in a cake diagram on the sheet. There are four more sheets in the document: "Lists", "Step calculations", "Normalization", and "Score calculation". These are not intended to be changed in any way by a user and only serve the purpose of separating the calculation from the sheets the user interacts with and maintaining order and structure in the document. The processes of these sheets are explained in appendix A.

3.2 Selection of criteria

As described in Chapter 3.1, the idea of labeling criteria by a theme with which they are associated, as done by the City of Oslo and Sweco Norge AS (2021), increases the flexibility of the model. As mentioned in Chapter 2.1, the report contains a list of suggested criteria for use in an MCA method. The criteria and criteria categories used in their report constitute a good starting point for the structure and assortment of criteria and are used as such in this study. However, some of the criteria suggested in their report overlap or fit thematically better within other categories for the purpose of this study. Some criteria will be disregarded due to requiring more detailed information of the SWM concepts than what can be expected at the early planning stage the method is intended for, and some for being irrelevant. In the case of some categories, additional criteria will be included where a more nuanced evaluation of the multifaceted properties of SWM systems is necessary.

The method builds upon the categories presented by the City of Oslo and Sweco Norge AS (2021), shown in the list below. In the following sub-chapters, the selected criteria and their category placement will be explained and accounted for.

- Hydraulic aspects
- Multifunctionality
- Surface area requirements
- Subsurface infrastructure
- Safety and accessibility
- Operation and maintenance
- Suitability to winter condition
- Soil conditions
- Environment and biodiversity

3.2.1 Hydraulic aspects

Considerations brought to light in the data-sheets accompanying *Structures in integrated stormwater systems* (City of Oslo and Sweco Norge AS, 2021) regarding each individual SWM structure revolve around aspects such as the structure's aptness for stormwater conveyance, throttling of outlet, necessary capacity, dimensioning to accommodate future needs, slope, roughness, and size. The structure should provide safe diversion of stormwater and have adequate erosion control. The SWM system must be adapted to the capacity of the recipient. Ideally, a comparison between SWM concepts would be made on the basis of hydraulic simulations.

Acquiring sufficiently detailed data to perform a simulation or on hydraulic parameters such as those mentioned above for usage in a decision-making model for the early planning stage the MCA is intended for is difficult and almost paradoxical. If this information was available, one would normally be past the stage where a comparison between concepts is necessary. Therefore, one will have to make do with what limited information is available.

Without hydraulic modeling, little can be said about the real-world performance of the SWM concepts. Yet, the concepts can be compared in simple terms.

The SWM system should drain the site effectively. That is to say, the water should be drained from the site within a sufficient time frame so that the efficiency of the system to handle subsequent rainfall events is not reduced. It is important to take into account the time it will take for the stormwater to drain through the system. Considerations suggested by CIRIA (2012, p. 43) in this regard are: (the following list is a direct quote)

- the impact of potential downstream constraints (e.g., high water levels in the receiving watercourse) on the rate and/or duration over which the effective drainage can occur

- the rate at which infiltration is likely to occur, which will determine the time taken for infiltration storage components to empty for any particular event
- the hydraulic gradient across the site and the design of storage and conveyance components, which will determine the time taken for runoff to drain through the SuDS (sustainable drainage system)

It is crucial to gauge the capacity of the recipient during a powerful downpour and flooding event and constrain the discharge from the site accordingly so that the water level of the recipient does not exceed tolerable levels. The likelihood of this occurring should be included in the design process (CIRIA, 2012, p. 43). The recipient can be a water body like a stream, river, lake, ocean, or sewer system. It is important with a risk assessment of the possibility of parts of the SWM system being flooded from external sources and other neighboring areas during torrential rain when planning the system.

As mentioned above, the City of Oslo (2021) points out that SWM systems must be dimensioned with future stormwater amounts in mind. This is particularly important for stormwater pipes and subsurface SW systems as expanding their capacity after the fact is more challenging than compared to a surface system. Surface systems are inherently more adaptable than subsurface drainage infrastructure. This adaptability makes it possible to increase the system's capacity as better climate change models become available, or if, for other reasons, a higher level of service becomes necessary (CIRIA, 2012, p. 44). One such reason is the urban creep, as mentioned in Chapter 1.

The criteria chosen for the category of "hydraulic aspects" based on the points raised above are:

1. **The SWM system is capable of effectively draining the site**
2. **The SWM system is adapted to the capacity and conditions of the recipient**
3. **The SWM system is adaptable to increasing service demands**

Four additional performance parameters are used in the MCA model under the category of "hydraulic aspects". These are based on the following data:

- Rainfall duration
- Total stormwater volume entering SWM system
- Stormwater detention capacity
- Stormwater diversion capacity
- Total surface area of SWM system
- Total length of SWM system

From these values, efficiency parameters are calculated through simple division: 1) detention capacity per area; 2) detention capacity per length; 3) stormwater diversion capacity per area; and 4) stormwater capacity per length. These parameters are then normalized so they can be compared between concepts. Otherwise, they would not conform to the rating and evaluation system used for the other criteria of the model. The input parameters are initially inextricably linked to quantifiable performance data of the concept and site, i.e., they are not dimensionless estimates made by a user on an arbitrary linguistic scale. As such, the criteria need to be made dimensionless through normalization to be used in the model. A basis for comparison could optionally be achieved by comparing the performance numbers to a scale containing an ideal and anti-ideal, such as in the case of TOPSIS, which would give better data on the concepts' hydraulic performance than normalization. However, such a performance scale would require more information on the site as well as the requirements and potential for SWM in the area.

Information regarding the hydraulic performance will naturally be quite imprecise if no hydraulic modeling of the concepts is at hand prior to the comparison. Then again, the comparison of their performance against these criteria is on a comparative scale consisting of seven intervals ranging from "very poor" to "very good". The evaluation can be loosely based on rough estimates and standard values for the SW structures comprising the concepts.

3.2.2 Multifunctionality

The report by the City of Oslo and Sweco Norge AS (2021) condenses all aspects of "multifunctionality" down to one single criterion, namely, "the SWM system is suitable for multifunctional purposes". The multifunctional applications of an SWM system cover a broad spectrum. Furthermore, some of these functions might be of greater importance than others. Considering all of these aspects under a single criterion might result in a somewhat imprecise portrayal of the concepts' multifunctionality.

Multifunctionality is a broad term. If any other functionality other than the SWM system's primary function, the safe detention and conveyance of stormwater, is said to be an instance of multifunctionality, there is a risk of overlapping criteria between the category of "multifunctionality" and the category of "environment and biodiversity". This can lead to an overrepresentation of some criteria in the MCA. This is best to be avoided. One option is to merge the categories of "multifunctionality" and "environment and biodiversity". On the other hand, the way the structure of the MCA tool is designed allows for uneven weighting of categories. If there exists a basis for a distinction between what can be argued to fall within the spectrum of "environment and biodiversity" and that of "multifunctionality", a user may wish to do so.

To exemplify this dilemma, Meerow and Newell (2017) and Kim and Song (2019) has done studies on the multifunctionalities of green infrastructure (GI) in communities, the benefits of which were divided into groups concerning cultural and regulating aspects in the former study and economic, socio-cultural and ecological aspects in the latter. The factors presented in these studies are relevant when evaluating the suitability of an SWM system, and they are, in their respective articles, discussed in the context of multifunctionality. However, these factors also strongly pertain thematically to what falls within the scope of “environment and biodiversity”.

In this study, “multifunctionality” will focus on the attributes of the SWM, the area it occupies, and the surrounding area appertaining to it that allows for people to partake in recreational activities and other functions that are of direct use to people. Many of the additional functions of SW structures that fall within the realm of “environment and biodiversity” are of a more passive nature. The benefits are still present whether or not people actively engage with it. These will be treated solely as environmental factors under the category “Environment and biodiversity” in Chapter 3.2.9.

Multifunctional solutions are always viable and cost-effective. This is particularly important in a dense, urban environment (CIRIA, 2012). Any secondary functionality in addition to the primary functionality of the SWM system can be described as a multifunctional property. A stormwater pipe, for example, does not serve any other purpose than the safe transportation of stormwater. Therefore, its multifunctional value is low. An underground detention magazine could be said to have some semblance of multifunctionality, as it enables the re-purposing and reuse of stormwater. The withheld stormwater may be used for applications such as watering or ice skating rinks, street-flushing, and other municipal tasks, or the area above ground can be used as, for example, a parking lot, pedestrian zone, or plaza. A flooding area, on the other hand, could serve other purposes when not flooded. A flooding area could be a soccer field, skatepark, a natural or constructed recess in the ground, or a pond with a large capacity, just to name a few. Its inundation frequency and the drainage and recovery speed will affect how suitable it is for other functions. Floodpaths (normally dry) are similar to flooding areas from the perspective of multifunctionality in that they occupy an area that normally serves a different purpose. Constructed floodpaths in stream/channel are normally part of a recreational area or trail and are somewhat multifunctional in that regard (City of Oslo and Sweco Norge AS, 2021).

GI such as floodpaths and flooding areas has the potential to be integrated into park environments which can provide recreational value for local communities. This is a multifunctional value that should be sought wherever possible. CIRIA (2012) points out that “larger open water and wetland areas can provide a focus for footpaths and trails, providing attractive areas for walkers, cyclists, and joggers, with access to water at appropriate locations." They also point out that "Water and play go well together." In addition to the great recreational value it provides for both children, adults, as well as pets, green areas with access to water constitute a good learning arena for children. Water areas such as these include but are not limited to shallow pools, artificial channels or properly secured natural ones, and chutes. Some of these will only carry water during rainfall. Kim and Song (2019) point to similar findings:

> "GI empowers residents to manage resources by themselves so they can improve the environment, which leads to an adaptive learning process where people can acquire knowledge to maximize ecosystem services. This induces resident participation, which strengthens the network, promotes a sense of attachment to a location and social cohesiveness, and creates regional harmony." (Kim and Song, 2019).

The criteria selected for the category of "multifunctionality" are:

1. **The stormwater can be reused**
2. **The area of- and the surrounding area appertaining to the SW structure provides accessible recreational value**
3. **The system and its associated area can be used for municipal tasks and activities**

The usage of both the stormwater and the area associated with the SW structure may differ throughout the seasons. Watering and street flushing, picnics, and ball games may be relevant during spring to autumn, while maintaining ice skating rinks and snow deposits may be a more relevant use during wintertime. This is important to keep in mind when comparing concepts against these criteria.

Data regarding the potential for "multifunctionality" can be gathered from the type of SW structures in the concept, as shown in the first paragraph of this section. To see how this can interact with the planned construction site, performing site inspections in person is a good lead. A major point is to communicate with stakeholders in the area. Green and sustainable solutions are often promoted for their multifunctionality and benefits in multiple areas. Regardless, when decisions are made regarding what and where to build, there is a tendency towards a particular benefit outweighing others, and some functions and benefits being undervalued or disregarded. This is partly due to a lack of involvement of stakeholders and residents of the connected area (Meerow and Newell, 2017; Kim and Song, 2019). Involving stakeholders and policymakers early in the process may inform them and help shed light on what use an SWM structure might see once realized, as well as what existing structures might be suited for retrofitting from the perspective of multifunctionality. Maps provided by the municipal office can show where components of drainage systems lie beneath the ground. Areas with drainage systems below hold potential for multifunctional value as detention systems may be constructed above ground with drainage to the systems beneath, or areas consisting of permeable material such as a permeable parking lot or recreational areas can be constructed above a subsurface attenuation system.

3.2.3 Surface area requirements

In a cramped urban environment, land is a precious commodity, and it should be used efficiently. This applies to SWM as well. The size of the SWM system is largely governed by the size of the design flood. The design flood poses a minimum requirement to the capacity of the SWM system, which in the case of a flash flood is mainly determined by the dimensioning of the system as factors such as infiltration can be neglected due to the relatively short time span of the event.

However, in terms of occupied land area, other factors come into play. In the case of stormwater pipes and underground retention magazines, no surface area is occupied by said structure, as both are placed below ground. Above-ground flooding areas require large surface areas, although they can be integrated into existing or new structures, in which case no surface area needs to be designated solely for the purpose of stormwater retention. Floodpaths (normally dry) are similar in the sense that the area they occupy normally serves another purpose. Thus, they are quite space-efficient. Floodpaths in stream/channel, on the other hand, are quite area intensive. The total required area is larger than that of the stream itself. The channel will need safeguarding against erosion which puts limits on the side slopes of the channel (Lindholm and Endresen, 2016). Compared to a normally dry floodpath, the area of a floodpath in stream/channel has no shared direct use. (City of Oslo and Sweco Norge AS, 2021)

The depth of the structure is another point of consideration. Floodpaths need a certain cross-sectional area for a given slope to reach the flow necessary for the design flood. For a trapezoidal cross-section, which is the most common design, the cross-sectional area is given as: $A = B + my^2$, where B is the width along the bottom of the channel, y is the depth of the channel, and m expresses the side slope. The top width of the channel is expressed as: $T = B + 2my$. If the cross-sectional area is to remain the same, a decrease in depth must be met with an increase in bottom width, thereby also an increase in top width and in the total surface area of the channel. The depth may put restriction on the situating of a structure, as it may collide with subsurface infrastructure.

The criteria chosen for the category of “surface area requirements” are:

1. **The SWM system requires little surface area**
2. **The SWM system requires little depth**

The area requirements of a project are relevant for socioeconomic considerations, which are usually assessed at an earlier planning stage than where the MCA method proposed in this study becomes relevant. Therefore, data on the area requirements of the different concepts to be compared may already be available. Going back to the relation of surface area and depth, knowing the area and the design flood gives an indication as to the required depth of the channel. This information should also be available for underground detention volumes.

3.2.4 Subsurface infrastructure

The criteria chosen for the category of "subsurface infrastructure" will be presented first, followed by their explanation and reasoning. The criteria are presented in the list below:

1. **The SWM system can easily be integrated into the development plan for the area**
2. **The SWM system is part of a multifunctional SWM solution**
3. **The SWM system is part of a comprehensive SWM solution**
4. **The SWM system can be placed above subsurface infrastructure**

In an area development scenario, as the planning phase progresses and the concern for SWM is set aside, the possibilities for an ideal integration of SWM diminish. Past a certain point, an ideal solution may no longer exist among the remaining options. However, if a plan for SWM is developed in unison with other development plans for a project site, a far greater selection of options is available (Paus, 2020). This counts positively toward an SWM concept's feasibility and potential performance. This is the focus of criterion number 1). Criterion 2), with respect to subsurface infrastructure, focuses on the SWM system's degree of interaction with existing subsurface drainage systems. As explained in 3.2.2, this is positive from the perspective of multifunctionality. Criterion 3) draws lines to the main delivery T4, mentioned in Chapter 2.1: "The main delivery of T4 is a principle map-based strategy for a comprehensive SWM system centered around the aforementioned SWM structures." The criterion asks to what extent the SWM concept adheres to this vision and to what extent the SWM concept is part of a larger and more extensive plan for the improvement of a community's resilience against urban flooding.

Not all SWM structures can be placed above underground infrastructure. This is the focus of Criterion 4). The depth of the structure is a major concern, as mentioned in Chapter 3.2.3, but also the existing and planned degree of utilization of the ground. It is important to be mindful of existing subsurface infrastructure as well as practice good coordination with ongoing construction projects.

Information regarding the first three criteria can be gathered from project development plans for the SWM project and connecting projects. The municipal office and other official bodies have maps of subsurface infrastructure.

3.2.5 Safety and accessibility

The criteria chosen for the category of “safety and accessibility” will be presented first, followed by their explanation and reasoning. The criteria are presented in the list below:

1. **It is safe for those living near or visiting the system and for those involved in its operation and maintenance**
2. **Accessibility is convenient**
3. **There is little risk of drowning**
4. **The stormwater system does not obstruct line of sight**

There are regulations and legislation concerning health, safety and accessibility, and the design of the SWM system must adhere to these. Among them are TEK17 (Direktoratet for Byggkvalitet, 2021) and the Street Norm for Oslo (Bymiljøetaten, 2020). However, as addressed by CIRIA (2012, p. 760), it is important to balance risks and benefits. Out of a mix of misunderstanding and fear of liability or prosecution, a duty holder may adopt an overly paternalistic approach to the design of the SWM structure at the expense of the leisure of the user. GI may have reduced yields with regards to recreational and multifunctional values as a direct consequence of more than necessary focus and attention being directed towards health and safety aspects. An abatement to this is a balanced risk assessment. Risk assessment is not a focus of this study, but having conducted a site-specific risk assessment will prove a good data basis for the evaluation of the criteria presented in this section.

Criterion 1) is derived from CIRIA (2012, p. 35). The wording of this criterion encourages the consideration of the structure’s safety from the perspective of someone engaging with it on a daily basis as well as maintenance personnel. Injuries can result from falls, slips, and entrapment due to slippery freeboards and banks, steep side slopes or vertical drops, poor condition of pathways next to water, or lack of safety grilles CIRIA (2012, pp. 765, 766). Steep or slippery slopes can also make maintenance work more difficult. Fouling of recreational water bodies is also a health and safety concern. Stormwater overflow may carry harmful substances and pathogens to a recipient. This might increase the public health risk.

Criterion 2) focuses not as much on the safety of the SWM structure as it does on the convenience of accessibility. A long, impassable swale or canal with no crossing is an example of poor accessibility. Accessibility should not be unreasonably impeded by the SWM system. In general, poor accessibility is a design that limits or hinders the mobility of individuals or services. “Oslo Street Norm” describes accessibility as follows (Bymiljøetaten, 2020, p. 43):

> “Accessibility involves a product or service which ensures useability, preferably without assistance. This implies the presence of alternatives to the primary solution, specifically adapted to people with functional impairment.”

During design, one needs to take into consideration special requirements for accessibility such as lowered curbs, access for emergency vehicles, disabled parking, winter gritting machines, and sweeping machines, just to name a few. On the other hand, during a powerful downpour, it can become necessary to physically block access to flooding areas as it can become a hazardous zone.

Drowning can occur wherever there is a water body. These can be permanent bodies of water or normally dry ones who hold water temporarily during or after a rainfall event, including swales/channels. CIRIA (2012, p. 761) points out that “drowning more frequently occurs from accidentally falling in rather than by deliberately accessing a water body and then getting into difficulty”. Such accidents are more likely to occur during nighttime when visibility is poor and in the case of young children and for people under the effect of alcohol or drugs. The design of the SWM structure should actively prevent such accidents. Design features that further exacerbate the risk of drowning are steep banks and side slopes, slippery surfaces, water-edge silt, and/or overhanging branches (CIRIA, 2012, p. 761). The risk of drowning increases with the velocity of the water and rapid inundation and rise in water levels. Martínez-Gomariz et al. (2016) has performed a study on the stability of pedestrians exposed to urban pluvial flooding. The stability threshold for all the instability points assessed in the study is given by the product $(y \times v) = 0.22\ m^2 s^{-1}$ for low depth and high-velocity conditions, which is most common for urban pluvial flooding. Their research suggests that if the product of water depth and water velocity exceeds $0.22\ m^2 s^{-1}$, the stability, and by extension, safety, of pedestrians is at risk. Low water levels in ponds and additionally velocities in open channels and swales will always reduce the safety hazard. However, the water level is never constant. It is important to be aware of the water level changing from normal conditions to that of a flood event.

