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Climate adaptation of Chalmers University of Technology for an increase in precipitation

A case study at a selected site on Campus Johanneberg

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

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DIVISION OF WATER ENVIRONMENT TECHNOLOGY

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2021
www.chalmers.se

MASTER'S THESIS ACEX30

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Cover:
The selected site on Campus Johanneberg (Authors' own picture, 2021).
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ABSTRACT

Due to the predicted climate change, there will be an increase in precipitation and the need for climate adaptation is getting more urgent around the world. This report covers how a selected site at Chalmers University of Technology could be adapted for the future change in climate. To get an understanding of where on Campus Johanneberg there is a need for stormwater management, an initial site selection with SCALGO Live and "Vatten i Göteborg (Water in Gothenburg)" was done for a cloudburst of 101 mm. The site selection was later confirmed through interviews with the property owners Akademiska Hus and Chalmersfastigheter. The selected site is the area outside the entrance to Kårrestaurangen, Geniknölen, Tågvagnen and Samhällsbyggnad I. The selected solution was developed with the campus plan in mind, which Chalmers University of Technology together with stakeholders developed in 2019. The solution was further developed after the feedback from the interviews and the survey, answered by the selected students. The survey also showed that the majority of the selected students thought that more visible stormwater management on campus would add something to their education. The selected solution is a combination of rain gardens, reinforced grass, covered gutters and an open stormwater storage area. A simplified version of the selected solution was modeled and simulated in SCALGO Live to get an understanding of how the selected site can be improved. The simulation was done for two scenarios, a moderate rain event of 10 mm and a cloudburst of 101 mm. The results show that the situation during a moderate rain event is greatly improved by the selected solution, but for a cloudburst the improvements are limited. The main conclusion of this study is that it is possible to climate adapt Campus Johanneberg to an increase in precipitation and this thesis shows one possible way of doing it.

Key words: campus environment, climate adaptation, cloudburst, stormwater modeling, stormwater solutions

Klimatanpassning av Chalmers tekniska högskola för ökad nederbörd

En fallstudie för ett utvalt område på campus Johanneberg

Examensarbete inom masterprogrammet Infrastruktur och miljöteknik

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SAMMANFATTNING

På grund av den förväntade klimatförändringen kommer mängden nederbörd att öka och behovet av klimatanpassning blir allt viktigare runt om i världen. Den här rapporten behandlar hur en utvald plats på Chalmers tekniska högskola kan anpassas till förändringar i klimatet. För att bilda en uppfattning av vilket område på campus Johanneberg som det finns ett behov av dagvattenhantering gjordes ett initialt val av plats med hjälp av SCALGO Live och ”Vatten i Göteborg” för ett skyfall på 101 mm. Detta val av plats bekräftades senare genom intervjuer med fastighetsägarna Akademiska Hus och Chalmersfastigheter. Den valda platsen är området utanför ingången till Kårrestaurangen, Geniknölen, Tågvagnen och Samhällsbyggnad I. Den föreslagna lösningen utvecklades med campusplanen i åtanke, vilken Chalmers tillsammans med intressenter utvecklade under 2019. Lösningen utvecklades vidare efter feedback från intervjuerna och enkäten som de utvalda studenterna svarade på. Enkäten påvisade att majoriteten av de utvalda studenterna ansåg att en mer synlig dagvattenhantering på campus skulle tillföra något till deras utbildning. Den föreslagna lösningen är en kombination av regnrabatter, armerat gräs, täckta markrännor och ett öppet dagvattenmagasin. En förenklad version av den föreslagna lösningen modellerades och simulerades i SCALGO Live för att förstå hur den valda platsen kan förbättras. Simuleringen gjordes för två scenarion, ett måttligt regn på 10 mm och ett skyfall på 101 mm. Resultaten visar att situationen under ett måttligt regn förbättras kraftigt av den föreslagna lösningen, men för ett skyfall är förbättringarna begränsade. Den huvudsakliga slutsatsen för denna studie är att det är möjligt att klimatanpassa campus Johanneberg för en ökning av nederbörd och detta examensarbete visar en möjlig lösning.

Nyckelord: campusmiljö, dagvattenmodellering, dagvattenlösningar, klimatanpassning, skyfall

Contents

List of Figures

List of Tables

Preface

This Master's thesis is part of the Master of Science in Infrastructure and Environmental Engineering at Chalmers University of Technology and was carried out during the spring of 2021.

We would like to start by thanking our examiner Mia Bondelind and our supervisor Sebastien Rauch, for making us a part of his dream of improving the stormwater situation at Campus Johanneberg. We would also like to thank the people at Akademiska Hus, Chalmersfastigheter and Rain Gothenburg for making time in your schedule for an interview with us, it was very helpful and interesting. Last but not least, we would like to thank our friends and classmates at Chalmers University of Technology who answered our student survey, we really enjoyed taking part in your ideas and inputs regarding stormwater at Campus Johanneberg.

Gothenburg, May 2021
Eva Gustafsson & Emma Wessberg

Terminology

Catchment area: An area that due to the topography drains to a specific watercourse (SMHI, 2021b).

Climate adaptation factor: A factor which is used to account for future changes in precipitation (Svenskt Vatten, 2016).

Cloudburst: A rain event with at least 50 mm/hour or 1 mm/min of precipitation (SMHI, 2017c) which often causes flooding (SMHI, 2017b).

Blue-green infrastructure: Infrastructure such as rain gardens, stormwater ponds, parks and green roofs that can handle the effects of an increase in precipitation (RISE, n.d.)

Impermeable surface: The opposite to permeable surfaces where water can infiltrate into the ground, an impermeable surface is a hard surface such as asphalt (SMHI, 2021c).

Precipitation: Water particles in liquid or solid form that fall through the atmosphere, such as rain, snow or hail (SMHI, 2017a).

Return time: A measure of how often, statistically, a rain event occurs (SMHI, 2021a). For example, a rain with a 10-year return time occurs statistically once every 10 years.

Stormwater: A temporary flow of rainwater and/or meltwater that does not infiltrate into the ground (Nationalencyklopedin, n.d.-a, n.d.-b). This flow could also be called runoff.

Watershed: A topographical boundary between different catchment areas (SMHI, 2021b).

100-year rain: A rain event with a return time of 100 year (SMHI, 2021a). Could also be called a cloudburst (Göteborgs Stad, 2017).

1 Introduction

Climate change is due to the improved greenhouse effect caused by increasing emissions of greenhouse gases from human activities (IPCC, 2019). The greenhouse effect is a natural process that plays an important role in the Earth's temperature (Kweku et al., 2018), but the improved greenhouse effect causes global warming which leads to a change in the climate. One issue that climate change is predicted to cause is an increase in the amount of precipitation together with an increase of frequency and intensity according to the United Nations (UN) climate change body, the Intergovernmental Panel on Climate Change (IPCC) (Hoegh-Guldberg et al., 2018).

Climate change is generally considered to be a global concern. In January 2021, the survey Peoples' Climate Vote was released in which 64% of the respondents considered climate change to be an emergency (Flynn et al., 2021). The survey was conducted by the United Nations Development Programme (UNDP) with 1.2 million respondents from 50 countries and is the largest survey ever conducted regarding climate change. According to the UNDP the survey can be considered to cover 56% of the world's population, making climate change a known threat to our future.

Cities are particularly vulnerable to climate change and an increase of precipitation. The impermeable land cover in dense urban areas is altering the natural hydrological cycle with more water remaining at the surface compared with a natural land cover where a larger proportion of water can infiltrate into the ground or return to the atmosphere through evapotranspiration (Ball et al., 2019; Zhou, 2014). There is a large difference between the flow rate in a developed and a rural catchment area, see Figure 1.1. In a developed catchment area, there is less natural retention and therefore less storage of water within the soil, which causes an increase in the amount and velocity of the stormwater in the urban water cycle.

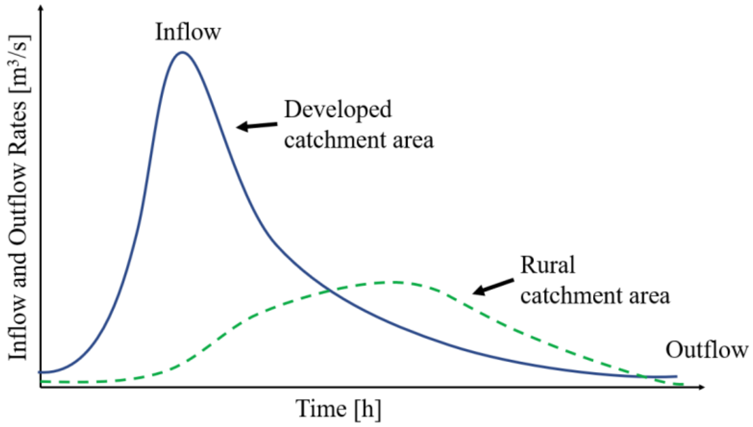

Figure 1.1 Hydrograph for rural and developed catchment area, adapted from (Dams et al., 2008).

Universities are a part of the research and problem solving for the world to become more sustainable and resilient to climate change (Storms et al., 2019). The research has so far focused on creating resilient cities and communities for natural disasters, but not on the university campus itself. Chalmers University of Technology in Gothenburg, Sweden, is one university that has just started investigating how to make their campuses more resilient to climate change (Chalmers University of Technology et al., 2019). In Gothenburg it rains on average every third day (Göteborgs Stad, 2017) and the forecast is that there will be an increase in extreme precipitation events with a short duration, mainly in the form of cloudbursts (Eklund et al., 2015), which is why climate resilience is an important aspect to consider for the future.

1.1 Aim

This thesis aims to answer the following research question: How can the climate resilience of campus areas, for an increase in precipitation, be improved? This was investigated through a case study at Chalmers Campus Johanneberg. The purpose is to locate a site at the campus that is at risk of being flooded, due to an increase in precipitation and cloudburst, and suggest adaptation measures. These measures should align with the vision "Chalmers campus - people and gatherings for a sustainable future" [Authors' translation] (Chalmers University of Technology et al., 2019, p. 1) to make this thesis a possible addition to the "Chalmers 2019-2050 Campusplan" (Chalmers University of Technology et al., 2019).

1.2 Specific objectives

The following objectives are studied to achieve the aim of this thesis:

1. Identifying a location in need of stormwater management at Campus Johanneberg.
2. Selecting which stormwater solutions that could be implemented to align with the vision for the future of Campus Johanneberg, according to the campus plan.
3. Assessing how much the proposed stormwater solutions improve the situation at the selected site.
4. Assessing added benefits of selected stormwater solutions, considering learning environments and opportunities for social interactions.

1.3 Limitations

- The stormwater situation at Chalmers Campus Lindholmen will not be included in this thesis.
- This thesis will consider the campus plan for 2035, and not the visions for 2050.
- The proposed solutions should have a positive impact on the stormwater management for both moderate precipitation and cloudburst.
- The solutions are primarily for storage and delaying stormwater, not for treatment.
- The solutions have not been evaluated financially.
- The only simulation program used for modeling in this thesis is SCALGO Live.
- This thesis only investigates flooding due to increase in precipitation, not from rising sea levels.

2 Background

This chapter will give a brief introduction to climate change prediction and how it affects stormwater management. Different stormwater solutions will be presented together with added benefits that can be achieved when implementing the solutions in the society. A brief overview over how campuses work with stormwater resilience and how students can be affected by the stormwater management on campuses. The chapter will also present different programs for modeling how the stormwater quality and quantity can be managed.

2.1 Climate change prediction

In the Fifth Assessment Report by IPCC, four different climate change scenarios, called RCPs, were introduced (IPCC, 2014). RCP stands for Representative Concentration Pathways and describes the pathway for climate change at different levels of greenhouse gas mitigation. The four original RCPs developed for the report in 2014 are (IPCC, 2014; SMHI, 2021d):

- RCP2.6: a culmination of carbon dioxide emission around the year 2020 and considered to be a more stringent climate policy. This scenario is likely to keep global warming between 0.3°C and 1.7°C at the end of the 21st century compared to the years 1986-2005.
- RCP4.5: an intermediate scenario with a culmination of carbon dioxide emissions in 2040. The temperature increase for the end of the 21st century, compared with the temperature in 1986-2005, is likely to be 1.1°C to 2.6°C.
- RCP6.0: the higher intermediate scenario with a culmination of carbon dioxide emissions in 2060. This scenario is predicted to lead to a temperature increase of 1.4°C to 3.1°C until the end of the 21st century compared to 1986-2005.
- RCP8.5: a representation of high greenhouse gas emission with an increase of the global mean surface temperature from 2.6°C to 4.8°C until the end of the 21st century compared to 1986-2005.

Apart from these four pathways there are several baseline scenarios with no efforts to constrain the emissions that can be represented by pathways between RCP6.0 and RCP8.5.

The municipal assembly in Gothenburg are the ones who decide what climate scenario and what kind of events that the city's climate adaptation should be aiming for (Göteborgs Stad, 2019). To be on the safe side, the municipal assembly has decided to follow the climate scenario RCP8.5, but today there are no specifics for the increase in cloudbursts included in RCP8.5. The City of Gothenburg has therefore decided that the dimensioning precipitation event should be a climate adapted 100-year rain event with a climate adaptation factor of 1.2. This climate adaptation factor represents an increase in precipitation of 20% compared to a 100-year rain event today. A cloudburst simulation program called "Vatten i Göteborg (Water in Gothenburg)" has been developed to show the flooding scenario that the City of Gothenburg prepares for (Göteborgs Stad, n.d.-e).

2.2 Stormwater solutions

The predicted change in climate together with the urbanization of cities leads to that more of the precipitation ends up on impermeable surfaces and will not be able to infiltrate into the ground, as it does in a natural landscape (Ball et al., 2019). Stormwater is because of this mainly seen as a problem and a hazard in the urban landscape, since it may be devastating to the infrastructure if a city is not adapted to handle large amounts of rain. Today, cities are starting to see stormwater as a possible resource instead of being a nuisance (Cousins, 2018). There are many different kinds of stormwater solutions to manage the stormwater. In this subchapter, solutions of relevance to the case study are presented.

2.2.1 Underground stormwater network

The traditional and most common stormwater solution in most European and North American cities is an underground stormwater network (NIWA, n.d.), also called gray infrastructure. The main purpose of the network is to lead the precipitation and snowmelt away from the streets and roads (Göteborgs Stad, 2017). The network consists mainly of pipes for transportation, but may also consist of smaller treatment systems, like an oil separator, or underground magazines for storage and delay. The stormwater can be led to different places depending on the city and how the sewage network is structured. In a combined network the sewage water and the stormwater will both be transported to the city's wastewater treatment plant for treatment (Svenskt Vatten, 2016). In a separated system, the stormwater can be led to a water recipient, like a watercourse, or directly to the sea (Svenskt Vatten, 2016). The benefit of a combined sewage network is that the stormwater gets treatment before being let out in the water cycle again. A disadvantage with a combined network is that in the event of a cloudburst, parts of the sewage water is let out without any treatment due to overflow in the system. A study have estimated that the overflow from a combined sewer network consists of 80-85% stormwater (Gillard, 2011). Another disadvantage with the traditional gray infrastructure is that it is not flexible and will have a hard time adapting to future urban development's together with climate change (Cristiano et al., 2021).

2.2.2 Nature-based solutions

Nature-based solutions are blue-green infrastructure that uses nature´s own resources to handle the environmental challenges such as cloudbursts (Brears, 2018; European Commission, n.d.-b). The European Commission (n.d.-a) defines nature-based solutions as:

"Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environment, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions."

Nature-based solutions have a number of benefits in addition to stormwater management, including environmental, social and economic benefits (Demuzere et al., 2014; Gómez-Baggethun et al., 2013; Prudencio & Null, 2018). They contribute to making the environment more climate resilient and foster biodiversity which supports the EU policy called European Green Deal (European Commission, n.d.-b). Nature-based solutions can be different types of rain gardens, wetlands, bioswales, green buildings, green roofs and trees (Berland et al., 2017; Brears, 2018; Cristiano et al., 2021; Prudencio & Null, 2018).

Rain gardens are a known nature-based solution that is used frequently in cities. A rain garden is a vegetated or landscaped feature that can collect rain and stormwater, from streets or roofs nearby, and allows it to slowly infiltrate into the soil layer (Brears, 2018; US EPA, n.d.-d). Rain gardens have the ability to treat the water with organic material in the soil, also called a biofilter (Göteborgs Stad, 2017). A rain garden can provide several additional ecosystem services such as provisioning water supply and storage, provide a recreational and educational benefit and climate regulation due to the vegetation cover (Prudencio & Null, 2018). The gardens usually consist of trees and other green plants that help clean and delay the water. A rain garden is a relatively cheap construction considering its effect, but it needs maintenance to prevent it from clogging over time causing it to retain less stormwater (Göteborgs Stad, 2017). One example of a rain garden at Chalmers University of Technology can be seen in Appendix A, Figure A.1.

Green roofs are a relatively complex stormwater construction (Göteborgs Stad, 2017) and one of the most effective blue-green infrastructures according to small-scale and laboratory investigations (Cristiano et al., 2021). Of the annual rainfall, green roofs can absorb 50-80% of rain and delay it from entering the sewer network (Brears, 2018). According to Brears (2018) green roofs also provide habitats for plants and animals and can reduce heat islands in urban areas. Green roofs can also contribute to biodiversity and noise reduction (Göteborgs Stad, 2017). But green roofs cannot be the only solution a city relies on for managing cloudbursts since when saturated, they can only store additional water in small amounts (Brears, 2018). From a stormwater management perspective green roofs can be expensive but the need for maintenance is quite low (Göteborgs Stad, 2017). New York City sees the benefits of green roofs and has introduced a tax reduction program for property owners to promote implementation of green roofs on their buildings (Brears, 2018). The Green Roof Tax Abatement program specifies that at least 50% of the roof space needs to be covered in vegetation to be eligible for the tax reduction (City of New York, n.d.). There are several structures with green roofs at Chalmers University of Technology, one example can be seen in Appendix A, Figure A.2.

