CHALMERS
UNIVERSITY OF TECHNOLOGY

INVESTIGATION AND ASSESSMENT OF PLUVIAL FLOOD MODELLING TOOLS IN URBAN AREAS

A RECOMMENDATION FOR FLOOD MANAGEMENT EXEMPLIFIED BY THE CATCHMENT AREA LINNÉSTADEN IN THE CITY OF GOTHENBURG IN SWEDEN

Master of Science Thesis within the Double Degree Program:

Infrastructure and Environmental Engineering (Chalmers University of Technology)

Water Resource Engineering and Management (University of Stuttgart)

JULIA THERESIA HERRMANN

Department of Architecture and Civil Engineering
Division of Water Environment Technology
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2019
Report No ACEX30-19-14

MASTER THESIS ACEX30-19-14

INVESTIGATION AND ASSESSMENT OF PLUVIAL FLOOD MODELLING TOOLS IN URBAN AREAS

A RECOMMENDATION FOR FLOOD MANAGEMENT EXEMPLIFIED BY THE CATCHMENT AREA LINNÉSTADEN IN THE CITY OF GOTHENBURG, SWEDEN

Master of Science Thesis within the Double Degree Program:

Infrastructure and Environmental Engineering (Chalmers University of Technology)

Water Resources Engineering and Management (University of Stuttgart)

JULIA THERESIA HERRMANN

Department of Architecture and Civil Engineering

Division of Water Environment Technology

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2019

Investigation and assessment of pluvial flood modelling tools in urban areas

A decision-making tool for flood management exemplified by the catchment area Linnéstaden in the City of Gothenburg in Sweden

Master of Science Thesis within the Double Degree Program:

Infrastructure and Environmental Engineering (Chalmers University of Technology)

Water Resources Engineering and Management (University of Stuttgart)

JULIA THERESIA HERRMANN

Supervisor:	PhD Mia Bondelind, Chalmers University of Technology
	PhD Stefan Haun, University of Stuttgart
	M.Sc. Dick Karlsson, Senior Specialist in Climate Adaption, Göteborg Stad
	M.Sc. Marie Larsson, Sweco Environment AB
Examiner:	Prof. Sebastien Rauch, Chalmers University of Technology
	Prof. Dr.-Ing. Silke Wieprecht, University of Stuttgart

Examensarbete ACEX30-19-14

Institutionen för arkitektur och samhällsbyggnadsteknik

Chalmers Tekniska Högskola, 2019

Department of Architecture and Civil Engineering

Division of Water Environment Technology

Chalmers University of Technology

SE-412 96 Gothenburg

Telephone: + 46 (0)31-772 1000

Department of Hydraulic Engineering and Water Resource Management

University of Stuttgart

DE – 70569 Stuttgart

Telephone: + 49 (0)711-685-66616

Report is available in full color at http://studentarbeten.chalmers.se/

Gothenburg, Sweden 2019

INVESTIGATION AND ASSESSMENT OF PLUVIAL FLOOD MODELLING TOOLS IN URBAN AREAS

A DECISION-MAKING TOOL FOR FLOOD MANAGEMENT EXEMPLIFIED BY THE CATCHMENT AREA LINNÉSTADEN IN THE CITY OF GOTHENBURG IN SWEDEN

Master of Science Thesis within the Double Degree Program:

Infrastructure and Environmental Engineering (Chalmers University of Technology; Sweden)

Water Resources Engineering and Management (University of Stuttgart; Germany)

JULIA THERESIA HERRMANN

Department of Architecture and Civil Engineering
Division of Water Environment Technology
Chalmers University of Technology

I. ABSTRACT

In the last decades, pluvial flooding in terms of torrential rain and urban flash floods has increased in Sweden. This caused the need for adaption to such natural hazards of urban areas by increasing their robustness. Flood modelling is a common tool in flood management especially for pluvial flooding. There are several software programs applicable for flood modelling. The main objective of this thesis was the investigation of the three different software programs SCALGO Live, MIKE 21 and MIKE FLOOD with regard to their applicability in flood management. The aim was to ease and refine the long-term decision-making and planning process of pluvial flood modelling. The objectives were demonstrated for the catchment area Linnéstaden in the City Gothenburg in the Western Götaland Region in Sweden. For the study existing models for MIKE 21 and MIKE FLOOD of the City of Gothenburg were used. The software programs were evaluated with regard to their scientific properties in hydraulics and hydrology, general features and the implementation of measures. The development of the measures was based on a risk assessment of the study area Linnéstaden. The legal basis and state of the art with regard to the local conditions in the City of Gothenburg but also Sweden in general, the EU, and for a comparison Germany were considered as well. Additionally, the implementation of the measures within the different software programs was assessed with a regional cost-benefit and multi-criteria analysis tool FloodMan of the City of Gothenburg. The main conclusions of the thesis were that SCALGO is a suitable tool for the early planning and especially the modelling of measures. MIKE 21 showed the least benefits compared to the other software program. MIKE FLOOD is recommended for detailed planning and should be considered as state of the art. The most crucial factor is the surface roughness. The effects on the infiltration were small. A detailed modelling of the sewer system, opposed to a general deduction by an assumed capacity, showed more accurate results; however, it also displayed the highest vulnerability to instabilities and errors.

Key words: pluvial flooding, torrential rain, flood management, flood modelling

INVESTIGATION AND ASSESSMENT OF PLUVIAL FLOOD MODELLING TOOLS IN URBAN AREAS

A DECISION-MAKING TOOL FOR FLOOD MANAGEMENT EXEMPLIFIED BY THE CATCHMENT AREA LINNÉSTADEN IN THE CITY OF GOTHENBURG IN SWEDEN

Examensarbete inom dubbelt utbildningsprogram:

Infrastructure and Environmental Engineering (Chalmers Tekniska Högskola; Sverige)

Water Resources Engineering and Management (Universitetet Stuttgart; Tyskland)

JULIA THERESIA HERRMANN

Institutionen för arkitektur och samhällsbyggnadsteknik
Avdelningen för Vatten Miljö Teknik
Chalmers Tekniska Högskola

II. SAMMANFATTNING

Under de senaste årtiondena har pluvial översvämning i form av skyfall och urbana översvämningar ökat i Sverige. Detta har gett upphov till ett behov av att anpassa sig till sådana naturliga faror i stadsområden genom att öka deras robusthet. Översvämningsmodellering är ett vanligt verktyg vid översvämningshantering, speciellt för pluvial översvämning Det finns flera program som kan användas för översvämningsmodellering. Huvudsyftet med detta exjobb var att undersöka de tre programmen SCALGO Live, MIKE 21 och MIKE FLOOD med avseende på deras användbarhet i pluvial översvämningshantering. Syftet var att underlätta och fördjupa det långsiktiga beslutsfattandet och planeringsprocessen för pluvial översvämningsmodellering. Avrinningsområdet Linnéstaden i Göteborg Stad i Västra Götalandsregionen i Sverige användes som studieområde. I detta examensarbete användes existerande modeller för MIKE 21 och MIKE FLOOD från Göteborgs Stad. Programvarorna utvärderades med avseende på deras vetenskapliga egenskaper inom hydraulik och hydrologi, allmänna funktioner och genomförande av åtgärder. Val av åtgärderna grundades på en riskbedömning av studieområdet Linnéstaden. Den juridisk grunden med hänsyn till de lokala förutsättning i Göteborg Stad, i Sverige i allmänhet, i EU och Tyskland har betraktats. De föreslagna åtgärderna utvärderades med en regional kostnads-nyttoanalys och multi-kriterium-analysverktyg FloodMan utvecklat av Göteborgs stad. De viktigaste slutsatserna i avhandlingen var att SCALGO är ett lämpligt verktyg för tidig planering och speciellt för modellering av åtgärder. För MIKE 21 framkom färre fördelar. MIKE FLOOD rekommenderas för detaljerad planering. Den viktigaste faktorn är ytans beskaffenhet. Effekterna av infiltrationen var mindre. En detaljerad modellering av avloppssystemet mot ett generellt avdrag med en antagen kapacitet visade mer exakta resultat men visade också den högsta sårbarheten för instabilitetet och fel.

Nyckelord: pluvial översvämning, skyfall, översvämningshantering, översvämningsmodellering

UNTERSUCHUNG UND BEWERTUNG VON PROGRAMMEN ZUR MODELLIERUNG VON STARKREGENEREIGNISSEN

EINE ENTSCHEIDUNGSHILFE FÜR DAS HOCHWASSERMANAGEMENT AM BEISPIEL DES EINZUGSGEBIETES LINNÉSTADEN IN DER STADT GÖTEBORG IN SCHWEDEN

Master of Science Thesis im Rahmen des Doppelmasterstudiengangs:

Infrastructure and Environmental Engineering (Technische Hochschule Chalmers; Schweden)

Water Resource and Environmental Engineering (Universität Stuttgart; Deutschland)

JULIA THERESIA HERRMANN

Fachbereich für Architektur und Bauingenieurswesen
Abteilung für Wasser- und Umwelttechnologien
Technische Hochschule Chalmers

III. ZUSAMMENFASSUNG

In den letzten Jahrzehnten nahm pluviales Hochwasser in der Form von Starkregen und urbane Sturzfluten in Schweden zu. Aus diesem Grund wurde eine Anpassung und gestärkte Widerstandsfähigkeit an solche eine Naturgefahr in städtischen Gebieten notwendig. Die Hochwassermodellierung ist ein gebräuchliches Instrument im Hochwasserschutz, wofür es verschiedene Software Programme gibt. Die Zielsetzung dieser Arbeit war die Untersuchung drei verschiedener Software Programme SCALGO, MIKE 21 und MIKE FLOOD in Bezug auf ihrer Anwendung im Hochwasserschutz. Das Bestreben lag darin den langfristigen Planungs- und Entscheidungsprozess für Starkregenereignisse und urbane Sturzfluten zu vereinfachen und zu verbessern. Die Untersuchung der Programme wurde am Gebiet Linnéstaden in der Stadt Göteborg in der Region Westliche Götaland Region in Schweden durchgeführt. Für die Arbeit wurden für die Software Programme MIKE 21 und MIKE FLOOD bestehende Modelle der Stadt Göteborg verwendet. Die Beurteilung der verschiedenen Programme erfolgte im Betracht auf die naturwissenschaftlichen Grundlagen in der Hydrologie und Hydraulik, sowie allgemeine Programmeigenschaften und der Modellierung von Schutzmaßnahmen. Die Hochwasserschutzmaßnahmen wurden basierend auf einer Gefährdungsbeurteilung des Einzugsgebiets Linnéstaden geplant und modelliert. Dafür wurden die planerischen und rechtlichen Grundlagen der Stadt Göteborg, Schweden im Allgemeinen sowie der EU und Deutschlands vergleichsweise untersucht. Zusätzlich wurde die Umsetzung der Maßnahmen anhand eines regionalen Instruments für die Kosten-Nutzen und Multi-Kriterien-Analyse FloodMan bewertet. Die größte Auswirkung auf die Ergebnisse zeigte sich bei Veränderung der Oberflächen-Rauheit. Im Gegensatz dazu waren die Auswirkungen der Simulationen mit und ohne Infiltration geringer als erwartet. SCALGO etablierte sich als angemessenes Programm für die Vorplanung und die Modellierung von Maßnahmen. MIKE 21 zeigte die geringsten Vorzüge in der Anwendung im Vergleich zu SCALGO und MIKE FLOOD. Basierend auf den Ergebnissen der Studie sollte MIKE FLOOD als technischer Stand betrachtet werden. Das Programm wird für eine genaue Entwurfsplanung empfohlen. Die Simulierung mit der Kanalisation zeigte sich als vorteilhaft gegenüber einer Pauschalreduktion der Regenmenge für die Kapazität in MIKE 21, auch wenn höhere Instabilitäten des Programms berücksichtigt werden müssen.

Schlüsselwörter: Pluviales Hochwasser, Starkregen, Hochwassermanagement, Hochwassermodellierung

IV. PREFACE

First of all, I would like to take this opportunity to thank all those who supported and motivated me during the development of this master thesis.

This report concludes my studies in the Master of Science double degree program Infrastructure and Environmental Engineering (Chalmers University of Technology) and Water Resources Engineering and Management (University of Stuttgart).

I would like to thank the staff at the *Department Sustainable Waste and Water* from the *City of Gothenburg* and *Sweco Environment AB* for the assistance and input for my thesis. Thank you for the opportunity to pursue my thesis with you. Moreover, I would like to thank the *City of Gothenburg* for the provision of data for my thesis.

In particular I want to thank the *Department of Sustainable Waste and Water* for the allowance to use existing models for MIKE 21 and MIKE FLOOD, as well as the usage of the FloodMan tool, with its corresponding FME workbench (Safe Software). I would also like to thank *Sweco Environment AB* for the usage of the SCALGO Software.

A special thanks to my supervisors Mia Bondelind, Stefan Haun, Dick Karlsson and Marie Larsson for their excellent support and guidance during this process. Further, I would like to thank Sebastian Rauch and Silke Wieprecht for the examination of my thesis.

I would also like to acknowledge DHI (Hørsholm, Denmark) for the educational time-limited MIKE by DHI Software License. I am grateful for the opportunity to carry out my thesis by using the MIKE Software Programs.

In addition, I would like to thank Västra Götalandsregionen for the provision of data about the Sahlgrenska University Hospital, especially Caisa Sahlqvist. I would also like to thank Lars Rosén for the support with the FloodMan tool.

Furthermore, thank you to Christian Brinkenberg (*Sustainable Waste and Water*) for the assistance with the FME – Safe Software.

I would also like especially Nicholas Schmidt for the utilization permission of recent pictures of torrential rain and flash flood events in Germany.

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

Gothenburg, April 2019

Julia Theresia Herrmann

V. List of Abbreviations

BW	Baden-Württemberg
BWK	Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau e.V.; Engineering Assoziation for Water Management, Waste Management and Land Improvement
CBA	Cost benefit analysis
CDS	Chicago Design Storm (Statistical rain data; Swedish CDS rain in present report)
DEM	Digital Elevation Model
DHI	Dansk Hydraulisk Institut (Danish Hydraulic Institute); Hørsholm, Denmark
DWA	Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V. (German Association for Water, Wastewater and Waste)
DWD	Deutscher Wetterdienst (German meteorological institute)
EU	European Union
FRG	Federal Republic of Germany
GIS	Geographic Information System
LAWA	Bund/Länder-Arbeitsgemeinschaft Wasser (German Working Group of Federal States for Water)
LUBW	Landesanstalt für Umwelt Baden-Württemberg (Federal Institute for Environment)
MCA	Multi criteria analysis
MSB	Myndigheten för samhällsskydd och beredskap (Swedish Civil Contingencies Agency)
SMHI	Sveriges meteorologiska och hydrologiska institute (Swedish meteorological and hydrologic institute
UNISDR	United Nations Office for Disaster Risk Reduction

TABLE OF CONTENT

1. RESEARCH OBJECTIVE

This chapter presents the research objective of the present thesis. It gives a general introduction and defines important terms in this research field. Subsequently, it determines the investigated problem, the aim of the thesis, and depicts the limitations.

1.1. INTRODUCTION

“Floods are the natural hazard with the highest frequency and the widest geographical distribution worldwide.”, as stated by the United Nations Office for Disaster Risk Reduction (2017 a).

The natural hazard of pluvial flooding in form of torrential rain and flash floods in urban areas increased over the last decades in Sweden (Wern, 2012). Therefore, the need for the adaption to more robust cities against this natural hazard increased too. However, one major issue in the field of flood management are competing interests. Measures preventing from flooding require space, which competes with new exploitation areas especially in an urban environment.

According to the United Nations Department of Economic and Social Affairs (2018 a) the world population living in urban environments will increase by 13 % from today till 2050. Furthermore, with the total growth of the world population, the United Nations expect an addition of 2.5 billion people to urban regions (United Nations, 2018 a). This trend of growth of urban population, becoming evident over the last decades, necessitated a change of mindset towards a sustainable development for urban areas to consider their robustness against natural hazards like floods.

Flood modelling is a common and widely used tool for the management of fluvial, pluvial and coastal flooding. Due to the lack of historical data for extreme weather events, like torrential rain and flash floods flood modelling offers the opportunity to simulate such extreme events in a very advanced manner. With pluvial flood modelling one has the opportunity to simulate flood propagations for extreme rain events. The mapping of flooding with the help of flood modelling can support processes like risk assessment, communication between the different stakeholders and illustrate the need for adaption despite competing interest (e.g. with exploitation areas).

1.2. Statement of the Problem

This thesis is carried out in cooperation with the municipality the *City of Gothenburg*, more accurately the *Department of Sustainable Waste and Water* and the consultancy company *Sweco AB*, precisely the department *Sweco Environment AB*. The contact persons are Dick Karlsson at the *Department of Sustainable Waste and Water* and Marie Larsson at *Sweco Environment AB*.

The state of the art of software programs deployed in the municipality *City of Gothenburg* are the software programs MIKE Powered by DHI (Hørsholm, Denmark), precisely MIKE 21 and MIKE FLOOD, and SCALGO Live.

In the recent years there has been an increased interest in the adaption to climate change. Therefore, the *City of Gothenburg* has carried out several project for the adaption to a robust city to climate change (Göteborg Stad, 2017a). The relevant studies from the municipality are: *Översiktsplan* (*Developing master pla*n), *Skyfallsmodellering* (*Cloudburst modelling*) and *Strukturplan* (*Structure Plan*). Whereby the last two studies are part of the *Översiktsplan* (Göteborg Stad, 2017a). The respective software programs, which have been used for the projects, are MIKE 21 for the *Cloudburst modelling* (Göteborg Stad, 2015a) and MIKE FLOOD for the *Structure Plan* (Göteborg Stad, 2017b).

One of the most significant current discussions in flood management is which software program can be applied to what extent and in which stage of the planning process. Previous studies have not dealt with a comparative investigation of the various software programs. Far too little attention has been paid to the attributes of the software programs and their effects on the results of the simulation.

This indicates a need to fully understand the scope of how the different software programs can be applied. A deeper understanding and classification to specific applications could support the planning process. Critical analysis with regard to the sustainability and adaption to climate change is needed.

1.3. Aim and objectives

The aim of this thesis is to ease and refine the long-term decision-making and planning process of pluvial flood modelling. The purpose is to determine which type of modelling is necessary to evaluate pluvial flood characteristics and features that are crucial in flood management.

The objectives are:

- Investigate three different software programs for pluvial flood modelling. These software programs are SCALGO, MIKE 21 and MIKE FLOOD. The software programs are representative for different (risk) analyses applied for flooding. SCALGO is representative for a topographical analysis, MIKE 21 for a 2D hydrodynamic numerical surface analysis and MIKE FLOOD for a coupled 2D hydrodynamic numerical surface and 1D hydrodynamic sewer system analysis.
- Compare the scientific features of the programs in terms of hydraulics and hydrology.
- Evaluate the accuracy and corresponding applicability of the programs, e.g. in the planning and design process for the implementation of preventative measures.

The above-mentioned objectives are demonstrated for the catchment area Linnéstaden, located in the central part of Gothenburg in the Western Götaland Region in Sweden. The investigation of the programs with regard to the measures is done for areas of potentially significant flood risk, which are defined by a risk assessment for the catchment area. In addition, the state of the art and legal basis was investigated for Sweden. For a broader perspective also, the EU and Germany were also considered and compared with Sweden. Furthermore, this thesis aims to conclude with a recommendation for the explicit application of the software programs for corresponding planning steps.

1.4. Limitations

The explicit focus of the present report is on pluvial flooding. Therefore, the effects of fluvial and coastal flooding are neglected. In further studies an integrated approach considering the interaction between all three types of flooding is recommended. This applies especially for the catchment area Linnéstaden as a final recipient of the area is the river Göta Älv, which itself is affected by a rising sea level. However, for this study negative or positive effects of such interactions are considered without affecting the results of pluvial flooding. Meaning that pluvial flooding should be solved to the extent of the explicit hazard and not cause additional flooding in other flood sectors.

The legal basis of this study is limited to the current legal situation for the Kingdom of Sweden and the Federal Republic of Germany (FRG), as well as the respective laws by the European Union (EU). Furthermore, the focus for the Kingdom of Sweden (Sweden) is on the county Västra Götaland and mainly on the municipality the *City of Gothenburg*. Equivalent, the focus for the FRG is on the federal state Baden-Württemberg (BW).

Planning of the flood prevention measures is restricted to the early stages in the planning process, as the aim is not to perform a full planning process of flood prevention measures, which can actually be implemented. Instead the target is the comparison of the software programs, with the implementation of measures only being one aspect of the comparison. Meaning the different application and implementation within the software programs of flood prevention measures are the focus. As a result, no accurate design and calculation process is carried out. For a deeper understanding a more accurate investigation of the impact of different kinds of measures could be carried out within a larger timeframe.

At the present state, the study is limited to the available historical data, meaning previous studies and statistical rain distributions, for torrential rains and floods in the catchment area. This data does not provide the basis for a calibration of the models. In addition, this report is limited to the current version of the investigated software programs as well as to the results of previous studies, based on older software versions. In this thesis the stormwater quality and the effects of flooding or different preventative measures on the water quality of groundwater or the surface water bodies were neglected.

1.5. Terminology

In the present report the subsequent terms highlighted with italic letters are defined as follows:

Precipitation (Deutscher Wetterdienst, 2018a)

The term precipitation refers to liquid precipitation in form of rainfall. This also applies to terms like precipitation height or intensity, thus meaning rainfall height or intensity.

Flash Flood (Deutscher Wetterdienst, 2018a)

A flash flood is a flood event caused by torrential rain.

Torrential Rain (Deutscher Wetterdienst, 2018a)

Torrential rain is defined as an extreme rainfall event. For direct Swedish translation the term cloudburst is used instead of torrential rain. The definition in terms of the hydrology and the amount of rain defined as torrential rain is shown in Chapter 2.1.3. The flood event caused by a torrential rain is defined a flash flood.

Validation:

With respect to a general scholastic meaning validation can be defined as a process of verification of expected results for a defined purview. For hydrological modelling validation can be is used to verify the models by simulations or a scientific analysis (Biondi, et al., 2011). In the scope of the present report the term validation means the verification with regard to previous results from simulations with the original model for MIKE 21 and MIKE FLOOD. It does not refer to a validation by a calibration or historical data for the rainfall events.

Simulation:

Simulation refers to the simulations done by the investigated software programs with MIKE Powered by DHI (Hørsholm, Denmark). For SCALGO the term simulation is equally applied for the usage of the tool "hydrological analysis" (SCALGO ApS, 2018c).

1.6. GUIDANCE NOTES

The work of the project of the present report was solely done by the author unless otherwise mentioned and sourced. Thus, investigated scenarios and simulations were innovatively done. This also applies to figures and tables in this report. For the software programs MIKE 21 and MIKE FLOOD the existing original models were provided by the *City of Gothenburg*. In SCALGO the "model" (workspace) was created by the author. The programs for the analysis used in the thesis FME and FloodMan were developed on behalf of the *City of Gothenburg* and are still in the experimental phase, whilst being applied in this thesis. Concluding, they were not developed by the author but newly applied to the investigated catchment in the manner of this thesis. This thesis is based on the FloodMan version from 18.06.2018.

The reference for all background maps for Gothenburg and Linnéstaden is OpenStreetMap® (2018), provided by the "© OpenStreetMap contributors", unless otherwise mentioned.

In this thesis "MIKE Powered by DHI" for the MIKE software products is defined by the term "MIKE" or "MIKE by DHI". The software products used in thesis are version MIKE 2017 release 2. The same accounts for the manuals referred to. The author has the permission by DHI (Hørsholm, Denmark) to refer and write about the manuals of DHI in this thesis (Blomgren, 2018).

In the present report the term Gothenburg is used for the city itself and the term the *City of Gothenburg* is used for the municipality Gothenburg in Swedish Göteborg Stad.

The proper translation for the relevant studies of the *City of Gothenburg* used in this thesis are "*Developing master plan*" for the Översiktsplan, "*Cloudburst modelling*" for Skyfallsmodellering and "*Structure Plan"* for Strukturplan (Karlsson, 2018).

2. LITERATURE STUDIES

This section of the present report is concerned with the relevant literature for the present thesis, which is presented in the following manner. At first the general aspects of pluvial flooding and torrential rain are presented. In a second step the state of the art in flood modeling with regard to pluvial flooding is specified. Followed by the presentation of the software programs applied in this thesis. In the subsequent chapter the catchment area Linnéstaden and essential previous studies are summarized. Afterwards the legal aspects concerning pluvial flooding are presented. The last part of the literature studies reviews types of flood measures with regard to the legal aspects.

2.1. HYDROLOGICAL AND METEOROLOGICAL BACKGROUND

This chapter presents the hydrological and meteorological aspects and main definitions.

2.1.1. GENERAL ASPECTS

In the field of flooding one differs between three usual types of flooding: fluvial, coastal and pluvial flooding. Fluvial flooding is generally caused when the water level in a river exceeds and leads to flooding. This can be due to heavy precipitation or precipitation over a long duration. Coastal flooding is caused by an increased water level of the sea, which can be triggered by extreme weather leading to extreme tides or hurricanes inducing storm surges. Pluvial flooding is generated by extreme rainfall, also known as torrential rain, leading to flooding so-called flash floods [(Maddox, 2014); (DWA, 2016a, p. 15)].

Pluvial flooding is different from coastal and fluvial flooding in a number of notable ways. As the name suggests, coastal and fluvial flooding are commonly localized nearby the coast and the sea and rivers, due to the overflowing water bodies. In contrast, pluvial flooding is not bounded to territories nearby water bodies. Pluvial flooding is also known as surface flooding and acts on the surface. However, pluvial flooding and the flooding on the surface can lead to additional fluvial flooding (LUBW, 2016a).

In meteorology, torrential rain is known as convective precipitation (SMHI, 2014a). Convective rain depends on the water vapor in the atmosphere, thus on the temperature. The likelihood of convective rain increases with a larger temperature difference between the ground and the atmosphere and the higher the water vapor in the atmosphere. If the vertical buoyancy forces are high enough warm and humid air rises and the respective condensation occurs. This leads to the formation of storm clouds. Once the water weight encounters the buoyancy forces the storm clouds collapse leading to a sudden and very intense rainfall. In the same manner, convective rains occur very suddenly once the storm clouds are “drained” [(Koch, 2003); (Starkregen, Sturzflut, Sintflut – sieht so der Sommer der Zukunft aus?, 2016)].

Due to the small size of the exposed areas of convective rain, forecasting is very complex and still inaccurate. Besides convective rain could possibly emerge all around the world, meaning that torrential rain can technically occur everywhere as well (LUBW, 2016a).

Other typical features of torrential rain apart from the short notice, is the high intensities, which is often accompanied by high flow velocities of flash flood. Furthermore, the behavior of the flooding can be unpredictable due to clogging of flow paths and the sewer system or tailbacks or increased peaks of flood discharges (Bronstert, et al., 2017).

Figure 2-1 illustrates the difference of normal and extreme precipitation (torrential rain) on the runoff behavior.

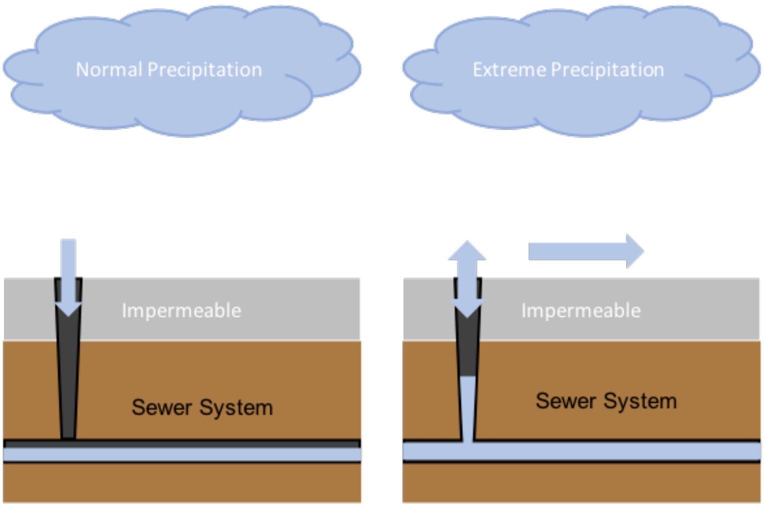


Figure 2-1: Illustration of effect on the sewer system of extreme precipitation and normal precipitation (created by the author)

As shown in Figure 2-1, the sewer system is designed for "normal rain events", but in case of extreme precipitation the capacity of the sewer system is often overloaded and backflow can occur leading to more surface runoff (LUBW, 2016a). The explicit dimensioning of the sewer system depends on the legal basis, see Chapter 2.5.

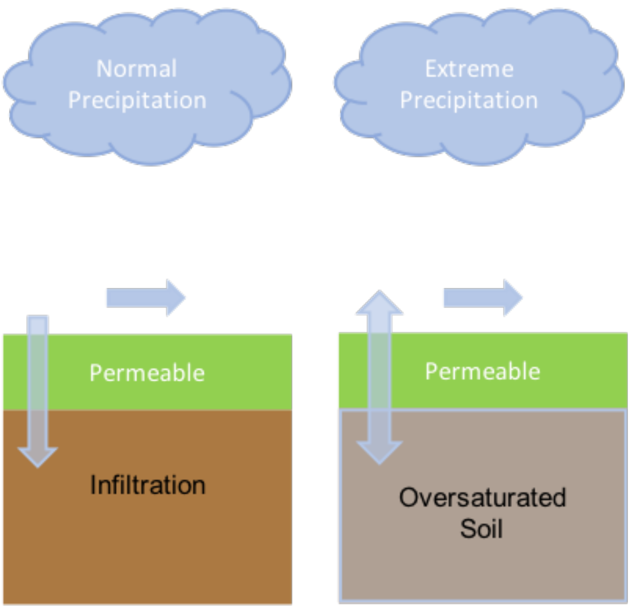


Figure 2-2: Illustration of effect on the infiltration of extreme precipitation and normal precipitation (created by author)

Figure 2-2 shows the effect on the infiltration. For normal precipitation soil can infiltrate a certain amount of water. For extreme precipitation the soil's capacity is reached very fast and the oversaturated soil cannot take in more water. More runoff is generated and the soil is more vulnerable to erosion (MSB, 2017a).

2.1.2. Dimensions of precipitation

In the field of pluvial flooding a crucial term is the precipitation, which can be described with various dimensions. The common dimensions for precipitation, thus torrential rain, used in the present report are listed in the following. They are defined with respect to the weather condition encyclopedia of the DWD (2018a).

1. Precipitation height

The precipitation height defines the height of precipitation measured in a horizontal manner from the ground level. This is assumed that the water does not evaporate, infiltrate, or runs off. The precipitation height is commonly measured in mm and is equal to l/m^2.

2. Precipitation intensity

The precipitation intensity describes the precipitation height over the duration of the event. The common unit is mm per hour, or any other time interval.

In this thesis the terms precipitation intensity and height are equally applied to the term rainfall height and rainfall intensity.

2.1.3. Torrential Rain and Flash Flood - definition

The definitions for torrential rain in terms of the precipitation height and rain intensity vary strongly and also depend on local conditions. Subsequently, definitions from meteorological and hydrological institutes in Sweden and Germany are presented.

2.1.3.1. Sveriges meteorologiska och hydrologiska institut (Swedish meteorological and hydrological institute)

The *Sveriges meteorologiska och hydrologiska institut* (SMHI), in English "Swedish meteorological and hydrological institute", classifies torrential rain into extreme punctual precipitation and extreme areal precipitation (2012). For extreme punctual precipitation, torrential rain is defined as a precipitation height of at least 50 mm within one hour of rainfall duration or 1 mm precipitation height in 1-minute rainfall duration. For extreme areal precipitation torrential rain is defined for at least 90 mm over the area of 1000 km during 24 hours. The investigated catchment area Linnéstaden has a size of approximately 6 km^2. Concluding solely the definition for extreme punctual precipitation is relevant for torrential rain in the scope of this thesis.

2.1.3.2. Deutscher Wetterdienst (German meteorological service)

The *Deutscher Wetterdienst* (DWD), in English "*German meteorological service"*, classifies heavy rain according to three different warning criteria for weather conditions. The classification after DWD (2018b) is shown in Table 2-1.

Table 2-1: Heavy rainfall classification according to DWD (2018b)

Warning Criteria	Description	Amount of rain per rain duration
Stage 2	Distinctive weather	15 - 25 l/m^2 (mm) in 1 h 20 to 35 l/ m^2 (mm) in 6 h
Stage 3	Thunderstorm	> 25 l/ m^2 (mm) in 1 h > 35 l/ m^2 (mm) in 6 h
Stage 4	Severe thunderstorm	> 40 l/ m^2 (mm) in 1 h > 60 l/ m^2 (mm) in 6 h

As shown in Table 2-1, torrential rain is solely classified to the warning criteria for Stage 2, Stage 3 and Stage 4. The DWD does not classify every weather element to four stages. For example, heavy rain is not assigned to "*Stage 1 - Weather warning"* (Deutscher Wetterdienst, 2018b). In the following, the definition for heavy rainfall according to "*Stage 4 - Severe Thunderstorm"* is used for torrential rain, when referring to the DWD.

2.1.3.3. Comparison

When comparing the classifications of both meteorological institutes the definition of torrential rain by SMHI is equal to the warning criteria Stage 4 of the DWD. However, the definition by the DWD is subordinating to the one by the SMHI. Throughout this thesis the term "flash flood" will be used to refer to flooding caused by torrential rain, as classified by SMHI and DWD.

2.1.4. Flooding

Pluvial flooding is caused by torrential rain and is also known as surface flooding. The runoff generated by precipitation is generally known as stormwater runoff. There a multiple definitions of stormwater runoff especially with regard to the discharged amount of water into the sewerage. The definitions strongly depend on the legal aspects, and will be explained further on in Chapter 2.5.

Runoff generation is one part of the hydrological cycle (Deutscher Wetterdienst, 2018c). According to P110 by the association *Svenskt Vatten* (Swedish Water and Wastewater Association) relevant hydrological concepts are precipitation, condensation (evaporation and transpiration), runoff, interception, capillary flow, groundwater recharge and percolation (Svenskt Vatten, 2016a). Pluvial floods are not solely influenced by the precipitation. Other crucial factors influencing flash floods depend on the catchment area. According to publication DWA T1/2013 by the "*Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V.*" relevant features are (DWA/ BWK, 2013, pp. 10-11):

- Technical drainage system
- Natural drainage system
- Topography
- General features of the catchment area

The technical drainage system refers to the sewer system. Meaning the dimensioning in terms of capacity, design of manholes, outlets and inlets (DWA/ BWK, 2013). The capacity of the drainage system determines if an overload occurs leading to tailback and surface flooding (DWA, 2016b, p. 17). The dimensioning of the technical drainage system is important as flash floods can carry flotsam and lead to clogging of the system (LUBW, 2016a, pp. 7-8).

Natural drainage system implies the natural water bodies in the catchment, like rivers or small streams (DWA/ BWK, 2013, pp. 10-11). In the case of a flash flood occurrence the flow accumulation also depends on inoperative water bodies or water bodies redirected into culverts. The flow paths tend to revert to those original water beds and flow directions (DWA, 2016b, p. 18).

Due to the topography, floods show different behaviors. Important features are the size of the catchment, the shape of the catchment and the slope (DWA/ BWK, 2013). The slope determines the velocity and the flow path of the runoff. In hillside areas, the runoff typically leads to erosion and carries flotsams with it.

The flotsam can lead to clogging and build a flow obstacle causing the redirection of flow paths and lead to additional accumulation in water bodies. In plain areas, flooding can typically lead to a tailback in the drainage system and water bodies, like rivers or streams. It is also likely that flooding in the plain leads to the overload of land drainage and causes large areas or flood propagation (Braasch, et al., 2013, p. 14). Furthermore, properties like land use, soil and vegetation of the catchment affect the infiltration behavior and the runoff generation (DWA/ BWK, 2013). The flood inundation also strongly depends on the structural conditions e.g. of the surface, especially for buildings and traffic areas (DWA, 2016b, p. 17).

Characteristics of floods determine their consequences. Relevant factors are the water depth, the velocity and the flow behavior, the water quality and the duration of the flooding. Those parameters should be considered when assessing floods (DWA, 2016a, p. 16).

2.1.5. Impact of Climate Change

Various studies have assessed the impact of climate change on extreme precipitation. According to Olson and Foster (2013) the intensity of future short-term precipitation will increase by 25 % for rain durations under 1 hour until 2100. One reasoning for the increase of extreme precipitation is the intensification of convective rain for higher temperatures, especially for the range of 12 to 20°C (SMHI, 2014b). This is based on the physical relation, that warmer air can uptake more water vapor than colder air (Becker, et al., 2016). This is based on the Clausius-Clapeyron relation with an increase of 7 % of water vapor per 1°C (Bronstert, et al., 2017, p. 159). Concluding one could assume an increase of extreme precipitation as temperature increases. However, the generation of precipitation is very complex and also depended on several other features, like the global distribution of large-scale weather patterns. Therefore, one must assume a regional difference of the increase in precipitation or even the decrease of precipitation in some areas (Becker, et al., 2016).

In the first global quantitative analysis by Colombia Engineering of the University of Colombia (USA), researchers could prove an increase of stormwater runoff caused by an increased intensity in precipitation and due to anthropogenic impacts. The study gives evidence that the impact of climate change is already affecting the runoff extremes. However, the study also demonstrated the influence of anthropogenic impacts on the increase of runoff extremes, meaning that not only climate change affects the increase of storm runoff (Yin, et al., 2018).

2.2. Flood Modelling

In this chapter the current state of art and research projects of flood modelling with regard to 1D, 2D and coupled models for pluvial flooding are presented.

Over the past decade, flood modelling has been further developed and the uncertainties of flood modelling could be decreased. Especially the field urban flood modelling increased significantly. Flood modeling can be done by a variety of models mathematical, conceptual, empirical or theoretical. Hydrodynamic modelling showed a growing application in the field, as it provides the features to disrobe the complexity of flood events. For example, the results can provide the data for the water depth and velocity over the whole duration of a flood event and over the whole catchment area (Paquier, et al., 2015).

A study published in the Journal of Hydrology by Mark et al. (2004) investigated the application of 1D modelling for urban flooding for pipe systems and surface flows. The flood propagation was visualized with GIS. The flooding investigated was caused by local rainfall. In 2004 a dynamically coupled model of a 1D sewer system and a 2D surface model was still in development (Mark, et al., 2004). Nevertheless, the study's results are still applicable today as 1D modelling is still a common procedure. The researchers investigated the modelling of the drainage network with two networks one for the free surface flow on the streets and one for the pipe network, with two models one for the hydraulics and one for the hydrology (Mark, et al., 2004). The results showed that the simulation with separate models for the hydraulics and hydrology may not be applicable for stormwater runoff as the runoff interacts depending on the sewer system capacity. A possibility to improve the modelling with two separated models was the description of the linkage of the models with a weir formula. As linkage, coupling and flow behavior are very complex the formula alone was also considered to be insufficient to model to full complexity. Nevertheless, the study still encourages the use of 1D modelling for urban flooding, at least for internal flooding due to heavy rainfall and especially for modelling on a large scale. A final recommendation implies a 2D hydrodynamic model for surface flow and 1D model for the sewerage (Mark, et al., 2004).

Paquier et al. (2015) investigated two sources of uncertainties in 2D hydro-meteorological modelling. One of them with regard to the flow process in complex environments and one with regard to model simplifications. The study stresses the complexity of flow paths in urban environments, which are originally limited by natural topographical features but strongly altered by urbanization. Those alterations should be covered in GIS data. However, the study implied the heterogeneity of GIS data and the need for manual meshing. The authors also highlight the intricacy of flow exchange of surface and subsurface flow, e.g. through vertical exchange structures, and the flow exchange of surface flow itself. Due to this variation they emphasize the distribution of hydraulic parameters over a flood event with regard to time and space. The results of the study showed that obstacle, especially in intersections can lead to a change in flow distribution of 10 to 15 %, implying a high level of uncertainty. Nevertheless, the results still showed a high accuracy of the 2D modelling. (Paquier, et al., 2015).

With regard to the uncertainties of the interaction of the sewer system, the study showed that the application of a two-layer flow with a 2D shallow water equation model for the surface flow and a 1D shallow water equation model for the sewerage and a calculation of the exchange rate with the Bernoulli equation and empirical formulas led to accurate results with less than 5 % error rates. For simpler methodologies the effects of head loss showed inaccuracies of up to 50 %. The study concludes that need for high accuracy models for flood mapping, which is commonly fulfilled by 2D shallow water equations, requiring sufficient input data. By slight adaptions of the modelling methods, more accurate results could be obtained under experimental conditions. The authors recommend the integration of local uncertainties in the models (Paquier, et al., 2015).

Moving on from 2D modelling, now consider coupled modelling of 2D and 1D models by a study from Löwe et al. (2017) with the modeling software MIKE FLOOD and the additional extension of an urban development model DAnCE4Water. The authors chose a 1D-2D hydrodynamic model to model all the effects of adaption measures on the drainage network and the surface flow. The additional development model offers the possibility to test flood adaption measures in the infrastructural or planning sector. The researchers adapted the hydrodynamic model by modification of the stormwater pipe network, rainfall portions of runoff and modifications of the surface flow paths. Uncertainties stressed by the study were assumptions of the future changes of the climate and city structures. The study stressed the uncertainties of hydrodynamic modelling: coupling, simplifications of both model descriptions. The results showed the suitability of the hydrodynamic model with regard to the simulation time and the sensitivity of the simulated flood damage caused by variation of urban developments (Löwe, et al., 2017).

2.3. Scientific background of software programs

This chapter illustrates the scientific background of the software programs investigated in the scope of the present report, which are: SCALGO, MIKE 21 and MIKE FLOOD. As previously mentioned those programs are considered the state of the art for the *City of Gothenburg* and *Sweco Environment AB*.

2.3.1. Scientific Background SCALGO

The software program SCALGO, which stands for "Scalable Algorithmics", is a mapping tool with high resolution terrain data. It can be applied for different matters of surface water (SCALGO ApS, 2018a). In the scope of this thesis the tool SCALGO live was used. In the following, the term SCALGO will be used to refer to the tool SCALGO live.

The terrain data in SCALGO can be analyzed with different types of so-called "hydrological analysis". The selectable analyses are "sea-level rise", "flow accumulation and watersheds" and "flash flood map" (SCALGO ApS, 2018b). In the present report the applied analysis is "flash flood map".

The analysis with the "flash flood map" is recommended for the application of extreme rain events. The "flash flood map" illustrates which area in the terrain is flooded after a certain event. The event, which serves as input data for the tool, is given with the amount of precipitation in mm (SCALGO ApS, 2018c). The precipitation in SCALGO will be considered as the precipitation height.

More accurately the water flow in the flash flood map is generated with the so-called D8 Algorithm. This algorithm defines the flow direction of the water (Walderveen, 2018).

The D8 Algorithm is a common raster to determine the flow direction (Philipps Unversität Marburg - Fachbereich Geographie, 2011). It assumes that the water flows into the direction of the steepest slope in an area of 9 raster cell points. For this the slope is calculated for each of the 8 surrounding cells of one central cell. One raster point is defined as one pixel (Philipps Unversität Marburg - Fachbereich Geographie, 2011). Each pixel is assigned to an integer number, which defines the possible direction of flow. A cell is coded to the associated integer number of the flow direction depending on the calculated slope (Esri, 2018).

The mapping in the flash flood map is based on a raster of cells corresponding to the terrain raster, where each cell is assigned to a threshold in mm defining when the terrain cell will be flooded. The analysis also considers dynamic flash flood events, referring to flooding of downstream depressions in case upstream depressions filled up and contribute water to downstream cells (SCALGO ApS, 2018c).

The water flow in SCALGO is illustrated in Figure 2-3, Figure 2-4 and Figure 2-5, created by the author. Figure 2-3 shows the initial situation for precipitation being loaded on the terrain model. The grey area represents the digital elevation model (DEM). The red arrows show the direction of the stormwater runoff from the highest to the lowest point in elevation. The blue arrows symbolize the rain load in terms of the precipitation height.

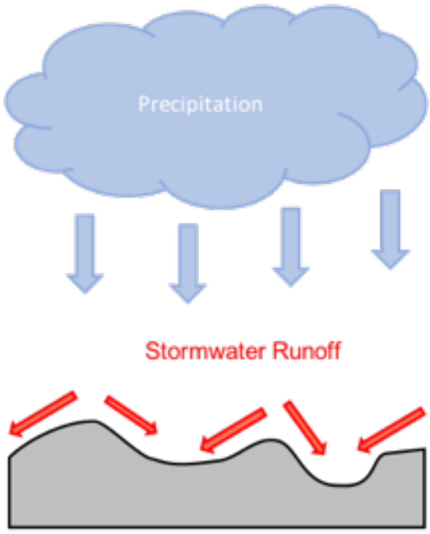


Figure 2-3: Illustration of stormwater runoff in flash flood map in SCALGO (created by author)

In Figure 2-4, three different images are used to illustrate the stages of the dynamic flash flood in SCALGO. The first stage on the left side shows steady water levels in the two depressions. Where the depression on the left is located in a slight upstream area and the depression on the right in a downstream area. The picture in the middle shows an increased water level in the left and upstream depression. The red arrow indicated a flow from the upstream depression to the downstream depression. The picture on the right side shows the new final steady state with adapted water levels in both depressions. Like in Figure 2-3 the blue arrows indicate the rain load.

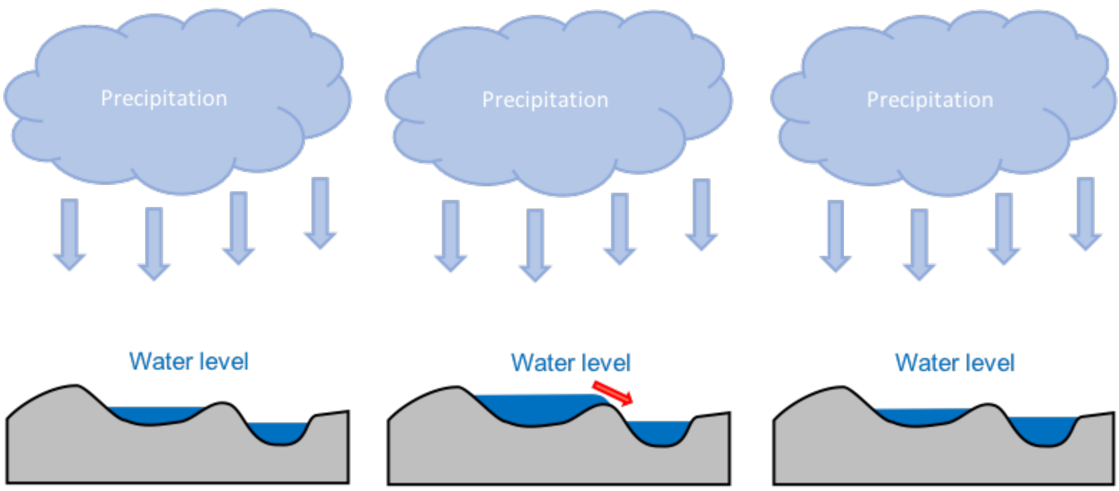


Figure 2-4: Illustration of dynamic flash flood events and its effects on the water level in depressions in flash flood map in SCALGO (created by author)

In the hydrological analysis, several tools can be used to investigate the flooding by the flash flood map. The tools are the point query tool in depressions and flow paths and the watershed tool. The point query tool for flooded areas shows the threshold of for flooding of the selected cell, the water depth and the volume in the depression. In flow accumulations the point query tool shows the size of the upstream area, the depression storage and the runoff volume at the selected point. The watershed tool illustrates the contributing upstream area of the selected point and marks this area in green. The data given by the watershed tool is the same as when using the point query tool in flow accumulations (SCALGO ApS, 2018c).

As previously mentioned, in SCALGO the input data for the flooding exclusively depends on the precipitation given in mm. In the SCALGO interface one can adjust the flooding shown by the water depth. However, the water depth only defines the minimum water depth presented in the map. With the flow accumulation calculated by the D8 Algorithm SCALGO considers no spatial or temporal difference in the distribution of the precipitation over the terrain model. Meaning the precipitation height is initially applied to the catchment with the exact same value for each point in the raster of the DEM. Consequentially the final water level is presented in a static and steady state, calculated with the D8 Algorithm. Thus, there is no statistical distribution of the rain for the catchment.

The ground surface of the elevation in SCALGO is classified as impermeable surface, as the software program has no possibility to consider infiltration. This behavior is shown with the simplified illustration Figure 2-5. The red arrow illustrates the stormwater runoff and the blue arrows the rain load. The grey area stands for the DEM. Due to the impermeable surface and the previously described runoff behavior modelled and simulated in SCALGO infiltration cannot be considered and the same accounts for other effects of the hydrological cycle, e.g. evaporation or other impacts like wind can be contemplated with the program SCALGO.

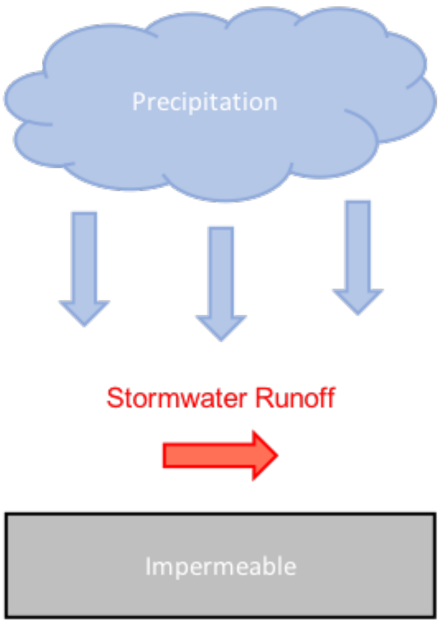


Figure 2-5: Runoff illustration and soil behavior in SCALGO (created by author)

In SCALGO the user has the option to use different elevation models. The DEM generally used for Sweden has a 2x2 m grid resolution and is based on the Lantmäteriet's GSD Höjddata grid 2+ (National Elevation model in Sweden). The DEM considers structures in two categories buildings and bridges and underpasses. Bridges and underpasses are recommended to a further assessment as they might have been removed in the original model by Lantmäteriet. For buildings grid cells were raised to "a height of 10 m above the highest terrain point within the building footprint". Building footprints are based on the data from GSD Fastighetskartan (SCALGO ApS, 2018d).

In SCALGO workspaces can be edited with different tools. One can either change the elevation or add structures (SCALGO ApS, 2018e). For changes to the elevation several tools are available with which one can for example lower or raise a path or area. A path can be changed by interpolating or changing the height by a chosen value, for which it will be adjusted by a linear interpolation between the first and last point of the selected path. There are two tools available to add structures, which are the tools "Subsurface Structure" and "Subsurface basin and sewage drains". With the "Subsurface Structure" tool one has the possibility to create a path or area to simulate an arbitrary measure. The tool is recommended by SCALGO (2018e) to be used for pipes or culverts. The structure has an unlimited capacity to transport water and cannot store any volume. By using the tool no changes to the elevation are made and the tool is considered to be subsurface (SCALGO ApS, 2018e). The tool "subsurface basin and sewage drains" allows the definition of a storage volume for the basin. This can be done by choosing a volume manually or the so-called "query tool", which will select the volume at the sink point for the given rain event (SCALGO ApS, 2018e).

2.3.2. SCIENTIFIC BACKGROUND MIKE ZERO

MIKE Powered by DHI (Hørsholm, Denmark) is a software program, consisting of several software products, which can be applied for the modelling of water environments (DHI, 2018a). In this section the software products MIKE 21 and MIKE FLOOD are described.

MIKE 21 is a 2D tool designed for coastal modelling, but is also typically applied to inland flooding (DHI, 2018b). The software product offers a choice of simulation engines, where the focus of the present report on the rectangular grid. Different modules can be used to create a customized modelling framework. In this thesis the module used is the Hydrodynamics (HD) module (DHI, 2018b).

The product MIKE FLOOD can be used to couple 1D and 2D flood simulation engines. It was designed for urban, coastal and riverine flooding, with a typical application e.g. for flood management (DHI, 2018c). In the present report the following simulation engines are considered. For the 1D simulation engine 1D Urban with the software product MIKE URBAN and for the 2D Overland flow the software product MIKE 21 with the HD module and a rectangular grid are described in this thesis (DHI, 2018c).

For copyright reasons the scientific background only covers the features of the MIKE Powered by DHI (Hørsholm, Denmark) software products applied in this thesis, with regard to features relevant later on. For a deeper insight the author refers to the scientific documentation of the MIKE by DHI software products, published by DHI (Hørsholm, Denmark).

The next sections describe the scientific background for parameters crucial for the thesis with regard to the models generated by the study *Cloudburst modelling* and the study *Strukturplan*, which are used in the present report.

2.3.2.1. MIKE 21

The MIKE 21 Flow model can be applied for the simulation of hydraulics and is a "2D free-surface flow modelling system" (DHI, 2017a). The hydrodynamic module (HD) for MIKE 21 can simulated water levels and flows (DHI, 2017a).

The MIKE 21 interface is divided into the so-called basic parameter overview and the dialog overview. In the basic parameter one specifies the parameters for the module selection, bathymetry, simulation period, boundary, source and sink, mass budget and flood and dry (DHI, 2017a).

For the models used in this thesis with the consent of the *City of Gothenburg* the module selected was just the HD module without any further additions. When modelling in urban areas on land, one needs to apply the specification for inland flooding, necessary when using the tool in an urban area. For the bathymetry the dynamics can be considered with a cold start or hot start, where a cold start defines that the initial velocity is zero. With the simulation period the user defines the time frame of the simulation in specifies time steps. The parameter boundary requires the selection of all open boundaries necessary for the computation, which can be done by using the bathymetry for a selection by the program. The source and sink tool can be used to add different types of inlets or outlets, however is not recommended to be applied on land. In the mass budget different polygon sections can be defined. The flood and dry parameter define the water depth for which a point is considered in the computation or not (DHI, 2017a).

In the dialog overview the initial surface elevation is specified, when using a cold start for the bathymetry in the basic parameters. This provides the information of the initial surface level or initial surface water level. In the source and sink of the dialog overview data for the precipitation is added. As MIKE 21 was originally designed for coastal areas, indata for precipitation needs to be defined to precipitation on dry land to considered dry cells for the computation as well. The infiltration can be described in two approaches. Either by describing the net infiltration or a constant infiltration with capacity. For a constant infiltration with capacity the infiltration rate, porosity of the infiltration zone, depth of the infiltration zone and leakage rate as well as the initial water content need to be given. The resistance of the ground must be defined by the Manning number, Chezy number or wave included resistance. In MIKE 21 the dialog overview additionally supports parameters like wind conditions, wave radiation and the eddy viscosity (DHI, 2017a).

A description of the selected parameters in this thesis is provided in the methodology section of the present report, see Chapter 3.3.1.2.

2.3.2.2. MIKE FLOOD

MIKE FLOOD is a software program that allows the coupling of a 2D hydraulic surface runoff model with a 1D model. The 1D Model can either be MIKE URBAN, MIKE HYDRO RIVER or MIKE 11 (DHI, 2017b). The 2D model is based on the software MIKE 21, therefore the same scientific background applies as previously described in Chapter 2.3.2.1.

This thesis uses the MIKE URBAN module for the 1D model, thus the scientific background is limited to the urban coupling, MIKE URBAN and MIKE 21.

With the urban link the interaction between the sewer system and the overland flow with the respective water level in manholes is described. For the urban links one can choose M21 to inlet, M21 to outlet, Weir to M21 or Pump to M21. Inlets can be depicted with orifice or weir equations, exponential functions and curb inlet functions. When coupling the models, the inlet level of a structure in MIKE URBAN must be equal to the ground level of MIKE 21. In the Urban linkage one also defines the maximum flow, the size of the inlet area and a discharge coefficient (DHI, 2017b).

For this thesis solely, the collection system is considered from the variety of MIKE URBAN modules. The MIKE URBAN Collection system and the CS-Pipeflow include the computation engine DHI's MOUSE. The basis for the dynamic flow in the hydrodynamic simulation is the St. Venant equations for the drainage network. The computational scheme used is an implicit, finite-difference numerical solution of the flow equation (DHI, 2017b).

A description of the selected parameters in this thesis is provided in the methodology section of the present report, see Chapter 3.3.1.3.

2.3.3. Comparison of Software Programs

This section gives a brief overview of the software programs investigated in this thesis to illustrate the variation of their distinctive properties. The overview is given by Table 2-2.

Table 2-2: Comparison of software programs investigated in present report

Properties	SCALGO	MIKE 21	MIKE FLOOD
Type of model	Mathematical model	2D hydrodynamic model	2D + 1D hydrodynamic model
Terrain model	Original 2x2 m raster; variable	4x4 m raster (as applied in present report); variable	
Input data	Precipitation	Complex range of input data	
Hydraulic features	Excluded	Setup of hydraulic parameters	
Hydrological features	Excluded	Setup of hydrological parameters	
Specification of surface properties	Excluded	Setup of surface with hydraulic and basic parameters	
Time and spatial distribution	Excluded	Specification for overall model and single features of the model set-up	
Possibility to model measures	Changes to DEM and structures	Changes to DEM and structures	Changes to DEM and structures surface and subsurface
Output features	Flood propagation, water depth, flow accumulation	Flood propagation, water depth, flow accumulation, fluxes, parameters over time et. al.	Flood propagation, water depth, flow accumulation, fluxes, parameters over time, interaction between urban linkage et. al.

In addition to the properties listed in Table 2-2, Figure 2-6 illustrates the runoff generation in a simplified manner for all three software programs. They are labelled as follows: (a) SCALGO, (b) MIKE 21, (c) MIKE FLOOD. The red arrows illustrate the runoff generation. The clouds illustrate the precipitation. The same illustration of the precipitation does not imply the exact same input data. Between the three software programs, the input data for the precipitation varies in the distribution (spatial and temporal) and the quantity of the rain load. Impermeable surfaces are colored in grey and permeable surfaces are colored in green. Figure 2-6 provides the main characteristics of stormwater runoff and stresses the increasing complexity from SCALGO to MIKE 21 and MIKE FLOOD. Further details information about the similarities and differences are given in the explicit model set-up for the investigated catchment, see Chapter 3.3.1.

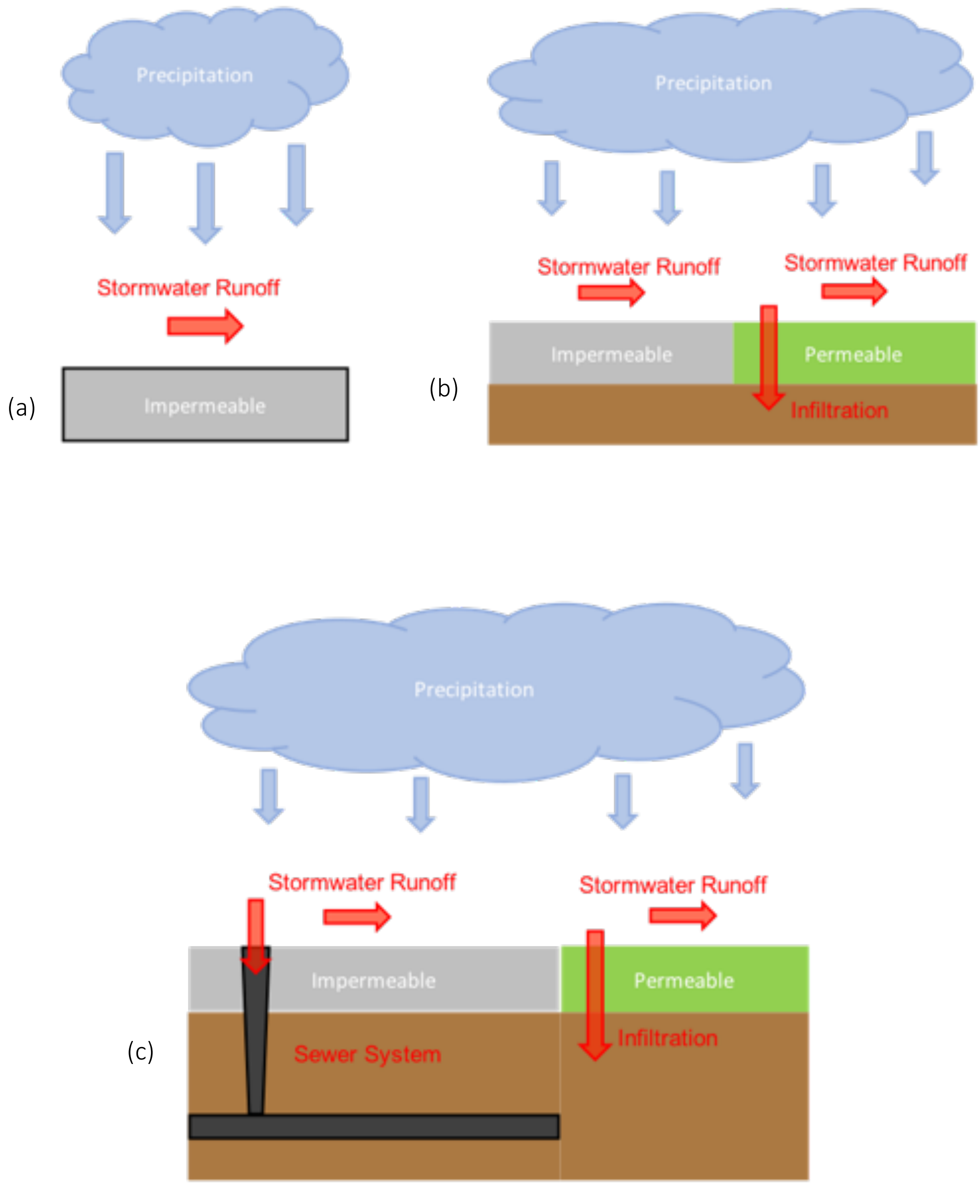


Figure 2-6: Illustration of stormwater runoff distribution in investigated software programs with SCALGO labelled with (a), MIKE 21 as (b) and MIKE FLOOD (c). (created by author)

2.4. Catchment area – Linnéstaden

The catchment area investigated in the present report is the district Linnéstaden. The district belongs to the city Gothenburg. It is located in the city's central area and is commonly referred to as Linné (Göteborg & Co, 2018a). Figure 2-7 shows the district Linnéstaden marked with the black doted area.

