CHALMERS
UNIVERSITY OF TECHNOLOGY

Uncertainty analysis of the rational method in stormwater management

A case study in Gråbo, Lerum municipality, using multi-criteria analysis

Master's thesis in Infrastructure and Environmental Engineering

SIGRID BONDESON

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021
www.chalmers.se

Master's thesis 2021

Uncertainty analysis of the rational method in stormwater management

A case study in Gråbo, Lerum municipality, using multi-criteria analysis

SIGRID BONDESON

Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Engineering Geology
Chalmers University of Technology
Gothenburg, Sweden 2021

Uncertainty analysis of the rational method in stormwater management
A case study in Gråbo, Lerum municipality, using multi-criteria analysis
SIGRID BONDESON

Supervisors:
Anna Ohlin Saletti, Department of Architecture and Civil Engineering
David Hirdman, Lerum municipality
Alva Kalm, Lerum municipality

Examiner:
Lars Rosén, Department of Architecture and Civil Engineering

Master's Thesis 2021
Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Engineering Geology
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Picture of a courtyard in the residential area Segerstaden in Gråbo, Lerum municipality. The picture was taken by the author in January 2021.

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2021

Uncertainty analysis of the rational method in stormwater management - A case study in Gråbo, Lerum municipality using multi-criteria analysis
Master's thesis in Infrastructure and Environmental Engineering
SIGRID BONDESON
Department of Architecture and Civil Engineering
Chalmers University of Technology

Abstract

Stormwater management is an important aspect for municipalities in Sweden and it is of high importance to have a sufficient stormwater system to ensure sustainable cities in regard to economic, social and environmental aspects. The rational method is the most widely used approach for estimating runoff rates in urban catchments. The method incorporates four parameters: rainfall intensity, catchment area, runoff coefficient and a climate factor. Depending on the estimations that are made for the inputs, the calculated, dimensioning flow will have an uncertainty attached to it. No evaluations of the extent of the uncertainty could be found prior to this work. Therefore, the aim with this study was to identify the potential uncertainties in the input parameters of the rational method and to evaluate what effect these uncertainties might have on stormwater management.

Segerstaden is a residential area in Gråbo, Lerum municipality, Sweden, that has problems with unwanted water accumulation. This study investigated suitable stormwater measures for Segerstaden and evaluated the measures with a multi-criteria analysis. The results from an uncertainty analysis of the rational method were integrated in a multi-criteria analysis to evaluate what effects parameter uncertainties in the rational method might have when choosing stormwater measures. The uncertainty analysis was made by means of Monte Carlo simulation in Excel using the ad-in software @Risk.

The study showed that all parameters in the rational method bring some uncertainty to the dimensioning flow as they are based on estimations. The magnitude of the uncertainty showed to be significant in this study, with the 5th percentile flow equal to 118 l/s and 95th percentile flow equal to 756 l/s. The rainfall intensity was shown to have the largest impact on the overall uncertainties in the rational method followed by the catchment area. However, all parameters contribute to the overall uncertainty and the magnitude of it will vary depending on how rough the estimations for the input parameters are. Since the stormwater measures are designed based on a dimensioning flow, the uncertainties in the rational method will have a direct impact on the design of the measures and hence the stormwater management.

Keywords: rational method, stormwater management, stormwater measures, sustainability, uncertainty analysis, multi-criteria analysis.

Acknowledgements

This master thesis is a part of the M.Sc. program in Civil Engineering, Infrastructure and Environmental Engineering, IEE, at Chalmers University of Technology, Gothenburg. The study has been conducted during the spring semester of 2021.

I am sincerely grateful for all the help I have received from my supervisor Anna Ohlin Saletti at Chalmers University of Technology. Thanks to your dedication and support this semester was fun, inspiring and educative.

I would also like to thank my supervisors at Lerum municipality, David Hirdman and Alva Kalm. Your support and feedback have been highly valuable throughout the project.

Last, but not least, I would like to thank the examiner of the thesis, Lars Rosén. Your feedback and input have been very helpful.

Sigrid Bondeson, Gothenburg, June 2021

Contents

List of Figures

List of Tables

1
Introduction

1.1 Background

Stormwater management is an important aspect for municipalities in Sweden. As areas develop and become urbanized, the water balance shifts. Due to the high proportion of hard surfaces in urban areas, there is a decrease in infiltration and an increase in surface runoff (MSB, 2017). Instead of infiltrating, water runs rapidly off the surface and into sewer systems or recipients. A water flow larger than what the system can handle poses a risk of flooding. Therefore, it is of high importance to have a sufficient stormwater system to ensure sustainable cities in regard to economic, social and environmental aspects.

The municipalities face future challenges regarding the stormwater management due to both climate change and densification in cities. Both the overall and extreme precipitation is expected to increase in Sweden, especially in the northern and western part of the country (Naturvårdsverket, 2020). The magnitude of the increase in precipitation depends on the amount of greenhouse gases that will be released. Different climate scenarios are being studied to see their potential effect on future precipitation. The international research on climate change is put together every seventh year by the UN Climate Panel IPCC. These compilations are an important basis for decisions regarding climate change in society (SMHI, 2019). Densification of urban areas can also aggravate the stormwater situation. Increased exploitation leads to increased proportion of hard surfaces which worsens the stormwater situation, hence it is important to consider the stormwater management as cities grow.

To achieve a sustainable stormwater management focus lies on creating opportunities for delay and infiltration of the water (Svenskt Vatten, 2016). The rational method is the most widely used approach for estimating runoff rates in urban catchments (Chin, 2019). The method is based on a linear relation between the runoff coefficient, area of the catchment and the rainfall intensity. A climate factor is often included to consider the future risks of increased precipitation due to climate change. Due to the reason that the dimensioning flow is calculated using estimations of the input parameters the flow will have uncertainty attached to it. However, no evaluations of the extent of the uncertainty could be found prior to this work.

The municipalities in Sweden are responsible for a number of infrastructure services affected by climate change, including stormwater management (Sjöberg et al., 2020).

The municipality of Lerum (situated in the south-west of Sweden, see Figure 1.1), has a goal of having a sustainable, climate adapted stormwater management by 2025, including the aspects of quality, quantity and design (Lerum, 2015b). Most municipalities in Sweden, including Lerum, uses the Swedish Waters publication P110 (Svenskt Vatten, 2016) as a guide and reference in their work with stormwater management. The stormwater runoff calculations in P110 are based on the rational method. That could imply that the stormwater management in Swedish municipalities includes many uncertainties that have not been investigated, which strengthens the need of this study.

Figure 1.1: *Map showing the location of Lerum municipality. The figure is retrieved from SCALGO Live (n.d.).*

In Gråbo, situated in Lerum municipality, more housing is planned to be built and according to an investigation conducted by Tyréns (2020) there are areas in Gråbo that are in the risk of being flooded. Segerstaden is a residential area in Gråbo that, in addition to having problems with water accumulation, also is considered to be uninspiring and unaesthetic with a lot of hard surfaces. It is desirable to create a more socially, economically and environmentally sustainable neighborhood in accordance with the municipality's goal. Inspiration has been looked for in the area of Augustenborg in Malmö which was built with the aim to handle 70% of the stormwater in open systems, something that also increased the aesthetic in the area (VASYD, n.d.).

This study looks deeper into stormwater measures suitable for the Segerstaden area. The proposed measures are evaluated with the help of criteria that are set up in accordance with Lerum municipality. Potential uncertainties in the rational method are investigated through an uncertainty analysis. The results from the analysis are integrated in the evaluation of the stormwater measures using a multi-criteria analysis (MCA) to identify what effects uncertainties in the rational method might have on stormwater management.

1.2 Aim and objectives

The aim of this study is to investigate potential uncertainties in the input parameters in the rational method and to assess these uncertainties' impact on stormwater management. This will be done by integrating the results of an uncertainty analysis of the rational method in a multi-criteria analysis set up to evaluate proposed stormwater measures in an area.

The area Segerstaden in Lerum municipality is used as a case study and three potential stormwater measures are evaluated for the area.

1.2.1 Research questions

The study aims at answering the following research questions:

1. Which are the potential uncertainties of the input parameters and the calculations of dimensioning flow using the rational method?

2. What effect do these uncertainties have on the stormwater management in an urban area?

1.2.2 Limitations of the study

The main aim of the study is to evaluate the rational method and focus is not on solving the stormwater related problems in Segerstaden but rather to suggest a few improvements. Since the rational method is used for stormwater calculations, cloud burst events is not considered. Furthermore, treatment of the stormwater is not taken into account. The stormwater measures that are proposed for Segerstaden are given a general design and needed assumptions are based on literature and discussions with supervisors from Lerum municipality. Details regarding design, construction and implementation of the measures are not presented, and the capacity and connection to the drainage system are not taken into account. Areas up- and downstream Segerstaden are not considered.

The evaluation of the rational method is based on an uncertainty analysis and other relevant evaluation techniques, such as comparison with modelling tools, are not made. Furthermore, the study investigates uncertainties in the parameters of the rational method and not uncertainties of the model. Therefore comparisons with other models used for calculating stormwater flow are not made.

2

Literature and case study

2.1 Climate change and future scenarios

Climate change results in an increase of both the amount and frequency of precipitation in the Västra Götaland region. The development of climate change depends on the amount of greenhouse gases that are emitted into the atmosphere (SMHI, 2015). To study the future climate, assumptions have to be made regarding several factors affecting the amount of greenhouse gas emissions and different modelling tools are used to project the future (IPCC, 2013). The World Climate Research Programme uses a set of scenarios called Representative Concentration Pathways (RCPs). In all RCPs, the concentration of CO_2 in the atmosphere is higher in 2100 relative to today. There are four RCP scenarios, RCP2.6, RCP4.5, RCP6.0 and RCP8.5, and the expected increase of greenhouse gas emissions in 2100 differs between the scenarios with the highest increase represented with RCP8.5 (Hausfather, 2019).

The region Västra Götaland, where Lerum municipality is situated, uses the RCP8.5 scenario in their work with climate adaptation. Two of the underlying assumptions for RCP8.5 is that the CO_2 emissions are three times higher in year 2100 compared to 2021 and that the population of the earth has increased to 12 billion people by 2100 (SMHI, 2015). With RCP8.5, the annual mean precipitation is expected to increase with 25% in the region, with more precipitation events during autumn, winter and spring and dryer periods during summer, see Figure 2.1.

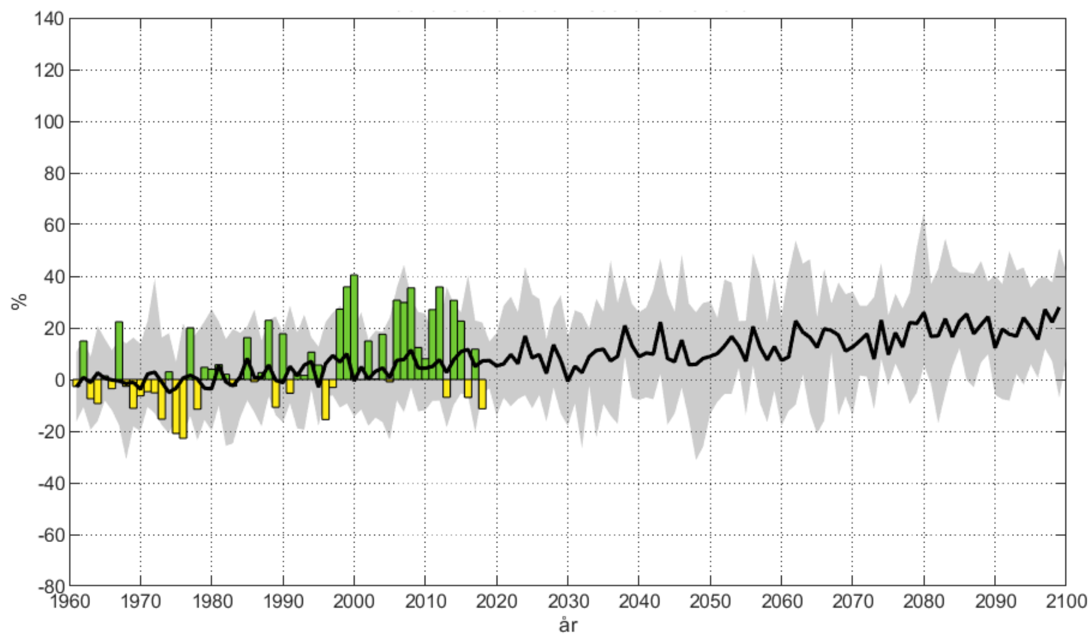


Figure 2.1: *Calculated change in annual precipitation in the Västra Götaland region during the year 1960-2100. The bars show observed data, green bars show precipitation above normal and yellow bars show precipitatin below normal. The black line shows the ensemble mean of nine climate scenarios for the RCP8.5 scenario. The grey field shows the range in variation between the highest and the lowest ensemble. The figure is retrieved from SMHI (n.d.).*

A climate factor can be used to consider the expected increase in precipitation when planning for stormwater infrastructure. It is a multiplier that is applied when calculating the stormwater flow. According to Olsson et al. (2017), a climate factor of 1.1-1.4 is reasonable to use when regarding the mid-century. For the end of the century and RCP8.5, the climate factor should be in the higher span, e.g. 1.3-1.4.

2.2 Urban stormwater management

Dealing with surface runoff is an important part of societies' water management. Expansion and densification of urban areas lead to a continuously increase of hard surfaces. As a result, the natural infiltration decreases leading to more surface runoff and larger peak flows (Stahre, 2004). The role of stormwater management is to collect and divert the precipitation in a sustainable way.

Before the 1950's it was custom to build combined sewers collecting both stormwater and wastewater in the same pipe and leading it to a wastewater treatment plant. However, after the 1960's it became common to separate the pipes constructing what is called a duplicate system (Stahre, 2004). The result of this is that cities today often have combined systems in the older parts and duplicate systems in the outer areas. As cities expand, larger areas is connected to the drainage system leading to an increased risk of exceeding its capacity during heavy precipitation. In areas with insufficient capacity of the drainage network, often areas with a combined sewer system, this might result in an overload of the drainage system with flooding, both in streets and basements, as a consequence (Stahre, 2004).

Floodings affect societal functions and depending on the severity of it, flooding can result in very expensive consequences. An example often referred to is the flooding that occurred in Copenhagen, Denmark, in 2011. The amount of precipitation that normally falls over the city spread out in three months fell down in a period of two hours. This caused severe damages and measured in monetary terms added up to several billion Danish crowns (Sveriges Radio, 2014). To avoid floodings, the water in the sewers might be by-passed into recipients. This is often referred to as combined sewer overflow (CSO) or separate sewer overflow (SSO) if it occurs in a separate system (Ohlin Saletti, 2021). The sewer overflows occur when the capacity of the drainage system is exceeded, leading to untreated water being released into the recipients.

The traditional engineering way of solving the stormwater problem has been to increase the capacity of the drainage system. This can be done in various ways, for example by reconstructing combined sewers into duplicate systems, increase the volume capacity of the pipes or constructing underground reservoirs for temporary delay of the water to flatten the flow peaks. However, expanding the drainage system tend to be a quite costly alternative (Stahre, 2004). A more sustainable approach to solving the problem has in the last decades shown to be various solutions of delaying the stormwater before it enters the sewer system.

2.2.1 Sustainable stormwater management

Sustainable stormwater management is about creating prerequisite for the stormwater to imitate the natural path of the water, including more open and greener stormwater measures. It is characterized by many types of actions which focuses on delaying the water near the source and to enable as much infiltration in the ground as possible (Svenskt Vatten, 2016). In addition to this, a sustainable stormwater measure should have capacity to retain water during extreme events such as cloud bursts.

The view of stormwater management has changed from being mostly about the quantity until around 1975, to integrate a focus on the water quality until around 1995 and since then to also include the design aspect (Svenskt Vatten, 2011). The Water authorities (Vattenmyndigheterna) have been assigned the task of implementing the EU Water Framework Directive (WFD) in Sweden (Vattenmyndigheterna, n.d.). They have developed the following eight aims to work towards to ensure a sustainable water management (Svenskt Vatten, 2011):

1. Decrease eutrophication
2. Decrease the effects of climate change

3. Protect groundwater
4. Balance between fishing industry and sustainable stocks
5. Prevent leakage from contaminated sites or sediment
6. Restore migration routes for fish etc.
7. Prevent flooding
8. Decrease emissions of toxic substances

Number 1, 2, 3, 7 and 8 from the list should be considered in the work with sustainable stormwater management. The momentary flows and potential toxic substances in stormwater should be minimized as much as possible before the water reaches the recipient (Svenskt Vatten, 2011).

