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Assessment of pluvial flooding at Mossen

A case study of Mossen football field in Gothenburg

Master's thesis in the Master's program of Infrastructure and Environmental Engineering

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Cover: Mossens IP from the northwest corner

Abstract

With the increased severeness of urban pluvial flooding due to climate change, cities have to increase their resilience against heavy cloudbursts. As a response to the upcoming challenges an interim target for all Swedish municipalities is to investigate and integrate sustainable stormwater management when planning new construction as well as existing stock. The city of Gothenburg is no exception, and in the structural plan the municipality presents several potential cloudburst surfaces, with the football field Mossens IP being one of them. The aim of this thesis was to investigate the resilience of the football field against a 100-year rain, and whether it is possible to mitigate the consequences at site through Nature-based solutions simultaneously as the area benefits socially and environmentally through increased recreational value and eco-system services. Further, the potential effect of flooding on the possibility for sport associations to utilize the field was investigated.

The thesis was scenario-based and applied three different scenarios. Scenario 1 was used as a baseline scenario, thus representing the current flooding situation during a 100-year rain at Mossen football field if no changes were made, whereas Scenario 2 involved Nature-based solutions e.g. rain gardens, green roofs, blue-green roofs and permeable paving within the catchment area. Lastly, Scenario 3 involved storage-focused solutions, e.g. retention ponds and detention basins within the catchment area. Modelling was conducted in SCALGO Live and thereafter analyzed with the decision making framework MCDA.

The study concluded that the nature-based solutions implemented in Scenario 2 are not preferred in this case from a strictly quantitative stormwater management point of view, as no notable reduction in flooding of the field was found. In this case study, the most beneficial stormwater solutions proved to be the detention basins in Scenario 3 with a total reduction of 23 cm. However, both scenarios performed well regarding increasing recreational values and eco-system services. Rain gardens and a multi-functional detention basin were found to be the most optimal ones.

Key words: Blue-Green solutions, Climate change, Cloudburst, MCDA, Nature-Based Solutions, Stormwater management, Stormwater modelling, Urban flooding

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Hanna Börjesson & Elin Pettersson, Gothenburg, June 2024

List of Acronyms

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

AHP	Analytic Hierarchy Process
BGI	Blue-Green Infrastructure
BMP	Best Management Practice
CBA	Cost Benefit Analysis
CDS	Chicago Design Storm
EPA	United States Environmental Protection Agency
LID	Low Impact Design
m.a.s.l.	Meters above sea level
MCDA	Multi-Criteria Decision Analysis
MSB	Myndigheten för Samhällsskydd och Beredskap (Swedish Civil Contingencies Agency)
NBS	Nature Based Solutions
NWRM	Natural Water Retention Measures
RR	Retention Rate
SGU	Sveriges Geologiska Undersökning (The Geological Survey of Sweden)
SMHI	Sveriges Meteorologiska och Hydrologiska Institut (Swedish Meteorological and Hydrological Institute)
SUDS	Sustainable Urban Drainage System
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution

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1 Introduction

Extreme rainfall is expected to become more frequent in the upcoming decades, with the intensity of cloudbursts increasing by approximately 10–40 % at the end of the century depending on climate scenarios (Olsson et al., 2017). Simultaneously with the increase of cloudbursts and heavy rainfall, the growing urbanization results in an increase of impermeable surfaces with reduced infiltration as a consequence (O'Donnell & Thorne, 2020). Hence, there is an increase in runoff and higher flood peaks regardless of if the rainfall might be of short duration (Suriya & Mudgal, 2012). Flooding is experienced in several parts all over the world (O'Donnell & Thorne, 2020) and the risk of flooding in Sweden due to heavy rain is expected to increase in the upcoming years (MSB, 2022). Urban areas are therefore especially vulnerable to cloudbursts which results in a need to increase the resilience against flooding to face the upcoming challenges of climate change and urbanization.

In response to these challenges, an interim target for all Swedish municipalities to integrate sustainable stormwater management when planning new construction was set for 2023 (CU 2021/22:13). Further, municipalities at risk of major impact or damage on already existing buildings and infrastructure should survey, plan and start to implement changes towards more sustainable stormwater management by 2025. According to the Swedish Environmental Protection Agency, sustainable stormwater management is a multifaceted issue with many aspects to consider (Naturvårdsverket, 2023). Examples of approaches that can be incorporated into a management plan are minimising runoff, diverting flow, and collecting runoff in designated detention areas. An option to implement these approaches, and in return increase sustainability and resilience during flood events, is to incorporate Blue-green infrastructure (BGI) (Lawson et al., 2014). This type of infrastructure combines blue options like ponds, waterways and basins with green options that utilizes plants and land based solutions such as rain gardens, green roofs, plant beds or constructed wetlands (Veerkamp et al., 2021). Additionally, focus is placed on ecosystem services and multi-functionality, i.e. the green-blue spaces should be beneficial both in flooded and non-flooded states (Jones et al., 2022). There has been several case studies where this type of stormwater management has been applied and even implemented in cloudburst plans of cities. For example in one of the leading cities within stormwater management, Copenhagen, Nature-based solutions (NBS) have been implemented in urban environments such as "Tåsinge square".

The area of investigation in this case study is a football field situated at Mossen, located in central Gothenburg. According to the structural plan, the municipality of Gothenburg is suggesting to use the field as a cloudburst area as a part of the stormwater management plan for 100-year rains (Göteborgs stad, 2020). Such a decision could result in a conflict of interest between the municipality and the sport associations utilizing the football field, as it would be out of commission during periods of flooding. Furthermore, the duration of flooding could vary, resulting in uncertainty concerning specific utilization of the football field for sport associations.

1.1 Aim

The aim of this master's thesis is to analyze the resilience of the football field Mossens IP, situated in Johanneberg in Gothenburg, against 100-year rains based on three scenarios. The purpose of this is to investigate where Blue-green stormwater solutions are possible to implement to limit flooding at Mossens IP, simultaneously as the area benefits socially and environmentally through increased recreational value and ecosystem services. The research questions presented in Section 1.2 below will be answered to achieve the aim of the thesis.

1.2 Research questions

The thesis will answer the following three research questions:

- What are the perception of the football associations regarding the role of the football field as a potential cloudburst area?
- To what extent would Mossen football field currently be affected by flooding during 100-year rains?
- Would the situation at Mossen football field, with regard to flooding reduction and social aspects, benefit from implementing Blue-green stormwater solutions in the surrounding area?

1.3 Limitations

The following limitations have been made in the thesis:

- The solutions are primarily investigated and modelled in the software SCALGO Live, therefore the results are mostly based on topography.
- Sea-level rise is not considered.
- The focus is reduction in stormwater quantity, thus water quality will not be considered.
- Only Nature-based solutions are investigated.

2 Background

This chapter presents the background of the thesis including information regarding climate change and precipitation, stormwater and Nature-based solutions, as well as previous research, case studies and information about the structure plan of Gothenburg.

2.1 Climate change and precipitation

The Intergovernmental Panel on Climate Change has presented several pathways for the future of global warming until year 2100, ranging from a temperature increase of 1.4 °C in very low green house gas emission scenarios, up to 4.4 °C in very high green house gas emission scenarios (IPCC, 2023). At an increase of 1.5 °C, local flooding events due to precipitation are expected to become more common as the frequency and intensity of heavy rain increases. In comparison to the years of 1850-1900, the global mean temperature had already risen by 1.15 °C by 2022 (WMO, 2023). Furthermore, the global mean precipitation is projected to increase by 1-3 % per degree rise of surface air temperature (W. Zhang et al., 2021).

The increased precipitation results in flooding problems all over the world. An example of severe flooding occurred in Copenhagen in 2011, when approximately 135 mm of rain fell under less than 3 hours (Kilhof, 2014). The amount of rain was extremely rare, thus classified as a 1000-year rain, and left around 5-6 billion DKK of damage in its wake. Additionally, there has been several severe flooding and cloudburst events in Sweden over recent years (SMHI, 2024). In 2014, parts of Malmö received more than 100 mm of rain over a six hour period (Hernebring et al., 2015). A way to characterise this type of heavy rain is to use terms such as 10- or 100-year rain. A 10-year rain is presumed to have a return time period of 10 years, whereas a 100-year rain statistically will return once over a period of 100 years. Additionally, a 10-year rain is twice as large as a 1-year rain, and a 100-year rain twice as large as a 10-year rain (Svenskt Vatten, 2018).

Due to large impermeable surfaces, these type of floods are considered extremely problematic in urban areas such as cities, and Gothenburg is no exception. To prepare for heavy precipitation events, the municipality of Gothenburg have produced a structural plan where the effects of a dimensioning rain event along with suggestions of possible mitigating measures are presented (Göteborgs stad, 2020). The dimensioning event utilized is a 100-year rain with a climate factor of 1.2, where the factor represents a 20 % increase in comparison to a current 100-year rain. What constitutes a 100-year rain varies from place to place, however in the structural plan a rain of approximately 102 mm was utilized and modelled as a Chicago Design Storm-rain (CDS) over the course of 6 hours (Göteborgs stad, 2021). CDS-rain referring to the rain event being split up in to blocks of different intensity and duration (MSB, 2017). Another common term, apart from 10- or 100-year rains, is cloudburst which the Swedish Meteorological and Hydrological Institute (SMHI) defines as an event with more than 50 mm of precipitation in one hour or more than 1 mm per minute (SMHI, 2021). However, flooding can also occur without cloudbursts. This can be exemplified by parts of Gothenburg flooding in 2006 when persistent rain fell during several weeks (SMHI, 2023). This event also lead to several landslides of different magnitude due to high water levels in watercourses, resulting in damage to roads and railways. Less severe and shorter rain events can also cause problems. An example of this occurred in 2012 when 30 mm of rain fell during an hour and Nordstan, one of Gothenburg's largest shopping malls, had to be evacuated since parts of the inner ceiling caved in (SVT, 2012).

2.2 Stormwater solutions

To handle the upcoming challenges connected to global warming, with increased precipitation and floods, the implementation of sufficient stormwater solutions is more relevant than ever. There are three categories within stormwater management solutions; blue, green and grey. Blue solutions are as previously mentioned water based, including for example retention ponds (Kopp & Preis, 2019), whereas the green solutions are vegetation based, including for example green roofs and rain gardens (Liberalesso et al., 2020). Lastly, the grey solutions refer to the underground network such as gutters, pipes and tunnels. The solutions that today's urban society strives for is a combination of blue and green, so called BGI, since the implementation and maintenance of grey solutions tend to be costly, in addition to less environmentally friendly to resolve urban pluvial flooding (Li et al., 2024)(EPA, 2013).

The implementation of BGI enables a multi-functional space where ecosystems can thrive, simultaneously as stormwater is handled. Through implementing natural elements such as green spaces and water bodies within an urban environment, it elevates the recreational value of the area in addition to climate resilience, thus the popularity (de Macedo et al., 2021). Another promising solution within stormwater management is the union of both grey solutions and BGI, often referred to as hybrid infrastructure (Li et al., 2024). Nature-based solutions (NBS) have lately gained increased popularity and awareness as an integrated approach regarding the twin crisis of climate change and biodiversity loss (Seddon, Daniels, et al., 2020). Moreover, this includes protection against climate change impacts, as well as decreasing further warming, supporting biodiversity and securing ecosystem services (Seddon, Chausson, et al., 2020).

2.3 Nature-based solutions

The definition of NBS, according to the European Commission, is:

> *"...living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to simultaneously provide economic, social, and environmental benefits"* (Maes & Jacobs, 2017).

Another standpoint with regard to NBS exists within The Agenda of 2030 by the

United Nations (UN) (Svenska FN-förbundet, 2024). The UN emphasizes the importance of functioning ecosystems as well as biodiversity in order to upkeep economic activities and thriving local communities (Martín et al., 2020). With reference to this, NBS performs better than most stormwater solutions since it can be strategically implemented within the already established urban landscape and provide multiple benefits at once (Boverket, 2010). According to Boverket some of these functions are; dealing with stormwater, heat management, social and recreational benefits, UV-protection from shading and support of biodiversity. Consequently, NBS provides several environmental, economic and social co-benefits due to their ability to protect and enhance certain ecosystems through buffering effects of climate change (Newell et al., 2013). Furthermore, NBS holds a great variety as there are several different stormwater solutions that are included within the NBS category such as rain gardens, green roofs, permeable surfaces and retention ponds. A more specific example of the benefits of NBS is tree planting since it manages stormwater through evaporation, infiltration and retention (Newell et al., 2013). This while simultaneously achieving expanded wild life habitat, urban heat island effect reduction and groundwater recharge, in addition to increased recreational values.

2.3.1 Rain gardens

Rain gardens, also known as bio-retention systems, are considered to be the most efficient stormwater management practice due to the range of utility regarding for example evapotranspiration and infiltration possibilities (Osheen & Singh, 2019). This type of NBS is popular within cities due to their multi-functionality and ability to remove sediments, pathogens, nutrients, heavy metals and hydrocarbons from stormwater, see example of different rain gardens in Figure 1 and Figure 2 below. They often consist of a vegetated area that with the help of plants, trees and soil collect stormwater through infiltration into the soil layers and the roots of the plants and trees (Brears, 2018). Moreover, the soil often consists of a engineered soil mixture layer and an optional sand or gravel drainage bed, which meets the reuse of water requirement. The use of engineered soil mixture is effective since it includes a variety of layers to optimize the infiltration along with the growth of the plants (L. Zhang et al., 2020). The amendments in the soil media lowers the sorption capacity, delays saturation, limits the mobility of pollutants and bio-accumulates metals and organic compounds (Sharma & Malaviya, 2021).

Figure 1: Rain garden complex outside Johanneberg Science Park (Picture by authors).

A typical rain garden structure mostly consists, as previously mentioned, of different layers. An example of a typical structure is a mulch layer as the top component, followed by a planting soil layer. Further, there is a engineered soil mixture layer that turns into the bottom layers of sand and gravel. Additionally, there often is a overflow pipe and a perforated drainage pipe (L. Zhang et al., 2020). This type of structure collects the runoff that later on travels throughout the system where the vegetation aids as a buffer that reduces the peak velocity. Moreover, the rain garden allows temporary storage of water since it takes time to flow through the layers of the structure as well as water filtration due to the engineering soil mixture. Possible excess water that exceeds the capacity of the rain garden is transported through the overflow pipe. The cost of implementing a rain garden varies depending on the structure of the rain garden. However, a number proposed when planning a rain garden next to Alelyckan water treatment plant in Gothenburg was 1500 SEK/m^2 (Adrian, 2015). This is in line with the general cost estimate of 1400 SEK/m^2 suggested by Andersson and Åkerman (2016) for a sunken plant bed with a depth of 40 cm.

Figure 2: Rain garden complex outside Chalmers University of Technology (Picture by authors).