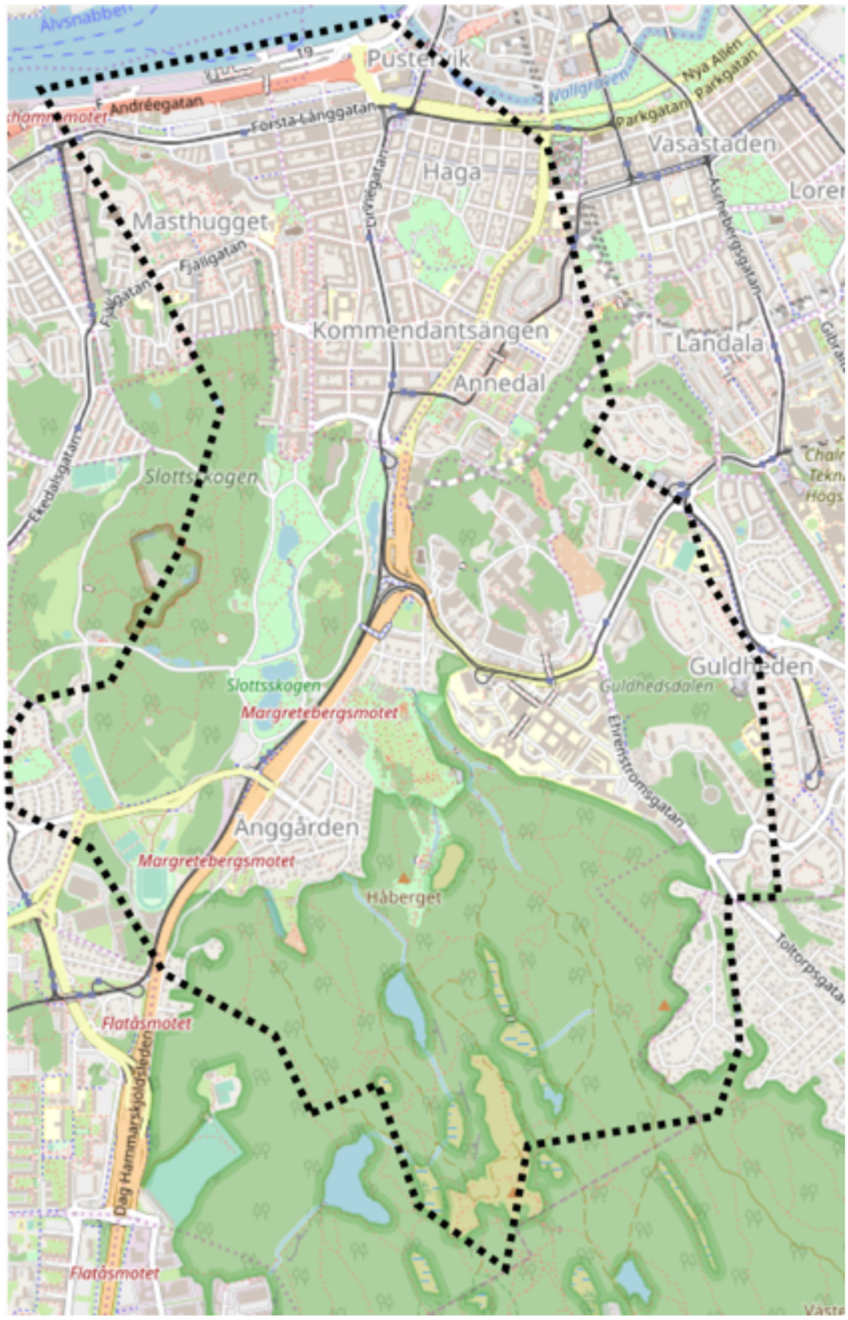


Figure 2-7: Catchment Linnéstaden located in the City of Gothenburg. The black dotted line represents the catchment area. (created by author)

Gothenburg belongs to the municipality *City of Gothenburg*, which belongs to the county Västra Götaland (Västra Götalands Län, 2018). It is located in the western part of Sweden and is Sweden's second largest city. The population of the City is around 533,000 inhabitants (Göteborg Stad, 2018a).

In 2017, the population in Sweden had exceeded 10 million and the population in the region of the *City of Gothenburg* had risen to over one million (Göteborg Stad, 2018b). For the *City of Gothenburg*, the demographic forecast predicts an average annual increase of population of 7,400 till 2035 (Göteborg Stad, 2018c). Based on these statistics a population concentration is expected for the *City of Gothenburg* and its districts. Concluding, pluvial flood management in Gothenburg and consequently Linnéstaden needs to consider the effects of urban densification in the city Gothenburg.

Before proceeding to describe the properties of the study area itself, it is important to consider the current situation in terms of flooding and climate change for the area.

According to a study by SMHI about the behavior of extreme precipitation in Sweden over the timeframe of 1900 to 2011, an increase of extreme precipitation over the last decades was determined with the extreme precipitation in 2011 being larger than in the 1930's. One of the severely affected areas is Västra Götaland, in which the city Gothenburg is located. The study also verified the occurrence of the most significant precipitation during the summer months of July and August. Moreover, it showed a correlation between the average temperatures and extreme precipitation in Sweden. However, the study does not imply forecasts for the future behavior of extreme precipitation (Wern, 2012). Nevertheless, the study by SMHI shows the urgent need for further developments in pluvial flood management in the *City of Gothenburg*.

Based on the likelihood of increased occurrence of pluvial flooding for Gothenburg, the municipality and city have developed adaption strategies to climate change. Those strategies also consider the competing field of urban densification. The recent studies of the *City of Gothenburg* are described in the following Chapter 2.4.1.

As indicated above the district Linnéstaden is located in the center of Gothenburg. Linnéstaden itself is divided into the local subdistricts Masthugget, Änggården, Haga, Annedal and Olivedal (Göteborg Stad, 2017c). The subdistricts Annedal and Masthugget are mostly pure residential areas. Haga and Olivedal are residential areas with small business and large traffic hubs. In the northern part of Masthugget, the harbor area, large businesses of the maritime industry are located. In addition to maritime industry the Stena Line ferry terminal is also located in this subdistrict with a high passenger volume, especially during the summer period. The subdistrict Änggården mostly consist of large green areas with the park Slottsskogen, the Botanical Garden (Botaniska Trädgården) and the nature area Änggårdsbergen. In the eastern part of the subdistrict Änggården one of the major commercial areas in Gothenburg is located around Medicinareberget including one of the most important health care institutions in the Gothenburg area, Sahlgrenska University Hospital (Kärna, et al., 2008).

Based on the original urban development Linnéstaden can be divided into four areas. One of them is the traditional settlements towards the river Göta Älv, located in the north of Linnéstaden, consisting of Haga, partially Olivedal and Masthugget. Those settlements present a diversity of architecture. Linnégatan, as one of the main streets, was originally built over the canalized Djupdalsbäcken. Järntorget is a central area and a main public transport intersection. Annedal and parts of Olivedal are rebuild areas with more modern architecture. The districts have clear boundaries forced by the topography, e.g. for Annedal which is adjacent to the mountainous area of the district Guldheden (Kärna, et al., 2008).

In Linnéstaden several cultural sites are located including educational facilities or religious sites spread throughout the district. Most of the sites are located in the northern part of Linnéstaden, however some sites like the Natural History Museum, located in the North of Slottsskogen at Linnéplatsen, are located further south.

The park Slottsskogen is a large park area established in the 1870s. Its distinctive features are large flat green areas with some smaller ponds, mountainous areas with a sharp descent and forestry areas. In the south of Slottskogen the sport stadium Slottskogsvallen is located, which is used for events during the summer, e.g. Göteborgsvarvet and Way out West (Kärna, et al., 2008).

The Botanical Garden, opened in 1923, is one of Gothenburg's main attractions in the region. The size of the garden is around 175 hectares. It consists of various landscaped gardens and undeveloped nature areas, belonging to Änggårdsbergen (Gothenburg Botanical Garden, 2018). Änggårdsbergen is a popular area for outdoor activities. The total area consists 320 hectares and stretches from the Botanical garden to the southern part of the City of Mölndal. Distinctive properties of the nature are typical for Western Sweden. The topography includes valleys and ridges and smaller lakes [(Göteborg & Co, 2018b); (Gothenburg Botanical Garden, 2017)].

The main businesses in the area are the maritime industry, with Gothenburg harbor being Scandinavia's largest harbor and the medical institutions belonging to Sahlgrenska University Hospital. Besides those larger commercial areas there are many small business areas in Linnéstaden. Most of the small commercial areas are located in the northern parts of Haga, around Järntorget and in Olivedal around Linnégatan (Kärna, et al., 2008).

A more detailed account on the land use in Linnéstaden is given in the following. The northern areas of the catchment are mostly residential and paved areas. In the south the green areas Botanical Garden and Slottsskogen mostly consist of flat large green areas with partially paved roads and some nature areas with unpaved roads and steep slopes. The nature area Änggården consist of pristine landscape with mountainous areas and some water bodies. The road Dag Hammerskjödsleden draws through the area with a heavy traffic volume. In the north the harbor area is also a traffic hub. Another intersection in the E45 and Andrégatan and the Götatunnel. Public transport is spread throughout the catchment with main intersection at Linnéplatsen, Järntorget and Medicinareberget (Kärna, et al., 2008).

There are no major water courses in the catchment. Some surface water bodies are located in the nature and park areas. Smaller streams turn into culverts once entering residential areas, e.g. under Linnégatan. The only streams are the river Göta Älv in the North, which is a recipient and the Roselundskanalen (Göteborg Stad, 2017d).

The sewer system in Linnéstaden is partially a combined or separated sewer system due to the different periods of construction. The combined sewer systems are mostly located in the traditional parts of Linnéstaden, e.g. Masthugget and Haga. The water is treated at Ryaverket. Because of the variation of construction periods, thus dimensioning requirements, the capacity of the sewerage varies throughout the district (Göteborg Stad, 2017d).

2.4.1. Previous studies

In the scope of flood management in the municipality the *City of Gothenburg* three crucial studies have been done in the recent past and are partially still in the process. Those are the project: Översiktsplan (*Developing master plan*), Skyfallsmodellering (*Cloudburst modelling*) and Strukturplan (*Structure Plan*). Whereby the last two projects are part of the Översiktsplan, the adaption of the site plans.

2.4.1.1. Översiktsplan – Developing master plan

The so called Översiktsplan with the official English name "*Developing master plan*" was carried out by the *City of Gothenburg*, precisely the *City Planning department* (in Swedish: Stadsbygnaddskontoret), in 2017. The aim of the project was the adaption of the municipalities approach in urban planning for floor plans to climate change, especially with regard to flood risks. The project itself was carried out by a working group from the *City Planning department* and the *Department for Sustainable Water and Waste* in cooperation with *the Environmental Administration* (in Swedish: Mijöförvaltningen), Gryaab, *Real Estate Department* (in Swedish: Fastighetskontoret), *Park and Nature Administration* (in Swedish: Park och naturförvaltningen) and *Traffic Administration* (in Swedish: Trafikkontoret) (Göteborg Stad, 2017a).

The purpose was to include recommendations and adaption strategies for the floor plan. Mapped risk areas for flooding caused by raising sea level, overflowing water streams and increasing torrential rain and flash floods were aimed to be considered in the planning. The project developed several adaption strategies for coastal, fluvial and pluvial flooding including site-specific planning levels. Because of the high uncertainties related to climate change the city decided to review new findings e.g. for pluvial flooding on a continuous basis. An additional subject to flooding covered in the *Developing master plan* was the densification of the city and its effects on flooding and runoff (Göteborg Stad, 2017a).

The *Developing master plan* aims to document the planning process in a two-step approach. In the first step a so-called *Structure Plan* and in a second step the action plan are implemented. The *Structure Plan*'s purpose is the assessment of how water can be handled within the city and with respect to natural flow paths of water. The action plan is based on the results of the *Structure Plan* and aims to implement multifunctional measures within the city. For this approach two pilot project areas were chosen. The areas are Linnéstaden and Kvillebäcken (Göteborg Stad, 2017a).

Another significant aspect of the *Developing master plan* is the request for further adaption of the legislation and organization. This matter was described to occur on all levels of planning between the different stakeholders in order to define the responsibilities (Göteborg Stad, 2017a).

However, the *Developing master plan* was designed to fulfill the political requirements with regard to the floor plan. For the decision-making process the *Developing master plan* is depending on the municipal council and building board (Göteborg Stad, 2017e). The aim of the *City of Gothenburg* is the implementation of a holistic approach of flood management. When planning measures for one type of flooding they should not influence the efficiency of measures for the other types of flooding (Göteborg Stad, 2017e). The safety against flooding should be increased by adapted planning, e.g. with regard to the floor level and by technical protection measures. The focus is set to long term improvement and to increase the safety for important facilities and escape routes. The basis for the development of new floor plans are flood simulation results from the so-called "hydromodell". The *Developing master plan* was considered as an amendment to existing building laws (Göteborg Stad, 2017a).

So far, this chapter has focused on the general aspects of the *Developing master plan*. In the consecutive part, the focus is on aspects of the *Developing master plan* affecting pluvial flooding. Meaning that only the risk "torrential rain and flash flood" (Swedish: Skyfall) will be considered.

Returning to the aim of Gothenburg becoming a robust city against flooding. The explicit objectives included the definition of dimensional climate scenarios and design events, the determination of planning levels and implementation of measures. (Göteborg Stad, 2017a).

With regard to determine a dimensional climate scenario the city aimed to show medium term and long-term flooding with 50- and 100-year return periods. For pluvial flooding the design event was set to a 100-year return period over a time horizon of 100 years. The simulations were defined by 100-year rain event with an additional rain of 20 % for the year 2100 (Göteborg Stad, 2017a). The margin levels for dimensioning for pluvial flooding are presented in Table 2-3.

Table 2-3: Dimensioning levels for pluvial flooding according to Översiktsplan [table 2] (Göteborg Stad, 2017a, p. 19)

Damage object	Dimensioning level
Important public facilities – new developments and existing	0.5 m margin to necessary parts for building function
Buildings and facilities – new developments	0.2 m margin to lower level of bottom flooding and parts necessary for building function
Accessible priority and escape routes	Max. 0.2 m water level

The dimensioning levels according to Table 2-3 are illustrated in Figure 2-8.

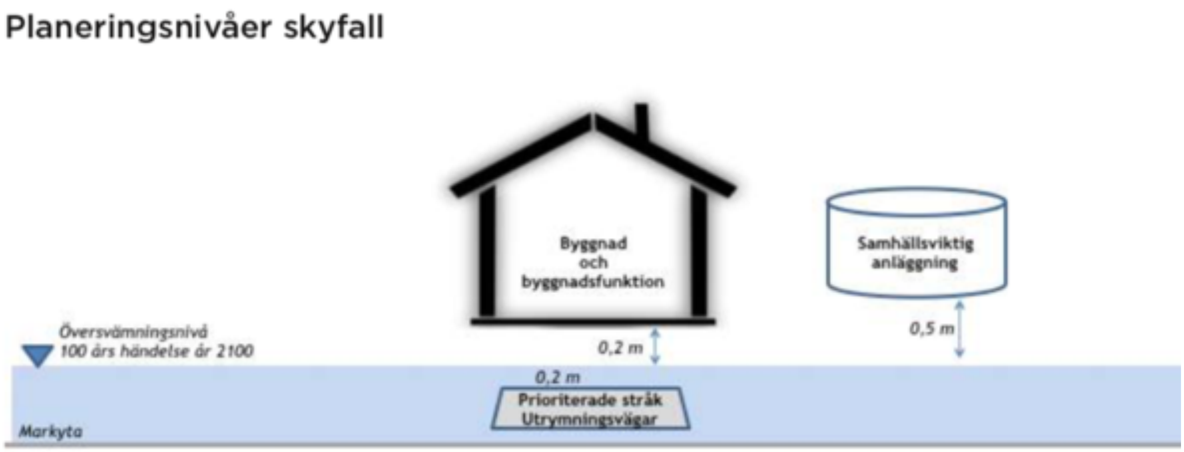


Figure 2-8: Dimensioning level for pluvial flooding for the City of Gothenburg; (Source: Översiktsplan (Göteborg Stad, 2017a, p. 20) [Figure 2)

Additionally, to the dimensioning levels for pluvial flooding priority roads and escape roads are defined in a general manner. Priority and escape routes, which should be accessible, are set to the dimensioning depth of 0.2 m. The accessible roads for emergency services should be set to 0.1 m. As the range between 0.1 m and 0.2 m was presumed to be difficult to be practically established the requirements mere simplified to 0.2 m (Göteborg Stad, 2017a).

In the planning process of the floor plan, which includes a detailed plan, the following steps were recommended by the *Developing master plan*. In a first step all flood risks are mapped. Second, the need for short-term, medium-term and long-term adaptions is evaluated. In a final step the adapted plans are verified for the achievement of the expected consequences (Göteborg Stad, 2017a).

Moreover, the capacity of the stormwater sewerage was considered. The design event was presumed to be a 10-year rain event. An investigation of the soil e.g. with regard to infiltration was be recommended too (Göteborg Stad, 2017a).

For pluvial flooding the *Developing master plan* defines an extreme rain events as a rain event, which exceeds the sewerage capacity and the runoff diversion in the main. The definition assumed that the sewerage and infiltration capacity are exploited for such an event, but also that the sewerage can exceed its capacity leading to flooding without torrential rain. The design event was stated to the range of 10 to 30-year return periods with the consideration of a climate factor. Still, the actual capacity for the most parts of sewerages was identified as a 10-year return period, even though the European Standard for impermeable surfaces is 30-years. The legal planning basis referred to in the *Developing master plan* for the design of the sewer system was the publication P 110 by *Svenskt Vatten*. Regarding the climate factor for dimensioning, a factor of 1.25 was proposed for short and heavy precipitation (Göteborg Stad, 2017e).

Returning to the "hydromodell" as basis for the simulations. For pluvial flooding the "hydromodell" simulated the return periods for 100-year and 500-year event. The respective climate factor applied by the *City of Gothenburg* is 1.2, recommended by SMHI. For the sewerage capacity a 10-year return period was presumed (Göteborg Stad, 2017e).

The implementation for measures for flash floods and torrential rain were based on the aforementioned planning process, including the *Structure Plan* and the action plan (Göteborg Stad, 2017e). The starting point for an adaption strategy for pluvial flooding was set to be able to manage a 100-year flood event (Göteborg Stad, 2017a). The *Structure Plan* for the two pilot projects provides recommendations for the location and types of measures in the catchments, which then are further investigated and possibly implemented in the next step the action plan (Göteborg Stad, 2017e).

As previously stated, one of the pilot areas for the planning approach of the *Developing master plan* is Linnéstaden. At the current state, a *Structure Plan* for Linnéstaden has been developed. The explicit document is explained in Chapter 2.4.1.3.2.

For further details about coastal and fluvial flooding discussed in the *Developing master plan* (Göteborg Stad, 2017a) and recommendations about the environmental consequences and the water quality the author refers to the *Developing master plan* and its appendix. As the water quality is not a matter of concern of the present report the recent developments and recommendations from the *City of Gothenburg* in this field are not included in this section. However, a general positive effect on the water quality was assumed by the *Developing master plan* by pluvial flooding measures (Göteborg Stad, 2017a).

2.4.1.2. SKYFALLSMODELLERING – CLOUDBURST MODELLING

This project in Swedish called "Skyfallsmodellering för Göteborg", which translates to torrential rain modelling, was carried out in the year 2015. In this present thesis, that report is referred to as *Cloudburst modelling*. It was developed on behalf of the departments "Kretslopp och Vatten" (*Department of Sustainable Water and Waste*) and "Stadsbygnaddskontoret" (*City Planning department*) of the *City of Gothenburg* and carried out by *Sweco Environment AB* and DHI (Hørsholm, Denmark).

The model area was set to cover the so called "mellanstaden", which included the urban areas of the City Gothenburg. The model area was divided into three models Hisingen, Northeast and West, see Figure 2-9 (Göteborg Stad, 2015a). Linnéstaden is part of the Western model.

Figure 2-9: Model areas of Cloudburst modelling; (Source: Cloudburst modelling Appendix (Göteborg Stad, 2015a) [Figure 2.1]

However, the *Cloudburst modelling* report does not cover the whole area of Linnéstaden to the same extent as investigated in this thesis. Some areas in southern Linnéstaden, e.g. part of Änggården are missing. The relevant detailed area in *Cloudburst modelling* (Göteborg Stad, 2015a) is the area called "Linnégatan". This difference needs to be considered when evaluating the results and is further described in the section of the model set-up of this thesis.

The aim of the *Cloudburst modelling* study was to map surface flooding of extreme rain events, serving as an adaption to the *Developing master plan*. The study was limited to the effects of pluvial flooding and did not consider fluvial flooding, of waterbodies like the river Göta Älv, or coastal flooding, due to the North Sea (Göteborg Stad, 2015a).

In the study the software program applied for the modeling was MIKE by DHI (Hørsholm, Denmark) and the calculations have been done with a 2D hydraulic surface runoff model. The function of the sewerage of the area was included in the model by reduction of the rain load in paved areas connected to the sewer system. The modelling of the extreme rain events was done for the return periods 100-years and 500-years including a climate factor of 1.2. In addition, the study included a sensitivity analysis with regard to the network capacity and the field infiltration of the model. The type of rain load was a Swedish Chicago design storm (CDS) rain, based on the report P104 by *Svenskt Vatten* (Göteborg Stad, 2015a).

The theoretical basis for this study was the report "Kartläggning av skyfalls påverkan på samhällsviktig verksamhet – Framtagande av metodik för utredning på kommunal nivå", published by *Myndigheten för samhällsskydd och beredskap* (MSB), in English the Swedish Civil Contingencies Agency (Göteborg Stad, 2015a).

The results of the *Cloudburst modelling* study were shown in flood maps for detailed areas. Parameters shown are flood propagation, maximum water depth and velocity, as well as flow directions (Göteborg Stad, 2015a).

The simulations for the area Linnégatan showed concurrent flood propagation and flow accumulation for a 100-year and a 500-year return period. The extent of the water depth and velocity increased from the 100-year event to the 500-year event, which was an expected result. This increase occurred for all three model areas and was stated as a general result (Göteborg Stad, 2015a).

The sensitivity analysis showed that the field infiltration and sewer system have a relevant effect on the results. The consideration of the sewer system without modeling leaves an uncertainty of the manner of the evaluation of the results. The study recommended to provide a coupled model with an additional hydraulic model for the piping system for prioritized areas. Moreover, a more detailed land use and elevation data were suggested to improve the accuracy of the results (Göteborg Stad, 2015a).

The usage of results of the study was implied to be for simplified cost benefit analysis, the identification of flood prone areas and corresponding measures and the development of contingency plans. In addition to the simulated rain loads other rain loads can also be simulated with the generated models (Göteborg Stad, 2015a).

2.4.1.3. Strukturplan – Structure Plan

As described in the previous chapter the *Structure Plan* (Swedish: Strukturplan) is part of the *City of Gothenburg*'s *Developing master plan* and climate adaption strategy. The *Structure Plan* has currently been implemented for the two pilot areas Linnéstaden and Kvillebäcken (Göteborg Stad, 2017b).

Linnéstaden is the catchment used to exemplify the investigation of the software programs in this thesis. Therefore, this chapter and thesis are limited to the general methodology of the *Structure Plan* and the *Structure Plan* for Linnéstaden of the *City of Gothenburg* and neglect the *Structure Plan* for Kvillebäcken. When referring to the *Structure Plan* the methodology and the explicit document for Linnéstaden are described.

2.4.1.3.1. Structure Plan – general methodology

The *Structure Plan* was aimed to provide a geographical planning documentation. The simulations with the models should be used to map the flood propagation and illustrate water depths and velocities caused by torrential rains and flash floods. Based on the mapping consequences of the floods were assessed and potential actions areas identified. For the assessment also the local conditions in terms of the topography, infrastructure and land use were evaluated (Göteborg Stad, 2017b).

The *Developing master plan*'s objective of a holistic approach for flood management was respected in the *Structure Plan*'s planning of actions. There are four types of measures and actions implemented in the *Structure Plan*, which are the diversion, retention and control of runoff and protection for temporary water level rise from coastal and pluvial flooding. However, the focus of the measures in the *Structure Plan* is on diversion (Skyfallsled), retention (Skyfallsyta) and control (Styrning) of runoff caused by pluvial flooding. The identified final recipients for runoff in Gothenburg are the sea and the river Göta Älv, for pluvial flooding. Nevertheless, a very important objective was defined in the *Structure Plan*, which states that measures for one type of flooding must not negatively affect measures of other types of flooding (Göteborg Stad, 2017b).

Primary focus of *Structure Plans* was set to handle the social risks caused by flooding, including infrastructure and important facilities. The *Structure Plan* has not dealt with aspects of personal safety in the impact assessment and privat properties. The study did not consider jurisdiction between privat and public properties. Besides the handling of stormwater itself was not addressed in the *Structure Plan*. Water quality and the impacts on the environmental standards for the recipients have not been examined. As the *Structure Plan* is still a pilot project it is vulnerable to errors within the methodology and might require further adaptions (Göteborg Stad, 2017b).

The prerequisite for the development of *Structure Plan*s are numerical models for pluvial flooding including the sewer system. For the *City of Gothenburg* those models were generated with the software MIKE ZERO by DHI (Hørsholm, Denmark), thus the *Structure Plan*'s study was partially specified to the software programs features. Further adaptions of the modelling of torrential rain and flash floods are recommended on a continuous basis with regard to climate change and GIS data (Göteborg Stad, 2017b).

The *City of Gothenburg*'s approach for the development of a *Structure Plan* was premised on three principles. The first principle aims for the establishment of an adapted model for pluvial flood modelling. The modelling should include complete hydrological and hydraulic descriptions of the catchment. The purpose of the second principle was set to analyze the results from the first principle in terms of local conditions of the catchment. The main emphasis was given to descriptions of water balance, topography, assessing potential for measure and action implementations. The actual development of a *Structure Plan* for a catchment was assigned to the third principle based on the results from the subsequent principles. The objectives were defined as follows. The type of measure, as described above, should be chosen. Water balances and storage volumes were set to be determined. Finally, measures and maps including measures and flood propagation for the overall and sub-areas within the catchment should be implemented and presented with GIS layers (Göteborg Stad, 2017b).

In the following the objectives of the three principles are presented.

<u>1st principle – Prerequisites for model</u>

The extreme rainfall modelling for the *Structure Plan* was based on the guideline from MSB "Kartläggning av skyfalls påverkan på samhällsviktig verksamhet" (MSB, 2014). The model simulations were done by *Sweco AB* and DHI (Hørsholm, Denmark) on behalf of the *City of Gothenburg*. The model calculations were based on dimensional rain for a 100-year return period and a climate factor of 1.2. From MIKE ZERO by DHI (Hørsholm, Denmark) the software MIKE 21, MIKE URBAN and MIKE FLOOD were used. MIKE 21 was used for the 2D-surface modelling coupled with MIKE URBAN in MIKE FLOOD (Göteborg Stad, 2017b).

The dimensional rain applied was the statistical distribution of the CDS rain for a central rainfall and a duration of 6 h. The surface model in MIKE 21 was charged with the most intense period of the rain, which was defined as 30 min. In addition, the period after the peak rain was charged to the surface model to investigate the impact of that load on e.g. depressions. The sewerage on the other hand was charged with the whole duration of the rain of 6 hours as for the sewerage the initial conditions in the piping system before the peak rain load is very important as well. In the surface model MIKE 21 infiltration was also considered. The capacity of the sewer system was set to a 10-year rain event. When exceeding this capacity, the water was charged to the surface model (Göteborg Stad, 2017b).

In general, the sewerage network was based on a standard rainfall deduction for the whole catchment. This simplification neglects fluctuations in the system, however oversizing and undersizing was assumed to the same extent so it was considered reasonable. In the sewerage model (MIKE URBAN) larger culverts and the main pipes with a diameter above 800 mm were modelled. The basis for the calculation of the sewerage network was the publication P110 by Svenskt Vatten (Göteborg Stad, 2017b).

In the model considerations were given to important culverts and shafts along main flow paths on roads and were modelled in the coupling of the sewerage and surface model. However, the impact of small shafts was assumed to be neglectable, to avoid an underestimation of the flooding on the surface (Göteborg Stad, 2017b).

Watercourses within the catchment were described in the surface model. For torrential rain and flash floods watercourses on main flow paths of surface runoff might be formed. The suggestion for the hydraulic description of water courses when developing a *Structure Plan* is that one considers the possibility of a watercourse turning into a main flow path of flash floods. Additionally, one must include the previously stated flood risk caused by the watercourse itself. The hydrological properties of the watercourse should be included (Göteborg Stad, 2017b).

The simulations of the models should include the following results for the subsequent principles. The flood maps must show max. flood depth and the discharge (Göteborg Stad, 2017b).

A calibration of the models for the *Structure Plan* was not determined as prerequisite. The basis for this decision was that there is a lack of data for the calibration of extreme events like torrential rains, as their occurrence is rare thus measured data for such events is not present or insufficient. However, the approach of the *City of Gothenburg* to assure the creditability of the models was to assure the accuracy of the crucial hydraulic and hydrological processes. This was done by an evaluation of model generated in the same manner as for the *City of Gothenburg* for the city Malmö in Sweden. The evaluation process proved the compliance of observed water levels and the model results. It was not possible to investigate the significant relationships of the infiltration capacity further, but it was the main source of uncertainty in the study in Malmö. With a deviation of +/- 10 cm and a mean error of +6 cm the *City of Gothenburg* verified the creditability of the model approach and simulations without further calibration for the *City of Gothenburg* (Göteborg Stad, 2017b).

For the simplification of the analysis done by the second principle the overall catchment was divided into sub-areas, based on the modeling results from the first simulations with the initial model set-up as described above. The sub-areas were limited to a size of 1 km^2 and were used for the analysis carried out in the second principle (Göteborg Stad, 2017b).

<u>2nd principle – model analysis</u>

In the second principle the results from the first principles model simulations were analyzed for the overall catchment and the sub-areas. The analysis was done with regard to the water balance, the impact assessment, analysis of measure potential and volume requirements for actual measures (Göteborg Stad, 2017b).

The objective of analyzing the water balance was to achieve a better understanding on flow paths and storage areas in the catchment. The equation used in the *Structure Plan* for calculating the water balance was set to the following (Göteborg Stad, 2017b).

$$F = A - B - C + D - E$$

Equation 2-1: Water balance equation of Structure Plan

With the following parameters and in parentheses the Swedish original terminology:

A: Precipitation (Nederbröd) B: Diversion to sewerage (Avledning till ledningssystem)

C: Infiltration (Infiltration) D: Inflow to catchment (Inflöde)

E: Outflow (Utflöde) F: Flooding (Översvämning)

The calculation of the explicit parameters was done by the sum of the calculations of the individual grid cells with 4 m sizing. The point of time for the calculation was set to the time of the maximum water depth for the majority of the cells. For the further analysis the *Structure Plan* implied the calculation of key ratios: The relative difference of flood and precipitation volume and the ratio for the peripheral volume causing flooding (Göteborg Stad, 2017b).

The water balance analysis is followed by the impact assessment. The purpose of the impact assessment was the quantification of indirect and direct consequences (damages) caused by flooding and the presentation in an intelligible manner (Göteborg Stad, 2017b).

The objectives for the assessment were the damages so called claims, social important infrastructure and accessibility to infrastructure. In four steps the impact was done. The first step was the classification and rating for damage costs based on insurance statistics of the *City of Gothenburg*. In a second step the water depth was assessed for the individual grid cells for a depth above 0.1 m. The results of the second step were so called impact points to identify relative impacts. Those impact points were evaluated for sub-areas and the respective categories. Due to divergences of impact points for different categories in one sub-area the last step calculated the overall unitary consequence for the individual objectives. Those were mapped in a final step (Göteborg Stad, 2017b).

The measures potential was ascertained rest on the impact assessment. The relative potential for the measures and actions was done with a similar method like the impact assessment. The aim was the identification of areas, which can handle excess water from sewerage and store runoff water (Göteborg Stad, 2017b).. For the detailed explanation of the rating the author refers to the actual document of the *Structure Plan* of the *City of Gothenburg* (2017b). Different potential was assigned based on the land use, property ownership and the load of dimensional rain on the areas (Göteborg Stad, 2017b).

The previous steps of the 2nd principles served as foundation for the distribution of water volumes by diversion, storage or a combination of both measures. Allocating of water volumes in the final version can differ from the initial flood management. Despite the theoretical volume distribution, the actual volumes in an extreme rain event might be differentially allocated in the catchment, meaning the storage capacity could be over- or undersized (Göteborg Stad, 2017b).

<u>3rd principle – basis for actions and measures</u>

With the 3rd principle of the *Structure Plan*, types of measures and the approach for their implementation was described. As described above there are three measures recommended, which are diversion (Skyfallsled), retention (Skyfallsyta) and control (Styrning) of runoff. All three measures can be implemented as a single measure or combined throughout the catchment. Measures should be implemented in a central manner and must be compatible with coastal and fluvial flood management. Besides the measures should be multifunctional and aspects of urbanization and densification of the city considered. For all measures in Gothenburg the final recipients for the water was assigned to the sea and the river Göta Älv (Göteborg Stad, 2017b).

The *Structure Plan* (Göteborg Stad, 2017b) defines the three measures as follows. A diversion (Skyfallsled) is a flow path to which the runoff from torrential rain is diverted. In general, every area can be used as a flow path independent from the land properties. However, priority and emergency roads should not be used as such.

The capacity of a diversion is determined by the size of the cross-sectional area, the slope and the roughness. A diversion should have uniform flow path properties (Göteborg Stad, 2017b).

Retention (Skyfallsyta) describes an area, where water from flash floods is stored. Those areas should be located in a depression. They serve as storage reservoir during the event and after the event the stored water is discharged into the sewer system for stormwater. Depending on the stormwater sewerage areas can discharge water during the event as well. A difficulty in the planning of retention measures is the allocation and the competing interests with new exploitation areas within the city. Retention areas can be built in one depression or in stepped arrangement (Göteborg Stad, 2017b).

A control measures (styrning) is defined as a supplementary measure to diversion and retention. It can be added to support a controlled design discharge. The measure describes any kind of flow obstacle in the flow path, e.g. a wall or changes in elevation (Göteborg Stad, 2017b).

As the principle aims to implement central measures the assessment prioritizes the safety of larger objects of public interest, like hospitals or emergency roads. Commonly this doesn't include privat properties (Göteborg Stad, 2017b).

After the planning of the measures based on the 1st and 2nd principle's assessment they are modelled in the MIKE ZERO software and the results are evaluated to assure the determined capacity for the reduction of the water depth or the changes to the flow propagation. For insufficient results the impact assessment and previous steps need to be repeated (Göteborg Stad, 2017b).

In addition to the torrential rain and flash flood impact analysis the third principle must prove the compatibility with fluvial and coastal flooding. Especially in downstream areas nearby the coast or the river Göta Älv the assessment is a crucial part of the *Structure Plan*. For the analysis the *Structure Plan* differs between permanent and temporary flood risk from the sea and water bodies like rivers. Those effects should be included in the hydraulic modelling of the flash flood (Göteborg Stad, 2017b).

The interaction between the stormwater system and measures for torrential rain was considered an important aspect for the 3rd principle. The aimed multifunctional use of measures could be complied by planning stormwater systems with additional capacity for torrential rain events and flash flood. Moreover, it could be economically beneficial as only small adaptions would be required for existing water systems (Göteborg Stad, 2017b).

Despite the measures implemented and recommended in the scope of a *Structure Plan* there will still be residual risk areas within one catchment or several sub-catchments. Those areas can be assigned to either individual objects not covered within the project or to areas with negative outcomes for cost benefit analysis (Göteborg Stad, 2017b).

Even though exploitation is a competing interest with flood management, measures and actions for flood prevention should be prioritized in the *Structure Plan*. The handling of this conflict requires the cooperation between the different stakeholders (Göteborg Stad, 2017b).

2.4.1.3.2. STRUCTURE PLAN – LINNÉSTADEN

With Linnéstaden being one of the pilot areas of the *Structure Plan* project of the *City of Gothenburg* a *Structure Plan* was developed based on the previously explained methodology. The model created in the scope of the project of the *Structure Plan* for Linnéstaden was used in this thesis for the comparison of the modelling software programs.

The *Structure Plan* for Linnéstaden included the implementation of 6 redirecting, 17 retention and 6 control measures in the catchment, shown in Figure 2-10. Linnéstaden was defined as an area of approximately 6 km^2. The measures and actions in Linnéstaden were assessed to lead to a reduction of damage costs of 42 % and decrease the impact on social important structures by 71 %. Moreover, the impact on accessibility was evaluated to be decreased by 87 % (Göteborg Stad, 2017d).

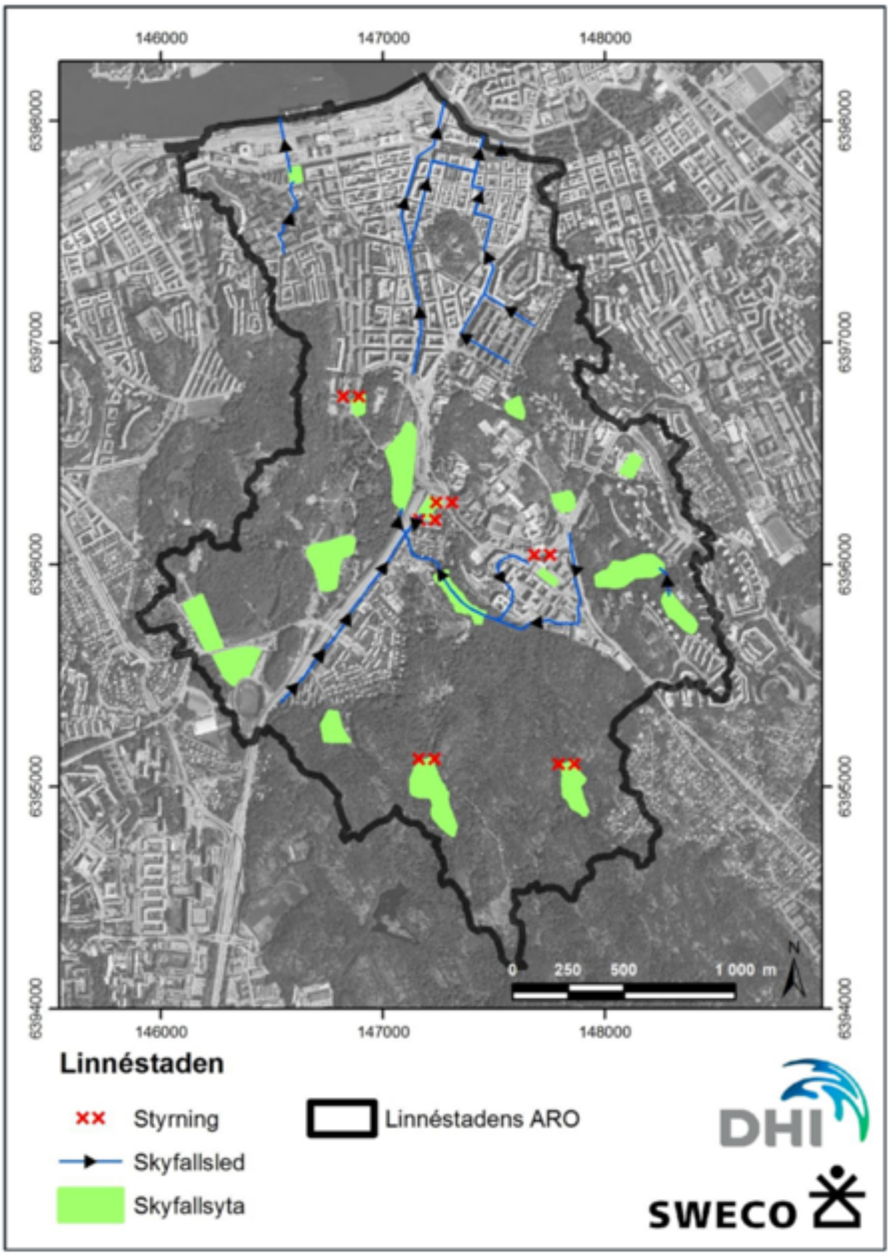


Figure 2-10: Structure Plan for Linnéstaden with implemented measures (Source: Structure Plan (2017d), [Figure 1-1])

Residual risk areas identified for Linnéstaden despite the measures were Annedalsmotet and Magretebergsmotet and Carl Grimbergsgatan located in the sub-district Annedal. The management of the stormwater system was considered in the planning and some measures benefited from existing stormwater systems (Göteborg Stad, 2017d).

The development of the *Structure Plan* for Linnéstaden was limited as follows. Technical feasibility, availability of assigned action and measure areas, geotechnical planning, cost assessments of proposed measures, evaluation of competing interests and a schedule for the planning were neglected (Göteborg Stad, 2017d).

For the pilot area Linnéstaden torrential rain and flash floods were handled as single and independent flood events not interacting with fluvial or coastal flooding. Nevertheless, the impact assessment considered such events and the compatibility of the *Structure Plan* Linnéstaden with them. Normal stormwater management, relevant for the design of the sewer system, was not part of the *Structure Plan* but a coordination between the systems was recommended (Göteborg Stad, 2017d).

With regard to the principles of the *Structure Plan*, as described in the methodology of the *Structure Plan*. The modelling according to the 1st principle for Linnéstaden was done with existing models for a 100-year rain event including a climate factor. In the case of Linnéstaden an existing 2-D surface model in MIKE 21 was linked to an existing pipe network model MIKE URBAN with the software MIKE FLOOD from DHI (Hørsholm, Denmark) (Göteborg Stad, 2017d).

The MIKE URBAN model includes the sewerage for the catchment Linnéstaden, but also includes the sewer system from Vasastaden and Lorensberg in the model. The model was set-up in 2008 by DHI (Hørsholm, Denmark). The piping network includes the mains and the combined parts of the system. A 10-year capacity was commonly assigned to the sewer system. The model in MIKE 21 was generated in 2015 by DHI (Hørsholm, Denmark) and *Sweco AB*. The coupled model in MIKE FLOOD linked outlets and inlets of the piping system to the surface model. This allowed the water flow between the sewerage and the surface to be considered in the calculations. The level for inlets and outlets was based on the terrain model and the flow between the two models was regulated by the dimensioning of the inlets and outlets. (Göteborg Stad, 2017d).

The models were charged with a 100-year rain including a climate factor of 1.2. The type of rain charged on the model was a CDS rain and the total duration was set to 6 hours. The rain load was distributed between the model in MIKE 21 and the model in MIKE URBAN based on the land use. The total duration was only loaded on the piping network in MIKE URBAN. The calculations over the whole rain period in MIKE URBAN led to the initial conditions for the rain load in the sewerage, which was applied in the coupled model in MIKE FLOOD. The coupled model was charged with the rain peak, with a duration of 30 min, and the after-rain. Initial conditions in MIKE 21 were manually calculated assuming a rain volume for the pre-rain, which was applied on the infiltration module in the model. The distribution of the rain according to the land use was as follows. Rain on impervious surfaces was generally diverted to MIKE URBAN and MIKE 21 according to the aforementioned time duration distribution of pre- and after-rain. The model in MIKE URBAN was charged with a rain load according to the capacity of 10-year. The rain exceeding this volume was charged on the model in MIKE 21. The rain on pervious surfaces was fully charged on the model in MIKE 21 (Göteborg Stad, 2017d).

The model set-up did not include a coupling of road tunnels to the sewerage or roads without a connection to the sewer system, but were modelled in MIKE 21. Open water bodies like ponds were described in the terrain model solely in MIKE 21. However, existing inlets and outlets of the water bodies were linked to the piping system (Göteborg Stad, 2017d).

For the model simulations a sensitivity analysis was done, leading to the adjustment of the mean water level in the recipient river Göta Älv to +0.85 m without correlating with the results of the simulations (Göteborg Stad, 2017d).

The results from the simulations were mapped for the catchment and the respective 15 sub-areas. Water depths below 10 cm were not reported. Main risk areas identified were the Sahlgrenska University Hospital, Carl Grimbergsgatan in Annedal, in general the areas along Dag Hammerskjödsleden mostly at Annedalsmotet and Magretebergsmotet. Linnégatan was identified as one of the main flow paths (Göteborg Stad, 2017d).

The water balance analysis for the ratio of the precipitation volume to the flood volume showed the highest adaption requirement for Sahlgrenska University Hospital and Linnéplatsen including Annedal- and Magretebergsmotet, followed by Vitsippsbäcken, Annedal and Slottsskogen. Large inflows from tributaries of the sub-areas were determined for Sahlgrenska University Hospital, Vitsippsbäcken, Linnéplatsen including Annedal- and Magretebergsmotet, some area in the north including of Haga in the downstream area and Slottsskogen (Göteborg Stad, 2017d).

The impact assessment defined the area of Sahlgrenska University Hospital to the highest risk for social important infrastructure. The highest claims (damages) were evaluated for Sahlgrenska University Hospital, followed by all areas north of Linnéplatsen in the downstream area. The highest risk for the accessibility was classified for the area of Slottsskogen (Göteborg Stad, 2017d).

The highest action potential was assigned to the park area of Slottsskogen. For the management of the flash floods and torrential rain runoff within the catchments they were assigned to measure types as follows. In the north the areas were assigned to redirecting measures, like Sahlgrenska University hospital and the sub-area connecting Sahlgrenska University Hospital to the downstream catchments. Annedal and the area around Medicinareberget were classified to a combination of storage and runoff like the northern part of Änggården. Slottsskogen and the area including Dag Hammerskjödsleden were identified as storage areas. The same accounts for Guldheden and the Southern parts of Änggården (Göteborg Stad, 2017d).

The measures taken were located throughout the catchment. Most of the redirecting measures were located in the north and were connected to the river Göta Älv. The 17 retention areas have a total storage capacity of 14,500 m3. They are mostly located south of Linnéplatsen and in the nature areas. The control measures were partially used to control the flow from redirecting and storage measures, but also for the prevention of flooding from natural water bodies. A special focus was given to one of the main flow paths Linnégatan and the area of the Sahlgrenska University Hospital. Redirecting and storage measures were implemented to improve the flooding in those areas (Göteborg Stad, 2017d).

There were several residual risk areas identified with the *Structure Plan* for Linnéstaden, assessed with respect to measures taken in the study. Two of the main areas were Annedalsmotet and Magretebergsmotet, both located in a depression and connected to flooding at the road Dag Hammarskjödsleden. The area Annedal was also classified as a residual risk, especially the road Carl Grimbergsgatan, which is located in a depression and embordering mountainous areas. Another residual risk area is the located in the North-East and in the South of the nature reservoir Änggården (Göteborg Stad, 2017d).

2.5. LEGAL ASPECTS

In this chapter the current legal situation of the *Federal Republic of Germany* (FRG) and the *Kingdom of Sweden* (Sweden) is compared with regard to the legal basis for flooding. The particular focus is on flooding due to cloudbursts. Since both countries are member states of the *European Union* (EU) the implementation of the EU's laws and regulations is considered as well. Before analyzing the legal situation, the legal structure of each country is studied, as Germany and Sweden have different forms of governments. In the second part of this chapter the current legal situation of each country is displayed and compared.

2.5.1. LEGAL STRUCTURE

2.5.1.1. THE FEDERAL REPUBLIC OF GERMANY (FRG)

The Federal Republic of Germany is a federal parliamentary republic. The country is separated in 16 federal states, the so-called "*Länder*". Each state has its own constitution. The head of government is the chancellor and the head of state is the president (European Union, 2018a).

The "*Länder*" have the sovereign power according to article 30, by the Basic Law for FRG, which states: "Except as otherwise provided or permitted by this Basic Law, the exercise of state powers and the discharge of state functions is a matter for the Länder." However, the general supremacy of the federal law is regulated in article 31 of the Basic Law, which says: "The Federal law shall take precedence over Länder law."

The federal legislation and the division of power between the "*Länder*" and the Federation is regulated according to article 70, by the Basic Law of the FRG. As written in article 70, paragraph (2): "The division of authority between the Federation and the Länder shall be governed by the provisions of this Basic Law concerning exclusive and concurrent legislative powers." The definition of exclusive legislative powers of the Federation is written in article 71 and 73, the Basic Law of the FRG. The concurrent legislative powers of the "*Länder*" are described in article 72 und 74, the Basic Law of the FRG.

In article 72, paragraph (3) and article 74, paragraph (1) "the management of water resources" is stated as a matter of concurrent legislative powers. Flooding, in general, can be categorized to the field of management of water resources. Therefore, it is a matter of the "*Länder*" law. This categorization is a simplification to classify the term flooding with regard to terms of the Basic Law of FRG. Meaning that flooding cannot only be assigned to the field of the management of water resources. Flooding has also a significant impact on other sectors like city planning, transportation and land use, which are regulated by different laws.

Due to the aims and objectives of the present report, a categorization of flooding as a matter of "management of water resources" is considered as sufficient. Whereas, for a further and more detailed study of the legal situation this simplification must be considered.

For this report the “*Länder*” law, will be exemplified by the federal state of Baden-Württemberg (BW), based on the concurrent legislative powers. For the state BW, the area of responsibility has the Ministry of Environment, Climate Protection and the Energy Sector Baden-Württemberg. Within this ministry the Federal Institute the so-called “*Landesanstalt für Umwelt*” (LUBW) is accountable for the matter flooding.

The LUBW is an institution, which is amenable to the legal and professional supervisory body of the Ministry of Environment, Climate Protection and the Energy Sector BW. It is a state-run facility, but also an autonomous public agency (LUBW, 2018a).

In addition to the laws by the LUBW for the federal state BW the so-called LAWA institution is a relevant authority in the water sector. LAWA, in German “Bund/Länder-Arbeitsgemeinschaft Wasser”, is a German Working Group of the Federal States and the Federal Environment Ministry, representative for the FRG. The Working Group covers the fields of water management and water legislation. The aim is the implementation of standardized legislations within the FRG and its federal states. The LUBW is a member of the Working Group LAWA (LAWA, 2018a).

In addition to the governmental facilities, the state of art and planning process in BW is significantly influenced by technical codes of the so-called “Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V.” (DWA), which is the German Association for Water, Wastewater and Waste.

The DWA is a charitable association. It acts politically and economically independent. The focus of the association lies on “the development of a secure and sustainable water and wastewater management”. (DWA, 2018a)

The DWA publishes DWA set of rules and DWA topics. Those publications substantiate laws and other legal standards and serve as an amendment to them. DWA committees with different professional backgrounds develop the DWA set of rules and topics. The DWA set of rules are similar to DIN-standards. The DWA set of rules must not conflict with DIN-standards, however they are developed in a more regional matter and are not subject of the German Institute of Standardization. The DWA set of rules are divided into two types of publications. The so-called DWA Arbeitsblatt (DWA-A), referred to as standard, and the DWA Merkblatt (DWA-M), referred to as guideline. The DWA-A is a standard in accordance to the general state of the art, whereas a DWA-M is a guideline, for which no state of the art exists. A DWA-M guideline should be considered as a recommendation and mostly deal with relatively new and more innovative technologies. (DWA, 2017a)

Within the scope of this thesis the focus will be on the aforementioned Ministry of Environment, Climate Protection and the Energy Sector Baden-Württemberg, with its institute LUBW in correlation to the applicable German law, and the DWA set of rules and DWA topics with regard to the main focus pluvial flooding.

2.5.1.2. The Kingdom of Sweden (Sweden)

The Kingdom of Sweden is a constitutional monarchy and a parliamentary democracy. The head of state is the monarch and the head of government the prime minister. Sweden is a centralized state. It is divided into 20 counties and 290 municipalities. (European Union, 2018b)

The centralized state Sweden has three levels of governmental administration: national, regional and local. On a national level the government consist of several Government offices, ministries, centralized government agencies and public administrations. On a regional level the governmental administration is the obligation of the counties. For the counties the political tasks are divided into the county council and the county administrative boards. On a local level the municipalities with the municipal board have the governmental administrative power. (The Government Offices of Sweden, 2015a)

The government agencies execute the policies of their associated Government offices or the ministries. They are controlled by the Government, however the so-called “ministerial rule” assures that the Government has no power to interfere with “an agency’s decisions in specific matters relating to the application of the law or the due exercise of its authority”. (The Government Offices of Sweden, 2015b)

On a national level, the *Miljö- och Engeri Deparementet* (in English the Ministry of the Environment and Energy) is responsible for aspects considering the water sector, which is carried out by the *Miljö och Climate* Divison (in English Environment and Climate Division) of the ministry. (The Government Offices of Sweden, 2015b) Additionally, the *Justitiedepartementet* (in English the Ministry of Justice) with its Division of *Krisberedskap* (in English the Division of Emgergency Preparedness), which aims to strengthen the society’s emergency preparedness. An important government agency within this ministry is the so-called *Myndigheten för samhällsskydd och beredskap* (MSB), which is the Swedish Civil Contingencies Agency. (The Government Offices of Sweden, 2017) According to the Ministry of Justice the Swedish Civil Contingencies Agency is accountable amongst others for public safety and emergency management. The action fields for measures are for pre-care, care during an event and after-care. (The Government Offices of Sweden, 2015c) Since flooding due to cloudbursts is a hazard and requires emergency preparedness the Ministry of Justice and the MSB are crucial to be regarded in addition to the Ministry of Environment and Energy.

The MSB as a government agency coordinates the Swedish structure for Civil Emergency Planning (CEP). In particular this means, that the MSB is responsible for the emergency management in terms of an integrated approach with regard to all possible hazards. The basis for the Swedish emergency preparedness system is premised on the “principle of responsibility”. Meaning that the institution bearing the responsibility in general has the responsibility for emergencies in this sector, including the tasks of emergency preparedness. The CEP acts on the same governmental administration structure as the government: national, regional and local. On a regional scale, the remit of county administrative boards is to execute risk and vulnerability analysis, to coordinate measure for emergencies and to define the liabilities between the public and private sector. On a local scale, the Swedish municipalities have the authority to enact the CEP autonomously. They are fostered by the county administrative boards. (MSB, 2015a)

Additionally, to the governmental institutions an important organization regarding guidelines and recommendations in Sweden is *Svenskt Vatten*, the Swedish Water and Wastewater Association. It is an association with members from almost all Swedish municipalities, at the current state 289. The Svenskt Vatten develops guidelines and recommendations for matters in the field of water and wastewater. The committees consist of experts from different fields of the member municipalities. Besides, Svenskt Vatten is a member of the European Union of National Association of Water Supplies and owing to the large number of participating municipalities the Svenskt Vatten is considered to "represent the national municipal units for water and wastewater". (Svenskt Vatten, 2015a)

To sum up, for the Kingdom of Sweden the legal authority for flooding is under the responsibility of the Ministry of Environment and Energy (*Miljö- och Engeri Deparementet*) and the Ministry of Justice (*Justitiedepartementet)*, with its governmental agency MSB. In addition, the *Svenskt Vatten* publications are seen as a fundamental supplement to the state of the art in Sweden and factored in the legal comparison. On a regional scale the country Västra Götaland and on a local scale the municipality Göteborg Stad are considered in this thesis.

2.5.1.3. The European Union (EU)

The Federal Republic of Germany and the Kingdom of Sweden are both member states of the EU. The FRG since 1958 and Sweden since 1995. (European Union, 2018c) Therefore, EU law is binding for both countries. The EU law is divided into regulations and decisions and directives. The National authorities of the member countries have to ensure the correct implementation of the regulation and decisions. In contrast, EU directives are incorporated in the national legislations. For such directives the EU member states have to execute the incorporation upon to a deadline and report to the EU Commission about the process.

2.5.2. Laws and Legislation

In this section explicit laws and legislation in the field are presented. The author emphasizes that this chapter can only give an overview and that it would exceed the scope of this thesis to present all laws and legislations that could be possibly considered in the field of pluvial flooding.

2.5.2.1. The European Union – EU

In the sector of flood risk management, the EU has implemented the so-called Flood Directive, with the complete designation of "Directive 2007/60/EC on the assessment and management of flood risk". Subsequently, this directive will be referred to as Flood Directive or Directive.

The aim of the Directive, in accordance to article 1 is the establishment "of a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences […] with floods in the Community". (EU, 2007) The member states have to establish flood risk maps and flood hazard maps and on the basis of those establish flood risk management plans, as stated in article 7, paragraph 1 of the Directive. (EU, 2007)

As reported in paragraph 6 of the official statement of the Directive, the directive shall follow the Directive 2000/60/EC, the so-called Water Framework Directive. The Water Framework Directive implies a corporation in the field of water policy, which does not focus on flooding itself.

Even though the Directive focuses on flood risk, the overall field of interest is on fluvial flooding. In paragraph 10 of the official statement flash floods and urban floods are mentioned as possible types of floods, but according to article 2 paragraph 1 the considered floods in the framework are "floods from rivers, mountain torrents, Mediterranean ephermal water courses and floods from the sea in coastal areas". (EU, 2007)

Therefore, one can conclude that pluvial flooding is not considered within the Flood Directive. Meaning there is no existing directive from the EU providing guidance for the member states on how to exactly handle pluvial flooding, like flash floods caused by torrential rain. Nevertheless, one can include basic ideas from the Flood Directive as they can partially be applied to flash floods, in view of the difference in e.g. forecast possibilities or the local occurrence, as flash floods are not limited to riverine or coastal areas.

Moreover, the general definition for flood can be applied to pluvial flooding as well. The definition is given in article 2, paragraph 1 of the Directive (EU, 2007) and states: "Flood means the temporary covering by water of land not normally covered by water."

2.5.2.2. The Federal Republic of Germany

As mentioned in Chapter 2.3.1. of this report the Ministry of Environment, Climate Protection and the Energy Sector Baden-Württemberg, the LUBW and the DWA are the investigated legal basis for this report corresponding with the current German and EU law.

The valid laws in the federal state of BW by the Ministry of Environment, Climate Protection and the Energy Sector Baden-Württemberg are the "Wasserhaushaltsgesetz" (Water Resource Act) and the "Wassergesetz" (Water Law).

For the Federal State BW an important publication describing the pluvial flood risk management in BW is the publication by the LUBW, with the original name is italicized and the English translation is written in print.

- Leitfaden – Kommunales Starkregenrisikomanagement in Baden-Württemberg
    - Guideline – Municipal torrential rain management in Baden-Württemberg
    - Published: December 2016

According to this guideline (LUBW, 2016a) the Water Resource Act generally defines flooding according to §72 as follows: "A flood is a time restricted inundation of an areas, which is usually not covered with water, especially through surface water bodies. An exception are inundations caused by the sewer system." Based on this definition torrential rain causing flooding is as well defined as a flood according to the Water Resource Act. This definition is limited to areas, that are not connected to the sewer system. For areas, mostly impervious and paved areas, connected to the sewer system the definition must be reconsidered. If the capacity of the sewer system is exceeded and the runoff leads to surface flooding as it cannot enter the sewer system it is also defined as a flood according to the Water Resource Act §72. However, torrential rain considered as stormwater is classified as sewage for the water, which is collected and redirected from paved and built-up areas into the sewer system. This definition is based on the Water Resource Act §54, paragraph 1. The obligation for the wastewater disposal behooves the municipalities. Nevertheless, the obligation for the wastewater disposal is restricted by the dimensioning criteria of the sewerage. Once the capacity of torrential rain exceeds the design capacity of the sewerage the term "flood" with the respective laws applies (LUBW, 2016a).

The explicit classification of municipal flood protection and pluvial flood risk management according to LUBW (2016a) and the publication "Starkregen und urbane Sturzfluten – Praxisleitfaden zur Überflutungsvorsorge" by the DWA (2013) is presented in Table 2-4.

Table 2-4: Classification of municipal flood protection and pluvial flood risk management translated and adapted from figure 8 (LUBW, 2016a) and figure 9 (DWA/ BWK, 2013)

Jurisdiction level	Municipal flood protection	Overlapping field of authorities	Municipal pluvial flood risk management
Rain events	Frequent (Design rain)	Rare torrential rain and runoff	Extraordinary torrential rain and runoff
Dimensioning rain event (return period)	1-5 years	10-30 years	> 50 years
Protection aim	Avoidance of overflow	Flood protection	Damage control
Objectives within jurisdiction level	Public drainage systems including backflow prevention for objects like buildings		
		Traffic and open areas (temporary flooding)	
			Technical and constructive object-protection for public and private properties

Table 2-4 shows the obligation of municipal flood protection varying between design events for 1 to 10-year return periods. A 30-year return periods is commonly used as a starting point for the dimensioning of pluvial flood management as one assumes the exceedance of the sewerage capacity for such an event (LUBW, 2016a). Despite of the assignments to return periods it is recommended to focus on the local damage potential for urban and municipal flood protection (DWA/ BWK, 2013).

In addition to the legal separation of municipal flood protection and pluvial flood risk management the LUBW (2016a) differentiates in the management of fluvial and pluvial flooding. As described in Chapter 2.1.1 pluvial flooding is not bound to water bodies and can occur anywhere, whereas fluvial flooding occurs when rivers overflow causing flooding of the surrounded areas. Fluvial flooding is managed according to the Flood Directive by the EU. Pluvial flooding caused by torrential rain is assessed in a different manner. Fluvial flooding is described by statistical return periods for the water body under investigation. Pluvial flooding is not assigned to a statistical return period as the simulation of the surface runoff is based on an adapted approach for torrential rain. Apart from the statistical difference pluvial flooding is simulated for areas up to 5 km^2 and fluvial flooding for areas larger than 10 km^2. For fluvial flooding the return period for 100-years is investigated and by law those areas are classified as "Überschwemmungsgebiete" (flooded areas) according to §65 of the Water Resource Act. As pluvial flooding cannot be assigned to a statistical return period it is not declared as "Überschwemmungs-gebiet" thus the mapping of torrential rain risk has no direct legal consequences. The LUBW implemented the following approach for the simulation of pluvial flooding. There are three investigated scenarios, which are a rare, extraordinary and extreme torrential rain event or pluvial flooding. The basis for the simulation is a hydrogeological assessment of the soil properties with regard to the corresponding rain event. The duration of the rain events is set to 1 hour for all three scenarios. The statistical rain event of a rare torrential rain is 30 - years. For an extraordinary event the statistical rain event is 100-years and for an extreme event the precipitation height is defined as 128 mm for the duration of 1 hour.

Because of the approach being based on statistical precipitation and soil properties, which are adapted according to the three scenarios the simulations cannot be assigned to statistical return periods like fluvial flooding. The soil properties were adapted with regard to groundwater recharge and the water and soil atlas with the respective modelling software programs (LUBW, 2016a).

For the modelling of pluvial flooding the LUBW (2016a) recommends 2D-hydrodynamic numerical models. The guideline does not recommend a coupled model including the sewer system. It is assumed that for a rare event of a statistical return period of 30 years the capacity of the sewer system is already exceeded. The design capacity of a sewer system is commonly below a 30-year event, as previously stated in Table 2-4. Hence it is concluded that for an extraordinary or extreme rain event the sewer system has no effect and can be neglected. Instead of a coupled modelling the LUBW illustrates the option of a simplified and percentual consideration of the sewer system capacity for a rare torrential rain (LUBW, 2016a).