Good visibility is important for SWM structures with open bodies of water. Vegetation and even structures to prevent people’s access can potentially obstruct line of sight, making it difficult to spot if someone moves past and finds themselves in need of help. Traffic also requires good visibility and an unobstructed line of sight. Vegetation next to roads should not obstruct the vision and line of sight of drivers.

A proper evaluation of accessibility and safety requires a certain level of detail from the concepts being evaluated. The available space and dimension need of a retention pond or open channel or stream can give some indication as to the depth and side slopes. As mentioned in the opening paragraph of this section, a site-specific risk assessment is a good data basis for comparison of the concepts with regards to potential health hazards. The design features of the concept can give a good indication of the concept's impact on accessibility.

3.2.6 Operation and maintenance

A distinction can be made between above-ground SWM systems and subsurface SWM systems. The operation and maintenance of above-ground facilities need to consider the landscape's broader context and amenity. In the case of ponds, streams, and swales, the labor associated with maintenance may exceed that of ensuring the required hydraulic performance. Operation and maintenance of subsurface SW systems will generally require engineering. A simple design will generally be less labor-intensive in terms of operation and maintenance, and many errors and faults can be detected in systems on the surface. However, remediating more complex systems such as bioretention ponds or systems with permeable surfaces may require more skill and knowledge. Regardless of whether it be overland or subsurface, the system should be understood by the maintenance personnel. (CIRIA, 2012, p. 691)

Flooding areas will require a minimum of maintenance work. They will be used in the context of SWM only during a strong downpour. In the aftermath of a pluvial flood, removal of debris may be necessary. If the area drains to stormwater pipes, the entry must be kept clear and prevented from clogging. Sand traps will also need cleaning. Retention magazines should be subjected to yearly inspections. Even though a retention magazine will need a sand trap at the inlet side, it may still be necessary to clean the retention magazine. These are tasks require that special equipment and must be performed by qualified personnel. Floodpaths (normally dry) require little maintenance or expertise. Operational tasks include removal of debris, lawn-mowing (if applicable), weed removal, repairs of potential damages to erosion control after a flood, maintenance during winter, and inspection of drains and inlets. Floodpaths in stream/channel are also quite low maintenance. Debris and finer particles can be carried by the stream to a recipient. Although the maintenance of stormwater pipes requires special expertise, it is seldom needed. The combined balance of frequency of maintenance and the required level of expertise is favorable (City of Oslo and Sweco Norge AS, 2021).

The criteria chosen for the category of “Operation and maintenance” based on the points raised above are:

1. **The SWM system has a low maintenance frequency around the year**
2. **Commonplace operation and maintenance is brief and not time-consuming**
3. **There is little need for clearing leaves, garbage, sediments, or other similar obstructive elements**

4. **Operation and maintenance does not depend greatly on the competence of specialists or access to special tools**
5. **The SWM system does not require watering**

3.2.7 Suitability to winter conditions

A cold climate with sub-zero conditions, snow, and ice formation brings its own set of challenges. It is essential that SWM systems are designed in such a way that they perform satisfactorily in these conditions. Ice and snow can potentially cover and block drains, inlets, and outlets. This may slow the effectiveness of underground retention magazines and stormwater pipes and prevent other drainage systems from functioning properly. However, ice will not form within the pipes when placed at sufficient depth or insulated. Ice does not pose a major impediment to the effectiveness of normally dry floodpaths; on the contrary, the smooth surface of the ice can increase the velocity of the water. Floodpaths in stream/channel might experience ice formation if the inflow is low, which can reduce the capacity. Streams/channels should be dimensioned with this in mind and fitted with floodplains to accommodate elevated water levels as not to cause damage to the surroundings during heavy rainfall. During wintertime, compacted snow may form in normally dry floodpaths. This can act as a blockage causing water to flow into the surrounding areas. This compacted snow should be cleared to secure proper functionality during wintertime. (City of Oslo and Sweco Norge AS, 2021)

Salt is not expected to affect the operation and efficiency of any of the five SWM structures themselves. However, road salt may lead to unwanted effects on the environment. Road salt and elevated chloride levels can have adverse impacts on the health of vegetation receiving the winter runoff (CIRIA, 2012, p. 152). The effects of road salt are not limited to the immediate surroundings of the SWM structure in question either but can have a negative, long-lasting impact on a wider area. "Consequences of historical salt applications have yet to reach their maximum and actions taken now to reduce salt contamination may not appear to be effective for several years to decades" (Findlay and Kelly, 2011). Field inspections can reveal runoff patterns from roads, and attempts can be made to direct it away from vegetated zones.

To discern whether or not an SWM structure or its associated area is suited to be used as a snow dump, a case-by-case evaluation may be necessary. Naturally, floodpaths and stormwater pipes are ill-suited for this purpose, as well as stormwater magazines being underground. Overland flooding areas may potentially serve as snow dumps if the area sees no other prioritized usage during wintertime and if its detention potential is not consequentially reduced by an unsafe margin. While snow can be beneficial to vegetation by acting as an insulation cover and protect against repeated thawing and freezing, the weight of too much snow may damage plant structures (Hughes and Bland Landscaping Co., 2021). Areas like retention ponds, swales, or other vegetated zones may sustain damage if used as a snow dump.

Winter conditions may equally cause damage to other SWM structures through the eroding effects of repeated freezing and thawing, such as congelifraction, frost weathering, frost wedging, and thermal expansion and contraction, which can be a legitimate concern. However, in this study, it is considered a prerequisite that the user would not knowingly select SWM structures that could sustain damage from snow alone. Information regarding the structures' resilience towards winter- and sub-zero conditions should be provided by the construction material supplier or contractor.

The criteria chosen for the category of "suitability to winter conditions" are:

1. **The SWM system works as intended during sub-zero conditions**
2. **The SWM system is not affected by road salt**
3. **The SWM system can be used as a snow dump**
4. **The SWM system can remain functional without the need for snow shoveling or plowing**
5. **The SWM system can withstand and remain operational through repeated freezing and thawing**

3.2.8 Soil conditions

Soil conditions affect every SWM structure, from the choice of system to construction and performance. Natural streams and floodpaths are in constant contact with the groundwater. If the groundwater decreases, so will the water in the stream. This is true for natural ponds as well. Underground detention magazines which employ infiltration are also affected by the groundwater level. In the planning work of a detention magazine, one must account for the possibility of groundwater permeating upwards through the ground and filling the chamber and weigh the decision of whether the use of infiltration is wise or not. In all cases with infiltration and contact with groundwater, contaminated soil is a concern. The water may mobilize pollutants and thereby pollute the groundwater (CIRIA, 2012, p. 62). Where the groundwater table is higher than the SWM structure, contaminated water may enter the SWM system. This could, for example, be a detention volume that uses the water for other purposes.

Detention areas and magazines must at some point be emptied in order to accommodate the next flood. This can be done through infiltration, drainage to municipal stormwater pipes, through usage for other purposes (e.g., watering), or a combination. Drainage can become necessary if the other means of discharge are inefficient or if the ground is contaminated.

Bedrock is disadvantageous from the aspect of construction and infiltration. Loose soil provides better conditions for infiltration and much easier working conditions.

Apart from stormwater pipes, the remaining four SWM structures can all utilize infiltration as a core functionality of their operation. Retention areas and magazines can be built around vacating their retained stormwater volume through infiltration and floodpaths, both normally dry, and those in streams/channel can be constructed with infiltration and flood diversion in mind. This requires adequate soil conditions.

The criteria chosen for the category of "soil conditions" are:

1. **The SWM system is not affected by groundwater level**
2. **Drainage of the SWM system is unnecessary**
3. **The infiltration capacity is adequate**
4. **The construction area consists of soils as opposed to bedrock**

Various sources may be necessary in order to properly evaluate these criteria. Soil maps can give an indication as to the general conditions of an area. NGU, Norway's central institution for bedrock, mineral resources, loose materials, and groundwater, provides various publicly available maps that are helpful in determining the soil conditions affecting an SWM system. Infiltration capacity, however, may vary locally, and site-specific tests may be necessary. A number of factors determine the infiltration capacity of the soil, some of which are listed below (Paus, 2020):

1. Type of soil, grain size distribution, porosity, aggregation, and structure
2. Biological activity and organic matter
3. Saturation level and distance to groundwater
4. Intensity and duration of rainfall event
5. Temperature
6. The slope of the terrain

There are various methods one can utilize to estimate the infiltration capacity of the soil. By performing a grain size distribution test, one can estimate the saturated hydraulic conductivity of the soil through Hazen's empirical formula (Weight, 2008, pp. 107, 108).

Gustafson's method is another similar empirical method that estimates saturated hydraulic conductivity from a grain distribution curve. These tests, however, are empirical and disregard most of the factors from the list above. For more precise data on the infiltration capacity for a given site, site surveys with infiltrometers may be necessary, of which there are a variety of methods available. Some of the more common infiltrometers are the Modified Philip-Dunne infiltrometer, double-ring infiltrometer, and the Mariotte infiltrometer (Solheim, 2017).

3.2.9 Environment and biodiversity

By weaving natural SWM systems such as swales, streams, parks and wetlands, and other GI outside of the five principle SW facilities of this study into the urban landscape, one can achieve not only better SWM, but also a number of other benefits. The United States Environmental Protection Agency (2017) states that GI can provide “a number of other environmental, social and economic benefits not typically provided by gray infrastructure”.

> “Green infrastructure increases exposure to the natural environment, reduces exposure to harmful substances and conditions, provides opportunity for recreation and physical activity, improves safety, promotes community identity and a sense of well-being, and provides economic benefits at both the community and household level.” (United States Environmental Protection Agency, 2017)

These benefits have a clear impact on public health. A study conducted by Stratus Consulting in 2009 for the City of Philadelphia Water Department found that “increased tree canopy can reduce ozone and particulate pollution enough to significantly reduce hospital admissions, lost work days, and mortality” (United States Environmental Protection Agency, 2017; Stratus Consulting, 2009). The findings of a health assessment conducted by the United States Environmental Protection Agency for a green street project in the city of Atlanta, Georgia, led to the green street in question being extended further to maximize the associated public health benefits (United States Environmental Protection Agency, 2017, 2015). The impact of GI on public health in an urban environment should not be understated. United States Environmental Protection Agency (2017) covers the extensive benefits of GI on both public health and the environment in much greater detail.

GI benefits the environment as well. As pointed out by the City of Oslo and Sweco Norge AS (2021), it enriches biodiversity by providing habitats hospitable to plants and vegetation, insects, and animals. GI can purify stormwater through infiltration and other natural processes. This is a feature inherent to GI by design, as it typically in an urban landscape will replace otherwise impervious surfaces. The effectiveness of the natural purification process is dependent on many factors, such as the amount of stormwater, soil conditions, biological activity, litter, and temperature.

Meerow and Newell (2017) have developed a method for identifying hotspots in a city landscape where GI is needed the most, taking into account the multifunctionality (not to be confused with the criterion “multifunctionality”) of GI. Multifunctionality is a very broad term that Meerow and Newell describe as encompassing a suite of socioeconomic, ecological and environmental benefits, much like the categorization of associated benefits by United States Environmental Protection Agency (2017). Besides stormwater abatement, their method considers five additional benefits of GI:

1. Improved air quality: Air quality is improved by vegetation as it reduces nitrogen dioxide, aerosols, and ozone levels.
2. Urban heat island mitigation: Canopies shade buildings and the ground, and evapotranspiration from trees and undergrowth vegetation cools the air. The urban heat island effect is projected to more severely affect the public's health with climate change (Stone Jr, 2012).
3. Improved communities and reduced social vulnerability: Vegetation improves people's mental and physical health and decreases their social vulnerability (Western Australia Department of Water and Environmental Regulation, 2017; Meerow and Newell, 2017). Meerow and Newell present a list of such positive benefits, which includes lower crime rates (Kuo and Sullivan, 2001); increased feelings of social safety (Maas et al., 2009a); better health (Kardan et al., 2015); better mental health (Alcock et al., 2014) and reduced stress (Ward Thompson et al., 2012) and increased social capital (Maas et al., 2009b; Rung et al., 2011).
4. Greater access to green space: The placement of green areas is of importance not only to achieve the greatest effect of flood mitigation; it is also deciding factor in to whom it will be accessible and effectively who will benefit from the other advantages it provides, such as the ones presented in this list.
5. Increased landscape connectivity: In an urbanized landscape, patches of green areas often become fragmented and are separated from one another. Conjoined and contiguous green areas provide benefits to, among other things, biodiversity (Kong et al., 2010; Meerow and Newell, 2017; CIRIA, 2012).

Based on the points raised above, the criteria chosen for the category of "environment and biodiversity" are:

1. **The SWM system enriches biodiversity**
2. **The SWM system purifies the stormwater**
3. **The SWM system improves air quality**
4. **The SWM system mitigates the urban heat island effect**
5. **The SWM system improves communities and reduced social vulnerability**
6. **The SWM system provides greater access to green space**
7. **The SWM system increases landscape connectivity**

Naturally, SWM concepts with elements of vegetation will outshine those without when evaluated against the criteria of "environment and biodiversity". Out of the five SWM systems used in T4 (ref. fig. 2.1), floodpaths (normally dry and in stream/channel) and overland flooding area has the potential to score high marks in this regard, as they can be part of a larger park system and green areas. Underground retention magazines have the potential to provide infiltration and a cleansing effect on the stormwater, as well as being used for watering or other purposes.

Surveys of the project site should be conducted to evaluate the possibilities for channels, streams, swales, ponds, and park facilities and for the planting of trees, shrubs, and other vegetation, or construction of park facilities. City maps and ground surveys can reveal suitable locations for siting these facilities.

3.3 Case study

3.3.1 Case area

The location of the case area is south of "Torshovdalen" in the Norwegian capital Oslo. The approximate location of the case area is shown in Figure 3.3. Under project T4, most of the catchment area of "Akerselva" was subdivided into sub-catchments. The borders of the sub-catchments were placed based on results from hydraulic modeling with 1D/2D MIKE FLOOD. In the model, the maximum area of sub-catchments was set to 1 km^2 for it to be possible to design SWM solutions at a later stage. Two zones, AKT2 and AKT3, were selected for a pilot study within T4 due to repeating stormwater damages in AKT2 caused by surface runoff from AKT3. The blue line in Figure 3.3 marks a segment of the border between these two zones. It is around 170 m in length and runs in parallel to "Chr. Michelsens vei" right in front of an underpass connecting the upstream and downstream zones. Results from the aforementioned hydraulic simulations on the movement of stormwater across the border of these two zones are shown in Table C.2 under appendix C.

3.3.2 Concepts

By devising a set of concepts intended to ameliorate the situation in the case area, the MCA method can simultaneously be tested. However, the primary purpose of the case study is the trial of the MCA method and not to provide grounds for the selection of any one particular concept. As mentioned in Chapter 1.1, these concepts are purely hypotheticals meant to demonstrate the use of the MCA method. Therefore, the concepts will be designed with clear distinctions from one another. Each concept will focus on a particular vision. Concept 1 will focus on recreating natural environments with bioswales, ponds, and green infrastructure and bolstering biodiversity. Concept 2 will focus on the reuse of stormwater; concept 3) will focus on the delayed discharge of stormwater to "Akerselva"; concept 4) will focus on providing the shortest path to the recipient, and the focus of concept 5) is the delayed discharge to municipal combined sewer (CS). Physical inspections and surveillance of the area were crucial for the design of the concepts. The author surveyed the case area in person in advance of drafting the concepts and utilized

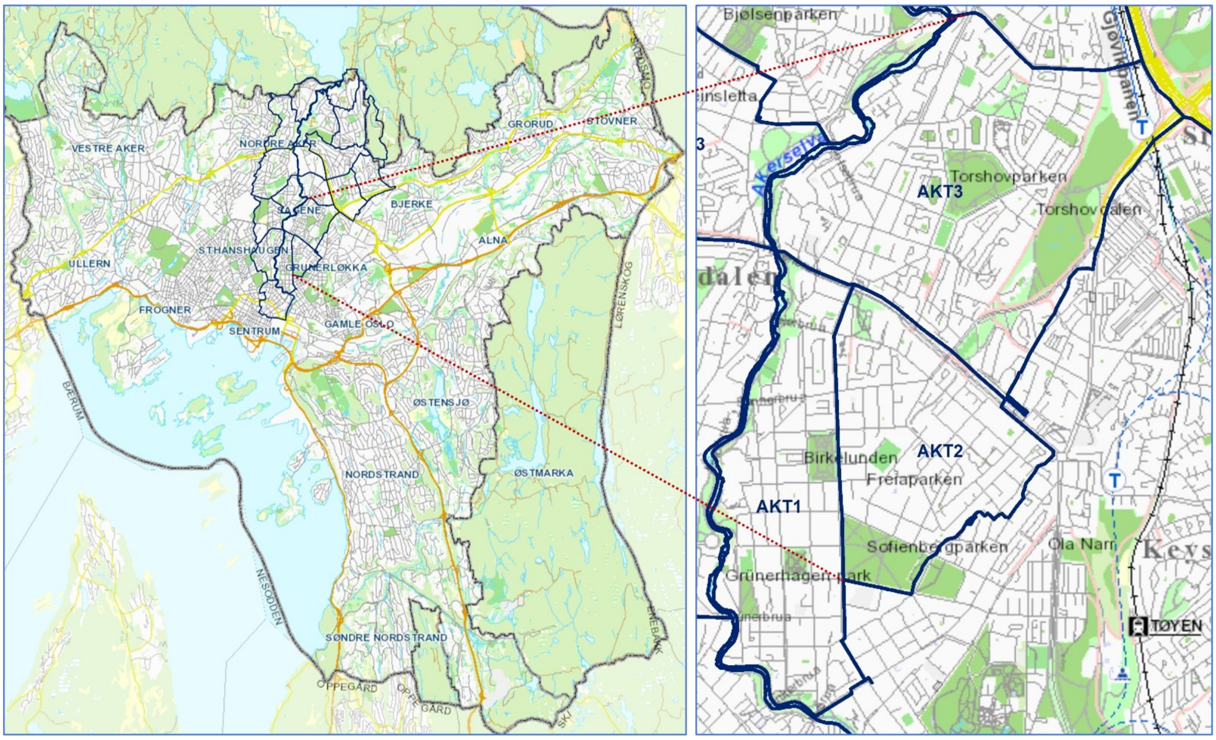


Figure 3.3: The figure shows the location of the case area within Oslo, capital of Norway. The concepts span the zones AKT3, AKT2, and AKT1. The figure is provided by Kvitsjøen and Agency for Water and Wastewater Services, City of Oslo (2021).

the online map services SCALGO Live by SCALGO and Høydedata by Geodata AS to better understand the terrain.