Several of the Nordic countries have suffered from flooding due to cloudbursts. These problems can not be solved by increasing the capacity of the traditional sub-terrain stormwater measures. The driving force to finding alternative and greener solutions is therefore large (Persson et al., 2018). These solutions are a complement to the traditional measures and they are capable of handling both lighter and heavier precipitation events. There are also requirements concerning the pollution of the stormwater. The European Water Framework Directive (WFD) aims at achieving a good status regarding pollution in all water bodies in the European Union (European Comission, n.d.). This should be achieved with emission limits and quality standards. In 2015, the European court settled that member states are compelled to refuse projects that would result in a worsening of the water quality of a water body. This case is commonly called "The Weser Case" and it affects what measures can be implemented e.g. concerning treatment of stormwater (Bjällås, Fröberg, & Sundelin, 2015). This is especially important if the recipient is sensitive. Furthermore, there is an increase in the interest of making the water visible and using stormwater measures as a positive element in the cityscape (Stahre, 2004).

Stormwater management affects the entire society and no person or authority has full responsibility of it. Multiple stakeholders such as authorities, municipalities, property owners and individuals are affecting and have responsibility of the content, flow and direction of the stormwater. The municipality, however, plays several roles and have a number of responsibilities in the work with stormwater management (Lans, 2020).

Three common stormwater measures are explained in section 2.2.2 - 2.2.4 below.

2.2.2 Green roofs

Green roofs offer an opportunity to locally slow down stormwater runoff. As the name implies, a green roof is a stormwater measure where vegetation on roofs are used to collect and delay precipitation (Stahre, 2004). It can be applied both on new and existing buildings as long as the inclination of the roofs are not to steep and that the constructions are able to carry the extra weight. With green roofs, the hard surfaced roofs with a high runoff coefficient are substituted with roofs with a lower coefficient. The thickness of the green roof may vary depending on its design and therefore the potential delay capacity varies. According to Lerum (2015b), a 50mm thick roof with sedum vegetation can decrease the yearly runoff from the roof with approximately 50%. The potential of treating the water with green roofs is low, however the water that falls on a roof is relatively clean since it has not yet come in contact with polluted surfaces.

There are several other reasons for building green roofs besides reducing stormwater runoff. They have a good insulation effect hindering heat from escaping the building but they can also have a cooling effect, reducing heat islands in cities. Moreover, green roofs increase the biodiversity in the area as well as improve the aesthetics. The vegetation on the roof allows for evapotranspiration and together with the storage capacity of the roof this can have big effect on the water balance. Even when there is runoff from a green roof this is normally low in relation to the runoff of other surfaces, and the delay of the runoff is beneficial in itself (Bengtsson et al., 2005).

The runoff from green roofs occurs when the soil on the roof is at its maximum capacity which corresponds to its storage capacity. When a precipitation event occurs, there will be no runoff from the roof in the beginning, given that the roof is not saturated at the start. The runoff will start if the precipitation continues after the roof is saturated. An example is shown in Figure 2.2 from Augustenborg in Malmö, 5 May 2002. As shown in the figure, precipitation begins slightly in the second hour of the day and increases for the third and fourth hour. The runoff is smaller than the precipitation until the fifth hour, indicating that the soil on the roof is saturated at that time. After the fifth hour the runoff is approximately the same as the precipitation.

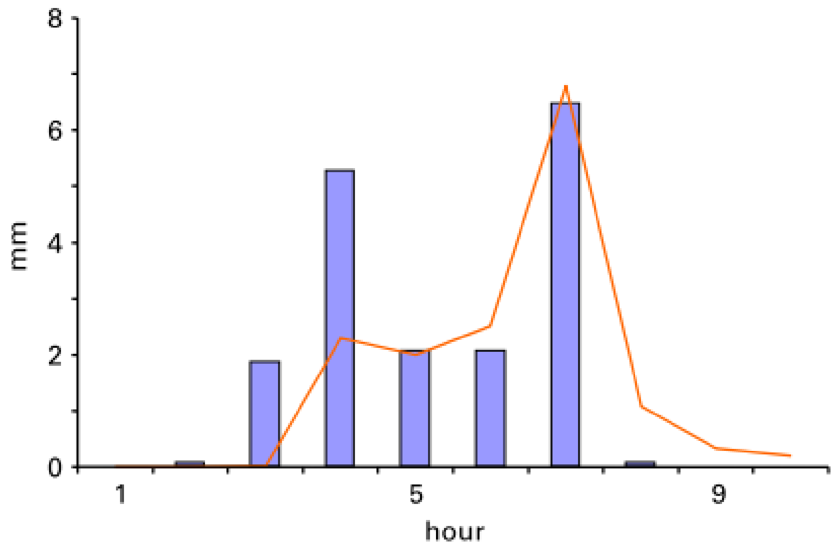


Figure 2.2: *Hourly precipitation (bars) and runoff (line) from a thin green roof in Augustenborg, Malmö, 5 May 2002. The figure is retrieved from Bengtsson et al. (2005).*

Green roofs require some maintenance, e.g. fertilization, raking and control of roof drains and gutters (Lerum, 2015b).

2.2.3 Wet pond with a flooding area

A wet pond is a pond with a permanent water mirror, i.e it does not dry out. It is one of today's most common stormwater measure to gather and delay stormwater before releasing it to the recipient (Stahre, 2004). To increase the capacity of the pond, it can be designed to have a flooding area around the permanent water mirror. A flooding area is an area that is allowed to be flooded during heavier precipitation. When ponds are located in residential areas they can contribute with recreational values. Moreover, ponds can provide ecosystem services in form of being a habitat for various species and taking up CO_2. Depending on the ponds dimensions and the choice of vegetation, some treatment of the water is possible where sedimentation is one of the most important treatment processes (Blecken, 2016).

Normally, the size of the pond should be somewhere between 100 - 300 m^2 per hectare contributing to runoff. Depending on the placement of the pond, the design of it must consider safety aspects. This is normally done by regarding the depth and side slopes of the pond. Maintenance is required to ensure a well functioning pond and often includes control of the inlet and outlet, sludge suction and overall maintenance of the vegetation (Lerum, 2015b).

2.2.4 Underground stormwater reservoir

There are several different versions of underground reservoirs and they are normally implemented in areas where there is no possibility to delay water on the surface (Lerum, 2015b). The reservoirs can be made out of different materials and with different shapes, e.g. concrete, casted in situ, or plastic, shaped as big pipes (Svenskt Vatten, 2004).

Underground reservoirs have a good ability to reduce the peak flow, preventing flooding and reducing the pressure on the drainage network. As the underground reservoir have a good ability to delay water, its treatment ability is not its main advantage. However some sedimentation could be enabled depending on the design of the reservoir (Larm & Blecken, 2019).

Implementing an underground reservoir could be a beneficial solution in areas with low infiltration capacity or where there is limited space. However, many of the above mentioned goals with sustainable stormwater management are not met with an underground reservoir. For example, it does not contribute to the aesthetics in the area (Lerum, 2015b).

2.3 The rational method

The rational method is one of the most common tools for urban runoff hand calculations (e.g., Schärer et al., 2020; Chin, 2019; Östlind, 2012). It is internationally recognized and has been used since the early 20th century. The rational method is applicable for dimension of both open and closed stormwater measures, i.e drainage pipes and open measures such as ponds and dikes. The method incorporates the basic parameters controlling the size of the stormwater flow: rainfall intensity, size and runoff coefficient of the catchment area (Svenskt Vatten, 2016). For the rational method the design flow is calculated as:

$$Q_d = i(t_r)A\varphi cf \tag{2.1}$$

Where:

Q_d	Dimensioning flow	[l/s]
$i(t_r)$	Rainfall intensity	[l/s, ha]
A	Catchment area	[m^2]
φ	Runoff coefficient	[−]
cf	Climate factor	[−]

The catchment area is based on the topographical boundary dividing adjacent catchments with a higher elevation, such as a ridge or crest. This is also called a water shed. However, during heavy rainfall the water flow could be high enough to overflow a catchment area and continue to another catchment with lower elevation. That makes the choice of boundaries, hence the size, of the catchment area dependent on the precipitation event.

The runoff coefficient is a measure of the proportion of a catchment area that contributes to the runoff. It always has a value between 0 and 1 which depends on the land use, the inclination of the area and the intensity of the rain. A larger precipitation event and steeper inclination gives a higher value of the runoff coefficient. For example, a green area might be considered having a runoff coefficient of 0.2, meaning that the runoff from that area is assumed to be 20%. When using dimensional rainfall intensities for areas with moderate inclination, as is the case for this study, tabulated values can be used for the runoff coefficient (Svenskt Vatten, 2016). When the studied catchment area is made up of subareas with different runoff coefficients, a weighted runoff coefficient can be used. This is calculated with equation 2.2.

$$\varphi = \frac{A_1\varphi_1 + A_2\varphi_2 + \ldots A_n\varphi_n}{A_1 + A_2 + \ldots A_n} \tag{2.2}$$

The rainfall intensity is calculated with equation 2.3.

$$i(t_r) = 190\sqrt[3]{T}\frac{\ln(t_r)}{(t_r)^{0.98}} + 2 \tag{2.3}$$

Where:

$i(tr)$	Rainfall intensity	[l/s, ha]
T	Return time	[months]
t_r	Duration	[minutes]

The climate factor in equation 2.1 is included to consider the future risk of increased precipitation when planning for new stormwater infrastructure or changes in the existing built-up areas. In Lerum municipality a climate factor of 1.4 is assumed to be reasonable to account for the possible scenarios in 2100 with RCP8.5 as mentioned in section 2.1 (Olsson et al., 2017).

Calculations with the rational method are normally made with the assumption of it and the input parameters being deterministic, i.e. that all necessary data is available and that the outcome can be calculated with a 100% certainty.

When using the rational method it is conventionally assumed that (1) the entire catchment area is contributing to the runoff, (2) the rainfall is equally distributed over the catchment and (3) the runoff coefficient incorporates all rainfall abstractions (Chin, 2019).

2.4 Uncertainty analysis

The use of the rational method is widespread and results from calculations where it is included form the basis for many important decisions. This motivates the need of an uncertainty analysis of the method (Behrouz & Alimohammadi, 2018). Whenever there is a lack of information and estimations have to be made when solving a problem, there will be an uncertainty connected to it. With an uncertainty analysis, it is possible to quantify the variability of the output that is due to the variability of the input. Uncertainties can be found in many places e.g. in a model or experiment set up, it can be due to numerical uncertainties or connected to the input parameters (Geffray et al., 2018). Regarding the rational method, estimations are made when defining the input parameters, making the outcome, the dimensioning flow, somewhat uncertain.

2.4.1 Aleatory and epistemic uncertainty

Uncertainty can be divided into different types, two of them being aleatory and epistemic uncertainty. Epistemic uncertainty has its origin in incomplete knowledge and can occur due to various reasons e.g. measurement error, natural variation, model uncertainty and subjective judgement (Burgman, 2005). Aleatory, or inherent, uncertainty is affected by inherent randomness of a variable and can not be reduced by increasing information. This is typically the case of measured quantities (Behrouz & Alimohammadi, 2018). Aleatory and epistemic uncertainty should be treated separately regarding uncertainty propagation and validation. Epistemic uncertainty should be described by an interval which is usually determined by judgement of what seems to be reasonable. An epistemic variable can be made aleatory if experiments are conducted to estimate its value. An uncertainty can be described by using a probability density function (Geffray et al., 2018), which is a statistical expression that defines the likelihood of an outcome for a variable (Burgman, 2005).

2.4.2 Monte Carlo method

The Monte Carlo method is a mathematical technique used to estimate the possible outcomes of an uncertain event (IBM, 2020). In a Monte Carlo simulation, statistical distributions are used to represent different kinds of uncertainty, combining them to generate estimates of an outcome (Burgman, 2005). A Monte Carlo simulation generates a range of possible outcomes with the probability of each result occurring (IBM, 2020). This enables justification of systems, clarification of problems and, not least, identification of important parameters. The method is often applied in risk management, not least for environmental risk assessment.

2.5 Multi-criteria analysis

To consistently handle large amounts of information in order to make a decision is sometimes challenging but can be facilitated using a decision support method such as multi-criteria analysis (MCA). MCA is used to establish preferences between alternatives. It is based on defined and chosen objectives for which measurable criteria has been established in order to assess to what extent the option meets the objectives. Depending on how the MCA is performed, it can provide a decision-maker with different results. A MCA can be conducted to identify a single most preferred option, to rank different options or to distinguish between acceptable and unacceptable options. The number of ways, and hence outcomes, of MCAs is dependent on several factors influencing it, such as time, data, analytical skills and requirements (Dodgson et al., 2009).

A few of the advantages of MCA is that it is open and explicit, that objectives and criteria may be changed if necessary and that it can be useful in the communication with stakeholders. It is common that the alternatives and criteria are displayed in a performance matrix, see Table 2.1.

Table 2.1: *Performance matrix of four alternative products (here toasters of different models) which are judged by five criteria. The criteria are of different types: quantitative (price and number of flaws) binary (reheat and adjustable opening) and qualitative (evenness in toasting). From Dodgson et al. (2009).*

Product	Price	Reheat setting	Warming rack	Adjustable sloth width	Evenness of toasting	Number of drawbacks
Model 1	18			✓	good	3
Model 2	27	✓	✓	✓	very good	3
Model 3	25	✓	✓		good	3
Model 4	20	✓		✓	very good	5
Model 5	22	✓			very good	2

An important aspect of MCA is the subjectivity that might be attached to it. As the analysis is conducted, the decision makers determine choices of objectives, criteria, weights and scores. These choices makes the analysis subjective (Dodgson et al., 2009).

2.5.1 The linear additive method

As already mentioned, a MCA can be conducted in different ways depending on the wanted outcome. One of the most commonly used methods within a MCA is the linear additive method where scoring and weighting are included to make a numerical analysis (Rosén et al., 2009).

Each alternative is given a score, R, within a set interval, e.g 0-100. This should reflect how well the alternative fulfill each criterion, i (i=1. . . N). The criteria are then assigned weights, W, with a numerical value, e.g. 0-10. This should reflect the importance of the specific criterion (Dodgson et al., 2009). The weights and scores are then added up to a total score for each specific alternative with the following formula:

$$Score = \sum_{i=1}^{N} W_i R_i \tag{2.4}$$

Thus, an option with a high score for a high weighted criterion will have a better overall score than a high score for a low weighted criterion.

The weighted score is summed up for each alternative which enables a ranking of the alternatives. For the linear additive method to work, it requires the criteria to be independent. If some criteria are dependent on each other there is a risk of some aspects receiving too big importance due to double counting (Rosén et al., 2009).

2.5.1.1 Local and global scaling

An interval scale has to be established before assigning scores to the alternatives. The scale should define the level of performance corresponding to any two reference points on the scale. It could vary between only positive scores, e.g. 0 to 100, or include negative scores, e.g. -10 to 10.

Furthermore, a choice between using global or local scaling has to be made. With a global scaling, the lowest score would represent the worst level of performance possible in a general decision of the type currently being addressed, and the highest score would represent the best possible level of performance. However, with a local scaling, the lowest score would represent the worst performance among the studied options and the highest score would represent the best performance. Thus when using local scaling, the scoring could change drastically if a new alternative is added to the study.

An advantage with global scaling is that it better enables the accommodation of new alternatives in the study, since it does not affect the scoring of the other alternatives. A disadvantage is that it requires more time since the extremes of the scale have to be identified in order to assign scores (Rosén et al., 2009). A local scaling does not require judgement of the worst or best performance. However, there is a risk of mislead scores when using a local scale. For example, if all studied alternatives perform badly for a criterion, the alternative performing least worst would still be assigned the highest score. The choice between local and global scaling should not make a difference to the ranking of alternatives.

2.5.1.2 Weighting

The weighting of the criteria can with advantage take place during a workshop where the attendants are concerned with the issue in some way (e.g., Brisvåg, 2017; Selin, 2020; Dodgson et al., 2009). The workshop enables a discussion between the participants in which they may agree upon the priority and importance of each criterion. It is important that a sufficient number of participants, representing a variety of views, attend the workshop to make sure different perspectives are taken into account.