Planting new trees in so-called skeletal soil, which is soil that can retain more water within its structure, is a simple nature-based solution but can be relatively expensive to implement (Göteborgs Stad, 2017). Berland et al. (2017) states in the article *The role of trees in urban stormwater management* that implementation of trees can increase infiltration and thereby reduce the stormwater and at the same time be an effective complement to other green infrastructure. Singapore is an example of a city that has brought nature into the city. The Singapore Green Plan 2030 contains goals that correspond to the UN’s 2030 Sustainable Development Agenda, which will help Singapore to reach its long-term zero emission goal (Ministry of Sustainability and the Environment, n.d.-b). Two of these goals are to plant 1 million more trees during a 10-year period, which will bind 78 000 tons of carbon dioxide, and to cover 80% of all buildings with plants over the next decade (Ministry of Sustainability and the Environment, n.d.-a), see Figure 2.1 for an example of a plant covered building.

Figure 2.1 Picture of the hotel Parkroyal Collection Pickering in Singapore and its vegetation (Authors’ own picture, 2015).

2.2.3 Canals and gutters

A constructed canal is an open stormwater solution that can lead the stormwater from a local nature-based solution to for example a pond or a wetland for further treatment and retention (Svenskt Vatten et al., n.d.). The canal can be either closed or open at the bottom, which makes it possible for water to infiltrate into the ground (Göteborgs Stad, 2017). The canal can also treat the stormwater through sedimentation, where the particles slowly sink to the bottom of the canal (Ramböll, 2015). A small canal could be considered a gutter, which can be either open or covered. Covered gutters can be used on streets and in urban areas since the grate covering it makes it possible for the water to drain into the gutter and at the same time making it possible for pedestrians and cyclists to safely cross (Urban green-blue grids, n.d.-a). The grate also protects the gutter from getting filled with leaves and litter, but has to be checked regularly in order to function properly (Göteborgs Stad, 2017). Canals and gutters can be used to divert stormwater to a stormwater storage or a water course. The construction can be fairly expensive but simple to construct if a prefabricated solution is used. Figure 2.2 shows examples of a canal and a gutter at Chalmers University of Technology.

Figure 2.2 Left picture: A canal at Chalmers University of Technology. Right picture: A covered gutter at Chalmers University of Technology (Authors' own picture, 2021).

2.2.4 Permeable surface

Permeable surface is a stormwater solution that manages the stormwater locally, instead of increasing the runoff, and can be seen as a nature-based solution (Cristiano et al., 2021). Permeable surfaces have many similarities with green roofs because they are both able to delay and treat the stormwater to some extent (Göteborgs Stad, 2017). Permeable pavement and reinforced grass are two kinds of permeable surfaces. These surfaces allow water to infiltrate into the underlying layers of gravel and soil (US EPA, n.d.-c).

Permeable pavements are commonly used in parking lots, pedestrian access and driveways (Scholz & Grabowiecki, 2007). Benefits with permeable pavements are that it can increase the safety of driving on a road during rain events and improve stormwater management (Chu & Fwa, 2019). Disadvantages are that it is expensive and requires a lot of maintenance to prevent the pores from clogging (Göteborgs Stad, 2017). If the pores in a permeable pavement are clogged the stormwater management will be limited (Chu & Fwa, 2019).

Reinforced grass is made of shaped concrete with holes, which makes it possible for the grass to grow, and is usually used in parking lots or as ground surface for bike stands (Göteborgs Stad, 2017), one example can be seen in Appendix A, Figure A.3. The City of Gothenburg (2017) explains that the reinforcement structure is placed on top of a drainage bed and filled with gravel or soil that the grass will grow on. It is considered to be a simple and economical construction in comparison with its benefits. A disadvantage with reinforced grass is that the holes can limit the accessibility for people with physical disabilities and strollers (Göteborgs Stad, 2017).

2.2.5 Multifunctional spaces

A multifunctional space is an open stormwater solution that may be a parking lot, a square, a park, a road, a skate park or a playground that is allowed to be flooded during a cloudburst (Göteborgs Stad, 2017). According to the City of Gothenburg (2017) a multifunctional space should be both useful and esthetically appealing during rain and sunshine. The cost and the type of maintenance needed depends on the type of multifunctional space and its use. Benthemplein in the Netherlands and Tanner Spring Park in the USA are two examples of multifunctional spaces.

Benthemplein is a multifunctional area located in Rotterdam, the Netherlands (DE URBANISTEN, n.d.). The water square was completed in 2013 and is situated in a business area surrounded by buildings and paved surfaces. The design and development of the water square was conducted together with the citizens working, living and attending school in the nearby area. All agreed that the square should be dynamic with a lot of space for play and places to meet, but at the same time have greenery. When it rains the stormwater from the surrounding area is collected in the three basins in Benthemplein, two shallow basins and one deep (DE URBANISTEN, n.d.). After the rain, the water from the shallow basins gradually seeps back into the groundwater and the water from the deep basins flows into the city’s water network, when the network is no longer under stress. In sunny weather, the basins can be used for many different activities. One of the shallow basins can be used by skaters, see Figure 2.3, and the other one contains an island which can be used as a stage. The deep basin is structured like a sports pit for football, basketball or volleyball with audience stands. The square also includes vegetation and private spaces to sit.

Figure 2.3 One of the shallow basins at Benthemplein water square, used for skating (CC BY-SA 4.0 (Cathrotterdam, 2017)).

Tanner Spring Park is a city park located in Portland, USA, in a new urban district and the inspiration for the park comes from the area's history and wetlands (Urban green-blue grids, n.d.-b). Stormwater from the surrounding roads and impermeable surfaces is collected in the park and flows through the vegetation down to the lowest point of the park, which is the pond, see Figure 2.4. The pond is built with a 60-meter-long footbridge that makes it possible to cross it. The park is also equipped with benches that are enjoyable during dry weather.

Figure 2.4 Tanner Spring Park in Portland, USA (CC BY-NC-ND 2.0 (Graham Ballantyne, 2011)).

2.3 Stormwater management and its added benefits

Implementing stormwater solutions can not only manage stormwater, but it can also contribute to environmental and social benefits as well as having an effect on economic aspects in the society.

2.3.1 Environmental benefits

Regulating the stormwater can have positive impacts on both the water quality and quantity in a city according to Cousins (2018), and blue-green infrastructure can help restore ecological functions in the urban landscape and thereby offer important socio-ecological benefits. One way that blue-green infrastructure can improve the stormwater quality is by promoting the ecosystem services that the infrastructure provides, for example removing pollutants with natural processes (Brears, 2018). Ecosystem services are services and products that the ecosystem provides to humans that increase our quality of life and contribute to our welfare (Johnston, 2018; Naturvårdsverket, 2020). Ecosystem services can benefit humans and the environment, direct or indirect, in many ways (Johnston, 2018). These ecosystem services can be enhanced by blue-green infrastructure and can contribute to better life quality for humans, enhance biodiversity, provide recreational benefits and replenish groundwater through infiltration (Brears, 2018).

In a report by Prudencio and Null (2018) 170 publications were reviewed to understand how ecosystem services and green infrastructure can be connected. The ecosystem services presented are divided into four categories in the report: provisioning, regulating, cultural and supporting services. It can be concluded from the report that green infrastructure for managing stormwater can control stormwater volumes and reduce flooding. The conventional gray infrastructure only directs the stormwater and reduces the ecosystem services such as infiltration and groundwater recharge. A combination of different green infrastructure, such as wetlands, rain gardens and urban green spaces, can be suitable to implement throughout the watershed of a city to benefit the most according to Prudencio and Null (2018).

BenDor et al. (2018) states in the article *Ecosystem services and U.S. stormwater planning: An approach for improving urban stormwater decisions* that when planning for an urban area, there should be a focus on ecosystem services. This focus can allow planners to better understand the width of ecological benefits that stormwater infrastructure can offer and to produce certain green infrastructure that the community finds more valuable. Greenway (2017) made a study on two retrofitted stormwater wetlands in Australia, also called a blue-green infrastructure, that provides ecosystem services. The study showed that the two constructed wetlands improved the quality of the water, and at the same time, created aquatic biodiversity in an urban setting. The community together with the involved stakeholders thought that the construction was successful since the wetlands had helped transform an open space into a wildlife haven and a community attraction.

2.3.2 Social benefits

Stormwater management and blue-green infrastructure can contribute to social benefits through contributing to green spaces which can improve mental health and well-being for humans and provide playscapes for children (Lõhmus et al., 2021; Mottaghi et al., 2021). Urban green spaces can also improve physical activities and contribute to an increase in the general health of urban residents (Wolch et al., 2014). An urban park can be a place for social interactions which is a need that the COVID-19 pandemic has made the importance of social interaction even clearer (Xie et al., 2020).

The article *Blue‑Green Playscapes: Exploring Children's Places in Stormwater Spaces in Augustenborg, Malmö* by Mottaghi et al. (2021) investigates into how blue-green solutions can be used in children's playscapes to integrate social and ecological values. The City of Gothenburg has started a project called Rain Gothenburg that opened one of its first features on the 8th of December 2018, being a playground at Rhenströmsparken (Göteborgs Stad, n.d.-a). The playground is constructed to be a fun place in all weathers, but where new opportunities arise with rainfall. This is supposed to inspire kids to be outside when it rains and is one of the first steps made by Rain Gothenburg to fulfill the city's vision of "The best city in the world when it's raining". Urban parks like Rhenströmsparken can provide spaces for social and outdoor activities and encourage different parts of the population to engage which promotes social interactions (Hayward & Weitzer, 1984; Xie et al., 2020).

Green spaces today are usually unequally distributed between socio-economic groups within a city (Brears, 2018; Wolch et al., 2014). When improving the neglected neighborhoods the improvements can paradoxically lead to both an improvement of green spaces, contributing to a more esthetically attractive and healthier society, and to social injustices within a community causing an ethical problem (Wolch et al., 2014). More green infrastructure can lead to gentrification due to the neighborhoods becoming more popular and the residents cannot afford to stay (Meerow, 2020; Wolch et al., 2014). Therefore it is important to not make the neighborhoods greener than necessary to protect both social and ecological values (Wolch et al., 2014).

2.3.3 Economic aspects

The economic aspect is another part of stormwater management that is important since the aftermath of a cloudburst event can be very expensive for a city. The City of Copenhagen was hit by two cloudbursts in 2011, one in July and one in August, with the first and larger one being 100 mm of precipitation in 1 hour (Troell & Thidell, 2018). These two cloudbursts cost the city DDK 5-6 billion (EUR 672-807 million) in repairs (The City of Copenhagen, 2012). The city's initiatives for stormwater management, stated in their cloudburst management plan released in 2012, are estimated to cost DDK 3.8 billion (EUR 511 million). If events like the ones in 2011 happen again the city will have saved around DDK 1.2-2.2 billion (EUR 161-296 million) according to their own calculations, so in economic terms stormwater management can have a long-term positive impact on a city. The City of Copenhagen also states that it is from a socio-economic perspective better to implement stormwater solutions that can handle both ordinary rainfalls and cloudburst events since both are projected to become more frequent in the future.

2.4 Stormwater management on campuses

A campus is a unique area because of the combination of activities focusing primarily on education and research. A study by Pierce et al. (2021) shows that when comparing a campus to a city, the stormwater management for the campus is limited by several factors, two of them are limitations in financing for infrastructure and the lack of coordinated decision-making. Storms et al. (2019) also acknowledge these limiting factors and add that many campuses have not developed plans for climate resilience, because they are in the early stages of understanding the issue with resilience and do not know where to start the implementation. These factors limit the development of physical characteristics on a campus which, according to Hajrasouliha (2017), can have an impact on the academic performance of students. Hajrasouliha further describes in his study that the purpose of a university campus is different from the purpose of a city or a neighborhood, the purpose of a campus is to be an environment for learning. One way to utilize the campus, for the education of students, is to implement stormwater solutions in new and innovative ways.

The United States Environmental Protection Agency, called US EPA, holds an annual competition called Campus RainWorks Challenge and has done so for the last nine years (US EPA, n.d.-b). The competition is directed to students that attend college or university in the USA. The competition strives to engage students to design green infrastructure and to raise awareness about the need for innovative stormwater management techniques. The instruction from the US EPA (n.d.-b) for the competition is:

"[…] to design an innovative green infrastructure project for their campus that effectively manages stormwater pollution and also provides additional benefits to the campus community and environment".

In 2017 the University of California, Berkeley, won the first prize in the Master Plan Category, by designing a future plan for the campus to capture 100% of the stormwater by the year 2100 (US EPA, n.d.-a). The plan is to replace all sidewalks with permeable pavements, to expand the vegetation area for infiltration and to incorporate green and blue rooftops on some of the buildings (McRae, 2017). All of these solutions will reduce both the pollution load and the peak flow within the watershed.

The University of British Columbia, called UBC, in Vancouver Canada has established an Integrated Stormwater Management Plan to manage the risk of flooding and the runoff from the campus (UBC, n.d.-b). With this plan UBC aims to turn the stormwater into a resource and become more resilient to climate change by building dry ponds, rain gardens, green roofs, detention tanks and bioswales (UBC, n.d.-a). A major challenge that UBC faces is that the university is restricted from infiltrating too much of the stormwater into the ground since it will cause erosion from the groundwater on the nearby cliffs.

A Swedish example of an innovative stormwater solution where the stormwater is put to use is the square by Novahuset at Örebro University. The concrete surface of the square is divided into sections to ensure that it does not crack and is also used for stormwater management (ByggTema, n.d.). These cuts are similar to gutters filled with gravel and transports the stormwater to the trees in the square, according to an employee at one of the companies that owns the property (B. Gustafsson, personal communication, March 3, 2021).

2.5 Stormwater modeling

A stormwater modeling program can be used to simulate the effects of implementing stormwater solutions in an affected area. Different stormwater models have been developed to understand the quality and quantity of the stormwater and the first modeling programs were developed in the early 1970s by the US EPA (Zoppou, 2001). Some of the different programs are:

- SWMM (Stormwater Management Model) by US EPA, can be used for simulating quality and quantity of runoff for a single event or continuous (Rangari et al., 2018).
- MIKE URBAN by DHI, can be used to design and model networks for water, sewer and stormwater distribution (Eckart et al., 2017).
- MOUSE (Model of Urban Sewers) by DHI, simulates water quality and surface runoff (Eckart et al., 2017).
- SCALGO Live, a web-based platform for administration of water courses, emergency management, urban planning and working with climate adaptation (SCALGO, n.d.-d).

These programs have been used in different ways by researchers and companies. Bisht et al. (2016) used SWMM in combination with MIKE URBAN to simulate runoff and design an efficient drainage system for a small urbanized area in India. Hossain Anni et al. (2020) used MIKE URBAN in their work to simulate flooding at the Tuscaloosa campus of the University of Alabama in the USA. MOUSE was used by Semadeni-Davies et al. (2008) to study the potential impact on stormwater and sewer flows by climate change and urbanization on a combined system in Helsingborg, Sweden. SCALGO Live has been used by the company WRS (Water Revival Systems) to evaluate risk of flooding outside Västerås, Sweden (Hernefeldt & Granath, 2019). All of these programs have different levels of complexity and a more complex model can lead to higher levels of uncertainty (Viklander et al., 2019). This uncertainty comes from the need for more input data and parameters, so Vikander et al. (2019) specify that a general rule for choosing a model is to base it on what kind of problem that needs to be solved. Rauch et al. (2002) says "It is not the most complex model that is the best one, but the least complex that answers the asked question reliably" (p. 10).

3 Case study description

The study presented in this thesis uses Chalmers University of Technology as a case study. This chapter will provide an insight to the past and the present situation together with the future plans for the university campuses. The university is divided into two campuses located in the central part of Gothenburg. More than 3 000 people work at the university and it has over 10 000 admitted students (Chalmers University of Technology et al., 2019). One of the main tasks for Chalmers University of Technology is utilization of how the knowledge from the university can impact society and contribute to a more sustainable future (Chalmers University of Technology et al., 2019). The university campuses are good places to try out new knowledge and innovations that can be utilized and help with climate adaptation. This thesis will focus on Campus Johanneberg, which is the larger of the two campuses.

3.1 The past of Campus Johanneberg

The university opened on the 5th of November in 1829 with only ten students and three teachers in a building by Lilla Bommen, in central Gothenburg (Chalmers University of Technology, 2020). The number of students increased, and the university had to move to a larger facility in 1869. It was not until 1920 that the university moved to Johanneberg, where it can be found today. The university evolved the most after the Second World War and the campus started to grow significantly (Chalmers University of Technology et al., 2019). The largest evolution was 1959 to 1969 when the university tripled its building stock. The development of the land use at Johanneberg and the campus between 1960 and 2020 can be seen in Figure 3.1.