2.3.2 Green roofs

Green roofs, also referred to as eco-roofs or living roofs, generally consist of a layer of vegetation, substrate, a filter layer and a drainage layer that are under-laid by a root barrier (Piccinini Scolaro & Ghisi, 2022). Further layers can also be added to change the function, such as water retention and insulation. They can be classified as intensive, semi-intensive or extensive depending on thickness of the soil layer and types of vegetation used (Klimatanpassning, 2018). Intensive green roofs have a soil depth of 15-100 cm, as compared to the 3-20 cm of extensive green roofs (Manso et al., 2021) (Klimatanpassning, 2018). The different substrate layer thicknesses allow for different types of vegetation to be implemented, with intensive roofs being able to sustain plants up to small trees in size (Manso et al., 2021). Extensive roofs are better suited for plants with shorter roots such as succulents, mosses or grasses, see Figure 3. Semi-intensive roofs is an intermediate option, typically with a thickness of 12-35 cm, which allows for a slightly wider choice of vegetation than extensive ones (Klimatanpassning, 2018). Compared to conventional roofing, green roofs provide benefits such as increased air quality, noise reduction, temperature regulation and stormwater retention (Manso et al., 2021). However, they are also more expensive to install (Klimatanpassning, 2018). A report used by the municipality of Stockholm states a cost of 530-820 SEK/m^2 for an extensive roof, with 700 SEK/m^2 normally being used as compared to a tin roof at 900 SEK/m^2 (Andersson & Åkerman, 2016). Semi-intensive and intensive roofs vary more greatly in price depending on e.g. plant choice, need for irrigation system and type of roof (Klimatanpassning, 2018).

Figure 3: Two examples of extensive green roofs for bicycles (Picture by authors).

Zheng et al. (2021) performed a meta analysis of the retention rate (RR) of green roofs which found that the mean RR per precipitation event was 62 %, although this varied significantly between samples. Further, the RR was found to increase by 0.1 % for every 1 % increase in substrate depth, and decrease by 0.14 % per every 1 % increase in rainfall intensity (Zheng et al., 2021). When taking only RR into account it would seem that intensive green roofs are the preferred option. However, they also have their drawbacks. Compared to extensive roofs, they potentially have a higher environmental footprint (Piccinini Scolaro & Ghisi, 2022), need more maintenance and are harder to retrofit due to larger strain being exerted on the construction by the extra weight (Manso et al., 2021).

As previously stated the RR decreases with rainfall intensity increasing, this is something to keep in mind when preparing for a 100-year rain. Castiglia Feitosa and Wilkinson (2016) studied the effect of soil depth and recorded a 114 mm rain event during the study period. The RR for soil depths of 5, 10, 20 and 40 cm during this event was 3 %, 4 %, 5 % and 15 % respectively. As the retention capacity of the roof during cloudbursts becomes limited by the available porosity, runoff is produced as the soil is saturated. One way to tackle this problem is to implement blue-green roofs instead. In a case studied by Busker et al. (2022), 8 cm deep plastic crates were added beneath the green soil layer for 71 mm extra storage capacity. An additional benefit besides the runoff reduction is that water stored in the crates can be used by plants during dry periods, increasing evapotranspiration and thus the cooling effect. Busker et al. (2022) investigated how weather forecasting could be used to regulate the amount of water released from the crates by smart valves. A total of eleven events with more than 40 mm of precipitation were recorded, where on average 70 % of rainfall was captured. During an event where 131 mm of rain fell in four hours the forecast was underestimated and not enough water was released beforehand, resulting in only 30 % of rainfall being captured. Other options are to keep the valves always open or always closed, or to regulate depending on e.g.

season, time since last rain or amount of water currently stored (Cristiano et al., 2023). Similar to intensive roofs, blue-green roofs could be difficult to retrofit due to their weight. The type used by Cristiano et al. weighed 259 kg/m^2 when fully saturated. However, depending on which management strategy that is chosen for the valve, the annual average weight can be lowered.

2.3.3 Permeable surfaces

One of the largest difficulties within urban areas regarding stormwater management is impermeable surfaces such as concrete and asphalt. Impervious areas contribute to increased runoff (Redfern et al., 2016), thus an increase of permeable surfaces such as green areas, is needed to alleviate the pressure through decreasing the runoff on impervious surfaces (Jiang et al., 2018) (Law et al., 2009). The difference between an impermeable surface and a permeable one is infiltration-capacity. A permeable surface allows for infiltration and soak up water through for example soil layers or vegetation. Examples of permeable surfaces are permeable and porous pavements. Porous pavements, such as porous concrete, are permeable throughout the whole surface whilst permeable pavements, such as interlocking concrete pavers, are made of impermeable material with partially permeable voids in between (Fini et al., 2017). These are often used at outside parking lots for bicycles or cars, see Figure 4. Estimates by Adrian (2015) and Andersson and Åkerman (2016) suggests a cost of 500-850 SEK/m^2 in order to install so called grasscrete pavers, a commonly utilized option in cities.

Figure 4: Grasscrete pavers at bicycle parking lot next to Johanneberg Science Park (Picture by authors).

2.3.4 Retention ponds and detention basins

Retention ponds and detention basins are depressions where runoff can be stored and released at a more controlled rate (NWRM, n.d.-a)(NWRM, n.d.-b), thus providing flow stabilisation. Detention basins are designed to dry out between periods of precipitation, leaving the area available for recreational use (NWRM, n.d.-a). The basin should be 0.5 m (Stockholms Vatten och Avfall, n.d.-b) to 3 m deep with a flat bottom (NWRM, n.d.-a) and have slopes flatter than a 10 degree angle to enable mechanical maintenance of the grass (Stockholms Vatten och Avfall, n.d.-b). The basin also allows suspended solids to settle, thus additional maintenance may be needed to remove sediment when it is dry (Stockholms Vatten och Avfall, n.d.-b)(NWRM, n.d.-a).

In contrast to detention basins, retention ponds are water-filled year-round, although with extra storage capacity for cloudburst events (NWRM, n.d.-b). The long time water storage of retention ponds can also be beneficial during dry periods when water is scarce (Staccione et al., 2021). The depth should be between 1 m (Stockholms Vatten och Avfall, n.d.-a) to 2 m (NWRM, n.d.-b) and the surface area between 1.5 % to 7 % of the upstream catchment area (Stockholms Vatten och Avfall, n.d.-a). One downside of retention ponds is the potential safety hazard of falling in to the water. This can be mitigated by putting up signs and/or fencing and implementing gentler slopes. Apart from being safer than 1:2, a slope at 1:4 may also improve the ecological function of the pond (Staccione et al., 2021). Like in detention basins, sedimentation occurs and needs to be removed from the pond to maintain optimal function over time (Stockholms Vatten och Avfall, n.d.-a)(NWRM, n.d.-b). Before implementing either basins or ponds investigations needs to be conducted to ensure stability, suitable soil conditions and groundwater levels (NWRM, n.d.-a)(NWRM, n.d.-b). A review of construction costs for 13 ponds in the municipality of Gothenburg shows an average of 990 SEK/m^2 of pond surface, when including expenses for parking, walkways and other park equipment (Berglund et al., 2022). In comparison, Keating et al. (2015) states that a detention basin would have a cost of 200-750 SEK/m^3.

2.4 Decision support

Previous research in implementation of NBS have made use of different types of decision making support models. In a study conducted in 2010 by Young et al., the decision-making tool Analytic Hierarchy Process (AHP), a computationally accessible mean within complex 'Multi-criteria-decision' making problems, was applied to systematically evaluate and rank Best Management Practices (BMP). This was based on various criteria for the selection and implementation of the BMP's. BMP are similar to NBS as they include for example rain gardens, infiltration trenches and permeable pavement. Young et al. mention that the main benefit of the AHP method is the possibility to stay objective during the ranking simultaneously as several criteria are considered, in addition to the ability to alter to what degree each included criterion influences the overall selection process. However, it was stated that a limitation with AHP is the algorithms ambition to satisfy potentially conflicting criteria during the selection of the criteria, through simultaneously adhering to the ranking of each criterion made by the implementer of the method. Thus, the final results might be affected due to the incapability to satisfy the criteria individually. Additionally, no combinations of solutions were taken account of.

Another study of relevance was conducted in 2018 by Jayasooriya et al., where Multi-criteria Decision Analysis (MCDA) was applied during the selection of green infrastructure as stormwater management for industrial areas. The application of MCDA in this study separates itself from other similar studies using the same decision-making tool since it attempts to address the difficulties regarding combination of solutions, or so called "treatment trains". This was done through the *Technique for Order Preference by Similarity to Ideal Solution* (TOPSIS), a method suitable for problems with large numbers of criteria in addition to quantitative data. The results of the study determined the TOPSIS method to be effective and robust due to its simplicity. However, caution must be taken concerning the subjective data, which in this case refers to the weighting done by the users. Furthermore, the aim was to achieve a solution that minimized the cost but maximized the benefit, a optimal solution desired in most cases. It was proven successful, due to the MCDA in combination with the proposed methodology achieved selecting and sizing the optimal green infrastructure treatment trains for the industrial area.

2.5 Stormwater modelling

There are many types of software with different functions and characteristics used to model stormwater and floods, developed by either academic institutions, government agencies or private companies (Saumya & Kumar, 2023). As information about for example soil types, land use and rainfall characteristics become more widely available, simplified and more user-friendly modelling tools have also been developed. The programs can make use of either stochastic or deterministic models, with the stochastic including probability distributions for at least one variable and thus producing different results each run (Zoppou, 2001). Deterministic models always give the same result until input variables are changed and can in turn be divided into hydrological or hydraulic. Zoppou states that hydrological models satisfy the continuity equation (i.e. conservation of mass) whilst hydraulic models also satisfy momentum or energy equations (i.e. conservation of momentum/energy). The variable of precipitation can either be modelled as an event or continuous process, with the former commonly used for design of stormwater infrastructure and the latter for water balance over longer periods of time (Zoppou, 2001).

2.5.1 SCALGO Live

The web-based SCALGO Live is an event-driven stormwater modelling tool which can be used to map flooding (SCALGO, n.d.). For the flash flood simulation an equal amount of precipitation is set for every raster cell, and as the duration of the event is not taken into account, each cell receive all water immediately. The simulation is hydrological and based on topography, but also takes infiltration based on land cover into account. The water that is not infiltrated becomes runoff and is routed downstream until it encounters a depression in the terrain, see Figure 5. If the storage volume of the depression is larger than the arriving volume of water, the water will remain and not continue downstream. However, if the volume of water is larger than the capacity of the depression, the depression will be filled to its threshold (marked by black dots) and water will then propagate further downstream. Consequently, a larger catchment area and heavier rain event will fill up more depression volume, thus resulting in a larger downstream area. Grey infrastructure such as pipes and sewers is not specifically included in the model, however, the infiltration setting for artificial land covers (urban surfaces) can be set to assume sewers. As the simulation does not include a time variable, no estimation for flooding duration is made.

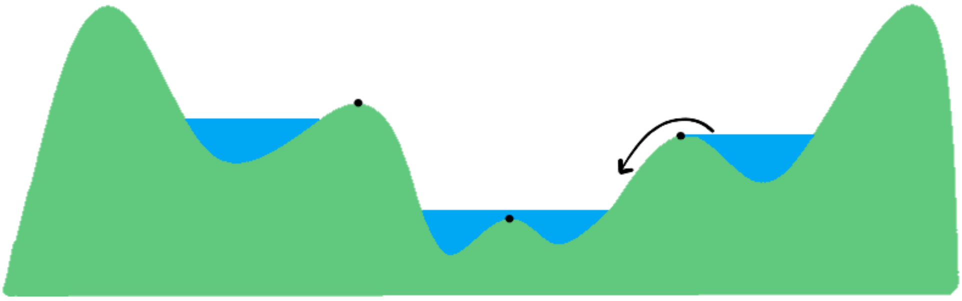

Figure 5: Illustration of water propagation through depressions in the flow model of SCALGO Live (Illustration by authors).

As compared to other programs, e.g. MIKE, there is a lack of published works where SCALGO Live is used to model the implementation of NBS. Warzecha and Dudek-Klimiuk (2023) used SCALGO Live to investigate how the proportion of vegetation in the land cover can influence infiltration in city centres and how suitable the program is for such modelling. The authors note that it is a fast and less expensive tool that can be used to estimate basic data, like the amount of surface runoff, whilst also underscoring its user-friendliness.

2.6 Previous case studies

The awareness of climate change and the importance of cities resilience within stormwater management is increasing all over the world. The urge of cities to protect themselves has been proved through initiatives such as cloudburst plans. An example of this is in the city of New York, where Ramboll has executed a Cloudburst Resiliency Planning Study (Ramboll, 2017). The project was built upon Ramboll's experience and city-to-city collaboration regarding cloudburst solutions development for the City of Copenhagen. The study involved a literature review of six cities that are considered leading within climate change adaption, a cloudburst master plan of the studied area, and a pilot testing project of specific smaller areas. The work involved a four step plan, see illustration in Figure 6 below.

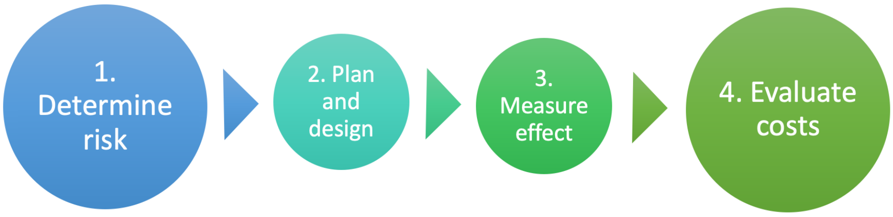

Figure 6: Illustration of the four steps utilized during the project (Illustration by authors).

The four steps involved everything from stormwater modelling in MIKE Urban, MIKE Flood and MIKE 21 to a Cost-benefit analysis (CBA) of the project. A CBA was considered to be superior to a direct cost analysis since it also considers the social and environmental costs and benefits associated with the project. Thus, the social impacts and co-benefits are easier to communicate to stakeholders and decision-makers. The CBA was scenario-based, where the master-plan of the studied area was compared to a baseline scenario to enable a full impact analysis. One of the main findings of the CBA was that it is possible to achieve increased urban value and co-benefits for capital investments through implementing BGI. One of the BGI suggested in the study is a conceptual cloudburst road with roadside rain gardens to enable retention, in addition to a green roundabout that can retain large volumes of water. Another finding stated is the significance of co-operation between stakeholders and city agencies.

As previously mentioned, the city of Copenhagen is considered leading within stormwater resilience adaptation. Copenhagen released a cloudburst plan as early as 2012 as a mean towards being carbon neutral in 2025. The cloudburst plan was estimated to have a cost of 3.8 billion DKK, a small sum in comparison to the 5-6 billion DKK used to repair the damages of the severe flooding in 2011 (The City of Copenhagen, 2012). Furthermore, is the case of the water park in Copenhagen named "Tåsinge square". After suffering heavy floods caused by cloudbursts, the City council decided to create an urban stormwater management area in the city center as a surface solution (Engberg, 2018). The square protects an area of up to 7000 m^2 and has solutions in the form of for example green surfaces, varying heights, vegetation and ditches. The rainwater that is not directly infiltrated at the square convey to a emergency overflow cloudburst tunnel. According to The National Network of Climate adaption, the central rain basins are used to 10 % capacity every year, 25 % every 25 years, and 40 % every 100 years (DNNK, 2022), indicating that it is a effective way to avoid flooding in the dense city area of Copenhagen.

Figure 7: Overview of the stormwater solution Tåsinge square located in central Copenhagen. Picture by Steven Achiam and Charlotte Brøndum (UIA, 2024).