2.6 Case study

Segerstaden is an area situated in Gråbo in the municipality of Lerum in the south-west of Sweden, see Figure 2.3.

Figure 2.3: *To the right: map showing where Lerum and Gråbo are situated in relation to Gothenburg. To the left: map showing where Segerstaden (marked with black line) is situated in Gråbo. The figures are retrieved from SCALGO Live (n.d.).*

Segerstaden is a residential area with 140 apartments divided on 10 two-storage buildings that were constructed in the 1960s (Förbo, n.d.). Two additional buildings (the two buildings in the south-west corner of the area) were constructed in 2020. The soil in Segerstaden is mostly comprised of clay (*SGUs Kartvisare*, n.d.-a), and its depth varies between 10 and 50 meters (*SGUs Kartvisare*, n.d.-b). The permeability varies in the area with high permeability in the north and low permeability in the south (*SGUs Kartvisare*, n.d.-c).

Exploitation of areas upstream Segerstaden have resulted in increased stormwater flow in Segerstaden and the area occasionally suffers from floodings. A study conducted by Tyréns (Björkman et al., 2019) shows how the urban areas in Lerum, including Gråbo and Segerstaden, might suffer from floodings during heavier precipitation events.

The municipality of Lerum has a vision of becoming the leading municipality in Sweden with regards to environmental sustainability by 2025 (Lerum, 2015a). According to the strategic plan for stormwater management in Lerum (Lerum, 2015a), sustainable stormwater management includes flattening of the peaks in runoff water, removal of pollutants in the stormwater and constructing stormwater measures that contributes positively to the design of the area. The stormwater management should be adapted to the recipient, topography, hydrology, climate change and extreme weather. In their stormwater manual (Lerum, 2015b) it is stated that the dimensioning of stormwater measures should be in accordance with Swedish Water's publication P110 (Svenskt Vatten, 2016).

3

Method

3.1 Flow chart

This study incorporated three different approaches to answer the research questions. These were: a literature and case study (Section 3.2), an uncertainty analysis (Section 3.3) and a multi-criteria analysis (Section 3.5). Figure 3.1 is a flow chart describing the steps of the approaches and their interrelations.

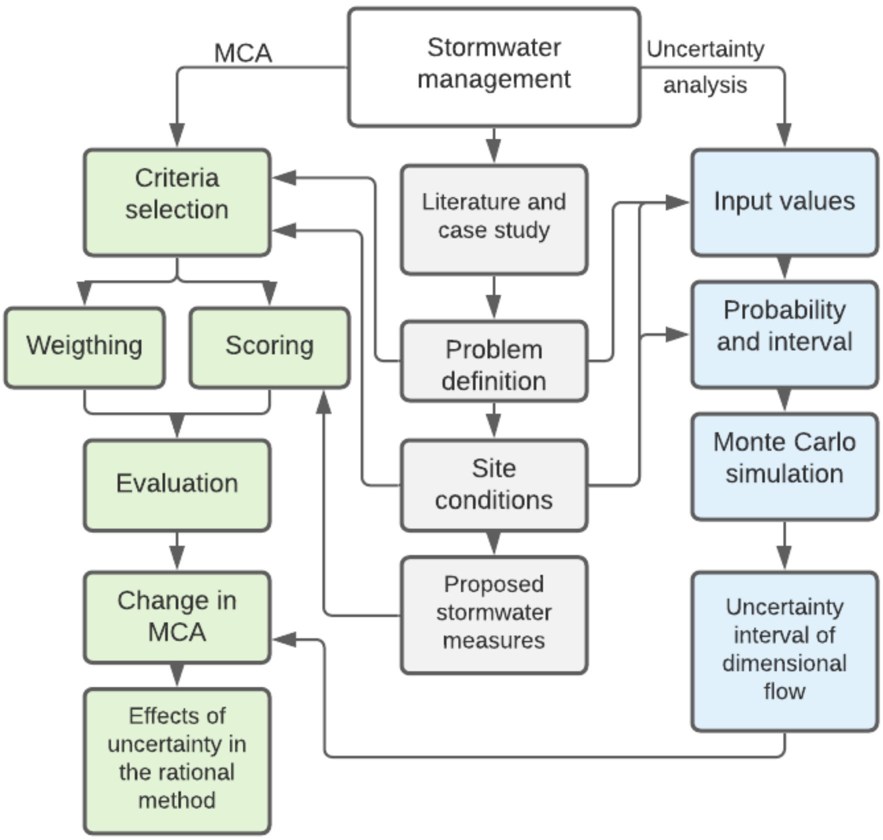


Figure 3.1: *Flow chart describing the steps and interrelations of the different approaches of the study. The steps of the literature and case study are shown in the grey boxes, the steps of the uncertainty analysis in the blue boxes and the steps of the multi-criteria analysis in the green boxes. The flow chart was developed with the online diagramming tool provided by Lucid (n.d.).*

3.2 Literature and case study

A literature study was conducted early in the project to gain knowledge about the topic. Five areas were focused on during the literature study in order to answer the research questions. These were; climate change, urban stormwater management, the rational method, uncertainty analysis and multi-criteria analysis. The results from the literature study is mainly what composes Chapter 2 in the report. In addition to this, the gained knowledge forms the basis of the choice and design of the proposed stormwater measures as well as the criteria for the MCA.

The literature study included scientific journals, other studies with similar approaches, documents from Lerum municipality as well as consulting reports. The Scopus database has been frequently used to search for relevant information as well as Google Scholar and Chalmers Library. Some examples of keywords that have been searched for are "climate adaptation", "stormwater measures", "uncertainty analysis" and "multi-criteria analysis". Furthermore, publications from Swedish Water (Svenskt Vatten) have been frequently used, especially P110 and P105 (Svenskt Vatten, 2016, 2011). The book "Sustainability in urban storm drainage: planning and examples" written by Stahre (2004) has been a rich source of both information and inspiration. The deceased Peter Stahre was an internationally recognized pioneer in sustainable stormwater handling.

Segerstaden served as a case area where the MCA could be applied. Problems with flooding in the area were investigated and based on that potential solutions, i.e. stormwater measures, were proposed. It was important to have an urban area that enabled the use of the rational method to calculate the stormwater flows. The stormwater strategy (Lerum, 2015a) and manual for stormwater handling in Lerum municipality (Lerum, 2015b) facilitated the choice of criteria for the MCA and had an impact on the choice of the proposed stormwater measures. Through the case study and the MCA, it was possible to evaluate the potential uncertainties in the rational method and their effects on the choice of stormwater measures.

3.2.1 Flow calculation

The dimensioning flow in Segerstaden was calculated using the rational method which is described in Section 2.3. The calculation was performed with the conventional use of the rational method where deterministic values are used as input data. To separate this flow from the flows generated in the uncertainty analysis, the conventionally calculated flow will from here on be called general flow.

Four factors are included in the rational method: catchment area, runoff coefficient, rainfall intensity and a climate factor. The two latter were based on requirements and recommendations from Lerum municipality and the climate factor was included as deterministic value in this project. The methods for retrieving information about the catchment area and runoff coefficient are described in Section 3.2.1.2 and 3.2.1.3. In the manual for stormwater management in Lerum municipality (Lerum, 2015b), it is stated that the stormwater measures can be designed to have an outflow of 15 l/s ha. To account for this, the allowed outflow was subtracted from the flow before calculating the required delay volume.

3.2.1.1 Rainfall intensity

The rainfall intensity was calculated with equation 2.3. The choice of return time and duration was based on Lerums demands. According to Lerum (2015b), the requirements for delay of stormwater within the municipality is to delay precipitation with a 10-year return time. For this type of calculations it is common to set the duration to 10 minutes and according to A. Kalm (personal communication, March 19, 2021) this was suitable for this study as well.

3.2.1.2 Catchment area

The site was investigated by using SCALGO Live which is a platform used for studying flood risks (SCALGO, n.d.). The precipitation event was simulated in the software tool which made it possible to see where the water tended to accumulate, i.e. where there is a potential risk of floodings. By placing a marker on that spot SCALGO Live provided information about the corresponding catchment area, including its size. This was made for the location where water tended to accumulate and it was possible to place the proposed stormwater measures.

3.2.1.3 Runoff coefficient

Three weighted runoff coefficients were calculated with different approaches using equation 2.2 and the tabulated values for runoff coefficients presented in Table 3.1. SCALGO Live provided information about the land cove of the catchment area, i.e. information about the subareas made up of buildings, hardened surfaces and green areas. This was used for the first approach when calculating the runoff coefficient. The second approach wast to more carefully retrieve the size of different sub-areas with different land covers in AutoCAD. The total area of roofs was calculated, as well as the total area of green areas, roads, etc. The third approach was to divide the catchment area into two areas, one with Open construction (the Segerstaden area) and one with Villas > 1000 m^2 (the area north of Segerstaden) and use the already weighted runoff coefficients.

The three approaches for calculating the runoff coefficient resulted in an interval of the weighted coefficient. This interval was used as an input for the uncertainty analysis of the rational method. The average value of the three weighted runoff coefficients were used for the general flow calculation with the rational method.

3.2.1.4 Climate factor

In the manual for stormwater management in Lerum municipality (Lerum, 2015b) it is specified that a climate factor of 1.25 should be used. However this has been updated to a climate factor of 1.4 to be up to date with more recent studies (D.

Table 3.1: *Runoff coefficients for different types of surfaces and building types for short duration design rainfall. Translated to English from P110 (Svenskt Vatten, 2016).*

Surface type	**Runoff coefficient, φ**
Roof without storage	0.9
Concrete or asphalt, outcrop with large slope	0.8
Cobbled stone with gravel joints	0.7
Gravel road	0.4
Outcrop with small slope	0.3
Gravel path	0.2
Park	0.1
Lawn, pasture, etc	0-0.1
Forest, no slopes	0-0.1
Weighted runoff coefficients	
Building type	**Runoff coefficient, φ**
Open construction (apartments)	0.4
Villas, sites < 1000 m^2	0.35
Villas, sites > 1000 m^2	0.2

Hirdman, personal communication, March 26, 2021). According to Olsson et al. (2017), a climate factor of 1.3 - 1.4 is better suited for when looking at RCP8.5 and planning for the end of the century. Lerum municipality is following a precautionary principle and hence a climate factor of 1.4 is used.

3.2.2 Choice and capacity of stormwater measures

The choice of the proposed storm water measures was based on the examples of sustainable stormwater from Stahre (2004) that could also be found in Lerum's manual for stormwater handling (Lerum, 2015b). Inspiration was also looked for by studying the area Augustenborg in Malmö (Scandinavian Green Roof Institute, 2016). In addition to this, it was considered interesting to propose measures with different focus. One alternative included more vegetation, being the greener alternative, another alternative focused more on being an open system showing the water, being the blue-green alternative, and the third focus was on proposing a construction solving the problem but not being an open, visible solution, being the grey alternative. This resulted in the three measures Green roofs (green alternative), Wet pond with a flooding area (blue-green alternative) and Underground stormwater reservoir (grey alternative). To facilitate the reading of the report, the wet pond with a flooding area will from here on be called Pond and the underground stormwater reservoir will be called Underground reservoir.

SCALGO Live was used to find the best location for the stormwater measures. The software provides tools to study the depressions in the area as well as the flow and water paths. This information made it possible to find a suitable location for the measures to be implemented, which is preferably where the water naturally tends to accumulate. The topography of the area was studied both in SCALGO Live and in AutoCAD, which is a computer-aided design software (AUTODESK, n.d.). A base map of the area, readable in AutoCAD, was provided by Lerum municipality. In AutoCAD it was possible to study the contour lines in the area. In SCALGO Live the topography was shown as a 3D map.

Information about site specific dimensions needed to design the stormwater measures were retrieved from AutoCAD. Principal designs were presented for all measures and detailed, more technical, design features were not investigated. Further information about the measures is presented in section 3.2.2.1 - 3.2.2.3.

3.2.2.1 Green roofs

For this alternative, it was assumed that all buildings in the Segerstaden area could carry the load from a sedum roof and that they have a suitable inclination.

The storage capacity of the green roofs was calculated based on P110 (Svenskt Vatten, 2016), which states that a 50 mm deep green roof have the capacity to store 5-10 mm of precipitation. Here 10 mm was used for the calculations. With the correlation 1 mm = 1 l/m^2 and the known area of the green roofs, the delay capacity could be calculated in litres and finally in m^3 for easier comparison with the other measures.

3.2.2.2 Pond

When designing the pond and flooding area, both the storage capacity as well as its aesthetics were considered important. The pond and its flooding area were designed based on recommendations from Larm and Blecken (2019) and discussions with supervisors at Lerum municipality.

It was assumed that an elongated, narrow, pond is perceived to be more safe than for example a wider or more circular pond. A narrower pond also allows for curves to be integrated in the shape, creating a more natural looking watercourse. For this case, however, the pond was designed as a straight watercourse as the specific shape and design were not assumed to have an effect on the results of the study.

3.2.2.3 Underground reservoir

The Underground reservoir was designed as a cuboid made in concrete with a depth of 1.2 m. According to Larm and Blecken (2019), underground reservoirs may have a size varying from a few cubic meters to for example a construction in Tokyo with a volume of 250 000 m^3. For this study it was assumed sufficient to use basic volume calculations regarding the dimensions of the reservoir.

3.2.3 Cost estimates of stormwater measures

Various literature, e.g. earlier studies, websites of suppliers and consultant reports, were studied in order to estimate both the investment and the operation and maintenance costs for the measures. However, the cost estimates were considered deficient in many reports. This was due to the fact that it is difficult to estimate costs in such an early stage and in most of the literature it was described that the cost estimates should be considered highly uncertain. Furthermore, different studies used different methods to estimate costs. If the cost estimation for green roofs had been retrieved in a very different way than the cost estimate for the reservoir, this could lead to an unfair comparison.

Finally, a Norwegian study conducted by Magnussen et al. (2015) was found most accurate for the cost estimates. The purpose of this study was to get an overview of the costs for implementing and maintaining measures to reduce the risk of flooding in urban areas. The three measures in this study were included in the Norwegian study. This meant that the method for estimating the costs were the same for all measures. The costs in the study were in NOK and was therefore converted to SEK according to the exchange rate for 2015, when the study was published. No net present value calculations were made in the study.

3.3 Uncertainty analysis

The uncertainty analysis of the parameters in the rational method was performed with @Risk which is an add-in to Microsoft Excel that enables risk analyses using Monte Carlo simulations. The obtained results show all possible outcomes, in this case all possible water flows, and how likely they are to occur.

In the Monte Carlo simulation, one or several inputs are each given an interval and a probability distribution. This means variables can have different probabilities of different outcomes occurring. There are a large number of probability distributions and which one to use depend on the behaviour of the input data.

3.4 Model setup for the uncertainty analysis

The model setup in @Risk was conducted with three steps:

1. Defining the problem in Excel

   A Spreadsheet was created in Excel with the four input parameters (rainfall intensity, area, runoff coefficient and climate factor) and a calculation according to equation 2.1 was defined.

2. Identifying uncertainties - defining possible values for the input parameters and assigning probability distributions to the parameters

   Possible intervals were identified for all input parameters, except for the climate factor which was assigned the deterministic value of 1.4. The choice of distribution was based on the explanations of the different probability distributions provided in @Risk and in dialog with the supervisor. The reasoning behind the inputs are presented in Table 3.2.

   @Risk allows for correlation between input parameters. It was assumed that the rainfall intensity and area had a positive correlation, i.e. a change in the intensity would result in a change of the area. The correlation was calculated with the Spearman's Rank Order Correlation with the following formula:

$$\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 (y_i - \bar{y})^2}}$$

   Where:

ρ	correlation
x_i, y_i	input values
$\bar{x}, \bar{y}$	average values

3. Running the model and analyzing the results

   The simulation was run with 10 000 iterations.