Data sources for the planning of concepts include the data from Table C.2 and Table C.1 under appendix C and surveys of the case area. The online map services SCALGO Live by SCALGO and Høydedata by Geodata AS were also utilized to understand the terrain better. ArcGIS Pro was used to sketch the layout of the concepts (ref. Figure B.1). The concepts are evaluated in line with *Structures in integrated stormwater systems* (City of Oslo and Sweco Norge AS, 2021) and the points raised in Chapter 3.2.

3.4 Trial of MCA

The concepts, outlined in greater detail in Chapter 4.2, are evaluated against the criteria discussed and concluded with in Chapter 3.2, as described in Chapter 3.1. The criteria are also compiled in Table 4.1. The evaluation process is briefly outlined in Chapters D.1, D.2, and D.3 under appendix D. The weights used are detailed in D.4. However, as mentioned in Chapter 1.1, developing a ruleset for assigning weights to the parameters is not a focus of this study, nor is it a priority to develop guidelines for how each criteria should ideally be evaluated.

The data from Table C.2 are used as input parameters under the "Physical parameters" segment of "Hydraulic aspects". Additionally, two limits, maximum discharge to the recipient and maximum drainage to CS, are set as input parameters for this segment. These limits are, in the trial of the MCA, entirely arbitrary. The input parameters are presented in Table 3.1 below. Concepts that fail to satisfy the limits or are unable to manage the design flood, leaving unmanaged stormwater, are unfit solutions and can be disregarded from the rest of the MCA.

Data on the length, area, and retention capacity of the concepts were extracted from the sketches made of the concepts in ArcGIS Pro. The total length of a concept is the sum of the length of pipe segments and that of the channels and swales. The total area of the concepts is the sum of individual zones on the surface (not counting subsurface retention volumes) multiplied with a factor of 0.25, as SWM structures would realistically not occupy every unit of area inside a zone. The resulting area was used as a basis for calculating detention capacity. For this trial, it was assumed that retention/detention volumes would have a depth of 1 m. The detention capacity of the concept was obtained by multiplying its area by 1 m. The retention capacity of subsurface retention/detention volumes was obtained by multiplying its area by 1 m and a factor of 0.8 to adjust for its support structures.

Flood parameters		
Parameter	**Value**	**Unit**
Dimensioning rainfall event	200 CF	year recurrence interval
Rainfall duration	4	hours
Total stormwater volume entering system	4742	m^3
Maximum discharge to recipient	3000	m^3
Maximum drainage to CS	2	m^3/min

Table 3.1: The table shows the input parameters under the "Physical parameters" segment of "Hydraulic aspects" for the trial of the MCA.

3.5 Sensitivity analysis

In order to test the sensitivity of the MCA model, a limited sensitivity analysis is conducted. An MCA was performed three times where preference was given concepts 1 to 3, one at a time. The goal is to emulate the uncertainty and bias a user might have when selecting a concept's score for a given criterion. Every second score of the concept given preference will be increased by one step. If a score is at the maximum and therefore cannot be increased, the next available score is increased instead so that approximately 50% of all scores for the given concept are increased by one step. The starting point of the sensitivity analysis is the results of the trial of the MCA for the case area, i.e., with identical scores and weights.

4. Results

4.1 Criteria

The criteria discussed and concluded with in chapter 3.2 are compiled in Table 4.1 on page 33. These are the criteria used in the MCA method. Each criterion is numbered by category and order. The numbering corresponds with the numbering of the tables under appendix D.1, D.2 and D.3, outlining some key considerations of each concept for the trial of the MCA method.

	Hydraulic aspects
1.1	The SWM system is capable of effectively draining the site
1.2	The SWM system is adapted to the capacity and conditions of the recipient
1.3	The SWM system is adaptable to increasing service demands

	Multifunctionality
2.1	The stormwater can be reused
2.2	The area of- and the surrounding area appertaining to the SW structure provides accessible recreational value
2.3	The system and its associated area can be used for municipal tasks and activities

	Surface area requirements
3.1	The SWM system requires little surface area
3.2	The SWM system requires little depth

Subsurface infrastructure

4.1 The SWM system can easily be integrated into the development plan for the area

4.2 The SWM system is part of a multifunctional SWM solution

4.3 The SWM system is part of a comprehensive SWM solution

4.4 The SWM system can be placed above subsurface infrastructure

Safety and accessibility

5.1 It is safe for those living near or visiting the system and for those involved in its operation and maintenance

5.2 Accessibility is convenient

5.3 There is little risk of drowning

5.4 The stormwater system does not obstruct line of sight

Operation and maintenance

6.1 The SWM system has a low maintenance frequency around the year

6.2 Commonplace operation and maintenance is brief and not time-consuming

6.3 There is little need for clearing leaves, garbage, sediments, or other similar obstructive elements

6.4 Operation and maintenance does not depend greatly on the competence of specialists or access to special tools

6.5 The SWM system does not require watering

Suitability to winter condition

7.1 The SWM system works as intended during sub-zero conditions

7.2 The SWM system is not affected by road salt

7.3 The SWM system can be used as a snow dump

7.4 The SWM system can remain functional without the need for snow shoveling or plowing

7.5 The SWM system can withstand and remain operational through repeated freezing and thawing

	Soil conditions
8.1	The SWM system is not affected by groundwater level
8.2	Drainage of the SWM system is unnecessary
8.3	The infiltration capacity is adequate
8.4	The construction area consists of soils as opposed to bedrock
	Environment and biodiversity
9.1	The SWM system enriches biodiversity
9.2	The SWM system purifies the stormwater
9.3	The SWM system improves air quality
9.4	The SWM system mitigates the urban heat island effect
9.5	The SWM system improves communities and reduced social vulnerability
9.6	The SWM system provides greater access to green space
9.7	The SWM system increases landscape connectivity

Table 4.1: The table lists all criteria selected in chapter 3.2 to be used in the MCA.

4.2 Concepts

The concepts drafted for the case area are presented in this chapter. The concepts are limited to the five primary SWM structures described in *Structures in integrated stormwater systems* (City of Oslo and Sweco Norge AS, 2021) (ref. chap. 2.1 and Figure 2.1), and each concept is focused on its own vision.

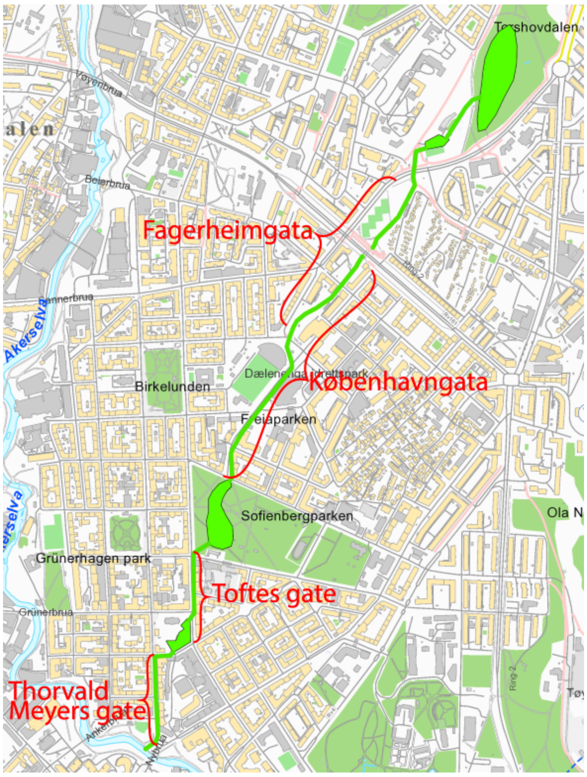


Figure 4.1: Map of concept 1

Concept 1 begins with overland flow and retention in small pond and swales in "Torshovdalen". Due to a depression in the terrain at the exit point of "Torshovdalen", a pipe leads the stormwater to the closest point downstream, where it may maintain a satisfactory slope. Constructed green overland stormwater channels and swales lead the stormwater through part of the pedestrian zone between "Fagerheimgata" and "Københavngata", connecting to the upstream stormwater pipe. Constructed overland stormwater channel or swales run along "Københavngata" towards "Sofienbergparken". The swale may connect to watering systems for existing and new trees and other vegetation. Swales following the natural topography of "Sofienbergparken" directs the stormwater to retention ponds in the park. These ponds may at times run dry, as reopening the previously closed stream is not an option. Stormwater is conveyed from "Sofienbergparken" to "Akerselva" in constructed channels along "Toftes gate" and "Thorvald Meyers gate".

In concept 2, the stormwater is transported in pipes from the depression in the terrain at the exit point of "Thorsovdalen" and from "Fagerheimgata" to subsurface retention magazines underneath the artificial turf of "Grünerbanen", from where it can be reused for various purposes or be drained to municipal stormwater pipes.

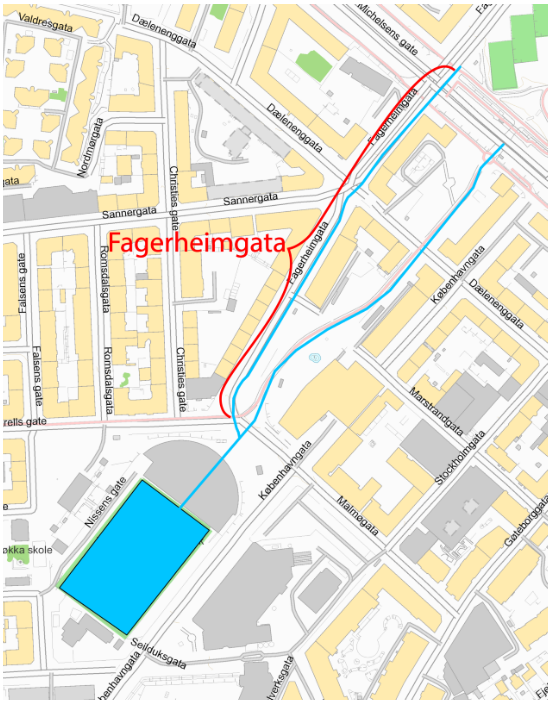


Figure 4.2: Map of concept 2

Concept 3 begins similar to concept 1 with overland flow and retention in small pond and swales in "Torshovdalen". A stormwater pipe starting at the depression by the underpass at the exit point of "Torshovdalen" conveys the stormwater to retention ponds in "Birkelunden" along "Schleppegrells gate". The stormwater can be gradually discharged to "Akerselva" via a stormwater pipe from "Birkelunden" running along "Helgesens gate".

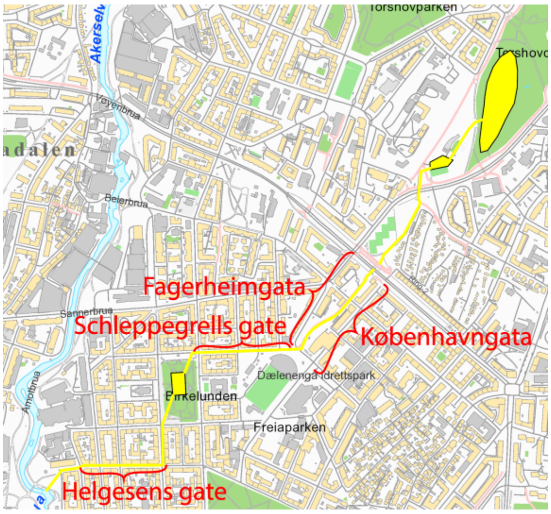


Figure 4.3: Map of concept 3

Concepts 4 and 5 differ from concepts 1 to 3 in that they are intended to be filtered out early in the MCA process and will not be scored in the MCA model. Concept 4 consists of conveying the stormwater to “Akerselva” directly via stormwater pipes along the shortest path down “Sannergata”. Concept 5 consists of facilitating delayed discharge to municipal stormwater pipes through subsurface retention magazines close to the exit of “Torshovdalen”. The retention magazine is placed along the natural flow lines.

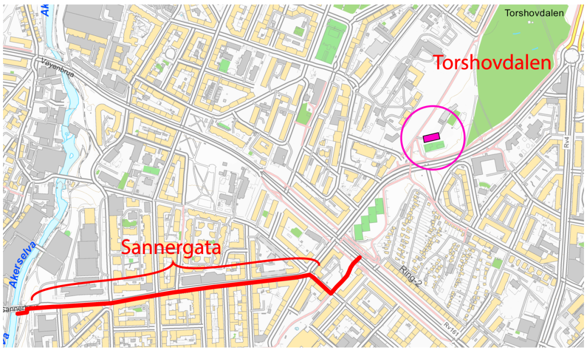
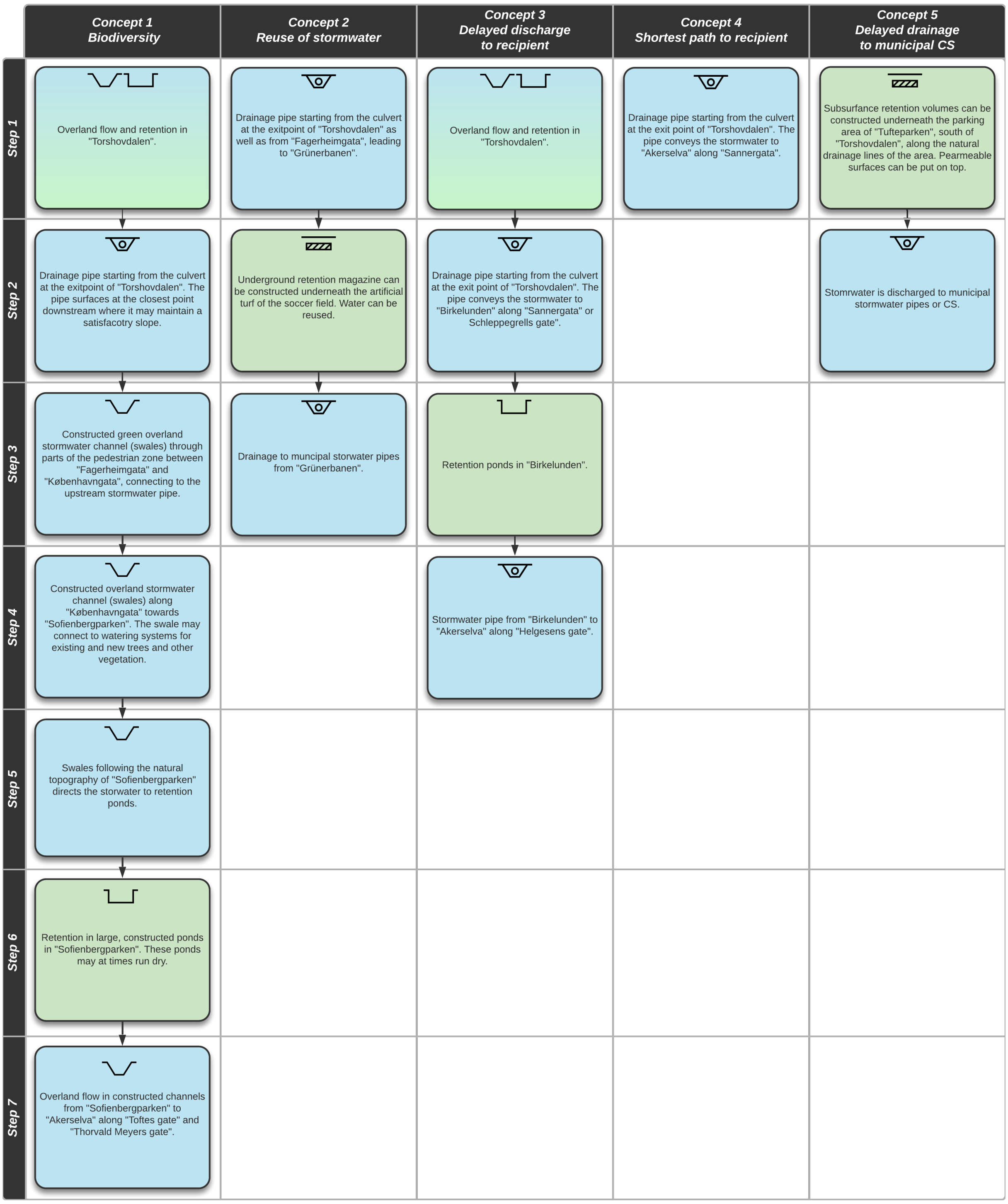


Figure 4.4: Map of concepts 4 and 5. Concept 4 is shown in red, and concept 5 in purple, outlined with a purple circle.

All concepts are described in figure 4.5. The geographical layout of each concept is also illustrated in figure B.1.



	Concept 1 Biodiversity	Concept 2 Reuse of stormwater	Concept 3 Delayed discharge to recipient	Concept 4 Shortest path to recipient	Concept 5 Delayed drainage to municipal CS
Step 1	Overland flow and retention in "Torshovdalen".	Drainage pipe starting from the culvert at the exitpoint of "Torshovdalen" as well as from "Fagerheimgata", leading to "Grünerbanen".	Overland flow and retention in "Torshovdalen".	Drainage pipe starting from the culvert at the exit point of "Torshovdalen". The pipe conveys the stormwater to "Akerselva" along "Sannergata".	Subsurfance retention volumes can be constructed underneath the parking area of "Tufteparken", south of "Torshovdalen", along the natural drainage lines of the area. Pearmeable surfaces can be put on top.
Step 2	Drainage pipe starting from the culvert at the exitpoint of "Torshovdalen". The pipe surfaces at the closest point downstream where it may maintain a satisfacotry slope.	Underground retention magazine can be constructed underneath the artificial turf of the soccer field. Water can be reused.	Drainage pipe starting from the culvert at the exit point of "Torshovdalen". The pipe conveys the stormwater to "Birkelunden" along "Sannergata" or Schleppegrells gate".		Stomrwater is discharged to municipal stormwater pipes or CS.
Step 3	Constructed green overland stormwater channel (swales) through parts of the pedestrian zone between "Fagerheimgata" and "Københavngata", connecting to the upstream stormwater pipe.	Drainage to muncipal storwater pipes from "Grünerbanen".	Retention ponds in "Birkelunden".		
Step 4	Constructed overland stormwater channel (swales) along "Københavngata" towards "Sofienbergparken". The swale may connect to watering systems for existing and new trees and other vegetation.		Stormwater pipe from "Birkelunden" to "Akerselva" along "Helgesens gate".		
Step 5	Swales following the natural topography of "Sofienbergparken" directs the storwater to retention ponds.				
Step 6	Retention in large, constructed ponds in "Sofienbergparken". These ponds may at times run dry.				
Step 7	Overland flow in constructed channels from "Sofienbergparken" to "Akerselva" along "Toftes gate" and "Thorvald Meyers gate".				

Figure 4.5: The figure shows all five concepts used to demonstrate the MCA. The color and icon used in the representation of each individual step corresponds with the system used by the City of Oslo and Sweco Norge AS (2021) for the primary structures in integrated SWM systems (ref. Figure 2.1.)