Even though pluvial flood risk maps in the manner recommended by the LUBW (2016a) have no direct legal consequences they can serve as a basis for risk analysis, in the manner presented by the guideline, and can be applied for the planning and management of further concepts for pluvial flood management (LUBW, 2016a).

In addition, a publication by the Working Group LAWA is notable.

- LAWA-Strategie für ein effektives Starkregenrisikomanagement
    - LAWA-Strategy for an effective torrential rain risk management
    - Published: January 2018

In this LAWA publication the current state and the need for torrential rain risk management are featured. The notable fields of actions are assigned to the analysis of data, information precaution measures, preparedness actions, improved protection and resilience actions. In the report the main jurisdiction is determined to the municipalities, but also implies the need for political support by the FRG and its federal states for the municipalities and the affected population. The main jurisdiction is given to the municipalities due to local restricted occurrence of torrential rain requiring local knowledge. Besides the municipalities have the obligation of hazard prevention, e.g. for hazards like pluvial flooding. Apart from the responsibility of the municipalities the report also highlights the obligation of every property owner living in flood risk areas to take actions for prevention. The aim of LAWA is the reduction of pluvial food risk and its adverse consequences for all object of protection. The approach for torrential rain risk management is based on the Water Framework Directive and Flood Directive by the EU. However, the report defines pluvial flooding as a “general risk” opposed to fluvial flooding being assigned to a “significant risk” by the Water Resource Act (LAWA, 2018b).

Concluding no risk areas can be assigned to pluvial flooding in the same manner as for fluvial flooding. The final recommendation by this publication is an integrated and holistic approach of the different stakeholders, for example in the water sector, forestry and agriculture as well as the city planning and infrastructural sector (LAWA, 2018b).

An overview of the relevant and considered DWA set of rules with subjects related to cloudburst flooding is listed consecutively. Hereby the original name is italicized and the English translation is written in print.

- DWA – Themen T1/2013
  - *Starkregen und urbane Sturzfluten – Praxisleitfaden zur Überflutungsvorsorge*
  - Torrential rain and torrents – a practical guideline for flooding precautions
  - Published: August 2013; in cooperation with the BWK
- DWA – M 119 (DWA, 2016b)
  - *Risikomanagement in der kommunalen Überflutungsvorsorge für Entwässerungs-systeme bei Starkregen*
  - Risk management on a municipal scale of flooding precautions for dewatering systems for torrential rain
  - Published: December 2016
- DWA – A 531 (DWA, 2012)
  - *Starkregen in Abhängigkeit von Wiederkehrzeit und Dauer*
  - Torrential rain as a function of the return period and duration
  - Published: September 2012
- DWA – M 550 (DWA, 2015)
  - *Dezentrale Maßnahmen zur Hochwasserminderung*
  - Decentralized measures for flood mitigation
  - Published: December 2015
- DWA – M 553 (DWA, 2016a)
  - *Hochwasserangepasstes Planen und Bauen*
  - Planning and Construction adapted to flooding
  - Published: December 2016

The publication DWA – Themen T1/2013 (2013) provides an overall guidance for the flood prevention caused by torrential rain and flash floods. It includes recommendations for risk assessments, measures and actions including the fields of communication and information (DWA/ BWK, 2013). DWA – M 119 (DWA, 2016b) focuses on the field of municipal flood prevention for sewer systems for the occurrence of torrential rain. It includes legal aspects for sewerage and torrential rain, recommendations for risk and damage analysis as well as for the design of measures (DWA, 2016b). The publication – A 531 (DWA, 2012) describes the state of the art for statistical analysis of torrential rain including data acquisition and analysis. DWA – M 550 (DWA, 2015) is a guideline for decentralized measures in flood management in general, however includes fields of application for torrential rain. In the publication DWA – M 553 (DWA, 2016a) planning and design recommendations are given for flood adaption measures.

2.5.2.3. THE KINGDOM OF SWEDEN

After the explanation of the legal structure of Sweden, see Chapter 2.5.1.2, in this section the applicable laws, guidelines and recommendations are presented. For the Kingdom of Sweden, the priority is on the governmental agency MSB and the association Svenskt Vatten, as well as on publications by the country Västra Götaland and on a local scale the municipality Göteborg Stad. Besides of those institutions and agencies the author would like to point out the legal force of laws like the general Building Act for Sweden, which are not illustrated further.

Fundamental publication by the MSB considering cloudburst are listed below. Hereby the original name is italicized and the English translation is written in print:

- *Vägledning för skyfallskartering – Tips för genomförande och exempel på användning*
  - Guidance for torrential rain mapping - tips for the implementation and examples for the application
  - Published: August 2017
- *Kartläggning av skyfalls påverkan på samhällsviktig verksamhet – Framtagande av metodik för utredning på kommunal nivå*
  - Mapping of cloudburst's impact on socially important activities - Development of a methodology for an investigation at municipal level
  - Published: May 2014
- *Pluviala översvämningar – Konsekvenser vid skyfall över tätorter en kunskapsöversikt*
  - Pluvial flooding – Impact of flooding on agglomerations a knowledge overview
  - Published: April 2013

The three documents above provide guidance for the management of pluvial flooding for the municipalities. The document "Pluviala översvämningar" (MSB, 2013) gives a general background for objectives of pluvial flooding. It describes the properties of torrential rain, consequences and damage costs for pluvial flooding, includes a methodology for flood calculations and measures for long-term and short-term (MSB, 2013). "Kartläggning av skyfalls påverkan på samhällsviktig verksamhet" (MSB, 2014) provides a methodological approach for the mapping of torrential rains and pluvial flooding with respect to socially important infrastructures for municipalities. The method recommends the modelling of pluvial flooding for urban areas with a 4 m grid resolution or smaller. For the modelling of pluvial flooding the "state of the art" was determined as a combined 1D sewerage and 2D surface model. Despite the recommendation is the application of a 2D- hydrodynamic, numerical surface model for example with software programs like MIKE 21 by DHI (Hørsholm, Denmark). The recommendation was based on the evaluation of the 2D surface model, which included a general deduction of the rain load to include the sewer system capacity. In a sensitivity analysis the deduction was proven to be sufficient compared to a combined 1D sewerage and 2D surface model. The study critically assessed the efficiency of the sewer system for an extreme rain event, thus the need of a combined modelling over a 2D model. The limitation of the flat-rate deduction of the rain load for the sewer system was recommended to a maximum 10-year capacity for the sewer system for a 100-year return period of the extreme rain event. However, a coupled 1D model for the sewerage and 2D-surface model was recommended for detailed studies. Moreover, the shorter computational time and required input data of a 2D model supported the recommendation (MSB, 2014).

The general capacity of the sewer system was assumed to be a 10-year return event. For pluvial flooding the investigated rain event was determined to have at least a 100-year return period, which refers to 55 mm rain load per 1 hour, like the definition by SMHI, see Chapter 2.1.3. In addition, the approach suggests an accurate modelling of the infiltration capacity or a deduction in the manner of the sewerage capacity deduction of the rain load based on the sensitivity analysis. (MSB, 2014). The surface roughness was also determined to be a crucial parameter and a detailed differentiation between the surface types is recommended "*Kartläggning av skyfalls påverkan på samhällsviktig verksamhet*" report by MSB served as planning basis for the structural plan, described in the section of the catchment's previous studies, see Chapter 2.4.1.

The latest document "*Vägledning för skyfallskartering*" (MSB, 2017a) contains details for the mapping of pluvial flooding with the respective planning steps, impact analysis and advice for the modelling. The report recommends that planning of measures should be included in the structure and detailed plans, based on adaptions of the *Developing master plan* (MSB, 2017a).

The association *Svenskt Vatten* published the following essential documents relevant considering stormwater, which are relevant for torrential rain management. The original name is italicized and the English translation is written in print.:

- *P 104 Nederbördsdata vid dimensionering och analysis av avloppssystem*
    - Precipitation data for the dimensioning and analysis of sewerage
    - Published: August 2011
- *P 105 Hållbar dag- och dränvattenhantering – Råd vid planering och utformning*
    - Sustainable stormwater and drainage water management – Recommendation for planning and implementation
    - Published: August 2011
- *P110 Avledning av dag-, drän- och spillvatten - Funktionskrav, hydraulisk dimensionering och utformning av allmänna avloppssystem*
    - Distribution of stormwater, drainage water and wastewater – Functional requirements, hydraulic dimensioning and design of public sewerage
    - Published: January 2016

The document P 104 (Svenskt Vatten, 2011a) describes the hydrological basis for the dimensioning of sewerage. It includes statistical rain distributions and calculations, which function as basis for the calculation of the input data for modelling with software programs, e.g. for MIKE 21 as applied in this thesis (Svenskt Vatten, 2011a). P 105 (Svenskt Vatten, 2011b) generally features the design of sustainable stormwater systems. It also aims to consider climate change, which includes the prevention of floods according to the 2015 formulated challenges by the association Svenskt Vatten. The report recommends an adapted and more sustainable implementation of stormwater systems. P 105 offers design ideas for stormwater measures, which can partially be applied for pluvial flooding as well (Svenskt Vatten, 2011b). In P 110 (Svenskt Vatten, 2016a) the basic design requirements and dimensioning guidelines for stormwater, drainage water and wastewater systems can be found.

Relevant publications for the planning process by the *City of Gothenburg* are: Översiktsplan (*Developing master plan*), Skyfallsmodellering (*Cloudburst modelling*) and Strukturplan (*Structure Plan*). Whereby the last two projects are part of the Översiktsplan, the adaption of the site plans. The content of the documents is explained in the earlier section of this thesis, see previous studies for Linnéstaden in Chapter 2.4.1.

2.5.3. Legal Basis - Comparison

In the following paragraph the legal aspects illustrated in the previous chapters are compared by the author in a neutral manner to illustrate the similarities and differences between the states Germany and Sweden, including the legal basis of the EU. For the analysis the author refers to the discussion section of the present report.

The literature review for the legal aspects could not lead to an explicit legal approach or basis provided by the EU on how to manage pluvial flooding. The Water Framework Directive and Flood Directive can partially be applied for pluvial flooding, but do not specify in pluvial flood management as opposed to fluvial flood management with the Flood Directive.

For the countries Germany and Sweden, the legal basis and jurisdiction for pluvial flood management remains unclear and partially inconclusive. Both countries developed guidelines and recommendations on how to manage pluvial floods and torrential rain. Legal consequences for those reports and studies are in the developing phase or non-existing. They have a unanimous opinion that an integrated and holistic approach for all sectors of flood management should be aimed for. Especially for torrential rain the different stakeholders on all authority levels should be included.

The conformity in the approach recommended for the modelling for Sweden and the Federal State of Baden-Württemberg is interesting. Both suggest 2D-surface modelling and a possible deduction for the consideration of the sewer system over a coupled 1D and 2D model. The main difference in the method is the classification of the analyzed scenarios to return periods. The approach recommended by MSB assigns the scenarios to return periods, whereas the LUBW rates such a classification as impossible. The difference is based on the disparate modelling of the soil properties for torrential rain events.

In Figure 2-11, the current state of the legal aspects from the present literature review is presented. The relevant legal institutions and laws of the three judicial systems of the EU, Federal State of Germany and the Kingdom of Sweden are listed under the corresponding state.

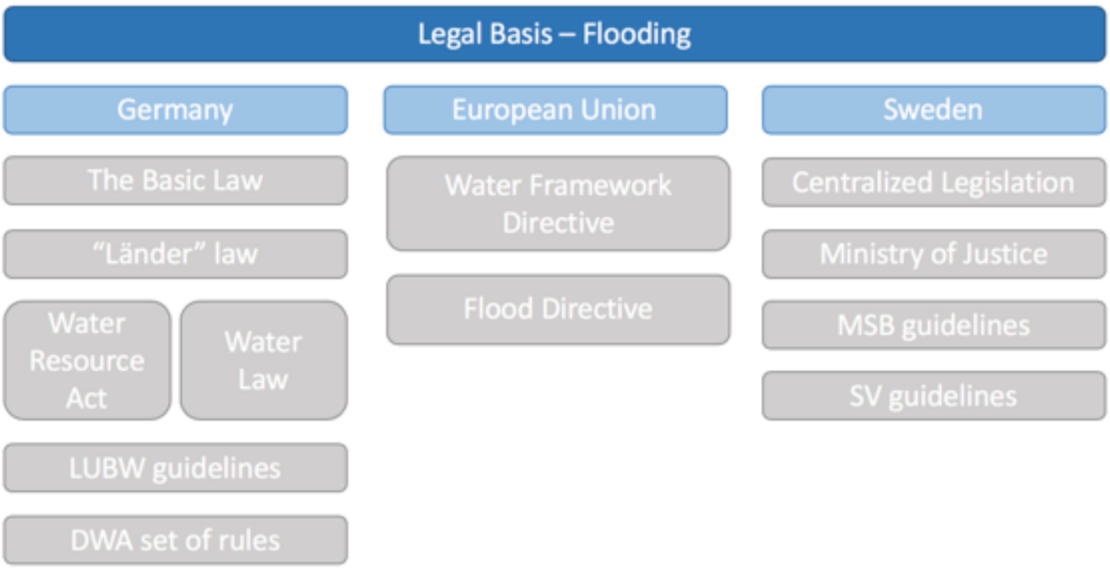


Figure 2-11: Comparison of Legal Basis Flooding (created by author)

2.6. Flood measures

“Floods are a natural phenomena which cannot be prevented.” This statement by the official justification of the Flood Directive of the European Union, paragraph 2, describes the difficulty and complexity of flooding. As floods as a natural hazard cannot be prevented the implementation of measures in terms of prevention, protection and preparedness is essential to manage floods.

In general, there are several types of measures and actions which can be taken to reduce or prevent flooding. Depending on the type of flooding, see Chapter 2.1, measures differ. Mainly responsible for the choice of measures is also the legal basis, in this thesis described in the previous Chapter 2.5 for the countries Sweden and Germany. As described in that section, the legal environment for pluvial flooding remains still unclear. However, measures for pluvial flooding can be planned similarly to e.g. fluvial measures.

In the subsequent section flood measures for pluvial flooding are prioritized. Besides general measures in flood management applicable for pluvial flooding are also presented.

In flood risk management there are three phases according to Müller (2010), which are preparedness, response and regeneration, in a continuous process. The individual phases of flood risk management can be described as follows:

1. Preparedness

The aim of preparedness is the reduction of vulnerability for flooding. It includes the fields of flood prevention and precaution (Müller, 2010, pp. 9-11). The field of action of preparedness covers precautionary land-use, construction precaution measures, natural flood retention, technical protection measures, precautionary information, precautionary behavior, hazard prevention and disaster preparedness [(Müller, 2010, pp. 9-11); (DWA, 2016a)].

2. Response

The field of response starts with the beginning of a flood event and aims to mitigate flood duration and extent (Müller, 2010, pp. 9-11). The objectives of this phase include flood defense and the defense of adverse consequences, including the execution of measures planned in the preparedness phase, as well as support service for affected persons and the documentation for the regeneration phase [(Müller, 2010, pp. 9-11); (DWA, 2016a)].

3. Regeneration

The phase of regeneration targets the reconstruction and rehabilitation. It also includes flood evaluation and analysis for the phase of preparedness [(Müller, 2010, pp. 9-11); (DWA, 2016a)].

Measures in the field of preparedness have proven to be the most reliable and robust against flooding (DWA, 2016a). Preparedness measures can be divided by execution level or the types of measures. With regard to the execution level one differs between infrastructural measures, which are under the authority of the respective municipality and object-related measures for buildings, which are under the authority of the property owners (DWA/ BWK, 2013). With respect to the types of measures one can differ between sewerage measures, infrastructural measures, measures for water streams, aerial measures, object-related measures and behavioral measures (DWA, 2016b)

In addition to the three stages according to Müller (2010), one also differs between local, centralized and decentralized measures in flood management. Local and central measures are located nearby the expected flooding causing a peak reduction of the discharge in the catchment. Local measures can include object protection and adaption measures for water streams. As central measures one classifies retention or detention basins and reservoirs. Decentral measures on the other hand lead to a smaller peak reduction in the catchment and are localized throughout the catchment. Example for decentralized measures are retention areas, renaturation measures and stormwater management. An advantage of decentralized measures is that they can be applied for regional risk areas. Especially for torrential rain, which occurs locally limited, decentralized measures have a higher potential to diminish the peak flow in local areas (DWA, 2015).

Decentralized measures applicable in urban areas are strongly dependent on the legal basis as they can also be assigned to the field of stormwater management. As described in the previous chapter of the legal aspects flood management requires a holistic approach including different stakeholders. The authorities between stormwater management and pluvial flood management are partially overlapping thus the dimensioning design and pre-requisites can differ depending on the classification of the measures. (DWA, 2015). Examples for decentralized measures in an urban area are (DWA, 2015):

- Measures to increase and improve the infiltration capacity, e.g. swale infiltration
- Measures for retention, e.g. a stormwater retention basin designed with a capacity to reduce pluvial flooding
- Measures to reduce the peak discharge through the adaption of the land use, e.g. green roofs or unsealing of impervious areas

As explained earlier the phase of preparedness according to Müller (2010, pp. 9-11) includes measures, which can be classified by different sectors. They are described in the subsequent section.

With regard to the legal basis one differs between municipal, for example infrastructural measures, and object-related, meaning privat properties, measures. This differentiation implies different responsibilities for the implementation of measures and actions. Nevertheless, the type of measures can be similar like measures of pre-cautionary land-use [(DWA/ BWK, 2013), (LUBW, 2016a)].

Object-related measures can be divided into three stages for the protection: avoidance, resistance and adaption. Those measures can be the rising of construction level in terms of avoidance, structural measures to hinder water from entering the building in terms of the resistance and adaption measures like changes of building material or changes to technical building services (DWA, 2016a).

Infrastructural measures under municipal authorities can be classified in technical preparedness measures, urban planning and urban development planning measures as well as administrative measures. Examples for measures are described in the following according to DWA T1/2013 (DWA/ BWK, 2013) and Leitfaden – Kommunales Starkregenrisikomanagement in Baden-Württemberg (LUBW, 2016a).

Technical preparedness measures include the retention of tributary water from the catchment or the redirection of the inflow water with retention areas, open channel constructions or the adaption of inlet structures. Adaption measures of natural water bodies and drainage ditches are preventative measures for erosion and the removal of flow obstacles. Besides measures for the urban drainage system are included. The measures aim to reduce sealing of surfaces and to increase the infiltration capacity. Measures of decentralized stormwater management are also classified in this sector. The adaption of roads and streets to increase the storage capacity by adaptions of the curb or inlet structures. The multifunctional usage of open and green areas to store water during a flood event also belongs to technical preparedness measures [(DWA/ BWK, 2013); (LUBW, 2016a)].

Urban planning and urban development planning include measures of municipal precautionary land use, risk management and municipal technical and structural measures. Among those measures are water-sensitive planning, the restriction and classification of land use, the classification of retention areas in respect to the land-use plan. For the development plan measures recommended are the determination of construction heights and the assignment of potentially high-risk areas [(DWA/ BWK, 2013); (LUBW, 2016a)].

Administrative and organizational measures include precautionary information and behavioral actions. An important field is the determination of the field of competences. Besides the development of emergency and operational plans as early warning systems are measures within this sector [(DWA/ BWK, 2013); (LUBW, 2016a)].

3. METHODS

This chapter illustrates the overall methodology of the present thesis. The workflow and decision-making process is explained with regard to each aspect of the thesis, finally leading to the development of a guideline. In this report, the term 'catchment area' refers to Linnéstaden in Gothenburg, Sweden. Linnéstaden is described in Chapter 0.

3.1. STUDY DESIGN AND ANALYTIC PLAN

The work of this thesis is generally divided in three steps, which are explained subsequently and shown in Figure 3-1.

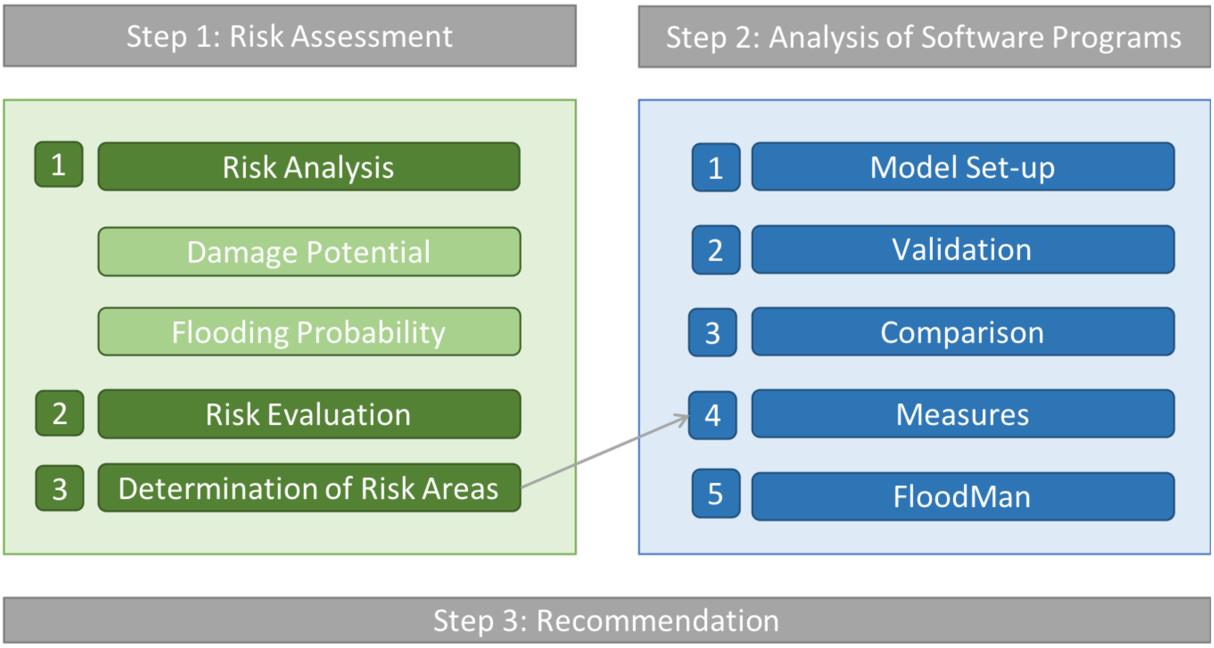


Figure 3-1: Overview analytic plan of present master thesis (created by author)

Figure 3-1 illustrates the workflow of this thesis. In general, the workflow is divided into three steps, which are labelled marked in grey. Preliminary to those steps of the workflow the catchment area Linnéstaden was described, see Chapter 0. The selection of Linnéstaden as the study area of this thesis was primarily due to the fact that Linnéstaden is located in the municipality *City of Gothenburg*. It has been examined in previous studies, which included the generation of models in MIKE 21 and MIKE FLOOD. In order to allow a thorough comparison of all three software programs investigated in this thesis, it would have not been possible to additionally establish models in MIKE 21 and MIKE FLOOD in the available time scope. At the present moment Linnéstaden is the only area within Gothenburg for which both models are available, which was the main reason for choosing Linnéstaden as a study area in this thesis.

The first and second step of the thesis are done simultaneously. For a better understanding they are labelled with Step 1 – Risk Assessment, colored in green and Step 2 – Analysis of Software Programs, marked in blue. Each of those concurrent steps has several work steps before they are combined. Step 1 – Risk Assessment is linked to Step 2 – Analysis of Software Programs, as the results from Step 1 Determination of Risk Areas are used as input for Step 2 Measures, depicted with the arrow. As third and final step of the thesis, Step 3 – Recommendation, a final recommendation is presented, which is based on the previous work steps.

The individual work steps of Step 1 and Step 2 are presented as follows.

- Step 1 – Risk Assessment

The purpose of this step was the determination of areas of potentially high flood risk within the catchment area Linnéstaden. In a first step the risk analysis, which is divided into the assessment of the damage potential and the assessment of flooding probability was determined. Afterwards a risk evaluation based on the analysis was done. The risk evaluation was followed by the final step of the risk assessment the determination of risk areas. The results of the risk assessment were used in the 4th step of Step 2 – Analysis of Software Programs. The work steps of the risk assessment are shown in Figure 3-2

Figure 3-2: Workflow of Step 1 – Risk Assessment (created by author)

- Step 2 – Analysis of Software programs

In a second step the analysis of the software programs was done, see Figure 3-3. In the first step the model set-up was investigated. This describes one model of each of the three investigated software programs. The models from MIKE 21 and MIKE FLOOD were taken from previous studies of the *City of Gothenburg*. In a subsequent step the validation, as defined in the terminology section, see Chapter 1.5, was done. In the scope of the present report the term validation means the verification with regard to previous results from simulations with the original model for MIKE 21 and MIKE FLOOD. It does not refer to a validation by a calibration or historical data for the rainfall events. The original models in MIKE 21 and MIKE FLOOD were generated with different software program versions than applied in this thesis. Further information about the applied software program versions is given in Chapter 3.3.1. For SCALGO, validation means an investigation of the results to assure they are within a reasonable range, based on a comparison with literature values and results of previous studies for the catchment. In a third step a comparison of the simulation results was done, which was divided into two steps. At first, flooding was compared for the original models in the software programs for a 100-year rain event including a climate factor of 1.2. In a second step the focus was on the basic hydrological and hydraulic factors applicable in each program. In a fourth step the results from the risk assessment were considered for the development of the measures. In addition to the analysis of the software programs with regard to the general scientific parameters, measures were implemented in all three software programs. The results, of this fourth step, were used as input for a quantitative and qualitative assessment with the FloodMan tool. In FloodMan a CBA and MCA was carried out. For the application of the FloodMan tool the results of the software programs had to be assessed with FME to be used in FloodMan.

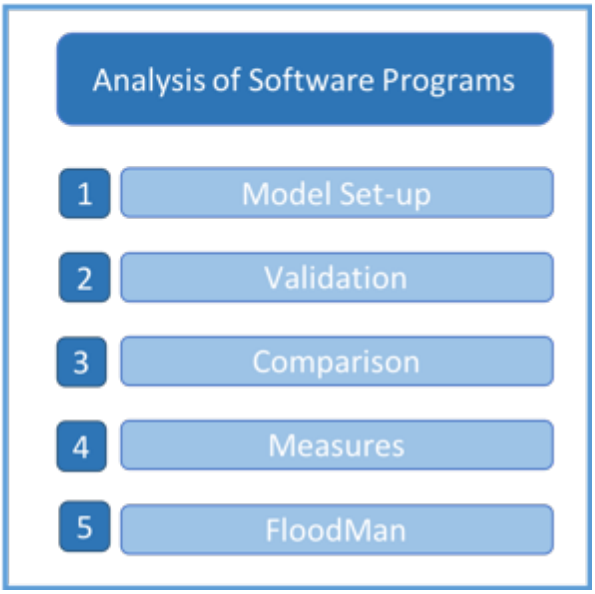


Figure 3-3: Workflow Step 2 - Analysis of software programs (created by author)

- Step 3 – Recommendation

In a final step a recommendation was developed to give guidance for the application of the software programs investigated in this thesis. The recommendation was based on the previous work steps 1 and 2, but also considers the background presented in Chapter 2.

3.2. SITE INVESTIGATION – RISK ASSESSMENT (STEP 1)

A risk assessment is a decision-making tool. A flood risk assessment should be considered as one aspect of the flood risk management and in order to achieve a holistic approach as one aspect of the water management at large (United Nations Office for Disaster Risk Reduction , 2017). However, a holistic approach for the risk assessment is beyond the scope of this thesis, thus only a flood risk assessment was done. For this thesis a preliminary flood risk assessment aiming to define priority areas of potentially significant flood risk was carried out (United Nations Office for Disaster Risk Reduction , 2017).

3.2.1. PURPOSE

The purpose of this risk assessment is to determine high risk areas, where measures need to be taken. Those areas will be regarded for the implementation of measures in the software programs. The purpose here is to investigate the manners of how the measures can be designed in the different software programs.

The risk areas shall cover all typical features of an urban environment within the catchment area Linnéstaden. The target is that all representative attributes are presented in a conclusive manner. In the scope of this thesis the following general aspects with regard to the variety of the areas of potentially significant flood risk are set for the risk assessment:

- Selection of a representative number of risk areas.
    - The selection of risk areas should be sufficient to describe the variety of environments within the catchment and describing the typical features of an urban area.
    - With regard to the time frame of this thesis the amount must allow a thorough investigation of the areas.
- Consideration of location and local conditions of the areas within the catchment area.
    - The intention is to cover areas upstream and downstream of the overall catchment, but also consider smaller catchment areas within Linnéstaden.
    - This includes considering local conditions like the topography and the land use.

In addition to the general aspects presented the risk assessment needs to correlate with the aims of the *City of Gothenburg*. Therefore, the final selection of the study areas is a joint decision with the *Department of Sustainable Waste and Water* from the *City of Gothenburg*.

3.2.2. APPROACH

In this thesis a qualitative approach was chosen by the author for the risk assessment. Based on the available data for the area Linnéstaden a combination of a simplified and topographical risk assessment was performed. For the risk assessment the inventory documents were appraised. In the scope of this risk assessment no hydraulic simulations were done, as a full hydraulic risk assessment lies beyond the scope of this risk assessment. However, the results of previous flood modelling simulations from the *Structure Plan* (Göteborg Stad, 2017b) for Linnéstaden were considered. Within the topographic analysis the topography was examined with the software program SCALGO. Despite the possibility of simulating pluvial flooding in SCALGO, the tool was solely used to investigate the topographical characteristics of Linnéstaden, for reasons stated earlier. The simulations in the scope of the *Structure Plan* were done with the software program MIKE FLOOD. As a result, the risk assessment includes the previous findings of the pluvial flood modelling with a coupled 2D surface model and a 1D sewer system model for Linnéstaden.

Throughout this thesis the term 'risk assessment' will be used to refer to the overall process including the steps of a hazard identification, the risk analysis and the risk evaluation. The risk analysis is used to the define the level of risk, which is then assessed by the risk evaluation (Canadian Centre for Occupational Health & Safety, 2018a).

Prior to the risk analysis the hazard and risk for the assessment were identified. According to United Nations Office for Disaster Risk Reduction (UNISDR) publication "Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction" in December 2016 a hazard can be defined as follows:

"A hazard is a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation."

The identified hazard for this risk assessment is flooding due to torrential rain possibly leading to flash floods. Thus, the hazard is identified as natural hazard as stated by the UNISDR (2016). Throughout this thesis the term 'risk' will be used to refer to the risk associated with the hazard torrential rain and flash flood.

The term 'risk' is defined, in accordance to the Canadian Centre for Occupational Health & Safety (2018), which defines risk as: "the combination of the likelihood of the occurrence of a harm and the severity of that harm." (Canadian Centre for Occupational Health and Safety, 2018b)

The likelihood of occurrence is the probability of the hazard happening, in this case the flash flood and pluvial flooding. The severity of the harm is described by the vulnerability, which is consecutively expressed by the damage potential.

While a variety of methods for risk analysis have been suggested, this thesis will use the approach suggested by the publication DWA T1/2013 (DWA/ BWK, 2013), which classifies the risk analysis in three steps:

1. The assessment of the damage potential
2. The assessment of the flooding probability
3. The calculation and evaluation of the flood risk

Both risk determining parameters were weighted equally in the frame of this thesis. The rating for each category was based on a scale from low risk to medium risk to high risk. Table 3-1 presents the risk categories with their representative scales, that were used in this risk assessment. At first each category was assigned to a number scale. In addition to the number scale, a second scale was implemented for the individual sub-categories, which were allocated to a sign.

Table 3-1: Scale of risk categorization for risk analysis and risk evaluation for the risk analysis of present thesis

Assumed Risk	Main Category Scale	Sub-Category Scale
Low	3	o
Medium	2	+
High	1	++

The vulnerability and probability were evaluated based on the grading in Table 3-1. The specific terms and conditions of the rating for each parameter are explained within the subsequent chapters.

For this risk assessment the subsequent steps taken, are illustrated in Figure 3-4.

Figure 3-4: Workflow risk assessment (created by author)

At first the risk analysis consisting of the two concurrent steps the assessment of the damage potential and flooding probability was carried out. At second the risk was evaluated based on the results of the risk analysis in step 1. In a third step the areas of a high probability for flood risk were identified.

3.2.3. Damage potential

In this chapter the method for the damage potential as one part of the risk analysis is described.

The damage potential was evaluated with regard to Chapter 2.2. of the publication DWA T1/2013 "Starkregen und urbane Sturzfluten – Praxisleitfaden zur Überflutungsvorsorge" ("Cloudbursts and urban flash flood - practical guideline for flood prevention"). The following definitions were adapted from the guideline.

“Damage is defined as any type of adverse consequences caused by flooding. Damage potential describes the possible and expected damage of flooding.” (DWA/ BWK, 2013)

One divides damage into monetary and non-monetary damage. Damage to buildings and its interior, public institutions or the infrastructure are examples for monetary damage. Environmental damage as well as a risk to human health and life are considered as non-monetary damage. The damage of cultural heritage is assigned to both types of damage (DWA/ BWK, 2013).

On the basis of the exemplified characterization of the damage potential of the publication DWA T1/2013 (2013, pp. 20, table 3) an analysis of the damage potential was done.

In a first step of the assessment of the damage potential five superior risk categories were determined. This system of classification provides a basis to evaluate the damage potential in Linnéstaden. The superior risk categories are:

- Risk for human life and health

The category for risk of human life and health is divided into three groups. Particularly vulnerable mankind, in terms of restricted mobility or limited risk awareness or restricted possibilities for evacuation. Areas with high passenger volumes, leading to a restricted possibility for evacuation and structural high-risk zones, which lead to a very high risk of livelihood and might provide insufficient possibilities for evacuation.

- Risk of damage and loss of cultural heritage

The term cultural heritage covers the field of archeological, historical, literary, scientific and artistic heritage. The category describes the possible loss of cultural valuable and protected heritage. The institutions might be used as evacuation centers.

- Environmental risks

The environmental damage can be caused by the following hazards: oil and gasoline, biochemical hazards, water treatment facilities, leisure facilities. Possible risks for nature conservation areas need to be considered. For such their usage is recommended to be evaluated.

- Economical and industrial risks

The risk of economical and industrial damages is categorized into the sector agriculture and forestry and the industrial sector.

- Risks to relevant infrastructures

The damage to relevant infrastructures is divided into public service and institutions as well as transport and logistical centers. Within those categorizes the objectives are relevant suppling facilities, communication, supply and evacuation and the coordination of disaster management. The term 'disaster management' is used to refer to the management of flooding due to torrential rain.

The first step was the rating of the risk of all superior risk groups by the scale for the main category, presented in Table 3-1. In the next step the objects and areas within the superior risk groups were valued, by the scale for sub-categories in Table 3-1. In addition, each superior risk group as well as the exemplified objects and areas were assigned to a type of damage, monetary or non-monetary. In the tables the type of damage assigned to the number 1 is non–monetary and the one to the number 2 is monetary.

Table 3-2 and Table 3-3 illustrate the superior risk groups with their assigned grade and the type of damage. The detailed decision-making process for the rating of the risk groups, presented in those tables, can be found in Appendix A Risk Analysis – Damage potential.

The objects and areas identified and classified by the aforementioned categories and presented in the results section of this thesis were chosen based on the local conditions in Linnéstaden. Those were assessed with the help of open street maps and local inspections by the author.

Table 3-2: Assessment of damage potential - part 1; based on DWA T1/2013 (created by author)

Superior risk categories	Risk objectives	Exemplified objects/ areas	Type of damage* 1	Type of damage* 2	Rating*
Risk for human life and health			x		1
particularly vulnerable groups	- restricted mobility	nursing home, hospital, health institution for people with disabilities	x		++
	- limited risk awareness	see above; nurseries, kindergarten, elementary schools	x		++
	- restricted evacuation	see above; penal institution	x		++
areas with high passenger volumes	- restricted evacuation (escape routes, safety zones) - institutions can be used as evacuation center	educational institutions	x		+
		hotels, hostels, …	x		+
		cultural and sportive venues (theater, public pools, church, …)	x		+
		public entities (city hall, court house, community center, …)	x		+
		shopping malls and busy pedestrian areas	x	x	+
		public transportation	x		+
structural high-risk zones	- very high risk of livelihood - limited risk awareness - insufficient possibilities for evacuation	tunnels, undercrossing (pedestrian, highway, public transport)	x		++
		underground parking, parking garages	x		++
		subterranean areas, e.g. basement flats	x		++
		underground facilities/buildings	x		++
Risk of damage and loss of cultural heritage			x	x	3
cultural heritage (archeological, historical, literary, scientific, artistic)	- loss of cultural valuable and protected heritages - high passenger volume - institution can be used as evacuation center	classified cultural sites, listed buildings	x	x	o
		museums, opera, theater, libraries	x	x	o
		church, religious sites	x	x	o
		research center	x	x	o

Table 3-3: Assessment of damage potential – part 2 based on DWA T1/2013

Superior risk categories	Risk objectives	Exemplified objects/ areas	Type of damage* 1	Type of damage* 2	Rating*
Environmental risks			x	x	2
oil and gasoline	- general contamination	gas station, fuel depots	x	x	++
biochemical hazards	- risk for human health and environment	production sites, industry	x	x	++
water treatment facilities	- high consequential damages	wastewater and drinking water treatment plants	x	x	++
leisure facilities	- endangered animal stock	zoo, wildlife park	x	x	++
nature conservation areas	- risk for human health and environment	biotope, water conservation, …	x	x	++
Economic and industrial risk				x	3
agriculture and forestry	- endangered animal stock - high consequential risk	farms and fields, park areas		x	o
industrial sector	- see above - high passenger volume	production sites		x	o
Risk to relevant infrastructure			x		2
public service and institutions	- coordination of disaster (flood) management	city hall, governmental institutions, court house, administration	x		++
		fire department, police station, military institutions	x		++
transport and logistical centers	- supply and evacuation	train station, airport, public transport, traffic hubs	x		++
	- communication	telecommunication and postal administrations	x		++
	- relevant supplies	energy supply (power plants, electricity, …)	x		++
		waste, wastewater, drinking water facilities	x		++

3.2.4. Flooding Probability

In this chapter the approach for the second aspect of the risk analysis the flooding probability is presented.

For to the evaluation of the flooding probability criteria were chosen as follows, according to the parameters recommended by (DWA/ BWK, 2013):

- Water depth and velocity
- Propagation of the flood
- Frequency of occurrence
- Dynamics of flash flood

The criteria 'water depth and velocity' and 'propagation of the flood' were evaluated based on the previous study by the *City Planning Department* of the *City of Gothenburg* the *Structure Plan* (Göteborg Stad, 2017b). It was not possible to investigate the criteria 'frequency of occurrence' due to the lack of records of flash floods and torrential rains for Gothenburg or even Linnéstaden. Furthermore the 'frequency of occurrence' is assumed to be the same for the catchment area Linnéstaden, as it is a relatively small area with about 6 km^2. The term 'dynamics of flash floods' will be used in this thesis to describe the flow paths. The criterion was assessed based on the previous study *Structure Plan* (Göteborg Stad, 2017b). In addition to the valuation due to the previous study the topography was considered, as one can conclude deeper water depths within depressions or higher velocities based on the slope or consider the flow paths based on the elevation.

In Chapter 3.2.4.1 and Chapter 3.2.4.2 the individual assessments with regard to the topography and the previous studies are explained. The flooding probability was rated according to the risk categorization in Table 3-1.

3.2.4.1. Topography

The topography of Linnéstaden was investigated with the usage of SCALGO. To identify the criteria, the characteristic features of the topography used were: depression, declination, elevation. All of these features effect the flow paths, velocity and depression. They were rated on the scale based on Table 3-1. An overview of the grades for each individual category is presented in Table 3-4.

Table 3-4: Assessment of flooding probability –rating scale for topography

Site specific topography (evaluated based on Scalgo Live)	rating*
depressions	1
assumption of high-water depth within depressions	++
declinations	2
high declinations and slopes are assumed to lead to high velocities	+
elevations	3
high elevated areas are considered as safe areas	o

Depressions are rated with the highest probability for flooding with regard to the criteria mentioned above. As a result, this category has the grade “1” and the sub-category the grade “++”. The second highest probability of flooding is assigned to the declinations. The velocity is the larger and more dangerous the higher the inclination. Subsequently, the grade given is “2” and for the sub-category “+”. The lowest probability was assigned to elevated areas, as the water will flow from the point of the highest elevation to the lowest elevation. Assuming a lower water depth at high elevated areas. This leads to the grade “3” for ‘elevations’ and the grade “o” for the sub-category.

3.2.4.2. Previous study – Structure Plan (Strukturplan)

The review was based on the previous study the *Structure Plan* (2017b). It was applied as it is the most recent study for the catchment area Linnéstaden as well as the most advanced in terms of the modelling software.

The *Structure Plan* identified several high-risk areas and residual risk areas in the catchment area Linnéstaden. All of those risk areas were classified to have a high flooding probability. The classification was based on the high reliability of the study carried out with a coupled model in MIKE FLOOD. The model covers all the aforementioned criteria apart from the ‘frequency of occurrence’.

The rating of the previous study was based on Table 3-1. All identified areas by the report were graded equally with the highest grade “1”. For the previous study there were no additional sub-categories identified as they are all given the highest grade.

3.2.4.3. Calculation of Probability

The probability was analyzed for three criteria evaluated by two equally weighted categories. In conclusion the probability was calculated as follows:

Probability = (Topography Assessment x Previous Studies): 2

Equation 3-1: Probability calculation

As shown in Equation 3-1 the probability was calculated by the multiplication of both parameters and was then divided by the number of multipliers to keep the grading scale based on Table 3-1. The grade for the probability was not limited to full numbers like the damage potential and also consists of decimals rounded to 0.25, 0.5 and 0.75. Equation 3-1 only applies if both parameters exist for the exemplified object or area in Linnéstaden. In case only one of the parameters of the flooding probability was determined, the probability is equal to the individual parameter.

3.2.5. Risk evaluation

In a final step of the risk assessment the risk for the exemplified areas and objects in Linnéstaden was defined by the multiplication of the damage potential, presenting the vulnerability and the flooding probability.

The calculation for the risk assessment is based on Equation 3-2:

Risk = (Damage potential x Flooding probability): 2

Equation 3-2: Risk evaluation

As the damage potential and the flooding probability are weighted equally it was decided to divide the risk by the number of disseminators. This allowed to maintain the grades used in the risk assessment for the final risk. Meaning that the risk categorization presented in Table 3-1 could be applied for the risk as well. However, the grade for the risk was not limited to full numbers and also consisted of decimals rounded to 0.25 and 0.5.

3.2.6. Determination of areas of potentially significant flood risk

Based on the results of the risk evaluation areas of potentially significant flood risk were identified. Due to the limited time frame of this thesis the specific focus of the measures will be on one area. The focus on measures in the scope of this thesis is only in terms of the comparison of the software programs and not on the measures themselves. Therefore, it is not necessary to present a variety of measures in different areas and instead focus on how they are modeled within the programs.

The determination of the areas was based on the preceding risk assessment. Nevertheless, the choice was also made in correlation with the aim of this thesis. As a result, the technical and practical implementation of measures to improve the situation in the high flood risk areas was a final criterion to determine for which area a measure was taken. Besides the identification of areas of high flood risk the risk assessment was also used to review areas of low flood risk. The areas of low flood risk were regarded as possible areas to implement measures e.g. serve as retention areas.

3.3. ANALYSIS OF SOFTWARE PROGRAMS (STEP 2)

This chapter determines how the different software programs are applied and evaluated. Figure 3-5 illustrates the steps of the analysis of the software programs. This chapter also gives an overview of the individual simulations and defines their purpose. The investigated software programs are SCALGO, MIKE 21 and MIKE FLOOD. The scientific background to each software program can be found in Chapter 2.2. of the literature study.

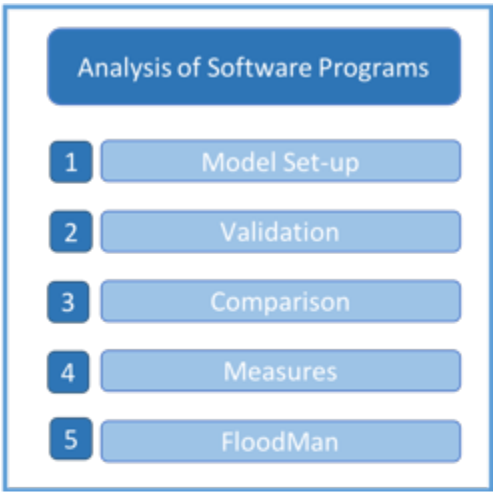


Figure 3-5: Workflow analysis of software programs (created by author)

In general, the mapping and comparison of the results of the simulations was done with ArcGIS, to be explicit with ArcMap. With the aid of ArcGIS water depth and flow accumulation for all three programs as well as flow velocity and time at maximum water depth were analyzed. All maps presented in the results were generated in ArcMap unless otherwise mentioned. In addition to the analysis with ArcGIS the results provided by the individual programs e.g. volume balances in MIKE ZERO by DHI software's were evaluated.

In the scope of this thesis all computational operations were done with the system: Windows 7 (64-bit operating system) and Intel® CoreTM i7 processor with 16 GB installed memory (RAM), provided by *Sweco Environment AB*. The system should be considered when comparing and rating the computational time of the simulations in the present report.

For this thesis the following versions were used in the respective software programs. For SCALGO Live the web interface is continuously updated but the latest major changes used in the scope of this thesis were the updates in March 2018 and the introduction of sub-surface tools like subsurface basins and sewage drains in the workspace in the beginning of September 2018 (SCALGO ApS, 2018h). The individual data source updates are described in the model set-up of this report. For the software programs MIKE 21 and MIKE FLOOD by DHI the version of MIKE ZERO – Release 2017 Service Pack 2 (Version 16.0.0.12105) was used in the present report. At time of the creation of the present report this version of MIKE ZERO by DHI (Hørsholm, Denmark) was the latest updated version (DHI, 2018d).

3.3.1. Description of model set-up

All three programs have a different scientific background, thus differ in what data is used to generate the models and how flooding is generated. In this section the generation of the models and their set-ups are explained. The models for MIKE 21 and MIKE FLOOD are existing models and were not generated in this thesis. For both programs of MIKE ZERO the models were created by DHI (Hørsholm, Denmark) on behalf of the *City of Gothenburg* in cooperation with *Sweco Environment AB* for previous studies of the city. For MIKE 21 the model is from the project *Cloudburst modelling* project generated in 2015. For MIKE FLOOD the model is from the project *Structure Plan* generated in 2017. For SCALGO no model set-up exists in the manner of MIKE 21 and MIKE FLOOD, but the initial data used in SCALGO for this thesis will be referred to as model set-up in the following as well.

In comparison to the software program version applied in the present report for the products of MIKE ZERO by DHI (Hørsholm, Denmark) the differences in the software versions of the original models of the *City of Gothenburg* need to be respected before further considerations of the model set-ups. The software version of the respective models and generations are summarized in Table 3-5 and Table 3-6:

Table 3-5: Comparison of software program version for MIKE 21 for original model and applied version in present report.

Source	MIKE ZERO	MIKE 21
Cloudburst modelling - Original set-up (Göteborg Stad, 2015a)	Presumably 2014 Release	PFS Type: Dec 16 2013 19:42:22
Present master thesis	MIKE ZERO 2017 Service Pack 2 (April 2018)	Version 16.0.0.12105

Table 3-6: Comparison of software program version for MIKE FLOOD for original model and applied version in present report

Source	MIKE ZERO	MIKE 21	MIKE FLOOD
Structure Plan – Original set-up (Göteborg Stad, 2017b)	MIKE ZERO 2016 Release (1.12.2015)	PFS Type: Nov 22 2015 02:58:09	MOUSE HD Computation Engine x64 v2016 Release Version (15.0.0.9324)
Present master thesis	MIKE ZERO 2017 Service Pack 2 (April 2018)	Version 16.0.0.12105	MOUSE HD Computation Engine x64 v2017 Release Version (16.0.0.12105)

As shown in Table 3-5 and Table 3-6 the applied software program version for MIKE ZERO by DHI differ for both models (MIKE 21, MIKE FLOOD). Due to those differences and regular updates since the generation of the models by DHI (Hørsholm, Denmark) on behalf of the *City of Gothenburg* for the *Cloudburst modelling* (Göteborg Stad, 2015a) and the *Structure Plan* (Göteborg Stad, 2017b) some adaptions had to be done of the original model set-up to adjust to the latest software version applied in this thesis. Those adaptions are described in the respective chapters of the model set-up for MIKE 21 (Chapter 3.3.1.2) and MIKE FLOOD (Chapter 3.3.1.3).

3.3.1.1. SCALGO

For this thesis a workspace of the catchment area Linnéstaden was manually created, see Figure 3-6. The boundary of the workspace was set equally to the boundary of the actual catchment based on the selection of the previous studies and a map of Gothenburg.

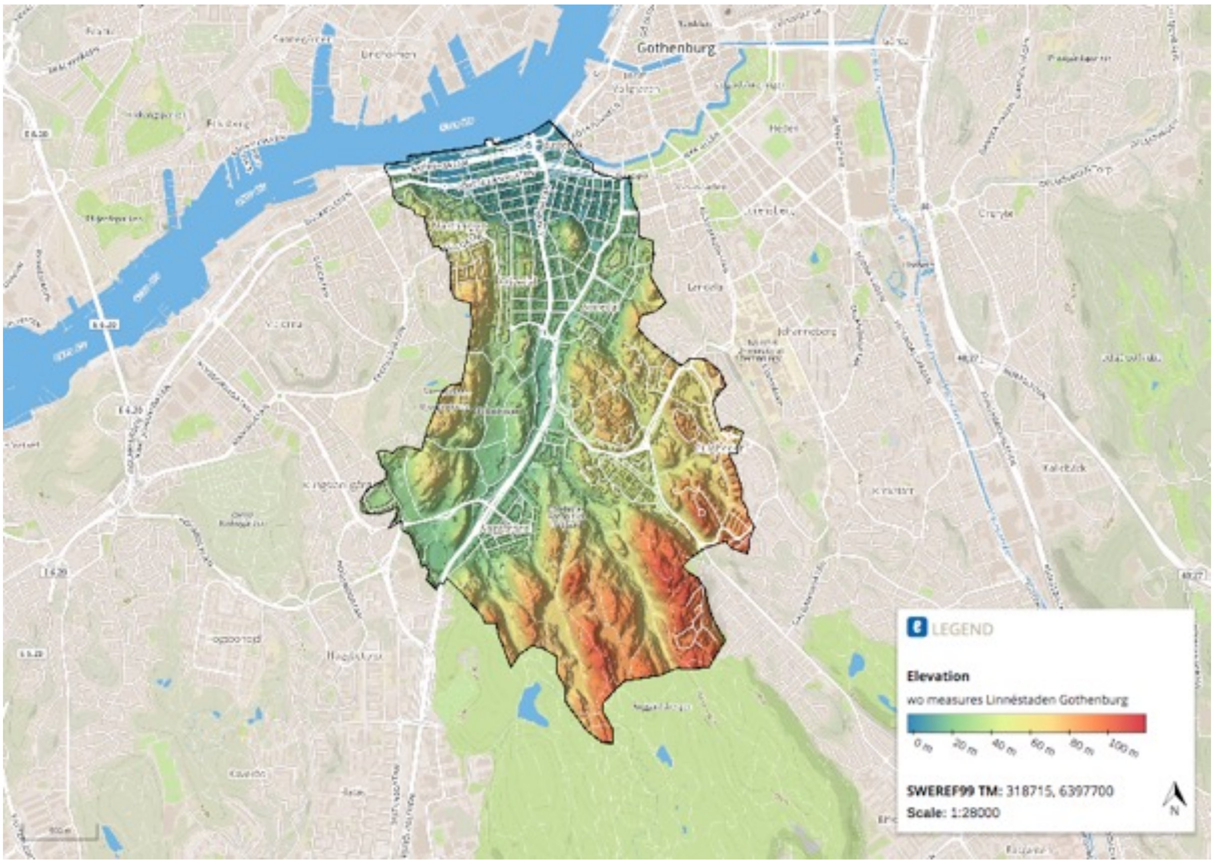


Figure 3-6: Illustration of model boundary in the software program SCALGO generated for present thesis. The black line marks the catchment area Linnéstaden. (generated in SCALGO with basic base map as background by author)

The workspace layer used in this thesis was based on the initial source for the digital elevation model in SCALGO for Sweden. The properties are outlined in the following.

The source for the catchment area Linnéstaden is based on the National Elevation Model for Sweden, generated by "Lantmäteriet's GSD Höjddata grid 2+", which has a grid resolution of 2x2 meter. The data was acquired on 23.7.2017 and is based on the airborne LIDAR scans from 2009 to 2016 (SCALGO ApS, 2018f).

The National Elevation Model, GSD elevation model grid2+, has the reference system SWEREF 99 TM, which can be transformed to any other regional refence system in the plane. In the height the reference system is RH 2000 (Lantmäteriet, 2016a). For the application of this program no changes in the elevation were done in the initial set-up.

The source for the buildings in the catchment area is the "GSD Fastighetskartan" from Lantmäteriet, which are the property maps acquired 23.7.2017 (SCALGO ApS, 2018f). The maps contain real property boundaries from the Cadastral Index Map, which displays information from the Real Property Register (Landmäteriet, 2017). The grid cells of a building are all raised to a height of 10 m above the highest terrain point within the building area (SCALGO ApS, 2018f).

In this thesis the so called the hydrological analysis was done with the so-called "Flash Flood Mapping". The analysis displays the flooded areas for the defined event, meaning the chosen precipitation and minimum water depth. The tool is used to display the depth of the flooding and show the flow accumulation for the event. In addition, the volume of depressions and the amount of precipitation from, which point the cell was flooded can be determined (SCALGO ApS, 2018g).

As aforementioned the precipitation is the pivotal and only input data determining the rain event in SCALGO. At the current state there is no established method on how to choose the precipitation height as input data in a scientific manner compared to more advanced programs. Therefore, this thesis aimed to investigated an approach applicable for the *City of Gothenburg* in the scope beyond of this thesis. The determination of the precipitation data with two approaches is described in the subsequent chapters of thesis.

3.3.1.1.1. Determination of Precipitation Indata

In this section the methodology for the selection of the input precipitation for SCALGO applied in the present report is described. For this thesis two approaches to determine the precipitation height in mm were applied by the author. The first approach was a visual assessment and the second approach a hydrological and mathematical assessment.

The first approach was based on achieving a similar flood propagation and depth like the previous studies solely from a visual selection of the precipitation height. The study used for this was the *Structure Plan* of the *City of Gothenburg*, as it was the most recent study for the investigated catchment. The value for the precipitation height was determined to be that value after which no or solely small changes occur for the flood propagation in Linnéstaden. The selection of the first value for the precipitation was done without the application of ArcMap to solely investigate the precipitation height within the scope of the SCALGO interface. A major uncertainty of this approach is the subjective selection of a precipitation and that previous results are required to use this approach. As one aim of this thesis is to give general guidance considering those programs it is a large limitation to narrow the results to a more subjective approach. Additionally, this approach requires flood maps from previous studies. When evaluating the results, one must consider that those existing flood maps from previous studies might be outdated, e.g. as newer Data sets of a DEM exists.

As a result, a second approach was considered to determine the precipitation in a scientific manner. Due to the limitation of SCALGO to just one precipitation value, this precipitation was defined as the mean precipitation of the catchment area, occurring to the same extent in the overall catchment. This mean precipitation is also assumed to be applied at exactly the same time throughout the whole catchment. This simplification is caused by to the fact that one cannot include a time factor in SCALGO.

The mean precipitation is assumed to occur with the mean rain intensity for the area. Based on the publication P104 (Svenskt Vatten, 2011a), the rain intensity for Swedish conditions shall be calculated by the method and equation after *Dahlström 2010*. The rain intensity according to *Dahlström 2010* is calculated as follows (Svenskt Vatten, 2011a):

$$i = 190 * \sqrt[3]{Å}\frac{\ln(T_R)}{T_r^{0,98}} + 2$$

Equation 3-3: rainfall intensity by Dahlström 2010 according to Svenskt Vatten P104 (2011a) equation1-5, page 24

With:

	Swedish original name	English translation	Unit
i	Regnintensitetet	Rainfall intensity	l/s*ha
Å	Återkomsttid, månader	Return period	Month
T_r	Regnvaraktighet, minuter	Rain duration	Minutes

The equation can be applied for rainfall durations up to one day and return periods up to 100-years (Svenskt Vatten, 2011a). Therefore, this equation is sufficient to be applied for torrential rain and flash floods as they are assigned to a 100-year return period. In addition, to the applicability of this equation in a general manner for Sweden the same equation is used to determine the CDS–rain for MIKE 21 and MIKE FLOOD by DHI (Hørsholm, Denmark), as described in the literature review of this thesis for the *Structure Plan* and the cloudburst mapping with regard to the *Developing master plan*. The CDS-rain is based on the principle of intensity-duration curves for maximum average intensities for differing durations (Svenskt Vatten, 2011a). See previous chapter 2.4.1 for further information. This correlation supports the accuracy of the comparison of the software programs investigated in the present report. A calculation of the CDS-rain for SCALGO was neglected as to many assumptions and simplification would be required for a utilization in SCALGO. As previously described in SCALGO, one cannot consider a time factor and must assume a simplified charging of the rain load at the same time in every grid cell of the model.

In order to apply the *Dahlström 2010* equation (Svenskt Vatten, 2011a) the following assumptions and simplifications have been made in the present report:

- The rainfall duration described with the duration in the *Dahlström 2010* equation should only cover the duration of the peak rain, meaning the most intensive rain period.
- The rainfall intensity as well as the precipitation are mean values for the catchment area and might differ to actual values measured in the area for the chosen return period.
- The investigated return periods are a 100-year rain, as defined for torrential rain and flash floods and for the application of the FloodMan tool the additional return periods 50-year and 200-year rain are investigated, see Chapter 3.4.
- The rain load in terms of the precipitation does not consider the capacity of the sewer system or the effects of infiltration in the catchment area.
- The intensity thus the precipitation calculated based on *Dahlström 2010* (Svenskt Vatten, 2011a) will be increased by a climate factor of 1.2, as applied by the *City of Gothenburg* according to the *Developing master plan* (Göteborg Stad, 2017e) based on a recommendation by Svenskt Vatten.

For those initial conditions the precipitation and rain intensity were calculated. The precipitation height was calculated with Equation 3-4 based on the relation of precipitation and rain intensity (Svenskt Vatten, 2011a).

$$P_{mean} = i_{mean} * T_R$$

Equation 3-4: Calculation of mean precipitation as input data for SCALGO (holistic approach)

With:

P_{mean}	Mean precipitation height	[mm]
i_{mean}	Mean rainfall intensity according to *Dahlström 2010* (Svenskt Vatten, 2011a)	[l/s*ha]
T_r	Rain duration	[min]

In an additional step the results for flooding with and without a climate factor solely in SCALGO were assessed. As previously mentioned the climate factor was chosen according to the *Developing master plan* with a value of 1.2 (Göteborg Stad, 2017e).

Both results from the visual and holistic approach were compared and evaluated with regard to the existing models and simulation results in MIKE 21 and MIKE FLOOD with the aid of ArcGIS, see the validation of SCALGO.

3.3.1.2. MIKE 21

The model in MIKE 21 has originally been generated by DHI (Hørsholm, Denmark) and *Sweco AB* on behalf of the *City of Gothenburg* for the project and report *Cloudburst modelling* in the year 2015. The set-up for the model in MIKE 21 was primarily applied in the manner described for the *Cloudburst modelling* study, see Chapter 2.4.1.2. The MIKE 21 model, applied in this thesis, was generated in MIKE 21 with the hydrodynamic module for inland flooding (Göteborg Stad, 2015a).

The map projection for the bathymetry was set to the SWEREF99 12:00. The elevation model was based on the *Swedish National Elevation Model*, the so called “*Lantmäterierts Nationella höjdmodellen*”. At the time of the model generation for the *Cloudburst modelling* the relevant laser scanning was from 2010/2011 and has a grid of a 4x4 m resolution. Some adaptions were done to the height modelling, which are as follows (Göteborg Stad, 2015a):

- For building locations, the height model was increased by two meters.
- Under bridges and in the port area the level was set to ground level.
- Water bodies in the model were defined as land. Errors have been adjusted with manual entering of water levels.
- The height model did not consider pipes or culverts in watercourses in any way.

With regard to soil properties like land use, surface roughness and infiltration the model was created in the following manner. The land use was classified by the soil map provided by the *Department of Sustainable Water and Waste* of the *City of Gothenburg* determining the field infiltration. The land use was taken from the "Urban Atlas" (Göteborg Stad, 2015a).The surface roughness was classified by the Manning number, depending on the land use classification into permeable or impermeable surfaces. The Manning number was adjusted to support the model stability. The field infiltration has been limited to permeable surfaces, thus impermeable surfaces have been assigned to no field infiltration. In MIKE 21 the infiltration was modelled with a constant infiltration capacity, constant in time and varying in space. In this scope the Manning numbers were adjusted with regard to the inclination. The amendments of the Manning number have been done by changes of the velocity, thus the Manning number themselves have not been changed (Göteborg Stad, 2015a).

In the *Cloudburst modelling report* the return periods investigated were 100-years and 500-years including a climate factor of 1.2. The rain load applied was the statistical rain distribution of the CDS rain, based on the report P104 of Svenskt Vatten. The simulation period for the model was determined to 3 hours. For the application on the infiltration module on the peak rain period of 30 min was applied on the model. In the rain load a deduction for the consideration of the sewer system was included. The capacity was set to 2-or 5-year rain events. The deduction was done for impermeable surfaces assumed to be connected to the sewer system. Permeable surfaces were charged with the whole rain load. The study also included a sensitivity analysis that illustrated the impact of field infiltration and sewer system deductions on the results (Göteborg Stad, 2015a).

Changes of the original model set-up of the *Cloudburst modelling* were made in the scope of this thesis. As described in the literature section, Chapter 2.4.1.2, the original model covers "mellanstaden" and not just the study area investigated in this thesis. In order to shorten the computational time, the original model was cropped to the area of Linnéstaden. As "mellanstaden" does not include the whole catchment of Linnéstaden the area was enlarged in the south to cover the full area of Änggården in the same manner as in the *Structure Plan* and possible with the software program SCALGO Live. This was done by using the DEM of the *Structure Plan*. Despite adaptions to the size of the area the original boundary conditions were maintained. Another adjustment to the original set-up was required due to the different software program versions of the generated model in the scope of the *Cloudburst modelling* and the present thesis. One major update was the adaption of the infiltration and leakage within the 2D surface flow modelling with the MIKE 2016 Release (DHI, 2018d). Due to this update adaptions of the model set-up for this thesis were necessary with the new interface including the infiltration and leakage. Several other updates and improvement must be considered due to the time period of about 4 years between the software versions applied and should be respected when evaluating the results.