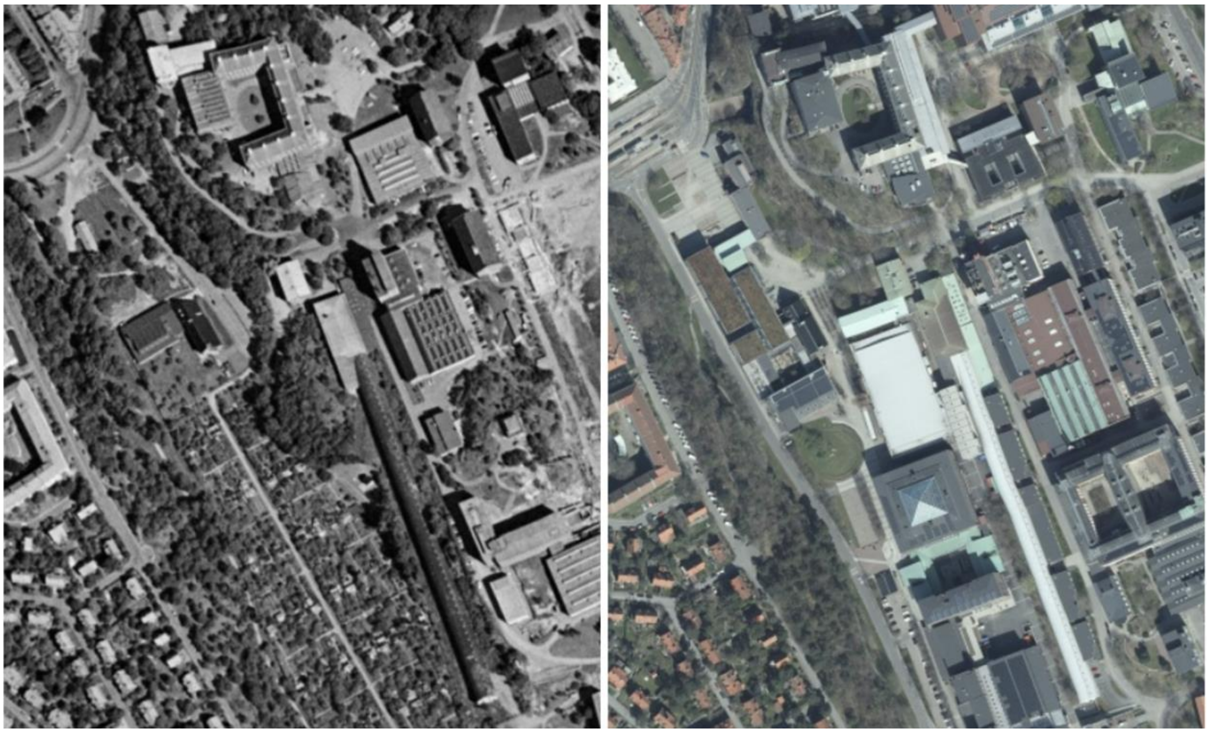

Figure 3.1 Pictures showing the changes in land use at Johanneberg. Left picture: Aerial photo of the development around 1960 (Lantmäteriet, n.d.). Right picture: Aerial photo of the development around 2020 (Lantmäteriet, n.d.).

As shown in Figure 3.1 a major development has taken place on Campus Johanneberg over the last 60 years. This extension has contributed to more and larger buildings leading to fewer permeable surfaces causing a change in the urban hydrological cycle.

3.2 The present situation at Campus Johanneberg

Chalmers University of Technology has together with Chalmersfastigheter, Akademiska Hus and Chalmers Student Union made a plan for the development of the campuses called Chalmers 2019-2050 Campusplan (Chalmers University of Technology et al., 2019). The campus plan points out that stormwater solutions, together with qualitative green areas that strengthen the recreational values, do not exist on Campus Johanneberg today. The green areas at the campus are limited and either too small or too steep to be attractive according to the campus plan. Recommendations in the campus plan say that 10% of the total surface area should consist of green areas, which is a recommendation that is not achieved at the moment, since most parts of Campus Johanneberg consist of impermeable surfaces.

3.3 The future plans for Campus Johanneberg

The campus plan contains future goals and visions for the facilities at the campus. The plan is divided into two construction stages with the first one finished in 2035 and the second one finished in 2050 (Chalmers University of Technology et al., 2019). This thesis will focus on the plan finished in 2035 since it is in the nearest future.

3.3.1 Goals and visions

The university's vision with the campus plan is "Chalmers campus – people and gatherings for a sustainable future" [Authors' translation] (Chalmers University of Technology et al., 2019, p. 1). Sustainability has been an important aspect and vision for Chalmers University of Technology for many years and the university strives to become an inspiration regarding this matter. To become an inspiration cannot be done without giving the opportunity for people to meet and share knowledge in an inspiring and innovative environment. The campus plan is produced and developed with six goals in mind, related to the UN's 17 Sustainable Development Goals. The six goals of the campus plan are as follows [Authors' translation]. The two goals in italic are the main focus of this thesis since the aim is to propose a stormwater solution that aligns with the campus vision:

- Cutting edge international learning environment
- Integrated part of the city with a clear character of its own
- Attractive living environment that contributes to human well-being
- Good accessibility with sustainable transportation
- *Green campus that promotes ecological values*
- *Responsible and efficient use of premises, land and other resources*

The campus plan continues by saying that green and blue infrastructure should be implemented to protect from the extreme weather that the future holds due to climate change (Chalmers University of Technology et al., 2019). This infrastructure for managing floods and cloudbursts should also be seen as a possible way to create meeting spots by implementing creative open stormwater solutions. The infrastructure should optimize the ecosystem services together with contributing to human well-being and at the same time be an inspiration to new techniques when reducing the climate impact.

3.3.2 Structural plan 2035

The structural plan contains new buildings that are planned to be built together with new roads and green areas, see Figure 3.2 (Chalmers University of Technology et al., 2019). The structural plan does not give any specific suggestions on solutions for the blue infrastructure, except suggesting where they could be built. The parts called 2G and 2H in Figure 3.2 are included in the detailed development plan called Gibraltarvallen, which is the first part of the structural plan for 2035 to be built.

Figure 3.2 Structural plan for 2035 showing both existing and new structures at Campus Johanneberg, legend translated by authors (Chalmers University of Technology et al., 2019).

3.3.3 Structural plan for the City of Gothenburg

During the last couple of years the City of Gothenburg have made an investigation analyzing what affects the future climate change can have on the city (Göteborgs Stad, 2018). The city considers stormwater to be a problem when it causes flooding of 0.2 meters on roads that are of high priority for transportation and for emergency roads to access entrances to buildings (Göteborgs Stad, 2019). The investigation made by the City of Gothenburg contains a compilation of strategies for the city to handle the effects, a so-called structural plan (Göteborgs Stad, 2018). The structural plan will contribute to the possibility of developing suggestions for how the stormwater handling, within a catchment area, could improve and decrease the risk of flooding during a cloudburst event. The structural plan is based on the flood modeling for a cloudburst event concerning high flows in watercourses, high levels in Göta Älv and high sea levels. The simulations are done with the dimensioning values that the city have chosen: a cloudburst with a 100-year return time and a climate factor of 1.2, high sea levels with a 200-year return time and flows in the watercourses with a 200-year return time (Göteborgs Stad, 2018). There are several aspects that the structural plan has not taken into consideration in the process of developing the suggested solutions, some examples are: the cost, the technical feasibility and the implementation plan. The structural plan is divided into nine catchment areas where Chalmers University of Technology belongs to the area called Centrum Södra. This catchment area covers 19 km^2 and consists for the most part of residential areas and steeply sloping green areas (Göteborgs Stad, 2018). The stormwater solutions mentioned in the structural plan for Centrum Södra are:

- Flood storage – to store the stormwater during a cloudburst.
- Flood conductor – to lead the stormwater downstream in a safe way.
- Flood diverter – a complement to strengthen the other two.

The structural plan for Centrum Södra consists in total of 32 flood storages, 43 flood conductors and 10 flood diverters (Göteborgs Stad, 2018). The flood storages are placed as far upstream as possible, to decrease the flooding within the residential areas, and along the flood conductors. The main part of the flood storage areas are green areas that must be developed to be able to hold the stormwater and the remaining are already existing ponds that need to be strengthened. There is a planned flood conductor within Campus Johanneberg, along Sven Hultins Gata, shown in Figure 3.3. This flood conductor leads the stormwater to the area called Mossens Idrottsplats, which is a suggested place for implementing a flood storage.

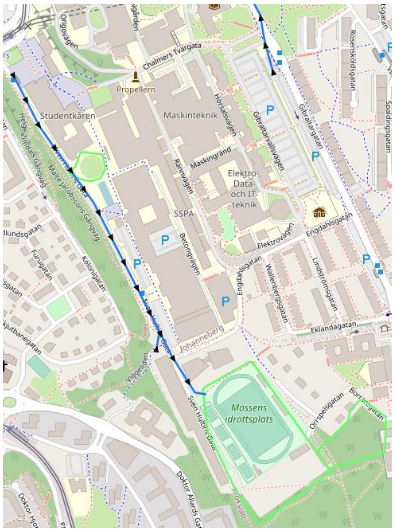

Figure 3.3 *Map over proposed stormwater solutions in the structural plan, flood conductor in blue and flood storage in light green at Campus Johanneberg* (Göteborgs Stad, n.d.-b).

4 Methodology

This chapter describes the methodology of the thesis and is divided into site selection, data collection, selection and modeling of solution. The specific objectives presented in subchapter 1.2 were investigated with the different methods and the connection between them can be seen in Figure 4.1.

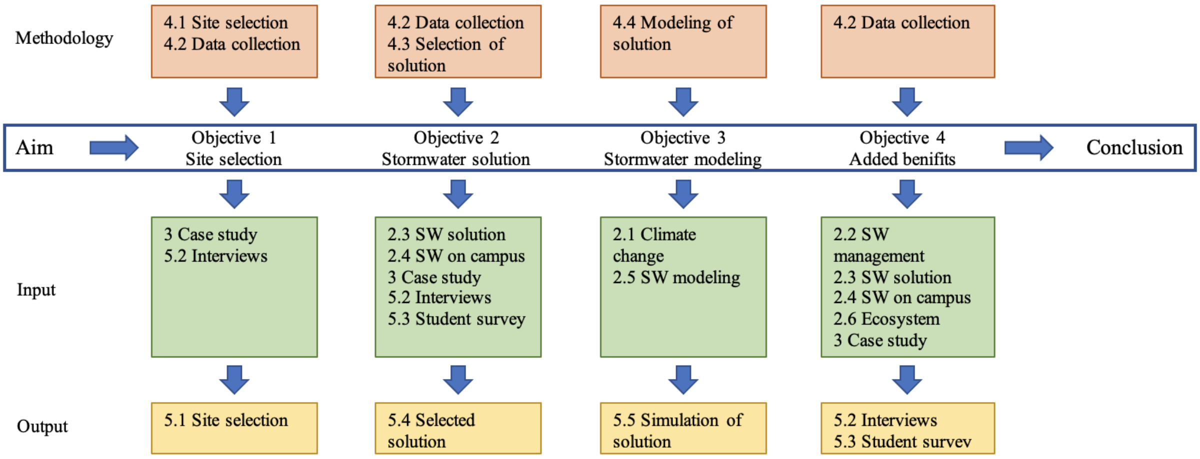

Figure 4.1 Overview of connection between methodology, specific objectives and the different chapters. SW stands for stormwater (Authors' own picture, 2021).

4.1 Site selection

Cloudburst simulations were conducted to get an understanding of the flooding at Campus Johanneberg. The simulation in SCALGO Live was compared with the City of Gothenburg´s cloudburst simulation Vatten i Göteborg, developed by DHI (Göteborgs Stad, n.d.-d) to investigate the similarities of the simulations. The simulations and field visits were done in order to answer the first specific objective about identifying a location on campus with a need of stormwater management.

4.1.1 SCALGO Live

SCALGO Live was chosen as the modeling tool in this thesis since it is presumed to be a good choice for the problem at hand. The base map in SCALGO Live comes from Lantmäteriet, the elevation is based on Lantmäteriet's GSD-Höjddata, grid 1+, which has a resolution of 1 meter, and has the coordinate system SWEREF99 TM and vertical reference RH 2000 (SCALGO, n.d.-c). The buildings in SCALGO Live come from GSD-Fastighetskartan and the modeling tool models them as 10-meter-high structures above the highest point of the ground surface (SCALGO, n.d.-c). SCALGO Live assumes that the precipitation that falls on the roofs drain towards the closest edge of the building onto the ground (F. van Walderveen, personal communication, March 30, 2021).

In SCALGO Live tools are provided for analyzing sea-level rise, flash flood mapping and depression-free flow (SCALGO, n.d.-b). In this thesis the flash flood mapping tool was used to analyze how the stormwater flows and accumulates during a climate adapted 100-year rain. *Flash flood mapping* is a tool that visualizes the outcome of a rain event and which areas that are affected (SCALGO, n.d.-b). *Flooded areas* is a subcategory to Flash flood mapping that makes it possible to choose the amount of rain and the minimum water depth that is to be visualized. Flooded areas can also show the *Flow accumulation* that makes it possible to see the flow direction in the terrain. The analyses conducted for the site selection were done with the Flooded areas tool in Flash flood mapping. The amount of precipitation in the rain event was set to 101 mm to simulate a climate adjusted 100-year rain with a duration of 6 hours, which is the rain event used by the City of Gothenburg in their cloudburst simulation Vatten i Göteborg (Göteborgs Stad, n.d.-c). The minimum water depth was set to 0 mm to show all of the flooding.

There are several limitations with the way SCALGO Live simulates stormwater. One limitation is with the interpretation of buildings in SCALGO Live, smaller bridges and underpasses are not interpreted by the program as a structure that water can flow under, but as a structure that blocks the flow of stormwater (SCALGO, n.d.-c). Due to this, the model had to be adjusted in two places since the interpretation of the topography in SCALGO Live was incorrect. The first place was the underpass from Chalmersplatsen to Teknologgården, see Figure 4.2, where SCALGO Live interpreted it as a building instead of an opening. The second adjustment was the bike garage outside Samhällsbyggnad II (SB II), see Figure 4.2, where SCALGO Live interpreted it as a solid building, but in reality it has openings in the east-west direction. Both adjustments were done with the *Interpolate path* tool which interpolates the elevation of a surface between the endpoints of the selected path. The underpass was modeled as a 7-meter-wide opening and the bike garage as two 2-meter-wide openings. Other limitations with SCALGO Live that affected this study, is that it does not account for soil properties such as infiltration and instead considers all surfaces to be impermeable. The simulation does not consider connections to any existing underground stormwater network nor the effects on the stormwater flow. Due to these limitations the amount of stormwater can be overestimated which is important to have in mind when analyzing the result.

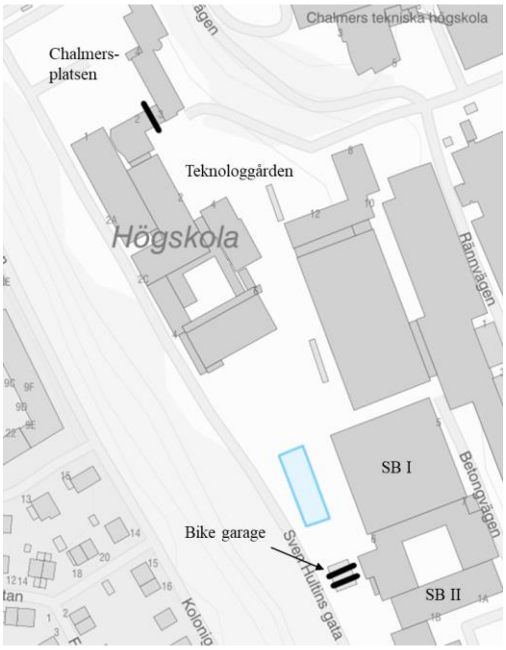

Figure 4.2 The two adjusted places in SCALGO Live. The underpass between Chalmersplatsen and Teknologgården and the bike garage outside SB II.

4.1.2 Vatten i Göteborg

Vatten i Göteborg is a simulation program developed by the company DHI for the City of Gothenburg (Göteborgs Stad, n.d.-d). The simulation visualizes floods caused by cloudburst, rain statistics, sewer flow, groundwater levels and floods caused by high flows and sea level rise.

The visualization for the site selection was done with the cloudburst function. The chosen scenario was the climate adjusted 100-year rain event, which has a duration of 6 hours and a total volume of 101 mm (Göteborgs Stad, n.d.-c). The flooding is visualized with the water depth tool.

4.1.3 Field visits

The plan for the field visits was to compare the results from the simulation with the present situation during a rainy day. The few times during the spring of 2021 when it rained more than 10 mm in one day, both authors of this thesis were working remotely from a location away from Gothenburg. Even though the authors were out of town they have attended the campus for five years and experienced the selected site during rain events. Several field visits took place during dry weather to investigate the topography of the selected site.

4.2 Data collection

The data collection for this thesis was conducted through a literature study, interviews and a student survey. This subchapter will further explain the process of these areas of research.

4.2.1 Literature study

A literature study was conducted to get a wider understanding of the background for this thesis. The second specific objective as what kind of stormwater solution that could be implemented to align with the campus plan and the fourth specific objective as what kind of added benefits the solutions can provide, were investigated. Literature for the literature study was found through: Google Scholar, Chalmers Library and Science Direct. The search words were: “Stormwater solutions”, “Climate change prediction”, “Stormwater management university”, “Stormwater modeling” and “Stormwater management and benefits”. The retrieved information helped broaden the understanding for the literature study in chapter 2.

An additional literature study was conducted to get an understanding of the case study area and the visions for the campus in order to study the second specific objective. The literature study included the campus plan from Chalmers University of Technology and information about the history of the university. Reports concerning the detailed development plan for Gibraltarvallen and the structural plan for flood risk management conducted by the City of Gothenburg, were also included in the study.