4.3 Trial of MCA method

The results of the MCA for the concepts are given in figures 4.6 and 4.7. The results are also presented as text in Table 4.2 below. Figure 4.8 shows the inputs and results of the “Physical parameters” segment of “Hydraulic aspects”. Concepts 4 and 5 are discarded from the rest of the MCA on the basis of not meeting the requirements of the “Physical parameters” segment. As seen in Figure 4.6, Concept 1 ranks highest with a score of 0.62, followed by concept 2 with a score of 0.56. Concept 3 comes in last with a score of 0.37. The exact scores are also shown in the bottom row of Table 4.2. Figure 4.7 shows that Concept 1 performs better than concept 2 in the categories of “Hydraulic aspects”, “Subsurface infrastructure”, “Soil conditions”, and “Environment and biodiversity”. Concept 2 performs better than concept 1 in the categories of “Surface area requirements”, “Safety and accessibility”, “Operation and maintenance”, and “Suitability to winter conditions”. Concept 3, fails to outperform concepts 1 and 2 in all categories. From both Figure 4.7 and Table 4.2, a quite tight grouping of the results from each category becomes apparent.

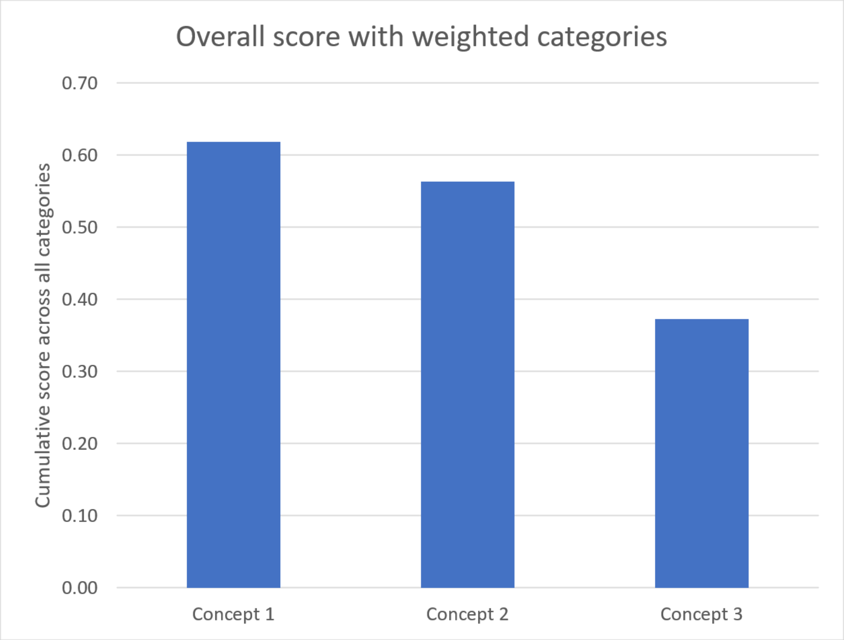


Figure 4.6: The diagram shows the overall score of concepts 1 to 3 (ref. chapter 4.2 and Figure 4.5) with the weights of each category applied.

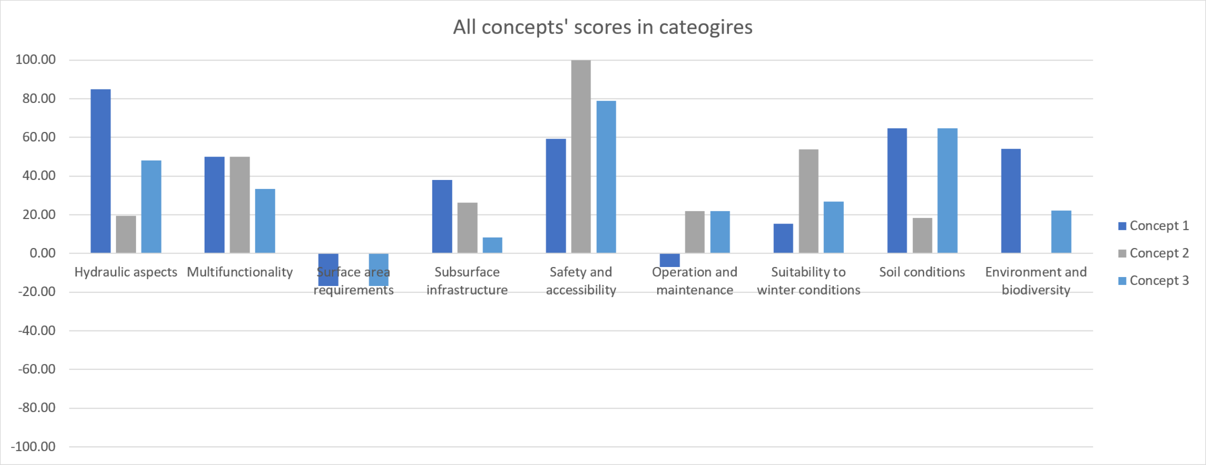
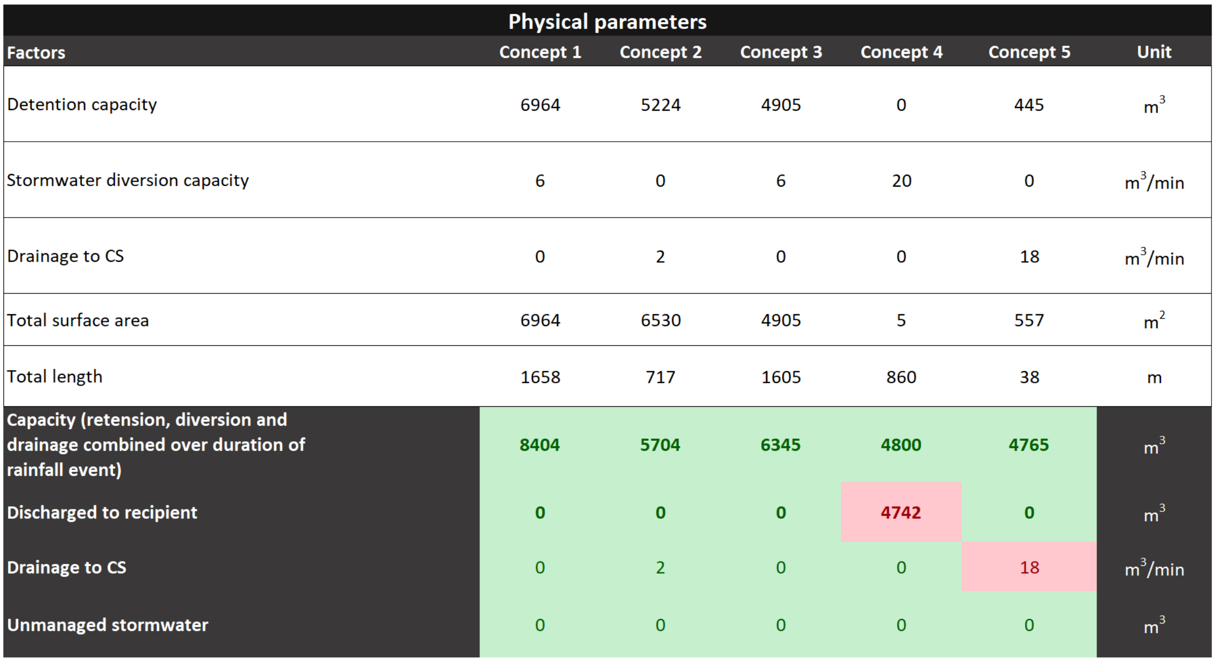


Figure 4.7: The diagram shows the scores of concepts 1 to 3 within each category.

Results from trial of MCA with concepts for case area			
Category\Concept	Concept 1	Concept 2	Concept 3
Hydraulic aspects	84.90	19.44	48.02
Multifunctionality	50.00	50.00	33.33
Surface area requirements	-16.67	0.00	-16.67
Subsurface infrastructure	38.10	26.19	8.33
Safety and accessibility	59.26	100.00	79.01
Operation and maintenance	-6.90	21.84	21.84
Suitability to winter conditions	15.38	53.85	26.92
Soil conditions	64.81	18.52	64.81
Environment and biodiversity	54.25	0.00	22.22
Overall score (normalized)	0.62	0.56	0.37

Table 4.2: The table shows the results from the trial of the MCA method with the concepts made for the case area. The numbers from this table are used to produce diagrams of figures 4.6 and 4.7



Physical parameters						
Factors	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**	**Unit**
Detention capacity	6964	5224	4905	0	445	m^3
Stormwater diversion capacity	6	0	6	20	0	m^3/min
Drainage to CS	0	2	0	0	18	m^3/min
Total surface area	6964	6530	4905	5	557	m^2
Total length	1658	717	1605	860	38	m
Capacity (retension, diversion and drainage combined over duration of rainfall event)	**8404**	**5704**	**6345**	**4800**	**4765**	m^3
Discharged to recipient	**0**	**0**	**0**	**4742**	**0**	m^3
Drainage to CS	0	2	0	0	18	m^3/min
Unmanaged stormwater	0	0	0	0	0	m^3

Figure 4.8: The figure shows the inputs and results of the “Physical parameters” segment of “Hydraulic aspects”. Stormwater diversion capacity is set to 20 $^{m^3}/_{min}$ for concept 4, and drainage to CS is set to 18 $^{m^3}/_{min}$ to avoid unmanaged stormwater.

4.4 Sensitivity analysis

In the following sections under Chapter 4.4, the results of the limited sensitivity analysis is presented, ordered by the concept given preference to. With the method described in Chapter 3.4, the concept given preference emerged as the better choice in the overall scoring in all three runs. These results are discussed in Chapter 5.3

4.4.1 Preference given to concept 1

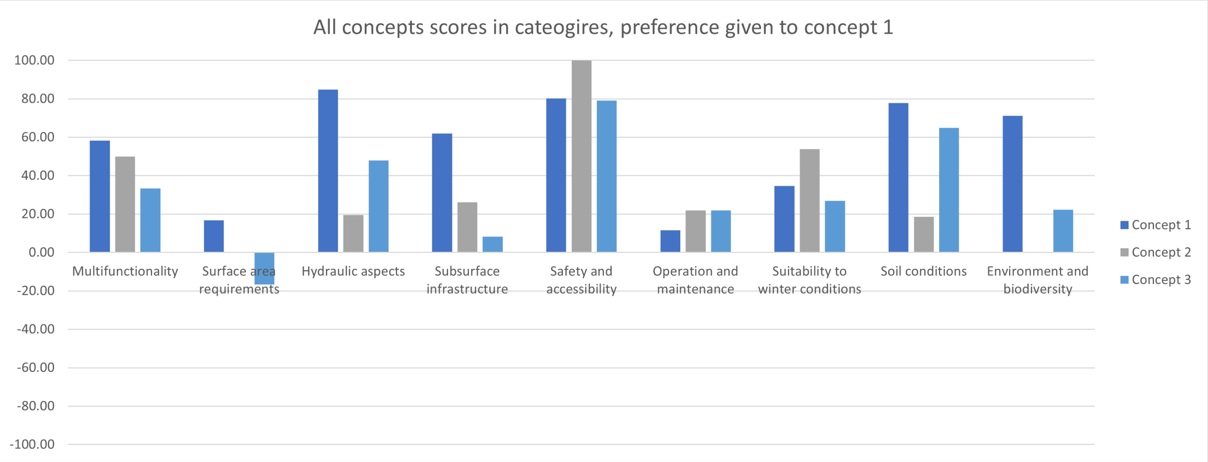
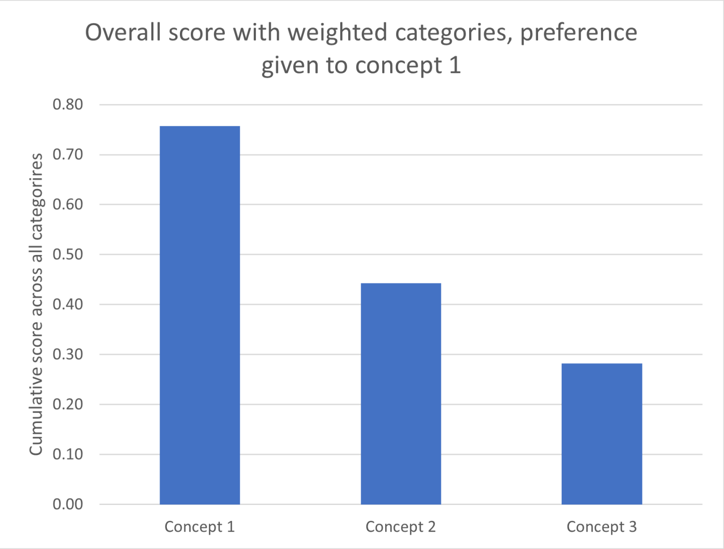


Figure 4.9: The figure shows the results from each category. Preference was given to concept 1.



Concept 1 preference	
Concept 1	0.76
Concept 2	0.44
Concept 3	0.28

Figure 4.10: The figure on the left shows the overall results, with preference given to concept 1. The table on the right shows the exact numerical values.

4.4.2 Preference given to concept 2

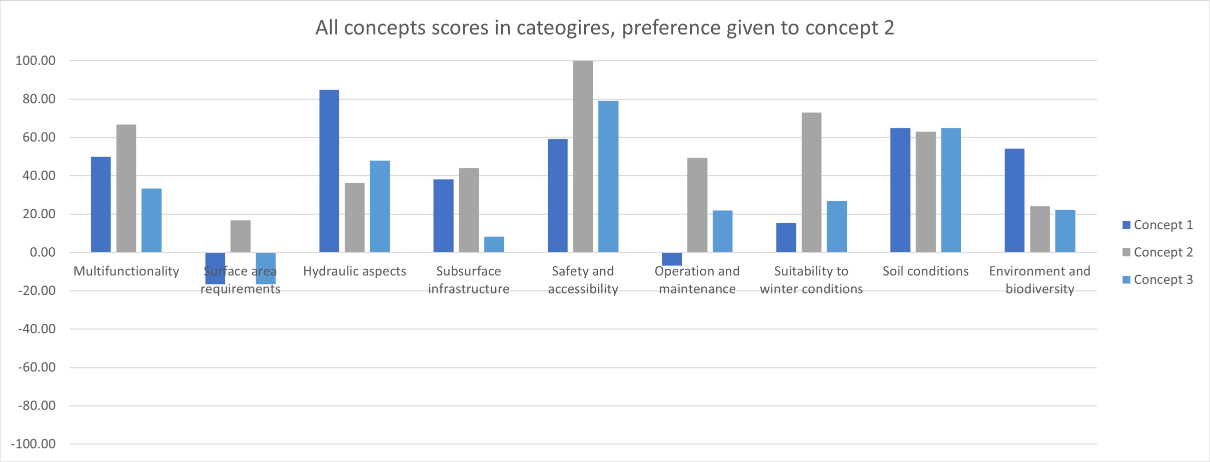
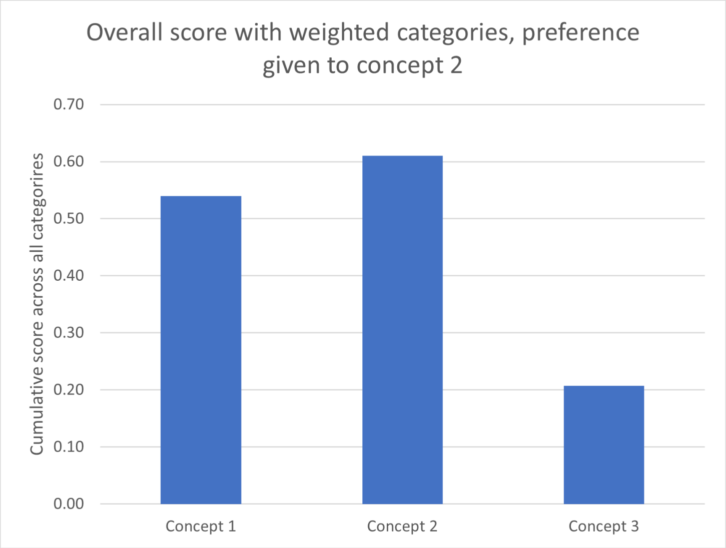


Figure 4.11: The figure shows the results from each category. Preference was given to concept 2.



Concept 1 preference	
Concept 1	0.54
Concept 2	0.61
Concept 3	0.21

Figure 4.12: The figure on the left shows the overall results, with preference given to concept 2. The table on the right shows the exact numerical values.

4.4.3 Preference given to concept 3

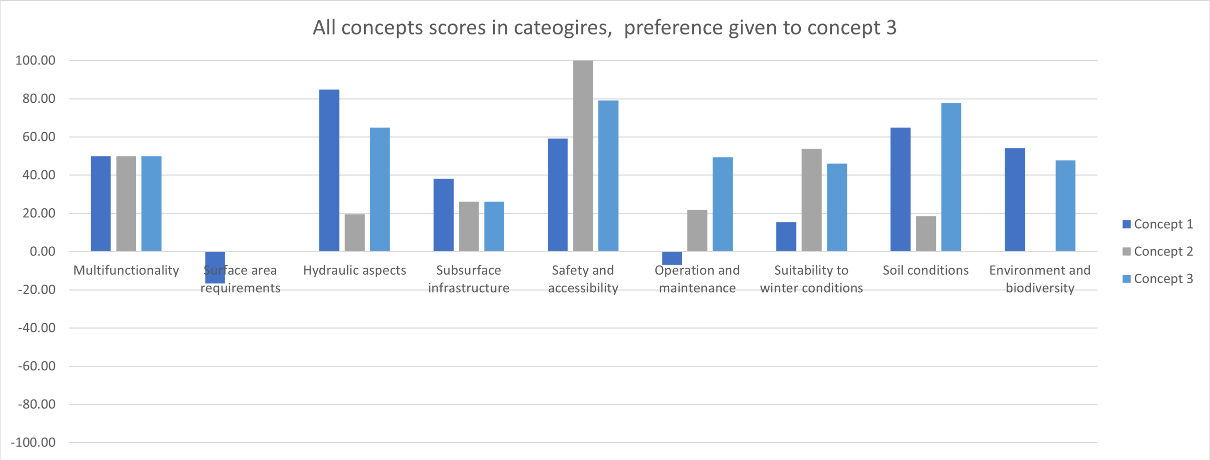
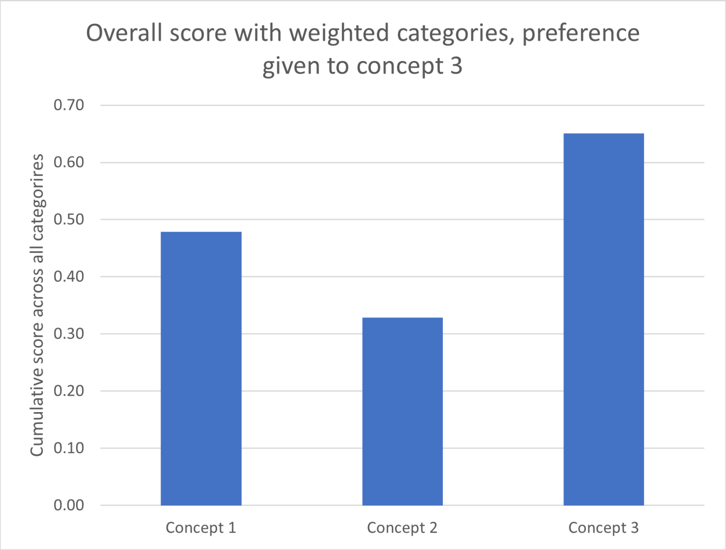


Figure 4.13: The figure shows the results from each category. Preference was given to concept 3.