There are more similar case studies that have different aspects of value for the thesis due to the utilization of NBS, recreational surfaces with multi-functionality, limited work surface, urban space, dynamic spaces and so forth. As for example, a case study where sustainable urban stormwater management had large focus through utilizing multi-functional solutions was in the district of Valdebebas in Madrid, Spain. The study had a preventative approach where urban design features such as topography and pavement selection was used in order to transport excess water from impermeable surfaces to permeable ones (Rodriguez-Sinobas et al., 2018). The case study had several techniques and criteria, where the possibilities using Low Impact Development (LID) and Sustainable Urban Drainage Systems (SUDS) on a large scale was investigated through utilizing for example drought tolerant shrub areas and infiltration boxes underground, solutions that are space-effective.

Lastly, the case of the "Water square" in Benthemplein located in the city of Rotterdam (Brao, 2013). The surroundings consist of a majority of impermeable surfaces and limited working space, similar to the city of Gothenburg. A unique aspect of the Water square is that it was created in collaboration with the citizens of the area, making the social aspect highly valued. A factor considered to be of great importance by the citizens was the possibility of using the area in several ways depending on weather, as well as creating a living space filled with green surfaces and recreational value in combination with possibilities to play (DE Urbanisten, 2024). Consequently, the Rotterdam City Council decided to construct three pools that fill up during heavy rainfall, see Figure 8. When the worst period of rain has passed, the water from the pools seeps into the underground water network of the city. Since the pools are empty most of the time, the Water square is often utilized as a recreational area with possibilities for dancing, playing football, wheel sports or simply to enjoy the weather, thus being used at all times regardless of the weather situation.

Figure 8: Overview of the stormwater solution Water square located in central Rotterdam. Picture by Ossip van Duivenbode (DE Urbanisten, 2024).

3 Case study

The municipality of Gothenburg has presented a structural plan for management of flood risks during 100-year rains, where the municipality is divided into 15 districts (Göteborgs stad, 2020). The area of topic in this case study falls under district "Centrum södra" (transl. "Center south"), which is marked with number 11 in Figure 9.

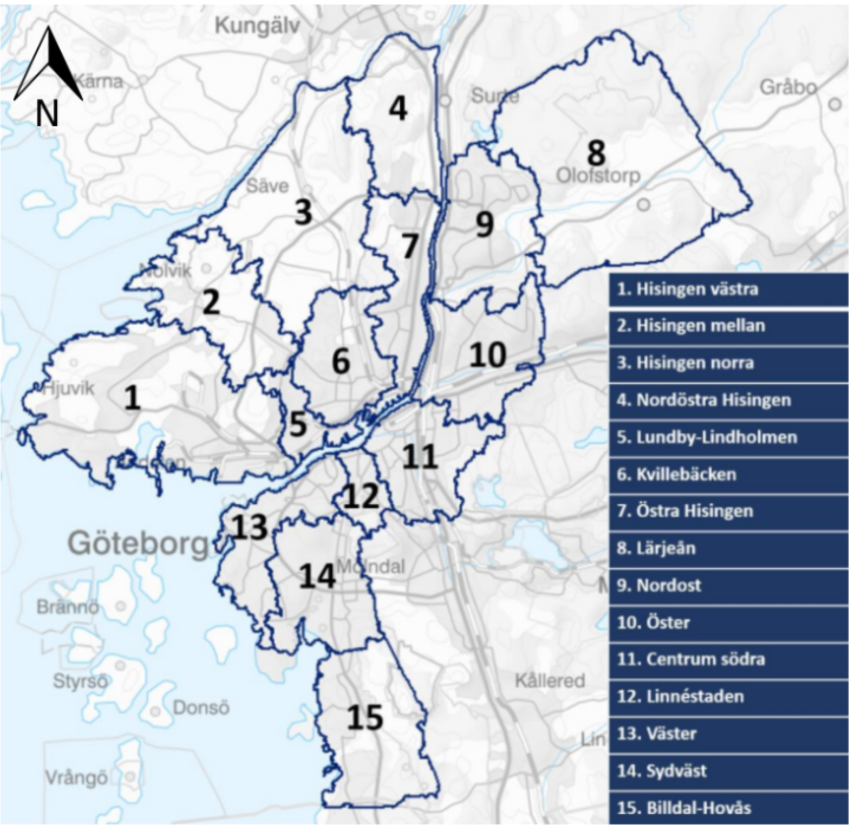

Figure 9: Overview of districts in the structural plan (Göteborgs stad, 2020).

A combination of MIKE softwares were used to conduct the modelling which the structural plan is based on; MIKE 21 for surface runoff, MIKE Urban for sewers and pipes, MIKE 11 for waterways, and finally MIKE Flood for combining all parts into one integrated model (Göteborgs stad, 2021). Results from the modelling are also presented by the municipality in a tool on their website "Vatten i staden" (transl. "Water in the city") (Göteborgs stad, n.d.). The measures proposed in the plan can be divided into three categories; cloudburst pathways, cloudburst areas and redirection (Göteborgs stad, 2020). One of the proposed cloudburst areas is Mossens IP, a football field which can be seen as a green square within the area marked with a red box in Figure 10 below. It is estimated to have a dimensioning capacity of 6600 m^3. There are also three cloudburst pathway segments proposed, leading more water towards the pitch. These can also be seen in Figure 10 as blue lines with the flow direction of the water indicated by the black triangles.

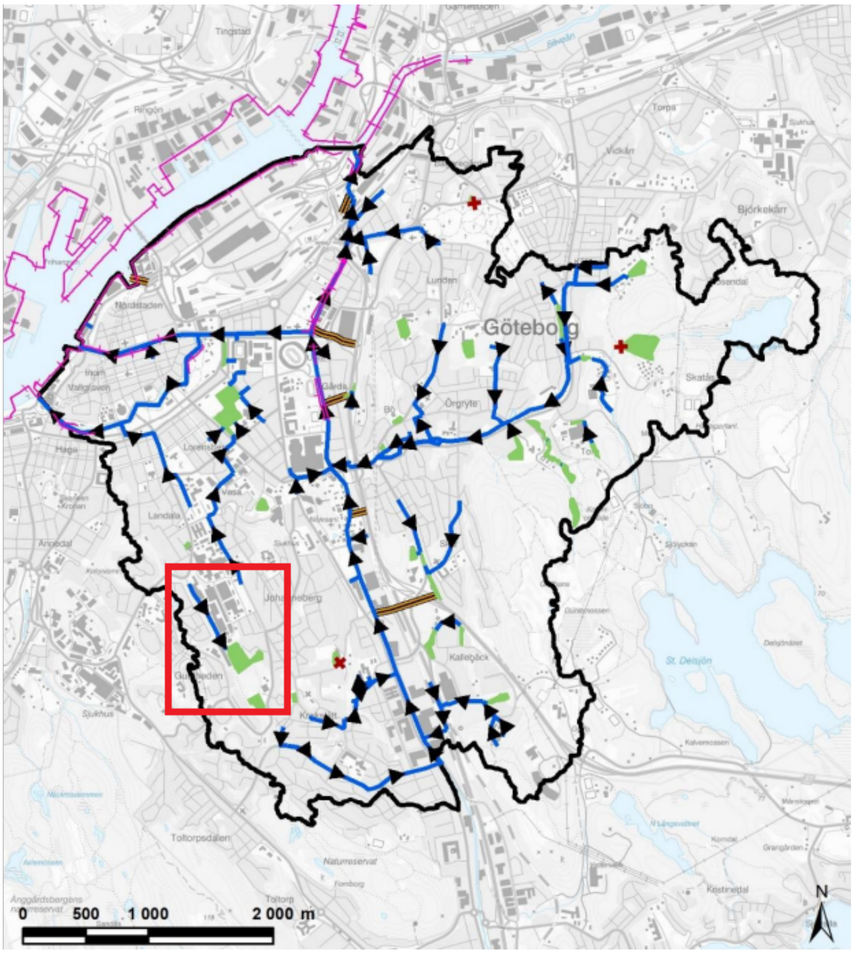

Figure 10: Overview of district Centrum Södra presented in the structural plan (Göteborgs stad, 2020).

3.1 Area description

Mossens IP is located in Johanneberg, central Gothenburg. An overview with relevant areas and functions in the vicinity marked with numbers 1-11 can be seen in Figure 11 and shortly described in Table 1.

Figure 11: Overview of Mossens IP and surroundings, with relevant areas and functions numbered (Ortophoto by Lantmäteriet, n.d.).

Table 1: List of areas marked in Figure 11.

Area	Label
1	Mossens IP
2	Tennis courts
3	Gravel area
4	Kindergarten
5	Green area
6	Johanneberg Science Park
7	Chalmers University of Technology
8a,b,c	Residential areas
9	Public transport hub
10	Bicycle parking
11	Forest area

Area number 1 is the sports ground named Mossens IP, which consists of the football field, a running track, two club houses in the east, as well as small areas of surrounding grass, see Figure 12. The club houses are solely utilized by the football association IK Virgo, whilst the field is shared with association Mossens BK as well. The sports ground is also open for rental, for example during larger events such as the football tournament "Gothia cup".

Figure 12: Overview of Mossens IP (Ortophoto by Lantmäteriet, n.d.).

Area number 2 ,*"Tennis courts"*, consists of four tennis courts to the west of the football pitch. Area 3, *"Gravel area"*, is located to the south of the pitch and is a flat area of gravel and sand currently used as both a parking lot and construction site storage. Also to the south of the pitch is Area 4, which is a kindergarten made out of barracks and an appurtenant playing area.

Area number 5 *"Green area"* includes a small rain garden in addition to an area of sand, a place for relaxing with seats, as well as a small car and bicycle parking made out of permeable pavers. Beside it lies Area number 6, Johanneberg Science Park, which includes the premises of Chalmers and Business Region Göteborg in the form of office buildings. Area number 7, Chalmers University of Technology, consists of the campus area of Johanneberg for the university. Area 8a-c are areas of multi-story residential buildings with accompanying parking spaces and Area 9, *"Public transport hub"*, consists of a small lawn and parking lot nestled between three bus stops. Lastly, area 11 is a small forest with a trail suitable for recreational activities such as running or walking.

The areas that are considered to have the greatest potential concerning implementation of solutions are Area 3 (*Gravel area*), 5 (*Green area*) and 8a-c (*Residential areas*). Furthermore, Area 4 (*Kindergarten*) was also of interest. The future of the area is however considered uncertain due to potential removal or refurbishment in the future as it currently consists of barracks. Another location of great interest was Area 11 (*Forest area*) due to the possibilities regarding the position and extension of the area. Nevertheless, the forest at Mossen is habited by a red listed endangered species of small woodpecker (Ålund & Ahlén, 2012), among other nature life. There are other areas in the surroundings that have the possibility to facilitate the preservation of the small woodpecker (Svedholm, 2014), however not as fit as the forest at Mossen. Thus, aligned with the Swedish environmental goals to consider and conserve nature and endangered species (Sveriges Miljömål, 2023), the biodiversity is prioritized and the forest left untouched in this project.

3.1.1 Topography and infiltration

Urban pluvial flooding is believed to be greatly affected by topography and urban surface characteristics such as terrain and land feature variables (X. Zhang et al., 2023) (Walczykiewicz & Skonieczna, 2020). This since, in urban areas, the presence of impervious surfaces limits natural drainage and routes water to grey stormwater infrastructure with finite capacity, making these areas especially prone to flooding. Thus, pluvial flooding is a risk at Mossens IP after intense rainfall as the drainage system gets overflowed and the infiltration capacity surpassed. The infiltration capacity of an area can be described through the Horton method and associated infiltration equation (Horton, 1940). Horton describes infiltration as the following:

> *"...the maximum rate at which a given soil when in a given condition can absorb rain as it falls".*

Johanneberg is situated at a relatively high altitude compared to the more central parts of Gothenburg closer to the Göta river (Lantmäteriet, n.d.). Thus, water is generally expected to flow away from Johanneberg towards lower areas such as Lorensberg or Heden (Göteborgs stad, 2020). According to Walczykiewicz and Skonieczna (2020), large terrain height differences is one of the most important factors regarding urban flooding. Since the terrain surrounding the site is uneven and of varying height the stormwater from the catchment naturally flows towards the lowest point, which is Mossens IP situated within the red square, see Figure 13 below. There is a range of elevations between 47.5-72.5 m surrounding Mossens IP located at 47.5 m.a.s.l., which makes it the lowest point in the investigated area. Consequently, as the pitch is placed in a depression as compared to the immediate surrounding area (Lantmäteriet, n.d.), water ends up gathering there.

Figure 13: Base map of the topography of the area (SCALGO, 2024).

According to maps by SGU (2024) the soil layer underlying the pitch consists of bog peat, see Figure 14. Large amounts of the overall surroundings of Mossens IP consists of exposed primeval rock (red) and glacial clay (yellow). There are also small areas of post glacial sand (orange with dots) as well as fill material (striped). Considering topography and typical soil stratigraphy, it is probable that the glacial clay also extends below the bog peat. According to Kaczmarek et al. (2023) studies show that the hydraulic conductivity, K, of peat seems to vary greatly from place to place, with values ranging between 10^{-12} and 10^{-4} m/s. K also decreases with an increase in degree of decomposition and compression, as such the lower range of values (10^{-12} to 10^{-6} m/s) is expected deeper down in the soil layer where the material is more decomposed and/or compressed (Kaczmarek et al., 2023). Clay typically has a K-value of around 10^{-9} m/s (Larsson, 2008). Low hydraulic conductivity could affect the drainage in the area and water might be slow to percolate even if the ground cover is permeable.

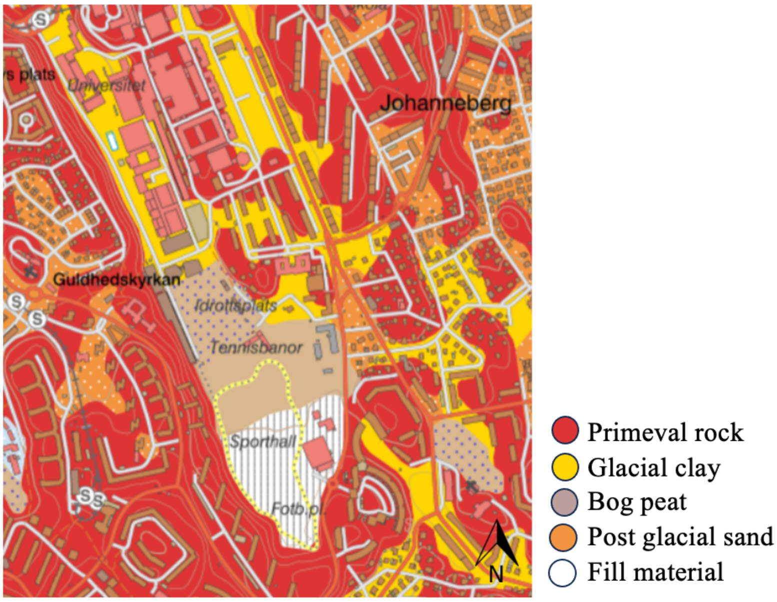

Figure 14: Map of top soil layer (SGU, 2024).