Table 3.2: *Chosen distributions and motivation for input parameters in @Risk.*

Rainfall intensity	
Distribution	LOGNORM. Rainfall intensities can be represented by a log-normal distribution (Ahmed & Ali, 2016) which has a limited lower value but no absolute upper limit.
Mean	The mean value of the rainfall intensities corresponding to rain events with 2-, 5-, 10- and 20-year return time as these return times are often considered in stormwater management.
Standard deviation	The calculated standard deviation of the rainfall intensities.
Area	
Distribution	Beta-PERT. The input values have an upper and lower limit and using a Beta-PERT distribution was assumed more realistic than using a triangular distribution.
Min.	The minimum value of the distribution was set to the smallest area retrieved from SCALGO Live. It corresponds to a precipitation event with a 2-year return time.
Max.	The maximum value of the distribution was set to the largest area retrieved from SCALGO Live. It corresponds to precipitation events from a 5-, 10- and 20-year return time.
Most likely	The maximal area was also assumed to be the most likely since it was retrieved for almost all studied rain events.
Runoff coefficient	
Distribution	Beta-PERT. The input vales have an upper and lower limit and using a Beta-PERT distribution was assumed more realistic than using a triangular distribution.
10%	The 10th percentile of the distribution was set to the lowest value retrieved with the different approaches described in section 3.2.1.3.
90%	The 90th percentile of the distribution was set to the highest value retrieved with the different approaches described in section 3.2.1.3.
Most likely	The most likely parameter was set to the average value of the three approaches described in section 3.2.1.3.

3.5 Multi-criteria analysis

The multi-criteria analysis method was used to evaluate the suggested stormwater measures in a transparent and structured way. The method can be divided into three steps, selection of criteria, scoring and weighting. These are described in section 3.5.1 - 3.5.3 below.

3.5.1 Selection of criteria

The selection of criteria was based on literature regarding the topic as well as demands and strategic goals posed by Lerum municipality. The demands and goals from Lerum focus on sustainability and the criteria were therefore connected to the three pillars of sustainability: social, economic and environmental aspects. A fourth category, technical, was also added. This enabled an evaluation of the performance of the measures outside the consideration of the sustainable aspects.

Each criterion had been used in at least one studied report which strengthens its motivation for being used in this study. The criteria were also discussed together with the supervisors to make sure they were appropriate.

3.5.2 Weighting

The weighting of the criteria was conducted in a workshop together with representatives from Lerum municipality. The method was inspired by the studies conducted by Brisvåg (2017) and Selin (2020).

Five participants from Lerum municipality were invited to the workshop. They had competences in varying areas and were supposed to bring different perspectives to the discussions. A list of the participants and their role in stormwater handling in Lerum municipality is presented in Appendix A. The workshop was digital and held on Zoom due to the Covid-19 pandemic. The schedule for the workshop is presented in Appendix B.

3.5.3 Scoring

The scoring followed a global scaling and it was conducted together with the supervisors of the study. For some criteria it was possible to define a quantitative scale and for the other criteria they were assigned scores with a qualitatively defined scale. Prior to the scoring of the measures, the supervisors from Lerum municipality were asked to decide what results that would give the highest and the lowest score for the criteria for which it was possible to follow a quantitatively defined scale.

During the scoring, the measures were assigned a score from -10 to 10 for each criterion. The three proposed scenarios, Green roofs, Pond and Underground reservoir, got scores based on how well they performed in comparison with a null alternative. The null alternative meant doing nothing, i.e. not implementing any measure to help with the stormwater handling in the area. See Table 3.3 for explanation.

Table 3.3: *Generic explanation of the scoring in the multi-criteria analysis.*

Score	Qualitatively defined scale	Quantitatively defined scale
-10	Performs very much worse than the null alternative	Example of the best possible (yet reasonable) result imaginable
0	Performs equal to the null alternative	Example of a result that would have the same effect as the null alternative
10	Performs very much better than the null alternative	Example of the worst possible (yet reasonable) result imaginable

4
Results

4.1 Site conditions

There are several depressions in Segerstaden which explains the problems with floodings in the area. The flow network as well as the depressions were investigated in SCALGO Live and can be seen in Figure 4.1.

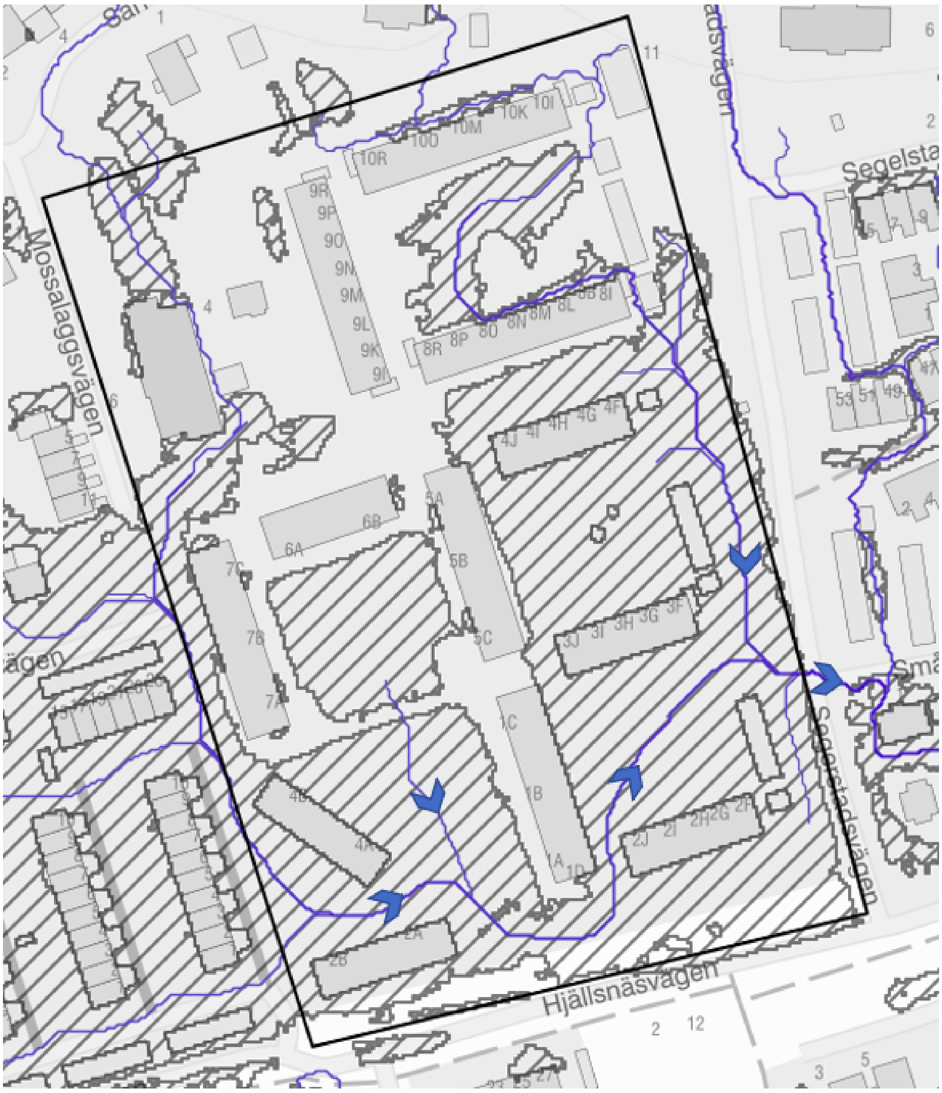


Figure 4.1: *Showing depressions (grey striped areas) and flow network (blue lines) in the Segerstaden area (marked with black line).*

The flow network shows that the water flows from the northern parts and ends up in the south-east courtyard. From there it flows out of the area, which can be seen in Figure 4.1. This makes the south-east courtyard a suitable location for the stormwater measures. Additionally, the south-east courtyard is accessible for machines by the road and parking located on its east side. This facilitates both the construction and maintenance of the stormwater measures.

4.2 General flow in Segerstaden

The general flow within the Segerstaden area was calculated using equation 2.1, 2.2 and 2.3. The catchment area and information about the sub-areas were retrieved from SCALGO Live, see figure 4.2.

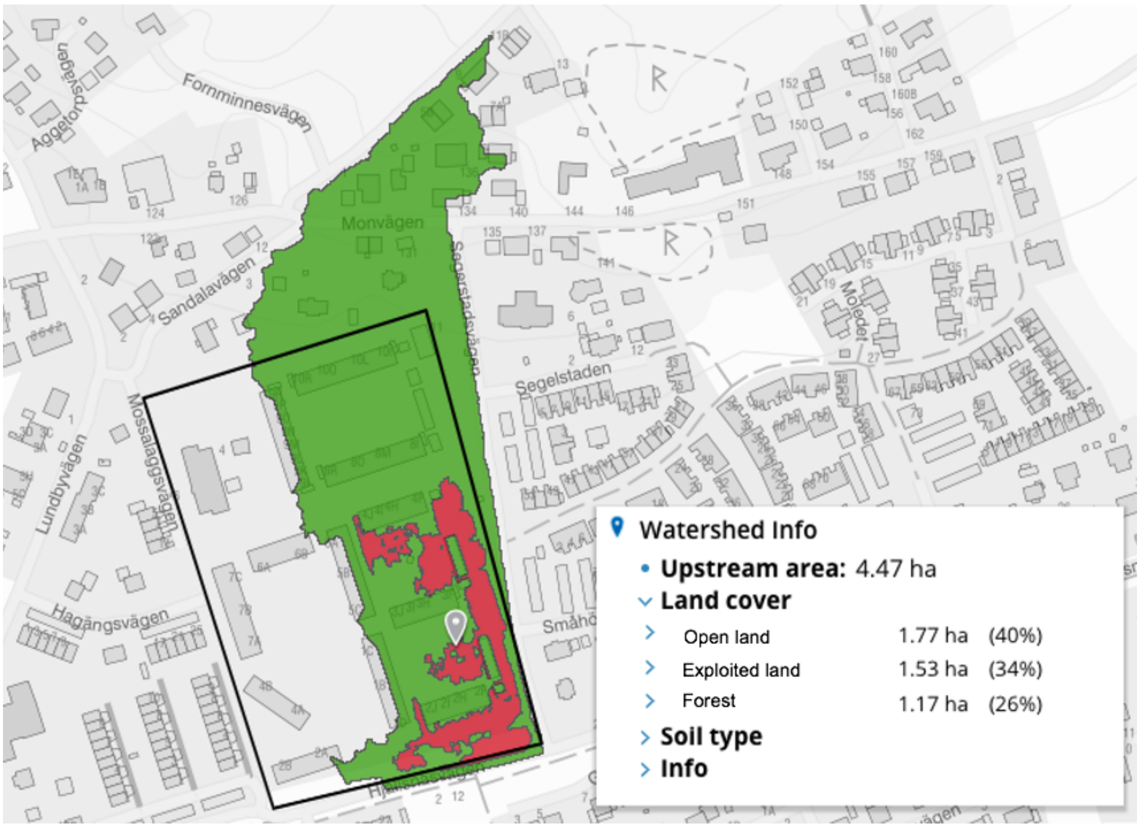


Figure 4.2: *Catchment area retrieved from SCALGO Live. The catchment corresponds to a 19.2 mm rain which corresponds to a rainfall intensity of 319 l/s,ha (which equals the calculated rainfall intensity of 228 l/s,ha times the climate factor of 1.4). The marker is placed at the proposed location of the stormwater measures and the black line shows the boundaries of the Segerstaden area.*

As described in Section 3.2.1.3, three weighted runoff coefficients were retrieved with different approaches. The first approach was to use information regarding the land cover in SCALGO Live and resulted in a weighted runoff coefficient of 0.34. The second approach was to more carefully retrieve the size of sub-areas from Auto CAD and resulted in a weighted runoff coefficient of 0.31. The third approach was to use the already weighted runoff coefficients presented in P110 (Svenskt Vatten, 2016) and resulted in a weighted runoff coefficient of 0.32. The average value was calculated to 0.32 and this was used to calculate the general flow.

The input values and the general flow are compiled in Table 4.1.

Table 4.1: *Input values and general flow for the Segerstaden area.*

Input values		
Rainfall intensity	228	[l/s ha]
Area	4.47	[ha]
Runoff coefficient	0.32	[-]
Climate factor	1.40	[-]
General flow		
Flow	463	[l/s]

The allowed outflow of 15 l/s,ha was subtracted from the general flow and then a required volume to delay for a duration of 10 minutes was calculated to 238 m^3. The calculation are presented in more detail in Appendix C.

4.3 Uncertainty analysis

The probability distributions used for the uncertainty analysis in the rational method are presented in Table 4.2

Table 4.2: *Input values for the uncertainty analysis conducted in @Risk.*

Rainfall intensity	(l/s,ha)
Distribution	LOGNORM
Mean	207
Standard deviation	90
Area	(ha)
Distribution	Beta-PERT
Min.	0.12
Max.	4.47
Most likely	4.47
Runoff coefficient	(-)
Distribution	Beta-PERT
10%	0.31
90%	0.34
Most likely	0.32

The correlation between the rainfall intensity and area was calculated to 0.75.

The results from the uncertainty analysis of the rational method show that the stormwater flow varies quite a lot depending on the input parameters, see Figure 4.3.

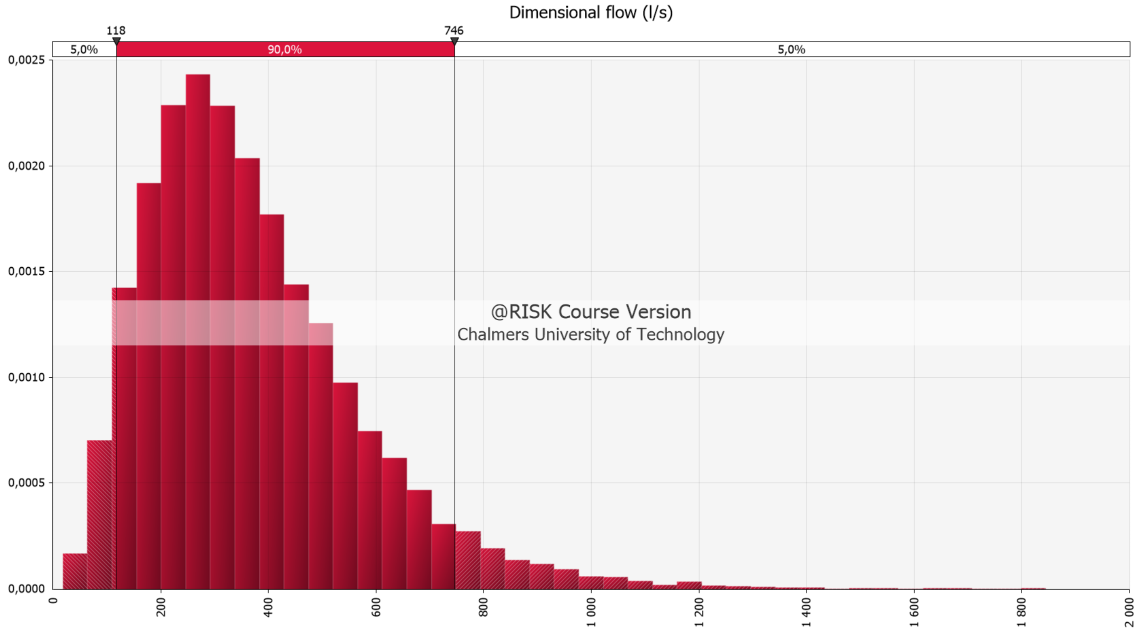


Figure 4.3: *Graph showing the probability density of the dimensioning flow. The 5th percentile flow equals 118 l/s and the 95th percentile flow equals to 756 l/s. The figure is retrieved from @Risk.*

As shown in Figure 4.3, the flow is 118 l/s for the 5th percentile and 746 l/s for the 95th percentile. The mean flow is equal to 369 l/s and the median flow is equal to 332 l/s.

Figure 4.4 shows the inputs ranked by the effect they have on the output mean. Each bar indicates how much the mean flow changes as a particular input parameter varies over its range. In this case, the rainfall intensity has the greatest effect on the mean flow. As the rainfall intensity varies between its values, and the other parameters remain at their static values, the mean flow varies between 121 and 790 l/s. All parameters have a positive correlation with the flow, i.e. an increase of a parameter will result in an increase of the flow.