4.2.2 Interviews

Qualitative research was conducted through interviews with stakeholders to get a further understanding of Campus Johanneberg and stormwater management in Gothenburg. The interviews were held in a semi-structured way with different sets of questions depending on the aim of the interview. The questions were asked in a way that made it possible for the stakeholders to answer freely and the questions were asked in an order that made the discussion flow naturally (Patel & Davidson, 2003). All the stakeholders that were interviewed are presented in Table 4.1.

Table 4.1 Conducted interviews.

Stakeholder	**Title**	**Date**
Akademiska Hus	Strategic Property Developer	22nd of February 2021
Chalmersfastigheter	Strategic Campus Developer	23rd of February 2021
Akademiska Hus	Landscape Manager	26th of February 2021
Rain Gothenburg	Project Manager, Creative Director	9th of March 2021

The stakeholders did not receive the interview questions beforehand, because the aim of the interviews was to get their spontaneous thoughts on the matter. The interviews were conducted and recorded in Swedish with the video conference services Zoom or Microsoft Teams. The stakeholders were asked if they wanted to take part of the results from their interviews before publication of this thesis but declined. The interviews were transcribed after the meeting to make it easier to extract the relevant information for this thesis. Citations from the interviews were translated by the authors in order to strengthen the claims. The information was divided into the following categories: Campus today, The campus plan and Future stormwater vision. These three categories were chosen as they were the main topics of all the interviews and are relevant for this thesis.

The selections of the stakeholders to be interviewed were done in consultation with Sebastien Rauch, the supervisor of this thesis. The aim of the interviews held with Akademiska Hus and Chalmersfastigheter was to get an understanding of the campus plan, the situation at campus today and potential problems areas on campus concerning stormwater. These two companies were selected to be interviewed since they are the main property owners at Campus Johanneberg. Representatives from Rain Gothenburg were interviewed to get an understanding of their work with making Gothenburg the best city in the world when it is raining and what challenges they face when trying to implement their solutions. The questions asked at these interviews can be seen in Appendix B.

4.2.3 Student survey

This thesis was written during the spring of 2021 when the COVID-19 pandemic took place. From the beginning the plan was to gather input from students through a workshop on campus, but due to COVID-19 this was not possible, and an online survey was conducted instead.

The student survey was conducted to investigate the fourth specific objective and the matter of if the students feel that a stormwater solution on campus would have affected their learning perspective regarding stormwater management. The questions focused on the students' opinions regarding the stormwater issue within the selected site, where within the site they would like to see a stormwater solution and their ideas for what type of solution to implement. The survey questions can be seen in Appendix C.

The survey was done in Google Forms and consisted of seven questions in total, written in English with Swedish translations for specific words. The survey was anonymous and kept short in order to ensure that the quality of the answers remained high (Ejlertsson, 2014). The survey started with two mandatory questions regarding what program and what year the students attended, the rest of the questions were voluntary to answer. Five of the questions were multiple-choice with fixed response options in order to make it easier for the students to answer it and to analyze the results afterwards in a quantitative way (Hagevi & Viscovi, 2016; Patel & Davidson, 2003). To increase the motivation for answering the survey it ended with two open questions where the students could answer freely (Ejlertsson, 2014).

Facebook was used to distribute the survey to the selected group of students. The selected students for this thesis were master students and graduated bachelor students from the civil engineering programs that started their studies in 2015, 2016 and 2017. These students were chosen to avoid confusion between this survey and a survey sent out by a bachelor thesis conducted during the same time period which was sent out to the attending bachelor students in civil engineering. The civil engineering master student and bachelor graduates were also chosen since they have attended the campus for several years, in the nearby area of the selected site, and have gotten in contact with the issue of stormwater through their education. These selected students were assumed to be motivated to answer the survey since they know the selected site, how it is affected by stormwater and could have an interest in how it is developed for the future. The total number of students in the selected group is 707 students (UHR, n.d.). The survey reached 94 students within the group, which corresponds to 13%, due to limitations in the contact network. The survey was available to the students between the 10th and 17th of March with no reminder sent out to the students.

4.3 Selection of stormwater solution

The design process for possible solutions started with the authors brainstorming different known solutions, described in subchapter 2.2 about stormwater solutions. This was followed by searching for visual examples to provide insight into esthetics, integration into the landscape and possible social values. The used search words were “Stormwater management”, “Stormwater park” and “Blue-green infrastructure”. The possible solutions that were found were evaluated with the campus plan vision in mind to develop a green and climate resilient campus that promotes ecological values (Chalmers University of Technology et al., 2019). The solutions should also align with the campus plan specifying that stormwater management should be a possible way to create meeting spots while being open and creative. Since the solutions are for a campus area where a lot of people spend their days, the possible added benefits with the solutions were evaluated to contribute to human well-being and an improved environment. The initial ideas were presented during the interviews with Akademiska Hus and Chalmersfastigheter and further developed from their interest in an open stormwater solution, importance of keeping the emergency access road and other feedback. The results from the student survey were taken into account with the wishes of more blue-green infrastructure such as rain gardens, permeable surfaces and open stormwater solutions where the water can be experienced.

4.4 Modeling and simulation of stormwater solutions

The selected stormwater solution was modeled and simulated in order to get an insight to the third specific objective about how the stormwater situation can be improved at the site. Two simplified versions of the selected solution, model A and B, were modeled in SCALGO Live by creating a workspace within the watershed that contributes to the flooding at the selected site. Model A includes the stormwater collection and storage while model B includes the stormwater collection, storage and overflow, both models can be seen in Figure 4.3. For the overflow the topography for Lennart Rönnmarks Plats and Sven Hultins Park, which is planned to be constructed during the next couple of years, was included in the model. The simplifications to the model were done in order to make it possible to model it in SCALGO Live with terrain edits. The terrain edit tools that were used are the following:

- *Lower path* - lowers a part of the terrain with a specified inclination.
- *Lower and flatten* - lowers an area to a specified height and makes it flat.
- *Raise and flatten* - raises an area to a specific height and makes it flat.
- *Contour as a closed curve* - makes contours at a specific height.

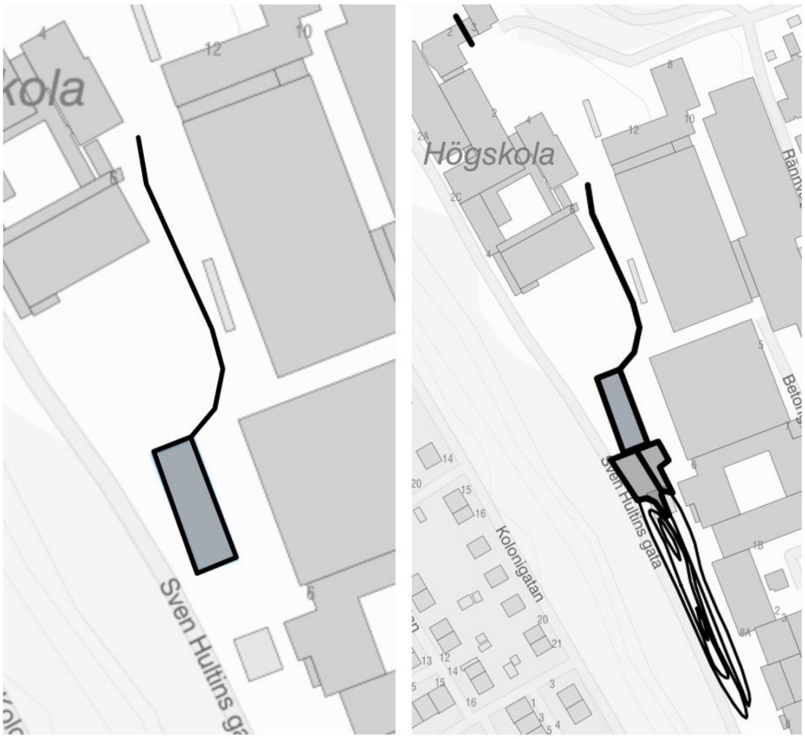

Figure 4.3 Left picture: Model A with stormwater collection and storage. Right picture: Model B with stormwater collection, storage, overflow and the new topography in the proposed Sven Hultins Park. Both models from SCALGO Live.

The modeling of the first part of the stormwater solutions, the stormwater collection, was simplified by only modeling the main gutter. The main gutter was modeled with the tool Lower path and started on the elevation +46.40 meters, had a width of 0.2 meters and an inclination of 0‰. An inclination of the gutter is preferable to ensure that the stormwater flows in the right direction, but to ensure that the main gutter enters A-dammen above the water level in the pond the inclination of the main gutter has to be limited to 0‰. This limitation is due to that a construction for preventing backflow from A-dammen into the gutter cannot be modeled in SCALGO Live. The main gutter diverts the stormwater to A-dammen from the open area in front of the entrance to Kårrestaurangen. Volume calculations comparing the main gutter to a gutter of 0.2 meters depth can be seen in Appendix D, calculations for modeling of gutter. A profile for the main gutter can be seen in Appendix D, Figure D.1.

The stormwater storage in A-dammen was modeled with the tool Lower and flatten. The surface level in A-dammen was lowered 0.45 meters, to a level of +46.04, to represent the amount of additional water that A-dammen can hold with the proposed reconstruction. How the depth was calculated can be seen in Appendix D, calculations for modeling of depth of A-dammen.

The stormwater overflow, only included in model B, was modeled in several steps in order to account for the changes in the terrain in the proposed Sven Hultins Park. The overflow gutter was modeled with the tool Lower path on a level of +46.55 meters with the same dimensions as the main gutter. The overflow connects A-dammen with the proposed Sven Hultins Park. The southern edge of A-dammen was modeled with Raise and flatten to imitate the edge of the pond, this was done on a level of +46.70 meters to prevent water from Sven Hultins Park from flowing into A-dammen. Lennart Rönnmarks Plats was simplified as a flat area with the tool Lower and flatten on a level of +46.60 meters. Sven Hultins Park was modeled with the

Contour as a closed curve tool. The west side of the park was modeled as a hill with the height starting on +46.75 meters and ending on +47.25 meters, the east side was modeled as a depression with a height of +46.55 meters.

The models were simulated with the terrain edits and the results were compared with the simulation for the site selection. The following two scenarios were simulated:

- Scenario 1 – Moderate rain event of 10 mm.
- Scenario 2 – Cloudburst of 101 mm.

The moderate rain event for scenario 1 is based on the City of Gothenburgs requirements for the amount of stormwater that has to be delayed on each property. The required amount is 10 mm/m^2 of rain for areas contributing to runoff in Gothenburg (Andersson, 2016). This required amount of precipitation can be compared with the measured data at the Swedish Meteorological and Hydrological Institute (SMHI) station Göteborg A (SMHI, n.d.), located 3 km from the selected site. To correspond with that it rains in Gothenburg on average every third day (Göteborgs Stad, 2017), the minimum precipitation amount evaluated is 1 mm over the timeperiod 2000-01-01 to 2020-12-31 at Gothenburg A. When analyzing the data, it can be calculated that 10 mm of rain during 24 hours corresponds to the 78 percentile of the precipitation data. This means that there have been 2 687 days with more than 1 mm and 613 days with more than 10 mm of precipitation measured during these 20 years, see Figure 4.4. Scenario 2 represents a climate adjusted 100-year rain with a duration of 6 hours of 101 mm (Göteborgs Stad, n.d.-c). These two scenarios were chosen to represent a more ordinary rain event and a worst-case scenario to see what kind of effects the proposed solution would have on the site.

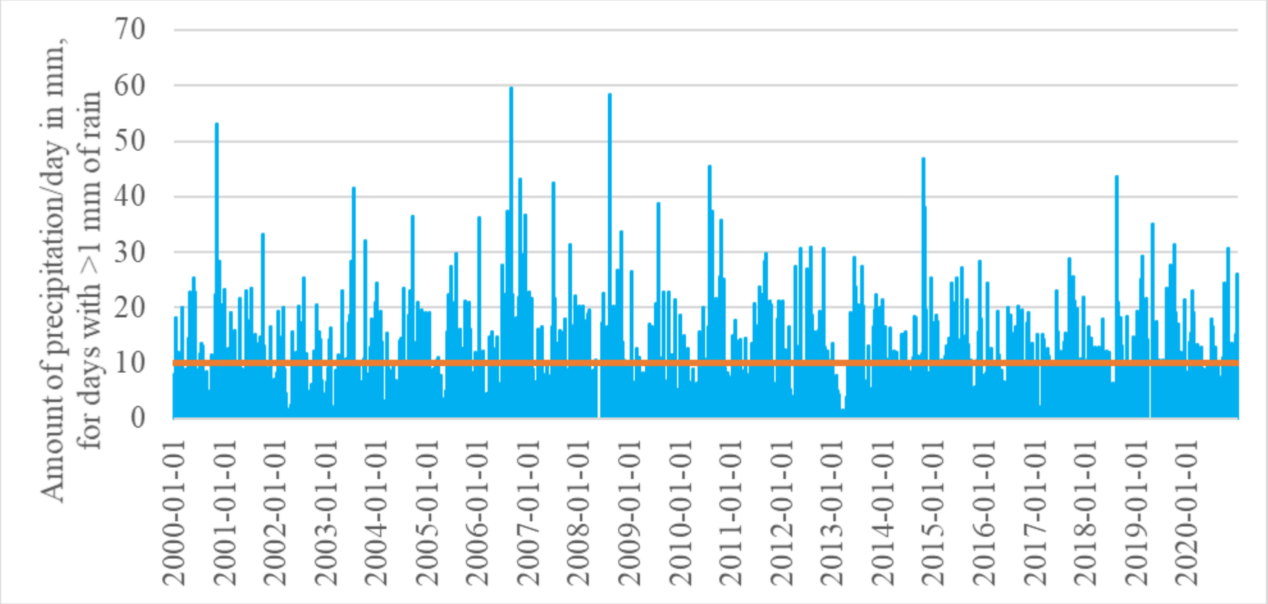

Figure 4.4 Precipitation data per day from Gothenburg between 2000-01-01 to 2020-12-31 in blue (SMHI, n.d.), 10 mm of precipitation in orange.

5 Results

This chapter presents the results from the site selection, the interviews and the student survey. Furthermore, the development of the selected solution and the outcome from the simulation of the solution are presented.

5.1 Site selection

The results from the simulation in SCALGO Live and Vatten i Göteborg are shown in Figure 5.1 and shows the amount of flooding at Campus Johanneberg. The simulations are done for a climate adjusted 100-year rain event of 101 mm, also called a cloudburst, and the results are similar for both simulations and show the same problem areas. The water depths are visualized for 0-20 cm in green, 20-50 cm in yellow and more than 50 cm in red for SCALGO Live and for Vatten i Göteborg 10-20 cm, 20-50 cm and 50-100 cm in different shades of blue and more than 100 cm in purple.

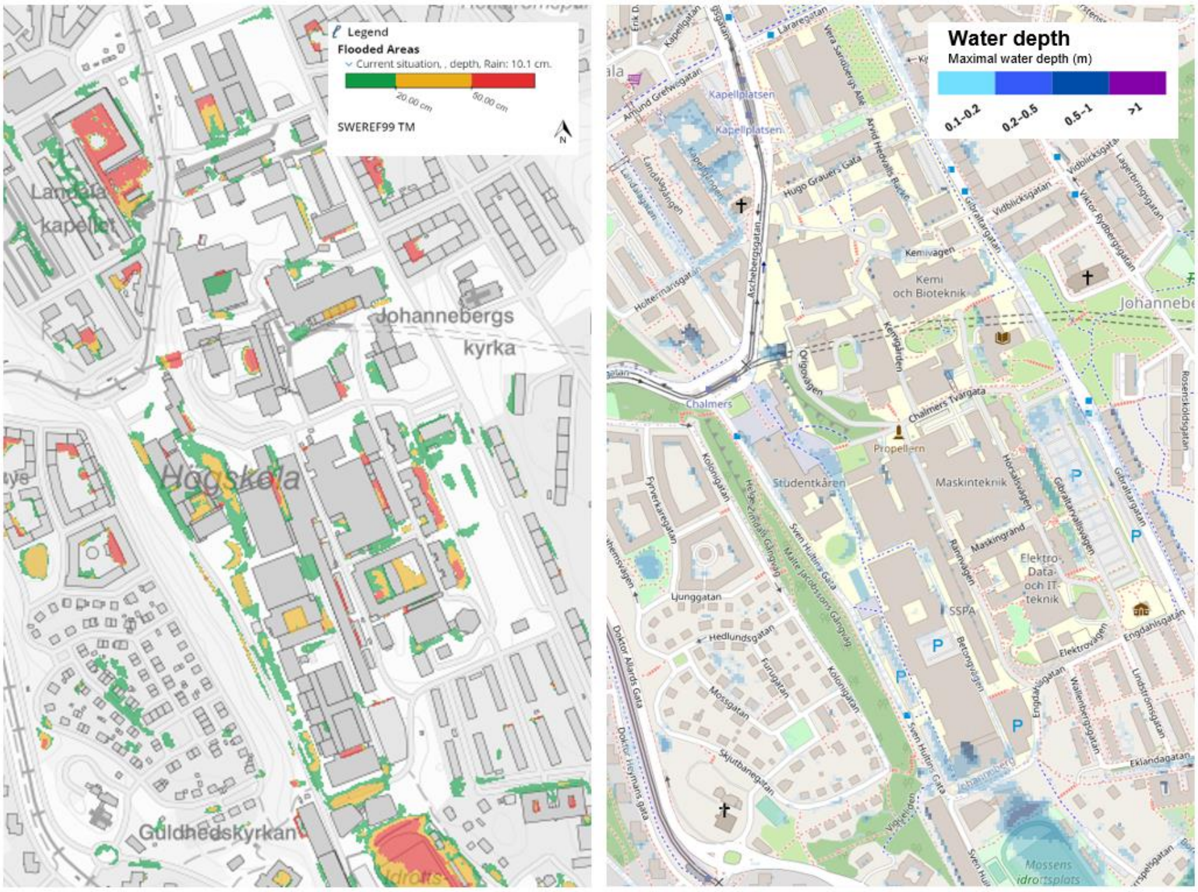

Figure 5.1 Left picture: Simulation over Campus Johanneberg from SCALGO Live with a cloudburst of 101 mm. Right picture: Simulation from Vatten i Göteborg with a cloudburst of 101 mm.