Concept 1 preference	
Concept 1	0.48
Concept 2	0.33
Concept 3	0.65

Figure 4.14: The figure on the left shows the overall results, with preference given to concept 3. The table on the right shows the exact numerical values.

5. Discussion

5.1 “Physical parameters”

The first sheet of the MCA document the user interacts with, after selecting the number of concepts on the “Frontpage”, is “Hydraulic aspects”, and the additional segment of this sheet called “Physical parameters”. With the data of the design flood provided by Kvitsjøen and Agency for Water and Wastewater Services, City of Oslo (2021) (ref. Table C.2), the necessary stormwater diversion capacity and drainage to CS for concepts 4 and 5, respectively, is 20 $^{m^3}/_{min}$ and 18 $^{m^3}/_{min}$, if unmanaged stormwater is to be avoided. This results in values outside the confines of the limits, and concepts 4 and 5 are removed. Alternatively, if the exact values for stormwater diversion capacity and drainage to CS for the concepts were known, these values could be entered instead. If the new values were lower than the ones used in this example and no other parameters for the two concepts were altered, the cells for unmanaged stormwater would turn red instead, and the concepts would be discarded. By filtering out concepts early in the process, one can avoid spending time and resources developing a concept that is ultimately inadequate. In this trial of the MCA for the case area, concepts 4 and 5 are removed, and the number of concepts is set to 3 on the “Frontpage” for the remaining three concepts.

The scores of the remaining three concepts from “Physical parameters” are included in the total score of “Hydraulic parameters” and the overall score spanning all categories. Incorporating hydraulic performance metrics such as this in an MCA method relying on dimensionless estimates made by a user on an arbitrary linguistic scale is somewhat tricky. At the same time, the inclusion of hydraulic performance aspects is a crucial step in assessing any SWM system. The optional “Hydraulic parameters” segment attempts to mix the incommensurable units of the design flood and properties of the concepts with that of the dimensionless scores selected by the user.

A weakness of the currently utilized min-max normalization operation is that regardless of how ideal a concept is compared to real-world optimal values, the best-performing concept of the mix will receive a maximum score. Similarly, the poorest performer receives a minimum score, given that not all concepts have identical performance numbers.

A better solution to the current one is perhaps to compare the performance of the concepts against a scale containing an ideal and anti-ideal. However, developing and utilizing such a performance scale is outside the scope of this thesis and would require a different choice of MCA method.

5.2 Interpreting the results of the MCA

With concepts 4 and 5 discarded (ref. Chapter 5.1), concept 1 emerged as the preferable concept through the MCA of the concepts for the case area, although only by a slim margin. Both concepts 1 and 2 performed notably better than concept 3.

It is worth noting at this point, however, that the weights of criteria and categories heavily shape these results. As mentioned in Chapter 1.1: finding the ideal weights for criteria and categories for the case area has not been a focus of this thesis. The table on the right shows the overall results of the MCA for the case area with all weights set to identical values; that includes weights for criteria and categories. As can be noted from the table, with uneven weighting out of the equation, concept 2 comes out on top by a substantial margin.

Overall results, equal weights	
Concept 1	0.48
Concept 2	0.63
Concept 3	0.43

Concepts 1 and 2 differ significantly from one another. Whereas concept 1 relies on transportation and stormwater retention through open surface treatment, concept 2 relies upon stormwater pipes and subsurface retention volumes. While concept 1 aims to improve urban amenity, concept 2 does nothing of the sort. Nevertheless, they are quite similarly rated, as shown in figure 4.6, as they achieve high scores in different categories. Where one concept performs poorly, the other excels and vice versa, as mentioned in Chapter 4.3 and shown in Figure 4.7.

Concept 3, on the other hand, attempts to strike a balance between concepts 1 and 2 with a combination of stormwater pipes and detention ponds on the surface. However, it consistently fails to outperform concepts 1 and 2 in all categories and falls behind on the performance metrics.

5.3 The sensitivity of the MCA method

The purpose of this sensitivity analysis is to emulate the combination of the bias a user might have in favor of a particular concept and uncertainty the user might harbor as to the precise performance of the concept for the given criterion. The sensitivity analysis was conducted as described in Chapter 3.5, the results of which are presented in Chapter 4.4. It is apparent from the results that the preferenced concept emerged as the best suited in all three cases. Both concepts 1 and 2 ranked first in six out of nine categories when they were given preference, while concept 3 ranked first in 4 categories, more than $^{1/3}/$, when it was given preference. Ranking first in the majority of categories is not necessarily enough as the weights of the categories also come into play in the overall score calculation. Nonetheless, given three concepts, nine categories, and equal weighting of categories, ranking highest in more than three categories will guarantee the highest placement in the overall score. However, concluding as to the model's actual sensitivity from these results is difficult for a number of reasons:

1. This sensitivity analysis increased the score of 50% of the criteria by 1 step for the preferenced concept. What percentage would be accurate to emulate bias?
2. This sensitivity analysis was performed by increasing the scores of the preferenced concept. Bias could perhaps also be expressed by decreasing the scores of non-favored concepts.
3. The criteria and concepts used for this sensitivity analysis are unevenly weighted. The method of the sensitivity analysis disregards the weights associated with the criteria and categories. Consequently, if the criteria scores being increased are weighted highly, it will be expressed in the resulting overall score. Likewise, if the criteria scores being increased are not weighted highly, the increase in overall score might be minuscule. The first scenario could be the case for one concept subjected to the sensitivity analysis, while the second could occur for another.
4. The sensitivity analysis disregards the spread of the concepts' scores from categories. As described in 3.1 and appendix A, regardless of the spread of the results from the categories, they are converted to the range $[0, 1]$ with formula 3.1. This is illustrated in figures 5.1 and 5.2. If the results are closely grouped, small changes to the score of a criterion may have a large impact on the overall score of the associated concept, and a certain sense of precision is lost. If the scores are more spread out, the increase owing to the sensitivity analysis might not tip the scale in favor of the preferenced concept to the same extent.

Increasing the score of 50% of criteria by 1 step for the preferenced concept might have been excessive, especially considering the tight grouping of the results from some of the categories of the original trial of the MCA (ref. Figure 4.7). The table on the right surmises the range of the results from the categories presented in Table 4.2 as a percentage of the total range $[100, -100]$. In no categories does the used range extend further than 33% of the total available, while it dips below 20% for five categories.

Spread of results measured as a percentage of total range

Category	Percentage
Hydraulic aspects	33%
Multifunctionality	8%
Surface area requirements	8%
Subsurface infrastructure	15%
Safety and accessibility	20%
Operation and maintenance	14%
Suitability to winter conditions	19%
Soil conditions	23%
Environment and biodiversity	27%

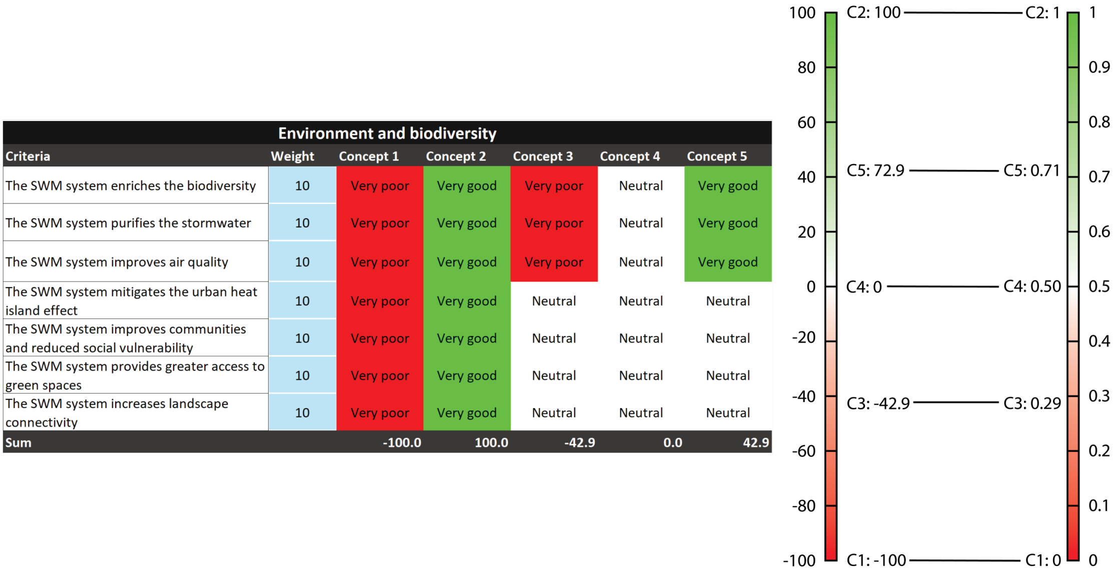
The spread is, in general, quite tight. This ties in with points 1 and 4 of the above list. Slight changes to the scores of a category can shift the ranking of the concepts within. Utilizing a larger percentage of the available range would likely increase the resilience to changes to the ranking of the concepts within categories and, consequentially, the overall ranking.

Regardless of the sensitivity analysis, what contributes to a higher overall score can be deduced from the mathematical structure of the MCA method.

1. Firstly, the weighted arithmetic mean is calculated from the weights and criteria pertaining to each concept under each category. At this step, the scores assigned to each criterion and the weights of each criterion affect concepts' total score from the categories. Additional criteria under a given category will also affect the weighted arithmetic mean. If, for example, all weights were equal, the criteria under a category with a low number of criteria would have a greater impact on the overall score of the concept than those of a category with a higher number of criteria.
2. Secondly comes the min-max normalization process (ref. equation 3.1). By the nature of this process, the score of one concept depends on all concepts' results from all categories. For example, if the score of concept 1 of figure 5.2 were lower, the normalized scores of concepts 3, 4, and 5 would be higher. Likewise, if the score of concept 2 were higher, the normalized scores of concepts 3, 4, and 5 would be lower.
3. Thirdly, a weighted arithmetic mean is calculated from the normalized score from each category, with the weights assigned to each category. Here, the balance of the weights will affect the overall score. As with the criteria, the number of categories, too, will affect the weighted arithmetic mean.

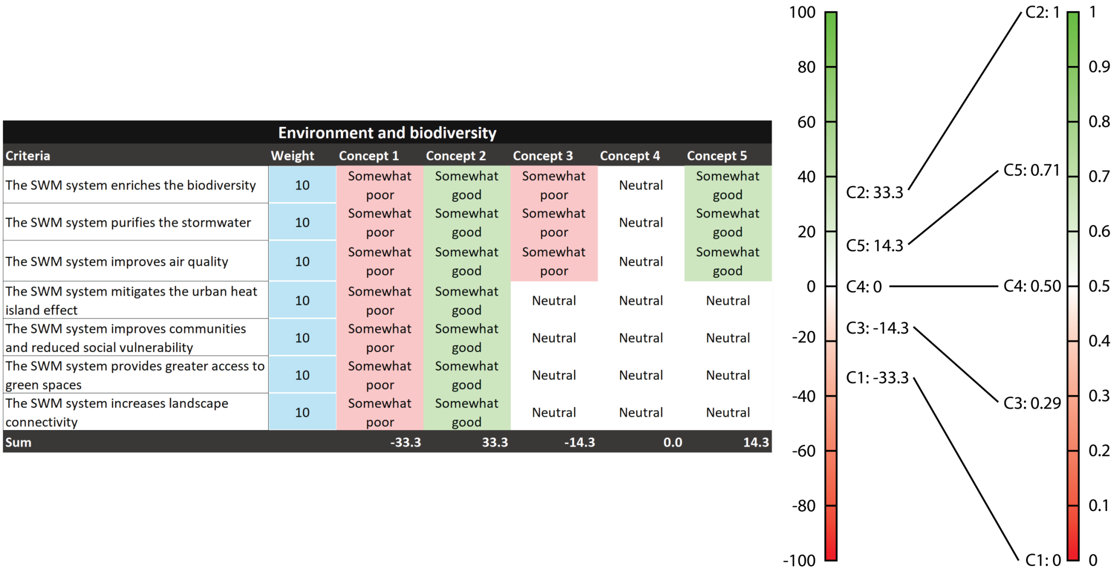
5.4 Criteria

The criteria of the MCA method cover the categories proposed by the City of Oslo and Sweco Norge AS (2021) and include some of the criteria suggested in their report. Additional and complementary criteria have been included following a limited literature review. The criteria are adapted to Norwegian conditions. Other climates and conditions could warrant a different set of criteria. All criteria are phrased as a positive statement and are answered with a degree of satisfaction as to their requirements. Unfortunately, the way the criteria are phrased might possibly contribute to the tight grouping of the results from the categories (the grouping is discussed in Chapter 5.3). Using the category “Environment and biodiversity” as an example, giving any of its criteria a negative score would signify that the concept in question actively detracts from the environmental values of the site in some way. “Multifunctionality”, “Safety and accessibility”, and “Environmental aspects” are categories that face this issue. The grouping of the results caused by this might lessen the accuracy of the model, as explained in Chapter 5.3.



Environment and biodiversity						
Criteria	**Weight**	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**
The SWM system enriches the biodiversity	10	Very poor	Very good	Very poor	Neutral	Very good
The SWM system purifies the stormwater	10	Very poor	Very good	Very poor	Neutral	Very good
The SWM system improves air quality	10	Very poor	Very good	Very poor	Neutral	Very good
The SWM system mitigates the urban heat island effect	10	Very poor	Very good	Neutral	Neutral	Neutral
The SWM system improves communities and reduced social vulnerability	10	Very poor	Very good	Neutral	Neutral	Neutral
The SWM system provides greater access to green spaces	10	Very poor	Very good	Neutral	Neutral	Neutral
The SWM system increases landscape connectivity	10	Very poor	Very good	Neutral	Neutral	Neutral
Sum		**-100.0**	**100.0**	**-42.9**	**0.0**	**42.9**

Figure 5.1: The figure illustrates the normalization of a hypothetical result from the category of "Environment and biodiversity", using equation 3.1. In this example, the entire range $[100, -100]$ for the resulting scores from categories is used. As seen from the figure, the values retain their relative position on the range $[0, 1]$.



Environment and biodiversity						
Criteria	**Weight**	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**
The SWM system enriches the biodiversity	10	Somewhat poor	Somewhat good	Somewhat poor	Neutral	Somewhat good
The SWM system purifies the stormwater	10	Somewhat poor	Somewhat good	Somewhat poor	Neutral	Somewhat good
The SWM system improves air quality	10	Somewhat poor	Somewhat good	Somewhat poor	Neutral	Somewhat good
The SWM system mitigates the urban heat island effect	10	Somewhat poor	Somewhat good	Neutral	Neutral	Neutral
The SWM system improves communities and reduced social vulnerability	10	Somewhat poor	Somewhat good	Neutral	Neutral	Neutral
The SWM system provides greater access to green spaces	10	Somewhat poor	Somewhat good	Neutral	Neutral	Neutral
The SWM system increases landscape connectivity	10	Somewhat poor	Somewhat good	Neutral	Neutral	Neutral
Sum		**-33.3**	**33.3**	**-14.3**	**0.0**	**14.3**

Figure 5.2: The figure illustrates the normalization of a hypothetical result from the category of "Environment and biodiversity", using equation 3.1. In this example, only a portion (1/3) of the range for the resulting scores from categories is used. The relative distance between the concepts' scores is maintained after the normalization using equation 3.1, but not their position on the scale's maximum and minimum value.

5.5 Versatility and adaptability

A number of circumstantial variations regarding the situations where the MCA method might be applied have not been investigated. Some such variations that may be of interest are:

- the size of the project site,
- the stakeholders and project developers involved in the project, and whether or not the project is private, municipal, or state-managed,
- for what stage of planning the MCA method is applied and what information is available at the time the decision is made.

The points above may affect the relevancy of specific criteria, expressed through their weights. The assortment of criteria included in the MCA may also differ with these variables. The priorities of a private client may differ from that of governmental bodies or municipalities, and stakeholders with interests in the area may hold varying views. How far the planning phase has progressed when the decision is made will also affect the precision of the outcome. Depending on the details of the decision environment, a different approach of MCA tailored towards the specifics of the case may even be considered. Weights might be assessed differently depending on whether the project is private, municipal, or state-managed. This goes for the selection of criteria as well, as municipalities and state-managed projects might need to consider elements private projects can disregard. Likewise, criteria that seem redundant from the perspective of a public project may be of greater importance to private ones and are thus included in the MCA. Modifications can easily be made to the MCA to accommodate these variations.

6. Conclusions and future studies

6.1 Conclusions

During this thesis, an MCA method for comparing different conceptual designs for SWM has been developed. The method is built in Microsoft Excel and relies primarily on SAW. The weighted arithmetic mean is calculated for factoring in the weights of each criterion under each category. A combination of min-max normalization and calculation of the weighted arithmetic mean is utilized to counteract the incommensurability of the categories in the presentation of the overall scores of the concepts. The MCA is intended to be used at an early planning stage to understand better which concepts can be worthwhile to pursue further and which ones can be discarded to avoid unnecessary spending of resources.

The criteria and categories of the MCA are primarily based on ideas by the City of Oslo (2021), which in this thesis have been discussed and expanded upon. Guesswork and conjectures are not eliminated with the use of this MCA, and consistency of judgment is required of the user. However, it can provide a framework for the systematization of what little information constitutes the decision environment at the time a decision must be made.

Furthermore, a case area has been studied during this thesis, and five conceptually different concepts have been designed and outlined based on data from the City of Oslo, with the purpose of being tried with the MCA method. The results and deducible insights have been presented and discussed.

Alterations were made to the scores of three of the concepts from the trial of the MCA with the intention of analyzing how the results of the MCA would be affected. While this limited sensitivity analysis was inconclusive, possible weaknesses of the MCA were revealed, which have been discussed.

While the MCA method of this thesis is insufficient on its own to provide clear-cut guidance and definitive results as to which concept is best suited to the conditions, goals, and interests of the site it is applied for, it can still provide some insight as to the strengths and weaknesses of concepts and how the importance of individual criteria and categories affects the final results. With further development and supporting manuals, this can be a helpful tool in the decision-making processes of SWM planning.

6.2 Future studies

As pointed out in Chapter 1.1, developing a ruleset for assigning weights to the parameters is not a focus of this study. However, such a ruleset would likely increase the consistency of the MCA method by substantially reducing the amount of guesswork and conjectures fed into the MCA. Appendix B of *The SuDS Manual* by CIRIA (2012) contains extensive checklists for a variety of topics associated with SWM. Adopting similar checklists for the categories and criteria presented in this thesis could be a possible approach to improve the consistency of criteria evaluation. Nonetheless, regardless of checklists or not, the details available in the decision environment will pose a limit to the preciseness of the MCA.