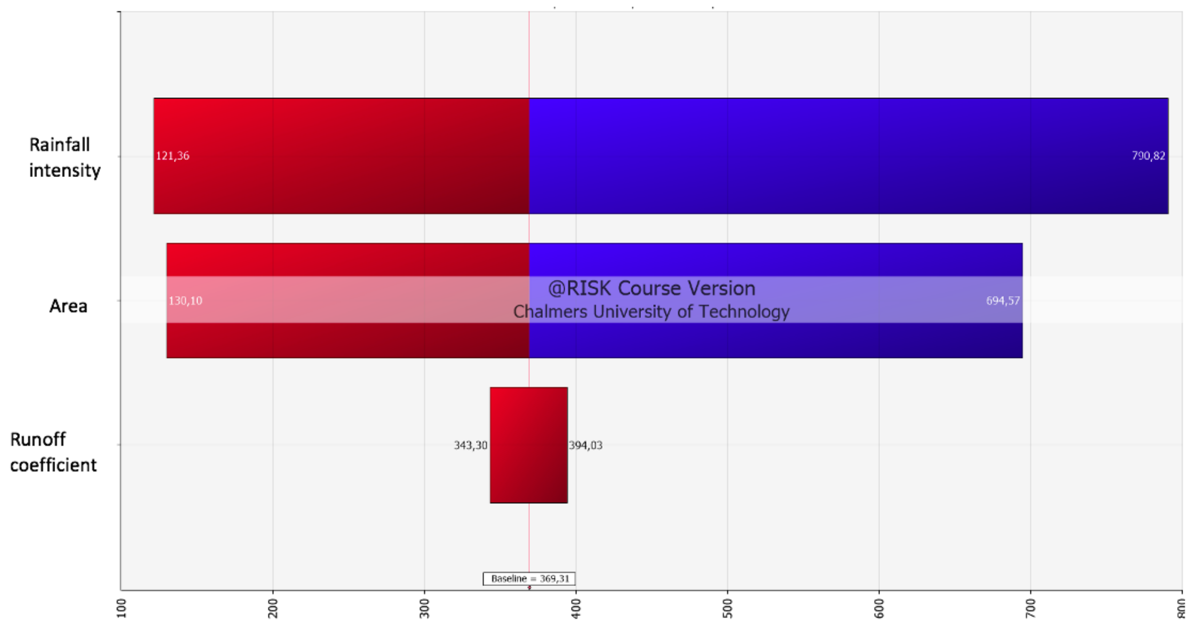


Figure 4.4: *Inputs ranked by effect on the output mean. The figure is retrieved from @Risk.*

More detailed results of the uncertainty analysis are presented in Appendix D. The flows and their corresponding required volume to delay are presented in Table 4.3. As for the general flow, the allowed outflow of 15 l/s,ha was subtracted from the 5th and 95th percentile flows before the required volumes to delay for a duration of 10 minutes were calculated.

Table 4.3: *The 5th and 95th percentile flows retrieved from @Risk and their corresponding required delay volume.*

5th percentile	
Flow	118 [l/s]
Required delay volume for a duration of 10 minutes	31 [m^3]
95th percentile	
Flow	746 [l/s]
Required delay volume for a duration of 10 minutes	407 [m^3]

4.4 Design of the stormwater measures

As mentioned in Section 3.2.2, the stormwater measures were given principal designs. The designs of the measures were adapted to the required volume to delay corresponding to the general flow, the 5th percentile flow and the 95th percentile flow.

The Pond and the Underground reservoir were designed with three different set of dimensions. The 5th percentile flow retrieved from the uncertainty analysis corresponds to the smallest dimensions and the 95th percentile flow corresponds to the largest dimensions. Hence the general flow corresponds to the second biggest design. The area of the Green roofs is limited by the area of the roofs in the catchment area. For the 5th percentile flow, not all roofs are needed to have a sufficient area of Green roofs. However, at a flow of 179 l/s, which corresponds to the 15th percentile flow, the Green roofs are maximized, being given to all buildings within Segerstaden and the catchment area.

With the different dimensions, the costs for constructions and maintaining the measures also changed. The dimensions and corresponding costs are presented in Table 4.4. For the Pond measure it is the dimensions of the flooding area that are described.

Table 4.4: *Dimensions, volume capacities, and costs for the stormwater measures presented for the general flow as well as the 5th and 95th percentile flows.*

	Green roofs	**Flooding area (Pond)**	**Underground reservoir**	Unit
General flow				
Length		34	20	m
Width		12.5	10	m
Depth		1	1.2	m
Area	6723 (maximized)	425	200	m^2
Delay volume	67	238	240	m^3
Investment cost	3 193 264	912 713	1 596 000	SEK
Operation and maintenance cost	38 319	6 617	11 400	SEK/Year
5th percentile				
Length		12	8	m
Width		3.5	4	m
Depth		1	1.2	m
Area	3057	42	32	m^2
Delay volume	31	30	38	m^3
Investment cost	1 708 600	106 020	255 360	SEK
Operation and maintenance cost	20 500	2 665	1 824	SEK/Year
95th percentile				
Length		40	30	m
Width		19	11.5	m
Depth		1	1.2	m
Area	6723 (maximized)	756	345	m^2
Delay volume	67	408	410	m^3
Investment cost	3 193 264	1 582 320	2 753 100	SEK
Operation and maintenance cost	38 319	9 845	19 665	SEK/Year

The flooding area of the pond was designed to have a slope of 1:7 and this was considered in the volume calculations.

Figure 4.5 shows sketches of the Pond and the Underground reservoir for all three flows at the selected location. As shown in Table 4.4, the widest and longest measure is the Pond designed for the 95th percentile flow which has a length of 40 m and a width of 19 m. Constructing a pond with these dimensions would occupy a large part of the available surface, however it should be considered that the dimensions presented in Table 4.4 are just proposals and their main purpose is to show that it is possible to delay the required volume.

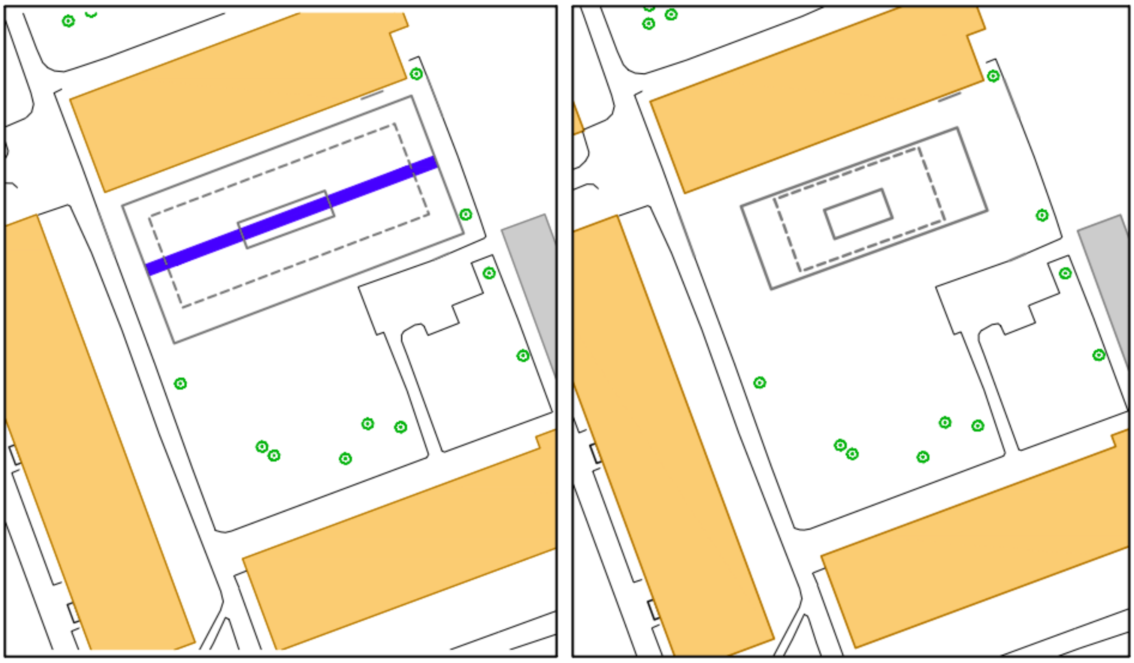


Figure 4.5: *Sketches of the Pond and Underground reservoir placed in the south-east courtyard which has a length of 46 m and a width of 23 m. The figure to the left shows sketches of the Pond. The biggest square shows the design for the 95th percentile flow, the striped square shows the design for the general flow and the smallest square shows the design for the 5th percentile flow. The blue rectangle shows the permanent water mirror. The figure to the right shows sketches of the Underground reservoir. The biggest square shows the design for the 95th percentile flow, the striped square shows the design for the general flow and the smallest square shows the design for the 5th percentile flow. The sketches are made in AutoCAD.*

Figure 4.6 shows a proposal of the buildings that could be given green roofs in Segerstaden.

Figure 4.6: *Buildings with green roofs. The figure to the left corresponds to the 5th percentile flow and the selection of buildings given green roofs is a proposal. The figure to the right shows that all buildings in the catchment area are given green roofs which corresponds to a flow of 179 l/s which is the 15th percentile flow retrieved from @Risk.*

4.5 Multi-criteria analysis

The results for the multi-criteria analysis are divided in different sections. First, the criteria are presented (4.5.1) followed by the weighting (4.5.2) followed by the scores (4.5.3).

4.5.1 Selection of criteria

The criteria that were identified and selected for the study are presented in Table 4.5.

Table 4.5: *Chosen criteria with references to studies using the same or similar criteria. In the referred studies multi-criteria analyses were also used as a decision support for stormwater measures.*

Category	Criterion	Reference to studies using similar criteria
Environmental	Biodiversity	Bergqvist (2014), Brisvåg (2017), Kangas (2016) and Selin (2020)
	Stormwater as a resource	Selin (2020), Makropoulos et al. (2008) and Ellis et al. (2004)
Socio-cultural	Acceptance	Makropoulos et al. (2008)
	Recreation	Brisvåg (2017), Ellis et al. (2004), Kangas (2016) and Selin (2020)
	Safety	Makropoulos et al. (2008)
	Innovation and development	Brisvåg (2017) and Selin (2020)
Economic	Investment cost	Bergqvist (2014), Brisvåg (2017), Ellis et al. (2004), Kangas (2016), López (2018), Makropoulos et al. (2008) and Selin (2020)
	Operation and maintenance cost	Bergqvist (2014), Brisvåg (2017), Kangas (2016), López (2018), Makropoulos et al. (2008) and Selin (2020)
	Land use	Bergqvist (2014), Brisvåg (2017), Makropoulos et al. (2008) and Selin (2020)
Technical	Performance stormwater	Bergqvist (2014), López (2018) and Makropoulos et al. (2008)
	Life span	Bergqvist (2014), Brisvåg (2017), Ellis et al. (2004), Kangas (2016), López (2018), Makropoulos et al. (2008) and Selin (2020)
	Adaptability	Brisvåg (2017), Makropoulos et al. (2008) and Selin (2020)

The categories and criteria are presented in more detail in section 4.5.1.1 - 4.5.1.4.

4.5.1.1 Environmental criteria

The Environmental category includes two criteria, Biodiversity and Stormwater as a resource. The criteria are presented in Table 4.6 with an explanation of what should be valued when performing the scoring in the MCA.

Table 4.6: *Criteria in the Environmental category with an explanation of what should be valued when performing the scoring in the multi-criteria analysis.*

Criterion	**Explanation**
Biodiversity	Values how well the measure increases the biodiversity in the area. For example, more vegetation would increase the biodiversity both by itself and by increasing the number of species in the area since it would provide food and shelter for insects
Stormwater as a resource	Values how well the measure can provide stormwater for reuse in the area, for example for irrigation

4.5.1.2 Socio-cultural criteria

The Socio-cultural category includes four criteria, Acceptance, Recreation, Safety and Innovation and development. The criteria are presented in Table 4.7 with an explanation of what should be valued when performing the scoring in the MCA.

Table 4.7: *Criteria in the Socio-cultural category with an explanation of what should be valued when performing the scoring in the multi-criteria analysis.*

Criterion	**Explanation**
Acceptance	Values how big the acceptance of the measure is assumed to be among the residents in the area
Recreation	Values how much recovery and pedagogical value the solution is expected to contribute with to the residents in the area and to the children in the nearby preschool
Safety	Values the health risk of the measure, e.g. risk of drowning or slipping
Innovation and development	Values the innovation of the measure and how well it contributes to the development of the area. An innovative system might lead to attention and a higher status of the area

4.5.1.3 Economic criteria

The Economic category includes three criteria, Investment cost, Operation and maintenance cost and Land use. The criteria are presented in Table 4.8 with an explanation of what should be valued when performing the scoring in the MCA.

Table 4.8: *Criteria in the Economic category with an explanation of what should be valued when performing the scoring in the multi-criteria analysis.*

Criterion	**Explanation**
Investment cost	Values how big the overall implementation cost is. An eventual expansion of the drainage network is not included
Operation and maintenance cost	Values how big the operation and maintenance cost is in average per year
Land use	Values how much land the measure occupies. The possibility to use the land for other functions should also be considered

4.5.1.4 Technical criteria

The Technical category includes three criteria, Performance stormwater, Life span and Adaptability. The criteria are presented in Table 4.9 with an explanation of what should be valued when performing the scoring in the MCA.

Table 4.9: *Criteria in the Technical category with an explanation of what should be valued when performing the scoring in the multi-criteria analysis.*

Criterion	**Explanation**
Performance stormwater	Values how well the measure performs during normal and lighter precipitation events, i.e., how much delay capacity the measure has
Life span	Values the expected life span of the measure
Adaptability	Values how flexible the measure is for changes, e.g., if its capacity needs to be increased

4.5.2 Weighting of criteria

The results from the weighting, which came out of the workshop with the municipality of Lerum, are presented in Table 4.10.

Table 4.10: *Weighting of criteria in the multi-criteria analysis.*

Category	Criterion	Weight	
Environmental	Biodiversity	15	7.5
	Stormwater as a resource		7.5
Socio-cultural	Acceptance	15	2.5
	Recreation		3.5
	Safety		2.0
	Innovation and development		7.0
Economic	Investment cost	30	10.0
	Operation and maintenance cost		15.0
	Land use		5.0
Technical	Performance stormwater	40	12.8
	Life span		20.8
	Adaptability		6.4

As can be seen in Table 4.10, the Technical category was considered most important with a weight of 40%. It was followed by the Economic category which got 30% and the Environmental and Socio-cultural categories got 15% each. The Life span criterion was considered most important with a weight of 20.8% and the Safety criterion was considered least important with a weight of 2%. It should however be noted that Lerum municipality during the workshop stated that they would not implement a solution that could pose a severe risk for the residents.

4.5.3 Scoring of measures

The scores in the MCA are presented in Table 4.11. These are the scores corresponding to the measures designed for the general flow presented in Table 4.1, i.e. without consideration of uncertainties in the rational method.

Table 4.11: *Scoring of measures in the multi-criteria analysis. The scores corresponds to the measures designed for the general flow.*

Category	Criterion	Score		
		Green roofs	Pond	Underground reservoir
Environmental	Biodiversity	4	5	0
	Stormwater as a resource	4	4	0
Socio-cultural	Acceptance	2	4	1
	Recreation	2	8	0
	Safety	1	-3	2
	Innovation and development	4	6	1
Economic	Investment cost	-2	4	2
	Operation and maintenance cost	-4	2	-1
	Land use	2	-6	-2
Technical	Performance stormwater	2.8	10	10
	Life span	4	3	3
	Adaptability	2	8	1

More detailed explanations of the scoring for each category are presented in section 4.5.3.1 - 4.5.3.4.

4.5.3.1 Environmental category

The scores in the Environmental category are presented in Table 4.12. It was assumed that the design of the pond and its flooding area was standardized when scores were assigned for the Biodiversity criterion. A standardized pond would have some vegetation hence there would be an increase of the biodiversity in the area. However, the increase would not be as big as it could have been if the focus on vegetation was bigger. Despite this, the Pond got the highest score among the alternatives. The Green roofs are assumed to contribute with more vegetation and therefore also with more insects, increasing the biodiversity in the area. The Underground reservoir was not assumed to have an effect on the biodiversity of the area and therefore it scored 0.

For the criterion Stormwater as a resource it was assumed that the water in the pond could potentially be used for irrigation, however it would depend on the purity of the water. When the Green roofs are saturated, the rain falling on them could be collected and used for irrigation as well, therefore the two measures scored the same. The water in the Underground reservoir would not be accessible and therefore it scored a 0 for the Stormwater as a resource criterion as well.