As shown in Figure 5.1 there are several problem areas on campus according to the simulation in SCALGO Live and Vatten i Göteborg. A problem area that was discussed during the interviews with Akademiska Hus and Chalmersfastigheter is the area along Sven Hultins Gata, from Kårrestaurangen to Lennart Rönnmarks Plats, shown in Figure 5.2. This area is also known by the authors to be a problem area regarding stormwater after their five years studying at the campus. The land use for the area agrees with the campus plan since it will remain an open area, see the structural plan in Figure 3.2, and has potential to be developed to meet the vision for the campus plan regarding ecological values and increasing social gatherings. When improving the stormwater management for the area this can also contribute to the learning environment and increase the academic performance of the students which is stated by Hajrasouliha (2017) to be important. The area, covering the selected site, is not included in an active detailed development plan since the implementation time has expired (Göteborgs Stad, 2020). Therefore, the selected site for this study is chosen as the area from Kårrestaurangen to Lennart Rönnmarks Plats. The site is divided into three parts with different stormwater management purposes seen in the right picture in Figure 5.2.

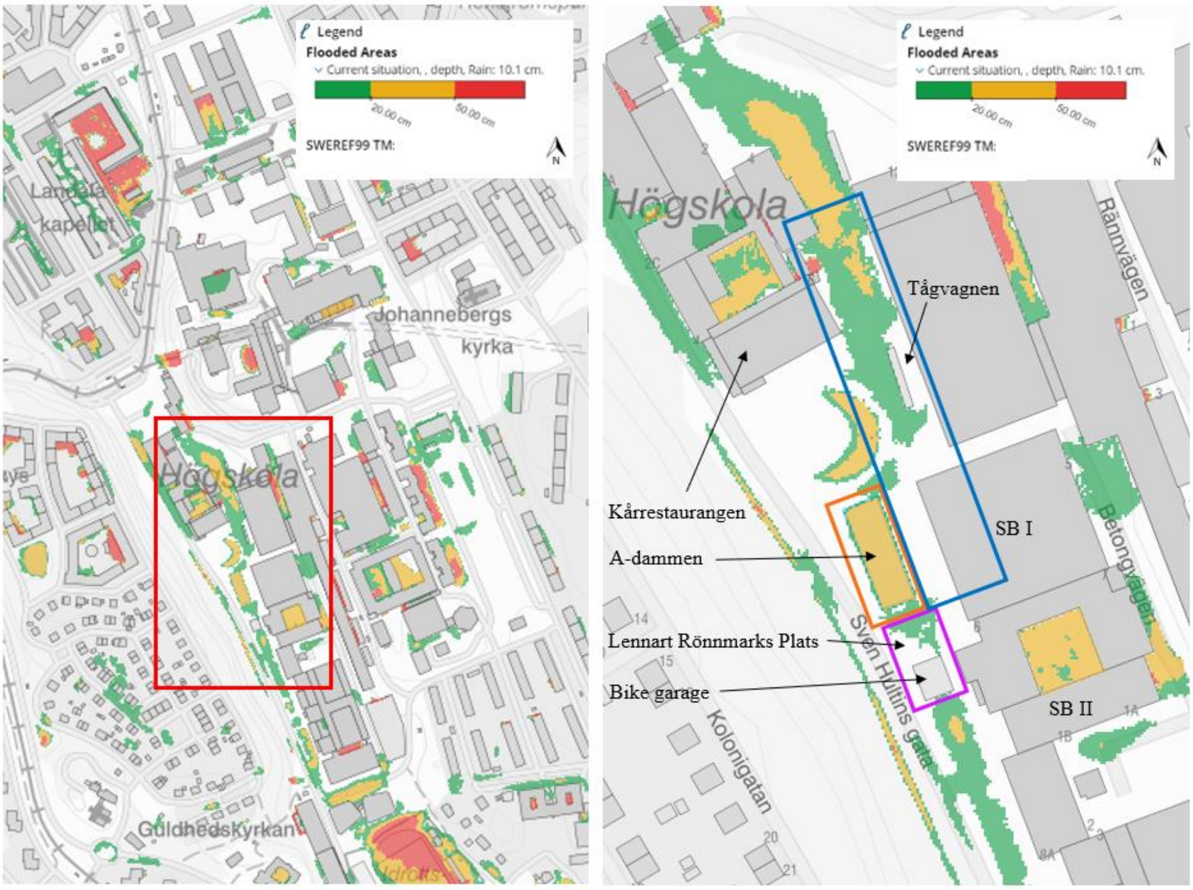

Figure 5.2 Left picture: Overview of the selected site at Campus Johanneberg. Right picture: Part 1 in blue box, part 2 in orange box and part 3 in purple box. Both simulations from SCALGO Live for a cloudburst of 101 mm.

The current stormwater management at the selected site is made up of stormwater wells and gutters seen in Figure 5.3, the wells are marked with red squares and the gutters with red lines. Figure 5.3 also shows how the stormwater flows within the selected site, according to the simulations from SCALGO Live. When simulating a 10 mm rain event, the selected site is divided into two catchment areas in SCALGO Live. One catchment area covers the orange, purple and the south area of the blue box outside Samhällsbyggnad I (SB I), seen in Figure 5.2, and the other catchment area covers the rest of the blue box and the area around Kårrestaurangen. When investigating a cloudburst event of 101 mm of precipitation, the simulation shows that the selected site is included in the catchment area covering most parts of central Gothenburg and up north along Göta Älv towards Vänern. This means that stormwater from other parts of the campus flows down into the selected site, continues on to Kapellplatsen and further down to Göta Älv as its final recipient.

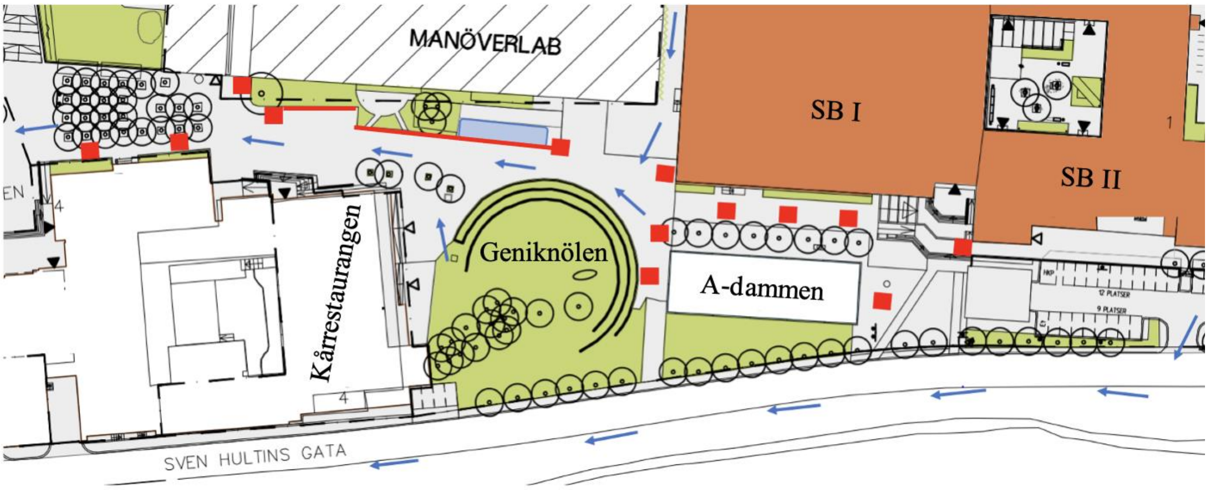

Figure 5.3 The current stormwater situation at the selected site. Stormwater wells in red squares, gutters as red lines and the main stormwater flow directions marked with blue arrows, according to SCALGO Live. Background drawing retrieved from Akademiska Hus and reprinted with permission.

5.1.1 Division of the selected site

The selected site is divided into three parts with three different stormwater management purposes. The first part is for collection of the excess stormwater from the open area in front of the entrance to Kårrestaurangen, Tågvagnen and outside SB I, marked in the right picture of Figure 5.2 with a blue box. The collection area is mainly made up of impermeable surfaces today. The paving stone within the area has been subject to settlements which prevent the stormwater to flow towards the stormwater drainage and instead create puddles that the students and workers have to walk around, see Figure 5.4. The pictures in Figure 5.4 are taken on different dates and at different amounts of precipitation, which is retrieved from SMHI (n.d.). The rainy left picture was taken on the 7th of March 2019 at 9:30 am during a rain event of 18 mm which had a duration of 15 hours. The rainy right picture was taken on the 27th of September 2019 at 4 pm. The rain event had a precipitation of 33.3 mm with a duration of 13 hours. The two sunny pictures were taken on the 23rd of April 2021 when it had not been raining for 43 hours.

Figure 5.4 The area for stormwater collection during different weathers. Rainy pictures by S. Rauch (2019) *and dry pictures by authors (2021).*

The second part of the selected site is for retention and storage of stormwater in A-dammen, marked with an orange box in Figure 5.2. Today A-dammen is a pond with small fountains in it, that the students use for different competitions and during the reception of the new students. Due to the seasonal changes in temperature the pond is empty most parts of the year and is not in use, see Figure 5.5.

Figure 5.5 A-dammen when it is empty (Authors' own picture, 2021).

The third and final part is a possible connection from A-dammen, crossing Lennart Rönnmarks Plats, to Sven Hultins Park for the stormwater to be able to infiltrate in the park. This area is marked with a purple box in Figure 5.2. Lennart Rönnmarks Plats is in front of the entrance to SB I and II and is not a well-used area today. The area is covered in gravel and has a bike garage connected to it on the south side, see Figure 5.6.

Figure 5.6 Lennart Rönnmarks Plats and the entrance to SB I and II (Authors' own picture, 2021).

5.2 Interviews

The results from the interviews with representatives from Akademiska Hus, Chalmersfastigheter and Rain Gothenburg are presented in this subchapter with the processed data divided into categories depending on the topic. The categories that evolved from the processed data are: Campus today, The campus plan and Future stormwater visions.

5.2.1 Campus today

Akademiska Hus and Chalmersfastigheter, the two main property owners at Campus Johanneberg, agree that the stormwater situation at Campus Johanneberg is acceptable but could be improved. They agree that there are problem areas on campus at Sven Hultins Plats by the Johanneberg Science Park and the path along the civil engineering buildings called SB I and II. The stakeholders work together regarding the development on campus, but when asked about the stormwater cooperation they all agree that there is a lack thereof, and that it could be improved in the future since stormwater flows over the property boundaries.

The representatives from Akademiska Hus and Chalmersfastigheter only knows about a few stormwater solutions implemented on campus today. The Landscape Manager from Akademiska Hus explains that ”we probably divert most of the water today, unfortunately” [Authors’ translation]. They continue by saying that there is a covered gutter by Tågvagnen that is not functioning properly due to neglected maintenance and settlements in the paving stones causing the water to flow away from the gutter. Chalmersfastigheter mention that they have built a rain garden outside their office in the northern part of the campus by Kapellplatsen. The rain garden was built to handle the stormwater from the roof of the building as well as the stormwater collected by the gutter on the nearby parking.

A-dammen is a part of the selected site in this thesis and its history is discussed with the Landscape Manager from Akademiska Hus to get an understanding of the function of the pond today. According to the Landscape Manager the pond was built in the 1970s as a cooling pond for computers in SBI and II. The pond was originally built to be 1.5 meters deep but was later filled up with gravel as a safety precaution when there was no need for cooling. The pond is a closed system preventing any water from infiltrating into the ground and the drain is connected to the sewer system. The Landscape Manager continues by saying that the road between Geniknölen and A-dammen is an emergency access road and needs to remain accessible.

5.2.2 The campus plan

The Strategic Campus Developer from Chalmersfastigheter explains that “there is an ambition with the campus plan that we want to decrease the amount of impermeable surfaces and increase the amount of local infiltration” [Authors’ translation] when discussing the campus. They also mention that the blue infrastructure marked on the campus plan map, see Figure 3.2, is not planned in detail and only shows possible locations for water arrangement both for stormwater and esthetic reasons.

The Strategic Property Developer from Akademiska Hus clarified the extent of the proposed Sven Hultins Park in the campus plan. The plan for the new park is to go along Sven Hultins Gata, from A-dammen to Johanneberg Science Park south of the selected site, making it a larger park than what is shown in Figure 3.2. Sven Hultins Park is divided into several parts, with the first section already under construction by Johanneberg Science Park. The plan is for the construction of the last part of the park to start in 2024 or 2025.

5.2.3 Future stormwater visions

The topic regarding the lack of stormwater management at Campus Johanneberg, and specifically around SB I and II, are discussed with all the stakeholders. Both the Landscape Manager from Akademiska Hus and the Strategic Campus Developer from Chalmersfastigheter express that the area around these buildings could be of interest to implement some kind of open stormwater solution. Implementing a stormwater solution around these buildings can add an educational perspective for the students studying civil engineering and infrastructure there. When renovating SB II, Chalmersfastigheter looked at the possibility of implementing an open stormwater solution in the courtyard of SB II. They investigated the possibility quite far, but it ended up being too expensive and not sufficiently beneficial for the environment.

The Landscape Manager from Akademiska Hus explains that they are in the middle of an investigation about how to improve the area around Tågvagnen. They have had discussions with the Student Union on how to improve this area and develop it into an area for activities, such as a volleyball court and outdoor seating for Kårrestaurangen, and the plan is that the reconstruction will start in the fall of 2021. The possibility to include Lennart Rönnmarks Plats in the reconstruction is discussed during the interview to see if this is a possible area to implement a stormwater solution as it is a forgotten area today. Both of the representatives from Akademiska Hus express that they have an advantage point regarding stormwater management and the Strategic Property Developer express it as “we are like the city in general since we also own the streets between the properties. This gives us a greater possibility to work with it in a more flexible and interesting way” [Authors’ translation].

The issue with implementing a stormwater solution in an already constructed area is often the budget, according to the Strategic Campus Developer from Chalmersfastigheter. They continue by explaining that it is easier to implement a stormwater solution if it is included in a construction project from the beginning. The Strategic Property Developer from Akademiska Hus explains that “sometimes you see it as part of a refinement so that you might share the cost with the customer […]. Sometimes it is something we as property owners want to do because we believe it can generate and increase the value for us” [Authors’ translation].

During the interview with the Creative Director and the Project Manager from Rain Gothenburg another financial issue was brought up, which is the issue of financing the maintenance and operation of stormwater solutions. The Creative Director explains it as that everyone involved in a project thinks the ideas are good in the beginning until they realize that the cost for maintenance and operation will be higher than expected and an annual expense. This contributes to the municipality backing out and implementing a solution that does not contribute to any additional value to the city. The project director explains that “the municipality is afraid of committing to future expenses” [Authors’ translation].

Rain Gothenburg explains their vision and how they see a future need for broader collaborations regarding stormwater management, for example with civil engineers, architects and designers. “We wish to broaden the teams, initially in projects, so that it does not stay as it has always been […] and there are no synergies” [Authors’ translation] the Creative Director says and further explains that experts from different areas will all gain from working together. When the experts work separately it is harder to work towards a common vision for the entire area and how it could contribute to human well-being.

The future stormwater visions for Campus Johanneberg can be summarized as that open stormwater solutions are of interest for the stakeholders and that it is beneficial to coordinate it with other constructions in order to solve the financing. Other aspects that have to be investigated is how to involve more people in the development process to ensure that human well-being is taken into account and that the maintenance and operation costs have to be covered in some way.

5.3 Student survey

This subchapter presents the results from the student survey that was open for the students during one week in mid-March and the survey was closed when no new responses had been received in two days. The survey got answers from 46 out of the 94 students that received the survey, which corresponds to 7% of the total student group with 707 students. The internal dropout rate was low for the multiple-choice question but for the two open questions the dropout rate was 20% and 35%. The distribution of the responses between the programs associated with civil engineering are:

- Bachelor in civil engineering: 2
- Design and Construction Project Management: 11
- Infrastructure and Environmental Engineering: 18
- Sound and Vibration: 1
- Structural Engineering and Building Technology: 10
- Industrial Ecology: 4

The selected site is divided into four different areas, shown in Figure 5.7, to simplify for the students when answering the questions. The complete survey can be seen in Appendix C.