3.3.1.3. MIKE FLOOD

The model in MIKE FLOOD used in the present report is the model for MIKE FLOOD generated in the scope of the *Structure Plan* for Linnéstaden (Göteborg Stad, 2017d). The model for the *Structure Plan* was set-up on behalf of the *City of Gothenburg* in the manner described in the methodology section, see Chapter 2.4.1.3. For better clarity the crucial parameters and aspects are described in this section as well.

The model in MIKE FLOOD was generated from an existing model in MIKE URBAN, from 2008 by DHI (Hørsholm, Denmark), and an existing model in MIKE 21 from 2015 by DHI (Hørsholm, Denmark) and *Sweco AB*. The sewerage capacity in MIKE URBAN was generally assigned to a 10-year rain event. The rain load applied on the model was a 100-year rain event with a climate factor of 1.2 and a central statistical rain distribution of a CDS rain (Göteborg Stad, 2017d).

The rain load was divided between the modules of the coupled model in MIKE FLOOD, meaning between MIKE 21 and MIKE URBAN. The rain from impermeable areas was charged to the sewer system in MIKE URBAN and to the surface model in MIKE 21. Rain on permeable areas was solely loaded to the surface model in MIKE 21. The model in MIKE URBAN includes the sewer system for Linnéstaden as well as the systems from Vasastaden and Lorensberg. Mains of the stormwater sewer with a diameter large than 800 mm are included in the model and the combined sewer systems. This model was simulated for the whole rain duration of 6 hours generating the initial situation in the sewerage applied for the simulation of the coupled model (Göteborg Stad, 2017d).

The pre-conditions for the infiltration capacity in MIKE 21 were calculated manually and classified as pre-rain. The basis for the rain load calculation was the CDS rain distribution and the rain intensity calculation according to *Dahlström 2010* (Göteborg Stad, 2017d).

The coupled model in MIKE FLOOD was charged for the peak duration of 30 min with the most intense rain and the after-rain. In case of the sewerage capacity in MIKE URBAN exceeding a 10-year rain the excess water was loaded on to the surface model in MIKE 21 (Göteborg Stad, 2017b).

A sensitivity analysis for the MIKE FLOOD was done leading to the adjustment of the water level of the river Göta Älv (Göteborg Stad, 2017d). For this sensitivity analysis done in the scope of the *Structure Plan* for Linnéstaden no further information was available describing the explicit approach and investigated scenarios. In addition to the sensitivity analysis the credibility of the models used in the *Structure Plan* (Göteborg Stad, 2017b). was demonstrated by the study for torrential rain modelling in Malmö, Sweden, as described in the general methodology for the development of *Structure Plan*'s, see Chapter 2.4.1.3.1.

In addition, the original model set-up one must consider updates and changes in the software program version used in the *Structure Plan* for the model generation and the applied software version in the present report. The software version used for the *Structure Plan* included the infiltration and leakage in the 2D surface modelling, thus no changes for the infiltration were required in in comparison to the model in MIKE 21 from the *Cloudburst modelling* study. Thus, updates did not require changes of the model set-up for MIKE FLOOD in this thesis, but should be considered when evaluating the results. Changes considering MIKE FLOOD include for example a better hardware usage of MIKE 1D in MIKE URBAN decreasing the computational time and adaptions of the MOUSE engine for better stability (DHI, 2018d).

3.3.2. VALIDATION

In this thesis the term validation was defined differently from a general scholastic meaning, see Chapter 1.5. For MIKE 21 and MIKE FLOOD the term was applied to describe the verification of the models used in the present report with the models used in the original studies, as the software programs were updated and the models had to be adapted. Validation in this thesis does not refer to a validation by a calibration or historical data for the rainfall events. For SCALGO the validation means an investigation of the results to assure they are within a reasonable range, based on literature value and previous studies for the catchment.

For MIKE 21 and MIKE FLOOD the validation of the models is done by a simulation of the models with the current software version opposed to the software version used for the generation of the models. Detailed information about the software program version is given in Chapter 3.3.1. Subsequently, a comparison of the results for flooding in terms of the water depth, the inundation areas and the velocity were done.

In this first step of the validation of the models, no major changes to the model set-up were done in respect to the original models generated by DHI (Hørsholm, Denmark) and *Sweco AB* on behalf of the *City of Gothenburg*. The studies *Cloudburst modelling* and the *Structure Plan* for Linnéstaden have included a sensitivity analysis for the respective MIKE 21 and MIKE FLOOD models [(Göteborg Stad, 2017d); (Göteborg Stad, 2015a)]. Moreover, the *Structure Plan* has proven that the modelling approach applied by the *City of Gothenburg* is sufficient without calibration based on the study for Malmö (Göteborg Stad, 2017b).

Therefore, the author decided that no further sensitivity analysis and calibration was required for the application of the models from the aforementioned and described studies for the catchment Linnéstaden. The pre-requisite for the use was that the sensitivity analysis and calibration are only valid, if the simulation of the models used in this thesis and with the software version 2017 for MIKE ZERO by DHI (Hørsholm, Denmark) show little or no discrepancy to the results from original simulation of the models with older software version of MIKE ZERO by DHI (Hørsholm, Denmark). For an actual planning process with the design and calculation of explicit measures a new sensitivity analysis is highly recommended. On the contrary for this thesis the focus is on the results and not on the design of measures. In conclusion, one can presume the sensitivity analysis for the existing models of MIKE 21 and MIKE FLOOD from the previous studies is sufficient if the pre-requisites are fulfilled.

3.3.2.1. SCALGO

The validation for the results of SCALGO was obtained with regard to the two approaches presented in the section of the model set-up. In a first assessment the visual approach was assessed. It was compared with results from the *Structure Plan* and compared to the results from the holistic approach. This comparison was done with the aid of ArcMap. The second assessment of the holistic approach was done by a comparison of results to existing literature values by *Dahlström 2010* (Svenskt Vatten, 2011a) and an assessment of the results with regard to the used models in MIKE 21 and MIKE FLOOD. For all scenarios a 100-year return period and a 100-year return period with a climate factor of 1.2 were considered. Subsequently to the previous consideration for SCALGO the possibility to consider the effects of the sewer system was attempted to be regarded as well. The consideration of the sewer system was based on the general deduction recommended by MSB (2014).

With respect to the literature, the values for the precipitation height were compared to values after *Dahlström 2010*, based on the values presented in P104 by Svenskt Vatten (2011a). The following scenarios were compared with the simulations of MIKE 21 and MIKE FLOOD of the original models from previous studies:

1. <u>Precipitation for peak duration 30 min</u>

The duration of the peak rain is the same duration for all software programs. The duration was set to a 30 min rain duration [(Göteborg Stad, 2015a); (Göteborg Stad, 2017b)].

2. <u>Precipitation for total duration</u>

The total duration of the simulation is 3 h in MIKE 21 and MIKE FLOOD 6 h. With regard to this duration the duration was adapted and a new precipitation calculated. The determination of the total rain load in form of the precipitation for MIKE 21 and MIKE FLOOD is subsequently explained.

In MIKE 21 the total rain load has been divided into the pre-rain and the peak rain, see Equation 3-5. The load of the pre-rain has been charged to the infiltration. As a result, the total rain for the 100-year rain event for a duration of 3 h, in the case of the MIKE 21 model used in this thesis, consists of the pre-rain and the peak rain in mm (Göteborg Stad, 2015a).

$$P_{total} = P_{pre-rain} + P_{peak} \qquad [mm]$$

Equation 3-5: Precipitation height MIKE 21

In MIKE FLOOD the total rain load has been divided into the pre-rain, peak rain and after-rain duration. The rain has been divided to the sewer system and the surface runoff. The pre-rain has been charged to the sewer system, thus MIKE URBAN. The after rain has been charged to MIKE 21 in addition to the peak rain. The rain load for the total duration was determined by the sum of the pre-rain, peak rain and pre-rain, see

$$P_{total} = P_{pre-rain} + P_{peak} + P_{after-rain}$$

Equation 3-6: Precipitation height MIKE FLOOD

3. <u>Precipitation with sewer system deduction</u>

For the precipitation with the sewer system different capacities were assigned to the sewer system in the previous studies of Linnéstaden. In MIKE 21 the sewer capacity was considered with a reduction of the rain load by 2-year and 5-year rain events (Göteborg Stad, 2015a). In MIKE FLOOD the actual sewer system is modelled in MIKE URBAN with a capacity of a 10-year rain event (Göteborg Stad, 2017b).

The input data for SCALGO must be considered as mean values and so the reduction of the rain load by a defined capacity according to the design criteria of the Swedish standard is a mean reduction assuming a reduction in every point of the catchment area to the same extent, which does not correspond with the actual sewer system. However, it is an attempt to compare the flooding with considering the sewer system. For a calculation of the precipitation with consideration of the sewer system one was must consider that the capacity the sewer system is assigned to is based on today's capacity and therefore no climate factor is applied to the sewer system's capacity.

Based on the validation of both approaches a final approach was chosen and applied in the further process.

3.3.2.2. MIKE ZERO

The validation of the results simulated with the software program MIKE ZERO by DHI were done in the same manner for MIKE 21, in respect to the project *Cloudburst modelling*, and for MIKE FLOOD ,with regard to the study *Structure Plan* for Linnéstaden. The explicit model set-up used in the present report is described in the previous Chapter 3.3.1.

The results from the simulations were mapped and compared with the help of the tool ArcGIS. The parameters for the comparison were the water depth, the flood propagation and the flow velocity. The flood mapping of the original results has been done for water depth's exceeding 10 cm [(Göteborg Stad, 2015a); (Göteborg Stad, 2017b).]. However, for the validation the whole range of water depths was evaluated. In MIKE FLOOD no changes were done to original set-up provided by the *City of Gothenburg*, generated for the *Structure Plan* of Linnéstaden. In MIKE 21 some adaptions had to be done to provide the same set-up due to changes of the software program. Adaptions were done to the infiltration module and to the DEM model to cover the whole study area.

3.3.3. Comparison without Measures

The comparison of the software programs in this step includes two comparisons. At first, flooding was compared for the original models in the software programs for a 100-year rain event including a climate factor of 1.2. In this step no additional simulations were run. In a second step a special focus was given to hydraulic parameters with respect to the runoff generation of the hydrodynamic software programs MIKE 21 and MIKE FLOOD. More precisely the focus was on the 2D modelling program MIKE 21. As MIKE FLOOD consists of the urban linkage model MIKE 21 and MIKE FLOOD, the same changes done in MIKE 21 for just MIKE 21 are applied in the coupled 2D model of MIKE FLOOD. The purpose of the second comparison with regard to those crucial parameters for the stormwater runoff was to show their effects on the modelling results. By simplifying the more advanced software programs one assumes that the results should be more similar to SCALGO. Resistance, defined with the Manning number for the applied models, and infiltration are determinants for the runoff generation.To illustrate the effect of those parameters five different scenarios were simulated in MIKE 21 and MIKE FLOOD and were compared to the results in SCALGO. For SCALGO no changes were done. The scenarios simulated for this comparison are presented in Table 3-7.

Table 3-7: Overview of simulations for basic comparison with variation of infiltration and resistance for present report

Comparison Scenarios	Infiltration	Resistance - Manning Number [$m^{1/3}/s$]
Scenario 1	None	50
Scenario 1-1	None	2
Scenario 2	Infiltration file	50
Scenario 2-1	Infiltration file	2
Scenario 3	None	Resistance File
Scenario 4	Infiltration file	Resistance File

Scenario 1, 2 and 3 are the simulations explicitly run for the comparison. Scenario 4 in the Table 3-7 is equivalent to the original scenario for the torrential rain simulation and only serves as an addition for a better overview. As shown in Table 3-7 the infiltration was set to no infiltration or the original infiltration file was used. The base for the infiltration files were from the original models used on this thesis. The infiltration type used in the infiltration file was a constant infiltration with capacity. A further description can be found in Chapter 3.3.1. For the infiltration the author decided to run a scenario without infiltration instead of a constant value for the infiltration, as SCALGO does not include the infiltration either. Besides the general effect of the infiltration on the individual program simulations was considered. Several studies have recommended an infiltration deduction or neglect infiltration due to oversaturated soil or the effects of erosion and capping of torrential rain. Therefore, the analyses of the individual program results were regarded as well.

The investigation of the Manning number was based on the simulation of the minimum and maximum Manning number chosen in the *Cloudburst modelling* study, equivalent to the values in the original set-up of the MIKE 21 model, see Chapter 3.3.1. The Manning number was set to a maximum value of 50 $m^{1/3}/s$ and a minimum value of 2 $m^{1/3}/s$. For simulations with the resistance file each point in the grid is assigned to a resistance, thus Manning number. Instabilities in MIKE 21 and MIKE FLOOD may occur due to the changes to the Manning number, as the Manning number is also commonly assigned to a specific range to assure the stability of the model according to the respective manual for MIKE ZERO by DHI (Hørsholm, Denmark). In case of the occurrence of instabilities due to changes of the Manning number no adaptions will be made as the simulations aim to illustrate the different effects of such changes and a sufficient model set-up with the resistance files in MIKE 21 and MIKE FLOOD exists and was validated in the previous step of the software program analysis.

3.3.4. Measure Implementation

This chapter presents the methodology for the implementation of measures with regard to the different software programs. The areas of high flood potential were identified by the risk assessment, see chapter 3.2. The measures were implemented in a preventative manner. This chapter includes a description of the design of the measures and the respective simulations and analysis. As described previously the measures were designed for pluvial flooding, aiming to improve the extent of the explicit hazard. Thus, they do not cause additional flooding but also do not hinder additional flooding in other flood sectors. This approach was also recommended by the *Developing master plan* (Göteborg Stad, 2017a).

Based on the legal aspects, presented in Chapter 2.5, and the state of the art for flood measures in respect to pluvial flooding, see Chapter 2.6, the measures were designed by the author in this thesis. The selection of the type of flood measures in the present report was carried out in line with the aims of the *City of Gothenburg*. The following design criteria were set for measures in cooperation with the *Department for Sustainable Waste and Water*, *City of Gothenburg*, and *Sweco Environment AB*:

- Due to competing interest a multifunctional usage of the measures was preferred (Göteborg Stad, 2017a). Meaning that the areas assigned to measures could also be used in flood-free periods.
- As torrential rain occurs without significant warning periods a permanent installation to assure the preparedness for the torrents was aimed for.
- Measures should function in a preventative matter, see reasoning as for permanent installation.
- The focus was given to the implementation of structural and technical measures.
- Considerations of non-structural measures, e.g. the planning and communication with the affected population were neglected in the execution of measures in this present report. Mainly for the reasons that they could not be compared in the investigated software programs.

The emphasis of simulating measures was to show the similarities and differences in the modeling of measures with SCALGO, MIKE 21 and MIKE FLOOD. In addition, the objective was to draw conclusion on the applicability of the software program. For the purpose of a better comparison the focus was on implementing similar measures in all programs in terms of what type of measures and location. But with the addition of an increased complexity of the embodiment of the measures from SCALGO to MIKE 21 and MIKE FLOOD, to the use the possibilities of each program to the fullest extent.

On this account the design of the measures for all software programs had the same and common first step, which were measures leading to adaptions to the DEM. For reasons of time and technical implementation the changes to the DEM were done in SCALGO. For this the DEM of MIKE ZERO, used for MIKE 21 and MIKE FLOOD was imported to SCALGO and after changes were done exported to MIKE ZERO again. This step also allowed a direct comparison of the different raster formats of the MIKE ZERO software programs and SCALGO. This process supported the creation of similar scenarios and measures for all software programs. The design event, which was primarily investigated was a 100-year return period with a climate factor of 1.2 according to the *City of Gothenburg*'s state of the art (Göteborg Stad, 2017e).

3.3.4.1. Overview Analysis and Simulations

For the implementation one simulation and analysis for each program was done for the 100-year return period with a climate factor of 1.2, with adaptions located in the catchment area Linnéstaden due to measures and actions taken.

In addition to the simulation for a 100-year return period with a climate factor simulations and analysis for different return periods, thus different rain loads, were required for the application of the tool *FloodMan*. The tool itself is described in the consecutive chapter, Chapter 3.4. For this scope the additional return periods of a 50-year and 200-year rain event were chosen to investigated, as at least three return periods are required to perform a full analysis (Rosén & Nimmermark, 2018). The reason for choosing those return periods was the availability of the rain files for the software programs MIKE 21 and MIKE FLOOD and the applicability for the holistic approach in SCALGO.

Table 3-8, gives an overview of the scenarios simulated for the investigation of the implementation of measure of the software programs.

Table 3-8: Overview of return periods and respective scenarios of present report

Scenario	Software Program	Return periods		
		100 year	50 year	200 year
1	SCALGO	Design event	FloodMan	FloodMan
2	MIKE 21	Design event	FloodMan	FloodMan
3	MIKE FLOOD	Design event	FloodMan	FloodMan

In Table 3-8 the return periods are assigned to their purpose and the scenarios are labeled in the same order as they were applied in the simulations. FloodMan refers to those simulations only required for the application of the tools FME and FloodMan. Design event refers to the 100-year event including a climate factor investigated in all simulations of this report. All return periods consider a climate factor in the simulations.

The return periods for MIKE 21 and MIKE FLOOD refer to the rain files used in those two programs. For SCALGO the return period was used to calculated the rain load with the final approach chosen for SCALGO, see Chapter 3.3.1.1. The calculation of the precipitation is shown in Table 3-9. The values shown in the last column of Table 3-9 were used as input data for SCALGO.

Table 3-9: Calculation of precipitation for SCALGO for different return periods (Calculation according to equation of Dahlström 2010 (Svenskt Vatten, 2011a))

Return period [year]	Duration [min]	Intensity [l/s*ha]	Intensity with climate factor [l/s*ha]	Precipitation [mm]
100	30	247.02	296.42	53.40
200	30	310.71	372.85	67.10
50	30	196.47	235.77	42.40

3.3.4.2. Implementation of Measures in Software Programs

In this section the design of the measures considered in each software program is described. The locations for the implementation of the measures were chosen according to the results of the risk assessment, as described in Chapter 3.2

3.3.4.2.1. SCALGO

In SCALGO measures can generally be implemented by editing the workspace created, as described in the SCALGO Live Documentation (SCALGO ApS, 2018e). With the tools one can either change the elevation or add structures. For changes to the elevation several tools are available with which one can for example lower or raise a path or area. There are two tools available to add structure, which are the tools “Subsurface Structure” and “Subsurface basin and sewage drains”. With the “Subsurface Structure” tool one has the possibility to create a path or area to simulate an arbitrary measure. The tool is recommended by SCALGO (2018e) to be used for pipes or culverts. The structure has an unlimited capacity to transport water and cannot store any volume. By using the tool no changes to the elevation are made and the tool is considered to be subsurface (SCALGO ApS, 2018e). The tool “subsurface basin and sewage drains” allows the definition of a storage volume for the basin. This can be done by choosing a volume manually or the so-called “query tool”, which will select the volume at the sink point for the given rain event (SCALGO ApS, 2018e). In this thesis the application of the tools to solely change the elevation were used to create a dam, e.g. by raising the elevation of a path or creating a basin, e.g. by lowering the elevation for an area.

The design process for measures in SCALGO was divided into four steps consecutively explained.

1. Assessment of depressions

In the first step the tool “Depression Map” and the tool “Flash Flood Modelling” were used to compare the volumes within a depression and to identify possible storage capacities in depressions. The focus for investigating depressions was on the areas assigned to a high probability of flooding based on the risk assessment.

2. Analysis of risk areas

In the second step volumes and water levels for identified risk areas were listed and an aim for the improvement of those areas was set. In order to improve the flooding for the high-risk areas the water level the surrounding areas and especially the tributaries were investigated for the possibility to implement measures. The volume of the tributaries was investigated with the “subsurface basin” tool. The “query runoff” for the 100-year rain event with a climate factor was used to determine a range of the volume flowing into the risk areas, e.g. to determine a storage volume for a retention basin.

3. Design of measures

In the final step several measures were investigated and designed. For the design all tools for the editing of the workspace in SCALGO were considered. The design of the measures was done step-by-step with the focus on each of the identified areas. As a result, several measures with the focus of improving one specific area, identified by the risk assessment, were implemented. Even though all tools for editing were considered for the design of the measures, the preferred tools were those for changing the elevation. This was done to allow a better comparison in the scope of this thesis for the different software programs. Furthermore, using the subsurface structures tools leads to high uncertainties on their effect on the whole catchment area as well as on the specific catchment itself. When using a subsurface structure to design a culvert, the capacity is unlimited thus all the water from tributaries of the location can possibly enter the culvert not just the water of the investigated depression. For subsurface basins the water volume is assumed to be stored, but the effects on the elevation or on the environment are not visible.

4. Assessment of the measures

In a last step the flooding especially for the areas of high flooding probability was compared for the scenario without and with measures. For the comparison flood propagation, water depth and volumes in depressions were compared.

3.3.4.2.2. MIKE ZERO – DEM

In a first step of the implementation of measures in MIKE ZERO the DEM was exported into SCALGO solely for changes to the DEM. The measures regarding the adaption of the DEM in SCALGO were modelled in the same manner in the DEM of MIKE ZERO. Concluding no subsurface tools were used to change the elevation of the DEM of MIKE ZERO. After changing the DEM in SCALGO the DEM was imported to MIKE ZERO where further changes to the DEM to use the possibilities of the MIKE ZERO Software were supported in the modelling process.

3.3.4.2.3. MIKE 21

In MIKE 21 one has the possibility to change the DEM to create storage areas or flow paths. In addition to those changes three types of structures can be added to the model. Those structures are: weirs, culverts and dikes. Another possibility to include structures in MIKE 21, supported by DHI, is to design those measures with MIKE URBAN and just add them coupled to the surface model. As this option is covered by including MIKE FLOOD it is not investigated further for MIKE 21. In consultation with the *City of Gothenburg* and *Sweco AB* about the common workflow and application of MIKE 21 the design of structures in MIKE 21 was neglected. Therefore, no additional structures were modelled in MIKE 21. The measures that were modelled by changes to the DEM were carried out in SCALGO and are the only changes to simulate the measures. However, the DEM changes were reviewed by looking at the bathymetry in MIKE ZERO to possibly consider slight adjustments.

3.3.4.2.4. MIKE FLOOD

As MIKE FLOOD in this thesis consists of the urban coupling with MIKE 21 and MIKE URBAN the changes were done within those two programs. The adaptions in MIKE 21 for the coupled model were the same as described for just MIKE 21. Additional modelling in MIKE URBAN was considered for the coupled program MIKE FLOOD. However, no changes were done to the coupling itself. For new structures modelled in MIKE URBAN with the DHI MOUSE engine the coupling was done respectively to the other coupled nodes.

3.4. FloodMan

The complete designation of the FloodMan is "*Sustainable Flood Management Assessment Tool*". The tool was created in Microsoft Excel by *Sweco Environment AB* under the authority of the *City of Gothenburg*. It is part of the city's adaption work to climate change. The purpose of FloodMan is to assess possible measures and strategies from the city's framework with a socioeconomic analysis and a sustainability analysis. For the socioeconomic part of the tool an uncertainty analysis can be done with the expansion program Oracle Crystal Ball® to Microsoft Excel. The application of FloodMan can generally be done in two ways with a complete analysis or a simplified analysis (Rosén & Nimmermark, 2018).

The input data for FloodMan result from the so-called "hydromodell" more precisely its simulations. The term "hydromodell" is a byword for flood modelling simulations in the Gothenburg area, done or on behalf of the *City of Gothenburg* and set as a basis for modelling in the *Developing master plan* (Göteborg Stad, 2017a). The simulations are possible for coastal, fluvial and pluvial flooding. The results from the "hydromodell" simulations are water levels for investigated return periods of a flood event. Those results are analyzed by the program FME (Feature Manipulation Engine) – Safe Software. In the final step the output from FME is added into FloodMan and FloodMan can be applied (Rosén & Nimmermark, 2018). The individual work steps of the preprocessing for the FloodMan application are illustrated in Figure 3-7.

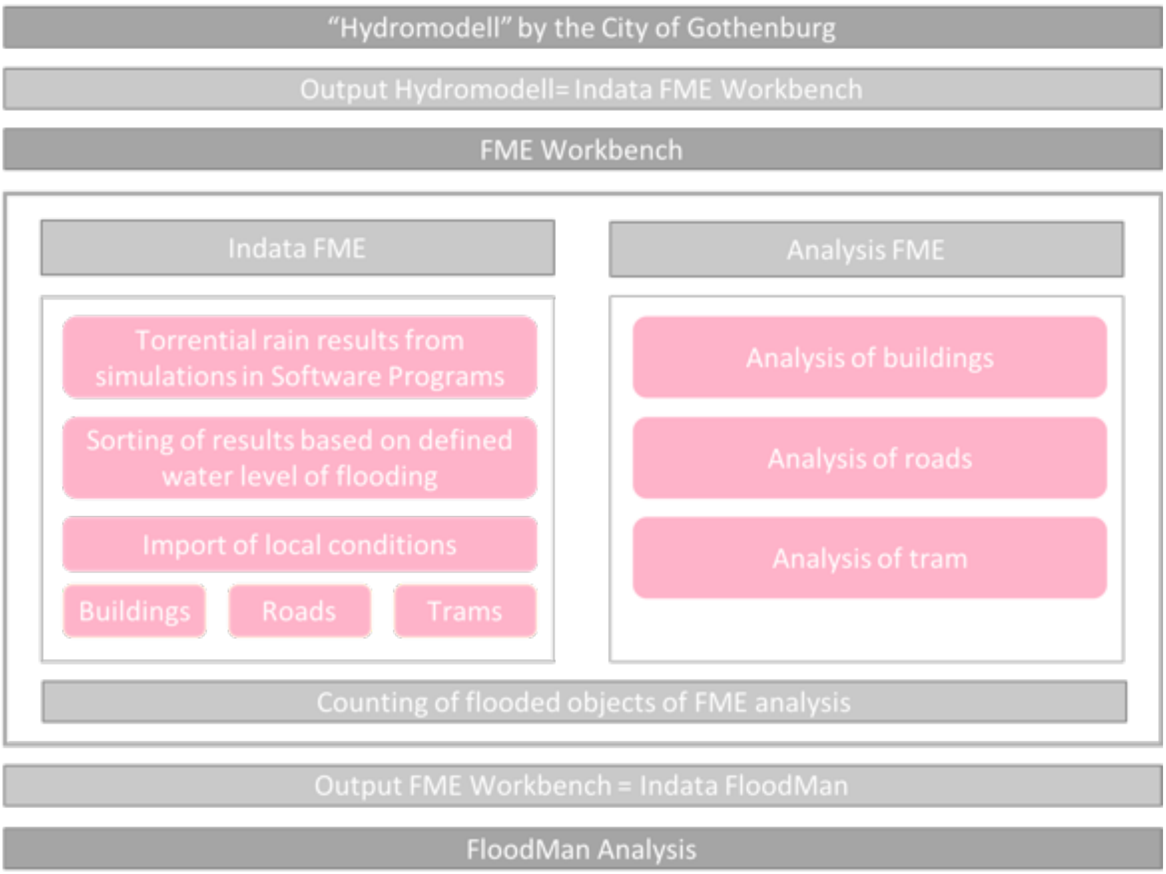


Figure 3-7: Illustration preceding work steps for FloodMan application. (created by author)

3.4.1. FloodMan

As previously mentioned FloodMan was developed in Microsoft Excel. The tool is applicable for pluvial, coastal and fluvial flooding (Rosén & Nimmermark, 2018). In the present report solely, pluvial flooding was investigated thus FloodMan is only used for pluvial flooding.

FloodMan offers the selection between a full and simplified analysis. The full analysis requires the results from simulations of at least three return periods. The simplified analysis is based on the results of the simulation of 10-year return period (Rosén & Nimmermark, 2018). In this thesis the main investigated return period was a 100-year return period in the scope of a full analysis. The additionally simulated return periods are a 50-year and a 200-year period. For the socioeconomic part the uncertainty analysis with the expansion tool Oracle Crystal Ball® was done.

3.4.1.1. Practical application of FloodMan

Generally, FloodMan offers the possibility to assess three alternatives. The alternatives can include different measures or actions in respect to the economic, social and environmental impacts. The idea is to evaluate the varying impacts of measures or no measures for the investigated catchment (Rosén & Nimmermark, 2018).

At the current state FloodMan is a pilot project and needs to be considered as such. The version of FloodMan applied in the present report is based on the introductory phase from September 2018. Later adaptions during the scope of this thesis were not possible to be considered. The application of FloodMan for Linnéstaden apart from the development stage in this thesis is one of the first utilizations of the tool, including FME.

In the present report the FloodMan tool was applied in an innovative and different manner. The alternatives were assigned to the three software programs evaluated in this thesis. Thus, each alternative represents results from the simulations in the respective programs. These simulations are from the models including the measures and actions implemented in SCALGO, MIKE 21 and MIKE FLOOD. The alternatives were labelled as follows:

1. Alternative 1: SCALGO
2. Alternative 2: MIKE 21
3. Alternative 3: MIKE FLOOD

In this thesis, the purpose of applying FloodMan is to quantify the results from the simulations with an assessment based on local conditions for costs of damages and measures. As FloodMan and the original models of MIKE 21 and MIKE FLOOD were both developed on behalf of the *City of Gothenburg* the models can be considered to be developed in the manner of the "*hydromodell*" application. Therefore, the application of the FloodMan tool for the study area Linnéstaden was a suitable and qualified approach. Besides, FloodMan also includes the additional assessment with an MCA for social and environmental impacts.

The practical application of simulation results from SCALGO in this thesis was a novel approach for FloodMan. The attempt was to use the results in the same manner as from the approach for the so-called "*hydromodell*" of the *City of Gothenburg*. For this purpose, the reference system in SCALGO needed to be adapted to the regional reference system for the Gothenburg area. The "hydromodell" originally refers to results from simulations with the software programs MIKE ZERO by DHI (Hørsholm, Denmark). The adaption needed to be done in SCALGO and was necessary for the results to serve as readable input data for FME.

The quantification of the different simulations especially with regard to the damages was the main aim of applying FloodMan. However, one needs to consider that implemented measures in this thesis are similar thus the effects of the measures with regard to the social and environmental impacts in the scope of the MCA as well as the costs of the measures might not differ significantly. Therefore, the range of the uncertainties of the results of economic analysis might provide interesting insights. Even though this application of the FloodMan tool might lead to smaller discrepancies in the results it supports the approach of the usage of the tool in this thesis. The application of FloodMan was therefore set out to assess the effects of conformity and disparity of the results caused by the distinctive scientific background of the programs. Those results are assumed to vary in the flood propagation and water depth leading to different damages and consequently to distinctions in FloodMan results.

3.4.1.2. FLOODMAN DESCRIPTION

The explicit specifications for each step in FloodMan for this thesis are described with the associated step of FloodMan, as described in this section. In this chapter only the methodology for the full analysis, which is applied in this report, is described. The full analysis has nine main steps, which are illustrated in the Figure 3-8.

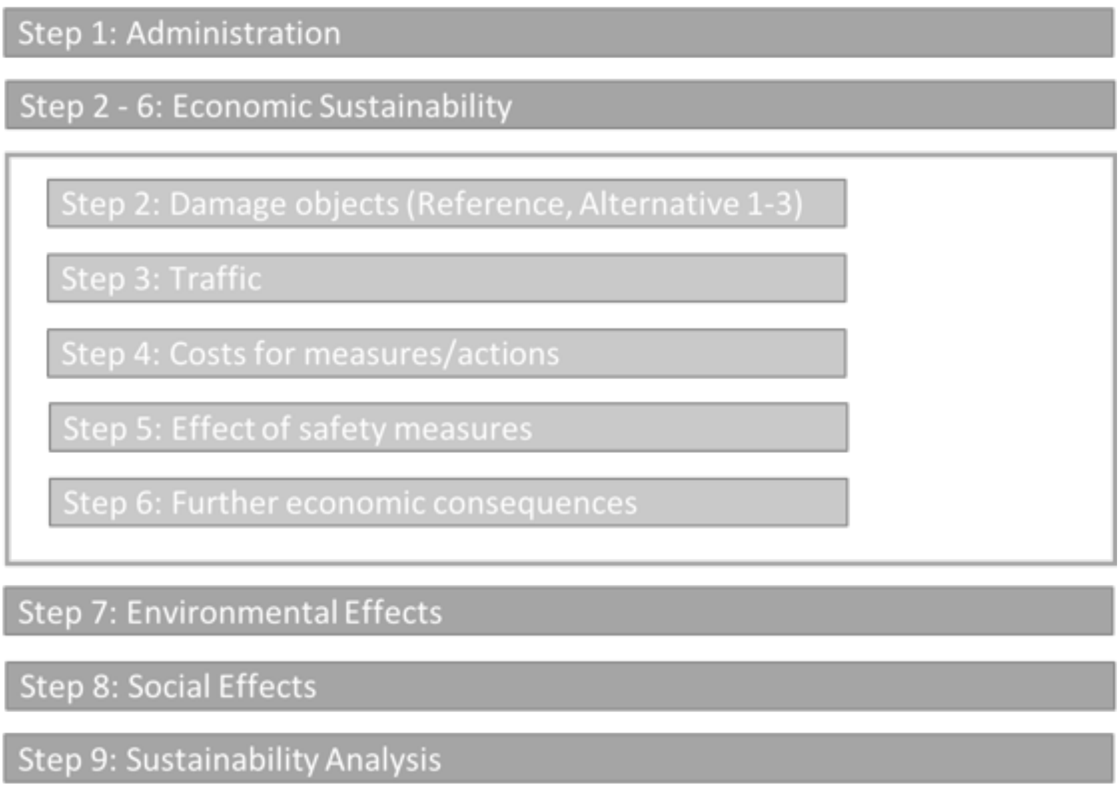


Figure 3-8: Illustration of FloodMan workflow (created by author)

It can be seen from the Figure 3-8 that the main part of FloodMan is the economic part, done in the manner of a cost-benefit analysis. The environmental and social effects are considered with a multi-criteria analysis (Rosén & Nimmermark, 2018).

The socioeconomic analysis assesses the costs and benefits of the measures in a quantitative manner. It includes internal and external effects in its analysis. The effects that cannot be described in a quantitative way are considered in a qualitative way by an MCA for the environmental and social effects in Step 7 and Step 8 (Rosén & Nimmermark, 2018).

The calculation of the CBA is done for a time horizon defined by the user of the FloodMan tool. The present value for the costs depends on the interest rate, which can be defined manually. However, FloodMan offers two interest rates, which were originally selected with respect to the Gothenburg area (Rosén & Nimmermark, 2018). For discounting the interest rates provided by the FloodMan report (2018), are 1.4 % based on the Stern report and 3.5 % provide by the Swedish Transport Administration. Those values were chosen in the scope of this thesis.

The financial risk in FloodMan was calculated with by a risk assessment ex ante. The costs for the damage are unit prices with regard to the Gothenburg area. The cost estimation for the measures are divided into the present value investment, reinvestment and operation and maintenance costs. The standard values in FloodMan are based on the Danish PLASK model, which has been adopted to the local conditions of the Gothenburg area (Rosén & Nimmermark, 2018).

The risk cost calculation considers the discounting over the given time horizon by a linear interpolation of the return period for the socioeconomic analysis (Rosén & Nimmermark, 2018).

The uncertainty analysis, which can be carried out with Oracle Crystal Ball® is a global uncertainty analysis by the Monte Carlo uncertainty distribution for the present net worth. The final results include the most probable value, lowest fair value and the highest fair value. The lowest fair value is the 5-percentile value and the highest fair value the 95-percentile value. The most probable value is given by a point value, which can also be determined if FloodMan is applied without an uncertainty analysis. The uncertainty analysis can be used to support the decision-making process for the ranking and to determine the highest uncertainties (Rosén & Nimmermark, 2018).

The sustainability analysis in FloodMan evaluates environmental, social and economic effects. The economic effects are evaluated by the CBA and the social and economic effects by an MCA. The MCA was adapted to the local conditions in Gothenburg. The method for the MCA was based on the linear additive method of the SCORE model. As final results a sustainability index is calculated with FloodMan (Rosén & Nimmermark, 2018).

This chapter has explained the general method and aspects of FloodMan. It is now necessary to explain the individual steps of the full analysis with the appropriate specification of the present report.

3.4.1.2.1. Step 1 - Administration

Step 1 in FloodMan is defined as the administrational step. One determines the type of the analysis with regard to the investigated flood events and the ambition level meaning a full or simplified analysis. Furthermore, the risk level, which shall be evaluated is assessed. The uncertainty analysis for the socioeconomic part can also be selected in this step. The time horizon and interest rates for the discounting are chosen and the return periods, which are analyzed as well (Rosén & Nimmermark, 2018).

The specifications for this thesis and the respective interface are shown in the results section. The selected event for this thesis was pluvial flooding “skyfall”. The design event is a 100-year return period, which correlates with the determined time horizon of 100 years. The analysis was set to a full analysis in order to use the entire scope of FloodMan and the “hydromodell”. For a full analysis the additional return periods of 50 and 200 years were investigated. The alternatives investigated are the different software programs. The reference option is based on the MIKE FLOOD results without measures for the study area. In this project a high risk was evaluated, as only a high risk was considered to be relevant for the investigation and assessment of flash floods and torrential rain. The uncertainty analysis was carried out to investigate the difference of uncertainties between and within the simulation results of the programs. The water level was set to the standard value of 20 cm. However, the water level which is selected in the administration interface is not relevant for the classification of high or low risk, as this is done based on the set-up in FME. Thus, the selection of the water level in the administration has no effect on the results.

3.4.1.2.2. Step 2 - Damage objects

In the second step the damage objects are entered in the FloodMan interface. This is done for the reference and the alternatives. The input data is generated in FME (Rosén & Nimmermark, 2018).

The input data generated in FME is based on the set-up of the “hydromodell”. Originally FloodMan was designed to read the data from two simulations for one return period. The simulation for the start year of the time horizon without a climate factor and the simulation of the end year with a climate factor (Rosén, 2018).

In this thesis all simulations done with the “hydromodell”. Meaning all simulations done with the three investigated software programs were set-up based on precipitation loads including a climate factor. Therefore, the results from the simulations were assigned to the end year of the FloodMan time horizon. For obtaining values for today’s situation the results from the simulations with a climate factor were reduced to 80 % as the climate factor applied was 1.2. Additional simulations, without a climate factor, were not considered due to limited time and lack of explicit data for the precipitation input files for MIKE 21 and MIKE FLOOD.

3.4.1.2.3. Step 3- Traffic

In a third step one enters the effects on the traffic within the investigated catchment area. The flat rate values for traffic in FloodMan were given by Trafikverket (Swedish Transport Administration) and were determined for the Gothenburg area with regard to Linnéstaden (Rosén & Nimmermark, 2018). As the catchment area investigated in this thesis corresponds with the area for which the flat rate values were determined those values considering the general traffic information were not changed in the present thesis. This included the values for the annual average daily traffic for cars, public transportation and passenger and freight trains. The same accounts for the traffic information regarding the capacity, number of shared trips and expected delays. It was assumed that the decisions by experts in the field of traffic should be applied. As in a real planning process several stakeholders from different fields of expertise would be involved as well and the field of expertise of this thesis is not traffic.

The changes done by the author in this section was the update of the effected transportation means. This applied for the trams and bus lines, where several lines were added. The reference used were the local traffic carriers “Västtraffik” (2018). The added lines were assigned to the same annual average daily traffic values as the lines in the FloodMan manual in the catchment area.

3.4.1.2.4. Step 4 - Action costs

The catalogue values given in the original FloodMan set-up were used in the present report. The values were adjusted to the local conditions as described in the FloodMan report (2018) and therefore were considered applicable by the author for this thesis.

In Step 4 one quantifies the dimensions of the measures implemented for the alternatives. The year of implementation can be chosen individually for each alternative. The catalogue for measures should be seen as estimated and target conditions like the costs for the measures. The prerequisites for the terms and conditions of the catalogue are that no existing structures are affected, no additional geotechnical measures are required and that the measures are located in suitable places (Rosén & Nimmermark, 2018).

In the present report, the determination of the action's costs was given based on the developed measures in the software programs, see Chapter 4.2.4.1. The point in time of implementation was set the same for all three alternatives, thus programs. It was set to year 3, meaning that the measures will be implemented in year 3 of the 100-year time horizon. The time span was chosen by the author as the *City of Gothenburg* plans to build a robust city to flooding till its jubilee in 2021, thus 3 years from now.

In this thesis, the action costs for the three alternatives were calculated based on the developed measures in the individual models. The measures listed in the "action catalogue" of FloodMan were considered as target prices but were not adapted further. The implemented measures were assigned to the closest object listed in the catalogue to avoid further uncertainties due to estimates for the costs of new categories chosen by the author.

3.4.1.2.5. STEP 5 - PROTECTION EFFICIENCY OF IMPLEMENTED MEASURES

In Step 5 the protection efficiency of the measures is evaluated. One chooses the year of implementation as given in Step 4. The input data is specified, meaning if modelling with the "hydromodell" was used. The protection effect is determined, if modelling was not select. In addition, the user choses the effects of the reduction of traffic disruption due to the implemented measures. The values are specified for each traffic category and alternative. The probability of malfunction of the measures is also determined by a percentile value in this step (Rosén & Nimmermark, 2018).

In this thesis all measures were modelled. Thus, modelling was selected for the selection of the input data and the return period was defined by the modelling time horizon for all alternatives.

The determination of the extent of traffic interruption reduction caused by each measure to its minimum and maximum degree was done by the author. All measures in the three alternatives, meaning the software program models, were designed in similar manner and so it was assumed that they have the same effects on the traffic. Concluding the same percentile values were assigned to all three alternatives.

The likelihood of the malfunction of the measures for the models of the software programs was classified by evaluating how reliable the designed modeled features are. The different programs and their reliability, the feasibility of the measures and the measures implemented were evaluated by the author and the probability was determined based on this evaluation.

3.4.1.2.6. STEP 6 – OTHER ECONOMIC CONSEQUENCES

In this step the user has the possibility to determine additional economic consequences. For example, one can add beneficial economic effects caused by the measures, which are not considered in the costs (Rosén & Nimmermark, 2018).

In the scope of the present report the design of the measures was done in a basic manner and a detailed planning would be required to decide on further beneficial aspects, e.g. for the recreation or cleaning of water. This thesis does not engage with aspects of the water quality. Therefore, cleansing effects of the water by the measures cannot be quantified like this step in FloodMan would require.

3.4.1.2.7. ECONOMIC EFFECTS – RESULTS

After Step 1 to Step 6 are done in FloodMan the economic analysis is done and carried out for the indata of the preceding steps.

3.4.1.2.8. Step 7 – Environmental effects

The environmental effects Step 7 are analyzed with the help of an MCA. The criteria for the MCA were selected based on the sustainability work of the *City of Gothenburg*. Each criterion needs to be weighted on a scale from 0 to 10, with 0 being not relevant and 10 being very relevant (Rosén & Nimmermark, 2018).

The criteria in FloodMan are described in a general manner and therefore it was decided to adapt the weighting to what type of measures were implemented in this thesis. This adaption was done by the author with respect to the actual measures implemented. The adaptions are described in the result section, as they are based on the results of the measure implementation. As previously mentioned the design of the measures did not include the detailed planning, meaning the material of open channels or retention basins was not planned in detail. Thus, aspects like filters for water remediation measures or the soil composition are not planned and thus the effects cannot be described in the assessment of the MCA. Therefore, not all criteria fit the present report, thus were adjusted by the author to suit the implemented measures, but were originally based on the FloodMan manual and tool.

In the first step the criteria were adapted. Subsequently the criteria were weighted. In a final step the effects for each alternative were rated with respect to the reference option, the situation in the catchment without any measures.

The rating of the alternative can be done on a scale from very negative to very positive, with the values of very negative -3 to very positive with +3 (Rosén & Nimmermark, 2018).

3.4.1.2.9. Step 8 – Social effects

The social effects have a similar interface than Step 7. The analysis is done by an MCA, with the criteria weighted from 0 to 10, with 0 being not relevant and 10 being very relevant. The alternatives can be rated on a scale from -3 to +3, with -3 being very negative and +3 very positive. The rating should be done with respect to the reference option (Rosén & Nimmermark, 2018).

According to Rosén and Nimmermark (2018), the criteria for the MCA are based on the sustainability work of the *City of Gothenburg* and were also adapted in the scope of this thesis. This was done in the same manner as described for the environmental effects with regard to the implemented measures.

In the first step the criteria were adapted. Subsequently the criteria were weighted. In a final step the effects for each alternative were rated with respect to the reference option, the situation in the catchment without any measures (Rosén & Nimmermark, 2018).

3.4.1.2.10. Step 9 – Sustainability analysis

In the final step of FloodMan a sustainability analysis for all types of impacts (environmental, social, economic) is done. The sustainability analysis evaluates the results for each alternative and finally calculated a sustainability index. The weighting of the three impacts is done manually by the use on a a scale from 0 to 10, with 0 being not relevant and 10 being very relevant.

In this thesis the categories were rated in the following manner. The economic analysis was assigned to the highest value 10, followed by the environmental analysis with 9 and the social analysis with the score 7. The relation of the weighting is shown in a pie chart in the FloodMan interface in Figure 3-9.

Figure 3-9: Weighting of sustainability shown in FloodMan interface for present master thesis.

In blue the social sustainability is illustrated, in red the economic sustainability and in green the environmental sustainability. The weighting for this thesis was done by the author. The economic sustainability was assigned to the highest value as it determines the feasibility of the measures. Another reason for the high relevance of the economic sustainability was that the tool in thesis was used to quantify the results and not just qualitatively assess the results of the simulation and the programs. In addition, the environmental and social effects were assumed to have the highest uncertainties and be the most sensitives to different interpretations of the criteria of the MCA and the adaptions for the catchment.

However, the environmental sustainability was rated as more important as the social sustainability as the environmental effects were classified to have higher consequential risks for human health and life and are assumed to be more important than the social sustainability. Moreover, the author would recommend a detailed planning for a full assessment of the social sustainability with a holistic approach for the whole catchment area. For such a holistic approach expertise in the field of city planning, infrastructure and strong integration of the affected population would be recommended. As this exceeds the scope of this thesis the social sustainability was assumed to be the most sensitive to changes and uncertainties, thus was rated with the lowest relevance.

3.4.2. FME – Safe Software

The FME workbench applicable for the FloodMan tool used in the present report was originally developed by Henrik Thorén (Ramböll) on behalf of. the *City Planning Department* of the *City of Gothenburg* and is called "Riskkartläggning vid skyfall" (Risk mapping for torrential rain). The workflow within this FME workbench is illustrated in Figure 3-10:

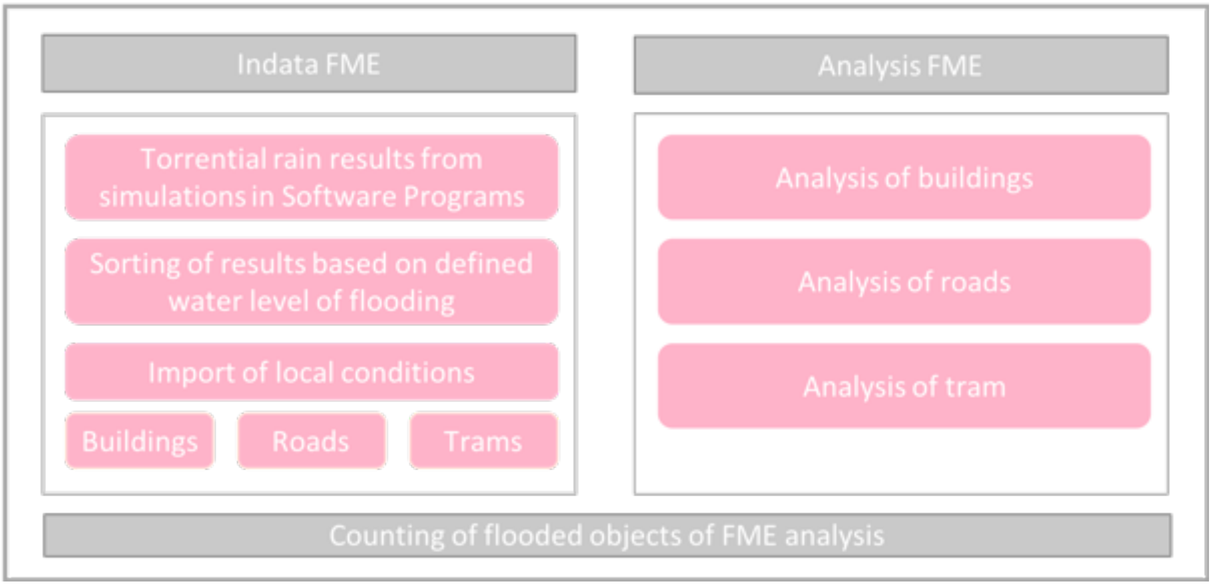


Figure 3-10: Illustration of FME workflow by the author with respect to City of Gothenburg's FME workbench "Riskkartläggning vid skyfall" (created by author)

As shown in Figure 3-10 the FME Workbench is generally divided into two parts. The indata and the analysis done within the program finally leading to counting of the flooded objects based on the different types of analysis generated in an Excel output file, which serves as input data for FloodMan.

The explicit product from Safe Software used for the FME workbench is FME Desktop. It is a complex tool, which supports data integration, format conversion and data transformation (Safe Software Inc, 2018).

3.4.2.1. FME – General Features

In the scope of this thesis the input data in form of the torrential rain results was obtained by the three investigated software programs SCALGO, MIKE 21 and MIKE FLOOD in form of ERDAS Imagine files. Those files were created for three return periods, as required for the full analysis in FloodMan. The return periods are: 50, 100 and 200 years.

For all three software programs the original set-up by the *City Planning Department* of the *City of Gothenburg* was applied for sorting as well as the imported data considering the local conditions. Meaning the indata of buildings, roads and trams in the catchment was used as generated for the original workbench. For FME the term 'trams' is used in a collective manner, e.g. including railroads. The same accounts for the assignment of the water level of flooding. In the workbench each analyzed sector, buildings, roads and trams can be assigned to a specific water level for which flooding is counted. The water depth of the flooding is also the key factor for the classification of the risk for the analysis in FME. The risk classification is high (hög) or low (låg). A high risk occurs, if the object has more than four cells within their individual area flooded by the determined critical water level for the sector.

In this thesis the sectors were assigned to the water levels as presented in Table 3-10.

Table 3-10: FME risk classification for different sectors by water depth; on the basis of "Riskkartläggning vid Skyfall" by the City of Gothenburg

Sector	Water depth assigned to flooding [cm]	Risk classification
Buildings	20	A high risk is assigned to buildings with more than 4 cells flooded above 20 cm.
Roads	30	A high risk is assigned to roads flooded by clusters consisting of more than 4 cells above 30 cm.
Trams	10	A high risk is assigned to roads flooded by clusters consisting of more than 4 cells above 30 cm.

One major source of uncertainty was identified as the difference of the risk classification and the critical water depth for the sector trams. The height assigned to flooding and the risk classification differs by 20 cm. Due to the limited time frame of this thesis it was not possible to investigate this matter further. However, the height of 10 cm is the determined critical height for trams according to the *City of Gothenburg*.

Another source for possible errors is the calculation of the point density and its effects on the risk classification. The original workbench was presumably designed for a 6x6 m raster, based on the investigation of original data set and the workbench itself. However, there is no documentation to ensure this assumption. The input data from the software programs differs from that raster, see Table 3-11.

Table 3-11: Overview point density and raster of software programs indata for FME

SCALGO	MIKE 21	MIKE FLOOD
2x2 m Raster	4x4 m Raster	4x4 m Raster

Point density and the raster size were investigated as they are crucial parameters for the determination of the flood risk based on the number of flooded cells in FME. The classification of high or low flood risk is done based on the number of cells flooded for the defined depth, varying for roads, trams and buildings. With the original raster being larger than the raster of the software programs the possibility of a higher risk than occurring in reality must be considered. The same applies for the assessment of the software programs in comparison. As SCALGO has a smaller raster it is more likely to be assigned to a higher flood risk than MIKE 21 and MIKE FLOOD.

At the current state it was assumed that FME counts the actual raster cells flooded without a conversion factor. In a simplified manner one can describe the effect of the raster size on the risk classification by FME. An increasing probability for a higher risk in FME is illustrated with Figure 3-11. The arrows indicate an increase of the risk probability. Meaning that in SCALGO an object has a nine times higher risk probability as the results from the original raster of FME and a four times higher risk probability than the MIKE software programs. This increased probability is a simplified assumption and the increase might not be proportional, besides the contrary effect could occur. Meaning that with a higher number of cells there is also the probability that the flooded cells are further distributed and not neighboring, which would lead to a lower risk instead of a higher risk classification by FME. However, with regard to the results for the flood propagation the probability of a higher risk is higher more likely than the probability of a lower risk cause by a larger distribution and was assumed in this thesis.

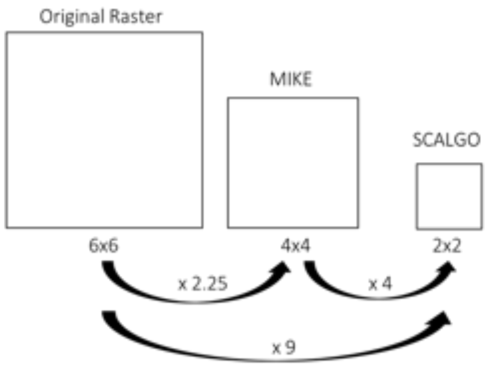


Figure 3-11: Illustration of FME relation of risk probability, raster and point density (created by the author)

Further data collection and investigation of this manner is required to determine exactly how the point density and raster affect the risk classification by FME and if the increase of the risk probability can be determined with the proportionality presented in Figure 3-11. Nevertheless, the raster of all investigated models is smaller than the original one, so all the results are assessed higher than they might be in reality. Assuming an overall higher risk can be defined as worst-case scenario and is therefore sufficient for this application of the tool.

For a more accurate application of FME it is recommended to adjust the raster to the actual raster cells of the models and set them in ratio to the original set-up. In this thesis the tool was only used to compare the models in a quantitative way and therefore a further investigation and more thorough approach is beyond the scope of this thesis.

The elevation of the FME workbench "*Riskkartläggning vid skyfall*" (Risk mapping for torrential rain) of the *City Planning Department* of the *City of Gothenburg* is based on a laser scanning for the National Elevation Model of Sweden, but has a 10 cm gridded data position accuracy (Lantmäteriet, 2016b). Therefore, a selection of a 10 cm water level in general is considered to be prone to errors and might not show the actual flooding.

The reference system required in plane for the application of the FME workbench by the *City of Gothenburg* is SWEREF 12°00. It is the regional reference system for Gothenburg. This reference system is used for the software programs MIKE 21 and MIKE FLOOD. For SCALGO the reference system is generally based on SWEREF 99 TM for Sweden. In order to use SCALGO in FME the results of SCALGO were reprojected to SWEREF 12°00 for the creation of the input file.

As previously described the implementation of the FloodMan tool including FME occurred very recently, in June 2018. Therefore, the tools are still vulnerable to errors and are considered to be in the pilot phase. For further investigation an analysis of the different relationships within the FME workbench is highly recommended. However, in the present report the tool is used to quantify the results of the software programs to illustrate the differences in a quantitative manner. It is assumed that the errors occur in the same manner for all software programs, thus the results are in the same ratio and can be applied for the purpose of this thesis. For an application of explicit calculations with the FloodMan tool, e.g. to compare explicit measures for one area with one program an assessment of the uncertainties of the FME workbench is crucial and highly recommended by the author. The above described uncertainties of the application of the tool were reviewed for the evaluation of the results.

3.4.2.2. FME Simulations

In the present report the following simulations were done in FME Desktop with the workbench "Riskkartläggning vid skyfall" (Risk mapping for torrential rain), developed by the *City Planning Department* of the *City of Gothenburg*.

1. Simulation of Reference Data

The generation of the reference data for FloodMan was done with the analysis of results from the MIKE FLOOD model. The simulation was done three times for the investigated return periods 50, 100 and 200 years without further adjustments of the models apart from the rain files.

2. Simulation of data for Alternative 1

Alternative 1 represents the results of the program SCALGO. The simulation was done with measures taken in the catchment area, see Chapter 3.3.4. The simulation was done three times for the investigated return periods 50, 100 and 200 years without further adjustments of the models apart from the rain files.

3. Simulation of data for Alternative 2

Alternative 2 represents the results of the program MIKE 21. The simulation was done with measures taken in the catchment area, see Chapter 3.3.4. The simulation was done three times for the investigated return periods 50, 100 and 200 years without further adjustments of the models apart from the rain files.

4. Simulation of data for Alternative 3

Alternative 3 represents the results of the program MIKE FLOOD. The simulation was done with measures taken in the catchment area, see Chapter 3.3.4. The simulation was done three times for the investigated return periods 50, 100 and 200 years without further adjustments of the models apart from the rain files.

3.5. Recommendation (Step 3)

This thesis aims to present a final recommendation not a guideline. In this chapter the structure of the recommendation and the criteria are presented. The reasoning for the development of a recommendation and not a guideline is stated in discussion part.

In general, the whole thesis can be read as a recommendation, but for better applicability a section with a summarized recommendation is presented in this report. The recommendation was based on the simulations and studies in the scope of this thesis, therefore a general application as a recommendation must be evaluated.

The recommendation consists of two parts. The first part is a general overview of the findings and results in this thesis presented in Table 6-1. The second part is a short description of the application of the tools for specific simulations and modelling aspects for pluvial flooding. It includes the advantages and disadvantages of the programs based on the present report.

Aspects considered in the recommendation are:

- Scientific background of the programs
- Set-up of the models in the scope of this thesis
- Properties of the software programs
- General handling of the software programs
- Implementation of measures within the software programs
- Application of the software programs

4. Results

Whilst the methodology of this thesis was explained in Chapter 3, this section presents the results of the applied methods.

4.1. Risk assessment

This chapter presents the results of the risk assessment, described in Chapter 3.2. The rating of this risk assessment is based on the risk categorization presented in Table 4-1.

Table 4-1: Scale of risk categorization for risk analysis and risk evaluation for the risk analysis of present thesis

Assumed Risk	Main Category Scale	Sub-Category Scale
Low	3	o
Medium	2	+
High	1	++

4.1.1. Damage potential

For the assessment of the damage potential the superior risk groups assessed were: Risk for human life and health, Risk of damage and loss of cultural heritage, Environmental risks, Economical and industrial risks, Risks to relevant infrastructures. The objects and areas identified and classified according to those categories were chosen based on the local conditions in Linnéstaden. They were assessed with the help of maps from the area and local inspections by the author. The results are visualized in Figure 4-1 and additionally described in the Table 4-2 and Table 4-3.

Figure 4-1 illustrates the results obtained from the damage potential assessment with regard to the superior risk groups with a map of Linnéstaden in the background. The damage potential in Linnéstaden is highlighted with a colored dot. The marking presents an object or area for which a damage potential was assigned. The colors of the marking are classified for each superior risk group of the damage potential, which are:

- Risk for human life and health: Red
- Risk of damage and loss of cultural heritage: Yellow
- Environmental risks: Orange
- Economical and industrial risks: Purple
- Risks to relevant infrastructures: Blue

Variations of the size of the colored markings are solely for the purpose of a better visualization and are not related to the severity of the damage potential.

For the superior risk groups, the following specification were made. For “Risk of human life and health” only the sub-categories for ‘particularly vulnerable groups’ and ‘structural high-risk zones’ were highlighted on the map. Due to the number of cultural sites within Linnéstaden the illustration for “Risk of damage and loss of cultural heritage” the dots were chosen to be smaller. There were no specifications for the category “Environmental risk”. For “Economic and Industrial Risk” only small businesses were reported within the area of Linnéstaden for the sub-category ‘industrial sector’, see Table 4-3. The small boutiques and businesses within this area are neither listed in Table 4-3 nor shown in Figure 4-1 for better visualization and due to limited time of this thesis, for which a classification of those businesses lies beyond the scope of this qualitative risk assessment. Consequently, the highlighted areas for this superior category were assigned to the sub-category ‘agriculture and forestry’. In the category “Risks to relevant infrastructures” identified objects doe all belong to the sub-category ‘supply and evacuation’.