Also specified in Chapter 1.1 is that developing guidelines for how each criterion should ideally be evaluated has not been a focus of this thesis. This is a complex task, and different entities and stakeholders may hold different views on these topics. It is both politically and locally dependent. A multidisciplinary committee must likely decide this.

The sensitivity analysis of this thesis was inconclusive. More in-depth sensitivity analyses should be conducted to understand better the significance of the difference between the overall result of the concepts.

Regarding future development of the MCA method itself, the author recommends considering utilizing the VBA functionality within Excel. While Excel is powerful enough to perform the simple calculations of this MCA method at a satisfying speed, it is, in the author's opinion, poorly suited to maintain an orderly structure and code readability without the use of VBA. The implementation of a broader array of functionality, like deactivating certain criteria for specific concepts, will be simpler to implement with VBA. Alternatively, the option of building an MCMD method in Python or other programming environments can be explored.

On a larger scale, individual categories can be segmented out and be reviewed in their own tailored MCA. Different MCA methods can be utilized depending on their suitability towards that particular application. For example, processes similar to that described by Meerow and Newell (2017) can be conducted for the categories of "Multifunctionality" and "Environment and biodiversity". Similarly, different approaches can be made for other categories. The results can be combined in an overall presentation, the results of which will, ideally, contain only a bare minimum of guesswork. This does, however, require quite detailed descriptions of the concepts, which might defeat the purpose of an MCA method intended for very early planning stages.

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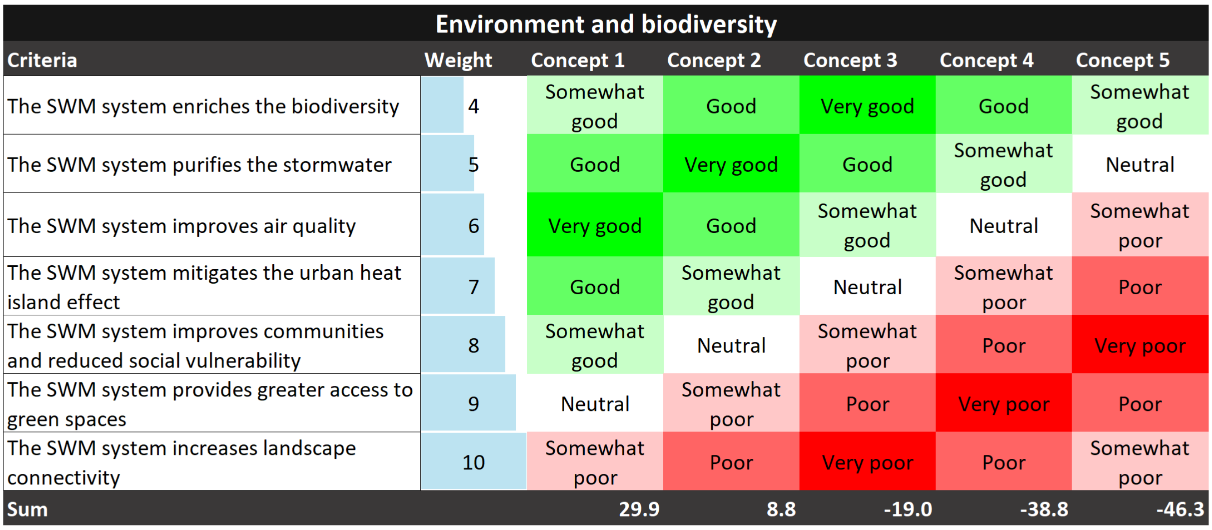
Appendix A. MCA documentation

Refer to Chapter 3.1 for an introduction to the general layout and operation of the MCA.

The scores, weights, and numbers used in figures in this appendix are entirely arbitrary.

The MCA is made in Microsoft Excel. The sheets of the Excel document taking user input are all structured in the same fashion, as described in Chapter 3.1 and shown in Figure A.1. In the dropdown menu for selecting a score, there are a total of seven options: 1) very poor; 2) poor; 3) somewhat poor; 4) neutral; 5) somewhat good; 6) good, and 7) very good. The linguistic scores correspond to a number value determined by a list on the sheet "Lists", shown in Figure A.2 under "Evaluation list".

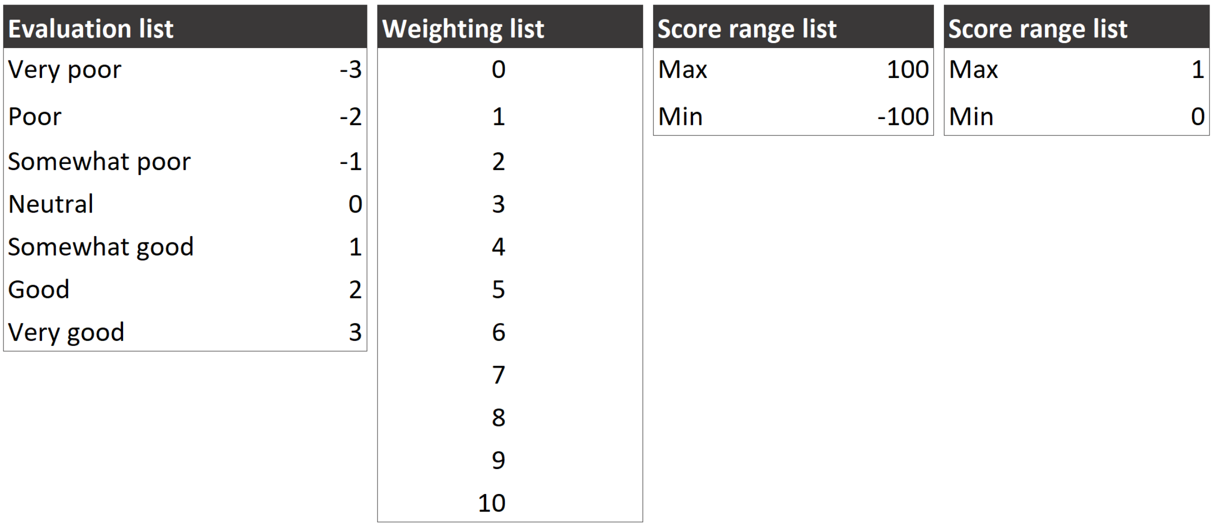


Environment and biodiversity

Criteria	Weight	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
The SWM system enriches the biodiversity	4	Somewhat good	Good	Very good	Good	Somewhat good
The SWM system purifies the stormwater	5	Good	Very good	Good	Somewhat good	Neutral
The SWM system improves air quality	6	Very good	Good	Somewhat good	Neutral	Somewhat poor
The SWM system mitigates the urban heat island effect	7	Good	Somewhat good	Neutral	Somewhat poor	Poor
The SWM system improves communities and reduced social vulnerability	8	Somewhat good	Neutral	Somewhat poor	Poor	Very poor
The SWM system provides greater access to green spaces	9	Neutral	Somewhat poor	Poor	Very poor	Poor
The SWM system increases landscape connectivity	10	Somewhat poor	Poor	Very poor	Poor	Somewhat poor
Sum		29.9	8.8	-19.0	-38.8	-46.3

Figure A.1: The figure shows the layout of the interactive elements of the MCA, where weights are assigned to criteria and scores are assigned to concepts.

On sheet "Step calculations", each concept's score for each criterion is calculated, taking into account each criterion's weight and the corresponding number-value for the linguistic variables. In every number-cell shown in Figure A.3, the user-selected score of the corresponding cell is referenced against the "Evaluation list" shown in Figure A.2 through a series of if-statements ("IF" is a function in Excel). This number value is multiplied with the corresponding criterion weight and divided by the sum of weights in that category. The sum of each column is always limited to the range of $[-3, 3]$. The bottom row of



Evaluation list	
Very poor	-3
Poor	-2
Somewhat poor	-1
Neutral	0
Somewhat good	1
Good	2
Very good	3

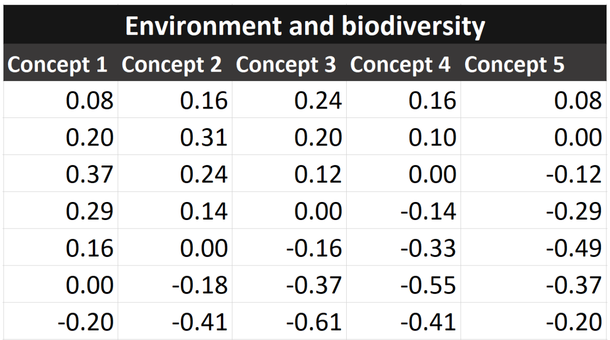
Weighting list
0
1
2
3
4
5
6
7
8
9
10

Score range list	
Max	100
Min	-100

Score range list	
Max	1
Min	0

Figure A.2: The figure shows various lists used for different elements of the MCA. The first from the left is used when converting the linguistic variables used as scores to numbers used in calculations. The second list is the values referenced for data validation in the dropdown menus of the weight selection cells. The last two lists from the left are used in various places where normalization and range conversion is performed.

each category sheet shows each concept's score sum for that category, as seen in Figure A.1. The number presented here is the sum of the corresponding column in the "Step calculations" sheet (ref. Figure A.3), divided by 3 and multiplied by 100, thus changing the range to $[-100, 100]$.



Environment and biodiversity				
Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
0.08	0.16	0.24	0.16	0.08
0.20	0.31	0.20	0.10	0.00
0.37	0.24	0.12	0.00	-0.12
0.29	0.14	0.00	-0.14	-0.29
0.16	0.00	-0.16	-0.33	-0.49
0.00	-0.18	-0.37	-0.55	-0.37
-0.20	-0.41	-0.61	-0.41	-0.20

Figure A.3: The figure is an example from the "Step calculations" sheet of the Excel document.

The "Hydraulic aspects" sheet contains an extra element labeled "Physical parameters" in addition to the same repeating pattern of criteria, weight, and linguistic variables explained in the paragraph above. This is shown in Figure A.4. This segment is optional and can be completely ignored by setting its weight to zero. Parameters regarding the pluvial flooding scenario are entered under "Flood parameters". This includes 1) dimensioning rainfall event given as recurrence interval; 2) rainfall duration given in hours; 3) Total stormwater volume entering SWM system given as cubic meters; 4) maximum discharge to recipient given as cubic meters, and 5) maximum drainage to CS given as cubic meters.

Under "Physical parameters", parameters regarding the concepts are entered. These are 1) estimated detention capacity as cubic meters; 2) estimated stormwater diversion capacity (the flow capacity of floodpaths) given as cubic meters per minute, 3) drainage to CS; 4) estimated total occupied surface area, and 5) estimated total length. From these input values, a series of simple calculations are performed to visualize how the concepts compare. Some of these parameters are associated with limits which, when exceeded, are displayed in a color of red as seen from Figure A.4. The remaining parameters are made dimensionless through normalization with equation 3.1. At this stage, weights can be assigned to the parameters. The parameters are 1) detention capacity per area; 2) detention capacity per length; 3) stormwater diversion capacity per area, and 4) stormwater diversion capacity per length. These are multiplied with their respective weights and divided by the sum of weights. In order to represent this new score on a scale ranging from -100 to 100, it is multiplied by 200 and subtracted by 100. This is done for each concept. The score from each panel on "Hydraulic aspects" is combined by multiplying their respective score and weight and dividing by the sum of their weights.

The resulting sums from each category, presented on the range $[-100, 100]$, are collected in a matrix on the sheet "Score calculation" under the table labeled "Score by concept" (ref. Figure A.5). This is for simplicity and clarity. All cells in this matrix contain an if-statement, where the condition is the specified number of concepts being reviewed. This variable is set on the "Frontpage" and will leave rows blank starting from the bottom so that only rows equal to the selected number of concepts contain values. All the cells in the matrix are referenced by the diagrams presented on the "Results" sheet. Accordingly, only the selected number of concepts are displayed in the diagrams.

The data presented in the diagram combining the results from all categories, "Overall score with weighted categories", is managed differently from the process described in the above paragraph. The sum of each column from sheet "Step calculations" (ref. Figure A.5) are transferred to the first row of numbers (row 1) in Figure A.6 on sheet "Normalization". However, the category of "Hydraulic aspects" is an exception to this rule, given the total score from this category is calculated in its respective sheet and given on the range $[-100, 100]$. Each cell of row 1 for "Hydraulic aspects" on sheet "Normalization" is scaled to the new range [0,1] with equation A.1 given below:

$$v \mapsto \frac{v - r_{min}}{r_{max} - r_{min}} \times (t_{max} - t_{min}) + t_{min} \tag{A.1}$$

where r_{min} is the minimum of the existing range, r_{max} is the maximum of the existing range, t_{min} is the minimum of the new range, t_{max} is the maximum of the new range, and

$v \in [r_{min}, r_{max}]$ is the specific value to be scaled. Where the equation is used in Excel, it references the "Score range lists" on sheet "Lists" (ref. Figure A.2).

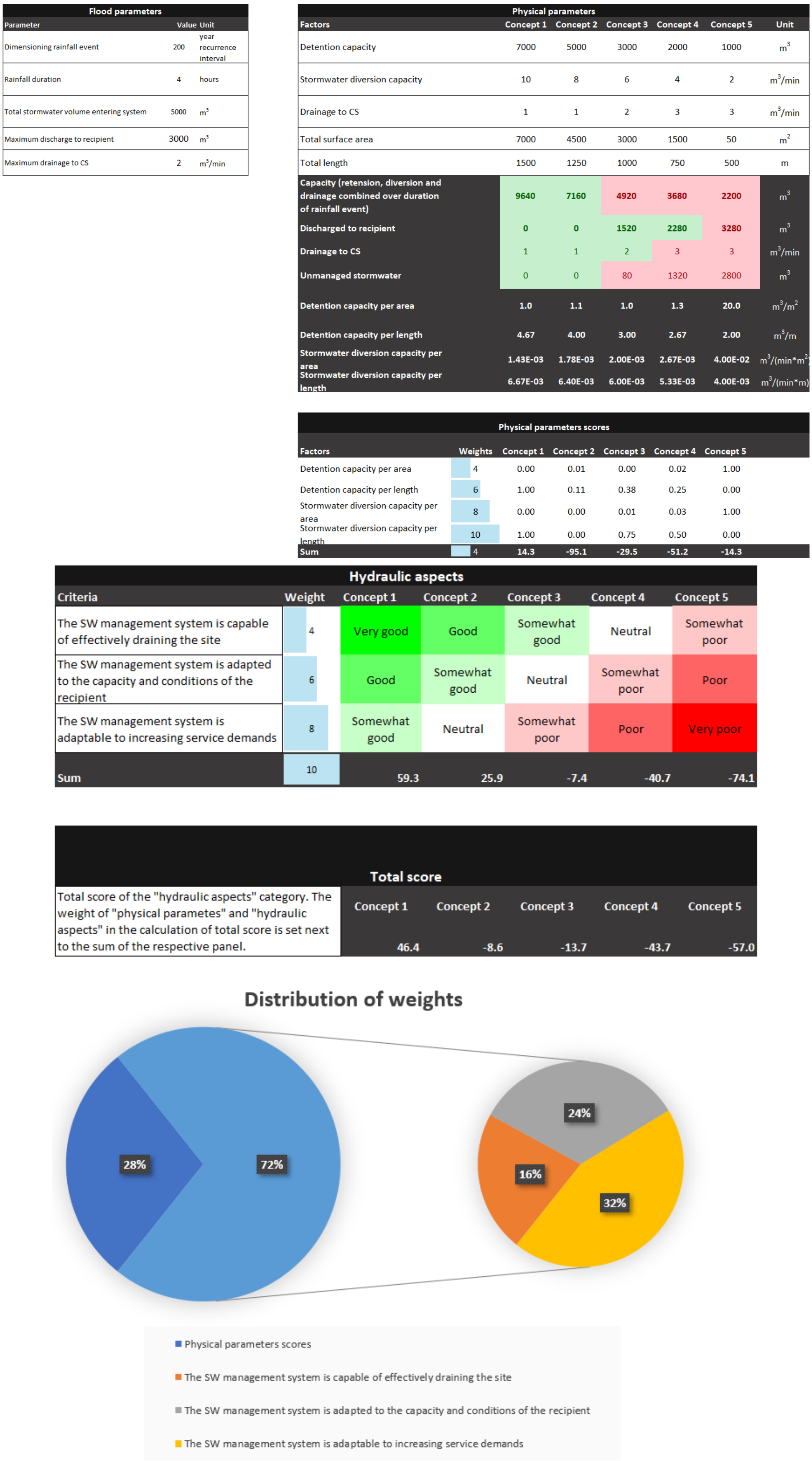
The cells of row 2 of Figure A.6 extract the lowest cell value from different intervals of row 1, using the "MIN" function. Cell B2 extracts the lowest value from the interval A1:A2, B3 from the interval A1:A3, B4 from the interval A1:A4, and lastly B5 from the interval A1:A5. The cells of row 3 operate in a similar way, with the difference being extracting the highest value using the "MAX" function.

These maximum and minimum values are used in row 4 for the normalization operation. The normalization utilizes the following formula, as also explained in Chapter 3.1 (Loukas, 2020):

$$z_i = \frac{x_i - min(x)}{max(x) - min(x)} \tag{3.1}$$

where $x = (x_1, ..., x_n)$ and z_i is the i^{th} normalized data. In other words, the formula converts the spread of data entries x_i of a vector x to the range $[0, 1]$, while keeping the relative distance between data entries unchanged from x to z. Through this process, the maximum and minimum value for any concept under any category is 1 and 0, and at least two concepts will hold these values for each category. Cell A to E of row 4 of Figure A.6 utilizes different values for $min(x)$ and $max(x)$ extracted from row 2 and 3, respectively, depending on the selected number of criteria. This is controlled through a series of if-statements. This system ensures that the correct normalization operation is performed for the selected number of concepts. Additionally, cells on row 4 corresponding to concepts being excluded by the selected number of concepts are left blank by the last of the if-statements.

Through the dropdown menus on sheet "Weighting of categories", uneven weights can be selected for the nine categories, as seen in Figure A.7. These weights are then applied on sheet "Score calculation" (ref. Figure A.5) in the table labeled "Overall score", where the normalized scores are multiplied with their respective weight. In the unlikely yet possible event that $min(x)$ and $max(x)$ should equal each other for a given number of concepts under a category on the "Normalization" sheet, a "#DIV/0!" error will occur. In response to this, each cell of table "Overall score" (with the exception of the last row) contains an "IFERROR"-function to display the cells as blank should said "#DIV/0!" error occur. This error can only occur if the concepts are scored equally under a category. In this solution, the blank cells are counted as zeroes, and the concepts are treated equally for the concepts in question. In the bottom row, the cells of the columns above are summed and divided by the sum of weights for all categories. The cells of the bottom row contain an "IFERROR"-function as well, but its purpose is different from that of the cells above it. As explained in the above paragraph, cells referenced in this table may be blank. This causes error messages to be displayed in columns belonging to inactive concepts. The “IFERROR”-function causes the cells of the bottom row containing the score of inactive concepts to be displayed as blank. The diagram labeled “Overall score with weighted categories” on the “Results” sheet will only display the active concepts’ results.