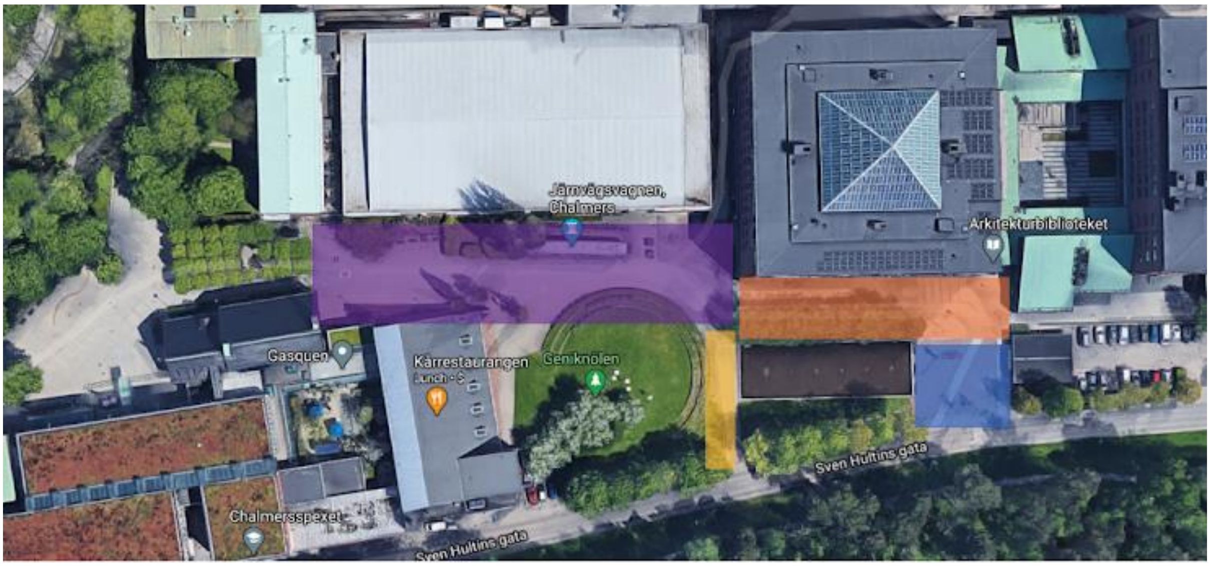

Figure 5.7 The figure used in the survey to clarify the four different areas within the selected site. Original picture taken from Google maps and edited by authors.

The answers to the question regarding problem areas within the selected site are illustrated in Figure 5.8 with red bars. It is clear from the graph that the students consider the purple and orange areas to have issues regarding stormwater. The students were able to select more than one area and the most common combination is the purple and orange area with 16 students selecting them both.

Figure 5.8 A graph illustrating the answers from the students regarding problem areas and areas for implementation of stormwater solutions.

The next question that the students answered was where within the selected site that the students would like to implement a stormwater solution. This question got roughly the same answers as the previous question, see the green bars in Figure 5.8. Purple and orange is once again the most common combination with 9 students selecting both areas. The graph shows a decrease for all areas except the blue area when asked about where to implement a stormwater solution.

37 of the selected students, which corresponds to 80%, answer that they think that some sort of stormwater management implemented within the selected site could add something to their education. One student mentioned that they would like the civil engineering department to work together with Akademiska Hus, who owns the property, to build solutions that both improve the environment and can be used as examples in education.

The survey also contained a more open question regarding what type of stormwater solution that the students would like to implement at the selected site. The most common response is that the students want more blue-green infrastructure implemented like rain gardens, more greenery and permeable surfaces. They also want open stormwater solutions where you can see the water and to implement something creative within the blue area in Figure 5.7.

5.4 Selected solution

As mentioned in subchapter 5.1, regarding the site selection, the solution that is developed in this thesis is divided into three parts with different stormwater management purposes: collection, storage and overflow. The solutions presented in this subchapter align with the vision from the campus plan, interviews and student survey specified in subchapter 4.3.

5.4.1 Part 1 – Stormwater collection

The area for the stormwater collection is specified in the campus plan to remain an open area for transportation. This is one of the main walking paths on campus as well as an emergency access road according to the Landscape Manager from Akademiska Hus. Blue-green infrastructure was desirable to be implemented in this area according to the interviews and the students survey, so that the water could be experienced. To comply with the accessibility but still keeping the stormwater visible, covered gutters are chosen for the stormwater collection.

The covered gutters will collect the stormwater and lead it to A-dammen, see Figure 5.9 for illustration. The main gutter will start in the open area in front of the entrance to Kårrestaurangen and go around Geniknölen to A-dammen, illustrated with a blue line. There will also be covered gutters going from SB I to the trees by A-dammen and a gutter for collecting the stormwater from the roof of Kårrestaurangen, the thick blue line, connecting to the main gutter. A connection between the main gutter and A-dammen has to be constructed to prevent backflow when A-dammen is filled. The ground surface in this area has to be reconstructed to slope toward the gutters to facilitate drainage.

The collection part is also suggested to include an area of nature-based solutions such as reinforced grass and rain gardens, see the darker green and yellow areas in Figure 5.9. These areas will contribute to the campus vision to become a green campus promoting ecological values. These solutions will contribute to making the campus more climate resilient and increase the biodiversity (European Commission, n.d.-b). To enable social interactions, in line with the campus plan, this area is also suggested to include benches and tables. To make this area usable even during rainy days, some of the tables can be equipped with parasols.

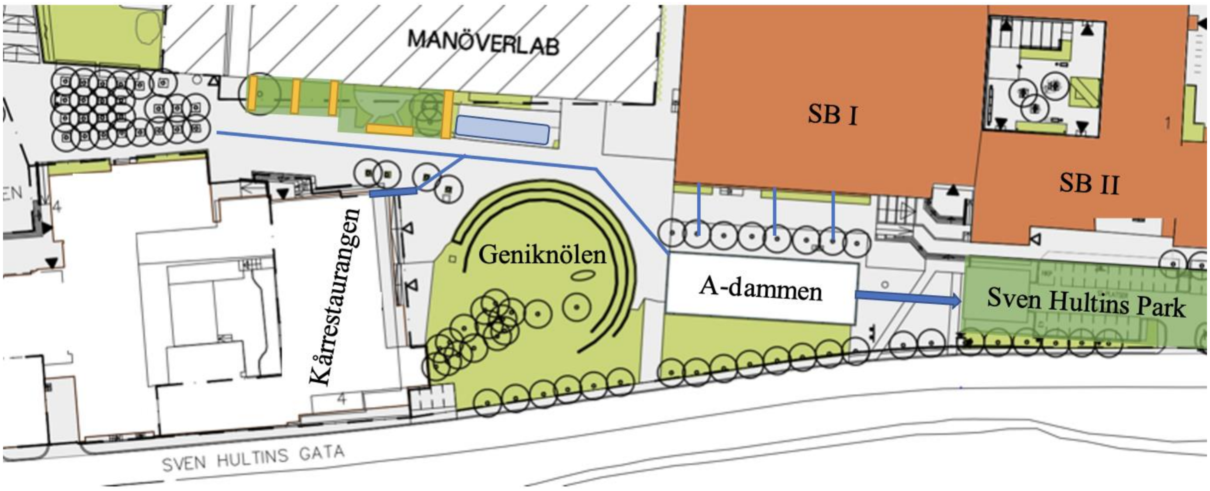

Figure 5.9 An illustrative picture over the selected solution with covered gutters in blue, reinforced grass in darker green and rain gardens in yellow. Background drawing retrieved from Akademiska Hus and reprinted with permission.

5.4.2 Part 2 – Stormwater storage

The simulation in SCALGO Live shows that during a cloudburst a large volume of stormwater will be gathered within the selected site. The campus plan specifies that its blue-green infrastructure should protect against future extreme weather and create meeting spots (Chalmers University of Technology et al., 2019). The interviews and the survey specified that an open stormwater solution, where the water can be experienced, would be desirable to implement. For these reasons, a storage area for the stormwater that also can provide meeting opportunities is proposed. The authors know that A-dammen is used by the students today during multiple occasions and therefore the suggestion is to renovate it to provide storage and meeting spots and it can therefore be seen as a multifunctional area. This can be connected with the need seen in the campus plan and the goal of “responsible and efficient use of premises, land and other resources” [Authors’ translation] (Chalmers University of Technology et al., 2019, p. 19) since it can be used for both stormwater management and as a social place.

There are several social benefits that can come with implementing stormwater management, as specified in subchapter 2.3.2, such as providing places for social gatherings to cover the need for social interactions which can improve the mental health for humans (Lõhmus et al., 2021; Mottaghi et al., 2021; Xie et al., 2020).

The suggested renovation of A-dammen is to lower the water level in the pond, in comparison with today, and equip the sides with steps which can be used as seating and at the same time give the water level the possibility to rise during a cloudburst event. Since A-dammen is 1.5 meters deep today according to the Landscape Manager from Akademiska Hus, the first 0.7 meters will still be filled with gravel and have the water surface 0.2 meters above the gravel, followed by 0.6 meters of steps. An illustrative picture of the proposed renovation of A-dammen can be seen in Figure 5.10.

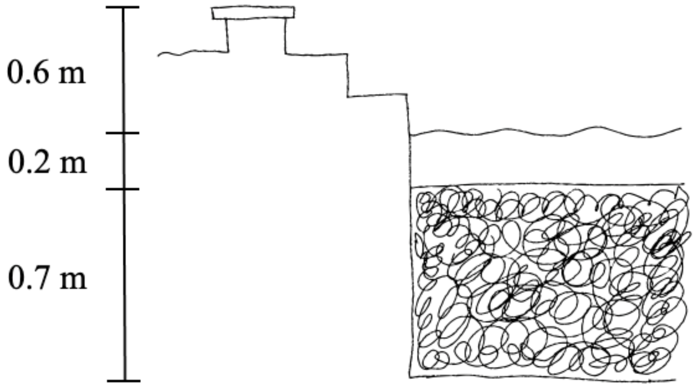

Figure 5.10 Illustrative picture of the renovated pond with its suggested dimensions (Authors' own picture, 2021).

5.4.3 Part 3 – Stormwater overflow

Since the volume of water during a cloudburst is so large, it can be beneficial to have several spaces for storing the stormwater and where it can be able to infiltrate into the ground. For these reasons, a connection from A-dammen to the proposed Sven Hultins Park is suggested. This connection is a stormwater overflow to direct the excess stormwater from the pond to the park, illustrated by the blue arrow in Figure 5.9. The overflow is suggested to be constructed as a waterfall at the south side of the pond facing Lennart Rönnmarks Plats. This makes it possible for the water to flow out of the pond when the water level in A-dammen reaches a certain level, an illustrative picture of this can be seen in Figure 5.11. The water will flow in a covered gutter that crosses Lennart Rönnmarks Plats and into the planned Sven Hultins Park where the stormwater can infiltrate into the ground. The waterfall and covered gutter will make it possible to see and hear the water which is desirable according to the interviews and the student survey. This also connects well with the campus plan specifying that open stormwater solutions create recreational values (Chalmers University of Technology et al., 2019).

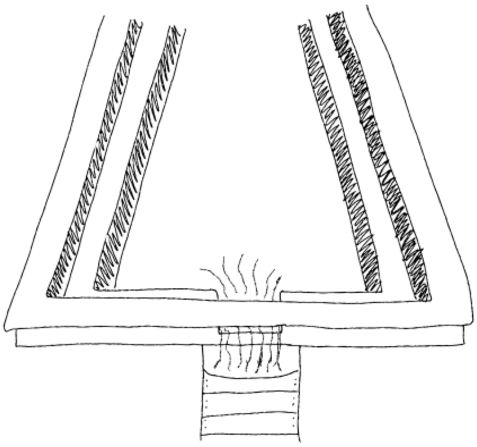

Figure 5.11 Illustrative picture of the overflow waterfall that prevents A-dammen from being flooded (Authors' own picture, 2021).

To further increase recreational values in this area, other blue-green infrastructures are suggested to be implemented in Lennart Rönnmarks Plats. These blue-green infrastructures are suggested to be rain gardens, reinforced grass and bike garages with green roofs. From the interviews with Akademiska Hus and Chalmersfastigheter together with the student survey, Lennart Rönnmarks Plats is specified as a neglected and forgotten area. By implementing the suggested blue-green solutions, together with benches and tables, the area can create social and ecological values to align with the campus plan vision. If these suggestions were to be implemented, the area would become greener and provide social spaces which could have a positive impact on human well-being (Lõhmus et al., 2021; Mottaghi et al., 2021).

The suggestions for Lennart Rönnmarks Plats are illustrated in Figure 5.12. The green area in the figure represents the reinforced grass, the yellow boxes are rain gardens and the orange boxes represent benches and tables. The brown path illustrates a wooden path that makes it possible for people to access the area while the water can flow under it and into Sven Hultins Park for infiltration. The green squares are bike garages with green roofs that also work as shielding from the road.

Figure 5.12 Illustrative picture of Lennart Rönnmarks Plats with reinforced grass (green), rain gardens (yellow), bike garages (green boxes), wooden path (brown) and benches and tables (orange). Original picture taken from Google maps and edited by authors.

5.5 Simulation of solution

The results presented in this subchapter are from the simulation of the selected solution in SCALGO Live. The two simulated models are model A with stormwater collection and storage and model B which also includes the overflow. Model B is considered to be a more complex model but with more simplifications and because of the simplifications the results are assumed to not correspond to reality in the same way as model A does. Due to the complexity in model B, the simulations from model A are the results that will be presented in this thesis. Simulations for model B can be seen in Appendix E, Figure E.1 and E.2.

5.5.1 Scenario 1 - Moderate rain event

The simulation for the moderate rain event was done with a precipitation level of 10 mm, see Figure 5.13 for result. The water depths are visualized for 0-10 cm in green, 10-20 cm in yellow and more than 20 cm in red. The maximum water depth without the solution is 29 cm at the black circle in the left picture. With the solution implemented, the maximum simulated water depth at the black circle, in the right picture, has decreased to 16 cm and the water depth within A-dammen is 30 cm.

Figure 5.13 Left picture: Without implemented solutions with 10 mm of precipitation. Right picture: With implemented solutions with 10 mm of precipitation. Both simulations from SCALGO Live.

5.5.2 Scenario 2 - Cloudburst

The cloudburst simulation is done with 101 mm precipitation, the result can be seen in Figure 5.14. The water depths are visualized for 0-10 cm in green, 10-20 cm in yellow and more than 20 cm in red. The maximum water depth without the solutions is 41 cm at the black circle in the left picture. With the solutions implemented, the maximum simulated water depth is 41 cm at the black circle in the right picture and 61 cm within A-dammen. The main gutter is flooded in Figure 5.14, which is concluded to happen when the precipitation exceeds 12 mm due to that the prevention of backflow is not accounted for in SCALGO Live.

Figure 5.14 *Left picture: Without implemented solutions during a cloudburst of 101 mm. Right picture: With implemented solutions during a cloudburst of 101 mm. Both simulations from SCALGO Live.*

If A-dammen should be able to store all of the stormwater, that drains to the main gutter, during a cloudburst event of 101 mm, A-dammen would need to be lowered an additional 7.26 meters to a level of +39.23 meters, see Figure 5.15.

Figure 5.15 *A-dammen lowered to a level of +39.23 meters in order to store all of the water from a cloudburst of 101 mm. Simulation from SCALGO Live.*

6 Discussion

In this chapter the results from the site selection, interviews, student survey, selected and simulated solution will be discussed together with related ethical aspects.

6.1 Site selection

The decision regarding the site selection is not necessarily the area on campus with the most problems concerning stormwater. The site was chosen because it is an area on campus that the authors know is problematic since puddles are created in the area when it rains. The choice of this specific site might have been biased due to that the authors attend school on this part of the campus, but since the representatives from Akademiska Hus and Chalmersfastigheter both agreed that it is a problem area the choice is still reasonable.

Since SCALGO Live does not consider the existing stormwater solutions in place, for example the stormwater wells shown in Figure 5.3, the water depth shown in the simulation can be assumed to be higher than reality. This limitation causes an overestimation of the water depth in the entire campus area and not only within the selected site. Therefore, this limitation is assumed to not have changed the outcome of the simulation for the site selection.

As mentioned in subchapter 5.1, regarding the site selection, the natural direction of the stormwater at the selected site is the opposite direction of the stormwater flow that this thesis aims for and what the City of Gothenburg specifies in their structural plan, mentioned in subchapter 3.3.3. The reasoning behind this is to divert the stormwater and infiltrate it locally instead of contributing to the runoff to Göta Älv. This corresponds with the principle that the City of Gothenburg mentions in their manual "Dagvatten, så här gör vi! (Stormwater, this is how we do it!)" (Göteborgs Stad, 2010).

This thesis was carried out during the spring of 2021, from January to mid-May, during this time there was a total of eight days with more than 10 mm of precipitation (SMHI, n.d.). Unfortunately, both authors for this thesis worked from other locations than Gothenburg during these days. Due to this, no comparison of the simulated rain for the site selection has taken place as a field visit during a day with more than 10 mm of rain by the authors. The site selection has instead been confirmed by the authors' memories, interviews, student survey and older pictures from the site.

6.2 Interviews and student survey

The results from the interviews with Akademiska Hus and Chalmersfastigheter showed that they have similar views on where there are problem areas on campus. Both of the stakeholders specified that there is a lack of stormwater solutions on campus today and that it could be interesting to construct an open stormwater solution around SB I and II for the students studying civil engineering. By implementing this, the learning environment could be improved for the university campus and have a positive impact on the students' academic performance (Hajrasouliha, 2017). Chalmersfastigheter have shown an interest in implementing something in this area before when they investigated a possible open stormwater solution in the courtyard of SB II. But this was never realized because the environmental benefits did not outweigh the costs. When discussing with Rain Gothenburg it was not the implementation cost that they brought up as an issue but the cost for maintenance and operation. The costs for implementation, maintenance and operation have to be weighed against how much the expected damage will be when a cloudburst of this size hits the campus.