3.1.2 Stormwater solutions in the area

The surroundings of Mossens IP consist of a lot of impermeable surfaces like asphalt and buildings. However, there are also NBS that have been implemented in connection to Johanneberg Science Park, which can be seen in Figure 15. This includes a rain garden and raised plant beds, as well as impermeable pavement being avoided by incorporating sand, gravel, permeable pavers and wooden walkways.

Figure 15: Stormwater solutions close to Mossens IP (Picture by authors).

The rain garden consists of three layers with a total height of 1080 mm, as can be seen in Figure 16 below. The top layer is composed of 50 mm of gravel, followed by a second layer of plant bed with 50-60 % sand, 20-30 % compost and 20-30 % top soil. The final layer consists of a moisture retention layer of 50 % sealing soil of 80 mm, and lastly 150 mm of draining gravel.

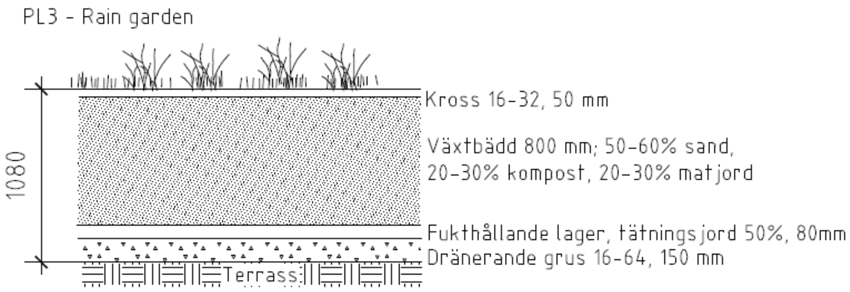

Figure 16: Illustration of the soil layers in the rain garden next to Johanneberg Science Park (Chalmers Fastigheter, n.d.).

4 Methodology

To answer the presented research questions in Chapter 1.2, the following methodology will be used throughout the project including literature study, description of scenarios, stormwater modelling, decision making framework and tool and interview technique, see Figure 17 below.

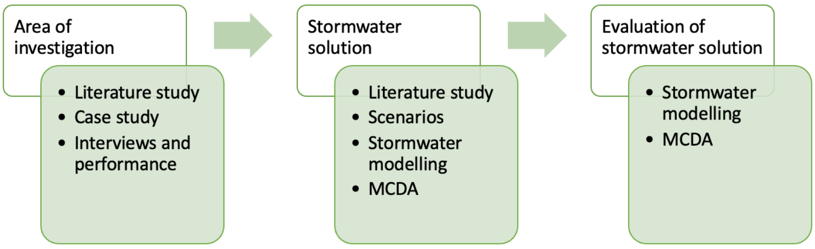

Figure 17: Overview of the methodology.

4.1 Literature study

Qualitative research was conducted through a literature study in order to get background information of the subject, relevant data to use during modelling, as well as information regarding stormwater solutions to implement and similar case studies. Both primary sources as well as grey literature were utilized. The data bases Google Scholar, Scopus and Science Direct were the platforms utilized in order to find scientific and academic papers that contain relevant case studies as well as information about methodology. The standard search engine of Google was also utilized to find information about Mossens IP and sports associations, in addition to for example regulations in Sweden or Gothenburg. Furthermore, the structural plan for flood risk management by the City of Gothenburg and the decision of flooding the Mossen football field was investigated. The technique mostly used was the *Snowballing technique*, which includes finding new literature through the reference list of other relevant literature (Badampudi et al., 2015).

Examples of keywords utilized during the literature study, both in combination with each other and separately:

Climate change, Precipitation, Stormwater management, Nature Based Solutions, Blue-Green solutions, Urban flooding, Stormwater modelling, MCDA

4.2 Scenarios

The project was scenario-based with three different scenarios in order to structure the quantification regarding the solutions and discussion, in addition to the decision making tool. The scenarios were created in consultation with the supervisor of the project, Sebastien Rauch. Furthermore, all scenarios were shaped differently to enable a wider analysis of the possible different outcomes that could affect Mossen football field. Consequently, the first scenario enabled an analysis of the current situation at the site without any changes implemented. Thus, an analysis of the area as it is, and its resilience against 100-year rains. Scenario 1 distinguishes from Scenario 2 and 3 since it is later used as base line of comparison to and between the other scenarios. The second scenario enabled an analysis of NBS, more specifically rain gardens, green roofs, blue-green roofs and permeable paving, being implemented in the catchment area presented in SCALGO Live. The third scenario enabled an analysis of storage-focused solutions, e.g. retention ponds and detention basins. See summary of the scenarios below:

- **Scenario 1:** The current flooding situation of the site at Mossen football field if no changes are made.

- **Scenario 2:** NBS, e.g. rain gardens, green roofs, blue-green roofs and permeable paving, are implemented within the catchment area.

- **Scenario 3:** Storage-focused solutions, e.g. retention ponds and detention basins, are implemented within the catchment area.

4.3 Stormwater modelling

The modelling method used for this project was mainly SCALGO Live. However, SCALGO Live has certain limitations, like not being able to determine the duration of flooding. Thus, a tool on the website "Vatten i staden" by the municipality of Gothenburg was utilized as a compliment.

4.3.1 SCALGO Live

The first step of stormwater modelling in SCALGO Live, utilizing the version available during the time period of March-May, was to create a workspace for flash flood analysis. To ensure correct and large enough boundaries the "Watershed" tool was used and the pinpoint was placed in the middle of the football pitch. This highlights the catchment area, which needs to be fully within the boundaries of the workspace. The amount of precipitation was set to 102 mm in accordance with the 100-year rain with a 1.2 climate factor used by the municipality of Gothenburg (Göteborgs stad, 2021).

The watershed analysis in SCALGO Live, see Figure 18, shows a catchment area of 0.35 km^2. The 2286 m^3 of runoff that is being created exits the field at its northern point and flows along Sven Hultins Gata towards the central parts of Gothenburg. 0.2 km^2 (58 %) of the watershed's land cover is classified as natural, with dense vegetation being the most common (39 %) followed by shallow vegetation (13 %), bare land (6 %) and bare rock (<1 %). The remaining 0.14 km^2 (42 %) is classified as artificial, consisting of paved roads (11 %), other paved surfaces such as parking spaces (19 %) and buildings (11 %).

Watershed Info	
Location	319944, 6397594
Upstream area	0.35 km²
Depression storage	10,496.93 m³
Runoff	2,286.55 m³
Infiltrated or drained	21,786.12 m³

Figure 18: Catchment area represented by green colour in SCALGO Live with Mossens IP as specific point (SCALGO, 2024).

For scenario 1, the next and final step was to tick the boxes "Flooded areas" and "Flow accumulation", which shows the flooding without any solutions applied. When modelling scenario two and three, the initial step was to determine suitable locations within the watershed to implement stormwater solutions. In Scenario 2, NBS were simulated by changing land cover and adding runoff functions. Runoff coefficients and initial losses used in the modelling can be found in Table 2. Extensive green roofs were added to all multi-story buildings and two long single story garage buildings in Area 8a-c, see Figure 30. However, multi-story buildings that were found to already have solar panels or green roofs installed were excluded. In cases where the building was partially outside the catchment, the land cover was still changed for the entire building. A blue-green roof was added to the kindergarten in Area 4 as it might be rebuilt in coming years, thus the extra weight of the blue-green roof could be taken into account during construction. Two areas were found to be potentially suitable for a rain garden; Area 3, *Gravel area*, and Area 5 *Green area* where the current rain garden could be expanded. Furthermore, permeable pavement was added to public asphalt covered parking spaces in the entire catchment. Regarding Scenario 3, the aim was to add storage in the form of e.g. basins or lowered multi-functional spaces. This was modelled by changing the elevation with the "Lower and flatten" tool. For grass detention basins a side slope of 10 degrees was added and depth was set to ensure that a flat bottom was achieved. As similar for Scenario 1, the final step was to tick the boxes "Flooded areas" and "Flow accumulation".

Table 2: Runoff coefficients and initial losses for NBS used in Scenario 2

Solution	**Runoff coefficient**	**Initial loss**	**Source**
Permeable Pavement	96 %	-	Hunt and Collins (2008)
Green Roof	-	6 mm	Castiglia Feitosa and Wilkinson (2016)
Blue-Green Roof	-	71 mm	Busker et al. (2022)
Raingarden	34 %	-	Yuan et al. (2017)

To evaluate changes in water level on the field, the "Profile" tool was used. The water depth is not constant as the field is not entirely flat, thus the changes were instead gauged by monitoring the elevation of the water level. The elevation was checked for every solution individually and then for all solutions of the scenario combined.

4.3.2 Vatten i staden

The tool on "Vatten i staden" presents data in five different categories; "Ocean and Water courses", "Cloudburst", "Rain data", "Sewer" and "Groundwater" (Göteborgs stad, n.d.). The second category, "Cloudburst", is of use for this project as it presents the flood situation that was estimated for a 100-year rain in the structural plan, as well as the measures proposed. When utilizing the tool, the scenario named "Current situation (Climate adapted 100-years rain)" was used as the base setting. The sub-categories "Water depth" and "Duration" were then assessed separately by ticking each box individually.

The catchment area of Mossens IP used by the municipality of Gothenburg can be seen in Figure 19.

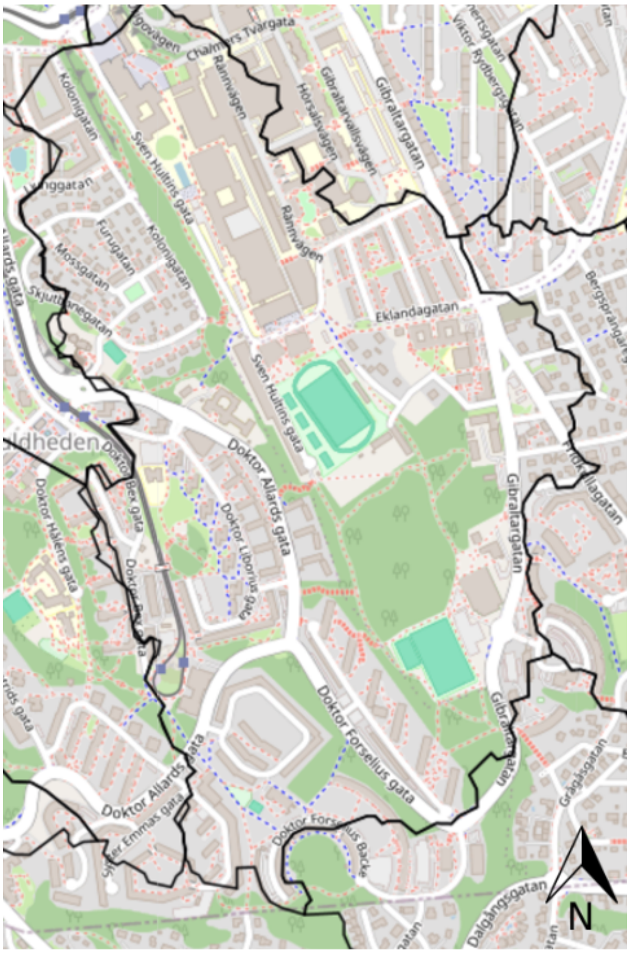

Figure 19: Simulation of catchment area (Göteborgs stad, n.d.).

4.4 Decision making framework

A decision making model was used to enable a credible and transparent comparison of the different solutions connected to each scenario. A well established and proven to be effective scoring tool used within decision-making is Multi-Criteria Decision Analysis, also known as Multi-Attribute Decision Analysis (Dodgson et al., 2009). The method was established around 40 years ago (Keeney & Raiffa, 1993) and is frequently used when comparing different scenarios, decisions or solutions within for example environmental problems (Xiong et al., 2020). Consequently, the method was considered to be a suitable methodology for this thesis.

There are many benefits of using a MCDA, with the principal one being the ability to determine to what extent which option creates value by achieving certain criteria which is suitable approach for this project. It can either be done retrospectively or prospectively, whereas for this project it was done prospectively. In this case, the MCDA was based on the manual of Communities and Local Government (Dodgson et al., 2009) which involves eight steps, see Figure 20, however they were adapted to suit the project, see Chapter 4.4.1 below. The steps were, if needed, conducted iteratively.

Figure 20: Description of the eight steps included in the MCDA.

The first step, *Establish decision context*, included deciding the aim of the MCDA by establishing the decision context, as for example the circumstances surrounding the decision-making process and the possible consequences to follow.

The second step, *Deciding solutions to be assessed*, involved the result phase of the project where the different solutions connected to each scenario were decided, that later on were evaluated in the MCDA.

The third step, *Scoring criteria*, included the identification of the main categories and criteria against which the alternatives were assessed. Thereafter, the main categories branched out into subcategories to enable a wider scoring.

The fourth step, *Scoring*, included the scoring of the alternatives based of the categories and criteria. The scoring scale was numerical with a range of (-5) to (5), where (-5) was considered the lowest value and (5) the highest.

The fifth step, *Weighting*, consisted of the weighting of each criterion. In other words, the relevance or importance that the criteria had for the project. Thus, each criterion was ranked based on priority for the project. This enabled a more transparent and structured assessment.

The sixth step, *Finalizing overall value*, was where the weighting scores were summed up and analyzed based on the previously determined hierarchy of priority mentioned in step five, as well as overall score.

The seventh step, *Examination of final results*, involved the critical evaluation of the final results. Thus, the correctness of the results was analyzed to ensure that no sources of error had occurred.

The eighth and last step of the MCDA, *Sensitivity analysis of the final result*, was where the final product of the MCDA was evaluated through a sensitivity analysis.

This was done through an assessment of the results regarding for example their reasonableness, weighting in relation to the project, transparency, possible disadvantages etc.

4.4.1 Decision making tool

With the decision making framework in Chapter 4.4 as a foundation, a decision making tool suited for the master's thesis was created. The purpose with the tool was to quantify what stormwater solution that performed the highest based on the chosen main categories, 'Economic', 'Social' and 'Environmental', and therefore was considered to be the most optimal for implementation. The main categories are divided into subcategories to, as previously mentioned, enable an easier scoring of each stormwater solution. The subcategories are *'Cost'*, *'Recreational value'*, *'Social meeting point'*, *'Eco system services'* and *'Reduced flooding'*, see overview in Figure 21.

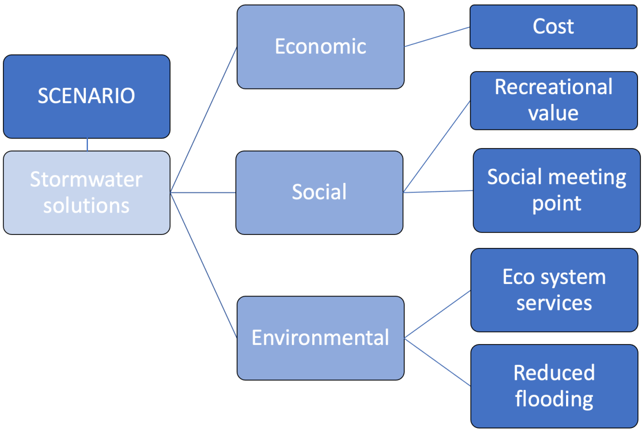

Figure 21: Flow chart describing the categories and subcategories applied in the MCDA rating.