Table 4.12: *Scores in the Environmental category.*

Criterion	Score		
	Green roofs	**Pond**	**Underground reservoir**
Biodiversity	4	5	0
Stormwater as a resource	4	4	0

4.5.3.2 Socio-cultural category

The scores in the Socio-cultural category are presented in Table 4.13. It was assumed that the overall acceptance of the Pond would be quite high as it would most likely contribute positively to the aesthetics in the area. However, complaints sometimes received from residents regarding ponds is that it attracts mosquitoes to the area. Therefore the Pond does not score higher than a 4. Regarding the Green roofs, they are assumed to be accepted as they also contribute to the aesthetics in the area. The underground reservoir is assumed to be accepted as it improves the stormwater situation in the area without taking up space on the surface. It is not, however, assumed to have a big positive impact on the acceptance and therefore it got a low, yet positive, score.

The Pond is assumed to contribute to the recreation as it would bring open water and more vegetation to the area. The Green roofs scored a 2 since they bring more vegetation to the area but it is on the roofs and not very accessible to the residents. The Underground reservoir was not assumed to have an impact on the recreation.

The Green roofs and the Underground reservoir are not assumed to have a direct impact on the safety in the area. However, they would improve the stormwater situation which could also be seen as a safety issue since floodings potentially can be harmful. Therefore they scored more than 0 but not very high. The Pond could pose a risk for small children and the slope on the flooding area could increase the risk of slipping, therefore it got a negative score.

Both the Green roofs and the Pond got quite high scores for the Innovation and development criteria. This is because they are assumed to contribute to the overall status in the area by reducing the problems with flooding with visible measures increasing the aesthetics. The Underground reservoir is assumed to increase the status as it improves the stormwater situation but in addition to that it is not assumed to contribute to innovation and development.

Table 4.13: *Scores in the Socio-cultural category.*

Criterion	**Score**		
	Green roofs	**Pond**	**Underground reservoir**
Acceptance	2	4	1
Recreation	2	8	0
Safety	1	-3	2
Innovation and development	4	6	1

4.5.3.3 Economic category

The scores in the Economic category are presented in Table 4.15. These are based on the quantitatively defined scale presented in Table 4.14 and the dimensions and inputs presented in Table 4.4.

Table 4.14: *Quantitatively defined scale for the Economic category.*

Criterion	**Unit**
Investment cost	**SEK**
Gives a score of -10	10 000 000
Gives a score of 0	2 000 000
Gives a score of 10	500 000
Operation and maintenance cost	**SEK/year**
Gives a score of -10	100 000
Gives a score of 0	10 000
Gives a score of 10	1000

For the Land use criterion, only the Green roof alternative receive a positive score. This is because the alternative does not claim any new land. In addition to this, green roofs are proven to increase the effect of solar panels which is considered beneficial in case solar panels are installed on the roofs in the future. The Pond scores quite low since it, and especially its flooding area, occupies a large area. The Underground reservoir does not claim a lot of land, however it might affect the future possibilities of usage of the area above it. For example, it might be restrictions regarding what vegetation could be planted on the area or how big load it can take.

Table 4.15: *Scores in the Economic category.*

Criterion	Score		
	Green roofs	Pond	Underground reservoir
Investment cost	-2	4	2
Operation and maintenance	-4	2	-1
Land use	2	-6	-2

4.5.3.4 Technical category

The scores in the Technical category are presented in Table 4.17. These are based on the quantitatively defined scale presented in Table 4.16 and the results presented in Table 4.1. The quantitatively defined scale for the Performance stormwater criterion is adapted to the studied site and scenario with a score of 10 corresponding to the delay requirement in Segerstaden for the general flow. A percentage of how much of the volume each measure could delay was calculated and the measures were assigned scores correspondingly. The purpose of the measures is to delay the stormwater and a delay of 0 m^3 would result in a score equal to 0 as this would represent the null alternative. It was assumed impossible for the measures to receive negative scores since that would imply that the measures added to the stormwater in the area which is unreasonable.

The life span for the Green roofs was assumed to be 50 years and for the Pond and Underground reservoir it was assumed to be 40 years. Based on this and the quantitatively defined scale, the Green roofs were assigned a score of 4 and the Pond and Underground reservoir were assigned a score of 3.

Table 4.16: *Quantitatively defined scale for the Performance stormwater criterion corresponding to the general flow.*

Criterion	Unit
Performance stormwater	**m^3**
Gives a score of -10	-
Gives a score of 0	0
Gives a score of 10	260
Life span	**Years**
Gives a score of -10	5
Gives a score of 0	20
Gives a score of 10	100

With two of the three criteria having a quantitatively defined scale, the scoring for this category was quite straight forward. Only the Adaptability criterion demanded a more thorough discussion. The Green roof alternative was not considered very adaptable after being implemented. The area is set, due to the limited square meters of roofs in the area. The depth of the roofs could be increased, however this would almost be to reconstruct the roofs completely. Therefore the Green roof alternative was given a 2 for the Adaptability criterion. The Pond is assumed to be very adaptable. It could be elongated, made deeper, given more vegetation, etc. Therefore it scored quite high for the Adaptability criterion. The Underground reservoir is not considered to be very adaptable however some small changes could be made and therefore is got a positive, but low, score.

Table 4.17: *Scores in the Technical category.*

Criterion	**Score**		
	Green roofs	**Pond**	**Underground reservoir**
Performance stormwater	2.8	10	10
Life span	4	3	3
Adaptability	2	8	1

4.5.4 Results of the multi-criteria analysis

The total scores for the general flow for each stormwater measure are presented in Table 4.18. The Pond scores much higher than both the other measures. However, the Green roofs and Underground reservoirs scores quite similar.

Table 4.18: *Results of the multi-criteria analysis for the general flow.*

	Green roofs	**Pond**	**Underground reservoir**
Environmental	60	68	0
Socio-cultural	42	74	13
Economic	-70	40	-5
Technical	131	241	197
Total score	163	423	205

The result of the MCA for the general flow is also presented in a diagram in Figure 4.7 for better visualization.

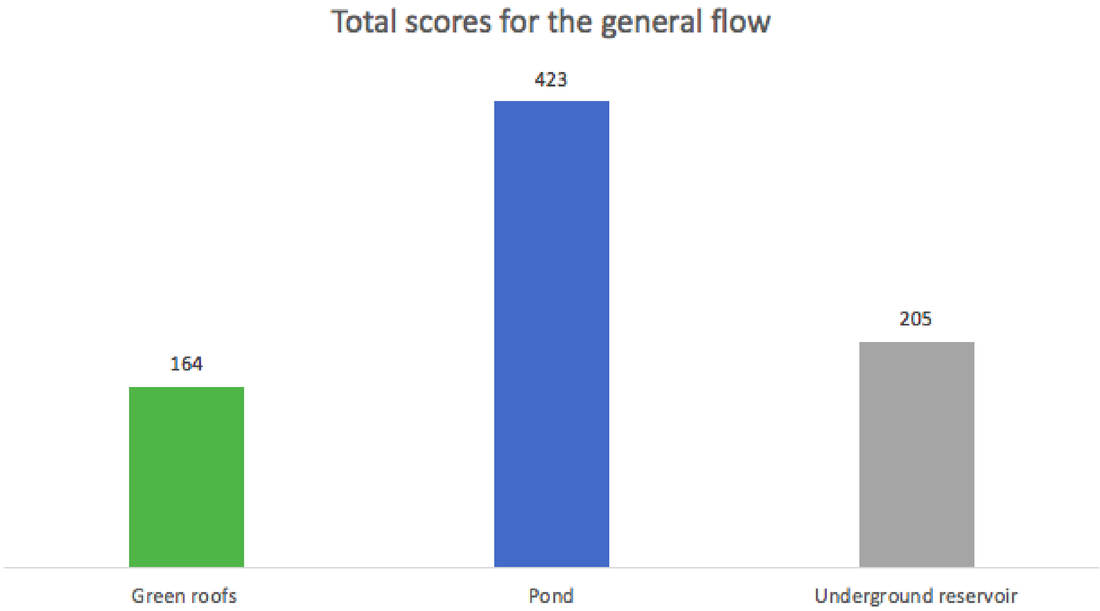


Figure 4.7: *Diagram with the total scores for the general flow in the multi-criteria analysis.*

4.5.5 Uncertainty integration in the multi-criteria analysis

To integrate the results from the uncertainty analysis in the MCA, the 5th and 95th percentile flows from the uncertainty analysis were used as inputs for new delay requirements. The 5th percentile flow corresponds to a delay requirement of 36 m^3 and the 95th percentile flow corresponds to a delay requirement of 452 m^3. The quantitatively defined scale for these flows are presented in Tables 4.19 and 4.20. As already mentioned, a delay of 0 m^3 would result in a score equal to 0, as this represents the null alternative and it was assumed impossible for the measures to receive negative scores.

Table 4.19: *Quantitatively defined scale for the Performance stormwater criterion corresponding to the 5th percentile flow.*

Criterion	Unit
Performance stormwater	$\mathbf{m^3}$
Gives a score of -10	-
Gives a score of 0	0
Gives a score of 10	36

Table 4.20: *Quantitatively defined scale for the Performance stormwater criterion corresponding to the 95th percentile flow.*

Criterion	Unit
Performance stormwater	$\mathbf{m^3}$
Gives a score of -10	-
Gives a score of 0	0
Gives a score of 10	452

All other quantitatively defined scales remained the same.

As shown in Table 4.4, the dimensions of the measures varied depending on the flow. This resulted in new scores for the Land use, Investment cost, Operation and maintenance cost and the Performance stormwater criteria. The new scores for these criteria for the 5th and 95th percentile are presented in Tables 4.21 and 4.22.

Table 4.21: *Changed scores for the 5thpercentile flow.*

Criterion	Score		
	Green roofs	**Pond**	**Underground reservoir**
Land use	3	-4	-1
Investment cost	4	10	10
Operation and maintenance cost	-1	6	8
Performance stormwater	10	10	10

Table 4.22: *Changed scores for the 95th percentile flow.*

Criterion	Score		
	Green roofs	**Pond**	**Underground reservoir**
Land use	2	-7	-3
Investment cost	-2	1	-1
Operation and maintenance cost	-4	1	-2
Performance stormwater	1.7	10	10

4.5.6 Alternative results of the multi-criteria analysis

The overall result of the MCA changed with the new scores for the 5th and 95th percentile flows. The results of the MCA for each flow are presented in Table 4.23.

Table 4.23: *Results of the multi-criteria analysis for all studied flows.*

Flow	Total score		
	Green roofs	**Pond**	**Underground reservoir**
General	164	423	205
5th percentile	366	553	425
95th percentile	150	373	155

The results of the MCA for each flow are also presented in a diagram in Figure 4.8 for better visualization.

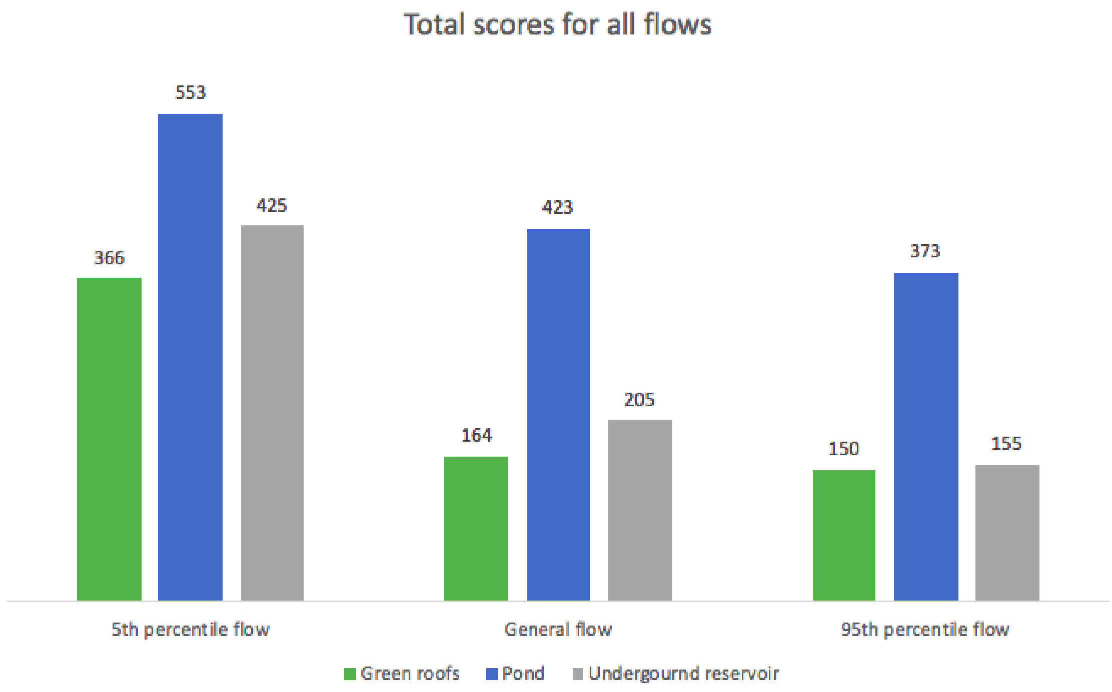


Figure 4.8: *Diagram with the total scores from the multi-criteria analysis for each measure and flow.*

5
Discussion

5.1 Proposed stormwater measures

The proposed stormwater measures were supposed to represent three different focuses; one green alternative, one blue-green alternative and one grey alternative. It was assumed interesting to see how well highly different measures responded to changes in the dimensioning flow. The Pond and the Green roofs are corresponding most to the idea of sustainable stormwater measures as they include more vegetation and open water and imitate natural conditions to a higher extent. Underground reservoirs are described in the manual for stormwater handling in Lerum municipality (Lerum, 2015b), however it is also stated that it is in general better to avoid underground measures. It should also be mentioned that it has not been investigated whether or not the proposed size of the measures are reasonable. Since the main focus of the study was to evaluate the rational method, and not to solve the stormwater related problems in Segerstaden, it was considered more interesting to propose varying measures rather than finding the best suited alternatives for the area. However, the method of the study can be used to evaluate other stormwater measures or combinations of measures.

5.2 Uncertainties in the rational method

The uncertainty analysis indicates that there are quite large uncertainties in the input parameters and the calculated dimensioning flow in the rational method. This is not very surprising since the values assigned to the parameters includes many assumptions and simplifications of the reality. The parameters in the rational method includes both epistemic and aleatory uncertainties. As mentioned in Section 2.4.1, epistemic uncertainty has its origin in incomplete knowledge and aleatory uncertainty has its origin in inherent randomness and can not be reduced with more knowledge. The rainfall intensity is an aleatory uncertainty since it is an estimation of a future event and it is impossible to know its exact value. The catchment area is uncertain since it is dependant on the rainfall event and is therefore treated as an aleatory uncertainty as well. The runoff coefficient, however, is an epistemic uncertainty. It could be assigned a very certain value if more knowledge about the land use and its actual runoff were gathered. However this would require a lot of work and for most cases, including this study, it is assumed to be unreasonable. It is therefore made aleatory by being assigned a reasonable interval which is then given a probability distribution.

One of the simplifications of the rational method is the attempt to employ a numerical value on the runoff. In reality, the actual runoff from an area is affected by many, varying, local parameters apart from just the surface type. For example, the saturation of the ground due to previous rainfall events and small depressions might have a big effect on the total runoff. To assign a runoff coefficient based on the construction type or whether an area is vegetated or not, is a rough simplification of reality which probably have a big impact on the overall uncertainty in the rational method.

The results show that the rainfall intensity have a big impact on the dimensioning flow. In this study, the rainfall intensities corresponding to a precipitation event with a 2-, 5-, 10- and 20-year return time were used. This is quite a wide range, however they are all precipitation events reasonable to consider when working with stormwater. The size of the area did also have a big impact on the dimensioning flow, however it is based on the topography and precipitation event and not on assumptions.

The 5th and 95th percentile flows that were used in the study indicate reasonable highest and lowest flows and not the absolute maximum and minimum. By using these flows it is assumed that values outside of the interval could occur however it is only a 10% probability of it happening.

The results of the MCA show that the Pond scores quite high for all flows, especially in relation to the other alternatives. This indicate that a pond with flooding area is better suited as stormwater measure compared to the other two alternatives, even when considering the uncertainties in the rational method. That would make the pond with flooding area a better investment for areas like Segerstaden.