Flood parameters

Parameter	Value	Unit
Dimensioning rainfall event	200	year recurrence interval
Rainfall duration	4	hours
Total stormwater volume entering system	5000	m^3
Maximum discharge to recipient	3000	m^3
Maximum drainage to CS	2	m^3/min

Physical parameters

Factors	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Unit
Detention capacity	7000	5000	3000	2000	1000	m^3
Stormwater diversion capacity	10	8	6	4	2	m^3/min
Drainage to CS	1	1	2	3	3	m^3/min
Total surface area	7000	4500	3000	1500	50	m^2
Total length	1500	1250	1000	750	500	m
Capacity (retension, diversion and drainage combined over duration of rainfall event)	**9640**	**7160**	**4920**	**3680**	**2200**	m^3
Discharged to recipient	**0**	**0**	**1520**	**2280**	**3280**	m^3
Drainage to CS	1	1	2	3	3	m^3/min
Unmanaged stormwater	0	0	80	1320	2800	m^3
Detention capacity per area	**1.0**	**1.1**	**1.0**	**1.3**	**20.0**	m^3/m^2
Detention capacity per length	**4.67**	**4.00**	**3.00**	**2.67**	**2.00**	m^3/m
Stormwater diversion capacity per area	**1.43E-03**	**1.78E-03**	**2.00E-03**	**2.67E-03**	**4.00E-02**	$m^3/(min*m^2$
Stormwater diversion capacity per length	**6.67E-03**	**6.40E-03**	**6.00E-03**	**5.33E-03**	**4.00E-03**	$m^3/(min*m)$

Physical parameters scores

Factors	Weights	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Detention capacity per area	4	0.00	0.01	0.00	0.02	1.00
Detention capacity per length	6	1.00	0.11	0.38	0.25	0.00
Stormwater diversion capacity per area	8	0.00	0.00	0.01	0.03	1.00
Stormwater diversion capacity per length	10	1.00	0.00	0.75	0.50	0.00
Sum	4	**14.3**	**-95.1**	**-29.5**	**-51.2**	**-14.3**

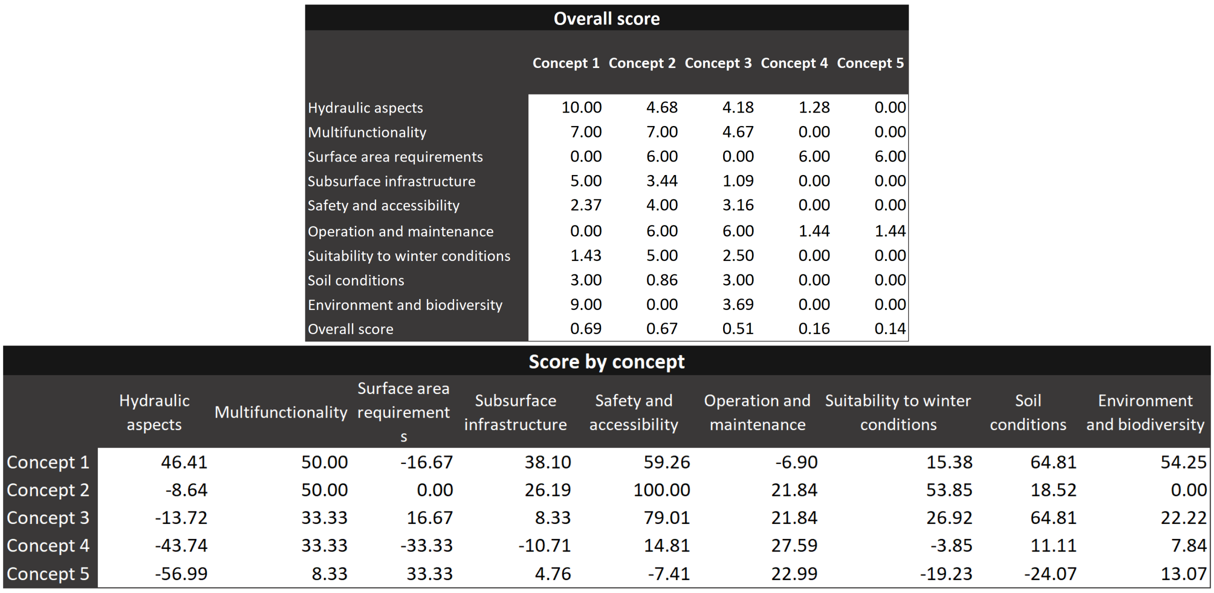
Hydraulic aspects

Criteria	Weight	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
The SW management system is capable of effectively draining the site	4	Very good	Good	Somewhat good	Neutral	Somewhat poor
The SW management system is adapted to the capacity and conditions of the recipient	6	Good	Somewhat good	Neutral	Somewhat poor	Poor
The SW management system is adaptable to increasing service demands	8	Somewhat good	Neutral	Somewhat poor	Poor	Very poor
Sum	10	**59.3**	**25.9**	**-7.4**	**-40.7**	**-74.1**

Total score

Total score of the "hydraulic aspects" category. The weight of "physical parameters" and "hydraulic aspects" in the calculation of total score is set next to the sum of the respective panel.	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
	46.4	**-8.6**	**-13.7**	**-43.7**	**-57.0**

Figure A.4: The figure shows the additional elements of the "Hydraulic aspects" sheet of the Excel document.



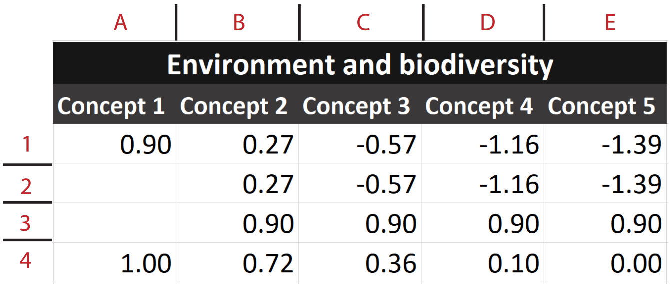
Overall score

	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Hydraulic aspects	10.00	4.68	4.18	1.28	0.00
Multifunctionality	7.00	7.00	4.67	0.00	0.00
Surface area requirements	0.00	6.00	0.00	6.00	6.00
Subsurface infrastructure	5.00	3.44	1.09	0.00	0.00
Safety and accessibility	2.37	4.00	3.16	0.00	0.00
Operation and maintenance	0.00	6.00	6.00	1.44	1.44
Suitability to winter conditions	1.43	5.00	2.50	0.00	0.00
Soil conditions	3.00	0.86	3.00	0.00	0.00
Environment and biodiversity	9.00	0.00	3.69	0.00	0.00
Overall score	0.69	0.67	0.51	0.16	0.14

Score by concept

	Hydraulic aspects	Multifunctionality	Surface area requirements	Subsurface infrastructure	Safety and accessibility	Operation and maintenance	Suitability to winter conditions	Soil conditions	Environment and biodiversity
Concept 1	46.41	50.00	-16.67	38.10	59.26	-6.90	15.38	64.81	54.25
Concept 2	-8.64	50.00	0.00	26.19	100.00	21.84	53.85	18.52	0.00
Concept 3	-13.72	33.33	16.67	8.33	79.01	21.84	26.92	64.81	22.22
Concept 4	-43.74	33.33	-33.33	-10.71	14.81	27.59	-3.85	11.11	7.84
Concept 5	-56.99	8.33	33.33	4.76	-7.41	22.99	-19.23	-24.07	13.07

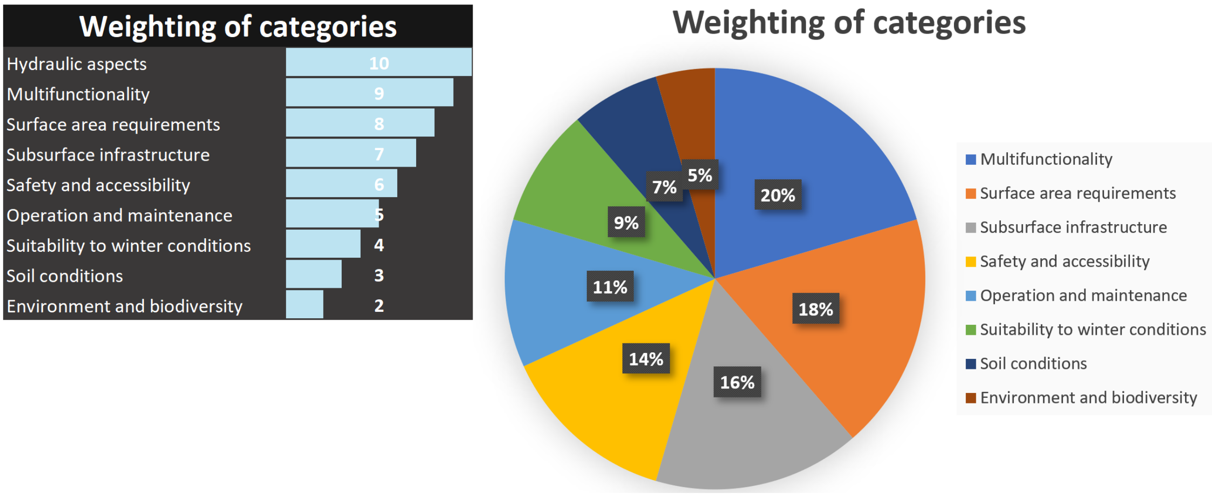
Figure A.5: The figure displays the "Score calculation" sheet. In the first box from the left, the values for the overall results, while the second box contains the result for each combination of concept and category.



Environment and biodiversity

	A	B	C	D	E
	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
1	0.90	0.27	-0.57	-1.16	-1.39
2		0.27	-0.57	-1.16	-1.39
3		0.90	0.90	0.90	0.90
4	1.00	0.72	0.36	0.10	0.00

Figure A.6: The figure shows an example from the "Normalization" sheet where the results from each category are normalized. The figure is outfitted with numbered rows from 1 to 4 and columns from A to E for explanatory purposes.



Weighting of categories

Hydraulic aspects	10
Multifunctionality	9
Surface area requirements	8
Subsurface infrastructure	7
Safety and accessibility	6
Operation and maintenance	5
Suitability to winter conditions	4
Soil conditions	3
Environment and biodiversity	2

Figure A.7: The figure shows the elements of the "Weighting of categories" sheet, where weights are assigned to each category. The diagram on the right shows the percentage-wise distribution of the weights.

Appendix B. Map of concepts

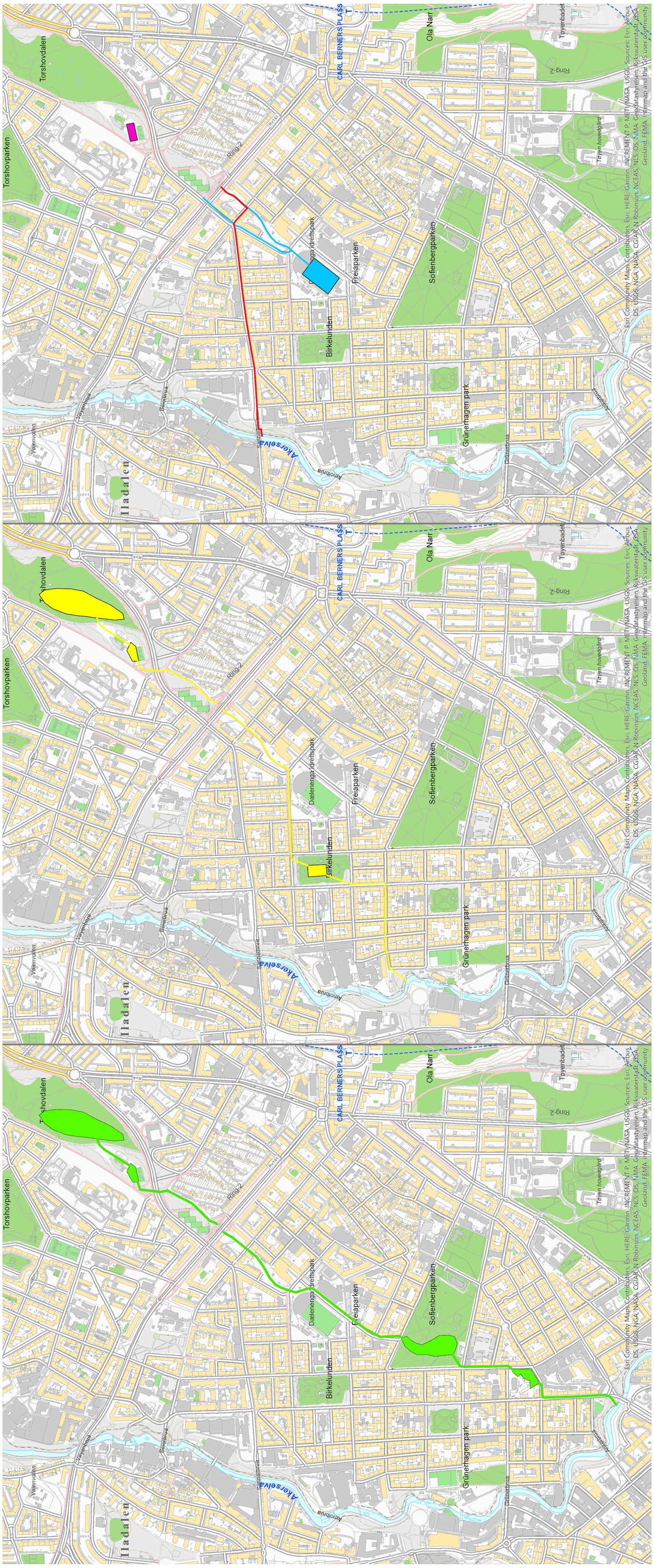


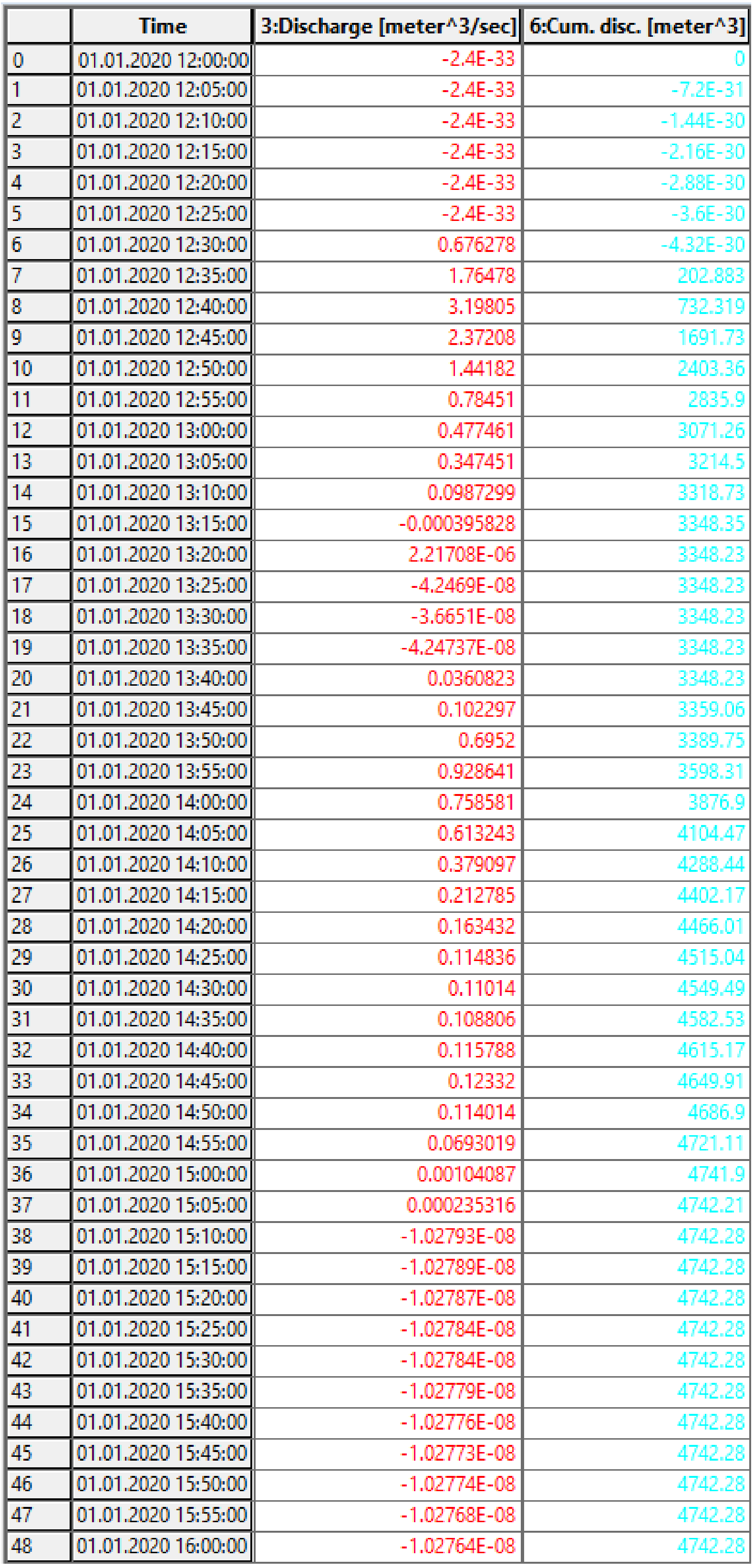
Figure B.1: The figure consists of three pictures, each with the same map view, but showing the layout of different concepts. Concept 1 is displayed in green, concept 2 in blue, concept 3 in yellow, concept 4 in red, and concept 5 in purple.