The scoring was conducted utilizing Scenario 1 as a base line, meaning that Scenario 1 is considered to be "point zero" since it describes the current situation at site regarding flooding without any changes. The solutions were scored individually for each criterion on a number based scale in between (-5) to (5), with (-5) as the lowest rating and (5) as the highest rating. All subcategories had different aspects and approaches regarding the scoring. The subcategory *Cost* was based on the numbers presented in Table 3 below multiplied with the specific area or volume needed for the stormwater solution. Regarding the four remaining subcategories, they were scored based on to what extent they could achieve the definitions presented in Table 4 below. Since the design of the stormwater solutions was not within the scope of the thesis, inspiration was taken from the case studies presented in Chapter 2.6 regarding the appearance and function of the solution.

Table 3: Cost of each stormwater solution with associated source.

Stormwater solution	**Average cost**	**Source**
Rain garden	475 (SEK/m^2)	(Adrian, 2015)
Green roof	700 (SEK/m^2)	(Andersson & Åkerman, 2016)
Blue-green roof	700 (SEK/m^2)	(Andersson & Åkerman, 2016)
Permeable paving	675 (SEK/m^2)	(Adrian, 2015) and (Andersson & Åkerman, 2016)
Detention basins	475 (SEK/m^3)	(Keating et al., 2015)

Furthermore, the subcategories were weighted between 'Low level', 'Moderate level' and 'High level' based on relevance and priority of the project. The weighting was performed to enable a structured and transparent assessment of the stormwater solutions within the scenarios, based on step 8 in Chapter 4.4. *Cost* was ranked as a low level subcategory since it is not the main focus in this report in comparison to the other subcategories. However, it is important to note that economy plays a large role within the civil engineering sector and therefore significant to include. *Recreational value* was ranked as moderate level due to the focus of the report mainly being stormwater solutions, such as NBS, with an assumed large contribution to the recreational value at the implementation site. Additionally, the case study area is in a social environment with a surrounding in the need of an increase of natural social meeting points. Nevertheless, the recreational value as improved quality of life and aesthetics is not considered to be of as high relevance as for example the subcategory *Flooding reduction*, therefore the lower level of rating. *Social meeting point* was ranked as high level since the current possibilities to meet in the area, in non-sport related terms, are considered low. However, through the scoring, sport will be applied within this subcategory since it is considered to be a social matter. *Eco system services* was ranked as moderate level due to the project focusing on stormwater solutions such as NBS and BGI, which both contribute to the preserving of nature life in a urban environment, in addition to decreasing the urban heat island effect. However, it is not the main priority of the project, and is therefore ranked as moderate. *Flooding reduction* was ranked as high level priority since it is the main priority and aim of the project, as well as the factor that will contribute to the most change regarding the general status of the site.

Thereafter, the weighting was translated to a factor of multiplication that was multiplied with the given score of each stormwater solution suggestion. 'Low level' had the multiplication factor (1), 'Moderate level' (1.25), and finally 'High level' (1.5), see Table 4 below.

Table 4: Implemented solutions of a scenario with associated rating within the subcategories.

Subcategory	**Definition**	**Weighting level**	**Multiplication factor**
Cost	The general cost of the stormwater solution in relation to the other solutions, translated to 'Low', 'Moderate' or 'High'.	Low	1
Recreational value	Recovery, improved quality of life and aesthetics.	Moderate	1.25
Social meeting point	Social contribution to the area in terms of seats and multi-functionality.	High	1.5
Eco system service	Services provided by the stormwater solutions such as decreased urban heat island effect and supported nature life.	Moderate	1.25
Flooding reduction	The amount of stormwater volume decreased.	High	1.5

The weighted scores were then summed up to a total score of each solution. Thereafter, a final summation of all the solutions' scores was done to allow comparison between the scenarios.

4.5 Interview technique and performance

The interviews were all based on a qualitative research method with a semi-structured interview technique. Thus, all the interviews followed pre-determined questions, although the pattern and formulation of the questions could vary depending on what stakeholder that was interviewed (Slade & Sergent, 2018). This allowed for open answers and a variety of follow up questions. Accordingly, this technique enables the interview to take different directions depending on the answers given by the correspondent as well as the follow-up questions delivered by the interviewer. Consequently, no areas are left unexplored, in addition to possible non-thought of subjects or areas being able to be discovered and investigated in time (Gill et al., 2008). The framework of the interview was based on and inspired by the following five stages (Piper et al., 2018) that originates from the results achieved in the research of Kallio et al. (2016), regarding a qualitative semi-structured interview framework, see Figure 22. The five steps were utilized in order to determine a guide for the interviews and associated structure. The steps were interpreted and reformed to create an interview guide suitable to achieve the purpose of the thesis, and were repeated if considered necessary.

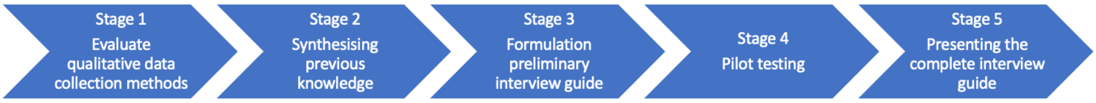

Figure 22: The five steps of the framework used as basis during the project.

The first step of the framework, *Evaluate qualitative data collection methods*, included the evaluation regarding whether a semi-structured interview technique was the most suitable methodology for the project with connection to the research questions (Piper et al., 2018). According to Barriball and While (1994), this technique is especially suitable for "...exploration of the perceptions and opinions of respondents regarding complex and sometimes sensitive issues and enable probing for more clarification of answers". Thus, it was considered to be an appropriate technique since the respondents were of varying background and education regarding to the subject, which precluded the possibility to use standardized questions.

The second step, *Synthesising previous knowledge*, was continuously performed during the project through a literature review, see Chapter 4.1. This included gathering new knowledge by reading up on existing research in the area, as well as ensuring that the previous knowledge of the subject was correct.

The third step, *Formulating preliminary interview guide*, was where the main structure of the interview was set, including for example what questions that were to be asked. This step did to some extent reoccur in preparation for each interview since it included the adaption of the questions to the stakeholder in question.

The fourth step, *Pilot testing*, was one of the most important phases. It involved testing the interview guide and reassuring that it performed as expected without being influenced by the creators of the interview guide or other external factors. This could also be referred to as "Internal testing" or "Expert assessment", and was done through allowing the interview guide with questions to be evaluated by the supervisor of the thesis Sebastien Rauch, before the final interview guide was set. Henceforth, the interview guide became transparent and potentially leading questions in addition to unwanted ambiguities was avoided. Moreover, another method entitled "Field testing" could be applied which is one of the most common ways to test the performance of an interview guide. In this case, the interview guide would be put to the test by simulating a real interview situation with potential participants (Barriball & While, 1994). However, this was not conducted due to lack of participants meaning that the existing potential participants was prioritized to be interviewed with the final product.

The fifth and final step of the framework, *Presenting the complete interview guide*, was where the finalized interview guide of the thesis was presented. By performing all these five steps of the framework it strengthened the trustworthiness of the semi-structured interview technique as a qualitative method, and consequently the overall trustworthiness of the final result.

The stakeholders to be interviewed were determined in consultation with the supervisor Sebastien Rauch, see Table 5 below. Chalmers Fastigheter were interviewed due to their knowledge regarding stormwater management at Chalmers University of Technology as well as at Johanneberg Science Park, since they are the owners of the property. The two football associations Mossens BK and IK Virgo were interviewed to get a insight in how actively the football field is used today, the amount of current rain and its effect, and how they view the future of the football field. Finally, Göteborgs Stad Kretslopp och Vatten was interviewed due to their insight in similar projects, stormwater management as well as the structural plan. Before the interviews, the participants were informed of the aim of the project and how the material would be handled. The interviews were conducted in person, voice recorded and then transcribed in a document in Microsoft Word to allow for easier extraction of the information. All interviews were done in Swedish, therefore any citations made were translated by the authors of the thesis. Moreover, it was decided with the participants of all the interviews and supervisor Sebastien Rauch to keep the participants anonymous in the report. They were also asked if they wanted to review the interviewed material and final report, but they declined. The questions asked can be seen in Appendix A.1, A.2 and A.3.

Table 5: Interviewed stakeholders with associated dates of interview performance.

Date of interview	**Stakeholder**
8/2	Chalmers Fastigheter
29/2	Mossens BK
15/3	IK Virgo
22/3	Göteborgs Stad Ketslopp och Vatten

5 Results

The following chapter includes results from the interviews, the stormwater modelling conducted using SCALGO Live and Vatten i staden. The chapter presents the catchment area, current flooding situation followed by the results of the scenarios including implementation of the NBS and storage solutions.

5.1 Interviews

This chapter presents the results of the interviews conducted with the stakeholders Chalmers Fastigheter, Göteborgs Stad and the sport associations IK Virgo and Mossens BK.

5.1.1 Chalmers Fastigheter and Göteborgs Stad

The results of the interview with Chalmers Fastigheter proved that it is not only Mossens IP who are facing challenges regarding stormwater. Chalmers Fastigheter stated that the stormwater management at Chalmers campus is lacking in several areas resulting in areas of flooding all over campus. Since Chalmers campus is in close connection to the Mossen area, see Figure 11, it is stated that the stormwater management of the two areas are of importance to one another. Chalmers Fastigheter emphasises the fact that they are constantly trying to improve the stormwater management on the campus through a decrease in impermeable surfaces through investigations of possible areas for implementation of NBS. An example of this is the previously mentioned rain garden in connection to Johanneberg Science Park, see Area 6 in Figure 11. However, the actual resulting decrease in stormwater is unknown due to insufficient follow up of the work by Chalmers Fastigheter. Chalmers Fastigheter specifies that data of the results of the rain garden do exist, although has become harder to access throughout the years. Moreover, the connection between Chalmers Campus and Mossen is stated to have a possible increase in importance and relation to each other in the future due to the plans and scenarios made by Göteborgs Stad in the structural plan regarding the cloudburst pathway alongside Chalmers campus in connection to Mossens IP.

In the interview with Göteborgs Stad the importance of stormwater management in all new urban planning projects is emphasized, as well as the structure of the stormwater management planning. Thus, although the structural plan is a preliminary investigation in an early state, it is still of significance. Furthermore, projects in the surroundings are discussed such as the rebuiltment of the kindergarten, see Area 4 in Figure 11, which is under investigation. Further, most of the projects and future implementations of solutions are dependant on cost. It is highlighted that not only the implementation cost is of importance, but also the possible cost of maintenance and operation. Thus, the total cost of the project always have to be weighed against the benefit of the solutions, meaning if it is financially justifiable to implement.

5.1.2 Evaluation of field use Mossen

The interviews with the sport associations utilizing Mossens IP, Mossens BK and IK Virgo, both had a similar outcome. The associations agree that the utilization of the football field has been low the recent years, although it has increased lately. They believe that in the past the municipality did not prioritize the maintenance of the field, thus a decrease in quality of the overall field. Consequently, the field was out of use during a period of time. However, they experience a slight increase in maintenance of the field today. Another factor influencing the utilization of the field is lack of light sources, making the field dependent on the hours of natural daylight. Additionally, they both state that there has been several plans made and discussed throughout the years for the area. However, the plans are never carried out or become postponed, resulting in a frustration and a general feeling of not being prioritized.

When asked regarding the flooding of the field, the current situation is described as moderate although sometimes severe enough to make the field unusable. This since, according to IK Virgo, water collects alongside the middle part of the whole field from south to north. Both associations argue that the football field has the opposite structure of how a football field should be constructed, meaning that it has the lowest point in the middle rather than along the sidelines. This results in water gathering with no other solution than to wait until it dissipates on its own.

> *"...[during a 100-year rain] the whole city of Gothenburg has more severe problems to handle than if we can play football at Mossens IP or not."*

In other words, the mindset of the associations is realistic regarding a future worst-case scenario, however optimistic regarding aiding the consequences at Mossens IP as much as possible. Thus, enabling an increase instead of a decrease in the usage of the field, a concern they have been aiming for during a long period of time. Furthermore, they state that there has been a discussion regarding refurbishment of the club house to create a more permanent and sufficient meeting point for children and youth. There is already a lot of activity not only related to the football field, but also in the surroundings as for example pedestrians and students of the university passing through the area, athletes in the running track, and people at the pizzeria and gym. Thus, the associations express a desire of a permanent meeting point which would encourage people to meet naturally, as well as increase the safety in the area. They also connect the safety of the area to the previously mentioned lack of light sources that in some areas of the surroundings creates a feeling of unsafety, in addition to unwanted criminal activity connected to drugs.

5.2 Scenario 1

An analysis of the current situation regarding flooding was required to get an understanding of the spread and depth of the water during a 100-year rain without any measures applied, see Figure 23 presented in Chapter 5.2.1. The water depth is represented through the colours light to dark blue in both stormwater modelling programs, with light blue as the lowest depth and dark blue as the highest depth.

5.2.1 Simulations in SCALGO Live

The flooding accumulates in the depressions and is most intense at the north of the football pitch with a water depth of 118 cm. The flooding continues at the south of the pitch with a water depth of 59 cm, as well as at the kindergarten and gravel area south of the football field with a water depth of 48 cm. Furthermore, the flooding spreads within the surroundings up to the green area and Johanneberg Science Park in the north. In other words, a large quantity of the investigated area is covered with water of an extensive amount.

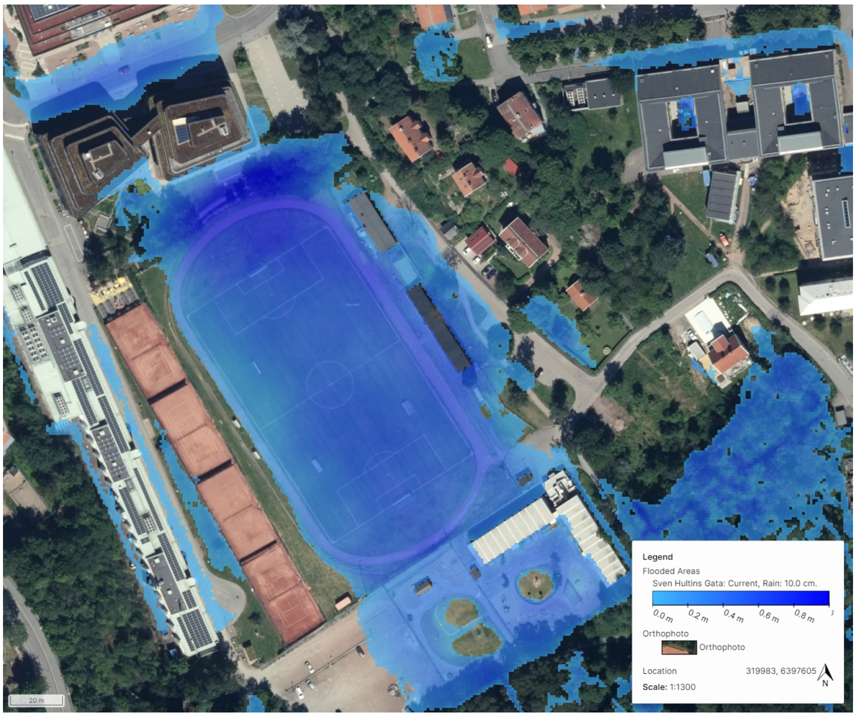

Figure 23: Overview of the flooding of the football pitch during a 100-year rain (SCALGO, 2024).