Since there are uncertainties in the parameters of the rational method it could be assumed that the Adaptability criterion is of high importance. If the dimensioning flow can vary it would probably be beneficial to be able to adapt the measure once it has been implemented. Also for this specific criterion, the Pond scored the highest, again indicating that it would be a suitable measure. However, the Adaptability criterion got a quite low weight. The discussion regarding this criterion was that it would be better to properly design the measures from the beginning, so that it would not need to be changed. This shows how big impact the discussion during the workshop have on the weights and therefore also on the final results.

5.3 Uncertainty analysis and model set up

The results from the uncertainty analysis is depending on the analysis method. For this study the Monte Carlo method was used with the simulation tool @Risk.

One of the biggest challenges when using @Risk is to assign probability distributions to the parameters. There are many different distributions, all with its own pros and cons, and the choice of distribution could be an uncertainty in itself. A Beta-PERT distribution was used for the runoff coefficient and area. When using a Beta-PERT distribution it is important to consider that it is assigned maximum and minimum values that will never be exceeded.

The calculated maximum and minimum values for the runoff coefficient were set to the 10th and 90th percentile. This was to keep a reasonable interval whilst accounting for values slightly outside of the interval, in case of errors in the assumptions for the calculations. For the catchments area, the minimum and maximum values were the areas corresponding to the biggest and smallest rainfall intensity of the study. To make sure this was reasonable, a precipitation event corresponding to a rainfall intensity with a 400-year return time was simulated in SCALGO Live. This resulted in the same catchment area as the precipitation event with a 20-year return time and it was therefore assumed reasonable to have a fixed maximum area.

A log-normal distribution was used for the rainfall intensity. The log-normal distribution is left-bounded, meaning it can not have a negative value. This corresponds well to the rainfall intensities which can not have negative values. The values in the distribution is then based on the mean and standard deviation of the parameter.

The impact that the choice of the probability distribution might have on the outcome can be investigated by choosing different sets of distributions and see how the results vary. However, this was not made for this study due to the limited time frame.

5.4 The use of multi-criteria analysis in this study

The role of the MCA in this study was to investigate whether or not uncertainties in the parameters of the rational method could have an impact on the choice of stormwater measures in a municipality. The results of the MCA varied when it was based on the 5th and 95th percentile flows retrieved from the uncertainty analysis. This indicates that the MCA is a useful tool for investigating what impact the uncertainties in the parameters of the rational method could have on stormwater management. However, the ranking of the measures in the MCA remained the same, with the Pond scoring the highest, and the Green roofs scoring the lowest for all flows. That underlines the importance of considering the specific scores, and not only the ranking, when analysing the results. Furthermore, it is important to be aware of how the MCA is conducted. The selection of criteria and methods for weighting and scoring will have a large impact on the results. Therefore it is important that the method of the MCA and the reasoning and motivation behind the decisions, are transparent and well described.

A comparison of more similar stormwater measures could have contributed with further interesting results. It could be considered quite unlikely that a choice between such different measures as in this study has to be made for an area. A more reasonable scenario could have been a comparison between two different ponds, or perhaps between green roofs and rain gardens.

Based on the results it can be assumed that there are uncertainties in the rational method and they can have a significant impact on the choice and evaluation of stormwater measures. For this study, the results from the MCA showed the ranking and total scores for the proposed measures for different flows. It should, however, be remembered that it is the dimensioning flow that is uncertain, and the main focus should be to consider the uncertainties when choosing the flow and not when designing the measures.

5.4.1 Sources of error

The are some potential sources of errors with the MCA method. These errors have undoubtedly had an effect on the results and they are therefore discussed in section 5.4.1.1 - 5.4.1.3.

5.4.1.1 Selected criteria

To identify and select criteria for the MCA proved to be a challenging task. Many aspects can be seen as interesting and rewarding to include. However, it is important to limit the criteria selection to keep the workload of the MCA at a reasonable level. To avoid a too big selection of criteria but still have a suitable selection, two requirements were followed. Firstly, it was required that the criteria were in line with the demands and ideas presented in Lerum's manual for stormwater handling (Lerum, 2015b). Secondly, is was required that the criteria had been successfully used in earlier studies. By following these requirements the selection of criteria included many aspects without being too comprehensive.

Due to the time limit of the study, a criterion regarding treatment of the stormwater was not included. A good evaluation of the pollution removal would have required calculations and simulations in a suitable modelling tool, e.g. StomTac. In addition to this, the stormwater in an area such as Segerstaden is assumed to have low to moderate pollution content (Lerum, 2015b) and the recipient, the lake Mjörn, is assessed to have a medium high sensitivity (Abrahamsson et al., 2009). With a low to moderate pollution content, and a medium high sensitivity of the recipient, the treatment of the stormwater was not prioritized in this study. However, pollutants in stormwater is an important aspect when considering sustainability and including a criterion regarding treatment could have had a positive contribution to the study. An alternative could have been to make a qualitative evaluation of the treatment efficiencies for the measures, however this was considered too late to be included in the study.

In the later stages of the study it became apparent that several of the criteria were not well adapted to the integration of the results from the uncertainty analysis. The results from the uncertainty analysis changed the flow which led to a change of the dimensions of the measures. This in turn had an effect on the criteria in the Economy category as well as the Performance stormwater criterion. All other criteria were unchanged despite the change in flow. Using more criteria that would have changed with a change in the flow could have lead to more distinct results. It could, however, be argued that more of the selected criteria could be changed with a change in flow. For example the acceptance could be lower for a bigger pond and the biodiversity could be larger with more green roofs. However, this would probably only generate a small change of the scores and was therefore assumed to be negligible.

5.4.1.2 Weighting and workshop

The weighting in the MCA has a great impact on the overall results since it defines which criteria that is of high importance. By assigning weights through a workshop with several participants the risk of subjectivity was minimized. In addition to this, all participants had different backgrounds and references which helped bring different aspects to the discussions. In general it can be assumed that more participants would result in a better weighting since it would decrease the risk of subjectivity and allow for more knowledge and perspectives. However, too many people would complicate a discussion. To account for this, the most beneficial approach would have been to have several groups small enough to allow for discussions. Though it should be remembered to keep a wide range of competences in each group to guarantee a broad knowledge base.

During the workshop it became clear that it can be somewhat difficult to isolate each criterion. For example, it was assumed that a higher investment costs could be allowed if the operation and maintenance costs would be lower. Arguments like these then had an effect on the weighting, in this case assigning a lower weight for the Investment cost and a higher weight for the Operation and maintenance cost.

The participants had received information about the criteria and proposed stormwater measures prior to the workshop which might have had an affect on the weighting. If a measure was considered more desirable it would have been possible for the participants to assign weights in a way that would benefit the desired measure. The study could perhaps have been more trustworthy if the participants had received information about the measures after the workshop. In addition to this, it is worth noticing that the description of the criteria might have had an impact on the weighting. The approach was to give a general and quite wide definition of the criteria to not guide the participants in any specific direction. The reason for this was to allow for the different competences and perspectives to take place without steering the thoughts and discussions in any direction.

5.4.1.3 Scoring

The scoring of the measures was somewhat challenging and it was apparent that the experience and opinions of the people participating in the scoring have a large impact on the assigned scores. That underlines the importance of being transparent with the reasoning behind the assigned scores. Furthermore, it can be quite difficult to define a quantitative scale since the parameters are often dependant the specific scenario.

For this study, quantitative scales were defined for the Investment cost, Operation and maintenance cost and the Performance stormwater criteria. The scale for the Investment cost was based on the budget for Lerum municipality which allow 2 million SEK to be spent on stormwater measures every year. Therefore it was assumed that 2 million SEK would not have either a negative nor a positive effect hence it was set to correspond to a score of 0. The costs corresponding to -10 and 10 points were discussed and identified by the supervisors at Lerum municipality. However, this approach is somewhat problematic. A score of 0 should be equal to a null alternative, i.e. doing nothing and it is not reasonable to assume that doing nothing would result in a cost of 2 million SEK. Though the null alternative would still be a cost for the municipality. It could for example lead to flooding resulting in costly damages. The size of the cost would be highly dependant on the severeness of the flooding and that can only be estimated in advance. Therefore it was assumed most reasonable to follow the chosen approach.

The scales for the Operation and maintenance cost and Life span criteria were also discussed and identified by the supervisors at Lerum municipality. It is important to consider that the quantitatively defined scales are affected by the knowledge and judgement of the supervisors. The scales are assumed to be reasonable for this study and for Segerstaden and can be used if studying additional stormwater measures in the area. However, if the same approach is used in other studies it is important to consider that the presumptions will be different and that the quantitative scales would have to be be updated.

Another important aspect regarding the economy is that cost estimates are difficult to make and they come with a high uncertainty. In combination with the relative high weights for the Economy category, this may be a significant source of error in the results. Different studies use varying methods for estimating costs. This makes it difficult to ensure that the same aspects have been considered for all measures. In an attempt to avoid this source of error, the same study was used for all cost estimates. However, it is important to consider the uncertainty connected to the cost estimates and to keep in mind that the final cost for implementing and maintaining a measure might be very different from the early approximations.

It would have been possible to perform net present value calculations for the operation and maintenance costs. That could have facilitated a comparison of the operation and maintenance costs for all measures and for the different flows. However, that could implicate a double counting of the criteria since life span of the measures would both be used in the net present value calculations as well as being a independent criterion.

Regarding the Performance stormwater criterion, the score corresponding to 10 points varied with the different flows. The measures where then assigned scores based on the percentage of how much of the required delay volume they could handle. By doing so, the measures were evaluated based on each new scenario. Since the dimensioning flow steered the other parameters, e.g. the costs, this was assumed to be the most reasonable approach. Another approach could have been to define a quantitative scale for the criterion applicable for all flows. This was attempted but, as mentioned, the chosen approach was assumed to be more reasonable.

Some assumptions were inevitably made by the participants when assigning scores to the measures. Their experience and knowledge formed the basis of these assumptions and had therefore a large impact on the results. To account for this the MCA was made transparent and the reasoning behind the assigned scores have been explained.

5.5 Future studies

In the case study using the method developed in this work, very different stormwater measures were evaluated. It would be interesting to conduct a similar study but with more similar measures to see how big the effect of the uncertainties in the rational method would have on those results. Furthermore, it would be interesting to add a criterion regarding stormwater treatment to the MCA since it is an important aspect in stormwater management.

In addition to the above, it could be interesting to perform the analysis assigning fixed values to some of the parameters. For example it could be reasonable to have a set budget for the implementation of stormwater measures and see the possibilities of delay based on that. Another parameter that could be fixed is the delay capacity, as it is also reasonable to have a requirement of the delay in an area.

This study investigated the uncertainties of the parameters in the rational method and did not consider uncertainties of the whole model. It would, however, be interesting to study the model-uncertainties of the rational method and compare the model with other methods for calculating stormwater flow.

6
Conclusion

6.1 Uncertainties in the rational method

The study shows that there are several potential uncertainties in the parameters of the rational method as they are based on simplifications and assumptions of the reality. All four parameters in the equation contribute to the uncertainties and it was found that the rainfall intensity had the greatest impact on the dimensioning flow. The rainfall intensity is based on a choice of duration and return time of a precipitation event and although the choices are assumed to be reasonable, it is impossible to predict the future rain events. The choice of rainfall intensity affects the catchment area which was also shown to have a large impact on the flow. The catchment area is estimated based on the topography and precipitation event. The runoff coefficient is a simplification of reality and the estimation of its value varies quite a lot depending on the approach used to retrieve it. The climate factor comes with an uncertainty in itself since it is an estimation of future scenarios. However, the climate factor is a multiplier and will only scale the flow interval up or down, not change its range.

The magnitude of the uncertainties in the parameters and hence the calculated flow of the rational method depends on the roughness of the estimations that are made when assigning their values. More knowledge and information can reduce the uncertainty, for example by allowing for a more accurate estimation regarding the runoff coefficient. However, not all estimations can be made with a higher certainty and calculations with the rational method will always be somewhat uncertain.

6.2 Effects on stormwater management

The study shows that the uncertainties in the rational method can have a large impact on the choice of stormwater measures, hence on the stormwater management, in an urban area. This was investigated with a multi-criteria analysis where stormwater measures were assigned scores that changed when different flows were used, i.e. when the uncertainties in the rational method were included. The scoring of the measures varied a lot for the different flows and despite not changing the ranking of the measures, the gap between them varied. This indicates that some measures could be better suited for a specific flow, which is an important aspect to consider when working with stormwater management.

It should be noticed that there are many ways of conducting a multi-criteria analysis and the results will vary with the approach. It can be concluded that the uncertainties in the rational method will affect the stormwater management, however the extent of the impact is dependent on the studied scenario.

References

Abrahamsson, I., Ternsell, A., & Bergdahl, D. (2009). *Vattenöversikt för Lerums kommun* (Tech. Rep.). Retrieved from https://www.lund.se/globalassets/regelsamling/renhallning_och_vatten/sjoochvattendragsplan_lundskommun.pdf

Ahmed, R., & Ali, S. (2016, dec). Modelling of intensity-duration-frequency curves for Lahore City using frequency analysis. In *Sustainable development and planning viii* (Vol. 1, pp. 725–733). WIT Press. doi: 10.2495/sdp160611

AUTODESK. (n.d.). *Overview - What is AutoCAD?* Retrieved 2021-03-23, from https://www.autodesk.com/products/autocad/overview?term=1-YEAR

Behrouz, M., & Alimohammadi, S. (2018). Uncertainty Analysis of Flood Control Measures Including Epistemic and Aleatory Uncertainties: Probability Theory and Evidence Theory. *Journal of Hydrologic Engineering*, *23*(8), 04018033. doi: 10.1061/(asce)he.1943-5584.0001675

Bengtsson, L., Grahn, L., & Olsson, J. (2005). Hydrological function of a thin extensive green roof in southern Sweden. *Nordic Hydrology*, *36*(3), 259–268. doi: 10.2166/nh.2005.0019

Bergqvist, N. (2014). *Environmental assessment and sustainable stormwater planning with regard to climate change through multi-criteria analysis (MCA) – Case study Guldheden* (Master's thesis). Retrieved from http://publications.lib.chalmers.se/records/fulltext/212409/212409.pdf

Bjällås, U., Fröberg, M., & Sundelin, A. (2015). *Hur ska EU-domstolens dom i mål C-461/13 (Weserdomen) tolkas och vad får den för betydelse?* Retrieved from https://www.svensktvatten.se/globalassets/avlopp-och-miljo/reningsverk-och-reningsprocesser/rapportweserdomen2015-12-15.pdf

Björkman, E., Vikingsson, H., Karlsson, A., & Svensson, G. (2019). *Skyfallskartering Lerums kommun* (Tech. Rep.).