The selection of the students for the student survey was done to get a group that both had knowledge of the site and of the subject of stormwater. The students in higher grades were assumed to have been on campus more frequently during rain events than the younger students, but both student groups have been on campus less during the last year due to COVID-19. The results from the survey points towards the orange area in Figure 5.7 being a problem area with 26 of 46 students specifying it as such. This result does not correspond to the simulation done in this thesis, see Figure 5.13 and Figure 5.14, which indicates that not even during a cloudburst there is a problem with flooding in this area. A possible reason for this might be that this group of students remembers the orange area to be worse than it actually is, due to that they attended the buildings before and during the renovations that took place in 2016-2017. Apart from the students' thoughts regarding the orange area, their responses correspond to the problem areas from the simulations in SCALGO Live. The choice of the selected student group can therefore be assumed to be reasonable.

The results in Figure 5.8 show that the blue and yellow areas are not considered as problem areas by the selected students today. A reason why the students do not think so could be because these two areas are not being used by the students. The students do consider the blue area to be a good place to implement some sort of stormwater management, which the representatives from Akademiska Hus and Chalmersfastigheter also specified during their interviews.

The timespan for the survey was sufficient, with 42 of the 46 students responding the first day the survey was sent out. The rest of the responses came the following days and the survey was closed two days after the last response was received. The number of responses was higher than expected since 49% of the students that received the survey answered it, even though this is only 7% of the total number of students that met the criteria. Answers were divided between six different programs with 85% of the responses coming from students attending one of the three larger master's programs. Due to the low number of responses in comparison with the entire student group of 707 students, the results from the survey may not be representative for the entire group of students. But since the division between the different master programs associated with civil engineering is quite even, the results can be assumed to cover the differences within the student group.

6.3 Selected solution

The selected solution was developed with the campus plan and its vision and goals in mind. Both the campus plan and the interview with Akademiska Hus specifies that an open stormwater solution is desirable for recreational, environmental and educational purposes. During the interview with Akademiska Hus the importance of keeping the emergency access road in the yellow area in Figure 5.7 was stated, which limited the type of stormwater solutions that could be implemented. A more detailed evaluation of the ground inclination and the specific placement of the gutters have to be done before this solution can be implemented and work properly.

The reason behind including blue-green infrastructure, such as rain gardens and reinforced grass, in the selected solution is that it connects with the visions in the campus plan and can add other benefits such as improving human well-being which is desirable for a campus to achieve (Lõhmus et al., 2021; Mottaghi et al., 2021). Research has also shown that green infrastructure has several social and ecological benefits such as improving public and mental health (Meerow, 2020). An issue with reinforced grass is that it can limit the accessibility for people with physical disabilities and strollers. Because of this, reinforced grass is only proposed on side areas and where benches are suggested and where it can be motivated with that it increases infiltration. Reinforced grass is not proposed in areas used for transport of people or vehicles, see Figure 5.9 and Figure 5.12, where there is a wooden path between the reinforced grass to make the area accessible for everyone. An issue that Meerow (2020) and Wolch et al. (2014) brings up is the ethical aspect with gentrification due to implementations of more open and green stormwater management. This is not seen as a problem at Campus Johanneberg since the campus has been there for a long time and the university has already had a large effect on the surrounding areas since it is already used as a test site for new technologies.

An important aspect to consider when increasing the infiltration, as in the case for the proposed Sven Hultins Park and the areas with reinforced grass, is that this cannot be done without further investigation and planning (Berland et al., 2017). An increase in infiltration can raise the groundwater table causing floods in new areas and an increase in the groundwater flow, as in the case for the University of British Columbia mentioned in subchapter 2.4.

Maintenance is a usual problem with stormwater solutions according to the representatives from Rain Gothenburg. By implementing the selected solution there will be an increase in the amount of maintenance needed. The new maintenance will be to keep the gutters in order by cleaning them from leaves, gravel and other things. After the reconstruction of A-dammen the maintenance will be similar to what it is today. The reinforced grass, the rain gardens and the green roofs have to be tended to, so they do not become overgrown.

6.4 SCALGO Live

SCALGO Live was chosen as the modeling tool in this thesis since it is a suitable program, with the right complexity, to model in. When simulating the results SCALGO Live was updated several times which caused problems with the simulations that were already made. The biggest update was the change of the elevation model used from Lantmäteriet GSD-Höjddata, grid 2+, acquired by SCALGO 2019-11-29, to Lantmäteriet GSD-Höjddata, grid 1+ acquired by SCALGO 2021-01-07 (SCALGO, n.d.-a), this update was released April 15th 2021. This caused several changes in the simulation of how the stormwater flows on the selected site, the most noticeable change was that SCALGO Live now understood that A-dammen was a lower area than the surroundings and could store water. This update changed the already simulated model and the entire modeling and simulation had to be done again with the improved elevation and the results shown in this thesis are with the updated elevation model.

It is important to remember that this thesis only considers water depth within the selected site and not the stormwater flow. It is possible to see what direction the water flows in with SCALGO Live, but it is not possible to see how much stormwater that is flowing in a certain direction. Since SCALGO Live does not consider any existing stormwater networks or infiltration, the results that can be retrieved from SCALGO Live can be assumed to be a worst-case scenario when the soil is saturated and the stormwater networks are flooded.

6.4.1 Modeling

The selected solution consists of covered gutters, a renovation of A-dammen, reinforced grass and rain gardens. SCALGO Live was not able to model all of these solutions, and that is why only the main gutter and A-dammen is included in model A, see Figure 4.3. There has not been an investigation on where exactly the most beneficial placement is for the main gutter and it is only placed roughly along the road. Some simplifications are also made to the model such as the shape of the gutter and the inclination. The main gutter is modeled as a square-formed gutter instead of round, which they are constructed as, and the modeled inclination is set to 0‰ to prevent backflow from A-dammen, which SCALGO could not account for.

Only after the update in April, from 2 meters resolution to 1 meter, did SCALGO Live consider A-dammen as a pond, which made the modeling easier. In SCALGO Live, A-dammen was seen as a 0.40 meters depression that could be filled with water. The calculations for the modeling of A-dammen, in Appendix D, are done for when A-dammen is filled, if a cloudburst occurs during the time of the year when A-dammen is empty this benefits the stormwater management. Considering how much the updated resolution affected the results from the simulation, future updates could have a large impact on how the selected solution is modeled and more accurate results can be achieved.

6.4.2 Simulation

It can be assumed that the simulations in SCALGO Live should be worse than in reality due to that the program does not consider infiltration nor the stormwater network. But when comparing the simulation for the moderate rain event of 10 mm, seen in the left picture of Figure 5.13, with the rainy picture taken by the trees, the right pictures in Figure 5.4, it is obvious that they have similarities. This indicates that the infiltration in the area by the trees in the north part of the selected site might be limited and that the stormwater well might not function properly, this could be due to for example leaves blocking it. So therefore, the simulations in SCALGO Live can be assumed to be closer to reality than expected concerning the water depth in this area.

For the moderate rain event of 10 mm the modeled solution improves the stormwater situation at the selected site significantly. But for the cloudburst event of 101 mm the situation in the main part of the selected site is not improved due to that the entire area is flooded and the excess stormwater flows outside the selected site. One area that is improved even during a cloudburst is the area around A-dammen. Even if the modeled solution does not improve the situation during a cloudburst that much, it is important to remember that it does not exceed 0.2 meters of water depth in the main parts which is the limit of the City of Gothenburg for emergency access roads (Göteborgs Stad, 2019). To be able to handle all of the stormwater from a cloudburst, with the stormwater collection and storage in model A, A-dammen would have to be lowered an additional 7.26 meters which is not reasonable to implement. But what depth is reasonable, both for implementing and as a future investment? The cost for implementing a storage area that could handle a cloudburst of 101 mm would be expensive but repairing the cost from such a cloudburst can be assumed to be even more expensive, as in the case for the City of Copenhagen mentioned in subchapter 2.3.3. Considering this, a deepening of A-dammen a few meters could be reasonable since it would limit the harm from a cloudburst, but this would limit the student use of A-dammen and increase the risk of drowning depending on the design. Another way to handle all of the stormwater during a cloudburst would be to implement more stormwater storage, which can be both on and off campus.

The construction preventing backflow between A-dammen and the main gutter cannot be modeled in SCALGO Live, this causes a backflow from A-dammen when the precipitation exceeds 12 mm. Neither the waterfall connecting A-dammen to the covered gutter leading the stormwater to Sven Hultins Park can be modeled in SCALGO Live. Since this cannot be modeled properly it causes the stormwater to flow both ways when the precipitation exceeds 20 mm. Both of these limitations with the modeling causes the simulation to seem worse than what can be expected in reality.

When analyzing the results from model A and B, shown in subchapter 5.5 and Appendix E, it is noticeable that there is not much difference during a moderate rain event, the changes that are visible are the flooding in Sven Hultins Park due to the new heights in model B. For the cloudburst scenario there are larger differences between model A and B. The flooding in the stormwater collection area has decreased since the stormwater can flow out of A-dammen in the overflow, whereas in model A it gets pushed back when A-dammen is full. But since the modeling of Sven Hultins Park is both simplified and complex, the results from model B are still assumed to be less trustworthy.

According to the City of Copenhagen (2012), as mentioned in subchapter 2.3.3, it is important to be able to handle both ordinary rainfalls and cloudburst and that it can be beneficial from a socio-economic perspective. So even though the modeled solution does not visibly improve the situation during a cloudburst it will be better than before. The situation will be improved for rain events with precipitation lower than 101 mm and the improvements can be seen as an investment for the future.

The simulated scenarios are chosen according to how the future climate is predicted today, with more research those predictions might change and new standards for the amount of precipitation will be needed. This will affect how well the results in this thesis will correspond to the future and if the solutions simulated in this thesis are over or under dimensioned.

7 Conclusion

The purpose of this master's thesis is to investigate how the climate resilience of campus areas can be improved for a future increase in precipitation. This was achieved by answering the following specific objectives:

1. *Identifying a location in need of stormwater management at Campus Johanneberg.*

There are several problematic sites on campus that are in need of stormwater solutions according to the simulation done in SCALGO Live. The selected site for this thesis is one of the larger areas that are affected by flooding during a cloudburst.

2. *Selecting which stormwater solutions that could be implemented to align with the vision for the future of Campus Johanneberg, according to the campus plan.*

Possible stormwater solutions are different kinds of open, green and multifunctional solutions. The stormwater solutions proposed in this thesis are covered gutters, rain gardens, reinforced grass and an open stormwater storage which all contribute to the campus being green and a more responsible land use to align with the vision for the campus plan.

3. *Assessing how much the proposed stormwater solutions improve the situation at the selected site.*

The results from the simulations show that during a moderate rain event of 10 mm the situation is improved significantly within the site. For a cloudburst there has only been minor improvements since the amount of stormwater is so large and cannot be handled within the selected site alone.

4. *Assessing added benefits of selected stormwater solutions, considering learning environments and opportunities for social interactions.*

There are several added benefits with the selected solution. With the selected site becoming greener it increases the ecosystem services, recreational values and the well-being for the people in the area. This can be assumed to have a positive impact on academic performance and provide the learning environment that 80% of the selected students from the survey want. The selected solution also increases the amount of meeting spots at campus that will increase the social interaction among the students.

To summarize, this thesis shows one possible way to climate adapt Chalmers Johanneberg for an increase in precipitation. It is clear from the work with this thesis that climate adaptation must be considered and that a cloudburst can cause a lot of damage if the right infrastructure is not in place. From the campus plan and the interviews with Akademiska Hus and Chalmersfastigheter, it is clear that the stakeholders at Chalmers University of Technology have started to think about these questions and that something has to be done. This thesis, with its selected solution, fulfills this vision and can therefore be seen as a start to an addition to the campus plan concerning how to handle stormwater. Another aspect that is clear from the campus plan and the interviews is that the issues connected with stormwater are well known but the question regarding the financing of the implementation remains. In the end the cost of implementing stormwater solutions have to be weighed against the cost of repairs after a cloudburst event.

7.1 Future recommendations

The recommendation for future research is to look into different simulation programs that are able to model more precisely, are more advanced and are more stable. Features to look for in a more advanced simulation program are if it accounts for infiltration, existing stormwater networks and how the site is affected by the rain event over time. If one does still want to use SCALGO Live it is recommended to investigate the possibility of creating your own terrain model over the selected site, in a more precise software. The flood can then be simulated in SCALGO Live, with the new terrain model, for a more accurate result.

More accurate predictions of the future climate can be expected to become available, so any future research must investigate this matter and make sure that they use the most accurate prediction of the climate change.

The selected solution and the simulations were presented to the Landscape Manager from Akademiska Hus and the Creative Director from Rain Gothenburg on the 7th of May. The meeting was held to get a second opinion on the selected solution and to discuss how the ideas in this thesis can be developed for the future. The Creative Director once again stressed the matter that he believes that there is a need to broaden the teams to achieve the common vision and contribute to human well-being. This could be done in future courses or theses at Chalmers by working together with architects or designers. The Landscape Manager informed that input from this thesis have been used in the planning of the remaking of the area around Tågvagnen, mentioned in subchapter 5.2.3 about future stormwater visions.

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APPENDIX A – Stormwater solutions

This appendix presents some examples of stormwater solutions found around Campus Johanneberg mentioned in subchapter 2.2 about stormwater solutions.

Figure A.1 A rain garden at Chalmers University of Technology by HSB Living Lab (Authors' own picture, 2021).

Figure A.2 *Bike garage with a green roof on Betonggården at Chalmers University of Technology (Authors' own picture, 2021).*

Figure A.3 *Reinforced grass at Johanneberg Science Park (Authors' own picture, 2021).*

APPENDIX B – Interview questions

This appendix contains the interview questions from the interviews with Akademiska Hus, Chalmersfastigheter and Rain Gothenburg. The interviews were held in Swedish, and the questions have been translated by the authors.

Interview question for the Strategic Property Developer (Akademiska Hus) and the Strategic Campus Developer (Chalmersfastigheter):

- Can you give a brief presentation of who you are and what you work with?
- What was Akademiska Hus/Chalmersfastigheter role in the development of the campus plan?
- Can you evolve your role in the development of the campus plan?
- We have some specific questions regarding the campus plan:
    - There are some areas marked in the map for water purposes, we wonder if there are any specific thoughts regarding stormwater solutions in those places or if they are only there for esthetic reasons?
- How do you at Akademiska Hus/Chalmersfastigheter view the current stormwater situation at Campus Johanneberg? Do you know of any problem areas?
    - Are there any stormwater solutions implemented at Campus Johanneberg today?
    - Is there any cooperation between the property owners at the campus? Since stormwater might flow between the different properties.
    - Do you have any thoughts of what kind of stormwater solutions that you would like to implement on campus in the future and what is the budget available for this purpose?
- Would you like to see our selected solutions that we have come up with so far?
- Do you want to be anonymous in our report or is it okay that we say that we have been in contact with you from Akademiska Hus/Chalmersfastigheter?

Interview questions only asked to the Strategic Property Developer (Akademiska Hus):

- We have some specific questions regarding the campus plan:
    - The houses on the hillside from Sven Hultins Gata towards Guldheden, will they be built on the hillside or will the road be moved?
    - Why is the area for the park next to Sven Hultins Gata presented in different ways in the campus plan for 2035 and 2050?
- Finishing questions about campus today that we have been thinking about:
    - Is A-dammen a closed pond or does the water infiltrate into the ground?
    - What are they constructing beside A Working Lab at Sven Hultins Gata?

Interview questions only asked to the Strategic Campus Developer (Chalmersfastigheter):

- In the detailed development plan for Gibraltarvallen there is an area south of Johanneberg Science Park included, do you know why?

Interview questions for the Landscape Manager (Akademiska Hus):

- Can you give a brief presentation of who you are and what you work with?
- We can start of by some questions about Campus Johanneberg:
  - Are there any stormwater solutions implemented at Campus Johanneberg today?
    - Do you have any maintenance and budget for that?
  - Do you know of any problem areas?
  - Is there any cooperation between the property owners at the campus? Since stormwater might flow between the different properties.
- Some questions about the potential park next to Sven Hultins Gata:
  - Do you have a time plan for the different stages?
- Would you like to see our selected solutions that we have come up with so far?
  - Is Lennart Rönnmarks Plats an access area for emergency vehicles or is there some other need for this open area?
  - Is A-dammen a closed pond or does the water infiltrate into the ground?
- Do you want to be anonymous in our report or is it okay that we say that we have been in contact with you from Akademiska Hus?

Interview questions for Rain Gothenburg:

- Can you give a brief presentation of who you are and what you work with?
- What are your visions with Rain Gothenburg?
- Would you say that the issue of maintenance and operations is one of your biggest challenges when it comes to getting your solutions realized, or is it something else?
- Is there some specific country or city that you look for inspiration in or where do you find it?
- Do you want to be anonymous in our report or is it okay that we say that we have been in contact with you from Rain Gothenburg?

APPENDIX C – Student survey

The questions from the student survey.
* mandatory questions.
● only one answer possible.
○ multiple answers possible.