The profile line drawn across the middle of the field, as shown in Figure 24, shows that the pitch is uneven and the water depth thus will vary all over the field. This unevenness can be seen in Figure 25, where it is confirmed that the largest depth is in the north part of the field. The elevation of the water level sits at 46.95 m.

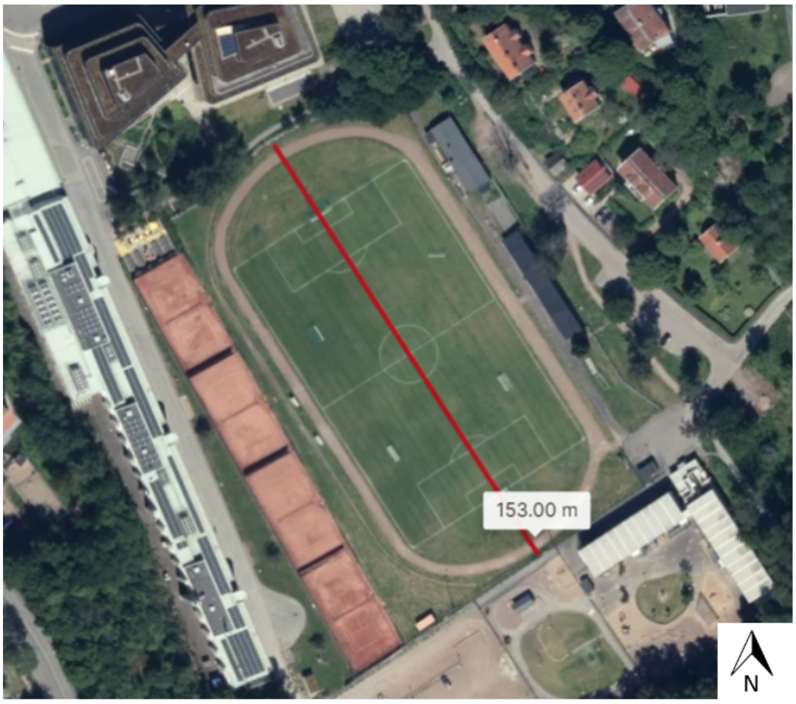

Figure 24: Profile line drawn in SCALGO Live (SCALGO, 2024).

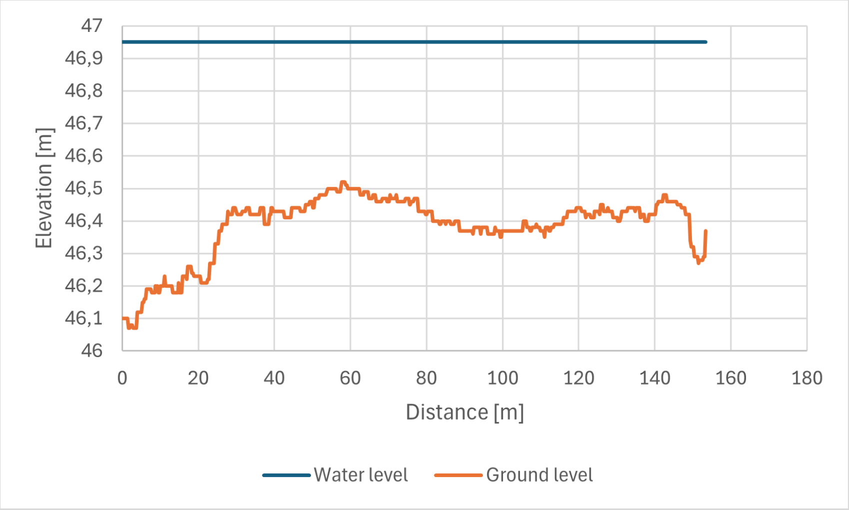

Figure 25: Water level in relation to the ground level along profile line in Figure 24.

5.2.2 Simulations in Vatten i staden

In Vatten i staden, maximum water depth and duration was simulated, see Figure 26 and 27. The color scale in the legend describes the water depth in meters with four stages ranging from the lowest of 0.1-0.2 up to >1. Thus, as can be seen in Figure 26, the maximum water depth occurs alongside half of the football pitch to the east with a water depth in between 0.5-1 m.

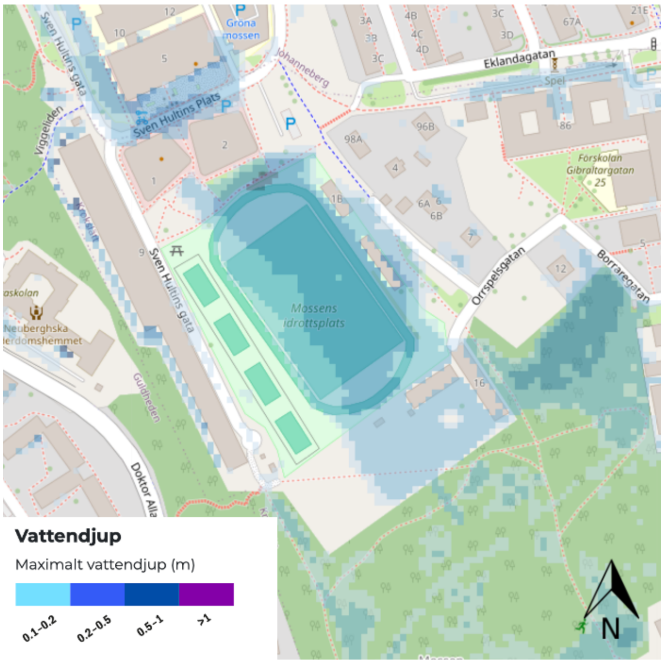

Figure 26: Maximum water depth from Vatten i staden (Göteborgs stad, n.d.).

The duration of the flooding is presented in Figure 28, with a 11 step color scale representing the flooding duration in hours, starting with <1 up to 10-11. The duration is classified as the amount of time that the water levels exceed 20 cm. The most critical part of the flooding is in the parts proven to have the largest water depth in the north and the south of the football pitch, with a duration around 8 hours.

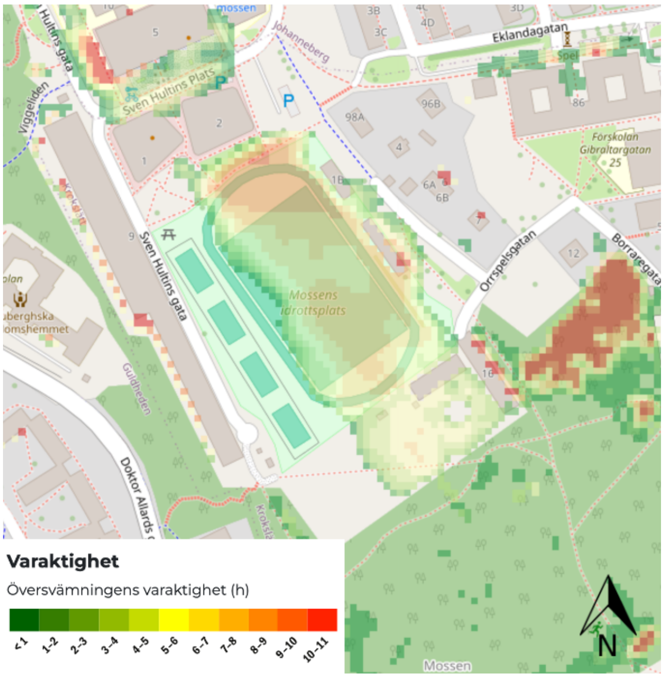

Figure 27: Duration of flooding from Vatten i staden (Göteborgs stad, n.d.)

5.3 Scenario 2

NBS were implemented at large number of areas within the catchment area as an attempt to mitigate the flooding at Mossens IP, see areas marked in Figure 28. The solutions are color coded where pink areas represent 'Green roofs' with the largest surface of 33.700 m^2, blue areas represent 'Rain gardens' with an area of 5820 m^2, green areas represent 'Blue-green roofs' of 1000 m^2, and finally the dark grey areas represent 'Permeable paving' with the area of 26.600 m^2.

Figure 28: Overview of NBS implemented within the catchment area (SCALGO, 2024).

As can be seen in Figure 29, the pitch remained completely under water. The elevation of the water level stayed at 46.95 m, which indicates that the implemented solutions did not have enough of an impact to significantly affect the water level at Mossens IP.

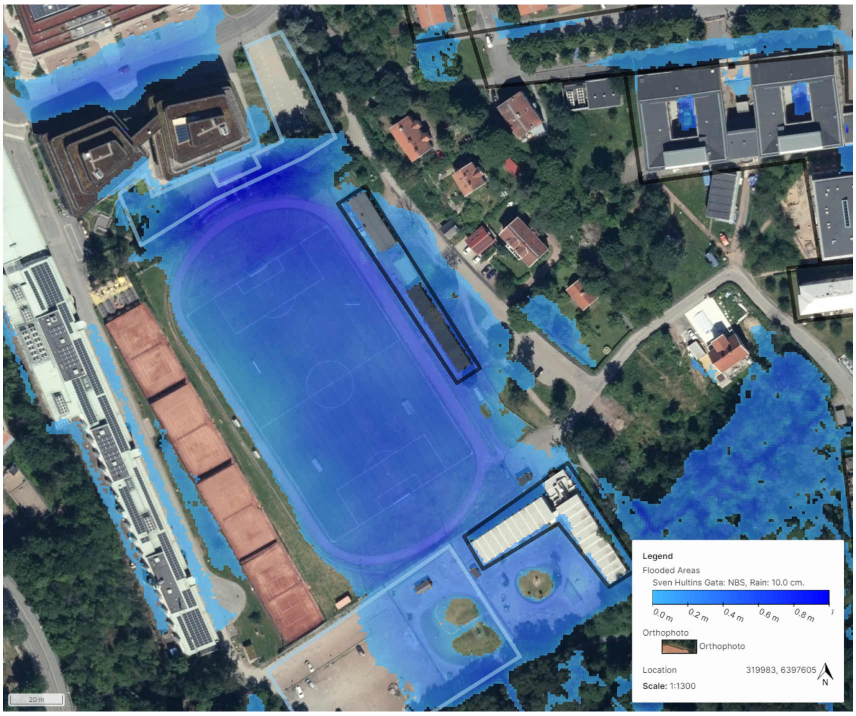

Figure 29: Flooding of Mossens IP after implementation of NBS (SCALGO, 2024).

5.4 Scenario 3

In Scenario 3 the focus was to add stormwater storage such as retention ponds, detention basins or other lowered surfaces. This resulted in six areas of implementation that were modeled in SCALGO Live, presented in Figure 30. Area number 3 is as previously mentioned a gravel surface used as a parking lot. Furthermore, since the site is quite extensive with an area of 3200 m^2, its development could take several directions. The direction chosen was a staircase-like design, consisting of three 0.5 m steps with a total depth of 1.5 m. This would create seating areas in addition to space at the bottom to be designed according to what stakeholders in the vicinity would prefer. As a result, this solution lowered the water level at Mossens IP by 12 cm. Area 2 currently consists of four tennis courts at a total area of 2500 m^2. If this area were to be lowered, 6 cm of water would gather, which according to SCALGO Live would not significantly impact the water level at Mossens IP.

Area 8a includes two roads connected by a parking strip in between them. A possibility with the area is that one of the roads, along with the parking strip, could be repurposed without significant negative impact on the accessibility of traffic. This since the multi-story buildings to the north still could be reached from another direction. Consequently, the area would become a lowered multi-functional space or park of about 2000 m^2 where water with a depth of 72.3 cm would gather. However, the modelling of the solution states that the water level at Mossens IP would not be decreased.

Area 9 consists of a small lawn in between three bus stops with an area of 550 m^2. Since it needs to be accessible for lawn mowers and pedestrians crossing the space, the slopes are set to 10 degrees. Additionally, as the bottom should be flat the depth is limited to 0.5 m. Similarly, Area 8b would also be a lowered green space at about 1800 m^2. Area 10 is currently a bicycle parking with permeable paving, located next to a gym as well as Guldheden Södra football pitch. This was the smallest space investigated at 440 m^2 and the slopes were again set to 10 degrees. None of the solutions in areas 8b, 9 and 10 allowed for enough stormwater to gather in order to impact the water level at Mossens IP.

Figure 30: Overview of placement of storage solutions (SCALGO, 2024).

If all the storage solutions were to be implemented in combination, SCALGO Live indicates that the water level at the field would be lowered by 23 cm. As the pitch is not completely flat, some parts of the field are left above the waterline whilst the middle of the field has a water depth around 15-30 cm. The reduced amount of water also improves the situation for the football club houses, the kindergarten and Johanneberg Science Park.

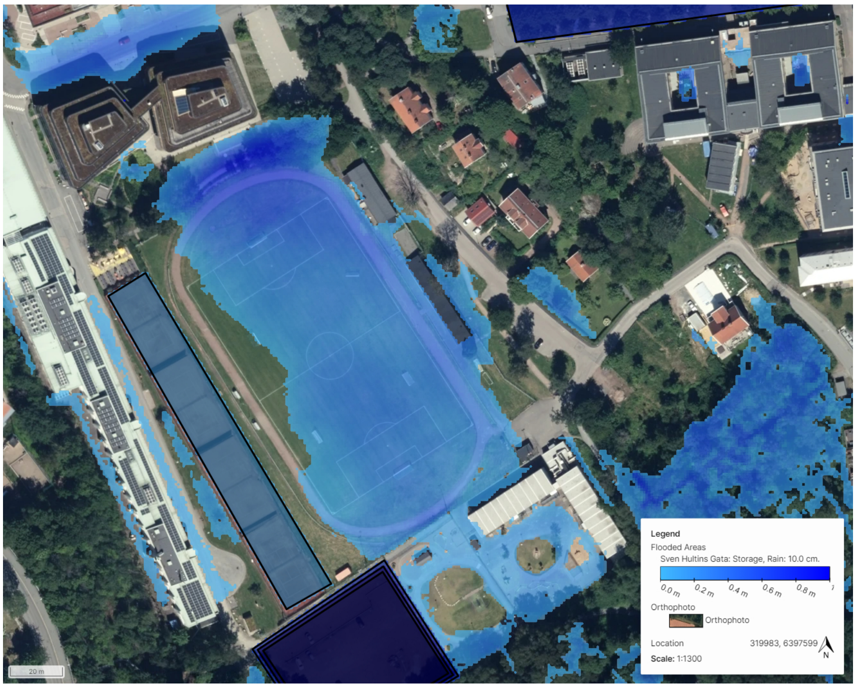

Figure 31: Water level at Mossens IP with all proposed storage solutions implemented (SCALGO, 2024).

5.5 MCDA

This chapter presents the scoring of the scenarios and the associated solutions.

5.5.1 Scoring of Scenario 2

The costs of the NBS applied in Scenario 2 are presented below in Figure 6. As can be seen, the cost varied between 475-700 SEK/m^2, with Permeable paving as the cheapest per m^2 and Rain garden as the most expensive. However, the two solutions demanding the most surface were Green roof and Permeable paving, resulting in the highest of estimated total cost, where Green roofs distinguishes with an estimated total cost of *23.590.000 SEK*. Consequently, as the weighting reflects these results, Green roof and Permeable paving were ranked as 'High level' with an initial score of (-5), whereas Rain garden was ranked at a 'Moderate level' with an initial score of (-2.5) and Blue-green roof at a 'Low level' resulting in a initial score of (-1).