Appendix C. Data used for trial of MCA

200-year recurrence interval, CF 1.5	
Time [min]	Precipitation $[\frac{l}{s \times ha}]$
20	45.8
40	93.4
60	153.9
80	157.7
100	273.6
120	522.3
140	522.3
160	273.6
180	157.7
200	153.9
220	93.4
240	45.8

Table C.1: The table shows the precipitation hyetograph used for the simulation in MIKE FLOOD. It includes a climate factor of 1.5. Data provided by Kvitsjøen and Agency for Water and Wastewater Services, City of Oslo (2021)

Results from simulated urban pluvial flood



	Time	3:Discharge [meter^3/sec]	6:Cum. disc. [meter^3]
0	01.01.2020 12:00:00	-2.4E-33	0
1	01.01.2020 12:05:00	-2.4E-33	-7.2E-31
2	01.01.2020 12:10:00	-2.4E-33	-1.44E-30
3	01.01.2020 12:15:00	-2.4E-33	-2.16E-30
4	01.01.2020 12:20:00	-2.4E-33	-2.88E-30
5	01.01.2020 12:25:00	-2.4E-33	-3.6E-30
6	01.01.2020 12:30:00	0.676278	-4.32E-30
7	01.01.2020 12:35:00	1.76478	202.883
8	01.01.2020 12:40:00	3.19805	732.319
9	01.01.2020 12:45:00	2.37208	1691.73
10	01.01.2020 12:50:00	1.44182	2403.36
11	01.01.2020 12:55:00	0.78451	2835.9
12	01.01.2020 13:00:00	0.477461	3071.26
13	01.01.2020 13:05:00	0.347451	3214.5
14	01.01.2020 13:10:00	0.0987299	3318.73
15	01.01.2020 13:15:00	-0.000395828	3348.35
16	01.01.2020 13:20:00	2.21708E-06	3348.23
17	01.01.2020 13:25:00	-4.2469E-08	3348.23
18	01.01.2020 13:30:00	-3.6651E-08	3348.23
19	01.01.2020 13:35:00	-4.24737E-08	3348.23
20	01.01.2020 13:40:00	0.0360823	3348.23
21	01.01.2020 13:45:00	0.102297	3359.06
22	01.01.2020 13:50:00	0.6952	3389.75
23	01.01.2020 13:55:00	0.928641	3598.31
24	01.01.2020 14:00:00	0.758581	3876.9
25	01.01.2020 14:05:00	0.613243	4104.47
26	01.01.2020 14:10:00	0.379097	4288.44
27	01.01.2020 14:15:00	0.212785	4402.17
28	01.01.2020 14:20:00	0.163432	4466.01
29	01.01.2020 14:25:00	0.114836	4515.04
30	01.01.2020 14:30:00	0.11014	4549.49
31	01.01.2020 14:35:00	0.108806	4582.53
32	01.01.2020 14:40:00	0.115788	4615.17
33	01.01.2020 14:45:00	0.12332	4649.91
34	01.01.2020 14:50:00	0.114014	4686.9
35	01.01.2020 14:55:00	0.0693019	4721.11
36	01.01.2020 15:00:00	0.00104087	4741.9
37	01.01.2020 15:05:00	0.000235316	4742.21
38	01.01.2020 15:10:00	-1.02793E-08	4742.28
39	01.01.2020 15:15:00	-1.02789E-08	4742.28
40	01.01.2020 15:20:00	-1.02787E-08	4742.28
41	01.01.2020 15:25:00	-1.02784E-08	4742.28
42	01.01.2020 15:30:00	-1.02784E-08	4742.28
43	01.01.2020 15:35:00	-1.02779E-08	4742.28
44	01.01.2020 15:40:00	-1.02776E-08	4742.28
45	01.01.2020 15:45:00	-1.02773E-08	4742.28
46	01.01.2020 15:50:00	-1.02774E-08	4742.28
47	01.01.2020 15:55:00	-1.02768E-08	4742.28
48	01.01.2020 16:00:00	-1.02764E-08	4742.28

Table C.2: The table shows the discharge per second and cumulative discharge of stormwater from zone AKT3 to zone AKT2 during a simulated rainfall event for the rainfall hyetograph shown in Table C.1. Table provided by Kvitsjøen and Agency for Water and Wastewater Services, City of Oslo (2021)

Appendix D. Notes from trial of MCA

Chapters D.1, D.2, and D.3 under appendix D go through some key features of concepts 1 to 3 and their scores for each criterion. The numbering corresponds to that of table 4.1 on page 33.

D.1 Concept 1: Evaluation notes

	Hydraulic aspects	
1.1	Given proper dimensioning of channels and swales, the system is well equipped to drain the area. This being a system with all elements accessible from the surface, it can drain stormwater entering the system from its highest point in the catchment all the way to the recipient.	Very good
1.2	The system is adapted to the capacity and conditions of the recipient.	Very good
1.3	As the system does not use pipes or other subsurface systems, it is very manageable to expand upon or adapt.	Very good

	Multifunctionality	
2.1	There is no system for the storage of stormwater, except in ponds.	Neutral
2.2	The green infrastructure of the concept increases the urban amenity and the recreational value of the surroundings.	Very good
2.3	Other than for the management of stormwater and the recreational benefits the system offers, other functions the system may serve are possibly few.	Neutral

	Surface area requirements	
3.1	The concept is quite area extensive. Retention ponds, swales, and channels are on the surface.	Poor
3.2	The swales and channels of the concept do not require much depth. On the other hand, the retention ponds require more depth, but these are placed in park zones and will likely not be problematic with respect to subsurface infrastructure or bedrock.	Somewhat good

Subsurface infrastructure		
4.1	The concept, being quite area-intensive, may be difficult to fit in the cityscape. It will require much coordination to facilitate properly.	Somewhat good
4.2	The concept is designed without a connection to the existing stormwater drainage system in mind. However, the retention ponds are placed above drainage pipes, so the systems should be possible to connect.	Neutral
4.3	For this demonstration, this question is irrelevant	Neutral
4.4	The concept does not require much depth. As long as the channels do not run too deep, the system should not interfere with subsurface infrastructure.	Very good

Safety and accessibility		
5.1	This depends on the depth of retention ponds and safety measures like fences where this might be necessary. During urban pluvial floods, the water depth should stay at a safe level in both ponds and the product of velocity and flow remaining safe levels for channels. Concept 1 is located exclusively on the surface, so extra attention must be put towards this. A section of the concept runs in between apartment blocks. With the terrain of the case area, there is little reason for steep slopes that could cause slippage or entrapment. Operation and maintenance do not require specially trained personnel and do not require accessing manholes. The concept could be just as safe as the current situation without stormwater management.	Good
5.2	Crossings can be built in key locations so that accessibility is not unreasonably impeded. However, this may be a difficult task in between the apartment blocks.	Somewhat good
5.3	There should be little risk of drowning if the concept if the system is built in compliance with safety protocols. However, being entirely on the surface, the risk is higher than concepts that are not, albeit a minuscule difference.	Good
5.4	Along the edges of the retention ponds, swales and channels, shrubs, and low understory vegetation can be planted. This will not unreasonably impede the line of sight. It is, however, important that people will be able to spot the running water and that it is not completely concealed behind the low vegetation.	Good

Operation and maintenance		
6.1	The maintenance frequency will likely be higher than for concepts 2 and 3 due to the entire system being on the surface, where it is more exposed to wear and tear and also due to it being vegetated.	Somewhat poor
6.2	The maintenance tasks are similar to that of a park area. However, the system is vast and, therefore, possibly quite time-consuming.	Neutral
6.3	This depends on the frequency of rain that can flush sediments out of the channels and swales. There will likely be a need for clearing of the channels to maintain the maximum capacity of the system, as well as for aesthetical concerns.	Poor
6.4	The maintenance need is similar to parks.	Good
6.5	This depends on the choice of vegetation, but for this test, it is assumed that watering will at times be necessary.	Somewhat poor

Suitability to winter condition		
7.1	A system that somewhat relies on infiltration will suffer some setbacks in efficiency during wintertime, as pores in the soil are clocked with ice.	Good
7.2	Vegetation is an integral part of concept 1. Vegetation is affected by road salt, but to what extent is difficult to predict in this study.	Somewhat poor
7.3	The channels and swales are not ideal to be used as snow dumps. One should be careful not to harm vegetation underneath heavy heaps of snow. The retention ponds can possibly be used as snow dumps. Their ability to hold water is not greatly affected by this, and infiltration is unlikely to make a difference during wintertime regardless.	Neutral
7.4	Hard-packed or re-frozen snow might clog channels or swales.	Neutral
7.5	Yes.	Good

Soil conditions		
8.1	The concept is affected by the groundwater level in the sense that a too high groundwater table might reduce the efficacy of infiltration. However, this is unlikely to be an issue in the case area.	Somewhat poor
8.2	Drainage to municipal stormwater pipes should not be necessary if the infiltration conditions are good. Stormwater exceeding the capacity of retention ponds will discharge to Akerselva.	Good
8.3	The actual conditions are unknown to the author. Good conditions are considered a prerequisite.	Very good
8.4	Yes.	Very good

	Environment and biodiversity	
9.1	More varied vegetation in already vegetated areas, such as the parks incorporated in the concepts and the transformation from asphalt and concrete to vegetated zones, provide better conditions for a variety of insects and animals and increase biodiversity.	Very good
9.2	The system facilitates the infiltration of stormwater. Although this is not the primary goal of the system, it is an effect nonetheless. It will replace some impervious surfaces with previous ones.	Very good
9.3	Yes, although not as much one would achieve with more trees. Trees would have a greater effect than shrubs and understory vegetation. There is also limited space for vegetation along many of the swales and channels of the concept.	Somewhat good
9.4	To some extent, yes. Here, trees would be greatly more efficient than understory vegetation, but shrubs and similar are still a contribution. Even water present on the surface contributes positively through evaporation.	Somewhat good
9.5	To some extent, yes. The zones with retention ponds are located in already existing park areas, so the contribution is limited. However, the further development of said park areas will likely make them more attractive to the public, and the additional swales and channels connecting them will contribute positively to the goal of the criteria.	Somewhat good
9.6	To some extent, yes, the reasoning is the same as for the criteria above.	Somewhat good
9.7	To some extent, yes. Additional, yet somewhat limited, greenery will be planted in between the park zones.	Somewhat good

D.2 Concept 2: Evaluation notes

	Hydraulic aspects	
1.1	The concept does not have the same potential to drain the stormwater from a wider area as concept 1 does. Furthermore, the capacity is to a larger extent limited due to the stormwater being conveyed in pipes as opposed to open channels. This does, of course, depend on the diameter of the pipe.	Good
1.2	This is a given in this thesis.	Very good
1.3	Expanding the capacity of this system will require digging and new pipes.	Somewhat poor

	Multifunctionality	
2.1	Stormwater can be stored in the subsurface retention volumes underneath the artificial turf of the soccer field.	Very good
2.2	The SWM system itself does not change the recreational value of the area.	Somewhat good
2.3	The system may be used for municipal tasks and activities. However, that was possibly already the case before the installation of the retention volumes.	Somewhat good

	Surface area requirements	
3.1	No parts of the concept are located on the surface.	Very good
3.2	The concept requires much digging. The stormwater pipes run in the ground, and the retention volumes are located underneath the soccer field.	Very poor

	Subsurface infrastructure	
4.1	The concept is not too large, and the subsurface retention volumes constituting a large portion of the entire system are placed underneath a soccer field which likely will not interfere too much with other city development. The pipes, however, might compete with other plans and infrastructure.	Good
4.2	The concept is designed with a connection to the existing stormwater drainage system in mind.	Good
4.3	For this demonstration, this question is irrelevant.	Neutral
4.4	The system is designed with about 700 meters of stormwater pipes. This might be tricky to fit in the ground.	Somewhat poor

	Safety and accessibility	
5.1	Concept 2 is entirely located beneath the surface. Operation and maintenance are also safe.	Very good
5.2	As the concept is located underground, the concept does not interfere with activities on the surface.	Very good
5.3	As the concept is located underground, the concept does not interfere with activities on the surface.	Very good
5.4	As the concept is located underground, the concept does not interfere with activities on the surface.	Very good

	Operation and maintenance	
6.1	The maintenance frequency is difficult to estimate. It will likely, for the most part, consist of clearing the sand trap.	Good
6.2	Commonplace operation and maintenance will likely, for the most part, consist of clearing the sand traps and inlet grates.	Good
6.3	From time to time, it may become necessary to flush the retention volumes themselves. This is not commonplace operation and maintenance, however.	Neutral
6.4	Trained personnel might be necessary for clearing sand traps and flushing retention volumes.	Very poor
6.5	It does not require watering.	Very good

Suitability to winter condition

7.1	The system does not rely on infiltration. As long as the retention volumes and stormwater pipes are placed below frost depth, they should not be too greatly affected by frost. However, the inlet grates might clog with snow or ice.	Very good
7.2	The concept does not employ vegetation as part of its SWM strategy. However, the vision of the concept is the reuse of water. The purposes for which the water can be reused might be limited by its concentration of road salts.	Somewhat poor
7.3	The soccer field can be used as a snow dump.	Good
7.4	The inlet grates might need cleaning.	Good
7.5	Yes.	Good

Soil conditions

8.1	The concept utilizes drainage to municipal pipes as opposed to utilizing infiltration. If infiltration were used, the groundwater table would be a concern for the efficacy of infiltration and possibly for upwards flow into the retention volumes.	Very good
8.2	Drainage is necessary for preparation for future rainfall events unless sufficient amounts of the retained stormwater are used in between rainfall events.	Poor
8.3	Infiltration does not concern this system.	Neutral
8.4	Yes.	Very good

Environment and biodiversity

9.1	No greenery is added as part of this concept, yet nothing is removed either.	Neutral
9.2	The system itself does not purify the stormwater, though it could be an effect depending on the usage of collected stormwater, as for example, if it was used for watering.	Neutral
9.3	No.	Neutral
9.4	No.	Neutral
9.5	No.	Neutral
9.6	No.	Neutral
9.7	No.	Neutral

D.3 Concept 3: Evaluation notes

	Hydraulic aspects	
1.1	The concept does not have the same potential to drain the stormwater from a wider area as concept 1 does, as instead of channels and swales, the concept utilizes pipes. The usage of pipes, as opposed to channels and swales, further limits the capacity of the system. This does, of course, depend on the diameter of the pipe. Compared to concept 2, There is more piping involved, but the stormwater is stored in open retention ponds.	Good
1.2	This is a given in this thesis.	Very good
1.3	Expanding the capacity of this system will require digging and new pipes.	Somewhat poor

	Multifunctionality	
2.1	There is no system for the storage of stormwater, except in ponds.	Neutral
2.2	The green infrastructure of the concept increases the urban amenity and the recreational value of the surroundings, albeit to a lesser extent than concept 1.	Good
2.3	Other than for the management of stormwater and the recreational benefits the system offers, other functions the system may serve are possibly few.	Neutral

	Surface area requirements	
3.1	The system is planned with less extensive use of surface area than concept 1. However, some of this stems from the use of pipes as opposed to swales and open channels.	Somewhat good
3.2	The concept requires much digging for the stormwater pipes.	Poor

	Subsurface infrastructure	
4.1	The concept is of a similar length to concept 1. Where there are channels and swales in concept 1 (apart from in Torshovdalen), concept 3 utilizes stormwater pipes in the ground. This might be challenging to fit amidst existing infrastructure unless existing stormwater pipes can be fitted into the concept.	Somewhat good
4.2	The concept is designed without a connection to the existing stormwater drainage system in mind. However, existing stormwater pipes could potentially be connected to the system.	Somewhat good
4.3	For this demonstration, this question is irrelevant.	Neutral
4.4	The concept has around 1.5 km of stormwater pipes, which may be difficult to fit.	Somewhat poor

Safety and accessibility		
5.1	The concept is, for the most part, located underground with the exception of the retention ponds and swales in Torhsovdalen and the retention pond in Birkelunden. The safety of the system should at least be as good as for concept 1.	Good
5.2	The ponds do not obstruct accessibility.	Very good
5.3	There should be little risk of drowning if the concept if the system is built in compliance with safety protocols.	Good
5.4	Along the edges of the retention ponds shrubs, and low understory vegetation can be planted. This will not unreasonably impede the line of sight.	Very good

Operation and maintenance		
6.1	The maintenance frequency is difficult to estimate. The retention ponds might require some maintenance, but the pipes, apart from inlet grates, require comparatively little maintenance.	Somewhat good
6.2	Commonplace operation and maintenance will likely not be time-consuming.	Good
6.3	Apart from inlet grates, there is little need for clearing leaves, garbage, or sediments on a regular basis. Seasonal maintenance of the retention ponds will likely include cleaning such as this.	Good
6.4	Trained personnel is necessary when maintaining the pipes.	Somewhat poor
6.5	It might require some watering if the retention ponds are dry over a longer period.	Neutral

Suitability to winter condition		
7.1	A system that somewhat relies on infiltration will suffer some setbacks in efficiency during wintertime, as pores in the soil are clocked with ice. Inlet grates might be clogged with snow/ice.	Good
7.2	The retention ponds and their surrounding vegetation might be affected by the road salt.	Somewhat poor
7.3	The ponds, if suited for such use, can potentially be used as a snow dump. One should consider, however, whether or not the ponds are intended for as efficient as possible infiltration or if they are meant to always hold water (detention/retention), as the infiltration capacity may suffer on a long-term basis under the weight of the snow.	Neutral
7.4	Hard packed or re-frozen snow might clog inlet grates.	Somewhat good
7.5	Yes.	Good

Soil conditions		
8.1	The concept is affected by the groundwater level in the sense that a too high groundwater table might reduce the efficacy of infiltration.	Somewhat poor
8.2	Drainage to municipal stormwater pipes should not be necessary if the infiltration conditions are good. Stormwater exceeding the capacity of retention ponds will discharge to Akerselva.	Good
8.3	The actual conditions are unknown to the author. Good conditions are considered a prerequisite.	Very good
8.4	Yes.	Very good

Environment and biodiversity		
9.1	Yes, although to a lesser extent than concept 1. More varied vegetation in already vegetated areas, such as the parks incorporated in the concepts and the transformation from asphalt and concrete to vegetated zones, provide better conditions for a variety of insects and animals and increase biodiversity.	Somewhat good
9.2	The system facilitates the infiltration of stormwater, albeit to a lesser extent than concept 1. Although this is not the primary goal of the system, it is an effect nonetheless.	Somewhat good
9.3	Yes, although not as much one would achieve with more trees. Trees would have a greater effect on this end than shrubs and understory vegetation. Concept 3 employs less vegetation than concept 1. However, one might not be able to quantify the difference in efficacy of air purification between concepts 3 and 1.	Somewhat good
9.4	To some extent, yes, although not as much as concept 1, the reasoning being the same as for the criteria above. Here, trees would be greatly more efficient than understory vegetation, but shrubs and similar are still a contribution. Even water present on the surface contributes positively through evaporation.	Somewhat good
9.5	To some extent, yes. The zones with retention ponds are located in already existing park areas, so the contribution is limited. However, the further development of said park areas will likely make them more attractive to the public.	Somewhat good
9.6	No.	Neutral
9.7	No, further development of existing parks does not count positively towards this criteria unless additional green zones are added.	Neutral

D.4 Weights used in the MCA trial and sensitivity analysis

Criterion No.	Weight	Criterion No.	Weight	Criterion No.	Weight
1.1	10	5.1	8	8.1	3
1.2	7	5.2	6	8.2	7
1.3	7	5.3	9	8.3	3
2.1	5	5.4	4	8.4	5
2.2	10	6.1	5	9.1	9
2.3	5	6.2	5	9.2	7
3.1	10	6.3	6	9.3	5
3.2	10	6.4	8	9.4	5
4.1	8	6.5	5	9.5	8
4.2	7	7.1	8	9.6	9
4.3	5	7.2	6	9.7	8
4.4	8	7.3	4		
		7.4	5		
		7.5	3		

Table D.1: The table shows the weights used for each criterion in the trial of the MCA. The weights are unchanged for the sensitivity analysis.

Category	Weight
Hydraulic aspects	10
Multifunctionality	7
Surface area requirements	6
Subsurface infrastructure	5
Safety and accessibility	4
Operation and maintenance	6
Suitability to winter conditions	5
Soil conditions	3
Environment and biodiversity	9

Table D.2: The table shows the weights used for each category in the trial of the MCA. The weights are unchanged for the sensitivity analysis.

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