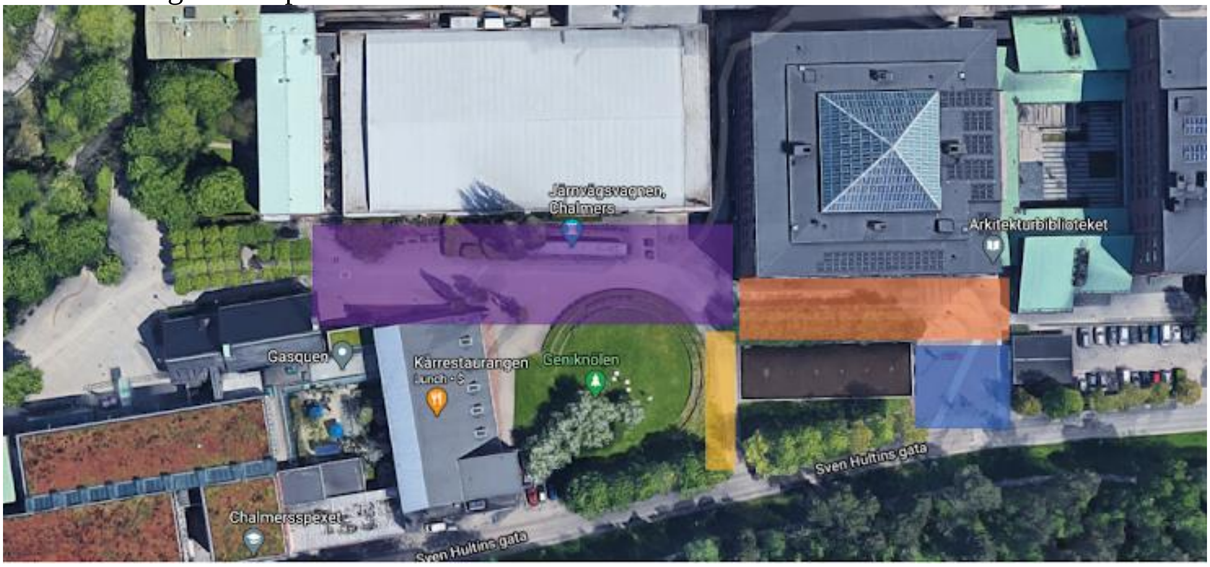
What program do you attend/have attended at Chalmers? *

- Högskoleingenjör inom Samhällsbyggnadsteknik (Bachelor in civil engineering)
- Design and Construction Project Management
- Infrastructure and Environmental Engineering
- Sound and Vibration
- Structural Engineering and Building Technology
- Other:

What year are you in? *

- Year 4
- Year 5
- Already graduated

If you think about your time at Chalmers, where within this area have you had issues with rain when walking on campus?

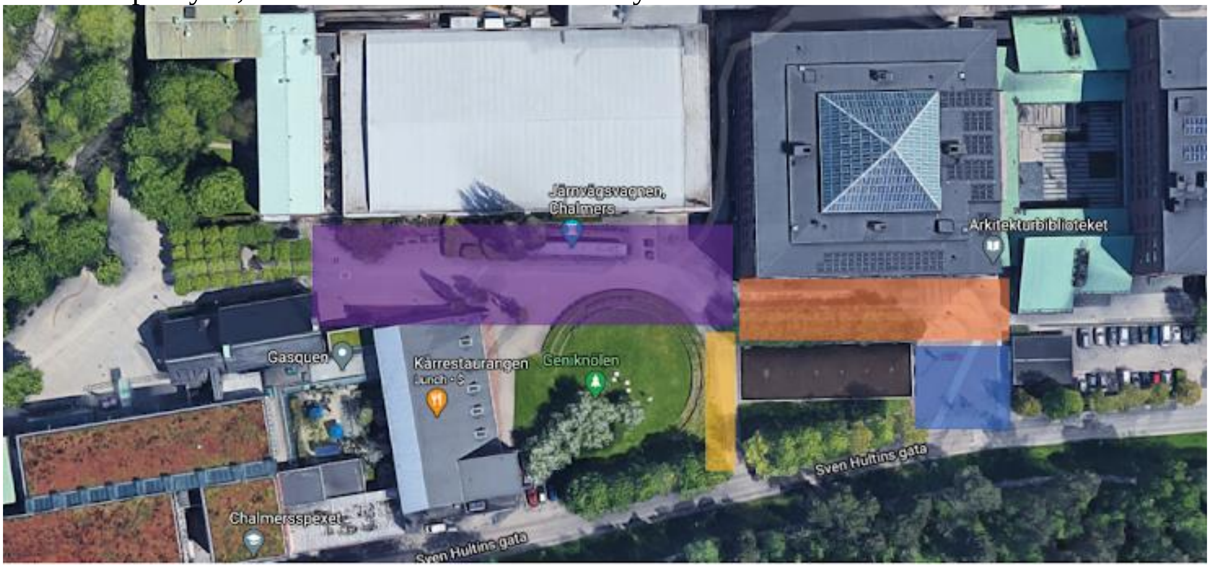


○ Purple
○ Yellow
○ Orange
○ Blue
○ Other:

Do you think it would have added something to your education if there had been some kind of stormwater management at campus that was discussed during lectures?

- Yes
- No
- Other:

If it was up to you, where within this area would you like to see a stormwater measure?



○ Purple
○ Yellow
○ Orange
○ Blue
○ Other:

What kind of stormwater measure would you like to see on campus? Think freely.

Have you seen any stormwater measure in your life that you have found interesting? If so, where and what? For example, multifunctional areas, rain gardens, greenery on buildings, etc.

APPENDIX D – Calculations for the gutter and A-dammen

Calculations for modeling of gutter

The profile of the main gutter can be seen in Figure D.1. The amount of excavated soil for the modeled main gutter is the area between the green and the red line in Figure D.1 with a width of 0.2 meters. This volume is calculated to be 3.2 m^3. If the gutter instead was 0.2 meters deep the entire length of the profile in Figure D.1, with a width of 0.2 meters, the removed soil would have a total volume of 4.1 m^3.

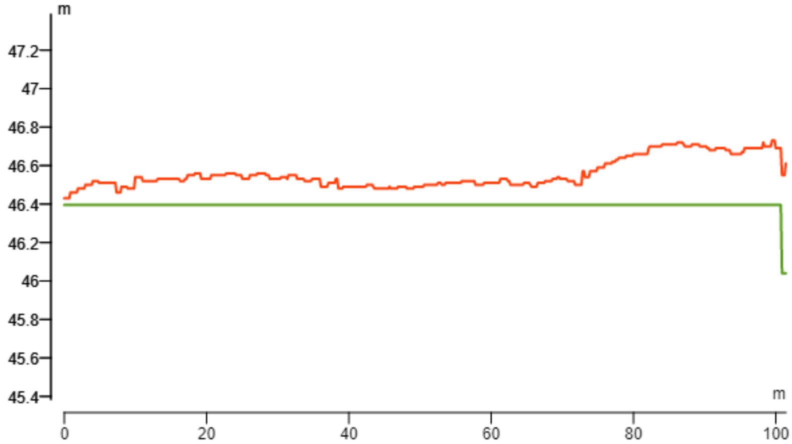


Figure D.1. Profile from SCALGO Live of the main gutter, the red line is the topography of the surface today and the green line is the gutter.

Calculations for modeling of depth of A-dammen

The calculations are made for a scenario when A-dammen is filled with water. The current dimensions of A-dammen are shown in Table D.1.

Table D.1 Dimensions of A-dammen today.

A-dammen today	**[m]**
Width	12.7
Length	40.3
Average depth	0.36
Average water depth	0.23

Potential expansion volume for A-dammen today:

$Expansion\ depth = average\ depth - average\ water\ depth = 0.36 - 0.23 = 0.13\ m$

$Expansion\ volume = V_E = width * length * expansion\ depth = 12.7 * 40.3 * 0.13 = 66.5\ m^3$

This means that A-dammen potentially can store 66.5 m^3 of additional water with the current construction, if filled to the limit.

Dimensions for the proposed renovation of A-dammen are shown in Table D.2 and an illustrative picture can be seen in Figure 5.10.

Table D.2 Values for calculating the new dimensions of A-dammen.

Proposed dimensions A-dammen	**[m]**
Width	12.7
Length	40.3
Height of one step	0.2
Depth of one step	0.2
Level of A-dammen in SCALGO Live	+46.49

Volume of top step, V_1:
$V_1 = width * length * step\ height = 12.7 * 40.3 * 0.2 = 102.4\ m^3$

Volume of middle step, V_2:
$V_2 = (width - step\ depth * 2) * (length - step\ depth * 2) * step\ height = (12.7 - 0.2 * 2) * (40.3 - 0.2 * 2) * 0.2 = 98.2\ m^3$

Volume of bottom step, V_3:
$V_3 = (width - step\ depth * 4) * (length - step\ depth * 4) * step\ height = (12.7 - 0.2 * 4) * (40.3 - 0.2 * 4) * 0.2 = 94.0\ m^3$

Total expansion volume:
$V_T = V_1 + V_2 + V_3 = 102.4 + 98.2 + 94.0 = 294.6\ m^3$

Increase in expansion volume:
$V = V_T - V_E = 294{,}6 - 66.5 = 228.1\ m^3$
This means that the renovated A-dammen can store 228 m^3 of additional water compared to the current construction, if filled to the limit.

The increase of expansion volume is recalculated to a corresponding average depth in order to simplify the modeling in SCALGO Live.
New average depth to model in SCALGO Live:
$D = \frac{V}{width*length} = \frac{228.1}{12.7*40.3} = 0.45\ m$

New level of A-dammen in SCALGO Live:
$\text{New level} = \text{Level of Adammen in SCALGO Live} - \text{D} = 46.49 - 0.45 = 46.04\ m$
This means that the level of the bottom of A-dammen in SCALGO Live will be modeled at +46.04 m to correspond to the new dimensions of the selected solution.

APPENDIX E – Simulation of model B

In this appendix the results from the simulations in SCALGO Live for model B are shown. All three parts of the stormwater management are included in the model: the stormwater collection, stormwater storage and overflow from A-dammen to Sven Hultins Park. In Figure E.1 the simulation of the moderate rain event with 10 mm of precipitation is shown and in Figure E.2 the simulation from a cloudburst with 101 mm is shown. It can be concluded that the stormwater starts flowing from A-dammen through the overflow to Sven Hultins Park when the precipitation exceeds 20 mm. A precipitation event of more than 20 mm has occurred 141 times between 2000-01-01 and 2020-12-31, which on average is seven times per year (SMHI, n.d.).

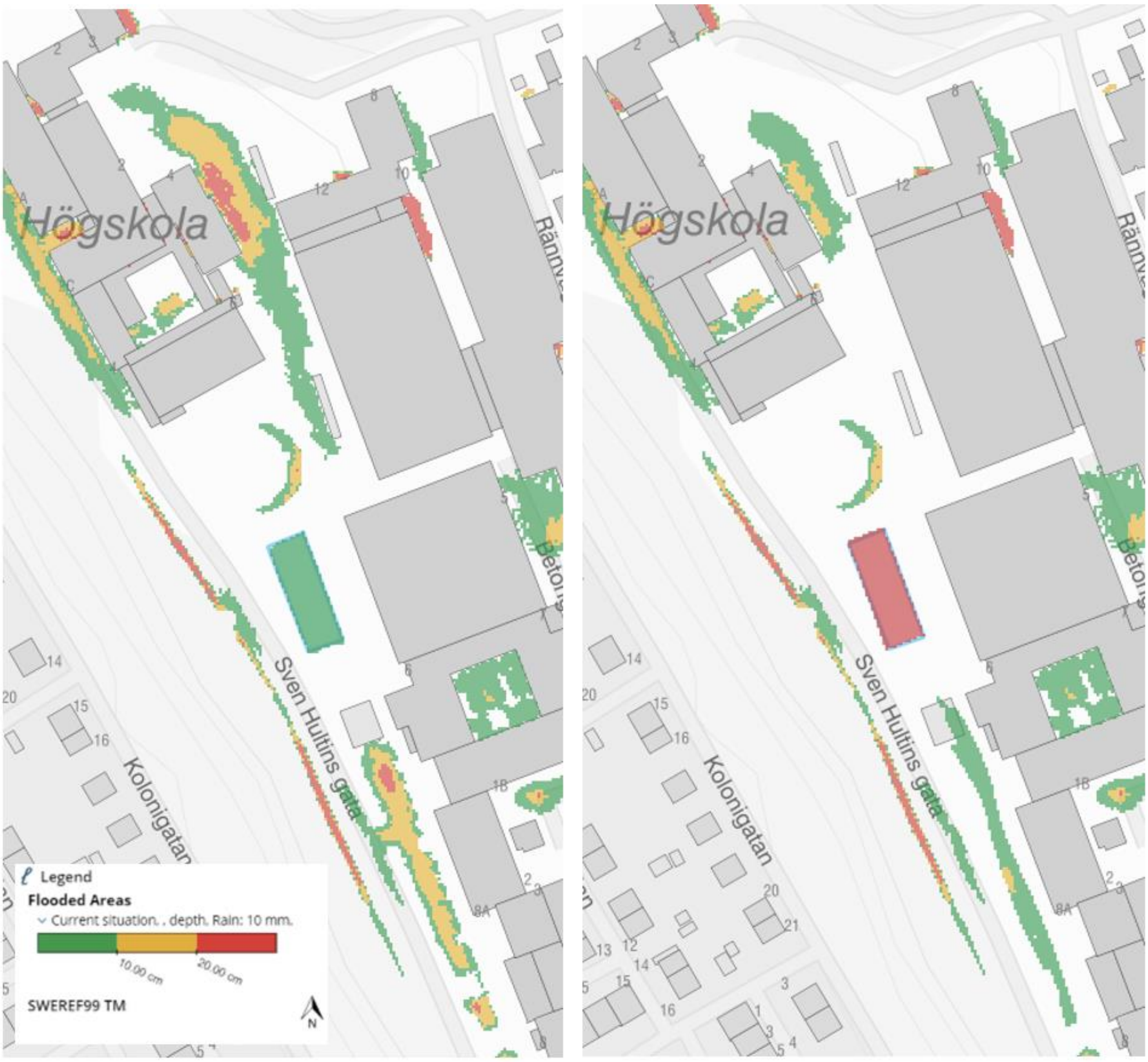


Figure E.1 Left picture: Model B without implemented solutions with 10 mm of precipitation. Right picture: Model B with implemented solutions with 10 mm of precipitation. Both simulations from SCALGO Live.

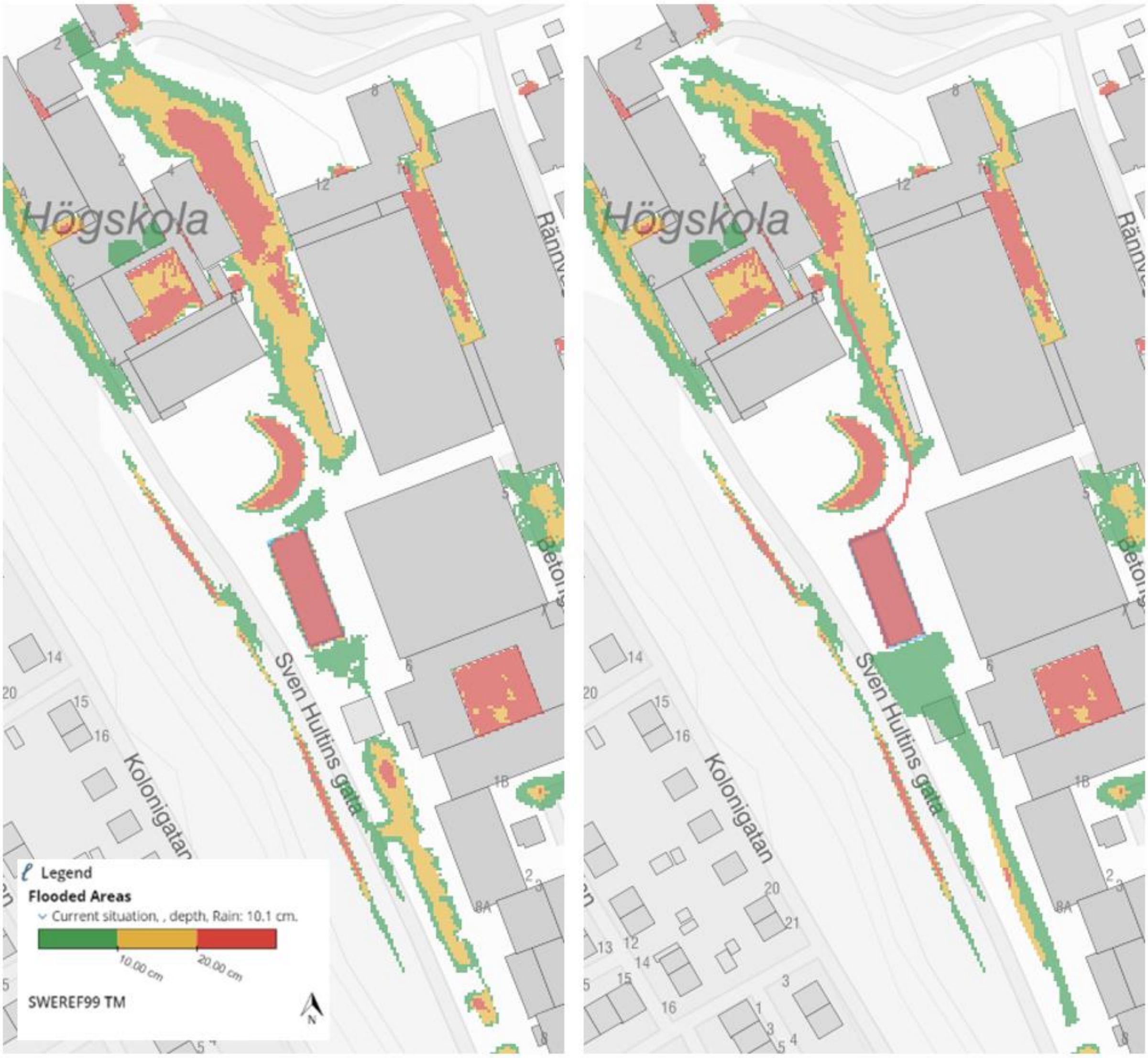


Figure E.2 *Left picture: Model B without implemented solutions during a cloudburst of 101 mm. Right picture: Model B with implemented solutions during a cloudburst of 101 mm. Both simulations from SCALGO Live.*

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