Table 6: Estimate and initial score of cost for stormwater solutions in Scenario 2.

Stormwater solution	**Average cost (SEK/m^2)**	**Area (m^2)**	**Estimated total cost (SEK)**	**Weighting level (-)**	**Initial score**
Rain garden	1500	5820	8.730.000	Moderate	**-2.5**
Green roof	700	33.700	23.590.000	High	**-5**
Blue-green roof	700	1000	70.000	Low	**-1**
Permeable paving	675	26.600	17.955.000	High	**-5**

Each stormwater solution was given a initial score within every subcategory. Rain garden performed the highest with a total score of (7.5), whereas Permeable paving was the least favourable solution with an initial score of (-3). It can be stated that none of the solutions had any effect on the flooding reduction, thus a score of (0) throughout the whole subcategory. However, Rain garden performed high in both subcategories Recreational value and Eco system services, thus the higher total score.

Table 7: Initial scoring of Scenario 2.

SCENARIO 2: Initial scores						
Stormwater solution	**Cost**	**Recreational value**	**Social meeting point**	**Eco system services**	**Reduced flooding**	**TOTAL SCORE**
Rain garden	-2.5	4	2	4	0	**7.5**
Green roof	-5	1	0	2	0	**-2**
Blue-green roof	-1	1	0	3	0	**3**
Permeable paving	-5	1	0	1	0	**-3**

The weighted scores of Scenario 2 are presented in Table 8 below where the initial score was multiplied with the weighting factor of each subcategory, see Table 4. As can be seen, the final result was similar to the previous result of the initial score presented in Table 7, with Rain garden as the top ranked solution with the total score of (8.5), and increase of 1 point from the initial score. The other three solutions also increased their score. However, regardless of the increase, Green roof and Permeable paving still ended up with a negative total score of (-1.25) respectively (-2.5).

Table 8: Final scoring with weighting factor of Scenario 2.

SCENARIO 2: Final scores						
Stormwater solution	**Cost**	**Recreational value**	**Social meeting point**	**Eco system services**	**Reduced flooding**	**TOTAL SCORE**
Rain garden	-2.5	5	3	5	0	**8.5**
Green roof	-5	1.25	0	2.5	0	**-1.25**
Blue-green roof	-1	1.25	0	3.75	0	**4**
Permeable paving	-5	1.25	0	1.25	0	**-2.5**

5.5.2 Scoring of Scenario 3

As mentioned in Section 5.4, the different storage solutions could take on different designs which would be associated with different construction costs. However, the assumption was made to set the average cost to 475 SEK/m^2 for all types of basins. The varying size and geometry of the solutions result in a spectrum of different volumes and prices, shown in Table 9. Areas 2, 8b, 9 and 10 had the smallest volumes and were therefore the cheapest, ranging from *35.625-209.000 SEK*. They were ranked as 'Low level', thus an initial score of (-1). Areas 3 and 8a had estimated costs of *760.000 SEK* and *2.034.425 SEK* respectively. Consequently, they were ranked as 'Moderate level' with an initial score of (-2.5).

Table 9: Estimate and initial score of cost for stormwater solutions in Scenario 3.

Detention basin	**Average cost (SEK/m^3)**	**Volume (m^3)**	**Estimated total cost (SEK)**	**Weighting level (-)**	**Initial score**
Area 2	475	250	118.750	Low	-1
Area 3	475	4283	2.034.425	Moderate	-2.5
Area 8a	475	1600	760.000	Moderate	-2.5
Area 8b	475	440	209.000	Low	-1
Area 9	475	170	80.750	Low	-1
Area 10	475	75	35.625	Low	-1

The initial scoring resulted in values presented in Table 10. As mentioned in section 5.4, the only solution that seemed to improve the water levels at Mossens IP was

Area 3, it was thus awarded a score of (3) whilst the rest received (0). Overall, only Area 3 and 8a were given positive scores for recreational value, social meeting point and ecosystem services. The other four either scored (0) or (-1) in all categories, resulting in a negative total score when cost was taken into account.

Table 10: Initial scoring of Scenario 3.

SCENARIO 3: Initial scores						
Detention basin	**Cost**	**Recreational value**	**Social meeting point**	**Eco system service**	**Reduced flooding**	**TOTAL SCORE**
Area 2	-1	0	-1	0	0	**-2**
Area 3	-2.5	3	4	1	3	**8.5**
Area 8a	-2.5	3	3	1	0	**4.5**
Area 8b	-1	0	0	0	0	**-1**
Area 9	-1	0	0	0	0	**-1**
Area 10	-1	-1	-1	0	0	**-3**

The weighting factor did not change the ranking between any of the options, rather just exaggerate the difference in expected performance between them. The weighted score ended up being (13) and (7) for Area 3 and Area 8a respectively, as shown in 11. The solutions in areas 2, 8b, 9 and 10 got negative scores ranging from (-1) to (-3.75).

Table 11: Final scoring with weighting factor of Scenario 3.

SCENARIO 3: Final scores						
Detention basin	**Cost**	**Recreational value**	**Social meeting point**	**Eco system service**	**Reduced flooding**	**TOTAL SCORE**
Area 2	-1	0	-1.5	0	0	**-2.5**
Area 3	-2.5	3.75	6	1.25	4.5	**13**
Area 8a	-2.5	3.75	4.5	1.25	0	**7**
Area 8b	-1	0	0	0	0	**-1**
Area 9	-1	0	0	0	0	**-1**
Area 10	-1	-1.25	-1.5	0	0	**-3.75**

5.6 Comparison of scenarios

As can be seen in Figure 32, Scenario 1 and Scenario 2 has an equal amount of flooding with a water level at an elevation of 46.95 m.a.s.l. Thus, the results clarifies that the implementation of NBS had no significant effect on the flooding when based on the conditions and criteria within the scenarios. However, with the implementation of storage solutions in Scenario 3 a water level of 46.72 m.a.s.l. is reached. This notably decreases the flooded area and water depth on the field, although a majority of the pitch is still under water.

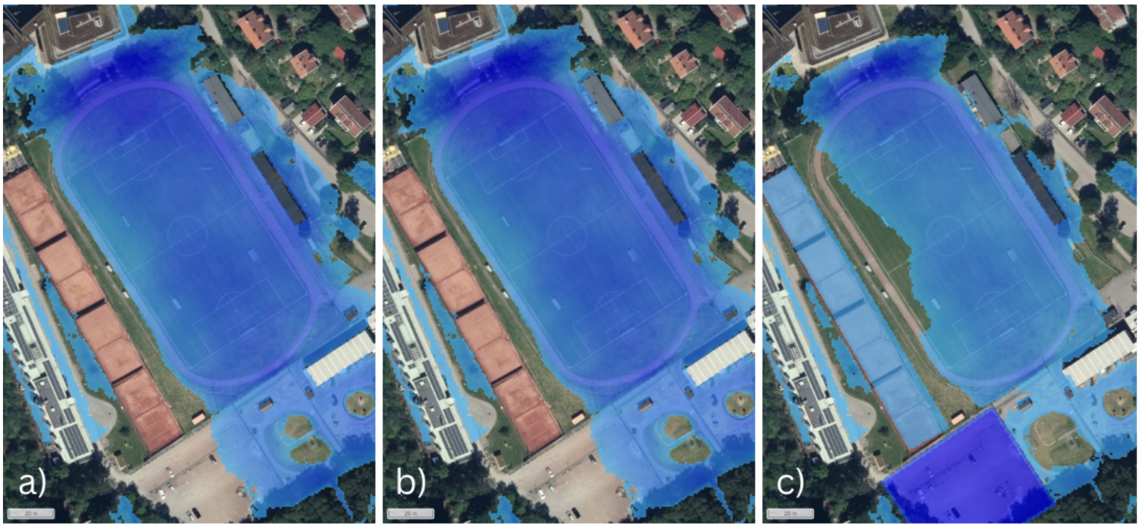

Figure 32: Water level for a) Scenario 1, b) Scenario 2 and c) Scenario 3 (SCALGO, 2024).

The final MCDA weighting resulted in a score of (8.75) for Scenario 2, whereas Scenario 3 received the highest scoring of (11.75), see Table 12. Additionally, the total estimated cost of Scenario 2 was higher in comparison to Scenario 3 at *50.345.000 SEK* as compared to *3.238.550 SEK*. Scenario 1 was not scored in the MCDA since no solutions were implemented, resulting in a total estimated cost of 0 SEK.

Table 12: Final weighted scores and estimated costs for Scenario 2 and 3.

Scenario	Final MCDA scoring	Total estimated cost (SEK)
1	-	0
2	8.75	50.345.000
3	11.75	3.238.550

6 Discussion

This chapter presents the discussion regarding the results of the interviews, Scenario 1-3, MCDA and model uncertainties.

6.1 Interviews

The interviews with Chalmers Fastigheter prove that they also are facing challenges regarding flooding and how to successfully implement stormwater management, a fact that is no surprise considering the results of the stormwater modelling conducted in SCALGO Live. The areas of Chalmers campus and Mossen is highlighted to be of importance to one another due to the geographic closeness of the two. Even though Chalmers campus is outside the catchment area presented in SCALGO Live, the runoff leaving the catchment area is transported through the cloudburst pathway along Sven Hultins gata, therefore alongside Chalmers campus. Thus, if the possibility exists, Chalmers Fastigheter expresses their appreciativeness as well as desire to potential stormwater management being implemented within the catchment area of Mossens IP, since it would work as a pro-active solution in their case. However, they are additionally investigating their own stormwater management where focus is to work with multi-functionality, as for example rain gardens. Some of the solutions already implemented might have a positive effect regarding the stormwater levels at Mossens IP, although it has not been proven. Nevertheless, the current cloudburst pathway might look different in the future. As stated in the interview with Göteborgs Stad, a possible scenario in the future involves a manipulation of the flow of the cloudburst pathway mentioned earlier, resulting in that the runoff from Chalmers campus would be transported to Mossens IP and not the other way around. In such a case, the stormwater management implemented at Chalmers campus would be of benefit to Mossens IP. Thus, the possibility of a collaboration between the two areas is considered to be beneficial for both parts. A factor presented by Göteborgs Stad affecting both areas, regardless of flow path of the cloudburst pathway, is the cost implementation, maintenance and operation for the solutions.

The interviews conducted with IK Virgo and Mossens BK indicate that they both have a similar mindset regarding the future of Mossens IP connected to stormwater and utilization of the field. They concur that if the football field suffer from flooding severe enough that it occupies the field for a extensive time period, the city of Gothenburg has more urgent matters than the possibilities to play football. However, the matter of prioritization is emphasized from another point of view regarding the prevention of ending up in such a dead-end. That being so, they express an aim towards a continued increase in utilization of the football field. Thus, they are positive regarding implementing stormwater solutions in the surroundings to mitigate the consequences of heavy rains at the field as much as possible. Additionally, the desire to increase meeting points and illuminated areas in order to counteract the experienced criminal activity of drug dealing in the area is high. Consequently, NBS that incorporate lights and visibility could be of value as it would deter shady activity simultaneously as the water level is decreased at the football field.

6.2 Scenario 1

As stated in the results of Scenario 1, the flooding is extensive throughout the whole field in addition to south of Mossens IP. Currently, the water level of between 59-118 cm presented in SCALGO Live in combination with the duration of the flooding presented in Vatten i staden, the sport associations will experience strain on the utilization of the football field, something that is also stated in the interview with IK Virgo and Mossens BK in Chapter 5.1.2. As can be seen in Chapter 5.6, the water level is the same as in Scenario 2 with the implemented NBS, however as presented in Table 11, without any cost. Therefore, in this case, Scenario 1 is superior to Scenario 2 regarding the subcategories cost and flooding reduction. Concerning the duration, the field will suffer from flooding during time periods of eight hours. However, an important note is that the model only simulates the duration during the time period the water level exceeds 20 cm. Thus, the football field will be flooded and out of use during an even longer period of time. Regardless of the time period and water level of the flooding, the sport associations are understanding regarding extreme events in the future, although they desire a mitigation of the current situation as well as future consequences.

Regarding the modelling of Scenario 1, both Vatten i staden and SCALGO Live were used since it was possible to gain knowledge regarding the duration of flooding in Vatten i staden. Vatten i staden is based on modeling in MIKE which works differently from SCALGO Live which is based on topography and also does not consider grey infrastructure. Additionally, the catchment areas presented in Figure 19-18 above, clearly states a geographical difference within the catchment areas where the catchment area presented in Vatten i staden is significantly larger. However, despite the differences of data background and extent of catchment area, the results regarding the water level of the flooding of Mossens IP are similar with an overall water level between 0.4-0.8 m in both models. Thus, the duration presented in Vatten i staden, see Figure 27, is determined to be considered as trustworthy since the other results produced by the modelling software's are so similar.

Since Scenario 1 is considered to be the base line of the project without any implemented solutions or changes, a scoring in the MCDA lacked purpose. However, the base line of Scenario 1 increased the structure of the bench marking of Scenario 2-3. The MCDA scoring states if the solution would improve or impair the conditions of Mossens IP within different subcategories. Thus, it was of great significance to the project to investigate the current situation properly, in order to evaluate potential positive or negative changes. It is important to keep in mind that the most optimal solution of a project is not always to implement changes, as the cost of implementation might not be worthwhile if the results are not large enough to make significant impact. On the other hand, the potential upside of saving money in the short run might be counteracted by the potential large cost of repairing damages. This can be exemplified with the estimated 3.8 billion DKK needed to implement the Copenhagen cloudburst plan, compared to the 5-6 billion DKK of damages in the wake of the 2011 cloudburst (The City of Copenhagen, 2012).

6.3 Scenario 2

The implementation of permeable pavement, green roofs, blue-green roofs and rain gardens did not have any effect on the water level at Mossens IP according to the simulation in SCALGO Live. One reason could be that some blue-green solutions seemingly perform worse with increasing rain intensity, a fact supported by the findings of Zheng et al. (2021) and L. Zhang et al. (2020) regarding the RR of green roofs and infiltration capacity of rain gardens respectively. This is not too surprising as runoff is created when the precipitation rate exceeds the infiltration rate. Moreover, to model the solutions with an as accurate runoff coefficient as possible, the aim was to find RRs from papers where heavy rains were recorded. This proved difficult, as many studies have just recorded "normal" rain events where the RR can be expected to be higher than during cloudbursts. For green roofs and blue-green roofs the choice was made to model with initial loss instead of runoff coefficient. The justification being that runoff will be created as the pores become saturated, since there is no time for significant evapotranspiration to occur during the event. Furthermore, the runoff coefficient for permeable pavement and rain gardens may also vary from numbers found in studies as they depend on e.g. maintenance and permeability of the underlying soil (L. Zhang et al., 2020). However, despite the lack of impact during the simulated cloudburst, it is possible that these solutions would perform better during smaller rain events with lower intensity. As Boverket (2010) states the main functions of NBS, such as dealing with stormwater, heat management, social and recreational benefits, UV-protection from shading and support of biodiversity, the NBS in Scenario 2 perform adequate since all functions are achieved with an exception of the function dealing with stormwater.