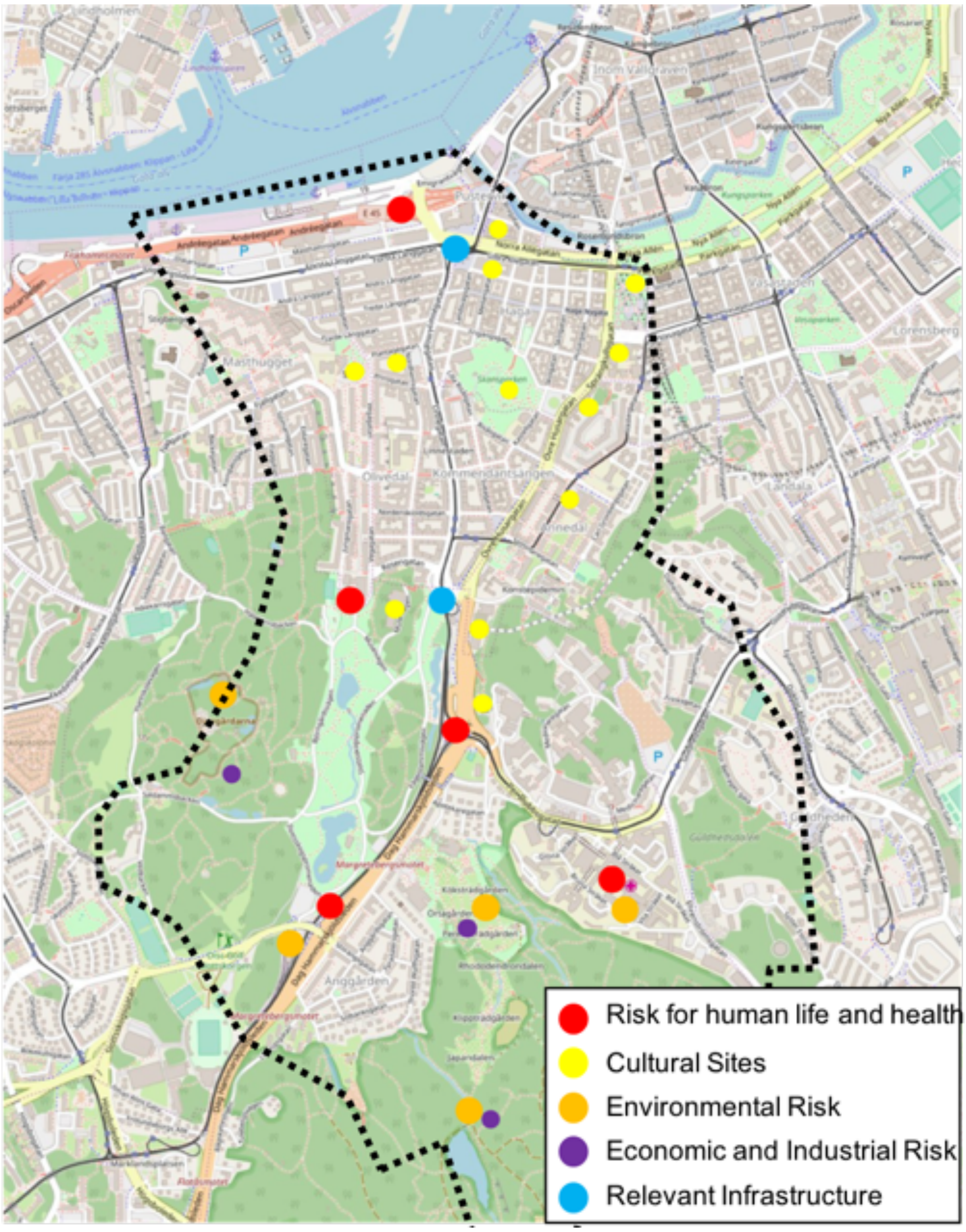


Figure 4-1: Visualization of results of damage potential by the author by assigning objects and areas to the superior risk groups chosen for the damage potential assessment. The superiors risk groups are each assigned to one color as illustrated in the legend of the picture. (created by author)

Table 4-2: Results of damage potential assessment – part 1; risk groups classified by the author with regard to DWA T1/2013

Superior risk categories	Risk objectives	Site specific areas and objects in catchment Linnéstaden	rating*
Risk for human life and health			1
particularly vulnerable groups	- restricted mobility	Sahlgrenska University Hospital, Närhalsan Slottsskogen	++
	- limited risk awareness	Förskola Nordostpassagen 17	++
	- restricted evacuation	no specific properties identified	++
areas with high passenger volumes	- restricted evacuation (escape routes, safety zones) - institutions can be used as evacuation center	Studietorget Campus Linné/ Hälsovetarbacken, Handelshögskolan, Biomedicinska Biblioteket, Institut for Psykologi	+
		Slottsskogen Vandrahem; Stena Line area, Linnéhostel	+
		Slottsskogen: Slottsskogsvallen, Guldheden, Oskar Fredriks Kyrka, Den Dankse Kirke, Annedalskyrkan, Saronkyrkan, Haga Kyrkan, Devotional complex of Salvation Army, Naturhistorika Museum, Hagateatern, Folkteatern, Hagabion, Bio Center	+
		no specific properties identified	+
		Järntorget, Linnégatan	+
		no underground stations only undercrossing (see next category)	+
structural high-risk zones	- very high risk of livelihood - limited risk awareness - insufficient possibilities for evacuation	Annedalsmotet, Magretebergsmotet, Götatunnel	++
		mostly nearby river towards the center	++
		no specific properties identified	++
		no specific properties identified	++
Risk of damage and loss of cultural heritage			3
cultural heritage (archeological, historical, literary, scientific, artistic)	- loss of cultural valuable and protected heritages - high passenger volume - institution can be used as evacuation center	Botaniska Trädgården, Skansen Kronan (Skansparken)	o
		Naturhistorika Museum in Slottsskogen; Hagateatern, Folkteatern; Hagabion, Bio Center	o
		Oskar Fredriks Kyrka, Den Dankse Kirke, Annedalskyrkan, Saronkyrkan, Haga Kyrkan, Devotional complex of Salvation Army	o
		Cellink nearby Sahlgrenska	o

Table 4-3: Results of damage potential assessment – part 2; risk groups classified by the author with regard to DWA T1/2013

Superior risk categories	Risk objectives	Site specific areas and objects in catchment Linnéstaden	rating*
Environmental risk			2
oil and gasoline	- general contamination - risk for human health and environment - high consequential damages	Gas station at Magretebergsgatan south of recreational area Slottsskogen	++
biochemical hazards		Hospital waste/laboratories (Sahlgrenska University Hospital)	++
water treatment facilities		no specific properties identified	++
leisure facilities	- endangered animal stock	Slottsskogen Djurgården	++
nature conservation areas	- risk for human health and environment	Botaniska Trädgården, Änggården	++
Economic and industrial risk			3
agriculture and forestry	- endangered animal stock - high consequential risk	no agriculture in the area; forestry to large content see nature conversation areas and Slottsskogen	o
industrial sector	- see above - high passenger volume	urban areas, only small businesses	o
Risk to relevant infrastructure			2
public service and institutions	- coordination of disaster (flood) management	no specific properties identified	++
		no specific properties identified	++
transport and logistical centers	- supply and evacuation	Järntorget as traffic hub, Linnéplatsen	++
	- communication	no specific properties identified	++
	- relevant supplies	no specific properties identified	++
		no specific properties identified	++

4.1.2. Flooding Probability

The flooding probability in this thesis is defined by the topography and the evaluation of the previous study the *Structure Plan* (2017b), commissioned by the *City Planning Department* of the *City of Gothenburg*.

The grade assigned to all identified high-risk areas is the grade 1, for the highest risk. The residual risk areas are listed in Table 4-4. For a better visualization those areas are marked in pink in Figure 4-2.

Table 4-4: Rating of flooding probability by the author for identified high risk areas of previous study "Structure Plan"

Results of previous studies (Strukturplan, 2017)	**rating***
Identified high risk areas	1
Annedal (residential area)	
Magretebergsmotet	
Annedalsmotet	
Sahlgrenska University Hospital	

For the topography the results were obtained by the digital elevation model in the software program SCALGO. The digital elevation model is presented in Figure 4-2. The flow paths assumed are marked with black arrows. The range of the elevation varies from red to blue. With red the highest elevated area and blue the lowest elevated area. The rating for the sub-categories of the topography is shown in Table 4-5.

Table 4-5: Rating of flooding probability by the author for site specific topography

Site specific topography (evaluated based on Scalgo Live)	**rating***
depressions	1
assumption of high-water depth within depressions	++
declinations	2
high declinations and slopes are assumed to lead to high velocities	+
elevations	3
high elevated areas are considered as safe areas	O

In Figure 4-2 all features of the flooding probability are illustrated. The analysis of the topography with regard to the identified risk zones based on the damage potential is listed in Table 4-6 in the column for 'site specific topography'.

Overall, the analysis of the topography of Linnéstaden can be summed up with the subsequent characteristic features:

- In the southern upstream part of the catchment the nature areas are mountainous and the points of the highest elevation of the whole catchment. This leads to a redirection of the runoff water towards the downstream areas.
- The downstream area towards the river Göta Älv is lower elevated and has a lower slope
- Within Linnéstaden there are no large surface water bodies, only small ponds in the nature areas like Slottsskogen, the Botanical Garden and Änggården. Small streams in the upper part of the catchment are discharged into culverts once entering the residential areas.
- The main flow direction is towards the receiving water body the river Göta Älv. One main flow path partially correlated with the street *Linnégatan*. This street used to be a water stream, therefore it is not unexpected that one main flow path is the same as the original flow path in the area. Besides this street there is no main flow path, but a variety of smaller flow paths within the catchment dividing Linnéstaden into several small catchment areas.
- Notable depressions in the catchment area are: Slottsskogsvallen, the area around Magretebergsmotet, the residential area Annedal, Annedalsmotet. The hospital is also located in a slight depression.

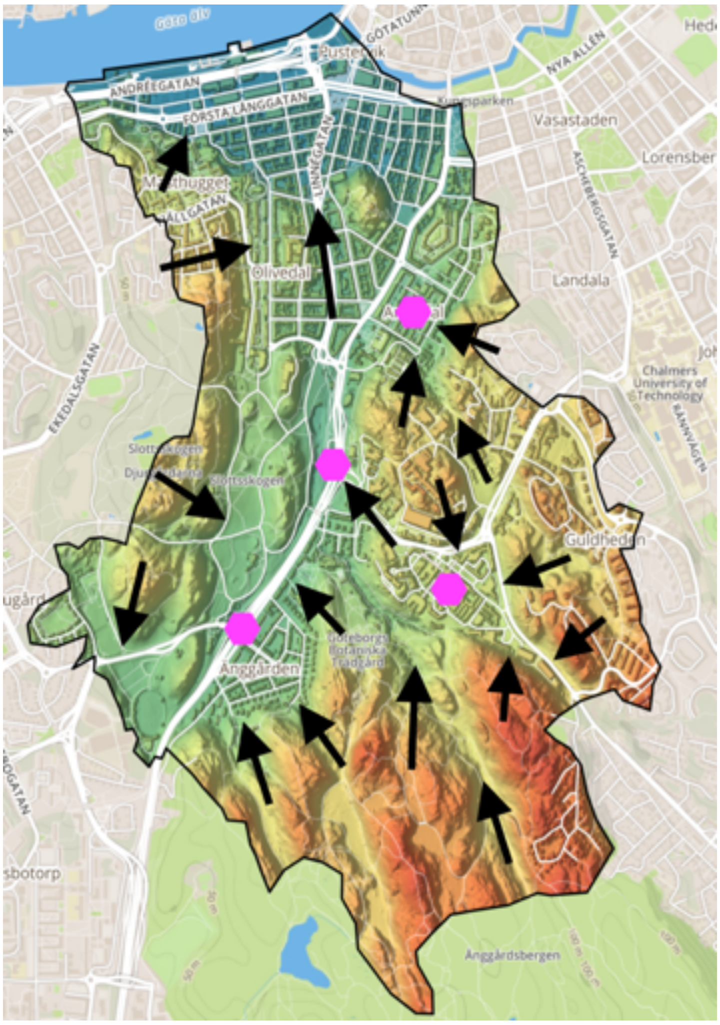


Figure 4-2: Presentation of results of analysis of flooding probability by the author. The figure shows the areal map of the catchment Linnéstaden. The areas highlighted in pink present residual risk areas from the previous study (see Table 4-4). The arrows present the flow paths of the surface runoff assigned by the author based on a topographical analysis done. The elevation was generated with SCALGO.

4.1.3. Risk Evaluation

As a final step the results from the risk analysis based on the assessment of the damage potential and flooding probability, as described in the methodology section (Chapter 3.2.5, Chapter 3.2.4.3) were evaluated. The results of the risk analysis and the risk evaluation are presented in Table 4-6.

Table 4-6: Risk assessment Linnéstaden results for present report

Damage potential (assumed vulnerability)	damage potential	Flooding Probability				probability	risk
		Site specific topography (assumed probability)	rating*	Previous studies	rating*		
Risk for human health and life	1						
Sahlgrenska University Hospital	++	located in slight depression, assumed tributaries	2	Sahlgrenska University Hospital	1	1.5	1.25
Annedalsmotet	++	in depression, tributaries	1	Annedalsmotet	1	1	1
Magretebergsmotet	++	in depression, tributaries	1	Magretebergsmotet	1	1	1
Götatunnel	++	downstream of overall catchment, declination towards river, relatively flat surrounding area	2			2	1.5
Risk of damage and loss of cultural heritage	3						
Cultural sites, listed buildings (Skansen Kronan)	o	no specific critical area; tributaries to downstream area	3			3	3
Cultural and religious sites	o	no specific critical area	3			3	3
Research Center	o	slightly elevated area	3			3	3
Environmental risks	2						
Gas station (nearby Magretebergsmotet)	++	located in depression	1	Magretebergsmotet	1	1	1.5
Biochemical Hazard (Sahlgrenska University Hospital)	++	Located in slight depression, assumed tributaries	2	Sahlgrenska University Hospital	1	1.5	1.75
Slottsskogen Djurgården	++	located in elevated area of Slottsskogen	3			3	2.5
Nature conservation areas (Botaniska Trädgården, Änggården)	++	high slopes, upstream area of catchment; tributaries to downstream area	2			2	2
Risk to relevant infrastructure	2						
Järntorget as traffic hub	++	in downstream area; no specific critical area	3			3	2.5
Linnéplatsen (public transport)	++		3			3	25
Unspecified risk category							
Residential area (Saronkyrkan)		in depression, tributaries	1	Annedal (residential area)	1	1	1
Slottsskogsvallen (high passenger volume)	1	in depression, tributaries	2			2	1.5

In the first column 'damage potential' of Table 4-6, the areas and objects identified for each superior risk group of the vulnerability assessment are presented. In addition, to the previous damage potential assessment the category 'unspecified risk category' was added. In this category identified risk areas in the assessment of the flooding probability were assigned to a damage potential characteristic with respect to the objectives of the damage assessment. It is apparent from Table 4-6, that no objects and areas for the superior risk category 'Economic and industrial risk' were identified and considered relevant for Linnéstaden, see Table 4-3.

In the column 'flooding probability' the analysis of the topography and the previous studies are listed. The topographical aspects of the identified objects and areas in the damage potential assessment were listed in the associated row of those. In the column 'previous studies' the identified risk objects and areas are listed with regard to the rows of the objects and areas of the damage potential. They were listed if the damage potential defined the same areas as the previous studies. In the scope of assessment of the flooding probability two risk areas were identified, that were not considered in the damage potential assessment so far. Those two are listed in the last rows of Table 4-6.

Based on the results of the risk analysis and evaluation, presented in Table 4-6, six areas were defined as areas of potentially highest flood risk. They are presented in Table 4-7.

Table 4-7: Presentation of areas of potentially highest flood risk resulting from the risk evaluation done by the author.

Area	Site specific objectives	Risk
Annedal	Annedal is a residential area located downstream in Linné-staden. The *Structure Plan* showed a high-water depth and defined the area as a residual risk area. It was not assigned to a superior risk category for the damage potential, but as it is a residential area with some cultural sites like Saronkyrkan and small businesses a medium damage potential was assumed. The area is located in a depression with assumed tributaries.	1.0
Annedalsmotet	The area is located in a depression and classified as a structural high-risk area. In the previous modelling results it was assigned as a residual risk area.	1.0
Götatunnel	The tunnel is located in the downstream area of the catchment nearby the river Göta Älv. It is defined as structural high-risk area. In the *Structure Plan* it was not identified as a residual risk area.	1.5
Magretebergsmotet	It is classified as a structural high-risk area. The area is located in a depression with tributaries from elevated upstream areas. The previous study assigned it as a residual risk area. In proximity to the under passing a gas station is located, defined as an environmental risk.	1.0
Sahlgrenska University Hospital	The hospital is located slight depression with a large number of tributaries. In the *Structure Plan* measures were recommended for the area, as they are not taken in this thesis the area remains a residual risk area. The hospital is classified as by the risk group for 'particularly vulnerable groups'. In addition, the hospital is also assumed to pose an environmental risk in terms of a biochemical hazard, in terms of hospital waste and laboratories.	1.25
Slottskogsvallen	The previous study showed a high-water depth for the sport stadium. The damage potential is not assigned to a superior risk group. Periodically the area can be assigned to the risk group for a 'high passenger volume', but that only applies for certain events and was not considered as a constant risk.	1.5

In Figure 4-3 the areas of potentially significant flood risk, described in Table 4-7, are highlighted in red. The dashed black line marks the catchment area.

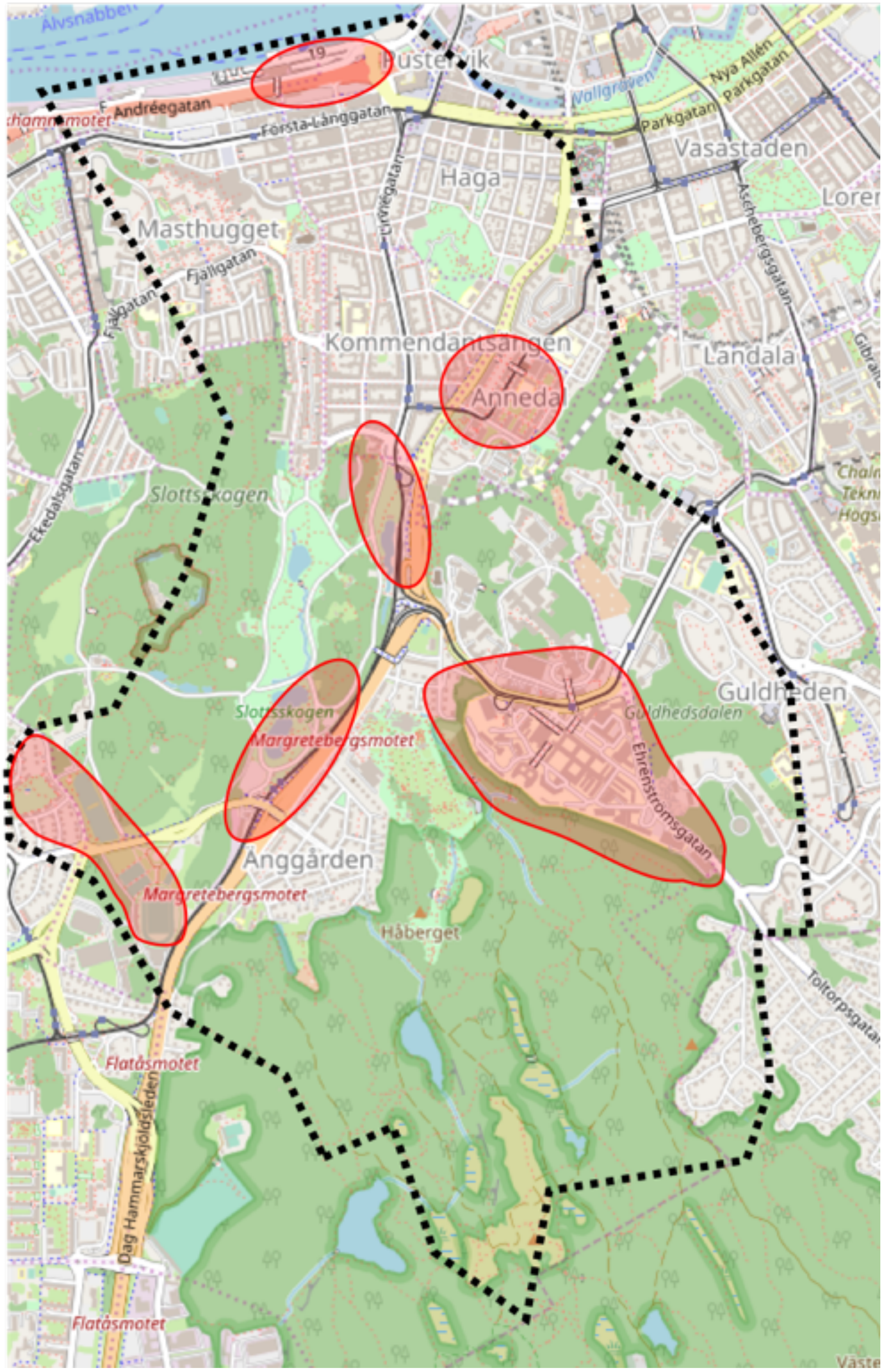


Figure 4-3: Map of catchment area Linnéstaden illustrating high flood risk areas colored in red. The catchment border is marked with black dashed lines. (created by author)

Due to the limited time frame of this thesis and the objectives of the risk assessment described in Chapter 3.2.1 measures cannot be investigated for all six areas. The final selection of an area was executed in cooperation with *Sweco AB* and the *Department for Sustainable Water and Waste* of the *City of Gothenburg*.

The purpose was to select a representative number of risk areas. Therefore, different environment and features of an urban area were aimed for. For Linnéstaden typical features are green areas, e.g. like parks, residential areas and areas of relevant infrastructures.

- Selection of a representative number of risk areas.
    - The selection of risk areas should be sufficient to describe the variety of environments within the catchment and describing the typical features of an urban area.
    - With regard to the time frame of this thesis the amount must allow a thorough investigation of the areas.
- Consideration of location and local conditions of the areas within the catchment area.
    - The intention is to cover areas upstream and downstream of the overall catchment, but also consider smaller catchment areas within Linnéstaden.
    - This includes considering local conditions like the topography and the land use.

An outstanding area of the risk analysis is the area of the Sahlgrenska University Hospital, which is not comparable to any of the other risk areas for the risk assessment. As a result, the Sahlgrenska University Hospital was determined as one of the high-risk areas to be investigated.

The areas Annedalsmotet, Götatunnel and Magretebergsmotet are fairly similar with regard to the topography, land use and the environment they represent in Linnéstaden. Hence only one of these areas was chosen to be representative in this study. Götatunnel achieved a high grade in the assessment. Nevertheless, the area is located further downstream and due to its location and structure a modelling of measures in this area was assumed to have a small effect on the overall catchment. Moreover, adjustments of such a complex structure like the Götatunnel are beyond of the scope of this thesis. Annedalsmotet and Magretebergsmotet were both identified in the *Structure Plan* (2017b) and both areas would allow measures in combination with the green area Slottsskogen. However, Magretebergsmotet also represents an area of an environmental risk and the location allows more options for modification in the modelling. Concluding Magretebergsmotet with regard to the implementation of measures in the park area Slottskogen was chosen as an additional high-risk area.

Slottsskogsvallen was rated with a high flooding probability in the risk assessment. It presents a combination of a green area and residential area within the catchment. However, the flooding of the sport stadium and the surrounding green areas is assigned to a very low damage potential throughout the year. Slottsskogsvallen is used for several events throughout the year, for which precautious measures and investigations are recommended and assumed. For the purpose of this study this area was defined as harmless inundation area and was neglected in the further investigation.

Annedal was determined as third high risk area. The area presents the residential and urban aspect of Linnéstaden. Due to the large number of tributaries, mostly from Guldheden the area has a high flooding probability.

Figure 4-4 illustrates the neglected areas of potentially significant flood risk, marked in grey and the investigated one's in red. The black dashed line describes the catchment area.

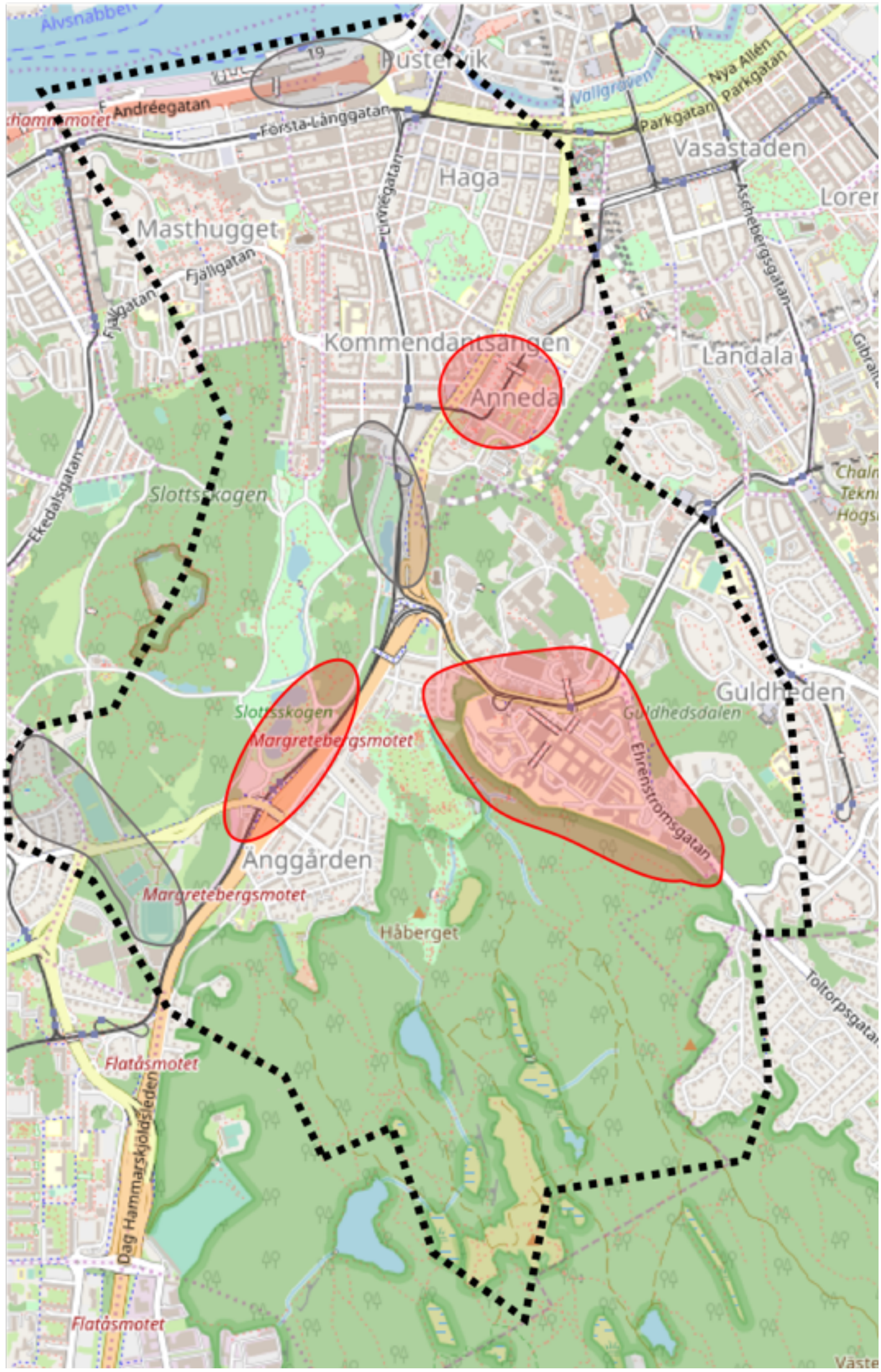


Figure 4-4: Areas of potentially significant flood risk in the catchment Linnéstaden. The selected sites marked in red, neglected sites marked in grey. (created by author)

4.1.4. DESCRIPTION OF AREAS OF POTENTIALLY SIGNIFICANT FLOOD RISK

In this chapter the risk areas chosen in the scope of the risk assessment for the catchment Linnéstaden are presented. All areas are shown in Figure 4-5. The catchment area is marked with the black dashed line and the risk areas are highlighted in red.

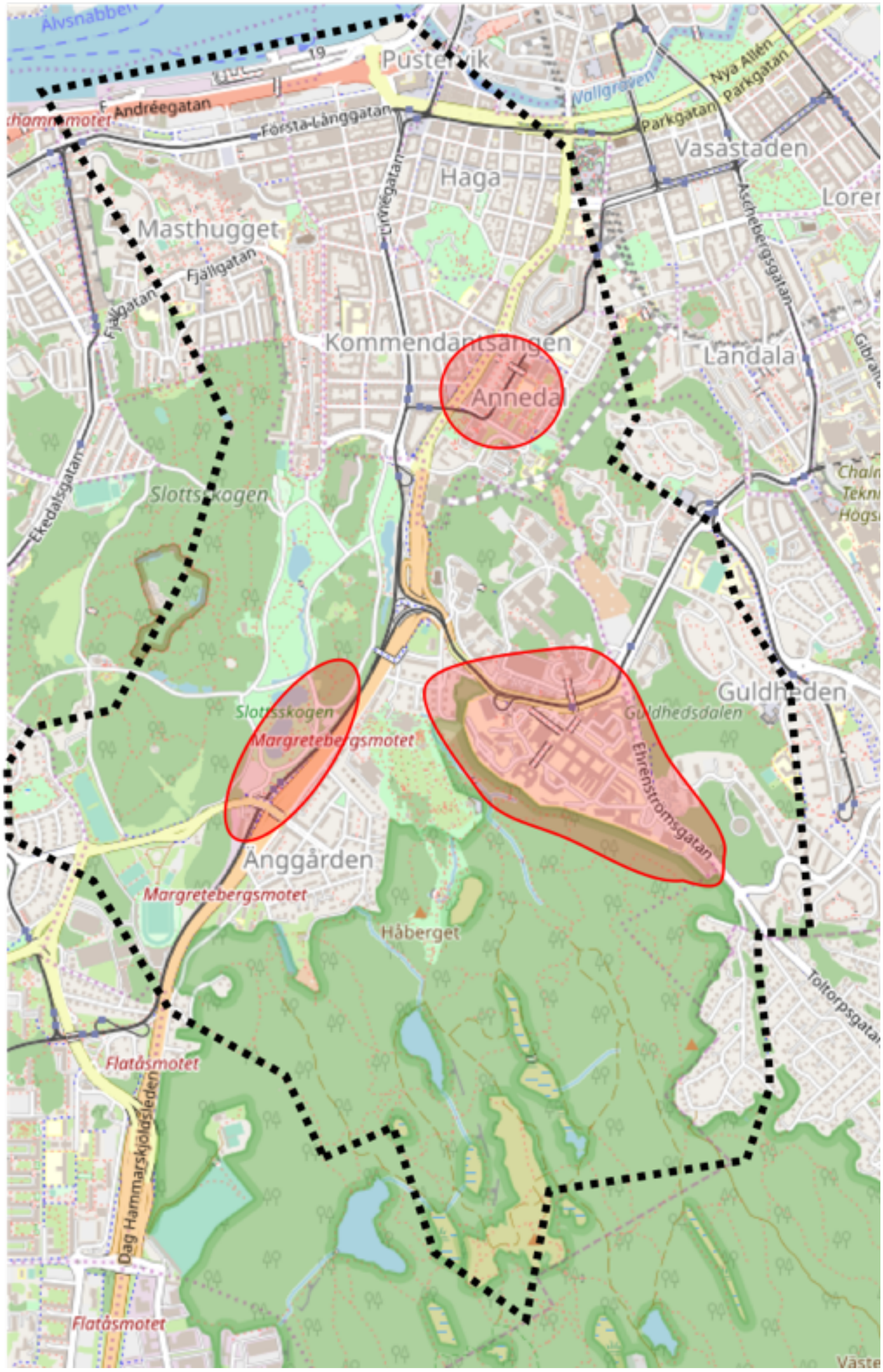


Figure 4-5: Risk areas Linnéstaden marked in red (created by author)

4.1.4.1. Sahlgrenska University Hospital

The hospital Sahlgrenska University Hospital is located in the south east of the overall catchment Linnéstaden. The hospital belongs to the subdistrict Änggården and present one of the most important health care institutions in the Gothenburg area (Kärna, et al., 2008).

As described in the risk assessment the hospital is located in a depression with a large number of tributaries from steep hillside areas. The hospital was classified to have a high vulnerability due to the risk for human health and life. In addition, the hospital was generally assumed to pose an environmental risk due to hospital waste and laboratories.

In the *Structure Plan* for Linnéstaden the area was also determined to present a high risk (2017b).

Figure 4-6: Map of study area 1 - Sahlgrenska University Hospital

With regard to the implementation of measures the hospital belonging to Västra Götalandsregionen one must consider that hospital is considered as a private property however measures that need to be taken or implemented are allocated within the private property but also within the municipal property.

Based on an interview with Caisa Sahlqvist from Teknisk Förvaltare at Västra Götalandsregionen a more thorough assessment of this risk area was done by the author to identify more specific risk areas within Sahlgrenska University Hospital.

With Sahlgrenska University Hospital being a private proper the legal obligation for the sewerage within the property is under the authority of Västra Götalandsregionen. Within the area the sewerage is a separate system. Once entering the sewer system from the *City of Gothenburg* the system is combined (Sahlqvist, 2018).

The different systems need to be considered with regard to decentral measures within the area, especially for the border areas of the hospital and the municipality.

The specified risk areas within the hospital's property were the emergency room and the area of the main entrance. In addition, the accessibility is a crucial for the main access roads like Guldhedsgatan and Per Dubbsgatan (Sahlqvist, 2018). Meaning that the aimed water level of 10 cm for emergency access according to the *Developing master plan* should be aimed for and the maximum water depth of 20 cm must be assured (Göteborg Stad, 2017a).

In virtue of discretion further risk areas are not discussed or assessed within the scope of this thesis upon consultation with Caisa Sahlqvist representative for Västra Götalandsregionen.

With regard to the additionally identified risk areas the local measures focusing on the storage and retention of the runoff are aimed for.

Due to the hospital's location upstream of the overall catchment additional discharge of the flow towards the city center and the embordering Vitsippsbäcken should be minimized. Another aspect, that needs to be considered is the water quality of the water entering the nature area Vitsippsbäcken. As the water quality is not assessed in the present report, the measures implemented are not subject to improve the water quality. For the avoidance of adverse consequences on the water quality in Vitsippsbäcken a redirection of the water into the nature area was not regarded as a possible measure.

4.1.4.2. MAGRETEBERGSMOTET

The potential risk area around Magretebergsmotet is mainly located around the road Dag Hammarskjödsleden. The area includes an under passing, which is classified to present a high structural risk. With regard to the allocation in the overall catchment the intersection is located in the southern and more upstream part of the catchment Linnéstaden. It emborders the park Slottsskogen and public transport, like a tram line are located in the area. In addition, a gas station presenting an environmental risk is situated next to the intersection. A map of the area is shown in Figure 4-7.

Figure 4-7: Map of study area 2 – Magretebergsmotet

In the *Structure Plan* for Linnéstaden a residual risk was assigned to the Magretebergsmotet and the need for a deduction of the risk (2017b).

For actions and measures the area is suitable for local or decentral measures. The embordering park Slottsskogen provides large areas, which could be used in a multifunctional manner and serve as storage and retention areas. Moreover, the parking lot area has an action potential. Besides the structural measures considered non-structural measures should also be investigated for the areas. However, non-structural measures are not within the scope of this thesis focusing on modelling and the software comparison.

4.1.4.3. Annedal – Residential area

As described in the literature studies Annedal is mostly a residential area with small businesses (Kärna, et al., 2008). The area also has small culture sites. The area is embordered by the streets Brunnsgatan, Övre husaregatan, Carl Grimbergsgata and Seminaregatan. Topographically it is located in a depression. The adjoining hillsides are green areas and rock formations. With regard to the location in the catchment it is located further downstream towards the city center. A more detailed map extract is shown in Figure 4-8.

Figure 4-8: Map of study Area 3 – Annedal

The previous study of the *Structure Plan* for Linnéstaden has shown flooding with high water depths towards Övre Husaregatan (2017b). As it is a residential area a high damage potential was assessed.

With regard to the implementation of measures for the area local measures and decentral stormwater management were assessed as the most suitable. However, for local measures the redirection instead of retention and storage measures is recommended as the embordering hillsides are very steep. Thus, the execution of retention measures in the area Annedal was assessed to be very difficult. Therefore, with regard to structural measures redirection measures and decentral measures in respect to stormwater management are suitable. Non-structural measures like urban development planning, hazard prevention as well as behavioral and informative measures are very important for a residential area and should be considered as well. Nevertheless, non-structural measures are not investigated further as the focus of the present report is on the modelling aspects.

4.2. PRESENTATION OF SOFTWARE PROGRAM RESULTS

In this section the results of the software program simulations are shown, the respective methodology is presented in chapter

As described in the methodology section the results, presented as flood maps of the area Linnéstaden, were generated with ArcGIS, precisely with ArcMap unless otherwise mentioned. The background layer for the presentation was generated in SCALGO with the “Aerial tool” for the set-up “Sweden 0.25 m” illustrating the GSD-Orthophoto provided by Lantmäteriet. A further description of the data provided by Lantmäteriet is provided in Chapter 3.3.1.1.

Flood maps illustrating the water depth were set to neglect water depths under 10 cm. The threshold was set to 10 cm as this height was determined as crucial for emergency services in the *Developing master plan* (Göteborg Stad, 2017a), see Chapter 2.4.1.1

In addition to the analysis with ArcGIS the results provided by the individual programs e.g. volume balances in MIKE ZERO by DHI software’s were evaluated.

4.2.1. VALIDATION

The results of the validation of the software programs are shown in this chapter. As previously defined in the terminology section (Chapter 1.5) the term validation described the process of verification of the models used in this thesis with the previous studies for MIKE Powered by DHI (Hørsholm, Denmark). For SCALGO the validation refers to the verification of the two investigated approaches for the model set-up.

4.2.1.1. SCALGO

In this chapter, the results and evaluation for the determination of the precipitation with both approaches are presented and validated. For each approach the determination of the precipitation height is described and subsequently assessed in terms of the validation. Followed by the selection of the approach and determination of the precipitation height for the scope of this thesis.

4.2.1.1.1. SCALGO – VISUAL APPROACH

In the first approach the precipitation height was chosen by a visual assessment. The value chosen by the author in a first step was 82 mm. The value was chosen based on a comparison of the flow accumulation and the water depth illustrated in SCALGO with the result simulations of the *Structure Plan* for Linnéstaden. In addition, the results of the hydrological analysis from the visual and holistic approach were assessed with ArcMap.

Figure 4-9 illustrates water depth and flow accumulation for the flash flood tool in the SCALGO interface. Figure 4-10 the *Structure Plan* of Linnéstaden is shown. The water depth in SCALGO was illustrated in the same stages as in the *Structure Plan*. Water depths between 0 cm and 30 cm are colored in green. Water depths between 30 cm and 50 cm in yellow and water depth’s above 50 cm in red. The flow accumulation solely is highlighted in blue and does not provide and details about the water depth in the flow path. The main flow paths in SCALGO and the *Structure Plan* correlate for the selected event of 82 mm. In addition, the water depth above 50 cm approximately correlate in the areas Slottskogsvallen, Magretebergsmotet, Sahlgrenska University Hospital, Annedal and around Guldheden.

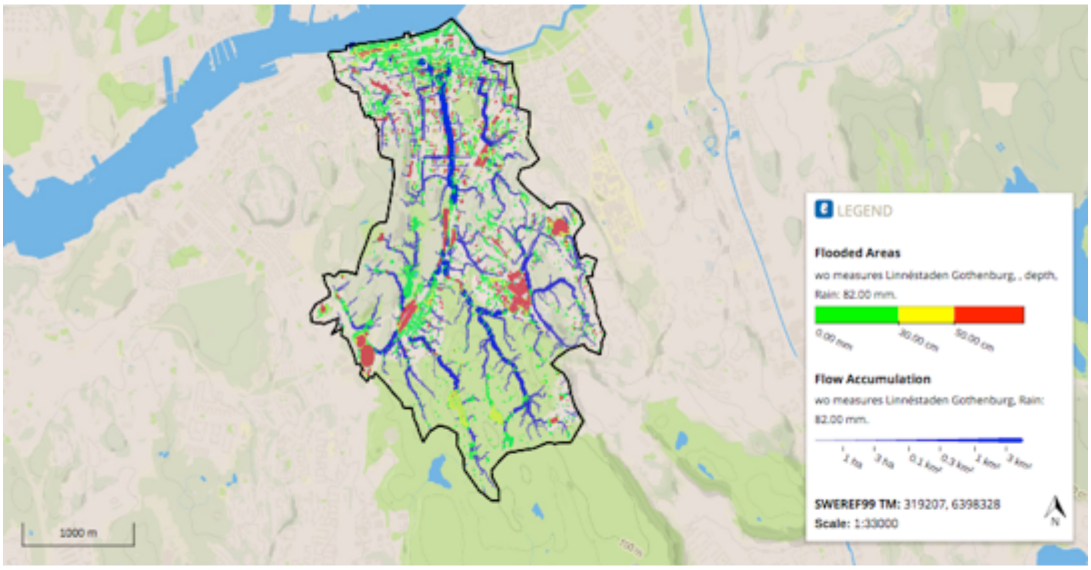


Figure 4-9: SCALGO - hydrological analysis for visual approach with water depth and flow accumulation

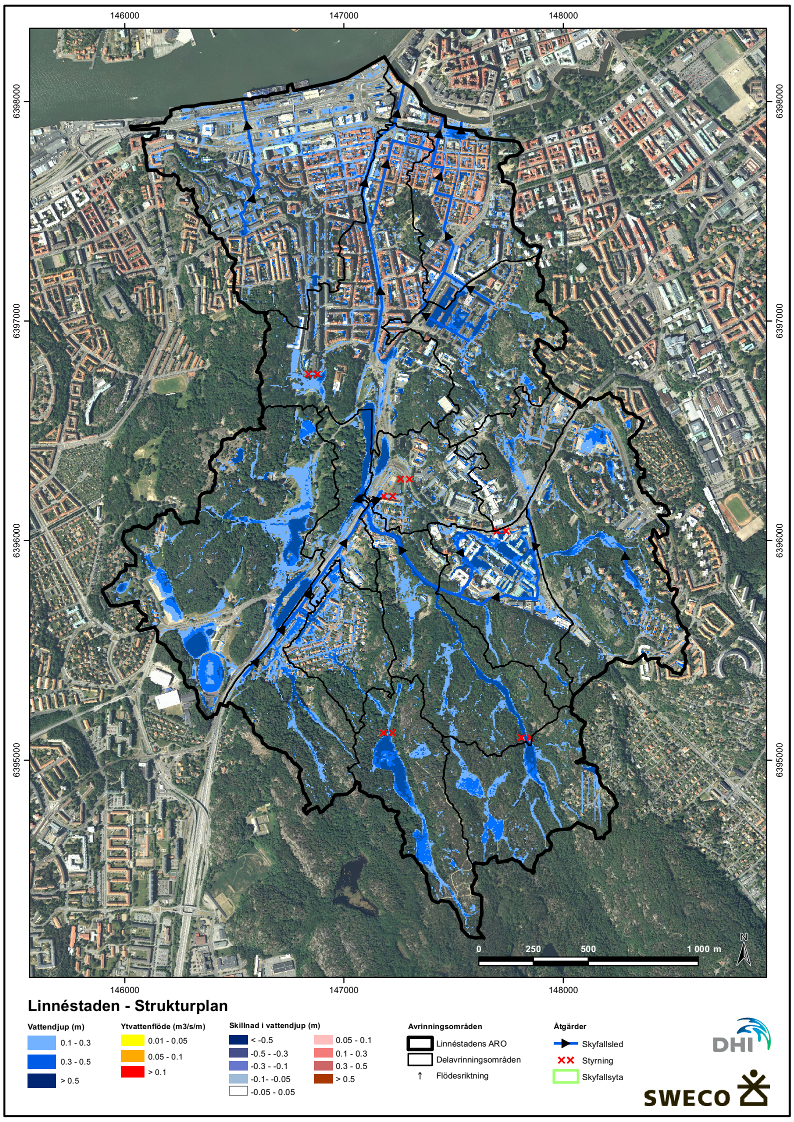


Figure 4-10: Structure Plan of Linnéstaden from the City of Gothenburg (Structure Plan, 2017)

The result of the comparison with the aid of ArcMap was counterintuitive with regard to the actual water depth. For the illustration the 3D Analyst Minus Tool was applied and the flood map is shown in Figure 4-11. A negative value implies higher flooding in SCALGO than in the *Structure Plan* and a positive value a higher flooding in the *Structure Plan* than in SCALGO.

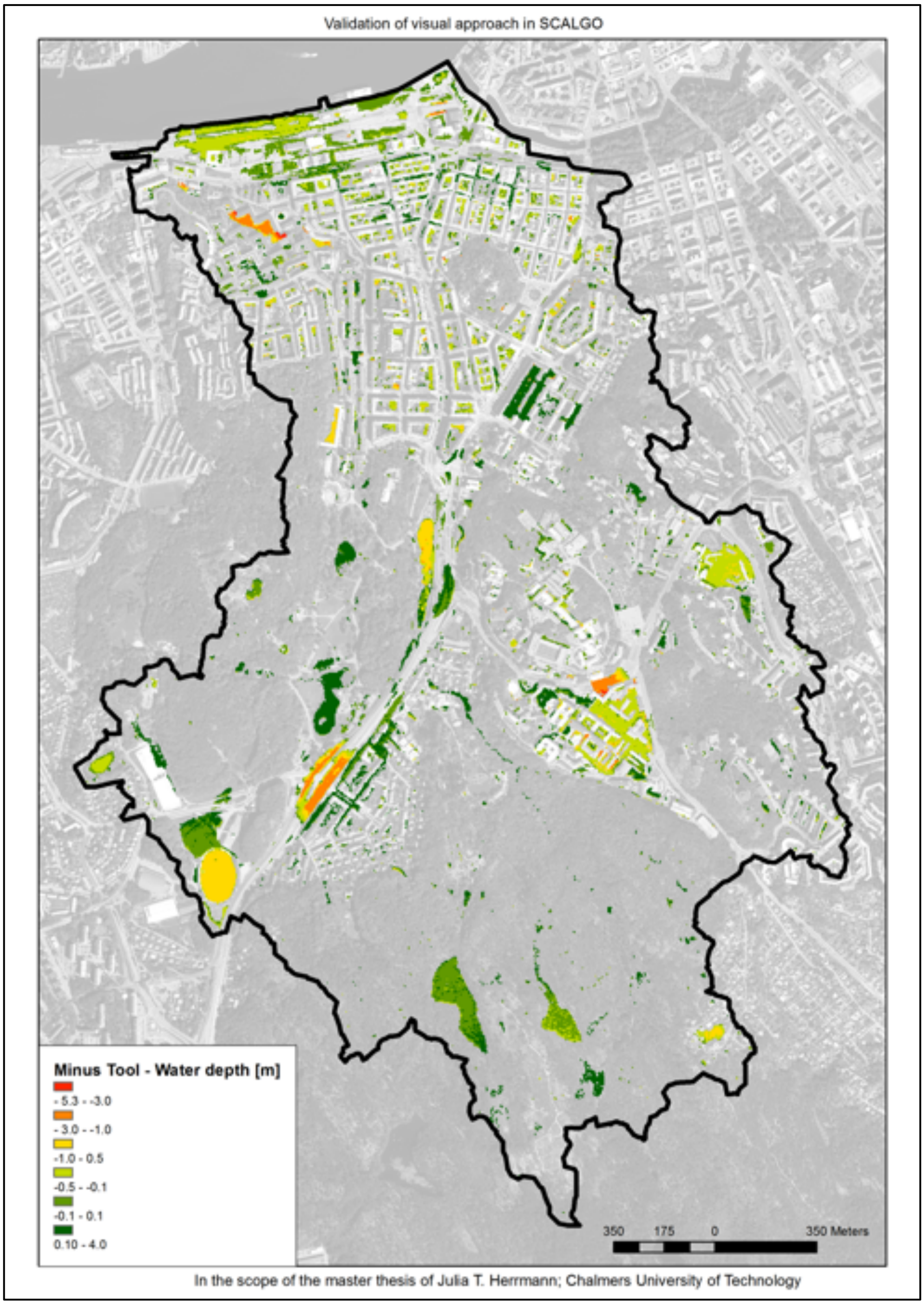


Figure 4-11: Validation of visual approach in SCALGO with Structure Plan in ArcMap (created by author)

From Figure 4-11 it is obvious that the actual water depth differs in many places. The higher water depth in SCALGO can be explained as it is mostly located in depressions and water in SCALGO accumulates in depressions until it overflows. However, the majority of the areas shows a higher water depth in the *Structure Plan* than in SCALGO with a difference larger than 10 cm. As the flooding is higher in many areas of the *Structure Plan* a larger flood propagation in some of those areas must be assumed.

Concluding the accuracy of the visual approach assumed in the first assessment must be critically reviewed and compared to the holistic approach for a final selection of the approach. However, the disadvantages of this approach in terms of the accuracy are obvious in the validation with the aid of ArcMap.

4.2.1.1.2. SCALGO – Holistic approach

This section presents the results for validating the precipitation chosen for the holistic approach SCALGO. The original tables of the calculation are presented in Appendix B Scalgo – Precipitation calculation.

The precipitation height in the holistic calculation was calculated with Equation 4-1 based on the relation of the precipitation and the rain intensity (Svenskt Vatten, 2011a):

$$P_{mean} = i_{mean} * T_R$$

Equation 4-1: Calculation of mean precipitation as input data for SCALGO (holistic approach)

With:

P_{mean}	Mean precipitation height	[mm]
i_{mean}	Mean rainfall intensity according to *Dahlström 2010* (Svenskt Vatten, 2011a)	[l/s*ha]
T_r	Rain duration	[min]

The mean values for the rain intensity according to *Dahlström 2010* (Svenskt Vatten, 2011a) were calculated for SCALGO as described in the methodology section. The results are presented in Table 4-8.

Table 4-8: Calculation of mean precipitation for SCALGO based on Dahlström 2010 (Svenskt Vatten, 2011a)

Return Period Å [year]	Duration of peak rain Tr [min]	Intensity i_{mean} [l/s*ha]	Precipitation P_{mean} [mm]
100	30	247.0	44.5
50	30	196.5	35.4
200	30	310.7	55.9
100 + 1.2	30	296.4	53.4
50 + 1.2	30	235.8	42.4
200 + 1.2	30	372.8	67.1

Table 4-8 shows the calculation of the precipitation for the return periods with and without a climate factor. The rows with +1.2 consider a climate factor. The peak rain was set to 30 min, which is equal to the peak rain of the models used in this thesis for the software program in MIKE 21 and MIKE FLOOD [(Göteborg Stad, 2015a); (Göteborg Stad, 2017d)]. A further description of the model generation for both programs in this thesis can be found in Chapter 2.4.1.

The effect of the climate factor for a 100-year return period is a difference of 8.9 mm. The difference in water depth and flood propagation with regard to the climate factor was illustrated in the Figure 4-12 with the 3D Analyst Minus Tool in ArcMap. A negative value presents higher flooding for a 100-year rain including a climate factor and a positive value means higher flooding for a 100-year rain without a climate factor.

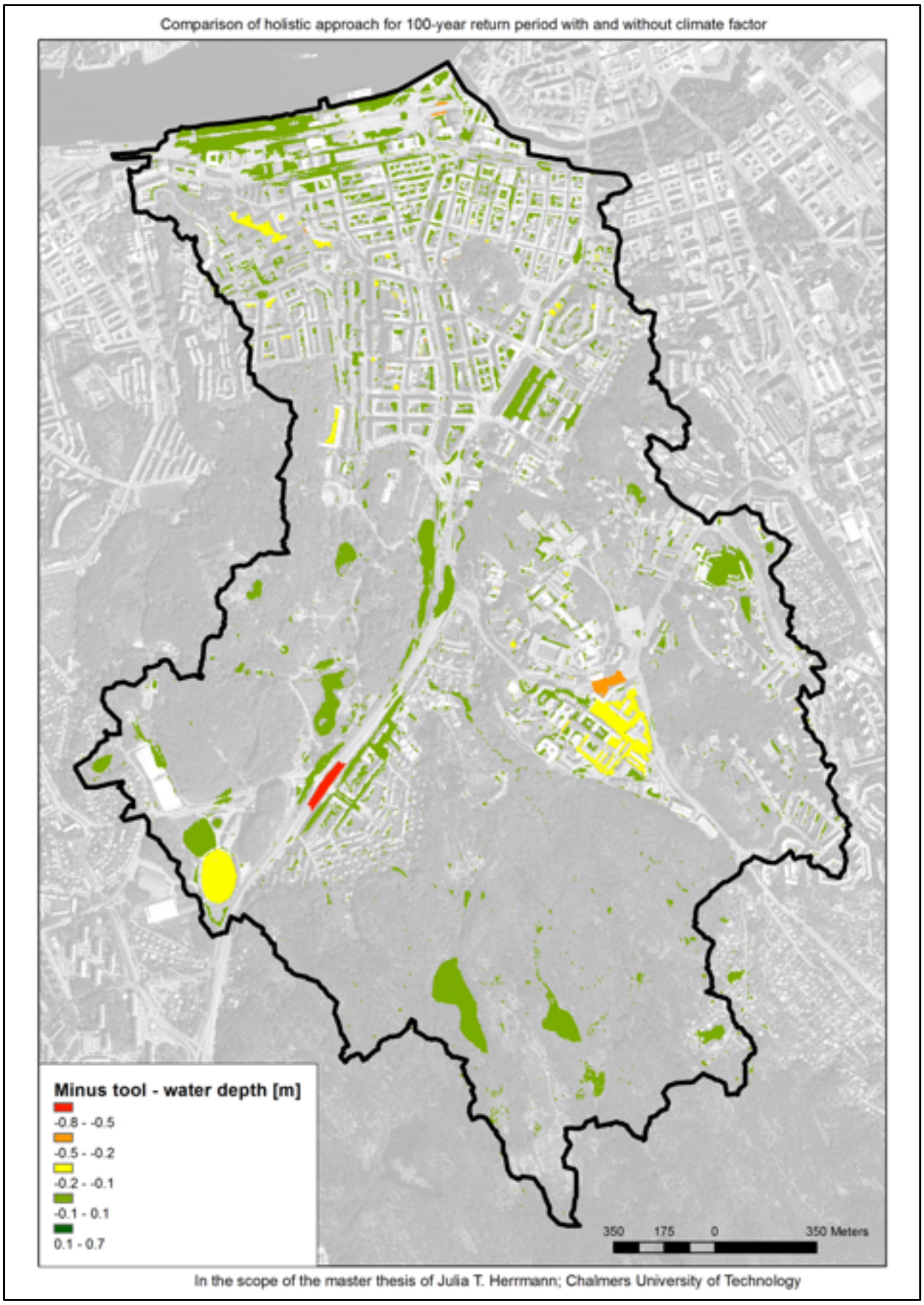


Figure 4-12: Holistic approach in SCALGO - comparison of effect of climate factor (created by author)

Figure 4-12 indicates a higher flooding for the return period including the climate factor for Magretebergsmotet and around parts of Sahlgrenska University Hospital especially at Per Dubbsgatan. Also, the stadium of Slottsskogsvallen shows a higher water depth for a 100-year rain with a climate factor. A higher flooding like this was expected as the precipitation load for a 100-year rain including a climate factor is also higher than for just a 100-year rain. However, the comparison highlights the importance of including a climate factor in the further process. It also illustrates the effect of just 8.9 mm difference in rain load on the water depth, e.g. in Magretebergsmotet with 0.58 m difference. Concluding the holistic approach including a climate factor was evaluated in the following validation.

In the subsequent section the results of the validation are presented. As described in the methodology section, see Chapter 3.3.2.1.

1. <u>Comparison to literature values of *Dahlström 2010*</u>

In a first step the values were compared to the literature values according to *Dahlström 2010*, published in P104 by Svenskt Vatten (Svenskt Vatten, 2011a). The values are presented in Table 4-9. In this step of the validation no climate factor was considered as no climate factor is applied in the original calculation. The calculation and comparison were done for a 100-year rain with varying durations.

Table 4-9: Precipitation and rain intensities - Scalgo and Dahlström 2010 (Svenskt Vatten, 2011a) - value comparison

Source	Duration	Rain intensity	Precipitation
	T_{total} [year]	[l/s*ha]	P_{mean} [mm]
SCALGO	6 h	39.1	84.5
Dahlström 2010	6 h	39.1	84.5
SCALGO	12 h	23.0	99.6
Dahlström 2010	12 h	23.0	99.6
SCALGO	24 h	13.8	119.2
Dahlström 2010	24 h	13.8	119.2

Table 4-9 shows the obvious correlation of the values, thus the values are validated by the literature values according to *Dahlström 2010*, as described in P104 by Svenskt Vatten (2011a).

2. <u>Precipitation for peak duration 30min</u>

For the peak duration of 30 min the values were compared to the data from the original model set-ups of the *Cloudburst Mapping* for MIKE 21 and *Structure Plan* for MIKE FLOOD [(Göteborg Stad, 2015a); (Göteborg Stad, 2017d)]. For this validation the climate factor was regarded in SCALGO.

Table 4-10: Precipitation height peak rain - Comparison of Software Programs

Software Programs	Duration of peak rain	Return Period	Precipitation	Percentual Correlation
	T_r [min]	Å [year]	P_{mean} [mm]	[%]
SCALGO	30	100 +1.2 CF	53.36	
MIKE 21	30	100 +1.2 CF	53.00	- 0.67
MIKE FLOOD	30	100 +1.2 CF	53.40	+ 0.08

As shown in Table 4-10 the values for the precipitation height are almost identical for the peak duration of 30 min in SCALGO, MIKE 21 and MIKE FLOOD. Therefore, the holistic approach was considered as validated with regard to the existing models for the study area.

3. Precipitation for total duration

For the comparison of the rain load for the total duration the rain load was calculated in MIKE 21 and MIKE FLOOD according to their model set-up.

For MIKE 21:

$$P_{total,M21} = P_{pre-rain} + P_{peak}$$

Equation 4-2: Precipitation height MIKE 21

Based on Equation 4-2 and with a precipitation height for the pre-rain of 24 mm (Göteborg Stad, 2015a) and 53 mm respectively for the peak rain (Göteborg Stad, 2015a), the total precipitation height for MIKE 21 was calculated as 77 mm. The total duration in MIKE 21 of the simulation is 3 hours.

For MIKE FLOOD:

$$P_{total,MF} = P_{pre-rain} + P_{peak} + P_{after-rain}$$

Equation 4-3: Precipitation height MIKE FLOOD

Based on Equation 4-3 and with a precipitation height for the pre-rain of 23.7 mm (Göteborg Stad, 2017d) and a precipitation height for the after-rain of 23.7 mm (Göteborg Stad, 2017d) and 53.4 mm for the peak rain (Göteborg Stad, 2017d) the total precipitation height for MIKE FLOOD was calculated as 100.8 mm. The total duration in MIKE FLLOOD of the simulation is 6 hours.

The precipitation heights calculated in SCALGO the total durations in MIKE 21 and MIKE FLOOD are shown in Table 4-11. For all calculations the return periods are 100-year rain events with a climate factor.

Table 4-11: Precipitation Height total rain duration - comparison of software programs

Software Programs	Total rain duration	Total rain duration	Precipitation	Percentual Correlation
	T_r [min]	T_r [hours]	P_{mean} [mm]	[%]
SCALGO	180	3	86.3	
MIKE 21	180	3	77.0	- 10.82
SCALGO	360	6	101.4	
MIKE FLOOD	360	6	100.8	- 0.63

For the total duration the values for the precipitation height differ for about 10 % in MIKE 21. This could be due to the general deduction of the sewer system in MIKE 21. When considering the pre-, after- and peak rain in MIKE FLOOD the difference is only 1 %. With regard to MIKE 21 further adjustments should be considered for the comparison of the total duration to investigate the source of the difference.

4. Precipitation with Sewer System

For the comparison of the precipitation height with a general deduction of the sewer system a 10-year capacity was chosen for SCALGO to compare with MIKE FLOOD. The comparison with MIKE FLOOD was done for the peak duration and the precipitation height in MIKE URBAN for that duration according to the *Structure Plan* (Göteborg Stad, 2017d).

Table 4-12: SCALGO and MIKE FLOOD comparison with sewer system deduction

Software Programs	Total rain duration	Precipitation
	T_r [min]	P_{mean} [mm]
SCALGO 10-year capacity	30	20.80
MIKE URBAN	30	20.84

As shown in Table 4-12 the value for the peak duration in SCALGO and MIKE URBAN are the same for the 10-year capacity. A deduction in SCALGO with that value would lead to a very small precipitation load for the peak duration of 30 min.

For MIKE 21 the capacity is a 2 and 5-year capacity according to the *Cloudburst Modelling* (Göteborg Stad, 2015a). The capacity of the sewer system was considered for the whole simulation period thus 3 hours and but the comparison of the precipitation height was done by considering the precipitation height of the peak rain in SCALGO adding the sewer system capacity to that height.

Table 4-13: SCALGO and MIKE 21 comparison with sewersystem deduction

Software Programs	Total rain duration	Precipitation
	T_r [min]	P_{mean} [mm]
SCALGO 2-year capacity	180	21.1
SCALGO 5-year capacity	180	27.9
SCALGO Averaged capacity	180	24.5
SCALGO	180	77.84
MIKE 21	180	77.0

Table 4-13 shows a correlation of the precipitation heights for the total duration when including the sewer system. In comparison to the assessment of just the whole duration between SCALGO and MIKE 21 the difference shown in Table 4-11 was as previously assumed due to the sewer system deduction in MIKE 21.

Based on the previous steps the holistic approach was in the range for MIKE 21 and MIKE FLOOD and correlated with the values from the literature. Therefore, the application of this equation was considered to be reasonable and supportive for the comparison of flash floods and torrential rain analysis and simulation in this thesis.

In a final step ArcMap was additionally applied to illustrated the difference in water depth between the holistic approach and MIKE FLOOD in the same manner as for the visual approach, see Figure 4-13. For the illustration the 3D Analyst Minus Tool was applied. A negative value implies higher flooding in SCALGO than in the *Structure Plan* and a positive value a higher flooding in the *Structure Plan* than in SCALGO.

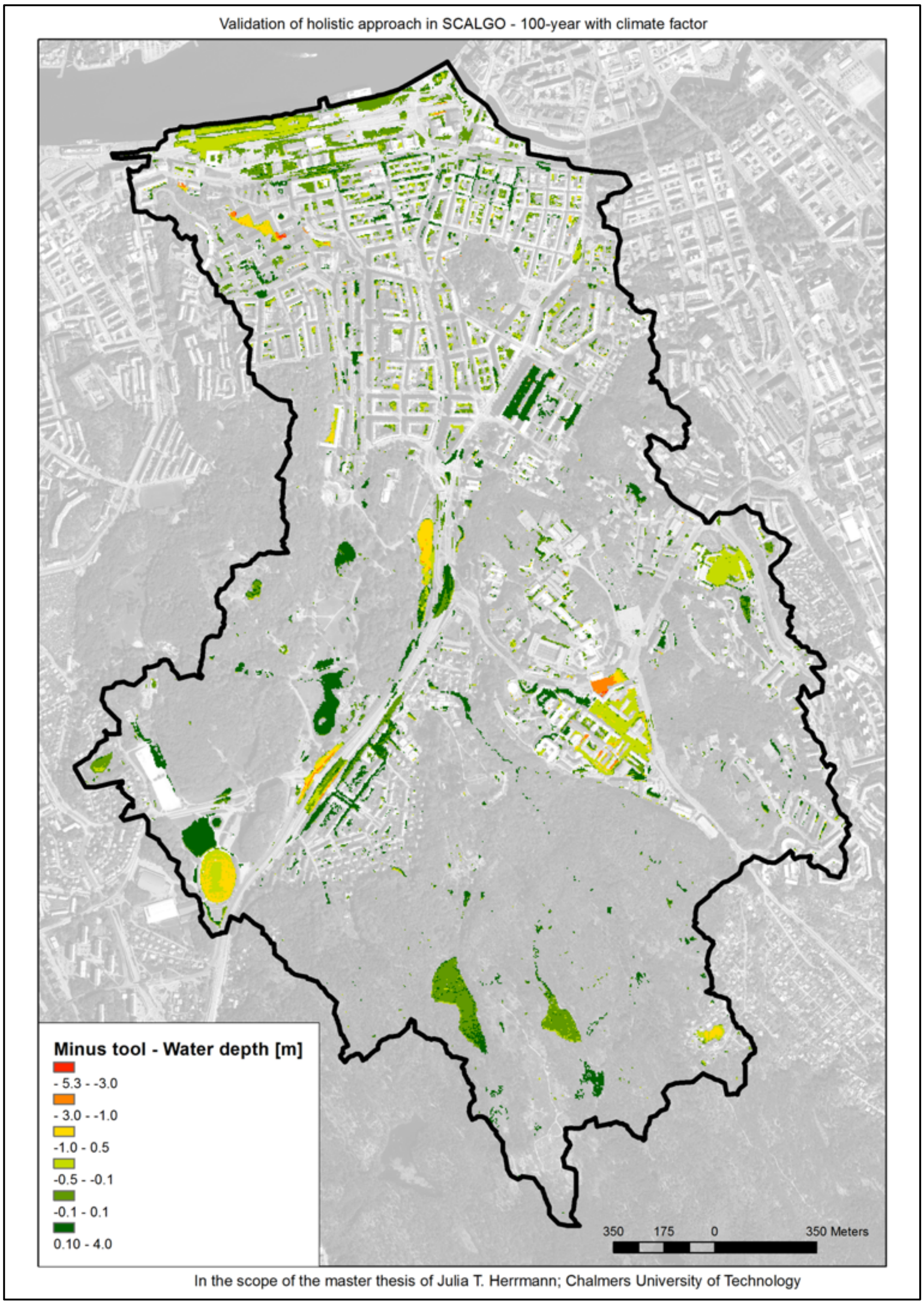


Figure 4-13: Validation of holistic approach with Structure Plan in ArcMap (created by author)

For most of the areas the flooding depth, shown in Figure 4-13, is larger in MIKE FLOOD than in SCALGO, which was expected due to the scientific background. However, the results differ less than in the visual approach.