Blecken, G. (2016). *Kunskapssammanställning Dagvattenrening* (Tech. Rep.). Svenskt Vatten Utveckling. Retrieved from https://www.svensktvatten.se/contentassets/979b8e35d47147ff87ef80a1a3c0b999/svu-rapport_2016-05.pdf

Brisvåg, J. (2017). *Utveckling av beslutsstöd för hållbara val av dagvattenhantering* (Master's thesis). Retrieved from http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1130686&dswid=-8124

Burgman, M. A. (2005). *Risks and Decisions for Conservation and Environmental Management*. Cambridge University Press. doi: https://doi.org/10.1017/CBO9780511614279

Chin, D. A. (2019). Estimating Peak Runoff Rates Using the Rational Method. *Journal of Irrigation and Drainage Engineering*, *145*(6), 04019006. doi: 10.1061/(asce)ir.1943-4774.0001387

Dodgson, J. S., Spackman, M., Pearman, A., & Phillips, L. D. (2009). *Multi-criteria analysis : a manual* (Vol. 11) (No. 1-3). Retrieved from http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf doi: 10.1002/mcda.399

Ellis, J. B., Deutsch, J. C., Mouchel, J. M., Scholes, L., & Revitt, M. D. (2004). Multicriteria decision approaches to support sustainable drainage options for the treatment of highway and urban runoff. *Science of the Total Environment*, *334-335*, 251–260. doi: 10.1016/j.scitotenv.2004.04.066

European Comission. (n.d.). *Introduction to the EU Water Framework Directive - Environment - European Commission.* Retrieved 2021-05-14, from https://ec.europa.eu/environment/water/water-framework/info/intro_en.htm

Förbo. (n.d.). *Segerstaden - Förbo.se.* Retrieved 2021-02-25, from https://www.f{ö}rbo.se/Vara-bostader/Vara-omraden-i-Lerums-kommun/Grabo/Segerstaden

Geffray, C., Gerschenfeld, A., Kudinov, P., Mickus, I., Jeltsov, M., Kööp, K., ... Pointer, D. (2018). Verification and validation and uncertainty quantification. *Thermal Hydraulics Aspects of Liquid Metal Cooled Nuclear Reactors*, 383–405. doi: 10.1016/B978-0-08-101980-1.00008-9

Hausfather, Z. (2019). *Explainer: The high-emissions 'RCP8.5' global warming scenario.* Retrieved 2021-02-22, from https://www.carbonbrief.org/explainer-the-high-emissions-rcp8-5-global-warming-scenario

IBM. (2020). *What is Monte Carlo Simulation? | IBM.* Retrieved 2021-05-21, from https://www.ibm.com/cloud/learn/monte-carlo-simulation

IPCC. (2013). *Climate Change 2013, The Physical Science Basis.* Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/03/WG1AR5_SummaryVolume_FINAL.pdf

Kangas, D. (2016). *Evaluating Stormwater Management Techniques for Dense Urban Areas using Multi-Criteria Decision Analysis* (Master's thesis). Retrieved from http://publications.lib.chalmers.se/records/fulltext/239709/239709.pdf

Lans, N. (2020). *Dagvatten - Naturvårdsverket.* Retrieved 2021-02-25, from https://www.naturvardsverket.se/Sa-mar-miljon/Vatten/Avloppsvatten/Dagvatten/

Larm, T., & Blecken, G. (2019). *Utformning och dimensionering av anläggningar för rening och flödesutjämning av dagvatten.*

Lerum. (2015a). *Dagvattenstrategi för Lerums kommun.* Retrieved from https://www.lerum.se/globalassets/documents/forvaltningssidorna/bygga-bo-och-miljo/va/strategi_dagvatten_150826.pdf

Lerum. (2015b). *Handbok för dagvattenhantering i Lerums kommun.* Retrieved from https://www.lerum.se/globalassets/documents/forvaltningssidorna/bygga-bo-och-miljo/va/handbok_dagvatten_171205-uppdaterad.pdf

López, H. (2018). *Performance Examination of Sustainable Urban Drainage Systems - A Multi-Criteria Analysis for the city of Gothenburg* (Master's thesis). Retrieved from http://studentarbeten.chalmers.se/publication/

255814-performance-examination-of-sustainable-urban-drainage-systems-a-multi-criteria-analysis-for-the-city

Lucid. (n.d.). *Documents.* Retrieved 2021-05-21, from https://lucid.app/documents#/dashboard?folder_id=home

Magnussen, K., Wingstedt, A., & Rasmussen, I. (2015). *Kostnader og nytte ved overvannstiltak* (Tech. Rep.). Vista Analyse. Retrieved from https://www.vista-analyse.no/site/assets/files/5632/kostnaderognyttevedovervannstiltakm305.pdf

Makropoulos, C. K., Natsis, K., Liu, S., Mittas, K., & Butler, D. (2008). Decision support for sustainable option selection in integrated urban water management. *Environmental Modelling and Software*, *23*(12), 1448–1460. doi: 10.1016/j.envsoft.2008.04.010

MSB. (2017). *Vägledning för skyfallskartering - Tips för genomförande och exempel för användning.* Retrieved from https://rib.msb.se/filer/pdf/28389.pdf

Naturvårdsverket. (2020). *Effekter i Sverige - Naturvårdsverket.* Retrieved 2021-02-17, from https://www.naturvardsverket.se/Sa-mar-miljon/Klimat-och-luft/Klimat/Klimatet-i-framtiden/Effekter-i-Sverige/

Ohlin Saletti, A. (2021). *Infiltration and inflow to wastewater sewer systems - A literature review on risk management.* Retrieved from https://research.chalmers.se/publication/522159/file/522159_Fulltext.pdf

Olsson, J., Berg, P., Eronn, A., Simonsson, L., Wern, L., & Yang, W. (2017). Extremregn i nuvarande och framtida klimat. *Klimatologi, SMHI*(47).

Östlind, J. (2012). *Sammanvägda avrinningskoefficienter i rationella metoden - en jämförelse mellan idag och 1970-talet* (Master's thesis). Retrieved from https://www.diva-portal.org/smash/get/diva2:536760/FULLTEXT01.pdf

Persson, G., Wikberger, C., & Amorim, J. H. (2018). Klimatanpassa nordiska städer med grön infrastruktur. *Klimatologi*, *50*(50). Retrieved from https://www.smhi.se/polopoly_fs/1.165087!/Klimatologi_50%20Klimatanpassa%20nordiska%20st%C3%A4der%20med%20gr%C3%B6n%20infrastruktur.pdf

Rosén, L., Back, P.-E., Söderqvist, T., Soutukorva, Å., Brodd, P., & Grahn, L. (2009). *Multikriterieanalys (MKA) för hållbar efterbehandling av förorenade områden* (Tech. Rep.). Naturvårdsverket. Retrieved from https://www.naturvardsverket.se/Documents/publikationer/978-91-620-5891-3.pdf

SCALGO. (n.d.). *SCALGO Live Flood Risk.* Retrieved 2021-05-05, from https://scalgo.com/en-US/live-flood-risk

SCALGO Live. (n.d.). *Sweden · SCALGO Live.* Retrieved 2021-05-21, from https://scalgo.com/live/sweden?res=1&ll=12.302735%2C57.839250&lrs=lantmateriet_topowebb_nedtonad%2Cw119077%3Aboundary&tool=zoom

Scandinavian Green Roof Institute. (2016). *Ekostaden Augustenborg.* Retrieved from http://greenroof.se/ekostaden-augustenborg/

Schärer, L. A., Busklein, J. O., Sivertsen, E., & Muthanna, T. M. (2020). Limitations in using runoff coefficients for green and gray roof design. *Hydrology Research*, *51* (2), 339–350. doi: 10.2166/nh.2020.049

Selin, L. (2020). *Multikriterieanalys för val av hållbar dagvattenhantering med fokus på skyfall och tillgänglighet* (Master's thesis). Retrieved from http://uu.diva-portal.org/smash/get/diva2:1448653/FULLTEXT01.pdf

SGUs Kartvisare. (n.d.-a). Retrieved 2021-05-06, from https://apps.sgu.se/kartvisare/kartvisare-jordarter-1-miljon.html?zoom=-1143889.4675269355,5919783.069676139,2323637.4675269355,7850106.930323861

SGUs Kartvisare. (n.d.-b). Retrieved 2021-05-16, from https://apps.sgu.se/kartvisare/kartvisare-jorddjup.html?zoom=269635.93764887535,6385952.283264574,471236.3408496818,6496412.504185015

SGUs Kartvisare. (n.d.-c). Retrieved 2021-05-06, from https://apps.sgu.se/kartvisare/kartvisare-genomslapplighet.html?zoom=339201.73395101115,6413743.022181274,340164.93587741494,6414279.223253677

Sjöberg, T., Hjerpe, K., Lundgren Kownacki, K., & Andersson, L. (2020). *Kommunernas arbete med klimatanpassning* (No. 55). Retrieved from http://www.diva-portal.org/smash/get/diva2:1436453/FULLTEXT01.pdf

SMHI. (n.d.). *Climate scenarios | SMHI.* Retrieved 2021-02-25, from https://www.smhi.se/en/climate/future-climate/climate-scenarios/sweden/county/vastra-gotalands/rcp85/year/precipitation

SMHI. (2015). Framtidsklimat i Västra Götalands län enligt RCP-scenarier. *Klimatologi*(24), 82. Retrieved from https://www.smhi.se/polopoly_fs/1.95726!/Menu/general/extGroup/attachmentColHold/mainCol1/file/Framtidsklimat_i_V{ä}stra_G{ö}talands_l{ä}n_Klimatologi_nr_24.pdf

SMHI. (2019). *Nederbörd | Klimatanpassning.se.* Retrieved 2021-02-17, from https://www.klimatanpassning.se/hur-klimatet-forandras/klimateffekter/nederbord-1.21297

Stahre, P. (2004). *En långsiktigt hållbar dagvattenhantering.* Svenskt Vatten.

Svenskt Vatten. (2004). *Publikation 90 - Dimensionering av allmänna avloppsledningar* (1st ed.). Stockholm: Svenskt Vatten.

Svenskt Vatten. (2011). *Publikation 105 - Hållbar dag- och dränvattenhantering. Råd vid planering och utförande* (1st ed.). Stockholm: Svenskt Vatten.

Svenskt Vatten. (2016). *Publikation P110 - Avledning av dag-, drän- och spillvatten. Funktionskrav, hydraulisk dimensionering och utformning av allmänna avloppssystem* (1st ed.). Stockholm: Svenskt Vatten.

Sveriges Radio. (2014). *Köpenhamn lärde översvämningsläxan 2011 - Vetenskapsradion Klotet | Sveriges Radio.* Retrieved 2021-05-31, from https://sverigesradio.se/artikel/5942507

Tyréns. (2020). *Åtgärdsutvärdering skyfall centrala Gråbo* (Tech. Rep.).

VASYD. (n.d.). the " Eco-City Augustenborg ". Retrieved from https://www.vasyd.se/-/media/Documents/Informationsmaterial/Vatten-och-avlopp/Dagvatten-och-oversvamning/Augustenborg_2008_en_webb.pdf

Vattenmyndigheterna. (n.d.). *Vattenmyndigheterna.* Retrieved 2021-02-25, from https://www.vattenmyndigheterna.se/other-languages/english.html

A

Appendix A

Below is a list of the participants of the workshop and their role in stormwater handling in Lerum municipality.

- **Alva Kalm** - Water and sewage engineer
  Alva is involved with questions concerning stormwater management in all stages, from planning to operation and maintenance. Her work involves investigating the stormwater situation in areas within Lerum, and identifying potential needs for improved stormwater handling.

- **David Hirdman** - Climate adaptation strategist
  David works with climate change's full spectrum of effects (high flows, torrential rains, floods, heat waves, droughts, storms, invasive species, biodiversity, cultural heritage, etc.) regarding both the present as well as the long-term perspective and from the comprehensive plan down to specific building permits and measures in municipal activities. David's work is connected to stormwater through cloud burst related flooding in the present and future climate.

- **Karolina Källstrand** – Nature conservation administrator
  Karolina is responsible for the questions regarding nature conservation in Lerum, including the nature conservation program decided by the municipality. Her work involves making sure the guidelines in the program are followed in for example the detailed development plan processes and projects in the municipality. Nature conservation and stormwater have intersecting areas, especially as Lerum's ambition is to have open, blue-green stormwater measures. From a nature conservation point of view, it is desirable to keep a natural stormwater handling and to let man-made measures imitate the natural stormwater handling.

- **Shir Mohammadi** - Park planner at the technical service department
  Shir works with the parks in Lerum municipality which includes playgrounds, football fields, green areas and urban plantations. His works involves both the present and as well as the long-term perspective and planning of the green areas. Shir must consider the stormwater management for these areas and is often involved in the maintenance of stormwater measures.

- **Clifford Holmén** - Supervisor at the road unit
  Clifford works with project management and project planning at the road

unit which involves roads, pedestrian and bicycle paths, bridges, rocks, street lighting, parking spaces, ditches, signs, building permit reviews, etc. Clifford must consider the stormwater from these areas which are most often composed of hardened surfaces.

B

Appendix B

Schedule
Workshop with participants from Lerum municipality
8th April 2021

9.30 – 9.50
Welcoming and introduction to the workshop. All participants are asked to introduce themselves and give a short explanation of their role in the municipality and its connection to stormwater management.

9.50 – 10.00
Short explanation of the multi-criteria analysis method and the linear additive method.

10.00 – 10.15
Presentation and explanation of the categories and criteria.

10.15 – 10.25
The participants are asked to distribute 100 points on the four categories (Economy, Environment, Socio-culture and Technique) by themselves.

10.25 – 10.40
Discussion of the weights distributed on the categories. Eventually we will be deciding on a distribution that suits everyone.

10.40 – 11.15
The participants are asked to distribute the points for each category on the criteria in the category. This will be done for one category at a time, followed by a discussion after each category. During the discussions we will eventually end up with weights that suits everyone.

11.15 – 11.30
Wrap up of the workshop.

C
Appendix C

General flow
$Q_d = i(t_r)A\varphi cf$
$i(t_r) = 228 l/s, ha$
$A = 4.47 ha$
$\varphi = 0.32$
$cf = 1.4$

$Q_d = 227.959 * 4.47 * 0.3247 * 1.4 = 463.15 l/s$

Allowed outflow = 15 l/s,ha
Allowed outflow = 15 *4.47 = 67 l/s

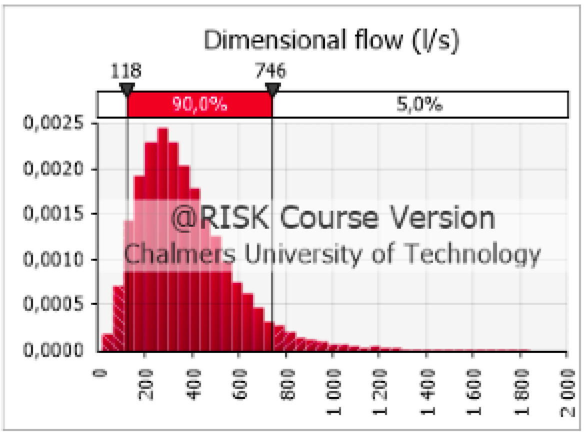
General flow – Allowed outflow = 463.15 – 67 = 396.15 l/s

389.5 l/s = 396.15/1000 m3/s = 0.39615 m3/s

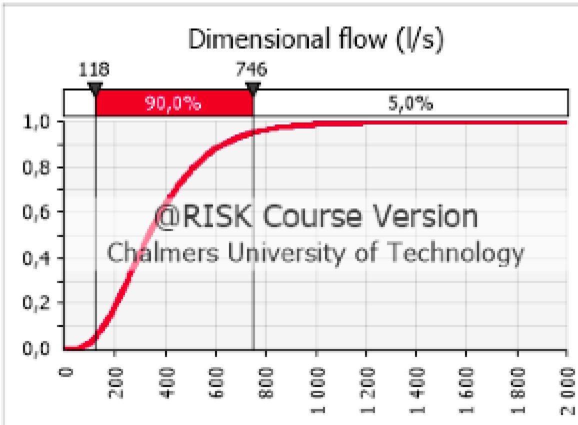
Required delay volume for 10 minutes
0.39615*600 = 237.69 m3

D

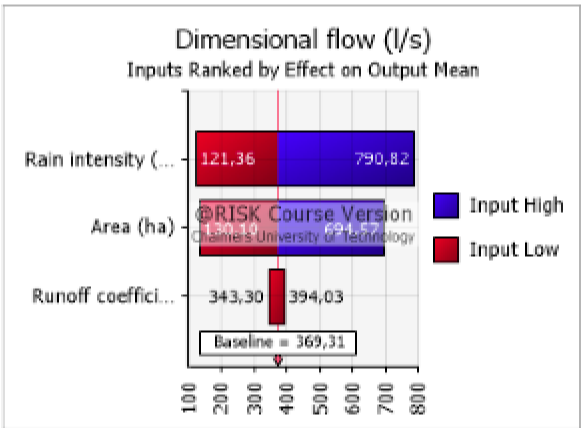
Appendix D



Summary Statistics	
Statistic	Value
Minimum	18,12
Maximum	1 844,42
Mean	369,31
Std. Deviation	199,78
Variance	39 912
Skewness	1,2592
Kurtosis	5,7072
Median	332,21
Mode	313,26
Left X	118,44
Left P	5%
Right X	746,09
Right P	95%



Percentiles	
Percentile	Value
1%	68,96
2,5%	92,41
5%	118,44
10%	151,77
20%	204,17
25%	224,97
50%	332,21
75%	473,68
80%	511,52
90%	628,53
95%	746,09
97,5%	857,82
99%	1 012,78



Change in Output			
Rank	Name	Lower	Upper
1	Rain intensity (l/s,ha)	121,36	790,82
2	Area (ha)	130,10	694,57
3	Runoff coefficient (-)	343,30	394,03

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

AVANCEZ
1829

CHALMERS
UNIVERSITY OF TECHNOLOGY