Although the estimation may not be completely accurate, the cost of implementing green roofs and permeable paving, *23.590.000 SEK* and *17.955.000 SEK* respectively, are striking compared to rain gardens and blue-green roofs with a cost of *8.730.000 SEK* and *70.000 SEK*. The expensive total costs are due to the large areas needed, and not necessarily that the costs per square meter is high. However, in reality it is improbable that green roofs would be retrofitted to all the buildings that where included when modelling. Some may not be fit to carry the extra weight, even if extensive roofs where assumed during modelling. Additionally, another factor is inclination, as some roofs may be too steep for implementation to be possible.

6.4 Scenario 3

The combined volume of all the suggested storage solutions was hypothesized to be enough to deal with a significant part of runoff and lower the expected water level at Mossens IP. However, it was only lowered by 23 cm, leaving about 20-30 cm of water remaining on most of the pitch. One reason could be that the solutions are not positioned optimally and thus can not be utilised to their full potential. For example, only 6 cm of water would collect at the lowered tennis courts in Area 2, regardless of the depth of the basin. The same could be said for Area 8b where, probably due to its high elevation within the catchment, much of the volume is left empty. The solutions in Areas 9 and 10 does not seem to be large enough to retain significant amounts of runoff. There also seems to be flaws in the geometry as the model indicates that water spills over before the entire volume is full, possibly due to pre-existing slant of the ground.

Even though a total volume of over 1400 m^3 of water collects in the basin in Area 8a it did not impact the water level at Mossen when implemented alone. An explanation for this may be that some water already gathers in the area. In that case, a portion of the 1400 m^3 volume would therefore be water that would not reach Mossens IP regardless. This solution scored second to best in the MCDA despite the lack of impact, mostly due to its possible multi-functionality through becoming a social meeting point and increasing recreational value. For this to be true, the design choices would play a critical role to ensure multi-functionality and incorporation of greenery. Another important aspect that will affect the specific size is accessibility to adjacent buildings, both for pedestrians and for example emergency vehicles.

The only solution that impacted the water level alone was Area 3, which resulted in a 12 cm decrease of the water level. This option also scored the highest in the MCDA, much for the same reasons as Area 8a. In this case the design choices are once again of importance. To increase its detention capacity the volume could be increased by making it deeper. However, this would probably not be optimal from the standpoint of increasing social value. The visibility would be negatively impacted with larger depth, e.g. people in the vicinity might have difficulty seeing whether anyone is there and vice versa. This could potentially lead to a loss in sense of safety, which is already to some extent a problem according to the football associations. To further combat this problem, adequate light sources should be added to increase visibility. Inspiration regarding not only multi-functionality but also citizen involvement during the planning stage, can be taken from the Water square in Rotterdam mentioned in Chapter 2.6. As the design was created in collaboration between the municipality and the citizens of Rotterdam, the social aspect was given high priority (DE Urbanisten, 2024). With the football associations expressing dissatisfaction with the communication from the municipality of Gothenburg, an increased collaboration could give better results for both parties. However, other stakeholders such as neighbours, the kindergarten, students and exercisers should also be included to achieve maximum benefit for the area in its dry state.

Further investigations would also have to be done before construction to ensure suitable hydro-geological conditions. If the ground water level is high and the soil is permeable, it might result in the detention basin becoming more similar to a pond. Again, this would raise safety concerns as it might not be optimal to place a constantly water-filled pond next to a kindergarten.

6.5 Comparison of MCDA

The results of the MCDA were presented in various steps, from initial and weighted scoring to final total scoring, as can be seen in Chapter 5.5. Scenario 3 was the best performing scenario with one of the solutions, Area 3, as the top scoring one with (13) points as the weighted score. The solution scored high within all subcategories except for one, *Cost*, where it received (-2.5) points. However, its importance was emphasized in subcategory *Reduced flooding*, where it achieved the highest score out of all solutions, and scenarios, with a score of (4.5) in comparison to the rest of the solutions with a score of (0) in the same subcategory of Scenario 3. This was of great value to the project since *Reduced flooding* was the subcategory weighted as the most significant one of the project. Moreover, Scenario 2 included a solution that was rated a score of (8.5), namely the rain garden proposed next to Johanneberg Science Park. Overall, the results of the scoring of Scenario 2 were more equally divided throughout all the subcategories, resulting in small contributions in several areas and a larger multi-functionality. However, the most important subcategory *Reduced flooding* was given a score of (0) for all solutions within Scenario 2. An influencing factor could be that the surroundings of Mossens IP at some parts are densely forested, see Area 11 in Figure 11. Thus, to complement a forested area with a green solution might not contribute to a larger reduction of stormwater. Although, as previously mentioned in Chapter 6.3 the NBS has the possibility to work efficiently regarding stormwater management referring to smaller volumes of precipitation. Thus, even though the final score of the rain garden was (8.5) and (13) for the basin in Area 3, they have different contributions to the project. Moreover, this can be seen in the final MCDA scoring of the scenarios, where Scenario 2 has (8.75) and Scenario 3 (11.75). The difference is relatively small at (3) points although the reduction of flooding is significantly higher in Scenario 3, as well as considerably more economically defendable.

The total estimated cost of Scenario 2 is *50.345.000 SEK* and *3.238.550 SEK* for Scenario 3, resulting in an economic difference of *47.106.450 SEK*. The cost was estimated based of numbers from previous research, as presented in Chapter 4.4.1 and Tables 6 and 9. However, it is important to note that the estimated total costs may not be accurate as they have not been adjusted for inflation. Consequently, although the proportions of the cost of the scenarios are assumed to remain similar, the total cost is likely to be higher than the one presented. Regarding the high final score of Scenario 2, an explanation is presumed to lie within the weighting of the subcategories. The weighting of subcategory *Reduced flooding* probably should have been considered to be of even higher value in relation to the other subcategories in order to prevent a misleading final result of the MCDA scoring, since the scenarios clearly performed differently within many areas.

6.6 Study uncertainties

As mentioned in Chapter 6.2, the modelling from Vatten i staden and in SCALGO Live have some inherent differences. Apart from the differing catchment areas and the lack of grey infrastructure in SCALGO Live, there is also a difference in how rain is modelled. The municipality of Gothenburg uses a CDS-rain over a period of six hours, as compared to SCALGO Live where all rain falls at once. Results from the two are similar, but a CDS-rain likely mimics reality better. Another point of uncertainty is the RRs used to extrapolate the runoff coefficients when modelling the different NBS in Scenario 2, as discussed in Chapter 6.3. Apart from the RRs being dependent on the precipitation intensity, they also vary depending on how the NBS are designed. For example, rain gardens and green roofs can have different kinds of soil layers and thicknesses and there are multiple types of permeable pavers. The infiltration capacity also depends on the underlying soil type.

Something that was not examined during the modelling was how the amount of runoff from the catchment was impacted. According to the watershed analysis 2286 m^3 of runoff leaves the catchment area from the northern part of the pitch and runs along the Chalmers campus towards the central parts of Gothenburg. It is possible that the solutions that were implemented did have an impact, but that the runoff is reduced before any change can be seen in water level on the pitch. This would explain the discrepancy found in Scenario 3 where the basin proposed for Area 3 lowered the water level by 12 cm whilst nothing else did so when modelled individually. However, with all solutions together the level was lowered by 23 cm. The extra 11 cm that seemingly disappear would then indicate that the other storage solutions also made an impact, just not large enough on their own to deal with enough runoff. The amount of runoff being reduced would in turn benefit downstream areas such as Chalmers campus and central Gothenburg.

For the evaluation and comparison of multiple options, an MCDA is a well established and effective tool. One of the weak points is however the potential influence of authors bias, as supported by Dodgson et al. (2009). To limit the human errors it is important to be transparent, assess sensitivities in the model and try to remain impartial. One possible point of uncertainty, apart from the weighting, is how the solutions were scored. Much of the scoring of soft values depend on how the solutions are designed. As design proposals were out of the scope for this thesis as previously mentioned, inspiration was taken from how similar areas have been developed at for example Tåsinge square and Water square mentioned in Chapter 2.6. Apart from the many possibilities of how an area could be developed, how an individual experience and thus would score the area will vary. One way to improve the analysis and refine the results could be to conduct a CBA, as was done in the case of the cloudburst plan for New York (Ramboll, 2017). In this way the benefits received from the implemented solutions are monetarily quantified and a more fair comparison between the scenarios can be made. For example, one solution could be more expensive than another, but if the benefits far outweigh the initial costs it could still be worthwhile to invest in the more expensive option. Although social and ecosystem benefits are taken into account in the MCDA of this thesis, actually quantifying them could also lessen the guesswork and combat bias during the scoring. Additionally, quantifying the potential damage to buildings and infrastructure inflicted by flooding if no solutions are implemented, i.e. Scenario 1, could also help achieve a more just comparison.

7 Conclusion and further research

This chapter presents the conclusion of the study in addition to the answers to the research questions in Chapter 1.2. Additionally, possible further research are presented.

7.1 Conclusion

- *What are the perception of the football associations regarding the role of the football field as a potential cloudburst area?*

The participants in the interviews from both football associations agree on that the possibility of utilizing the football field Mossens IP as a potential cloudburst area is an applicable last resort. However, they both imply the urge to mitigate the consequences done at the football field to as high extent as possible. Thus, a desire to increase the stormwater management at site simultaneously as the safety of the area is improved is of high priority.

- *To what extent would Mossen football field currently be affected by flooding during heavy cloudbursts?*

The results of the stormwater modelling state that if the situation of Mossens IP is left untouched as described in Scenario 1, the flooding would reach a maximum water level in the north of the pitch of 118 cm, and be flooded during a time period of over 8 hours. Furthermore, the flooding would cover the whole pitch, with the largest volumes of water gathering in the north of the field. However, according to the football associations, the most problematic areas of the field regarding flooding during lesser rain events tend to be the middle part of the field. The users of the sport area would be affected to the extent that the pitch would sometime be out of use during a period of time.

- *Would the situation at Mossen football field, with regard to flooding reduction and social aspects, benefit from implementing Blue-green stormwater solutions in the surrounding area?*

Firstly, with respect to the flooding reduction at Mossens IP, the results state that the NBS analyzed in Scenario 2, e.g. rain gardens and permeable paving, are insufficient due to no notable reduction of the water level. However, regarding the recreational value of the site in addition to eco-system services, the NBS performed high in the MCDA. The area would benefit from an implementation of NBS since they would contribute to an increase of the recreational value according to the MCDA, which in turn could lessen the feeling of unsafety conveyed by the sport associations. In Scenario 3, the flooding reduction reached a total level of 23 cm, leaving 20-30 cm of water remaining on the pitch. Thus, the flooding reduction is significant, although not enough.

As a conclusion, the thesis states that the area of Mossens IP would not benefit from implementing NBS with concern to the flooding reduction needed for a 100-year rain. In combination with the structural plan presented by the municipality of Gothenburg, the possibility of utilizing the pitch as a cloudburst area is relatively well received by the sport associations, even though countermeasures are desired. Thus, the recreational values and eco-system services provided from the stormwater solutions are welcomed co-benefits. Regarding the financing of stormwater solutions, there is no doubt that it is expensive. However, the cost of implementing stormwater solutions have to be weighed against the cost of possible damage done by a cloudburst event in order to provide a equitable comparison.

7.2 Further research

Regarding further research there are a few aspects that would be of interest. The following section will provide a summary of possible areas to analyze further.

- It would be beneficial to apply other stormwater modelling programs since it could provide a higher variation of functions within the program and therefore an increased nuance of the analysis with more precise and advanced modelling. Then for example the existing stormwater networks such as the grey network could be taken into account as well as time periods. Though, SCALGO Live is considered a suitable modelling program in the early stage of a project due to its simplicity and ability to combine detailed data and results. However, it could be of benefit to create the terrain model manually in a complementing software to extract into SCALGO Live for increased accuracy.

- Since the NBS implemented in Scenario 2 were stated to be insufficient regarding flooding reduction of 100-year rain, it does not necessarily imply that the NBS investigated have no effect regarding smaller volumes of water. Therefore, a 10-year rain could be analyzed. The relevance of a 10-year rain is also of value since it occurs more frequently in comparison to a 100-year rain, even though it does not have the same effect on flooding. Additionally, it could be analyzed at what amount of rain suggested NBS become relevant as well as to how large volume of water that can be infiltrated before exceeding the infiltration capacity and creating unwanted runoff.

- To further investigate and consider the thoughts and preferences of the sport associations and other stakeholders of the area for design suggestions of stormwater solutions, for example a work shop or survey could be conducted to reach users of concern.

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A Appendix: Interview questions

A.1 Chalmers Fastigheter

1. Hur arbetar ni idag med dagvattenhantering på/vid era fastigheter?

2. Finns det bakgrundsmaterial samt resultat för regnträdgården? Hur gick beslutsprocessen till och dylikt?

3. Har ni något material angående andra dagvattenlösningar?

4. Vilket program använde ni vid simulering av dagvatten?

5. Gjorde ni förundersökningar kring vad användarna hade för åsikter kring nuvarande situation samt eventuella lösningar, några sociala undersökningar?

6. Finns det möjlighet att delge det material som finns angående exempelvis regnträdgården vid Science park?

7. Hur ser ni kring samverkan mellan omkringliggande områden, till exempel Mossens IP?

A.2 Mossens BK and IK Virgo

1. Hur mycket används planen i dagsläget? Vilka föreningar och övriga använder planen?

2. Hur upplever ni situationen med regn idag?
- Påverkar regnet er verksamhet? Om ja, hur ofta och till vilken grad?
- Hur lång tid är det vatten kvar på fotbollsplanen efter kraftigt regn?

3. Har ni själva försökt/behövt åtgärda situationen kring regn på något sätt?

4. Göteborgs Stad har föreslagit att använda några fotbollsplaner för att samla dagvatten vid extrema regn. Detta har redovisats i såväl strukturplanen som i översiktsplanen.
- Hur ställer ni er till lösningen som Göteborgs Stad har presenterat i strukturplanen?
- Hur stort problem är det för er om planen översvämmas t.ex. en gång om året eller en gång vart tionde år?

5. Om Mossens gräsplan skulle byggas om för att tackla kommande vattenmängder, hur skulle det påverka er verksamhet?

6. Är det något annat kring regn i samband med er verksamhet ni vill lyfta?

A.3 Göteborgs Stad Kretslopp och Vatten

1. Hur gick processen till när strukturplanen för de olika avrinningsområdena togs fram?

2. I strukturplanen nämns att typanläggningar så som skyfallsytor, skyfallsleder och styrning kommer implementeras i ett senare skede. Hur fortskrider arbetet kring detta?
  - Vad är det för sorters anläggningar som har implementerats?
  - Hur ser planerna ut för skyfallslederna på Sven Hultins gata och skyfallsytan på Mossens IP?

3. Har ni haft någon kontakt med fotbollsföreningarna?

4. Har det gjorts någon undersökning kring hur och till vilken utsträckning fotbollsplanerna kan påverkas?

5. Är det något annat du vill tillägga kring ämnet?

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