4.2.1.1.3. FINAL APPROACH

Based on the results of the visual and holistic approach only the results of the holistic approach were considered as validated. The precipitation height of the different approaches is listed in Table 4-14.

Table 4-14: Comparison of precipitation height for visual and holistic approach in SCALGO

Approach	Precipitation P_{mean} [mm]
Visual Approach	82.0
Holistic Approach 100year + 1.2 CF	53.4

The difference in water depth between the two approaches was 28.6 mm. As the holistic approach was validated by the previous studies and literature the visual approach is considered as not validated. For the final comparison of the water depth of the visual and holistic approach the 3D Analyst minus tool in ArcMap was applied, see Figure 4-14.. A negative value means a higher flooding of the holistic approach and a positive value means a higher flooding of the visual approach.

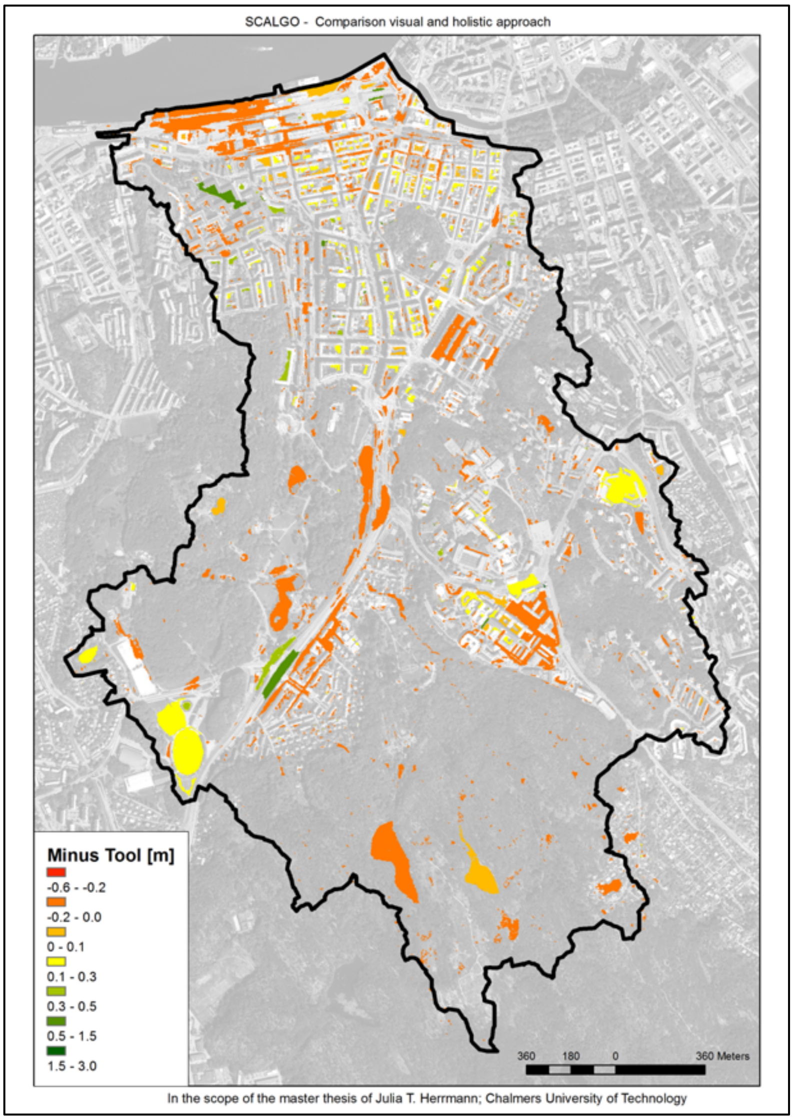


Figure 4-14: Comparison visual and holistic approach with ArcMap (created by author)

The flood map, Figure 4-14, in ArcMap shows higher flooding for the visual approach in almost all areas apart from the depression in Magretebergsmotet. The flooding with the holistic approach is slightly larger for Slottskogsvallen, Guldheden and the roads next to Sahlgrenska University Hospital.

With regard to the previous investigation the visual approach was neglected in the further studies and the holistic approach was applied. The holistic approach was applied with a climate factor of 1.2 and without a general deduction of the sewer system.

An additional validation in the scope of a sensitivity analysis like in the software programs of MIKE ZERO by DHI (Hørsholm, Denmark) is not possible for SCALGO and thus could not be done. Nevertheless, the holistic approach was decided to be valid for the application and could serve as an approach for Sweden. The holistic approach requires a known return period for the event and determined peak rain durations.

4.2.1.2. MIKE 21

For the validation in MIKE 21 the Minus-tool was applied in ArcMap, presented in Figure 4-15. A negative value implies that the water depth in the current model is larger than in the original set-up.

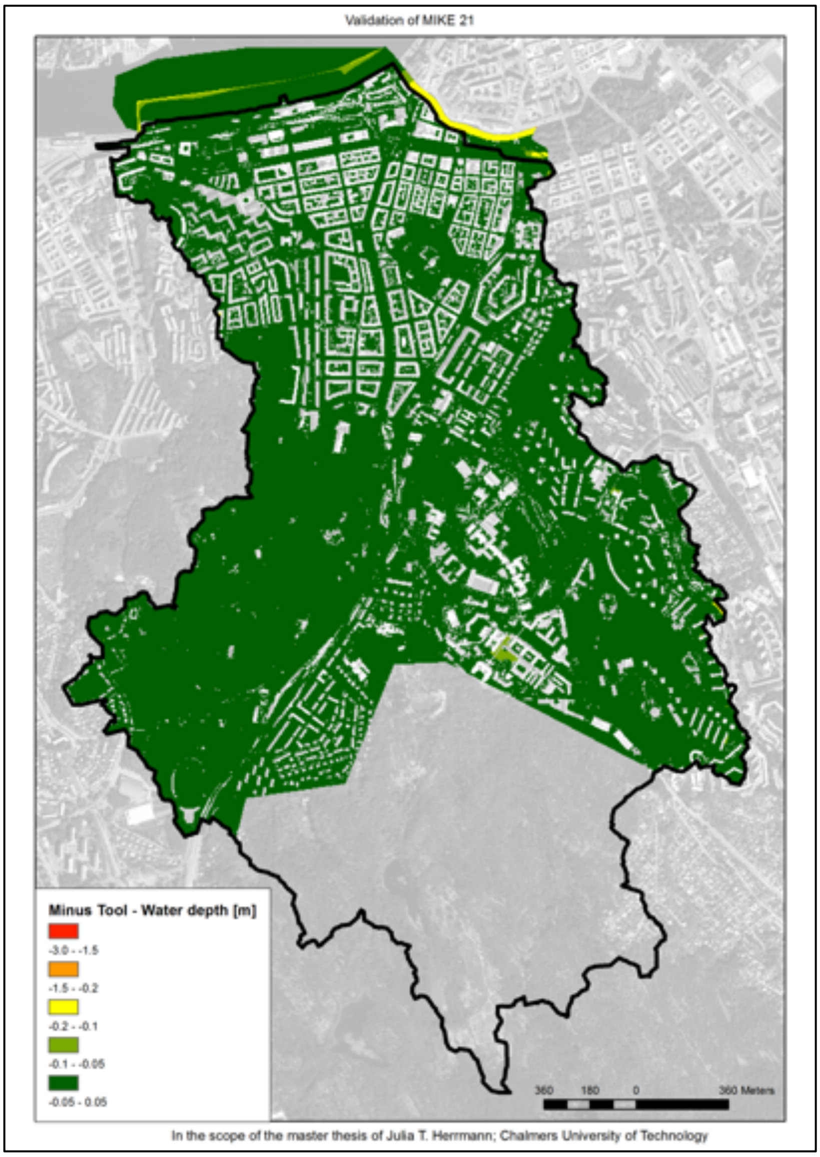


Figure 4-15: MIKE 21 validation of model set-up for the water depth (created by author)

In the case of the MIKE 21 simulation the area can only be validated for the areas modelled in the *Cloudburst modelling* and investigated in this study. Therefore, the nature area Änggården in the south cannot be compared as it was not modelled in the *Cloudburst modelling* study. The model was adapted for the present thesis to correspond to the area in SCALGO and MIKE FLOOD with regard to the DEM. AS the model set-up was taken from the original model of the *Cloudburst modelling* that study was chosen for the validation. The discrepancy of 5 cm for the main part of Linnéstaden was considered to be reasonable. The main difference in flooding is located in the area of the Sahlgrenska University Hospital within 5 to 10 cm was considered reasonable. Thus, the model validation successful for the scope of the present report. As a consequence, the sensitivity analysis of the previous studies for MIKE 21 is validated for this report, since an additional sensitivity analysis would only be a repetition of preceding work.

Due to the lack of the data an assessment of the volume balance in the terms of the validation was not possible for MIKE 21.

4.2.1.3. MIKE FLOOD

In the following the flood maps (Figure 4-16, Figure 4-17) presenting the results of the simulation for the validation of MIKE FLOOD are shown.

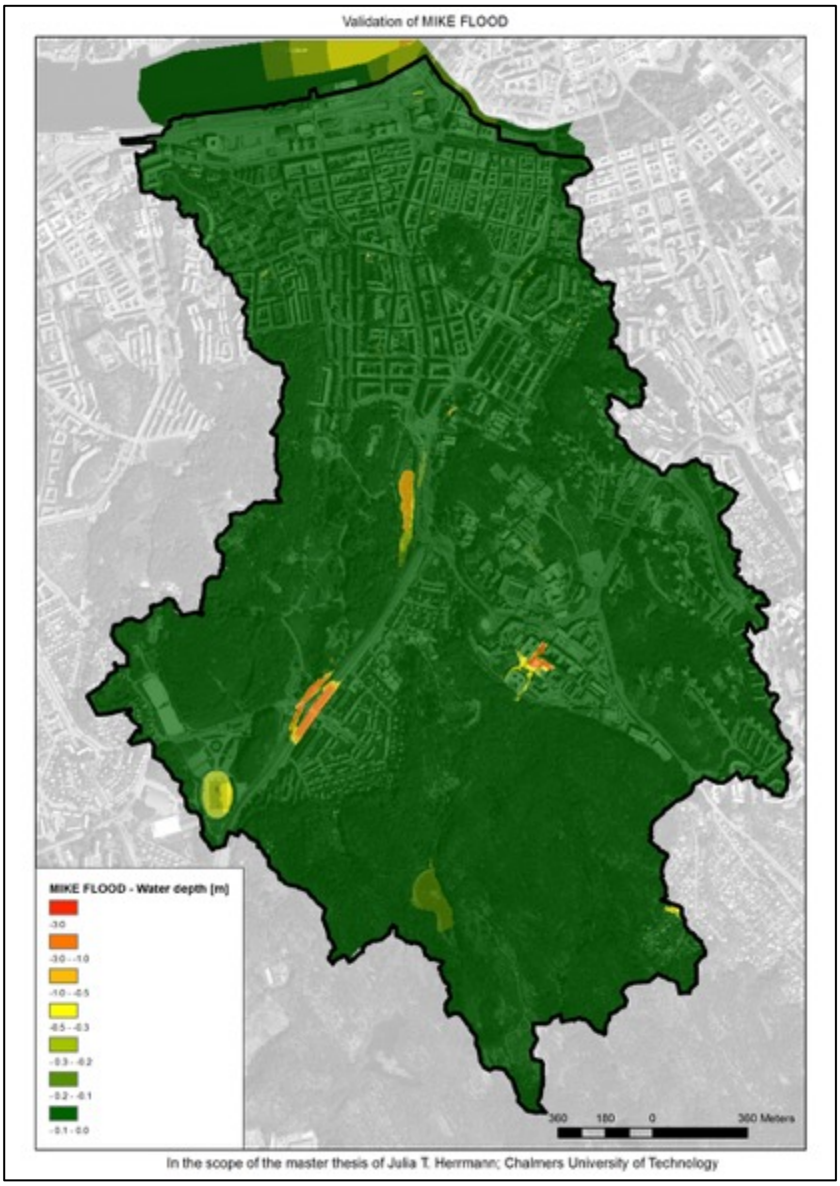


Figure 4-16: Validation MIKE FLOOD with previous study results for water depth (created by author)

For the validation the Minus-tool was applied in ArcMap as presented in the Figure 4-16. A negative value implies that the water depth in the current model is larger than in the original set-up. As previously described there have been no changes to the set-up. An obvious difference of the water depth occurs at the area of Magretebergsmotet and in part of Sahlgrenska University Hospital. The difference is marked in orange and red and presents a negative value, thus the current simulation showed a higher flood depth than the original set-up.

Overall the difference of 10 cm through the main areas of the catchment is reasonable. The large difference for Magretebergsmotet and the hospital however is unexpected. The same applies for the difference in Slottsskogen nearby Annedalsmotet.

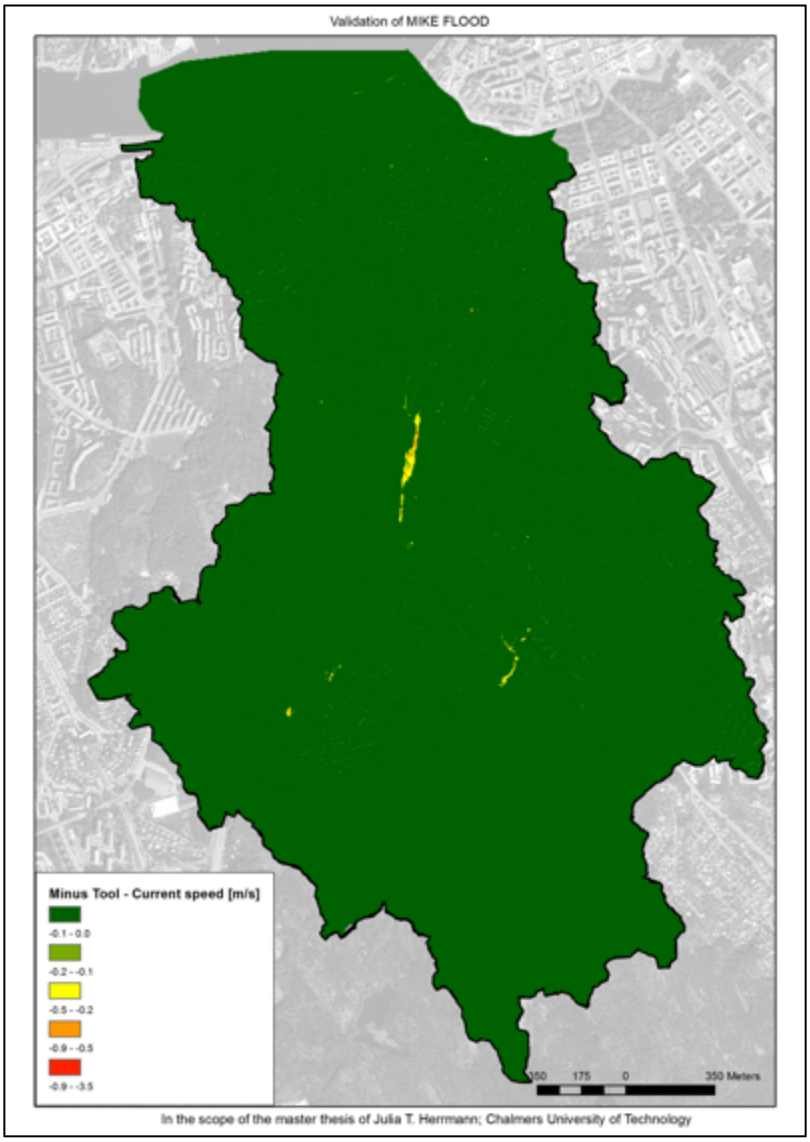


Figure 4-17: Validation MIKE FLOOD with previous study results for current speed (created by author)

With respect to the current speed illustrated in Figure 4-17 the main difference occurs around Linnéplatsen and from the inflow of the Sahlgrenska University Hospital towards Vitsippsbäcken. The difference is within 0.2 to 0.5 m/s, with the current model showing a faster current speed than the original set-up. The main difference of 0.1 m/s through the catchment is reasonable. The difference in current speed at Linnéstaden and the hospital are unsuspected though.

Nevertheless, the margins are reasonable and the models are considered to be validated for MIKE FLOOD. The water depth and velocity are larger in the current set-up thus a worse case than in the previous study occurs. As a consequence, the sensitivity analysis of the MIKE FLOOD is validated as well for this report, since an additional sensitivity analysis would only be a repetition of preceding work.

In MIKE FLOOD the volume balance was compared for MIKE 21 and MIKE FLOOD. The volumes were evaluated as in a reasonable range especially with regard to the results of the flood mapping of the water depth and current speed. However, they showed some differences with a larger inflow and outflow from the sewer system in connection to the overland flow in MIKE 21. The volume balance can be found in Appendix D of the present report.

4.2.2. Comparison of Software Programs

In this section the results from the models without any changes for a 100-year rain with a climate factor were compared and the results are presented.

4.2.2.1. SCALGO

Figure 4-18 shows the validated flood map for the simulation of a 100-year return period with a climate factor of 1.2 according to the setup generated in this thesis for to the holistic approach described in the previous section. The flooding was simulated in SCALGO and the map generated in ArcMap.

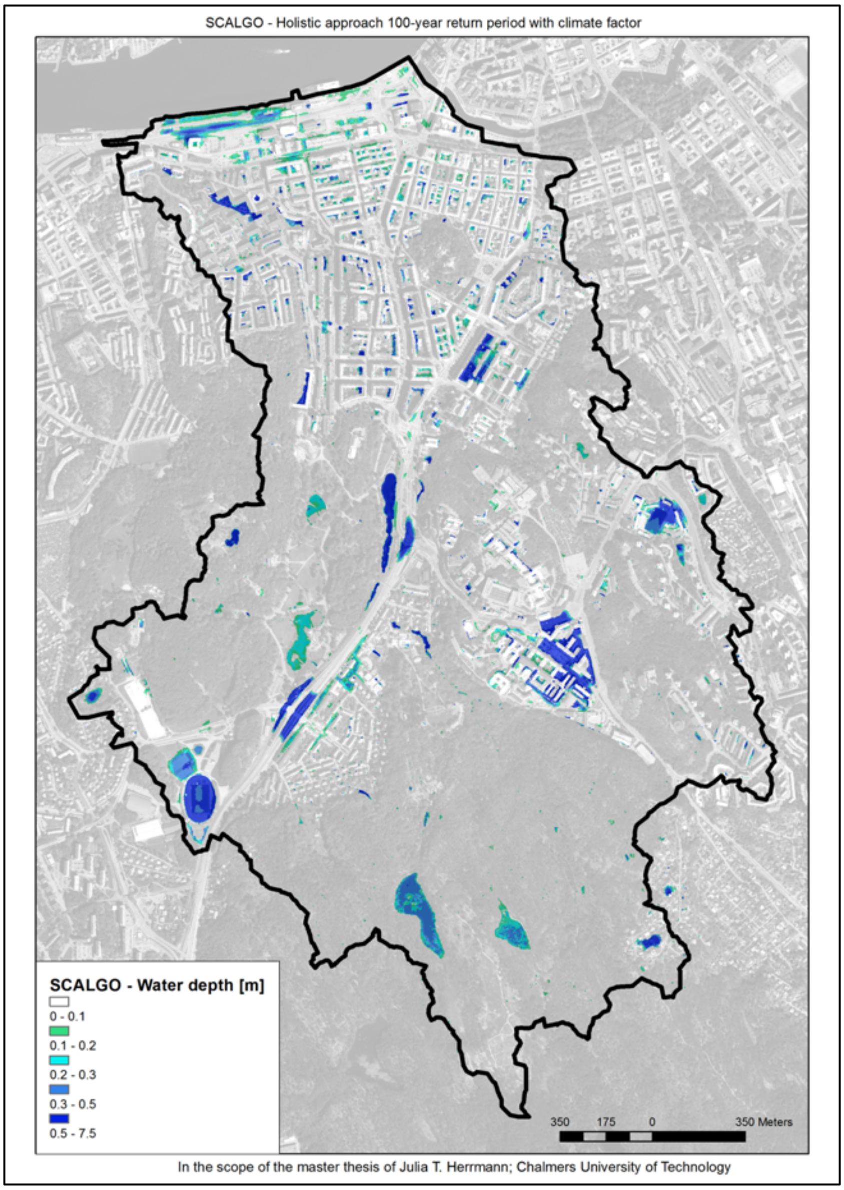


Figure 4-18: SCALGO flood map for 100-year return period in the scope of this thesis (created by author)

The flood map for SCALGO for a 100-year rain event with a climate factor illustrating the water depth in Figure 4-18 shows the flooding above 10 cm.

A positive correlation of the flooding for the main areas with the previous study was found. As the model set-up in SCALGO was based on the comparison with the other programs this outcome was expected.

The main flooded areas in SCALGO are from upstream to downstream:

- Two areas in the nature reservoir Änggården
- Slottsskogsvallen
- Magretebergsmotet in Änggården
- The water body in the park Slottsskogen
- The area of the hospital Sahlgrenska University Hospital
- Annedalsmotet and the embordering area in Slottsskogen
- Annedal
- Downstream in Masthugget towards the Götatunnel

For a 100-year rain event the flooding presented in the flood map for SCALGO has a relatively small flood propagation. This can be explained as SCALGO only shows the flooding in depressions and the flooding can be seen as a snapshot not representative for the depths occurring over the whole flood event.

Through the catchment the map shows small depressions filled, which can be used to illustrate the flow path in addition to the flood map from SCALGO. The map itself does not show the flow paths and the depths occurring on flow paths over the event.

4.2.2.2. MIKE 21

In Figure 4-19 the validated flood map for the simulation of a 100-year return period with a climate factor of 1.2 according to the setup in the Cloudburst mapping is shown. The flooding was simulated in MIKE 21 and the map generated in ArcMap.

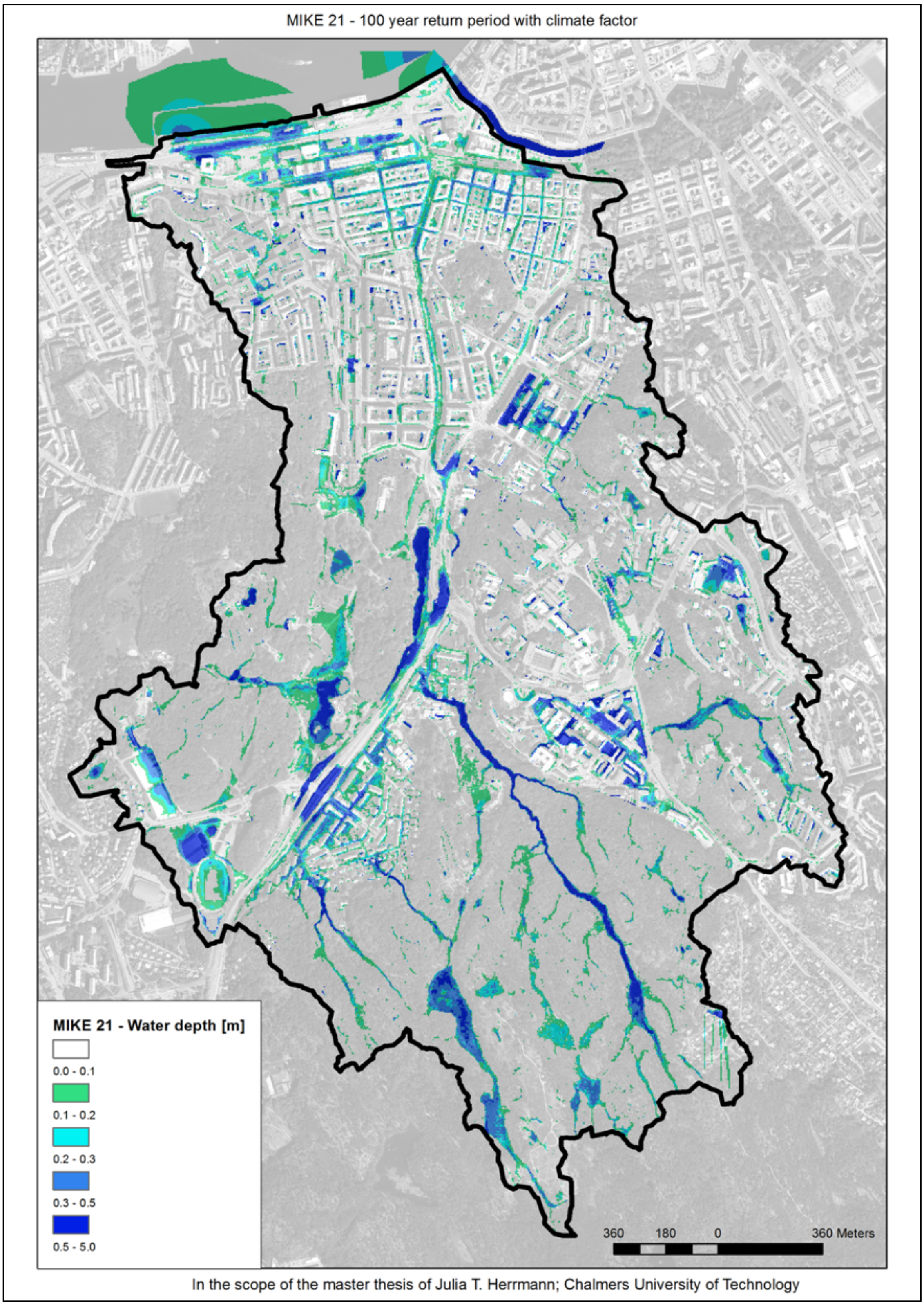


Figure 4-19: MIKE 21 - Flood map generated in the scope of thesis with simulations in MIKE 21 generated in ArcMap (created by author)

What stand out for Figure 4-19, generated in MIKE 21, in comparison to Figure 4-18 is the larger flood propagation for the water depth. The reason is that MIKE 21 can consider the time factor and presents the maximum water depth for the whole simulation period of 3h. Therefore, it was expected that MIKE 21 will have a larger flow propagation than SCALGO.

The main flooded areas identified correlate with the one's in MIKE 21, but with MIKE 21 the flow paths are also illustrated. The main flow paths illustrated are tributaries from the south of Änggården towards Annedalsmotet and one tributary from the nature area Änggården towards the sub-areas residential area. The main flow path in the downstream area is the road Linnégatan. For the Sahlgrenska University Hospital the main tributary is from the area Guldheden allocated at the hillside. For Annedal the tributaries come from the steep hillsides. In Slottsskogen the flow paths towards the central part of the catchment is shown. In general, there is little flooding in Olivedal and the southern part of Haga.

4.2.2.3. MIKE FLOOD

Figure 4-20 shows the validated flood map for the simulation of a 100-year return period with a climate factor of 1.2 according to the setup in the *Structure Plan* is shown. The flooding was simulated in MIKE FLOOD and the map generated in ArcMap.

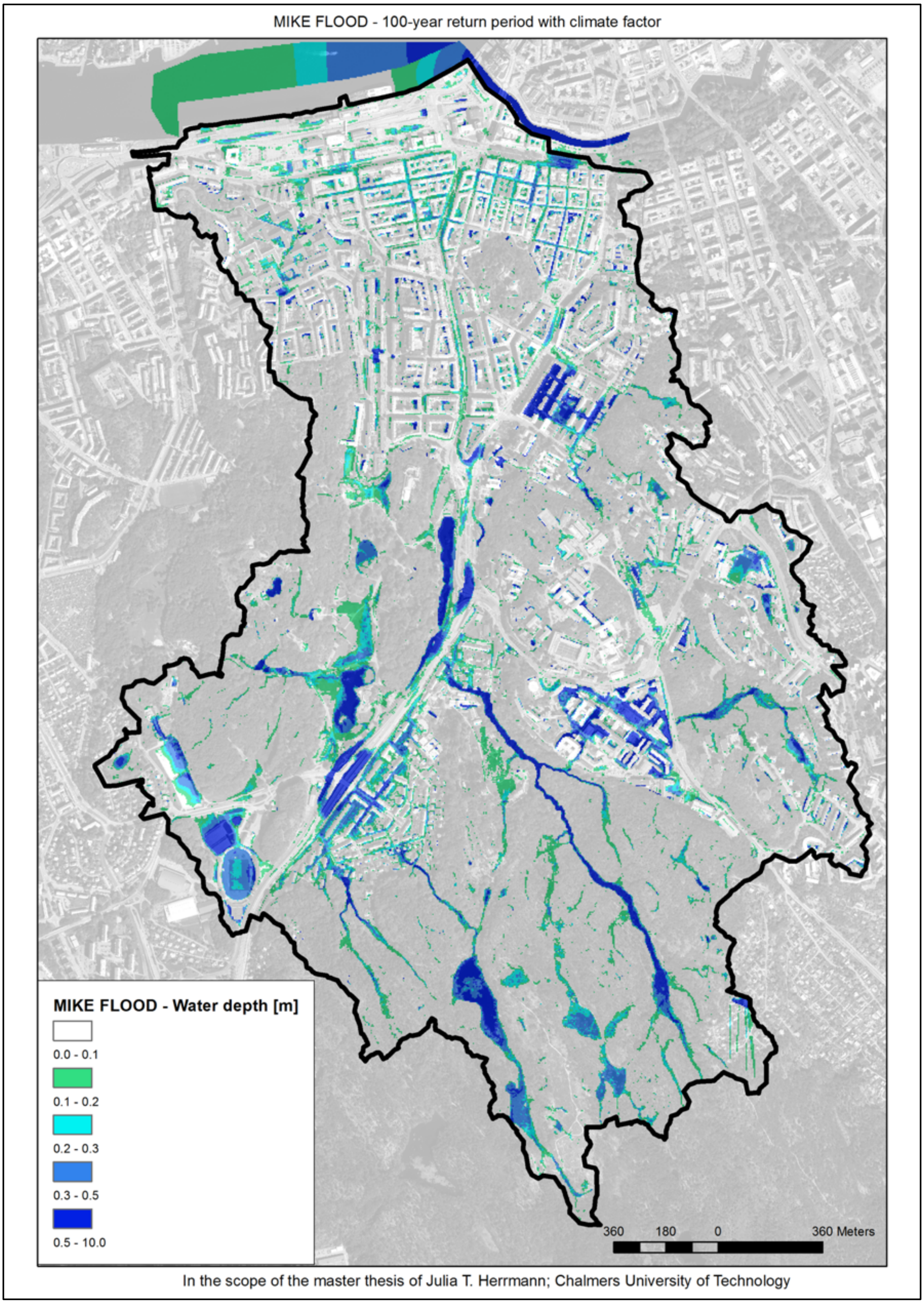


Figure 4-20: MIKE FLOOD - flood map for 100-year rain with climate factor in the scope of this thesis (created by author)

The flood map for MIKE FLOOD (Figure 4-20) corresponds for the most part of the flood propagation. The water depth in the main flooded areas Annedal, Magretebergsmotet, Annedalsmotet and Sahlgrenska University Hospital and Slottsskogsvallen is higher than in the simulation from MIKE 21. The water depth in the northern and downstream part of the catchment is lower in MIKE FLOOD than in MIKE 21.

4.2.2.4. COMPARISON - WATER DEPTH

The flood map presented in Figure 4-21, shows all three flood simulations for a 100-year rain event with a climate factor is illustrated.

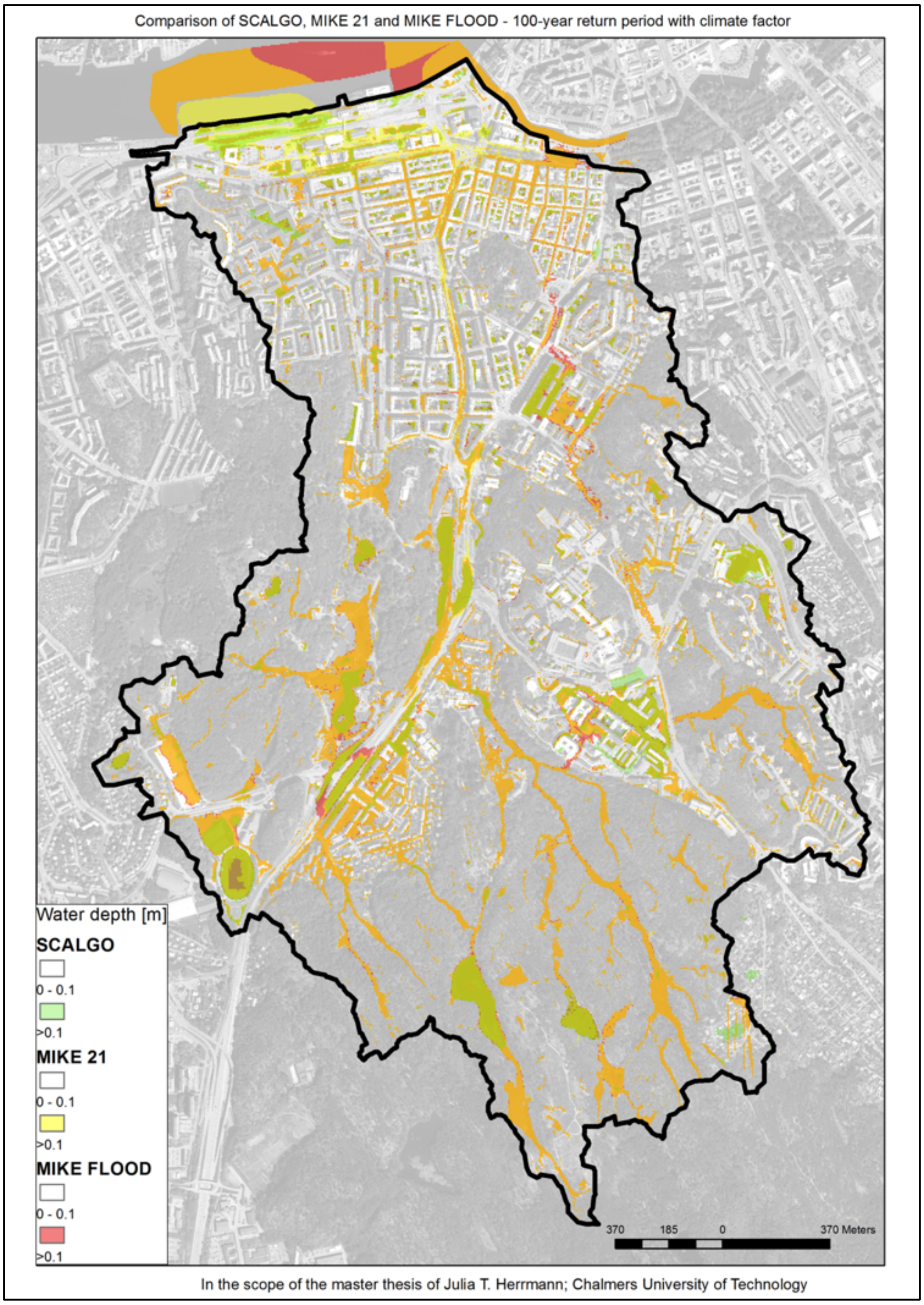


Figure 4-21: Flood map of basic comparison for SCALGO, MIKE 21 and MIKE FLOOD (created by author)

In Figure 4-21 each software program was assigned to a color presenting the flood depth above 10 cm. The flood maps show the correlation of the main flooded areas between all three software programs. It points out the severe difference within the flood propagation of SCALGO and MIKE ZERO software programs. An unexpected result shown in the map is the flooding of some areas only in SCALGO. One of those areas is located in the upstream area of Änggården. The other areas solely flooded in SCALGO are nearby the hospital areas around Per Dubbsgatan and some small areas in Masthugget.

Most of the flow paths are colored in orange indicating the same flow paths for MIKE 21 and MIKE FLOOD. Rather remarkable are the areas just flooded in MIKE FLOOD. This occurs in the area of the Sahlgrenska University Hospital towards Vitsippsbäcken. The flood propagation in MIKE FLOOD at Magretebergsmotet is larger as well as towards the residential area Annedal and in Annedal around Brunnsgatan towards Övre Husargatan.

Areas that are just flooded in MIKE 21 are located in the north of the catchment in Masthugget and at Järntorget and partially along Linnégatan.

4.2.2.5. COMPARISON – CURRENT SPEED

The current speed could only be compared for MIKE 21 and MIKE FLOOD. The flood map illustrating the difference of the current speed is presented in Figure 4-22. The minus-tool in ArcMap was used for the presentation of the results. With a negative value indicating a higher speed in MIKE FLOOD and a positive value indicating a higher speed in MIKE 21.

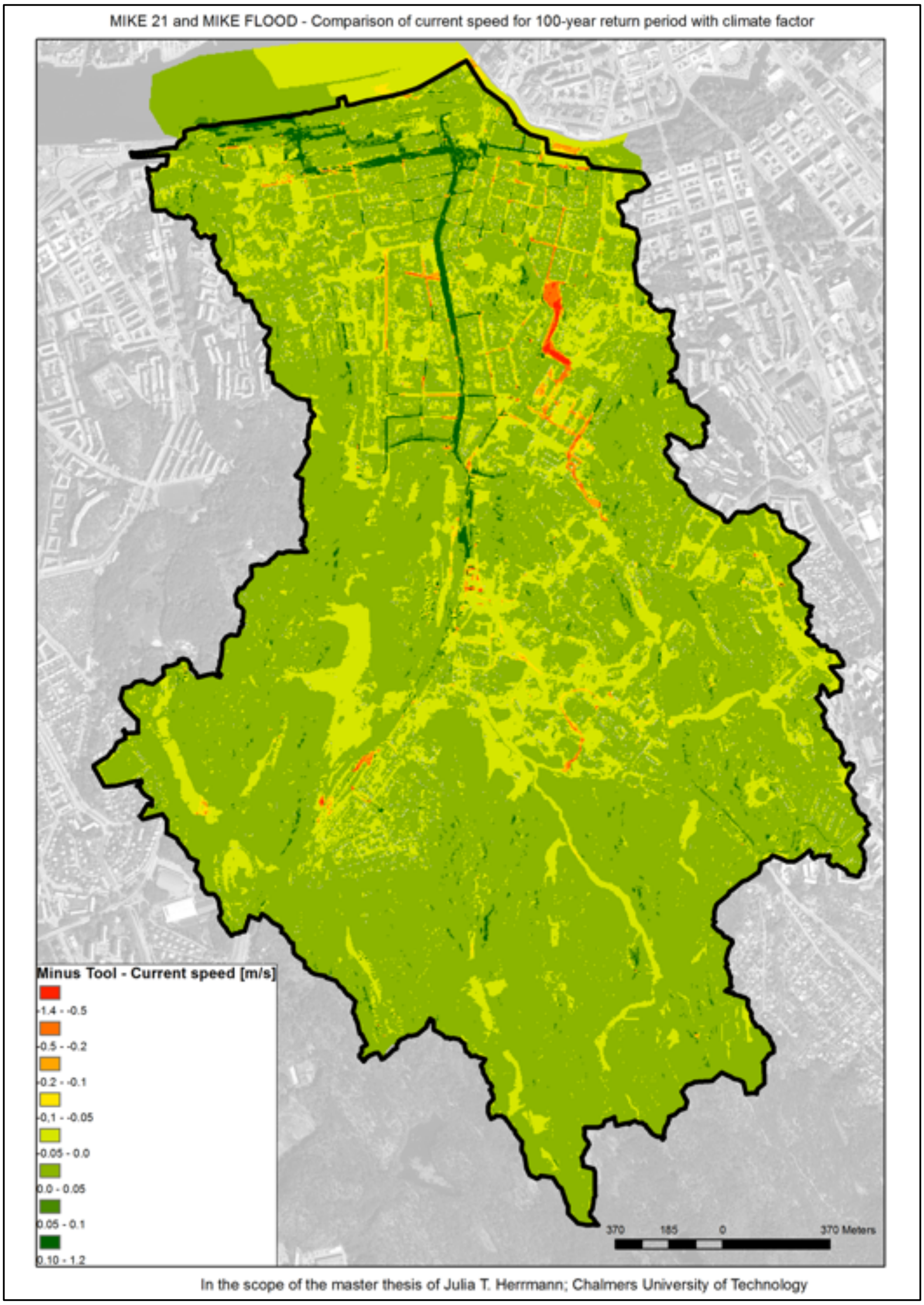


Figure 4-22: Comparison of current speed generated in ArcMap (created by author)

As illustrated with Figure 4-22, the largest difference for the current speed is shown at Linnégatan towards Masthugget colored in dark green. The positive value indicated the higher speed in MIKE 21. Vice versa occurs for the area in Annedal marked in red, showing a higher speed in MIKE FLOOD. The additional areas colored in red showing a higher speed in MIKE FLOOD are expected findings, as those areas are not flooded in MIKE 21. For the highlighted areas in Masthugget the flood propagation was larger in MIKE 21 than in MIKE FLOOD thus the results were also expected. Unsuspectedly were the results nearby Annedal and at Linnégatan.

4.2.2.6. COMPARISON – WATER DEPTH OVER TIME

The time for the maximum water depth could only be assessed for the software programs of MIKE ZERO by DHI (Hørsholm, Denmark) and are presented with the aid of ArcMap in Figure 4-23 and Figure 4-24.

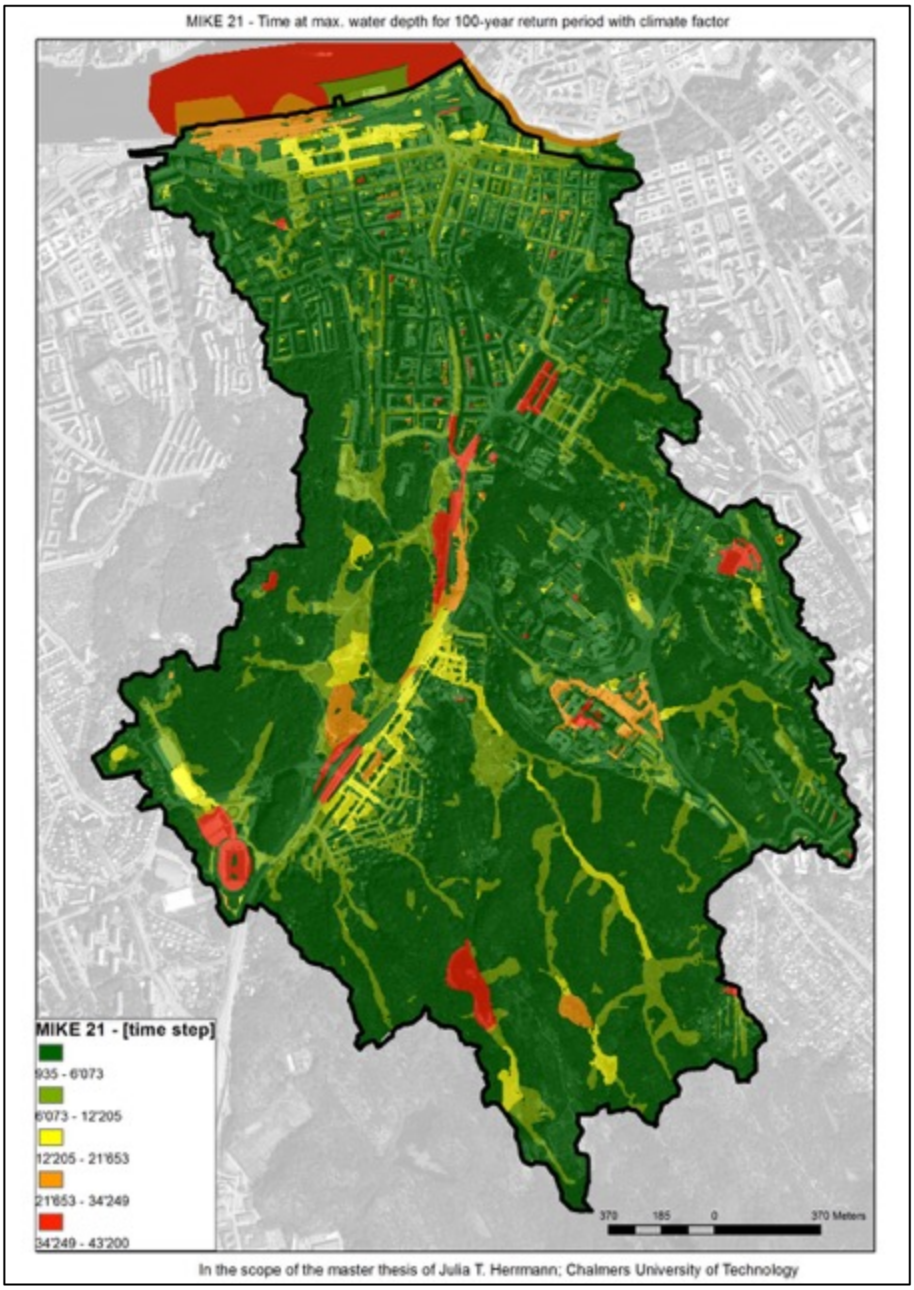


Figure 4-23: MIKE 21 - flood map of time at maximum water depth in ArcMap (created by author)

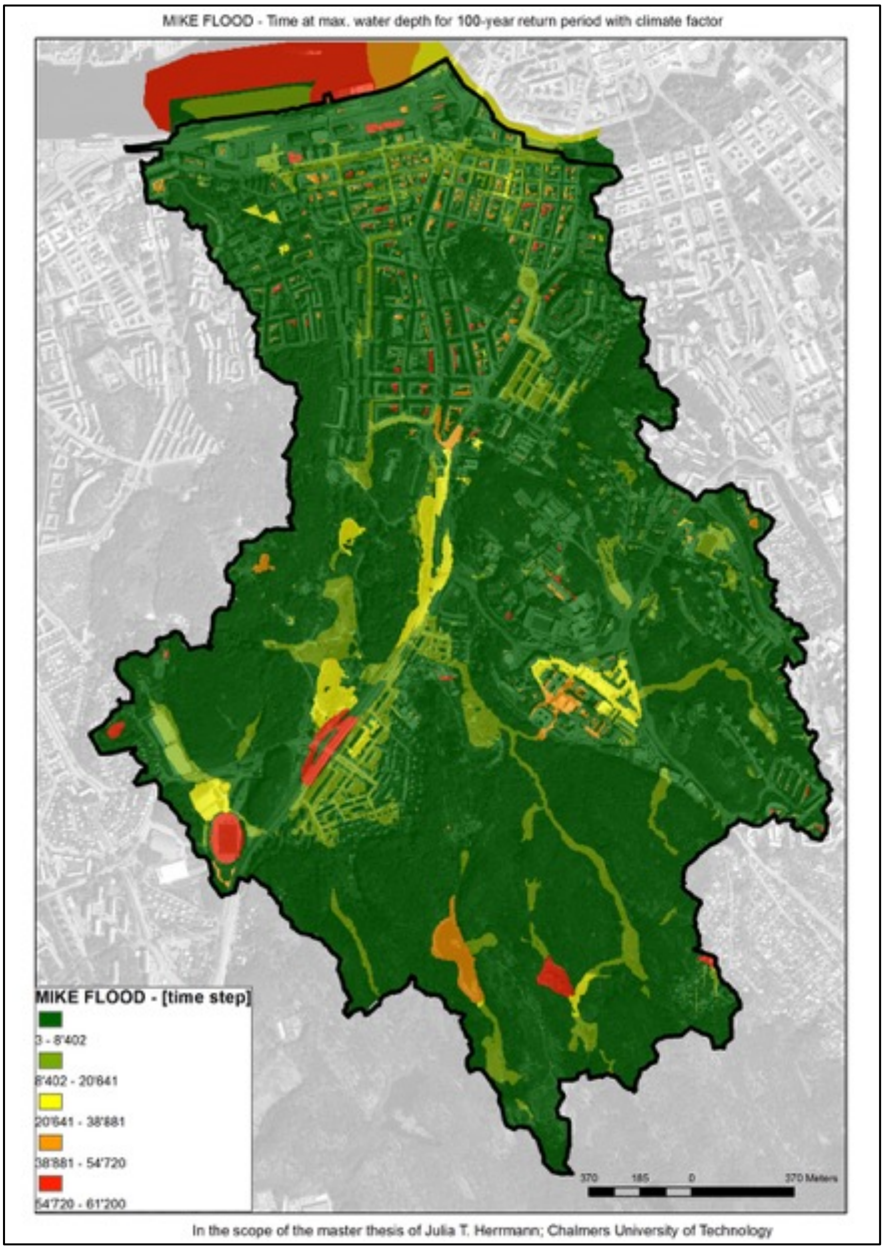


Figure 4-24: MIKE FLOOD - flood map time at maximum water depth in ArcMap (created by author)

The time for the maximum water depth cannot only be used for the comparison but also allows the assessment of the model themselves. Areas, which are flooded in the end of the simulation might not be flooded to their full extent. Meaning if the simulation period would be longer more flooding could occur for those areas. Concluding those areas require a critical assessment.

When comparing both programs, the time steps for the flooding are similar, as one must consider the longer time of simulation for MIKE FLOOD with 6 hours and the short time of simulation for MIKE 21 with 3 hours.

A more unforeseeable difference occurs for the area in Guldheden, which is flooded in the beginning in MIKE FLOOD and at the end in MIKE 21. The same accounts for the residential area at Annedal. The other areas are flooded in the same range of the time with respect to the different simulation periods.

4.2.3. COMPARISON OF HYDRAULIC PARAMETERS

The findings of the simulations in the frame of the comparison are presented in this chapter. The scenarios investigated are presented in Table 4-15.

Table 4-15: Scenarios for software comparison of hydraulic parameters

Scenarios	Infiltration	Resistance - Manning Number [$m^{1/3}/s$]
Scenario 1	No Infiltration	50
Scenario 1-1	No Infiltration	2
Scenario 2	Infiltration file	50
Scenario 2-1	Infiltration file	2
Scenario 3	No Infiltration	Resistance File
Scenario 4	Infiltration file	Resistance File

In the following sub-chapters, the results of the simulation are presented. In the first section the simulations with no infiltration and the different Manning numbers are compared. In the next section the results with infiltration and the different resistance files are shown. In the last section the most simplified results are shown in comparison to SCALGO.

4.2.3.1. SCENARIO 1, SCENARIO 1-1 AND SCENARIO 3

The scenarios displayed in Figure 4-25 and Figure 4-26 show the water depth without infiltration and varying resistance. For Scenario 1 the resistance was set to the maximum value and for Scenario 1_1 the resistance was set to the lowest value. As expected the scenario with a higher Manning number showed more correlations with the simulation with the resistance file. The simulation with the higher Manning number should less flooding in the upstream areas of the catchment and watersheds and higher flooding in the main flow paths and the downstream area. Downstream some areas were only flooded for the Scenario 1. With a higher Manning number, a faster flow towards the downstream area and less resistance was assumed and the simulations showed the expected results. For the scenario with the lower Manning number the flood propagation is more distributed especially in the upstream and green areas of the catchment. One area is solely flooded in for the lowest Manning number, which was expected to a higher resistance thus lower current speed of the flow. In general, the upstream areas correlate for the lower Manning number and the resistance file and the downstream areas correlate for the higher Manning number. The main flooded areas from the previous simulation without any adaptions correlate for all three simulations. However, the flood propagation especially for the main flow paths like Linnéstaden is larger without infiltration.

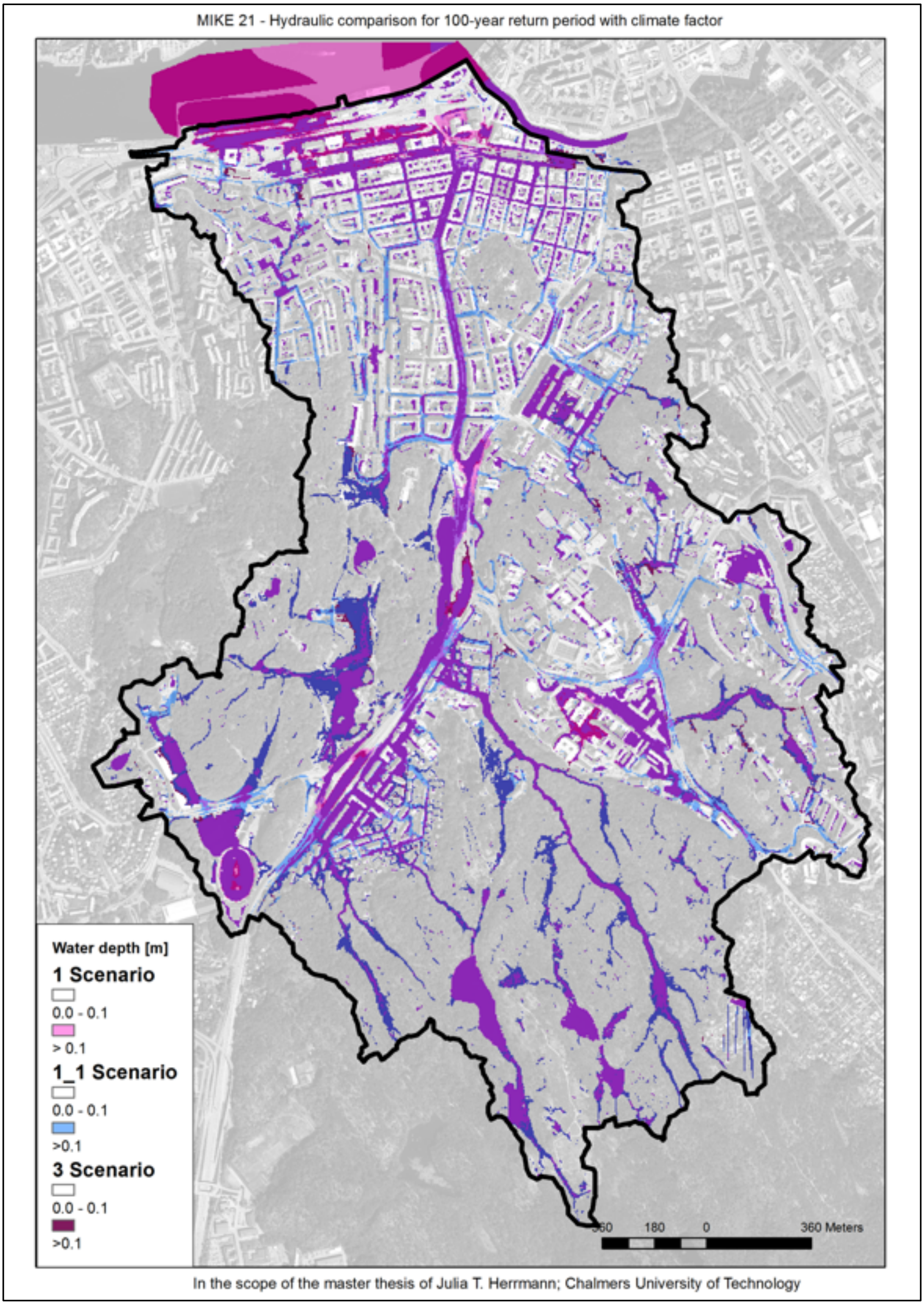


Figure 4-25: MIKE 21 - Hydraulic comparison for no infiltration and varying resistance in ArcMap (created by author)

For the simulation with MIKE FLOOD the findings from MIKE 21 correlate with regard to the correlations of the Manning numbers upstream and downstream. Despite the correlation the flooding at Linnéplatsen differed to MIKE 21. In MIKE FLOOD the simulations with the minimum and maximum Manning number were more similar in flood propagation. Also, the flooding in the downstream area solely occurring for the higher Manning number could not be found in MIKE FLOOD.

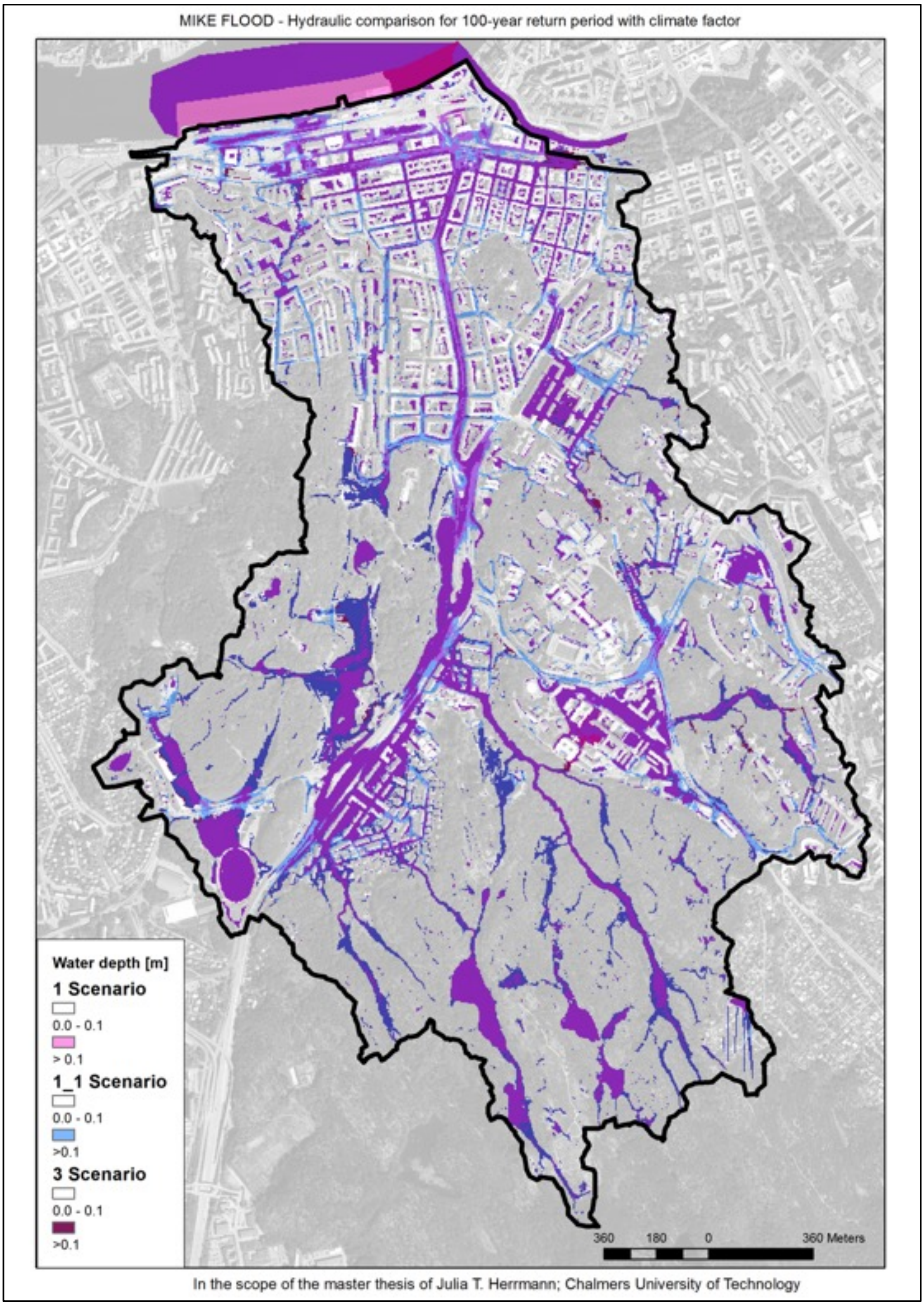


Figure 4-26: MIKE FLOOD - Hydraulic comparison for no infiltration and varying resistance in ArcMap (created by author)

The difference between the flood propagation for MIKE 21 and MIKE FLOOD is assumed to be caused by the sewer system differences. With a lower resistance the velocity is higher and the discharge into the sewer system for those areas can be assumed, even a higher discharge into the sewer system in MIKE FLOOD. Therefore, the higher correlation of the simulation with a higher Manning number and the simulations with a resistance file were expected. The flooding of areas with a lower resistance file, which are not flooded when applying the resistance file might lead to the assumption that the water is not discharged into the sewer system. The possibility of simulating the interactions of the sewer system in MIKE FLOOD opposed to MIKE 21 with a general deduction could be the cause for the difference.

4.2.3.2. Scenario 2, Scenario 2-1 and Original

Subsequently, the flood maps with infiltration and varying surface roughness are shown for MIKE 21 and MIKE FLOOD, see Figure 4-27 and Figure 4-28. The surface roughness was adapted in the same manner as for the simulations without infiltration.

In MIKE 21 and MIKE FLOOD the main flow paths and flood propagation correlate for all three scenarios. The differences and similarities are almost the same as for the simulation without the infiltration. With regard to the flow propagation there are no major differences between the simulation with and without the infiltration. The simulations without infiltration did not lead to more flood propagation as might be expected from the first investigated scenarios. Thus, the effect can be assumed to be mainly caused by the changes of the surface resistance. It was unexpected that the difference of the infiltration is much smaller than the flow resistance.

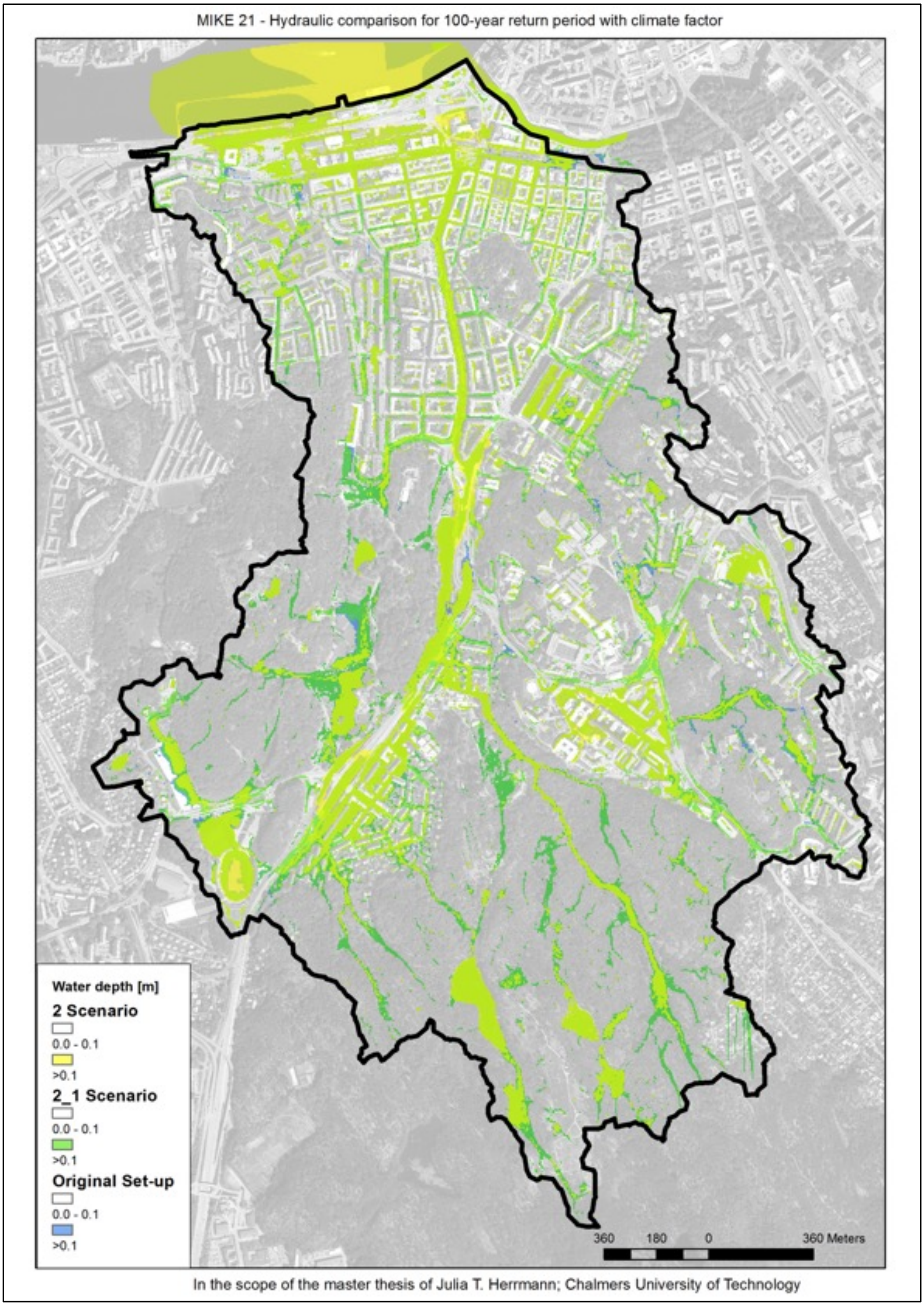


Figure 4-27: MIKE 21 - Hydraulic comparison for infiltration and varying resistance in ArcMap (created by author)

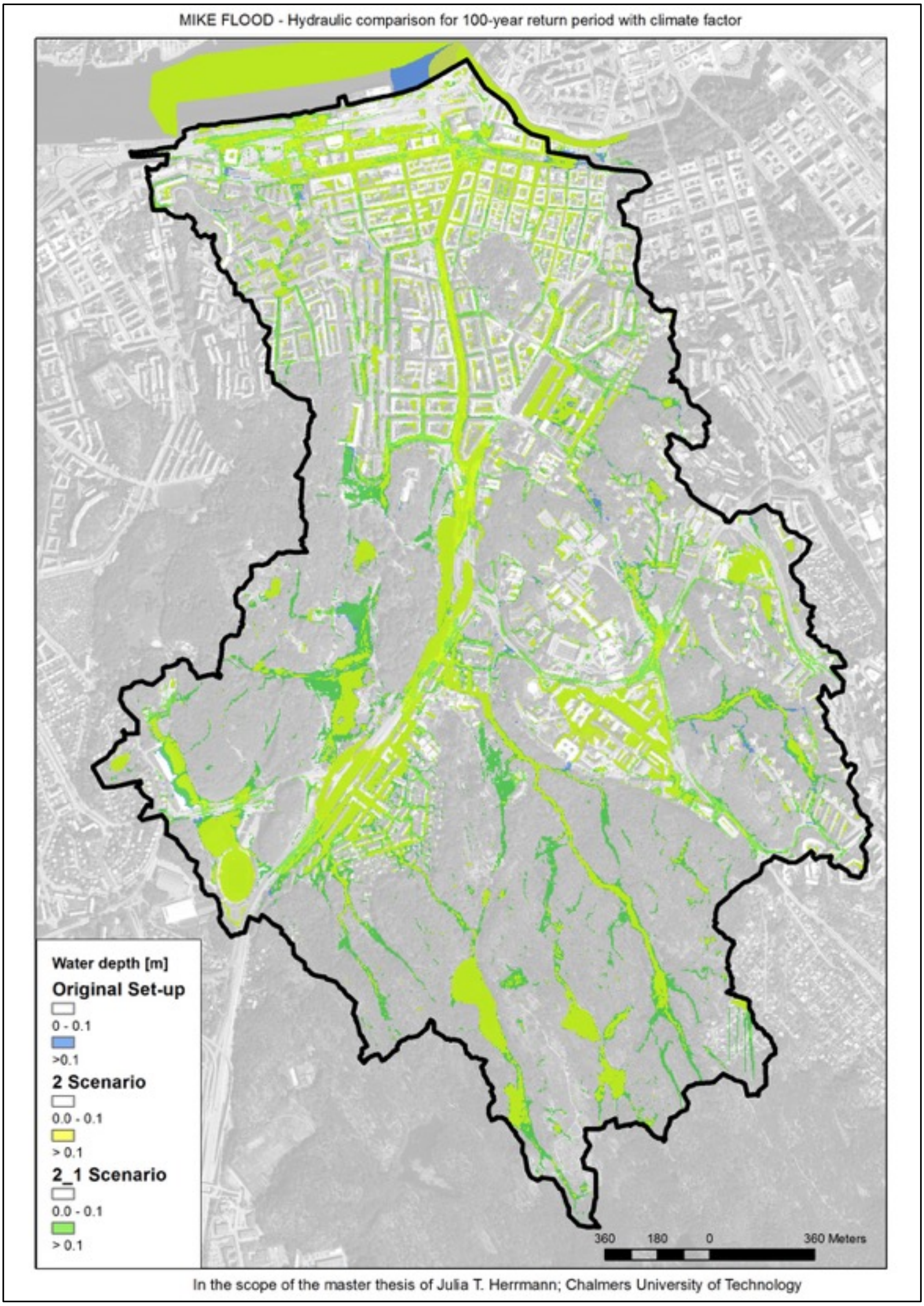


Figure 4-28: MIKE FLOOD - Hydraulic comparison for infiltration and varying resistance in ArcMap (created by author)

4.2.3.3. COMPARISON WITH SCALGO

In this section the results of the flood map with the different hydraulic variations is presented. In Figure 4-29 and Figure 4-30, the flooding without infiltration and the maximum and the minimum Manning number is displayed. There are no obvious differences with regard to SCALGO. For the maximum Manning number, the area solely flooded in SCALGO was larger, whereas the area was smaller for the smaller Manning number. This area is located at Per Dubbsgatan nearby Sahlgrenska University Hospital.

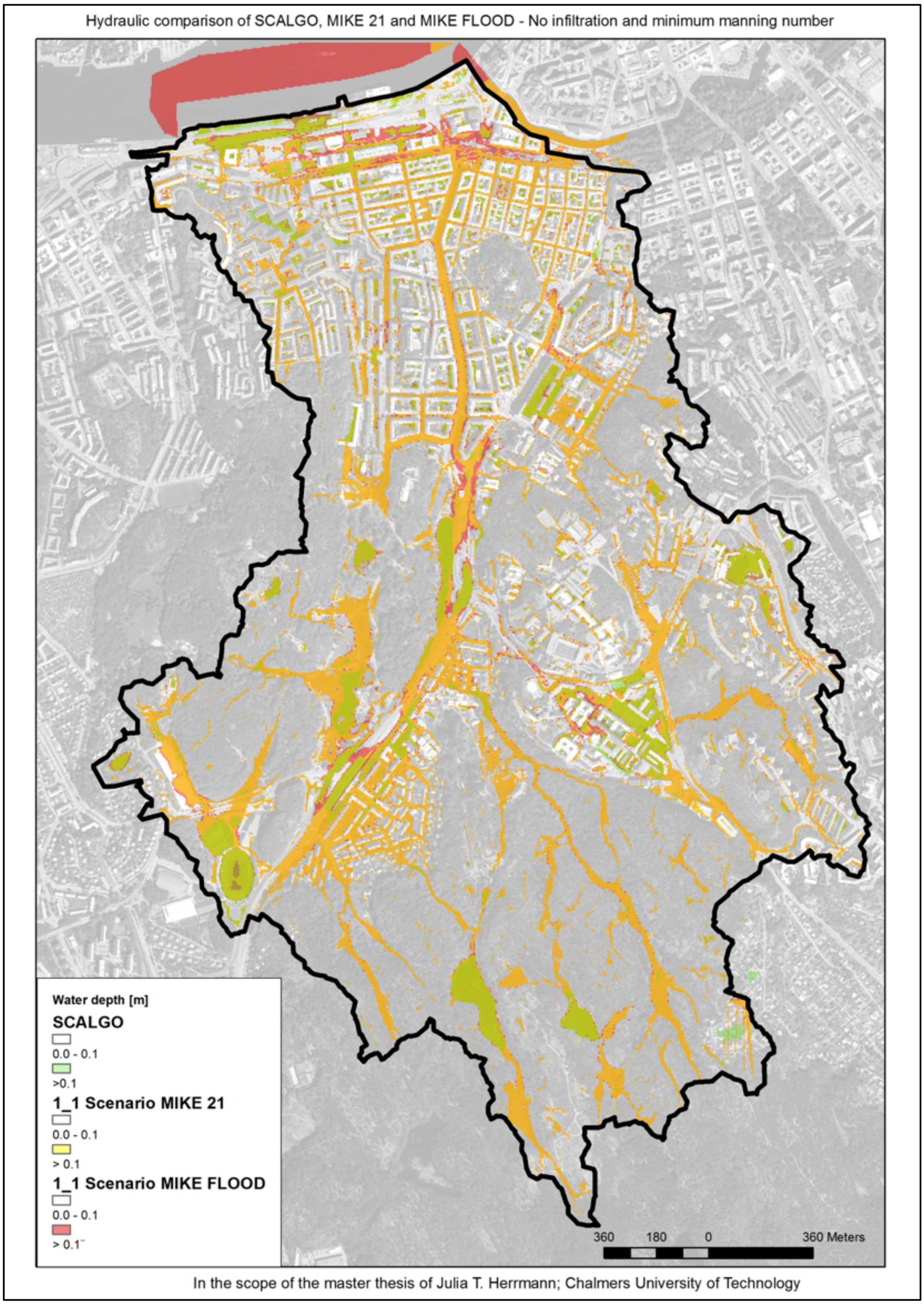


Figure 4-29: Comparison of SCALGO, MIKE 21 and MIKE FLOOD with hydraulic properties set to no infiltration and minimum Manning-number in MIKE ZERO software (created by author)

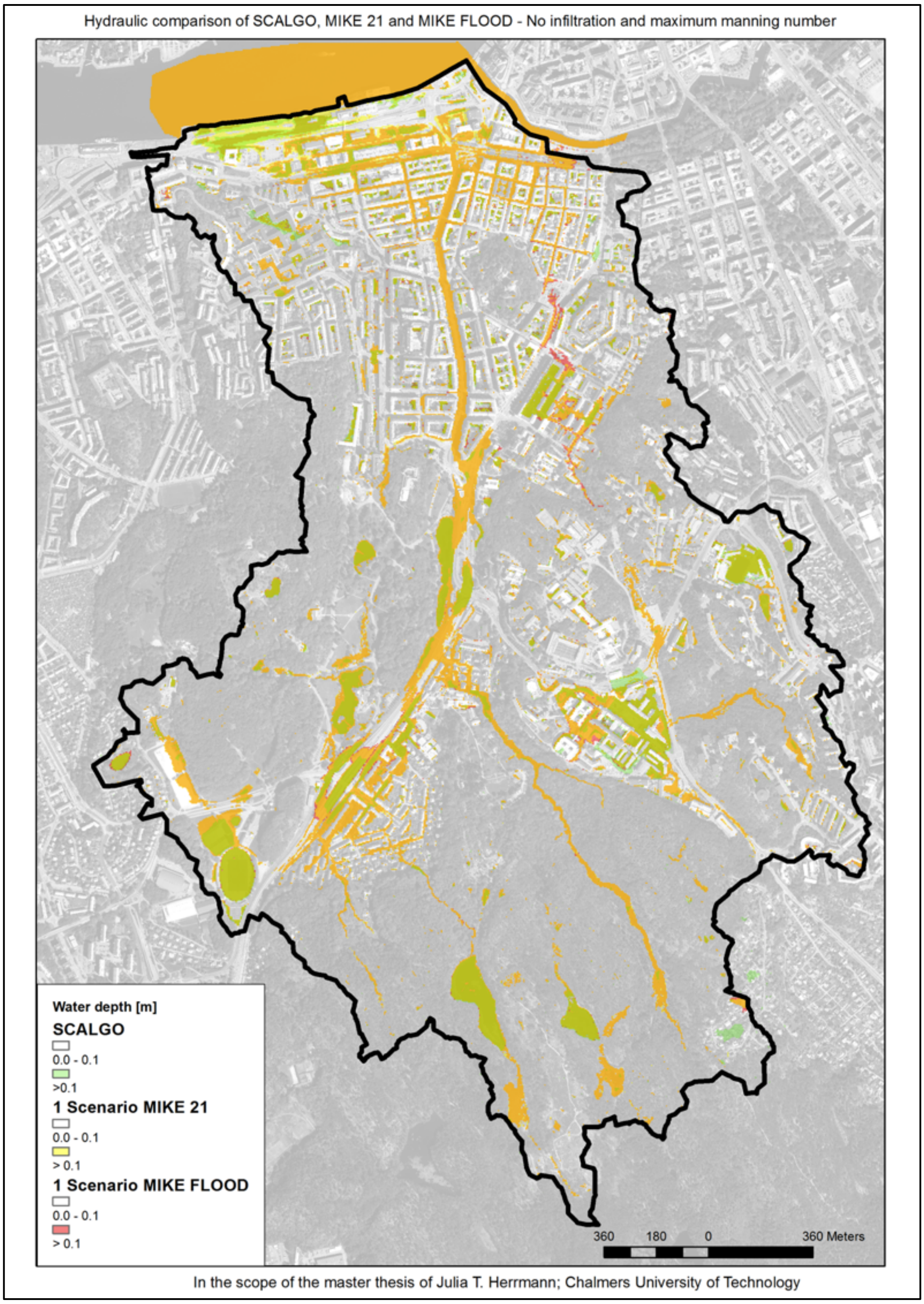


Figure 4-30: Comparison of SCALGO, MIKE 21 and MIKE FLOOD with hydraulic properties set to no infiltration and maximum Manning-number in MIKE ZERO software (created by author)

When comparing MIKE 21 and MIKE FLOOD a higher correlation was found for the simulation with the maximum Manning number and a lower correspondence for the lower Manning number. For the minimum Manning number more areas were flooded in MIKE FLOOD than in MIKE 21, e.g. in the downstream area, around Linnéplatsen and around Annedal.

With regard to the volume balances in MIKE 21 and MIKE FLOOD for the different scenarios and the hydraulic adaptions the previous results were supported. With a small Manning number of 2 the inflow into MIKE URBAN was zero from MIKE 21 leading to a larger volume in the model area. This occurred to the same extent for the simulations with and without infiltration. The volume balance supports the explanation that the water with a lower resistance is not discharged into the sewer system thus the flooding in MIKE FLOOD is larger than in MIKE 21, as in MIKE 21 a general deduction is considered independent from the Manning number. For a higher Manning number, the discharged volume into the sewerage increases compared to the simulation with the resistance file. In MIKE 21 there are no major changes in the volume balance apart from the increased volume in the model area without infiltration. The water balance is presented in Appendix D Volume balance of simulations in MIKE 21 and MIKE FLOOD

4.2.4. Results with measures

This chapter presents the modelling steps of the measures in each program including results of the simulations of the models with measures taken with regard to the different study areas.

4.2.4.1. Presentation of measures

As described in the methodology part of the present report the measures with respect to the DEM were designed in a first step with the software program SCALGO. For MIKE 21 and MIKE FLOOD the measures from SCALGO were further developed in the respective software programs.

4.2.4.1.1. Measures in Scalgo

The measures were implemented in the manner of the aforementioned design process, shown with the results in the following.

1. Assessment of Depressions

The depressions were assessed with the tools “Depression Map” and the “Flash Flood Modelling”. The basic assumption was that additional storage of water in depressions located in high risk areas could increase the risk and should be avoided. The surrounded depressions and tributaries were assessed however for none of the study areas additional and sufficient capacity was found in allocating depressions serving as natural storage areas.

2. Analysis of Risk Areas and design of Measures

In the second step the tributaries of the risk areas were investigated with the aid of the “Subsurface Basin tool” and the “query runoff” selection. The runoff volume from the tributaries effecting the risk areas was listed and possible retention areas storing that identified runoff volume were investigated. The volume balance for all areas is shown in Appendix C.

For Sahlgrenska University Hospital specific risk areas were set in coordination with the hospital itself. The objectives linked to those areas were the reduction of the water load to the main entrance and the emergency room. In addition, the water level on the roads to the hospital should be lowered to allow ambulances to access the hospital area, thus should not exceed 20 cm and aim for a maximum water depth of 10 cm. Based on the surrounding a retention basin for the tributaries from Guldheden to Sahlgrenska was designed. The basin led to a reduction of the water level in the main entrance and emergency room depressions. Furthermore, the water level was reduced by lowering an existing parking lot area at Marklandsgatan, to serve as additional retention space. This measure successfully reduced the water level below 10 cm on the main access road. The aim of those measures was also to minimize the flow towards the downstream area, the city center and Vitsippsbäcken.

For Magretebergsmotet the main tributaries were determined as flows from upstream areas within Slottsskogen. Based on the local conditions a retention area in Slottsskogen was investigated. The aim was to design a basin fitting in the landscape also providing the option for a multifunctional use of the recreational areas throughout non-flooded periods. As a result, the basin was designed to have a relatively low depth but large surface area, which corresponds with one of the green areas in Slottsskogen. To support the discharge to this area a flow path towards the basin was modelled by modeling changes to the elevation. The measures showed a reduction of the water volume in the depressions of Magretebergsmotet.

For Annedal the surrounding areas offer limited possibilities to store the water of the tributaries in a basin. Therefore, it was decided to model a pipe from Annedal to a suitable retention place or downstream area. In the present report a pipe from Annedal to a green area nearby Linnéplatsen located in Slottsskogen was chosen as a retention space. As mentioned in the methodology one must consider the unlimited capacity of this pipe, when evaluating the results. Meaning the tributaries flowing towards that point in Annedal might all be discharged into the pipe and lead to the exceedance of the volume of the designed retention basin in Slottsskogen for Annedal. Concluding the flow accumulations of the flood change and the water discharged from Annedal to Linnéplatsen might cause more severe flooding in other downstream areas. The explicit assessment of such flow accumulations could not be done in SCALGO as one can only display the water depth in depressions.

3. <u>Assessment of flooding results</u>

In a final step the results of the simulation with and without measures was compared and served as input data for FloodMan.

The measures modelled in SCALGO are shown in the SCALGO interface in Figure 4-31. The black line stresses the border of the catchment area. The edits to the DEM are presented with the four black marked areas. The elevation of the DEM is highlighted in the colors of the legend,

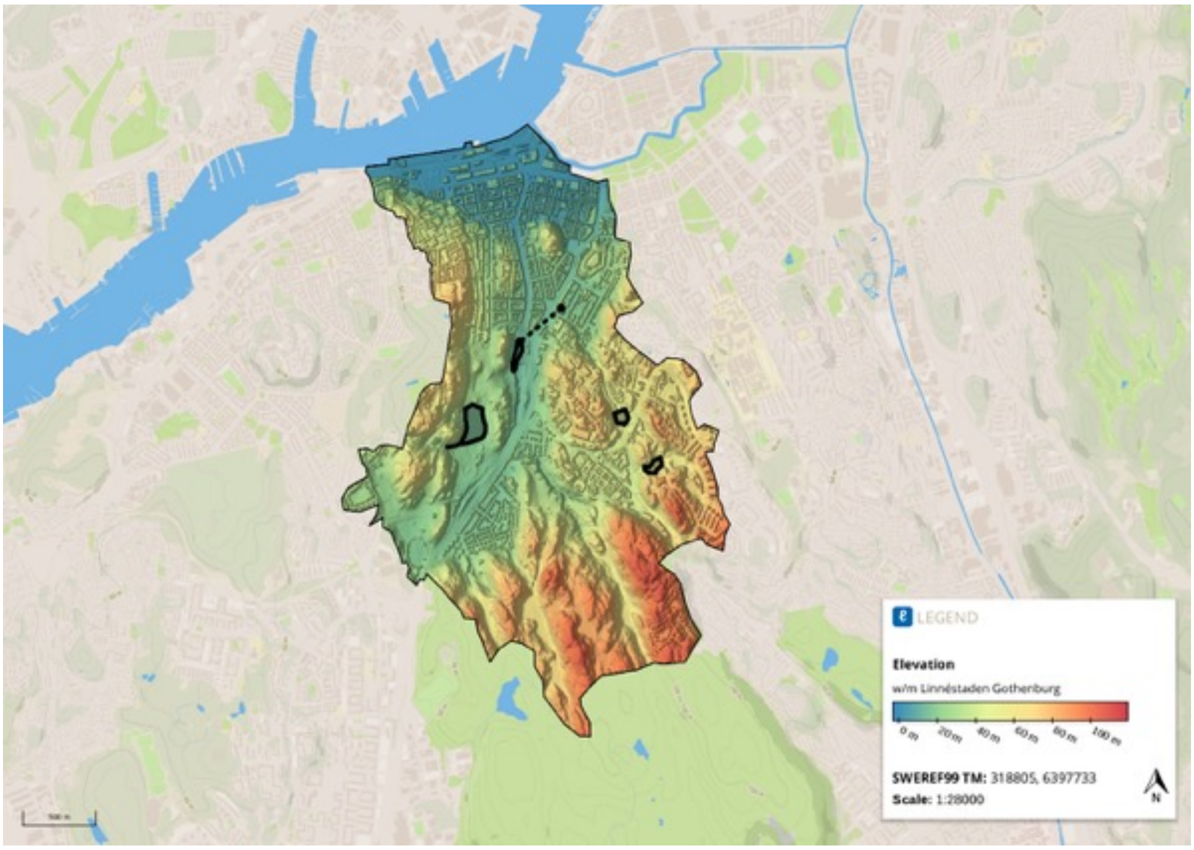


Figure 4-31: Map illustrating edits in elevation and terrain edits of the original terrain generated by the author for this thesis in SCALGO. The edited areas of the DEM are marked with marked in black. The black dashed line illustrates the pipe. (created by author)

4.2.4.1.2. Measures in MIKE 21

The measures done in SCALGO were modelled in the same manner for the DEM of the MIKE ZERO software programs. For the changes to the DEM SCALGO solely served as a modelling tool to change the elevation. One interesting aspect when exporting the DEM into the SCALGO interface was the obvious difference of the raster in SCALGO and MIKE 21. The difference is illustrated in Figure 4-32, Figure 4-33, Figure 4-34 and Figure 4-35 comparing the DEM of SCALGO and MIKE 21 and MIKE FLOOD in the SCALGO interface.

Figure 4-32: DEM model in SCALGO with 2x2 m raster for area around Sahlgrenska University Hospital (created by author)

Figure 4-33: DEM model in SCALGO with 4x4 m raster of MIKE ZERO for area around Sahlgrenska University Hospital (created by author)

Figure 4-34: DEM model in SCALGO with 2x2 m raster for Annedal area (created by author)

Figure 4-35: DEM model in SCALGO with 4x4 raster of MIKE ZERO for Annedal area (created by author)

From Figure 4-32, Figure 4-33, Figure 4-34 and Figure 4-35, it is clear that a planning and design of the measures in SCALGO with the more accurate DEM is easier for the user and allows a more detailed design opposed to for MIKE ZERO.

After the changes to the DEM in SCALGO the DEM was exported to MIKE ZERO. The bathymetry of the original model was changed in the model set-up and was investigated. Based on the assessment further changes to the bathymetry were not considered as necessary. Therefore, the terrain changes are the same in SCALGO and for MIKE 21, just have different raster formats.

Modelling additional structures in MIKE 21 was neglected as it is not the common approach and state of the art for pluvial flood management according to the *City of Gothenburg* and *Sweco Environment AB*. The aim of the present report was to present a recommendation with regard to the extent of the current usage of the software programs, thus structures in MIKE 21 are not considered.

Concluding the measures in MIKE 21 are the retention basins in Guldheden and nearby Medicinaregatan and the retention basin in Slottsskogen. The pipe from Annedal to discharge water into Slottsskogen cannot be modelled in the same manner as in SCALGO in MIKE 21, however the retention area was kept in MIKE 21 as well.

In Figure 4-36 the changes done in SCALGO to the DEM of MIKE are shown. Figure 4-36 illustrate sthe boundary area marked with the rectangle and red area. The changes to the elevation are highlighted with the black marked areas.

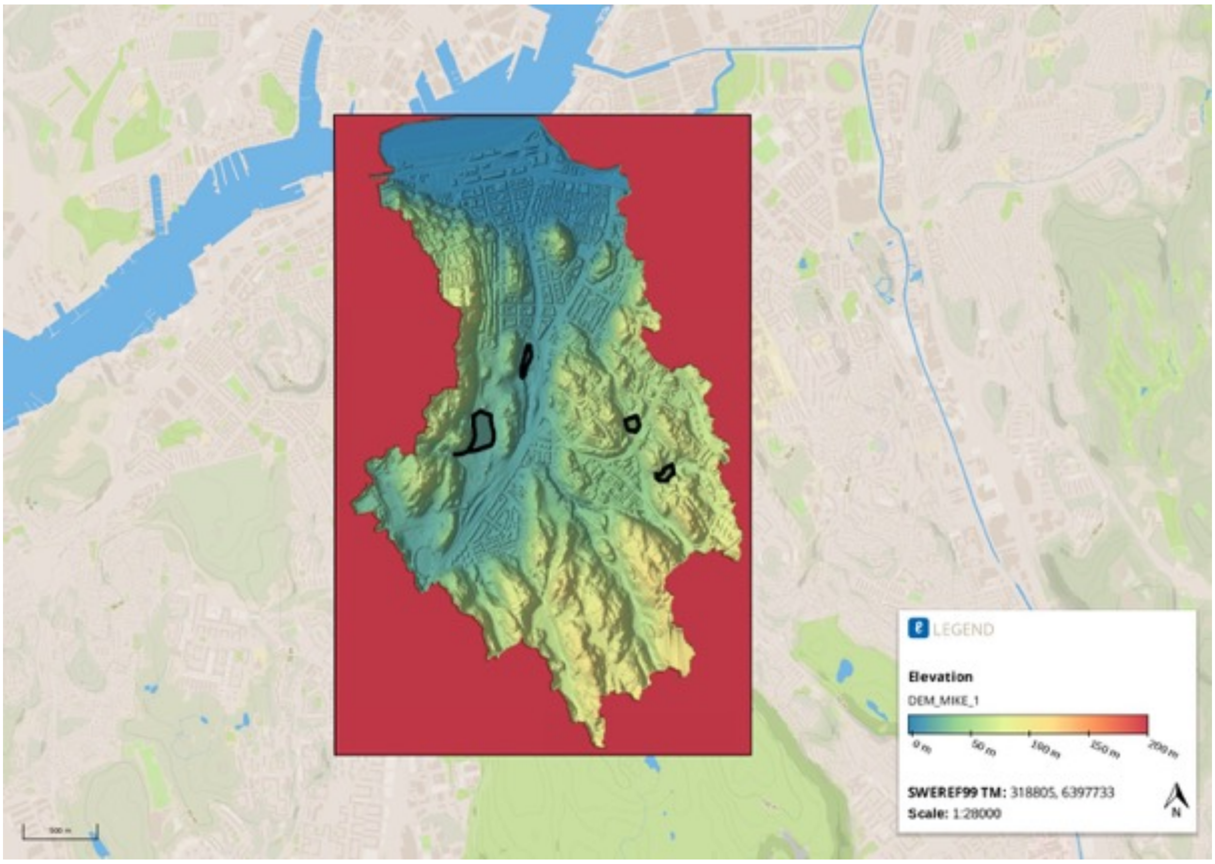


Figure 4-36: Map illustrating edits in elevation and terrain edits of the original terrain generated by the author for this thesis in SCALGO for the DEM of MIKE 21. The edited areas of the DEM are marked with marked in black. The black dashed line illustrates the pipe. (created by author)

4.2.4.1.3. MEASURES IN MIKE FLOOD

In MIKE FLOOD the 2D model of MIKE 21 was applied in the same way as for the investigation of just MIKE 21. In addition, the modelling of features of the network in MIKE URBAN with the MOUSE engine was considered. The pipe modelled in SCALGO to discharge water to the retention basin in Slottsskogen was not modelled in MIKE URBAN. The existing sewer system showed that a pipe in that area is unreasonable. For the implementation of such that pipe one would need to design a pipe under the existing sewerage in terms of the elevation and would need to pump the water to Slottsskogen. The feasibility of such a pipe is not given and was not modelled in the present report.

For the basin designed for Magretebergsmotet the open channel culverts designed by changes to the elevation were changed to closed pipes and manholes in the same area with an outlet to the retention basin, see Figure 4-37. A closed concrete pipe was considered to be a more realistic measure as the contributing areas are paved roads, thus runoff to manholes was considered a reasonable solution. In this way the water level on the surface on those roads could also be adjusted.

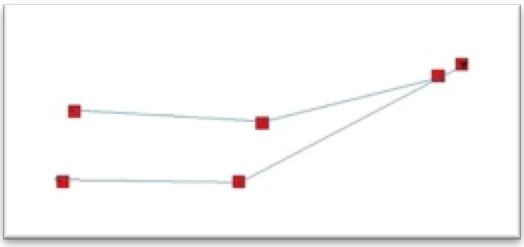


Figure 4-37: MIKE URBAN measure modelled for MIKE FLOOD in present report

For the pipes the dimensioning determined for all pipes was:

- The diameter was set to 1 m.
- The material selected was concrete with a Manning number of 85.

For the manholes (inlets) the following design was chosen:

- Diameter: 2.0 m
- Spill coefficient 1.00
- Critical level: 1.00

For the coupling of the manholes the exchange flow was classified for the same rate as for the rest of the catchment:

- Max. Flow: 99.9 m^3/s
- Discharge coefficient: 0.98
- Inlet area: 0.16 m
- Freeboard: 0.15 cm
- Crest width: 1.00 m

For the outlet the dimensioning was as follows:

- Spill coefficient: 1.00
- Buffer pressure: 0.00

4.2.4.1.4. DIMENSIONS OF IMPLEMENTED MEASURES

The measures implemented in the models of the software programs in terms of their size are listed in Table 4-13 and are labelled as shown in Figure 4-38 and Figure 4-39. The catchment area is marked with a black dotted line. The location of the measures is marked in blue. In Figure 4-39 the high-risk areas for which the measures were implemented are additionally highlighted in red.

Figure 4-38: Map of catchment area Linnéstaden with labeling of implemented measures, colored in blue. (created by author)

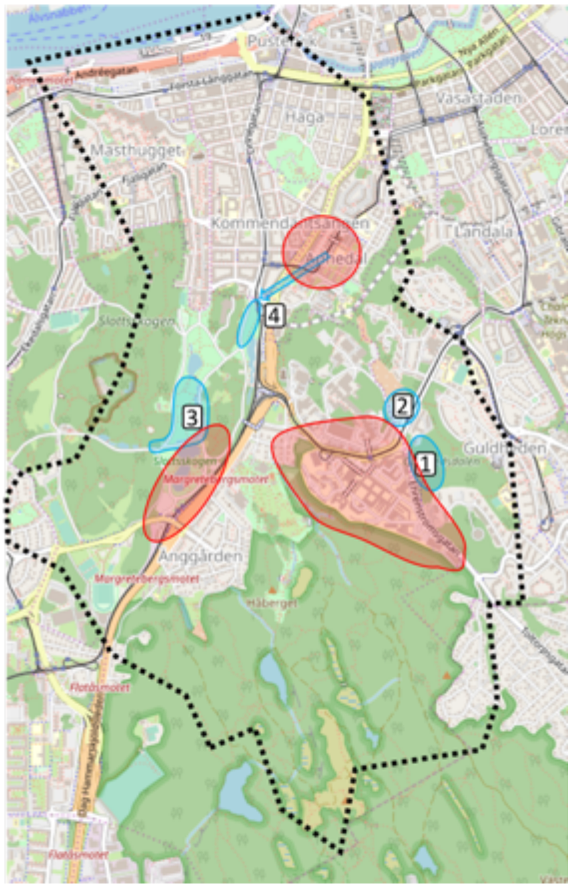


Figure 4-39: Map of Linnéstaden with labeled implemented measures in blue and the respective high risk-areas colored in red. The catchment ins marked with the black dotted line. (created by author)

Figure 4-38 shows the catchment Linnéstaden with the implemented measures. The measures are marked in blue and labelled with the numbers 1 to 4. Area 1 represents the retention basin at Guldheden for Sahlgrenska University Hospital. Area 2 is the parking lot serving as retention area nearby Medicinaregatan. Area 3 is the area serving as a retention area located in Slottsskogen. Area 4 is located in Slottsskogen nearby the intersection Linnéplatsen. The blue arrow illustrated the pipe modelled in SCALGO discharging water from Annedal to the area in Slottsskogen.

In Table 4-16 the dimensions of the implemented measures are presented. The data for the dimensioning of changes to the elevation, the size of the areas and the storage volume was gathered in SCALGO.

Table 4-16: Dimensions of implemented measures in the present report. The areas are labelled according to Figure 4-38.

Area	Size [ha]	Storage Volume [m^3]	Notes to dimensioning
1	0.64	9,876.6	The length of the dam was set to 28 m and the crest width to 2 m. The original elevation of the area was lowered by 2 m.
2	0.65	7,656.3	The original DEM of the parking lot area was lowered by 1 m.
3	2.91	11,667.1	The original DEM of the area was lowered by 30 cm. The runoff paths were designed with a width of 1 m. The path has a length of 110 m and a depth of 20 cm. For MIKE FLOOD the pipes were designed with a diameter of 1 m and the total length of the pipes in MIKE Urban were counted as approximately 280 m.
4	0.64	1,632.0	The original DEM of the area was lowered by 30 cm. For SCALGO the pipe was designed with a pipe length of 364 m.

4.2.4.2. SCALGO

The flooding for SCALGO with measures is illustrated in Figure 4-40.

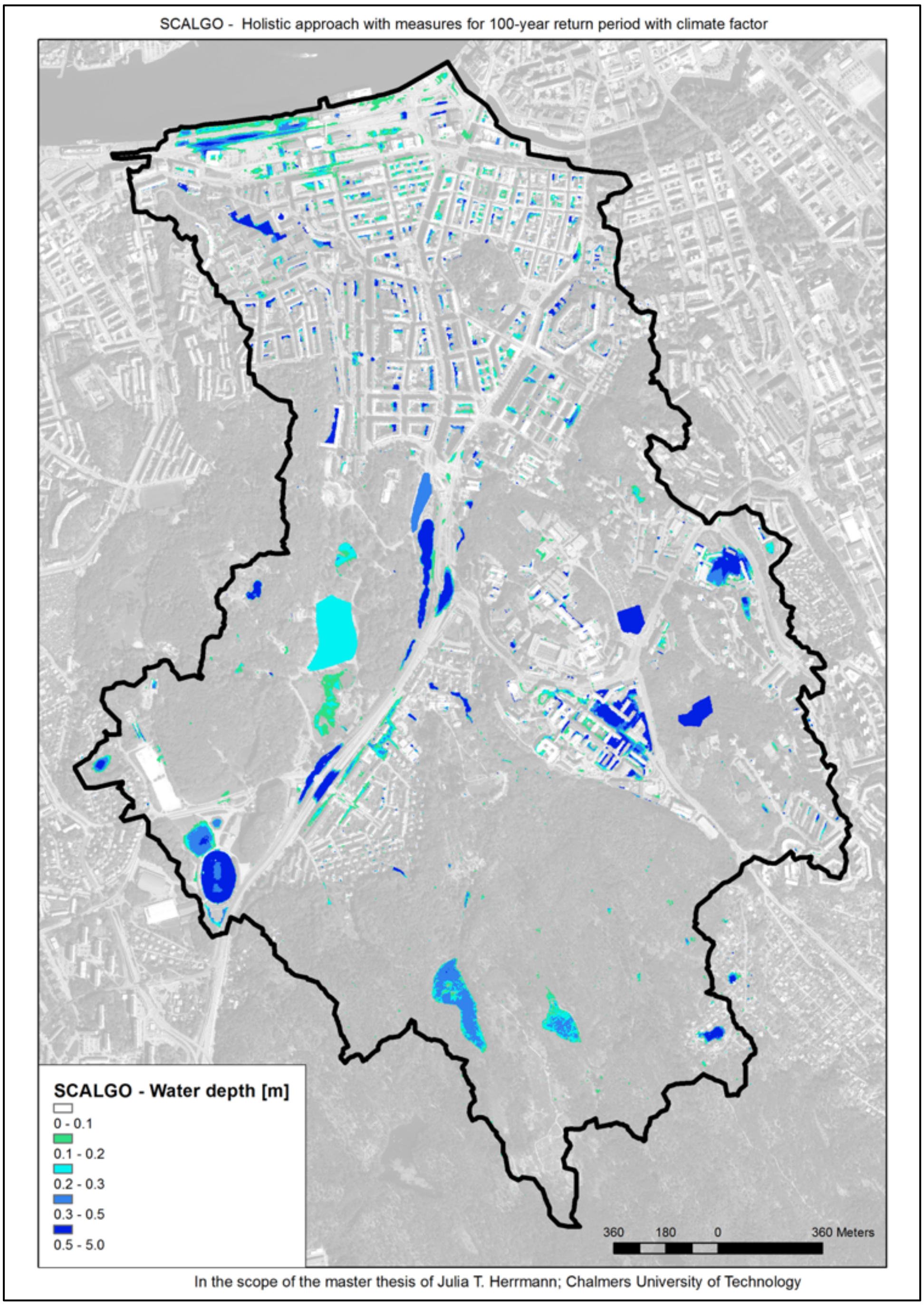


Figure 4-40: Flood map in SCALGO with holistic approach including implemented measures (created by author)

In Figure 4-40, the flood map with measures the areas used for action measures are flooded, this is due to the new depressions created within SCALGO. The redirection of the runoff from Annedal with a pipe towards Linnéplatsen and Slottsskogen successfully removed the water and lowered the water depth. However, the water depth in the downstream area did not increase which is unexpected, as the volume of the retaining area in Slottsskogen for the discharges volume from Annedal was expected to cause an overflow of the storage area and cause more flooding down-stream. It remains unclear within the possibilities of the flood map from SCALGO in which way the water flow was changed due to the pipe simulation.

4.2.4.3. MIKE 21

Figure 4-41 shows the flood map for the simulation in MIKE 21 with measures. The volume balance showed almost no changes for the simulation with and without measures and is added in Appendix D - Volume balance of simulations in MIKE 21 and MIKE FLOOD.

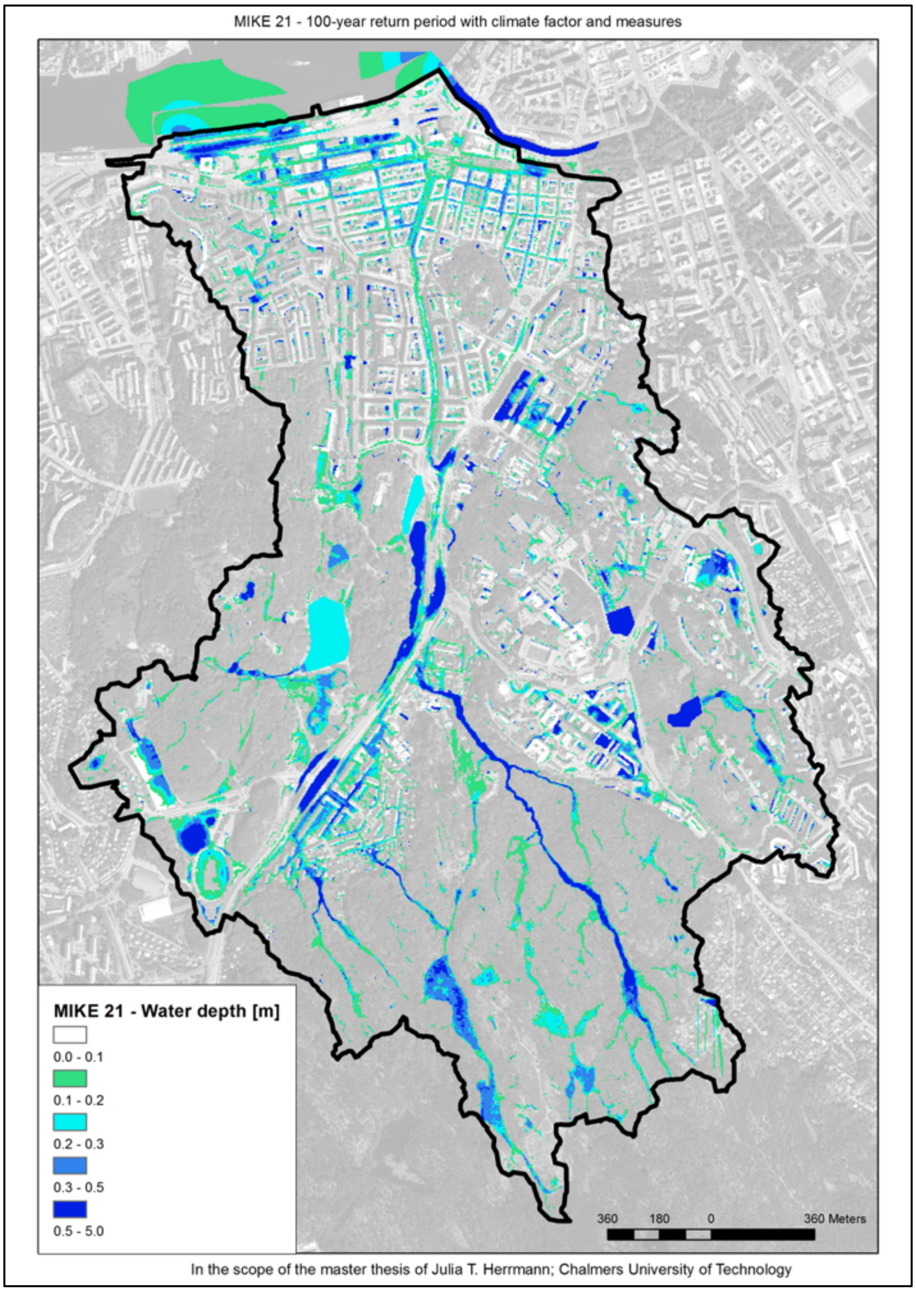


Figure 4-41: Flood map in MIKE 21 including implemented measures (created by author)

With respect to the implemented measures the expected results of a lower flood propagation in the risk areas was achieved. The flood retention and storage areas show a higher water depth, as expected. In Slottsskogen the flow diversion towards the green area is visible in the flood map and shows a reduction of the flow towards the pond in Slottsskogen.

With regard to the current speed the 3D Analysis Minus Tool was applied in ArcMap, see Figure 4-42. A positive value shows a reduced current speed for the simulation with measures and a negative value a higher current speed without measures. The current speed increased especially around the Sahlgrenska University Hospital at Per Dubbsgatan. An increase of the current speed around the borders of the designed measures can be seen in red in the flood map. The increase of the current speed is caused by the changes of elevation. The transition in this area would need to be smoothened in a detailed planning process.

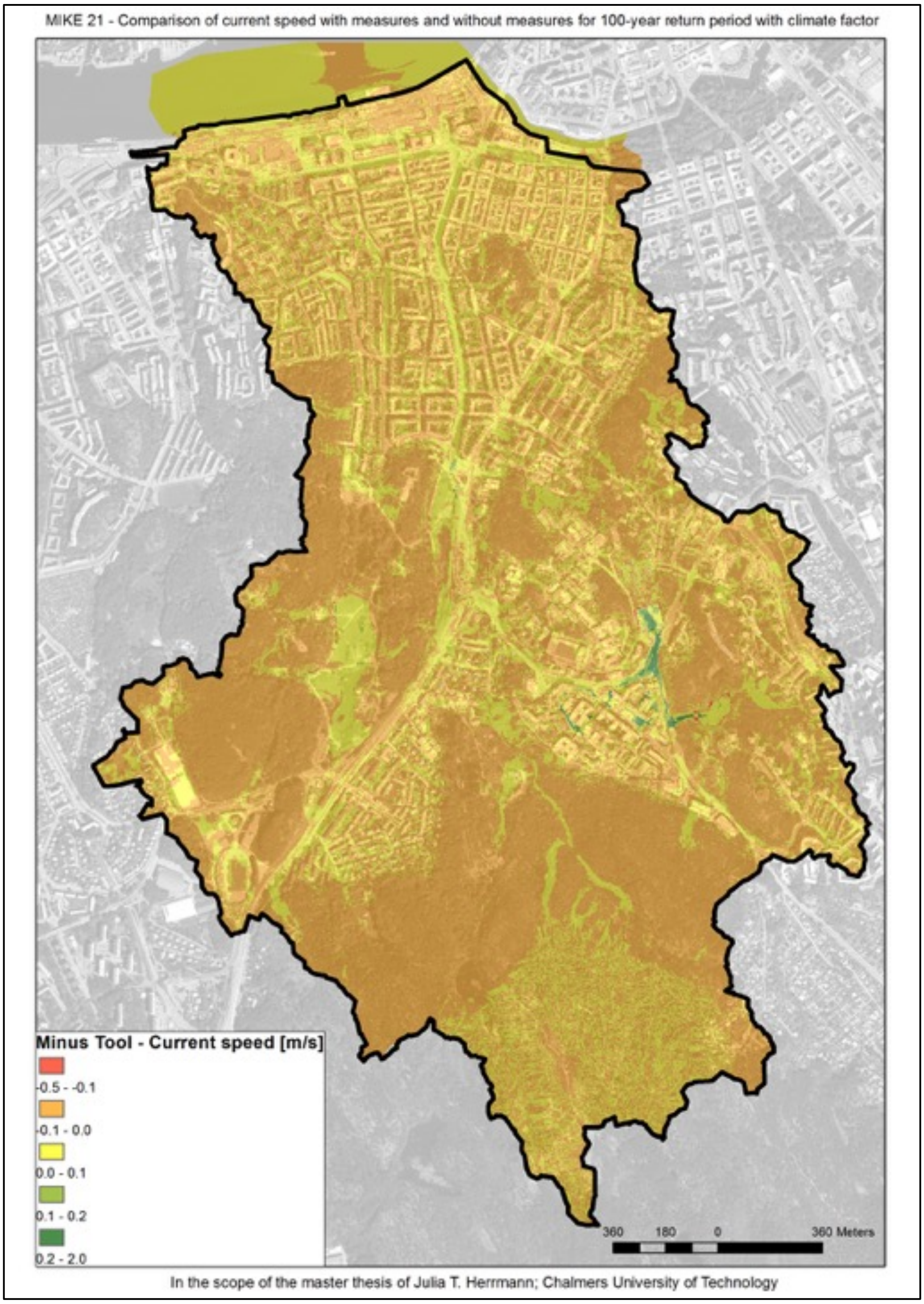


Figure 4-42: Comparison of current speed in MIKE 21 with and without measures in ArcMap (created by author)

4.2.4.4. MIKE FLOOD

Figure 4-43 shows the flood map for the simulation in MIKE FLOOD with measures. The volume balance for MIKE FLOOD was similar to the simulation without measures and is shown in Appendix D.

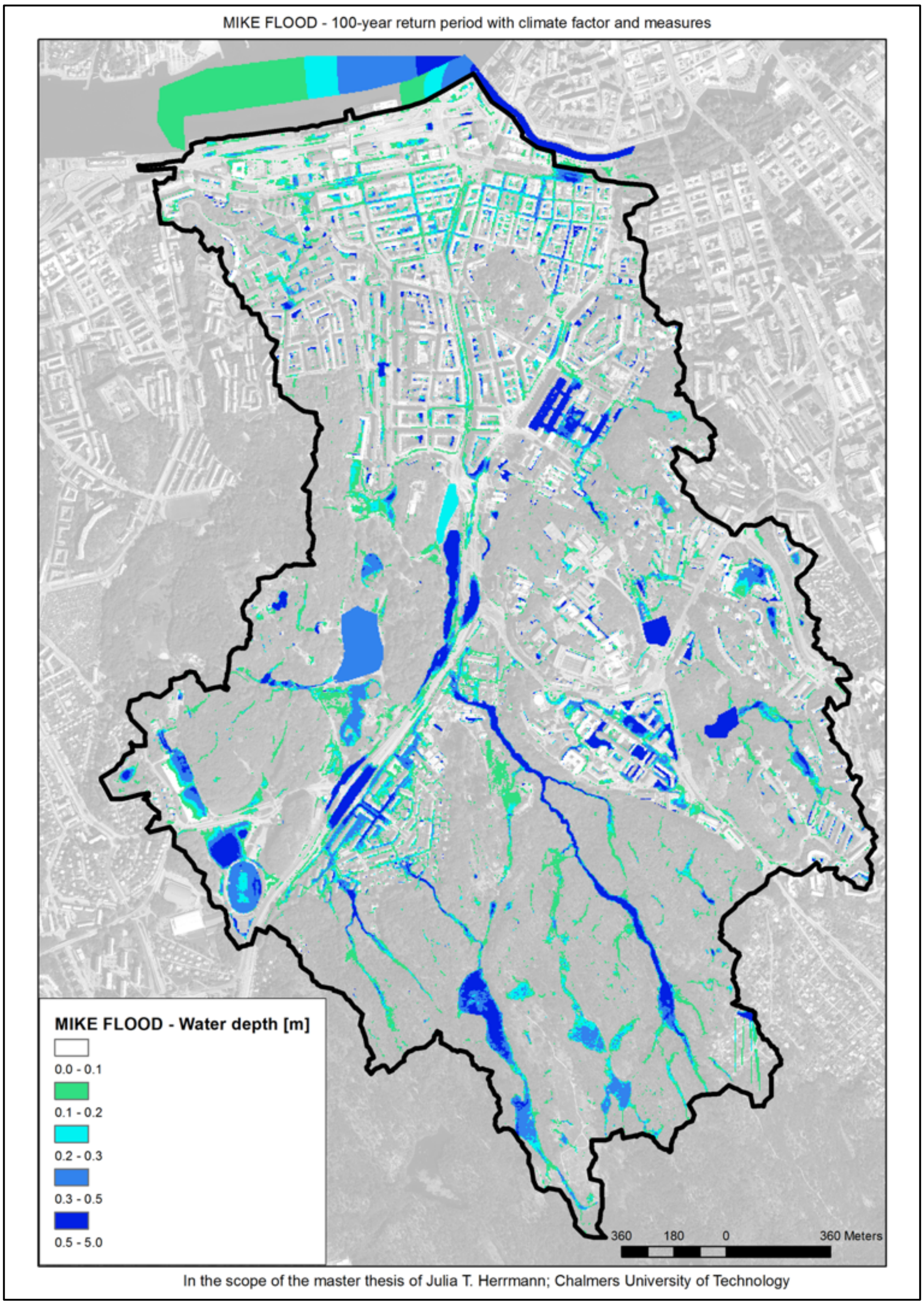


Figure 4-43: Flood map in MIKE FLOOD with implemented measures in ArcMap (created by author)

In MIKE FLOOD the results are as expected like in MIKE 21. The flow towards Vitsippsbäcken was reduced and the water depth decreased. The flow path in Slottsskogen was successful and the subsurface modelling of a pipe system shows less surface flooding on the road than before and in comparison, to MIKE 21.

With regard to the current speed the 3D Analysis Minus Tool was applied in ArcMap, shown in Figure 4-44. A positive value shows a reduced current speed for the simulation with measures and a negative value a higher current speed without measures. The current speed increased especially around the Sahlgrenska University Hospital at Per Dubbsgatan and towards Vittsippsbäcken, which could not be found in MIKE 21. An increase of the current speed around the borders of the designed measures can be seen in red in the flood map. The increase of the current speed is caused by the changes of elevation. The transition in this area would need to be smoothened in a detailed planning process.

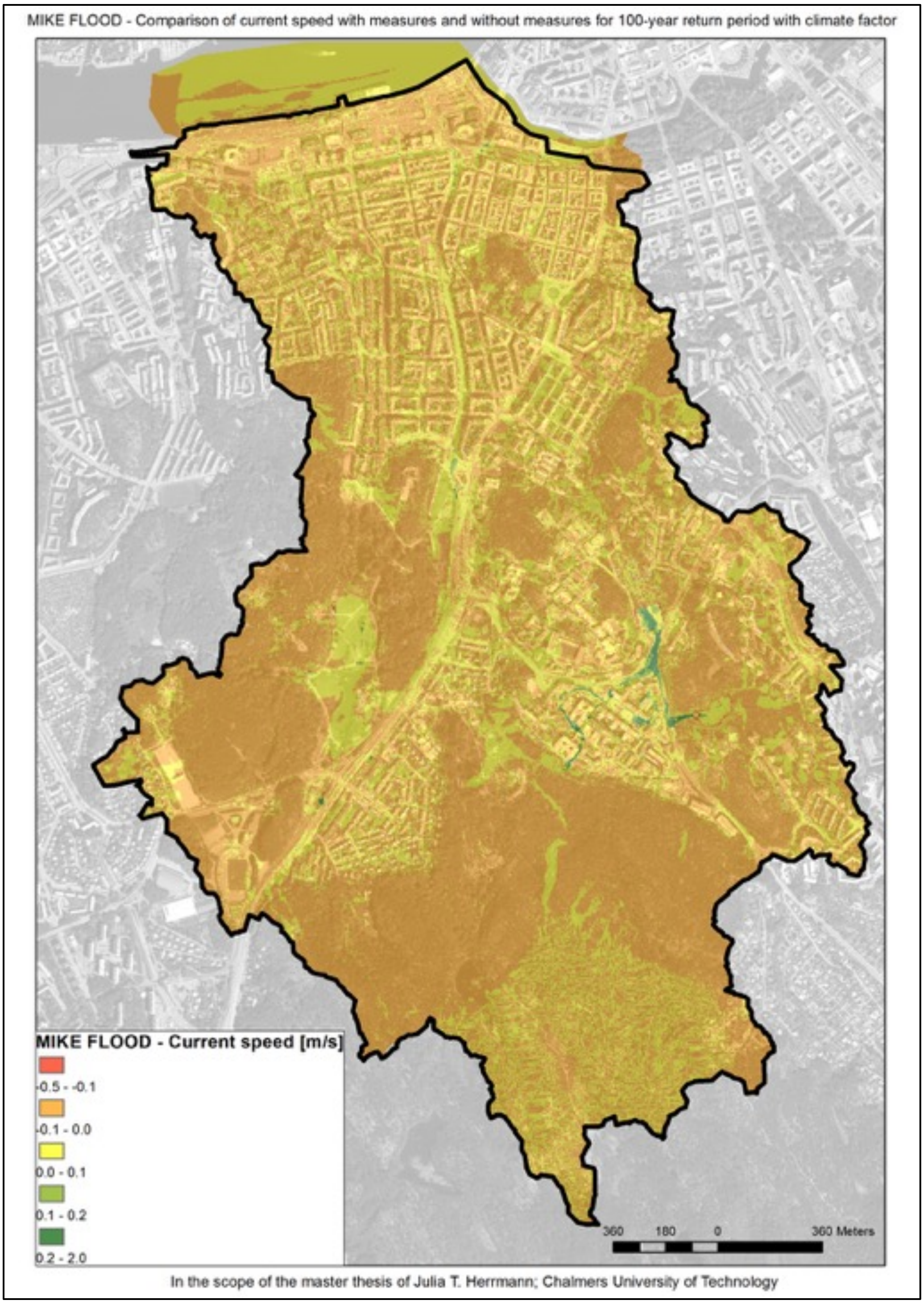


Figure 4-44: Comparison of current speed in MIKE FLOOD with and without measures (created by author)

4.2.4.5. Comparison - Results of simulations with measures

In this section the results are presented and compared for the three software programs investigated in the present report, see Figure 4-45

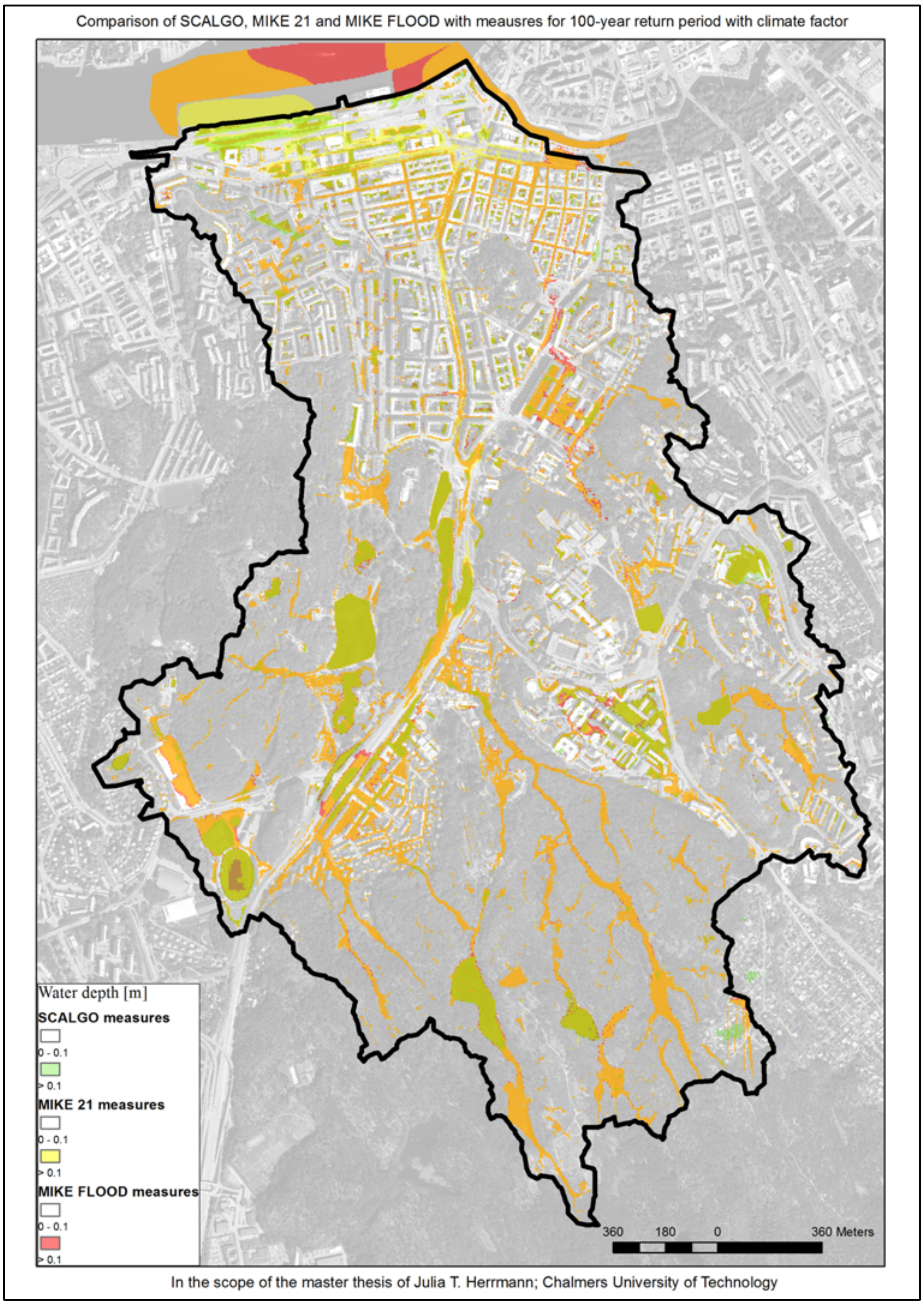


Figure 4-45: Comparison of SCALGO, MIKE 21 and MIKE FLOOD with implemented measures (created by author)

With respect to simulation without and with measures there is no significant difference for the simulations between the software programs. The flood map (Figure 4-45) illustrates the efficiency of the implemented measures with the depth reduction in Sahlgrenska University Hospital and in MIKE FLOOD for flow towards Vitsippsbäcken as aimed for. The retention and storage areas implemented show the expected higher water depths than before.

The flooding only occurring in SCALGO nearby the hospital was retained with the measures taken. The accessibility of the hospital was sufficient with the measures taken.

In MIKE 21 and MIKE FLOOD the current speed was compared for the simulations with and without measures showing the reduction of the current speed in the hospital area for MIKE FLOOD and MIKE 21. Increased current speed was found in the embordering areas for the measures implemented. The reason for the increased velocity can be assumed to be cause of the abrupt change in topography as the measures were implemented in a rough manner instead of accurate detailed planning. Further adjustments of the measures to adjust the hydraulic structures is recommended. This finding can only be assessed for the programs of MIKE ZERO and not for SCALGO.

4.3. FloodMan Results

According to the prior description of the FloodMan methodology the tool was applied for the study area Linnéstaden. Within this area measures were implemented chosen with respect to the risk assessment of this thesis.

As the FME results serve directly as input for the FloodMan tool the results of the FME simulations are not presented in this section. The results of those simulations are illustrated in FloodMan in terms of the evaluation of the flooded buildings, traffic areas and roads. The explicit input data can be found in Appendix C.

The result section of FloodMan first presents the indata based on the results from the simulations with measures taken. The section is followed by the results of FloodMan, meaning the economic analysis, environmental and social effects and finally the sustainability analysis.

4.3.1. FloodMan – Input data

This section presents the input data for FloodMan, including the decisions made in the process of applying the FloodMan tool.

As discussed above the application of FloodMan in the present report varies to the typical aimed application of this tool, as the alternatives compared within this study were the investigated software programs SCALGO, MIKE 21 and MIKE FLOOD. Simulations from MIKE FLOOD also served as the reference option, however the simulation for the reference option did not have any measures implemented. In the following the input data is presented in the manner of the nine steps in FloodMan.

4.3.1.1. Step 1 - Administration

The input data in the administration part is presented in Figure 4-46, which shows the original surface in Swedish.

Projektnamn
Master Thesis Julia T. Herrmann - Linnéstaden, City of Gothenburg, Sweden

Åtgärdsalternativ		Analysera åtgärd?
0-alternativet	Reference option (MIKE FLOOD)	Ja
Alternativ 1	SCALGO - actions simulated in SCALGO	Ja
Alternativ 2	MIKE 21 - actions simulated in MIKE 21	Ja
Alternativ 3	MIKE FLOOD - actions simulated in MIKE FLOOD	Ja

Återkomsttider								
Återkomsttid (år)	1	2	5	10	20	50	100	200
Sannolikhet (1/år)	1	0,5	0,2	0,1	0,05	0,02	0,01	0,005
Analysera nivå?	Nej	Nej	Nej	Nej	Nej	Ja	Ja	Ja

Tidshorisont och diskontering	
Startår	2018
Slutår	2118
Tidshorisont (år)	100
Räntesats 1	1,4
Räntesats 2	3,5

Definiera scenario			
Typ av analys	Skyfall	Vattendjup	2 dm
Ambitionsnivå	Fullständig	Risknivå	Hög
Osäkerhetsanalsys (Monte Carlo simulering)?	Ja		

Figure 4-46: Administration indata for FloodMan of present thesis shown in FloodMan interface

Alternatives and reference options selected were assigned to SCALGO, MIKE 21 and MIKE FLOOD. In order to compare them the analysis was chosen for all alternatives and the reference, which is labelled as “0-alternativet”. The return period chosen are: 50, 100 and 200 years. The time horizon was set to 100 years. It was chosen based on the design event for torrential rain and flash floods assigned to 100-year events for the *City of Gothenburg*. The starting year was set to the year of the development of this thesis 2018. The interest rates (“Räntesats”) selected are the given values from the FloodMan manual. The defined scenario is the analysis for a torrential rain (“skyfall”) and the chosen form of analysis was a full analysis. The investigated risk level is the high-risk level (“hög”), based on the results from FME. As mentioned in the methodology section of FloodMan the crucial water levels for the assignments to the risk levels were defined in FME. Thus, the selection of the water level in the administration with the standard value of 20 cm had no effect on the results. In addition, the uncertainty analysis was chosen for the evaluation of the alternatives.

4.3.1.2. Step 2 - Damage objects

In the section of the damage objects the indata for the reference, alternatives and the possibility of adding other damages was done.

The indata for the reference and alternatives is shown in the Appendix C with values for the three investigated return periods 50, 100 and 200 years.

Before proceeding to the “other damages” it is important to point out, that the simulations of the models were all done with the consideration of the climate factor. However, FloodMan assumes that the climate factor is solely applied to the future scenario, for which the time horizon was chosen. Concluding, the results from the simulation were assigned to the end year of the FloodMan time horizon. For obtaining the values for today’s situation the results from the simulations with a climate factor were reduced to a 100-year event without a climate factor. Additional simulations, without a climate factor, were not considered due to limit time and lack of explicit data for the precipitation input files, where the climate factor was considered.

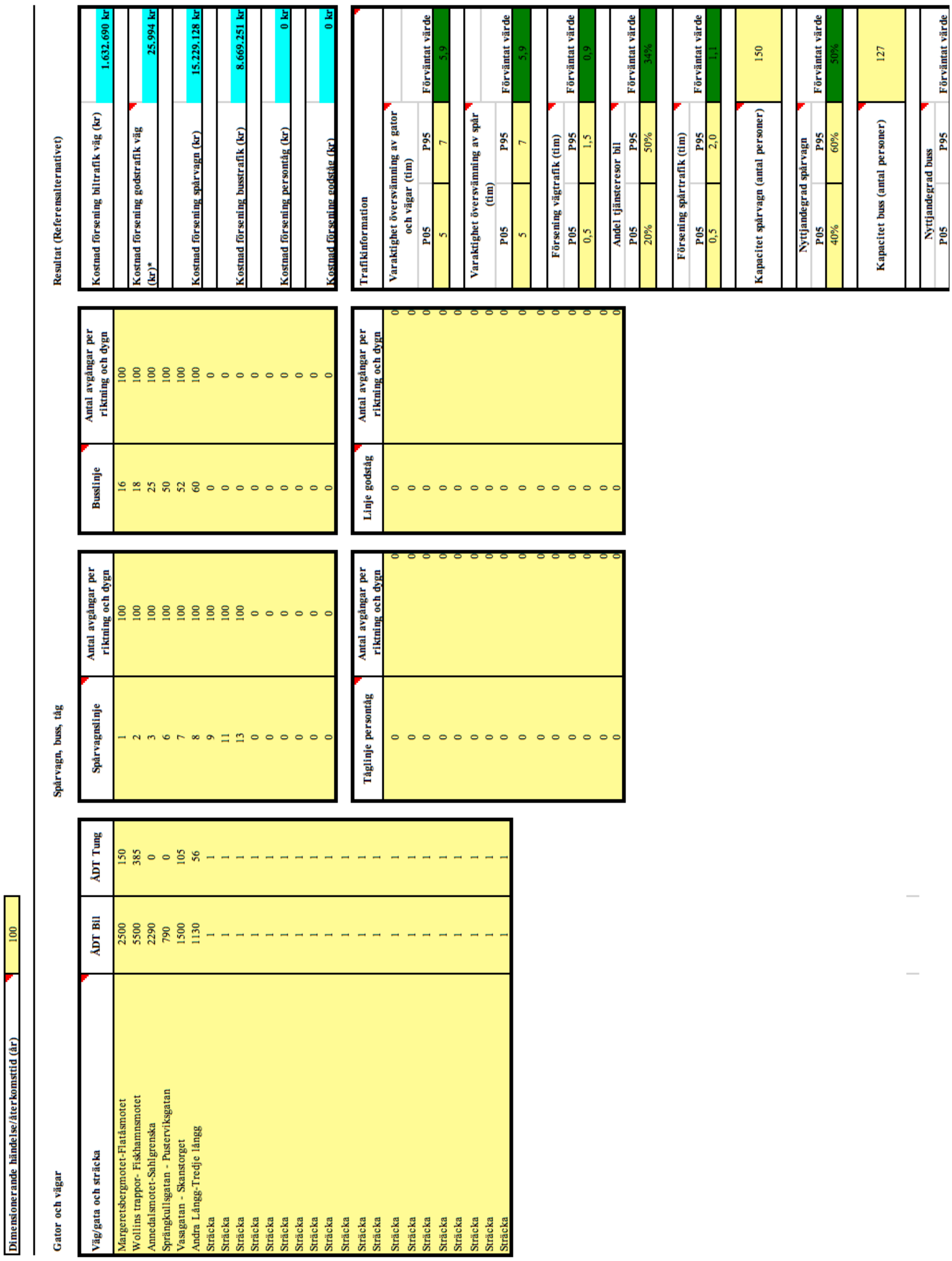
In the section “other damages” no additional values were added by the author. In the scope of the present report, FloodMan was applied for a comparison. For additional adjustments to costs and claims in this section a site-specific evaluation of the costs, e.g. to Sahlgrenska University Hospital would have to be done. As the focus of this thesis is not on the cost benefit analysis but on the comparison a further investigation of the economic aspects beyond the extent of FloodMan was neglected.

4.3.1.3. Step 3- Traffic

In the “Traffic” – section the given values in the original set-up FloodMan were designed for Linnéstaden by the “Trafikverket”, thus no changes were done by the author to values considering the general traffic information. This included the values for the annual average daily traffic for cars, public transportation and passenger and freight trains. The same accounts for the traffic information regarding the capacity, number of shared trips and expected delays. It was assumed that the decisions by experts in the field of traffic should be chosen as in a real planning process several stakeholders from different fields of expertise would be involved as well.

The changes done by the author in this section was the update of the effected transportation means. This applied for the trams and bus lines, where several lines were added. The reference used were the local traffic carriers “Västtraffik” (2018).

The added lines were assigned to the same annual average daily traffic values as the lines in the FloodMan manual in the catchment area. The input data for the traffic section is shown in Figure 4-47.



Dimensionerande händelse/återkomsttid (år)	100

Gator och vägar

Väg/gata och sträcka	ÅDT Bil	ÅDT Tung
Margeretsbergmotet-Flatåsmotet	2500	150
Wollins trappor- Fiskhamnsmotet	5500	385
Annedalsmotet-Sahlgrenska	2290	0
Sprängkullsgatan - Pusterviksgatan	790	0
Vasagatan - Skanstorget	1500	105
Andra Långg-Tredje långg	1130	56
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1
Sträcka	1	1

Spårvagn, buss, tåg

Spårvagnslinje	Antal avgångar per riktning och dygn	Busslinje	Antal avgångar per riktning och dygn
1	100	16	100
2	100	18	100
3	100	25	100
6	100	50	100
7	100	52	100
8	100	60	100
9	100	0	0
11	100	0	0
13	100	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Tåglinje persontåg	Antal avgångar per riktning och dygn	Linje godståg	Antal avgångar per riktning och dygn
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Resultat (Referensalternativet)

Kostnad försening biltrafik väg (kr)	1.632.690 kr
Kostnad försening godstrafik väg (kr)*	25.994 kr
Kostnad försening spårvagn (kr)	15.229.128 kr
Kostnad försening busstrafik (kr)	8.669.251 kr
Kostnad försening persontåg (kr)	0 kr
Kostnad försening godståg (kr)	0 kr

Trafikinformation

	P05	P95	Förväntat värde
Varaktighet översvämning av gator och vägar (tim)	5	7	5,9
Varaktighet översvämning av spår (tim)	5	7	5,9
Försening vägtrafik (tim)	0,5	1,5	0,9
Andel tjänsteresor bil	20%	50%	34%
Försening spårtrafik (tim)	0,5	2,0	1,1
Kapacitet spårvagn (antal personer)			150
Nyttjandegrad spårvagn	40%	60%	50%
Kapacitet buss (antal personer)			127
Nyttjandegrad buss			

Figure 4-47: Traffic flow indata for FloodMan of the present report shown in FloodMan interface.

4.3.1.4. STEP 4 - ACTION COSTS

The catalogue values given in the original FloodMan set-up were used in the present report. As mentioned in the methodology the values were adjusted to the local conditions as described in the FloodMan manual and therefore were seen applicable for this thesis.

The actions costs were given based on the developed measures in the software programs, see Chapter 4.2.4.1. The point in time of implementation was set the same for all three alternatives, thus programs. It was set to year 3, meaning that the measures will be implemented in year 3 of the 100-year time horizon. The time span was chosen by the author as the *City of Gothenburg* plans to build a robust city to flooding till its jubilee in 2021, thus 3 years from now.

The action costs for the three alternatives were calculated based on the developed measures in the individual models. The measures listed in the "action catalogue" of FloodMan were considered as target prices. The implemented measures were assigned to the closest object listed in the catalogue.

The parking lot area, nearby Medicinaregatan was assigned to the category "Skyfallsytor", which describes an open retention basin or area assigned to be flooded. The stored volume was rounded to 7,660 m^3 for the assessment in FloodMan. The flood area was assigned to be built with concrete "Skyfallsyta – betong" as it is currently used as a parking lot. However, in a detailed planning process as green parking lot would be a possible solution as well. This assignment was done for all three alternatives.

The retention basin at Guldhelden to protect Sahlgrenska University Hospital was defined as "Skyfallsytor" as well. For the area the basin was decided to be "green basin" and thus was assigned to "Skyfallsyta grön klass B". The retained volume was rounded to 9,880 m^3 for the application in FloodMan. This classification was done for all three alternatives.

The retaining area in Slottsskogen, nearby the Slottsskogspromenaden, defined as "Skyfallsytor" in the category of "Skyfallsyta grön klass B". The retained volume was set to 11,700 m^3. The assignment was done for all three alternatives. In MIKE 21 and SCALGO the designed water paths to this area were modelled by changes to the elevation. For these two alternatives the category "Skyfallsvägar" was chosen with the subgroup "Liten Skyfallsväg". The path was assumed to be built as green road, but the category "Gröna vägar" would require further explicit planning of the measure and the category "liten Skyfallsväg" was considered to allow the assessment of a more general type of this measure. The length of the water path was measured and rounded to 110 m. In MIKE FLOOD two water paths were modelled in MIKE FLOOD, with the design of pipes, manholes and an outlet to the retention area. The culverts were assigned to the category "Skyfallstunnlar". The pipes were designed with a diameter of 1 m. In FloodMan the smallest subcategory with a 2 m diameter was chosen from the action catalogue to describe the pipes. The total length of the pipes was measured in MIKE URBAN and accounts 280 m.

The retaining area at Linnéplatsen stores the volume of 1,630 m^3. This was applied to all three alternatives. In SCALGO a pipe with unlimited capacity was modelled to discharge water from Annedal towards the green area in Slottsskogen. In the action catalogue the largest culvert was chosen for the assessment of this pipe. The chosen category is "Skyfallstunnlar" with the subcategory "Skyfallstunnel 2m/diameter".

All retention areas and basins were decided to be open thus the category "Slutna magasin" was not applied for this thesis, as it solely describes closed subsurface basins.

The calculated costs are shown in Figure 4-48, Figure 4-49, Figure 4-50, Figure 4-50 and Figure 4-51 within the FloodMan interface and the chosen values in the present report. Figure 4-48 shows the action catalogue adapted and applied in the scope of this thesis. For the action catalogue category "Skyfallstunnlar" no values were assigned to "Driftskostnad", meaning costs for operation and maintenance the author decided to choose the same value as for the category "Skyfallsvägar", which is given by 25kr/enhet/år (Swedish Crowns/unit/year).

Åtgärdskatalog					
	Investeringskostnad		Driftskostnad	Livslängd	Återinvestering
	kr/enhet	enhet	kr/enhet/år	år	%
Skyfallsvägar					
Skyfallsväg, 100 års regn med 10 cm djup	10.000.000	km	10.000	40	100%
Gröna vägar med regnbädd, biflöde skyfallsväg	10.000	m	25	20	100%
Stor skyfallsväg >5000 ÅDT	20.000	m	25	50	100%
Liten skyfallsväg < 5000 ÅDT	10.000	m	25	50	100%
Skyfallsytor					
Skyfallsyta (öppet magasin i betong)	10.000	m3	40	75	100%
Skyfallsyta grön klass B (öppet magasin jord, grön)	950	m3	25	50	50%
Fördröjningsyta på befintlig plats	600	m3	25	50	100%
Skyfallstunnlar					
Skyfallstunnel 2 m/diameter	80000	m	25	50	100%
Skyfallstunnel 3 m/diameter	110000	m	25	50	100%
Slutna magasin i befintligt nät					
Slutet magasin utan rensning, <1000 m³	10.000	m3	40	50	100%
Slutet magasin med rensning, 500-1000 m³	10.000	m3	40	75	100%
Slutet magasin med rensning, 1000-3000 m³	8.000	m3	40	75	100%
Slutet magasin med rensning, 5000-10000 m³	6.000	m3	40	75	100%
Slutet magasin med rensning, >10.000 m³	4.000	m3	40	75	100%
Styrning					
Dämning med betong, 1 m höjd	5.000	m	20	50	100%
Svackdike					
Dike, bottenbredd 1 m, djup 0,2 m, bredd dikestopp 3m	550	m	25	100	100%
Dike, bottenbredd 1 m, djup 0,4 m, bredd dikestopp 5m	1200	m	30	100	100%
Dike, bottenbredd 2 m, djup 0,4 m, bredd dikestopp 6m	1550	m	35	100	100%
Vattenväg i naturmark					
Vattenväg, bottenbredd 0,5 m, djup 1 m	2.100.000	km	900	100	100%
Vattenväg, bottenbredd 0,5 m, djup 2 m	6.600.000	km	1700	100	100%
Vattenväg, bottenbredd 1 m, djup 1 m	2.600.000	km	1000	100	100%
Vattenväg, bottenbredd 1 m, djup 2 m	7.250.000	km	1800	100	100%
Övriga åtgärder					
Tillträde till mark					
VA-lösningar, exmpelvis pumpstationer, ledningsdragning					
Trafikstörningar under anläggning					
Tillkommande kostnader geotekniska åtgärder					
Tillkommande kostnader konstruktioner					
Tillkommande kostnader för bergarbeten					
Trafikstörningar under anläggning					
Annan åtgärd					

Swecos har bedömt att dessa priser inte är möjliga att uppskatta schablonmässigt. Priserna är hämtade direkt från PLASK-metoden. Priserna ska därför endast ses som en mycket grov uppskattning av kostnadernas storleksordning. Priserna måste användas med mycket stor försiktighet och en platsspecifik värdering av dessa kostnader bör göras i varje enskilt fall.

Figure 4-48: Action catalogue of FloodMan interface.

Alternativ 1 – SCALGO - actions simulated in SCALGO							
	Tidpunkt	Nuvärde Investering		Nuvärde Återinvestering		Nuvärde Drift och underhåll	
Antal	3	R1	R2	R1	R2	R1	R2
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
110	3	1.069.835 kr	1.026.862 kr	541.324 kr	190.298 kr	142.131 kr	70.828 kr
7660	3	74.499.415 kr	71.506.920 kr	26.628.346 kr	5.607.408 kr	15.835.939 kr	7.891.556 kr
23210	3	21.444.841 kr	20.583.444 kr	5.425.416 kr	1.907.264 kr	29.989.569 kr	14.944.763 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
365	3	39.048.975 kr	37.480.455 kr	19.758.312 kr	6.945.887 kr	471.615 kr	235.021 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
Summa nuvärden		136.063.066 kr	130.597.680 kr	52.353.398 kr	14.650.858 kr	46.439.254 kr	23.142.168 kr

Åtgärdskostnadernas osäkerhet	**Kostnadspost**	**Osäkerhet (%)**
Uppskatta den generella osäkerheten (0-99 %) för respektive kostnadskategori. OBS! Görs endast om Monte Carlo simulering.	Investering	*20%*
	Drift och underhåll	*20%*
	Återinvestering	*20%*

Sammanställning kostnader Alternativ 1 (kr)		
	R1	**R2**
Nuvärde Investeringskostnader Alt 1	136.063.066 kr	130.597.680 kr
Nuvärde Drift och underhåll Alt 1	46.439.254 kr	23.142.168 kr
Nuvärde Återinvestering Alt 1	52.353.398 kr	14.650.858 kr
Nuvärde total kostnad Alt 1	**234.855.718 kr**	**168.390.707 kr**

Figure 4-49: Action costs for Alternative 1 in FloodMan interface.

Alternativ 2 – MIKE 21 - actions simulated in MIKE 21							
	Tidpunkt	Nuvärde Investering		Nuvärde Återinvestering		Nuvärde Drift och underhåll	
Antal	3	R1	R2	R1	R2	R1	R2
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
110	3	1.069.835 kr	1.026.862 kr	541.324 kr	190.298 kr	142.131 kr	70.828 kr
7660	3	74.499.415 kr	71.506.920 kr	26.628.346 kr	5.607.408 kr	15.835.939 kr	7.891.556 kr
23210	3	21.444.841 kr	20.583.444 kr	5.425.416 kr	1.907.264 kr	29.989.569 kr	14.944.763 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
Summa nuvärden		97.014.091 kr	93.117.226 kr	32.595.086 kr	7.704.971 kr	45.967.639 kr	22.907.147 kr

Åtgärdskostnadernas osäkerhet	**Kostnadspost**	**Osäkerhet (%)**
Uppskatta den generella osäkerheten (0-99 %) för respektive kostnadskategori. OBS! Görs endast om Monte Carlo simulering.	Investering	*20%*
	Drift och underhåll	*20%*
	Återinvestering	*20%*

Sammanställning kostnader Alternativ 2 (kr)		
	R1	**R2**
Nuvärde Investeringskostnader Alt 2	97.014.091 kr	93.117.226 kr
Nuvärde Drift och underhåll Alt 2	45.967.639 kr	22.907.147 kr
Nuvärde Återinvestering Alt 2	32.595.086 kr	7.704.971 kr
Nuvärde total kostnad Alt 2	**175.576.815 kr**	**123.729.344 kr**

Figure 4-50: Action costs for Alternative 2 in FloodMan interface.

Alternativ 3 – MIKE FLOOD - actions simulated in MIKE FLOOD							
	Tidpunkt	Nuvärde Investering		Nuvärde Återinvestering		Nuvärde Drift och underhåll	
Antal	3	R1	R2	R1	R2	R1	R2
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
7660	3	74.499.415 kr	71.506.920 kr	26.628.346 kr	5.607.408 kr	15.835.939 kr	7.891.556 kr
23210	3	21.444.841 kr	20.583.444 kr	5.425.416 kr	1.907.264 kr	29.989.569 kr	14.944.763 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
280	3	21.785.730 kr	20.910.640 kr	11.023.317 kr	3.875.165 kr	361.787 kr	180.290 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
0	3	0 kr	0 kr	0 kr	0 kr	0 kr	0 kr
Summa nuvärden		117.729.985 kr	113.001.004 kr	43.077.079 kr	11.389.838 kr	46.187.295 kr	23.016.609 kr

Åtgärdskostnadernas osäkerhet	Kostnadspost	Osäkerhet (%)
Uppskatta den generella osäkerheten (0-99 %) för respektive kostnadskategori. OBS! Görs endast om Monte Carlo simulering.	Investering	*20%*
	Drift och underhåll	*20%*
	Återinvestering	*20%*

Sammanställning kostnader Alternativ 3 (kr)		
	R1	**R2**
Nuvärde Investeringskostnader Alt 3	117.729.985 kr	113.001.004 kr
Nuvärde Drift och underhåll Alt 3	46.187.295 kr	23.016.609 kr
Nuvärde Återinvestering Alt 3	43.077.079 kr	11.389.838 kr
Nuvärde total kostnad Alt 3	**206.994.360 kr**	**147.407.450 kr**

Figure 4-51: Action costs for Alternative 3 in FloodMan interface.

As shown in Figure 4-48, Figure 4-49, Figure 4-50 and Figure 4-51 the action costs vary even though only small adjustments were made within in the three software programs for implementing the measures. An overview of the costs of each alternative is shown in comparison in Table 4-17 and Table 4-18.

Table 4-17: Action costs of alternatives in FloodMan for present thesis with an interest rate of 1.4

Costs for present value	Alternative 1 SCALGO	Alternative 2 MIKE 21	Alternative 3 MIKE FLOOD
Investment Costs	136,063,066 kr	97,014,091 kr	117,729,985 kr
Operation and Maintenance	46,439,254 kr	45,967,639 kr	46,187,295 kr
Reinvestment	52,353,398 kr	32,595,086 kr	43,077,079 kr
Total costs	234,855,718 kr	175,576,815 kr	206,994,360 kr

Table 4-18: Action costs of alternatives in FloodMan for present thesis with an interest rate of 3.5

Costs for present value	Alternative 1 SCALGO	Alternative 2 MIKE 21	Alternative 3 MIKE FLOOD
Investment Costs	130,597,680 kr	93,117,226 kr	113,001,004 kr
Operation and Maintenance	23,142,168 kr	22,907,147 kr	23,016,609 kr
Reinvestment	14,650,858 kr	7,704,971 kr	11,389,838 kr
Total costs	168,390,686 kr	123,729,344 kr	147,407,160 kr

It is apparent from Table 4-17 and Table 4-18, that Alternative 1 has the highest total costs of present value. This result shows a positive correlation with the number of implemented measures. In SCALGO (Alternative 1) the number of implemented measures was higher as in MIKE FLOOD (Alternative 3) followed by MIKE 21 (Alternative 2)

It stands out that there is no significant difference of the costs for the operation and maintenance costs between the three alternatives. This finding shows that the additional costs for culverts are lower than expected. The surcharge for the additional measures shows in the costs for the reinvestment.

4.3.1.5. Step 5 - Protection efficiency of implemented measures

In this step the protection efficiency of the measures was evaluated based on the selection criteria of the FloodMan interface. All measures were modelled. Thus, modelling was selected for the selection of the input data and the return period was defined by the modelling time horizon. The determination of the extent of traffic interruption reduction caused by each measure to its minimum and maximum degree was done by the author. All measures in the three alternatives, meaning the software program models, were designed in similar manner and so it was assumed that they have the same effects on the traffic.

For roads and paths the flood propagation improved by at least 50 % and the most of 70 %, for example on “Per Dubbsgatan” next to Sahlgrenska University Hospital. For trams the reduction was considered to be lower, as trams have a higher vulnerability to water depths and several main areas like Magretebergsmotet could have only been reduced to a certain degree. No trains were listed in the “Traffic” – Section. The FloodMan interface requires values for this section and so the stated values 10 % and 90 % from the manual were chosen. However, they had no effect on the results.

The likelihood of the malfunction of the measures for the models of the software programs was classified by evaluating how reliable the designed modeled features are. For SCALGO the changes in the DEM were considered to be reliable. The designed pipe with an unlimited capacity however was assumed to not be feasible in the way the model might induce. Consequently, the software program was assigned to the highest uncertainty of 10 %. For MIKE 21 the measures were solely done by changes to the DEM and do not rely on any mechanical operations. The failure of measures modeled by changes to the DEM was assumed to be highly unlikely and therefore MIKE 21 was assigned to the uncertainty of 1 %. The measures in MIKE FLOOD were assumed to be reliable for the designed pipes, as the design was performed with MIKE URBAN and thus inflow and outflow of the modelled pipes were leveled according to the elevation and the pipes were properly designed. As clogging of manholes to sewer systems is likely for sloping terrain, like in the inflow areas of Slottsskogen, the uncertainty of the measures not working in relation to MIKE 21 was increased to 5 %.

The following figures (Figure 4-52, Figure 4-53, Figure 4-54) present the interface for the protective efficiency of each alternative (software program) is presented.

Alternativ 1 – SCALGO - actions simulated in SCALGO

Åtgärden genomförs under år (Du anger denna uppgift i fliken "Åtgärdskostnad")	**3**

Har modellering använts för att uppskatta åtgärdens skyddseffekt eller är skyddsåtgärden utformad för att skydda mot händelser med specifik återkomsttid?	**Modellering**

Åtgärdens skyddseffekt baseard på återkomsttid Om inte modellering genomförts, *ange* *till och med* *vilken återkomsttid åtgärden kan förväntas skydda mot översvämning. Ange detta för startår och slutår inom den studerade tidsperioden.*	**Startår**	**Slutår**
	1	*1*

Reduktion av trafikstörning (%)	*Om modellering gjorts, ange för varje typ av infrastruktur i vilken grad åtgärden kan förväntas minska trafikstörningarna jämfört med den dimensionerande händelsen (%). OBS! Om inte osäkerhetsanalys används (simulering i Crystal Ball) så anges förväntad reduktion av trafikstörning på respektive rad i kolumn F.*		
	Lägsta rimligt värde	**Högsta rimligt värde**	**Förväntat värde**
Väg	50%	70%	60%
Spårvagn	40%	60%	50%
Tåg	10%	90%	0%
		Dimensionerande händelse (återkomsttid, år)	100

Sannolikhet att åtgärden inte fungerar *Uppskatta sannolikheten att åtgärden inte kommer att ge avsett skydd (0-100%).*	***Sannolikhet (%)***
	10%

Figure 4-52: Protective efficiency for alternative 1 "SCALGO" in FloodMan interface

Alternativ 2 – MIKE 21 - actions simulated in MIKE 21

Åtgärden genomförs under år (Du anger denna uppgift i fliken "Åtgärdskostnad")	**3**

Har modellering använts för att uppskatta åtgärdens skyddseffekt eller är skyddsåtgärden utformad för att skydda mot händelser med specifik återkomsttid?	**Modellering**

Åtgärdens skyddseffekt baseard på återkomsttid	**Startår**	**Slutår**
Om inte modellering genomförts, ange till och med vilken återkomsttid åtgärden kan förväntas skydda mot översvämning. Ange detta för startår och slutår inom den studerade tidsperioden.	*1*	*1*

Reduktion av trafikstörning (%)	*Om modellering gjorts, ange för varje typ av infrastruktur i vilken grad åtgärden kan förväntas minska trafikstörningarna jämfört med den dimensionerande händelsen (%). OBS! Om inte osäkerhetsanalys används (simulering i Crystal Ball) så anges förväntad reduktion av trafikstörning på respektive rad i kolumn M.*		
	Lägsta rimligt värde	**Högsta rimligt värde**	**Förväntat värde**
Väg	50%	70%	60%
Spårvagn	40%	60%	50%
Tåg	10%	90%	0%
		Dimensionerande händelse (återkomsttid, år)	100

Sannolikhet att åtgärden inte fungerar	**Sannolikhet**
Uppskatta sannolikheten att åtgärden inte kommer att ge avsett skydd (0-100%).	*1%*

Figure 4-53: Protective efficiency for alternative 2 "MIKE21" in FloodMan interface

Alternativ 3 – MIKE FLOOD - actions simulated in MIKE FLOOD

Åtgärden genomförs under år (Du anger denna uppgift i fliken "Åtgärdskostnad")	**3**

Har modellering använts för att uppskatta åtgärdens skyddseffekt eller är skyddsåtgärden utformad för att skydda mot händelser med specifik återkomsttid?	**Modellering**

Åtgärdens skyddseffekt baseard på återkomsttid	**Startår**	**Slutår**
Om inte modellering genomförts, ange till och med vilken återkomsttid åtgärden kan förväntas skydda mot översvämning. Ange detta för startår och slutår inom den studerade tidsperioden.	*1*	*1*

Reduktion av trafikstörning (%)	*Om modellering gjorts, ange för varje typ av infrastruktur i vilken grad åtgärden kan förväntas minska trafikstörningarna jämfört med den dimensionerande händelsen (%). OBS! Om inte osäkerhetsanalys används (simulering i Crystal Ball) så anges förväntad reduktion av trafikstörning på respektive rad i kolumn T.*		
	Lägsta rimligt värde	**Högsta rimligt värde**	**Förväntat värde**
Väg	50%	70%	60%
Spårvagn	40%	60%	50%
Tåg	10%	90%	0%
		Dimensionerande händelse (återkomsttid, år)	100

Sannolikhet att åtgärden inte fungerar	**Sannolikhet (%)**
Uppskatta sannolikheten att åtgärden inte kommer att ge avsett skydd (0-100%).	*5%*

Figure 4-54: Protective efficiency for alternative 3 "MIKE FLOOD" in FloodMan interface

4.3.1.6. STEP 6 - OTHER FINANCIAL CONSEQUENCES

This step provides the option to add beneficial economic effects caused by the measures, which are not considered in the costs. In the scope of the present report the design of the measures was done in a basic manner and a detailed planning would be required to decide on beneficial aspects, e.g. for the recreation or cleaning of water. This thesis does not engage with aspects of the water quality. Therefore, cleansing effects of the water by the measures cannot be quantified like this step in FloodMan would require. The interface of this thesis for this step is shown in the Appendix E-5 - Other financial consequences – FloodMan Interface.

4.3.2. FLOODMAN – RESULTS ANALYSIS

In this chapter the results of the FloodMan tool, referring to results of the CBA part “Economic Consequences” and the Steps 7, 8 and 9 are presented.

4.3.2.1. ECONOMIC CONSEQUENCES

In this section the economic consequences based on Step 1 to Step 6 of the FloodMan tool are presented.

Figure 4-55: Economic consequences FloodMan tool - results for risk costs

As shown in Figure 4-55 the risk costs differ between the three alternatives, but all three show a reduction of the original risk costs with respect to the reference option. This result was expected and proves the positive effects of the measures on the damage potential.

The results of uncertainty analysis with Oracle Crystal Ball® leading to the 5-percentil and 95-percentil values show a higher range of uncertainties for the lower interest rate and a smaller range of uncertainties for the higher interest rate. The difference within the programs was the smallest for Alternative 1-SCALGO and similar for Alternative 2-MIKE 21 and Alternative 3-MIKE FLOOD for both interest rates. It is unsuspected that the least advanced program showed the lowest range of uncertainty for the risk costs in FloodMan.

Figure 4-56 shows the different costs for the measures and actions for the three alternatives. As expected the highest costs were reported for SCALGO, in which the number of measures implemented was the highest. Alternative 2-MIKE 21 showed the lowest costs for the measures which was anticipated as well. It was not expected, that Alternative 3-MIKE FLOOD presented the highest range of discrepancy followed by Alternative 1-SCALGO and Alternative 2-MIKE 21 for the first interest rate. For the second interest rate Alternative 1 and Alternative 2 had similar differences.

Additionally, to the costs for the measures and actions Figure 4-56 presents the risk and action costs for the different categories like trams, roads and different buildings within Linnéstaden. All three alternatives show similar results apart from the category tram (Spårväg), with the lowest action costs for Alternative 1-SCALGO, which is a unforeseeable result. In general, the highest risk and action costs are located for apartment blocks (Flerbostdadshus) and for public institutions.

Figure 4-56: Economic consequences FloodMan tool - Measures and action costs

Figure 4-57 shows the risk reduction for the alternatives with their percentile values. In the category of other economic consequences, no assessments were done in the present report, thus no costs and cost reductions were reported.

With regard to the risk reduction the risk reduction is higher for a lower interest rate than a higher interest rate. The highest risk reduction could be achieved with Alternative 1-SCALGO where and additional pipe was implemented, thus a higher amount of measures opposed to the other alternatives. The lowest risk reduction was expected for Alternative 2-MIKE 21 however it occurred for Alternative 3-MIKE FLOOD even though improved measures were implemented.

For the higher interest rate the range of discrepancy was similar for all alternatives. For the lower interest rate a general higher discrepancy was reported and the difference was between the alternatives was larger. The highest difference was shown for the risk reduction for Alternative 1-SCALGO.

Figure 4-57: Economic consequences FloodMan - risk reduction and other economic consequences

The ratio of the risk reduction to the invested costs is shown in Figure 4-58. The range between the percentile values is the largest for Alternative 1 and the same for Alterative 2 and 3 for interest rate 1 and for interest rate 2 the same for Alternative 1 and 2 and the smallest for Alternative 3. The highest sensitivities were found for the costs of the planning for all three alternatives above 40 %, whereas the other sensitives differed for each alternative. The probability for the highest present net value was found for *Alternative 2* followed by *Alternative 1* and *Alternative 3*.

Figure 4-58: Economic Consequences FloodMan - Uncertainties

4.3.2.2. Step 7 - Environmental effects

In a first step of ‘Step 7 – Environmental Effects’, the criteria were weighted on the scale from 0 to 10, with 0 being not relevant and 10 being very relevant. The criteria in FloodMan are described in a general manner and therefore it was decided to adapt the weighting to what type of measures were implemented in the present report. As previously mentioned the design of the measures did not include the detailed planning, e.g. if the open channels in MIKE 21 and SCALGO were made out of rock material or include filters for water remediation measures. Therefore, not all criteria fit the present report, thus were adjusted in what was implied.

The criteria were weighted as presented in Table 4-19. The criteria were partially adapted by the author to fit the features present in the catchment and an urban environment in general. However, they were originally based on the FloodMan manual and tool. Effects like the water quality or air emission were not assessed in the scope of this thesis, therefore a rating of those effects could only be done in a qualitative and simplified manner. For this reason, the rating might be adapted, if air emission and water quality are investigated in a quantitative manner well.

Table 4-19: Criteria of environmental assessment in FloodMan tool. Weighting scale according to FloodMan. The description of the criteria was adapted for the present thesis and was based on the FloodMan tool.

Criteria	Weighting (0 to 10)	Criteria description of present thesis
Fresh Air	6	Impact of measures on fresh air quality, excluding greenhouse gases.
No eutrophication, Living lakes and streams, Balanced sea and live coast and archipelago	7	Living conditions for wild life, meaning plants and animals in general. The focus is on nature reservoir and park areas with their water bodies as the catchment does not include larger lakes or streams or the coastal area.
Natural resources	5	Natural resources refer to the consumption of such in the process of the measure implementation. Included are general building materials. The criterion excludes contamination by fossil fuels etc.
Non-toxic environment	8	A non-toxic environment refers to toxics in the soil or water and on how the measures increase or decrease those effects.
Groundwater	8	This criterion generally describes the effects on groundwater.
Rich farming landscape and vibrant wetlands	6	The effects on the ecosystem were limited to wetlands as no farming landscape exists in the catchment.
Limited Climate Impact	6	The climate impact refers to greenhouse gas emission.

An overview of the weighted criteria is shown in a pie chart, see Figure 4-59.

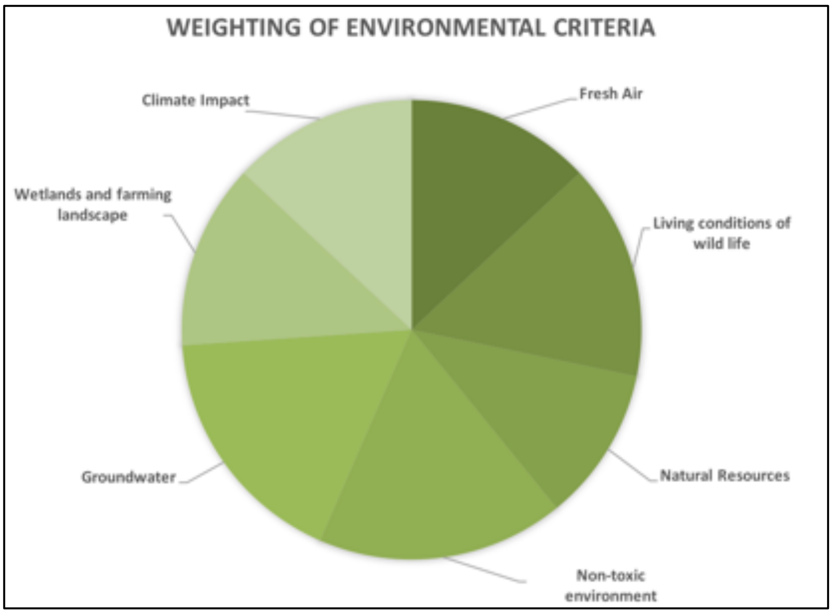


Figure 4-59: Criteria of environmental assessment. Overview of weighted criteria as presented in Table 4-19 of the present report. Pie chart from FloodMan interface

The decision-making process of the weighting by the author is consecutively explained. The criteria are presented in the order from least to most important.

1. Natural Resources

Natural resources were rated with the lowest weight. When carrying out a detailed planning of the measures the volumes of excavated soil could be used as filling material for another measure. This would also require a geotechnical assessment. Concluding this criterion was weighted with a lower importance as it was considered to be less relevant for the scope of this project. Furthermore, the sustainable usage of natural resources was considered important but less important than the other criteria.

2. Fresh Air, Climate Impact and Wetlands and Farming landscape

All three criteria were rated with the value 6, the second lowest value. Fresh air and climate impact were difficult to assess for the implemented measures as the measures hardly have an effect or detailed planning would be required for further assessment the weighting was assigned to a lower value. For wetlands and farming landscape was limited to the ecosystem of wetlands as no farming landscape can be found in the catchment. As the ecosystem in wetlands was considered to partially overlap with the criteria living conditions of wildlife it was rated lower.

3. Living conditions of wildlife

The criterion considering the water quality of surface water bodies and the wildlife of plants and animals was rated with the value 7. It was considered to be relatively important and could be assessed for the taken measures.

4. Groundwater and Non-toxic environment

These two criteria were rated with the highest weight of the value 8. Groundwater is a very important resource for fresh water. Groundwater formations are very complex and require sensitive treatment. In general, a non-toxic environment was assigned to a large importance for the environment as the contamination of the environment can lead to large consequential damage.

In the final step the different alternatives (software programs) were rated for each criterion. The application of FloodMan to compare different software programs and not different measures required the author to assess the measures taken for each alternative individually and finally decide on one overall effect as input data for the environmental effects.

The assessment for each criterion is presented as follows for each Alternative. The scale for the rating is -3 to +3, where -3 means a very negative and +3 a very positive effect and 0 no effect.

The assessment for the Alternative 1 – SCALGO is shown in Table 4-20. In SCALGO the measures were labelled as:

1. Parking lot as retaining area at Medicinaregatan
2. Retention basin at Guldheden for Sahlgrenska University Hospital
3. Retaining area at Slottsskogen nearby Slottsskogspromenaden
4. Pipe from Annedal to retaining area nearby Linnéplatsen

Table 4-20: Rating of environmental effects for Alternative 1 - SCALGO. Criteria according to FloodMan tool

Criteria	1	2	3	4	Σ
Fresh Air	0	0	0	0	0
Living conditions of wildlife	0	-1	-1	-2	-2
Natural resources	0	-1	0	0	0
Non-toxic environment	-2	+ 2	+2	-1	+1
Groundwater	0	+1	+1	+1	+1
Rich farming landscape and vibrant wetlands	0	0	+2	+1	+1
Limited Climate Impact	0	0	0	0	0

The assessment for the Alternative 2 – MIKE 21 is presented in Table 4-21: Rating of environmental effects for Alternative 2 – MIKE 21. Criteria according to FloodMan tool. In MIKE 21 the measures were labelled in the following manner.

1. Parking lot as retaining area at Medicinaregatan
2. Retention basin at Guldheden for Sahlgrenska University Hospital
5. Retaining area at Slottsskogen nearby Slottsskogspromenaden
3. Retaining area nearby Linnéplatsen

Table 4-21: Rating of environmental effects for Alternative 2 – MIKE 21. Criteria according to FloodMan tool

Criteria	1	2	3	4	Σ
Fresh Air	0	0	0	0	0
Living conditions of wildlife	0	-1	-1	-1	-1
Natural resources	0	-1	0	0	0
Non-toxic environment	-2	+ 2	+2	+2	+2
Groundwater	0	+1	+1	+1	+1
Rich farming landscape and vibrant wetlands	0	0	+2	+1	+1
Limited Climate Impact	0	0	0	0	0

The assessment for the Alternative 3 – MIKE FLOOD is shown in Table 4-22.In MIKE 21 the measures were labelled in the subsequent manner.

1. Parking lot as retaining area at Medicinaregatan
2. Retention basin at Guldheden for Sahlgrenska University Hospital
6. Retaining area at Slottsskogen nearby Slottsskogspromenaden including the stormwater channel and outlet
3. Retaining area nearby Linnéplatsen

Table 4-22: Rating of environmental effects for Alternative 3 – MIKE FLOOD. Criteria according to FloodMan tool

Criteria	1	2	3	4	Σ
Fresh Air	0	0	0	0	0
Living conditions of wildlife	0	-1	-1	-1	-1
Natural resources	0	-1	0	0	0
Non-toxic environment	-2	+ 2	0	+2	+1
Groundwater	0	+1	+1	+1	+1
Rich farming landscape and vibrant wetlands	0	0	+2	+1	+1
Limited Climate Impact	0	0	0	0	0

Based on the results presented in Table 4-20, Table 4-21 and Table 4-22and the environmental effects for the three alternatives were chosen. The final results are presented in Figure 4-60.

Alternativ	
0-alternativet	Reference option (MIKE FLOOD)
Alternativ 1	SCALGO - actions simulated in SCALGO
Alternativ 2	MIKE 21 - actions simulated in MIKE 21
Alternativ 3	MIKE FLOOD - actions simulated in MIKE FLOOD

Miljöeffekter	**Master Thesis Julia T. Herrmann - Linnéstaden, City of Gothenburg, Sweden**			
	Viktning	***Effekter***		
Kriterium	***0 = Inte relevant 10 = Mycket viktig***	**Alternativ 1**	**Alternativ 2**	**Alternativ 3**
Frisk Luft. *Vilken påverkan på luftmiljön medför åtgärden?* Exempelvis utsläpp av SOx, NOx och partiklar. OBS! Växthusgaser hanteras separat, se nedan.	6	Ingen effekt	Ingen effekt	Ingen effekt
Ingen övergödning/Levande sjöar och vattendrag/Hav i balans samt levande kust och skärgård. Vilka effekter medför åtgärden på förutsättningar för att fånga partiklar och näringsämnen? Hur påverkas livsbetingelser för växter och djur i vattendrag, sjöar och havet?	7	Negativ	Viss negativ	Viss negativ
Naturresurser. Vilka effekter har åtgärden på förbrukning av ändliga naturrresurser? Exempelvis användning av fossila bränslen eller användning av nyproducerad sand och grus för återfyllning.	5	Ingen effekt	Ingen effekt	Ingen effekt
Giftfri miljö. Vilka effekter uppstår avseende förekomst av föroreningar i mark och vatten till följd av åtgärden? Vilken produktion av icke-återvinningsbart avfall medför åtgärden? Exempelvis deponering av förorenade massor.	8	Viss positiv	Positiv	Viss positiv
Grundvatten. Vika effekter har åtgärden på grundvattnets kvalitet eller dess betydelse för ekosystem som nyttjar grundvatten? Påverkas möjligheten till grundvattenbildning positivt eller negativt?	8	Viss positiv	Viss positiv	Viss positiv
Ett rikt odlingslandskap och myllrande våtmarker. Vilka effekter får åtgärden på förutsättningarna för ekosystem i odlingslandskapet och i våtmarker?	6	Viss positiv	Viss positiv	Viss positiv
Begränsad klimatpåverkan. Vilka effekter har åtgärden på utsläpp av växthusgaser, såsom CO_2, metan, etc?	6	Ingen effekt	Ingen effekt	Ingen effekt
Samlad bedömning		6	17	11

Figure 4-60: Environmental effects for three alternatives shown in FloodMan interface.

Figure 4-60 shows the results for the environmental effects. The lower the value the weaker the positive environmental effects of the alternative and the higher the value the higher the positive environmental effects of the measure.

Consequently, Alternative 2 has the best environmental effects with a score of 17. Followed by Alternative 3, with a score of 11. The lowest score was achieved by Alternative 1 with a score of 6. One can assume that the best environmental effects for Alternative 2 were caused by the least impact on the environment due to the most simplified measures in MIKE 21 compared to the other software programs.

4.3.2.3. Step 8 - Social Effects

For 'Step 8 - Social Effects' at first the criteria were weighted by the author on the scale from 0 to 10, with 0 being not relevant and 10 being very relevant. The criteria in FloodMan are described in a general manner and therefore it was decided to adapt the weighting to what type of measures were implemented in the present report. As previously mentioned the design of the measures did not include the detailed planning thus the criteria were weighted in the same manner as the "Environmental effects" criteria. Meaning that not all criteria fit the present report and were adjusted.

The criteria were weighted as presented in Table 4-23. The criteria were partially adapted by the author to fit the features present in the catchment, but were originally based on the FloodMan manual and tool. The social effects in general were not assessed in the scope of this thesis, therefore a rating of those effects could only be done in a qualitative and simplified manner.

Table 4-23: Criteria of social effects assessment in FloodMan tool. Weighting scale according to FloodMan. The description of the criteria was adapted for the present thesis and was based on the FloodMan tool.

Criteria	Weighting (0 to 10)	Criteria description of present thesis
Identity	5	The criterion describes the attractiveness of the urban area and possible changes due to measures.
Cohesive city	8	A cohesive city was considered to refer to the creation of possible social barriers caused by the measures.
Recreation and interaction	7	This criterion describes the recreational effects of the measures and how they support social interaction.
Health and Safety	10	The health and safety are described by the likelihood of accidents or the exposure to hazards.
Cultural Environment	5	The cultural environment refers to the effects on cultural heritage.
Daily life	7	The effects on the daily life of society effected by the implemented measure are described by this chapter.

The decision-making process of the weighting by the author is explained as follows. The criteria are presented in the order from least to most important.

1. Identity and Cultural Environment

The attractiveness was defined as a very subjective evaluation and thus rated with a low score of 5. For flood events the effects on the cultural environment were rated with a low score in relation to the other criteria that effect the daily life, thus the criteria were also assigned to the score 5.

2. Recreation and daily life

These two criteria were rated with a score of 7. Their importance was considered as relevant. However, in relation to a cohesive city and health and safety the criteria were considered to be less important.

3. Cohesive City

The cohesive city was defined as a crucial factor for the society. Therefore, it was rated with the second highest score of 8.

4. Health and Safety

The health and safety of society were rated with the highest possible score of 10.

An overview of the weighted criteria is shown in a pie chart, see Figure 4-61.

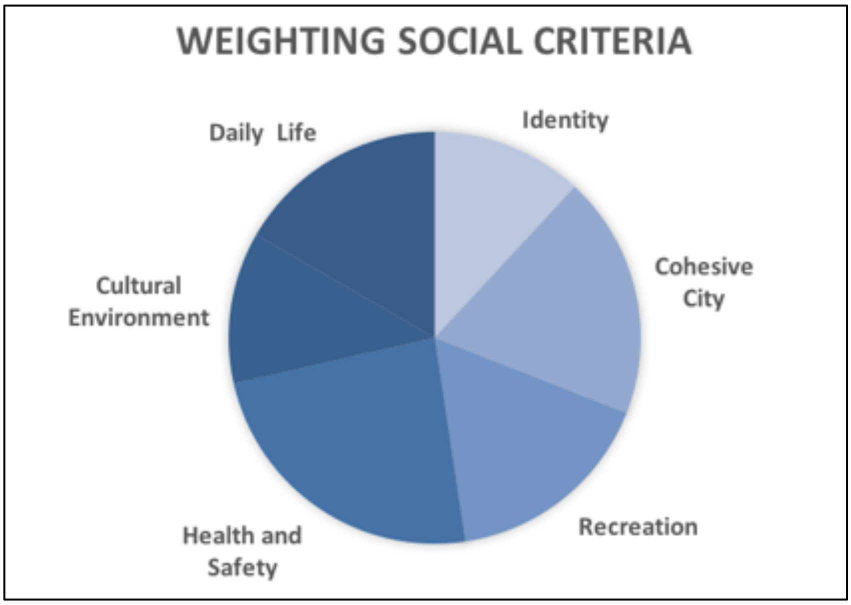


Figure 4-61: Weighting social effects in scope of thesis based on FloodMan interface.

Finally, the different alternatives, software programs, were rated for each criterion. In comparison to the rating of the environmental effects, where to author rated the individual measures of the software programs for the social effects the alternatives were rated in general. This was decided as the social effects are more depending on the overall situation compared to site specific environmental effects of the implemented measures.

The assessment for each criterion is presented as follows for each Alternative. The scale for the rating is –3 to +3, where -3 means a very negative and +3 a very positive effect and 0 no effect.

The assessment for the alternatives is shown in the interface of FloodMan, shown in Figure 4-62: Social effects for three alternatives shown in FloodMan interface.

Alternativ	
0-alternativet	Reference option (MIKE FLOOD)
Alternativ 1	SCALGO - actions simulated in SCALGO
Alternativ 2	MIKE 21 - actions simulated in MIKE 21
Alternativ 3	MIKE FLOOD - actions simulated in MIKE FLOOD

Sociala effekter	**Master Thesis Julia T. Herrmann - Linnéstaden, City of Gothenburg, Sweden**			
		Effekter		
Kriterium	***Viktning 0 = Inte relevant 10 = Mycket viktig***	**Alternativ 1**	**Alternativ 2**	**Alternativ 3**
Identitet. Vilka effekter medför åtgärden på stadsmiljön i området? Är stadsmiljön väl omhändertagen, speglar åtgärden dess karaktär och bidrar den till ökad eller minskad attraktivitet?	5	Positiv	Positiv	Positiv
Sammanhållen stad. Vilka effekter medför åtgärden avseende områdets sammanhållenhet? Kommer barns perspektiv påverkas av åtgärden och i så fall hur? Skapas nya barriärer eller strukturer som sammanbinder staden? Påverkas möjligheterna till möten positivt eller negativt? Medför åtgärderna en blanding i skala och variation?	8	Viss positiv	Ingen effekt	Positiv
Rekreation, samspel lek och lärande. Vilka effekter medför åtgärden avseende rekreation? Kan åtgärden medföra förändrad rekreation i området eller dess omgivning? Skapas eller reduceras platser för möten, lek, lärande, kultur och idrott? Hur påverkas den upplevda tryggheten av åtgärden? Hur påverkas orienterbarheten i området?	7	Viss positiv	Viss positiv	Viss positiv
Hälsa och säkerhet. Vilka effekter medför åtgärden på hälsa och säkerhet? Påverkas människors närmiljö avseende hälsorisker och olycksrisker positivt eller negativt? Blir människor mera eller mindre exponerade för olycksrisker till följd av åtgärden? Kan åtgärden medföra att riskerna för kriminalitet ökar eller minskar? Kan åtgärden medföra att människor blir mer eller mindre exponerade för hälsofarliga ämnen, exempelvis luftföroreningar?	10	Positiv	Positiv	Positiv
Kulturmiljö. Vilka effekter medför åtgärden på kulturmiljön? Påverkas platser eller objekt med höga kulturvärden? Påverkas arkeologiska objekt? Kan åtgärderna innebära att platsens eller områdets kulturella värden ökar eller minskar?	5	Viss negativ	Viss negativ	Viss negativ
Vardagsliv. Vilka effekter medför åtgärden i människors vardagsliv? Bryts eller förbättras kommunikationsstråk? Blir det enklare eller svårare för människor att utföra vardagssysslor, såsom att handla, utföra fritidsaktiviteter, etc?	7	Viss negativ	Viss negativ	Viss negativ
Samlad bedömning		**22**	**16**	**29**

Figure 4-62: Social effects for three alternatives shown in FloodMan interface.

Figure 4-62 shows that the best social score was achieved by Alternative 3 with 29. Followed by the second highest score of 22 by Alternative 1. The lowest score was achieved by Alternative 2 with a score of 16. This result was anticipated and indicates the highest improvements for MIKE FLOOD followed by SCALGO and finally MIKE 21.

4.3.2.4. Sustainability Analysis

In this section the results of the sustainability analysis are presented. As described in the methodology the economic, environmental and social analysis were weighted. The economic analysis was assigned to the highest value 10, followed by the environmental analysis with 9 and the social analysis with the score 7. The weighting is shown in the Figure 4-63.

Figure 4-63: Weighting of sustainability shown in FloodMan interface for present master thesis.

The FloodMan interface with the results of the present thesis is shown in Figure 4-64.

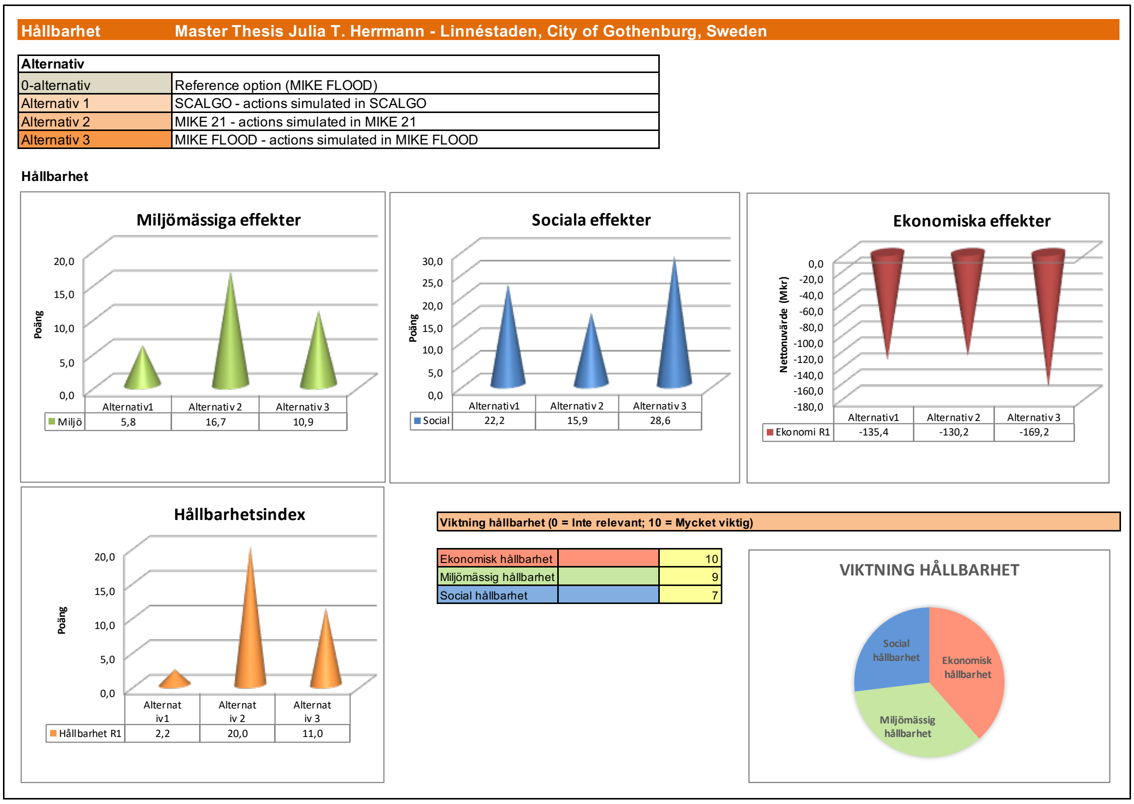


Figure 4-64: Sustainability analysis of present report in FloodMan interface

The environmental sustainability had the lowest score for Alternative 1, followed by Alternative 3 and the best score for Alternative 2. Alternative 2 – MIKE 21 had the least measures thus the least negative effects on the environment and therefore the result was expected and correlates with the environmental analysis.

The same accounts for the social effects in the sustainability and the analysis in Step 8. With an improved flooding due to more implemented measures in Alternative 1 and 3 the social effects are better than in Alternative 2.

The economic sustainability with regard to the present net value was rated negatively for all alternatives increasing from Alternative 2 to Alternative 1 and finally to Alternative 3.

The overall sustainability index is the best for Alternative 2 thus MIKE 21 and the worst for Alternative 1 - SCALGO with Alternative 3 MIKE FLOOD being in between. The positive result for Alternative 2 can be explained with the least measures, thus the lowest costs for measures which have a positive effect on the criteria environmental effects and economic consequences. Therefore, the best score could be expected for MIKE 21 for the sustainability analysis.

5. DISCUSSION AND CONCLUSION

In this section the discussion and conclusion of the previous findings are presented.

5.1. LEGAL ASPECTS

In the literature review of the present report the legal aspects for the EU, the Federal Republic of Germany and the Kingdom of Sweden were compared with regard to pluvial flooding. The current state was illustrated with Figure 5-1 including the relevant legal institutions and laws of the three judicial systems.

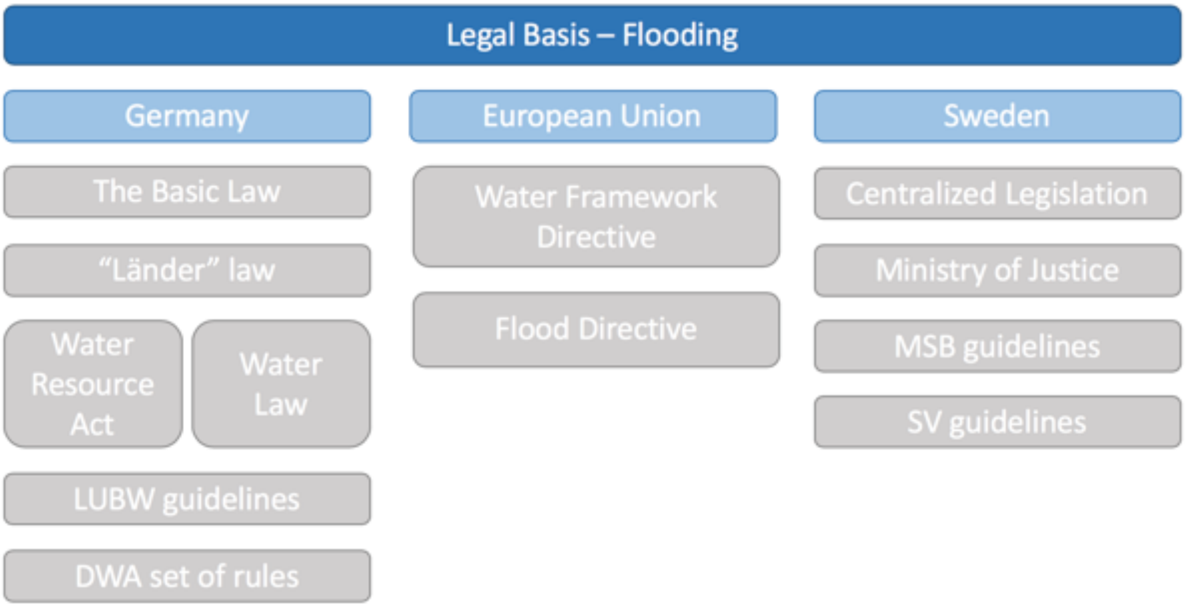


Figure 5-1: Legal Basis for pluvial flooding (created by author)

The findings of legal aspects for pluvial flooding in general were found to be inconclusive. This means that there is neither an explicit legislation for pluvial flood management from the EU nor Sweden or Germany. There are guidelines and recommendations for pluvial flooding, as well as laws considering flooding in general, but no directly binding documents like the Flood Directive from the EU for fluvial flooding. Further work is required to implement a definite legal structure for pluvial flood management to support countries in the EU in the planning process.

It could be argued that the properties of torrential rain, e.g. the local restricted occurrence causing the need for local knowledge, are the reason for the lack of a legal basis on a higher level. However, pluvial flood management requires the knowledge and integration of various stakeholders in for example water, city planning or forestry and agriculture sector. The allocation of the field of competence in pluvial flooding for torrential rain and flash floods is inevitable to simplify and ease the process.

Despite the differences of the legal structure of both countries and thus discrepancies in jurisdiction they developed similar approaches for the management of pluvial flooding and aim for a holistic approach. Assistance could be given by a common and unitary legal basis from the EU.

Especially with respect to the modelling and presentation of flood maps for torrential rain and flash floods, a unitary approach like the Flood Directive could be a helpful tool. Even though the FRG, exemplified by the state BW, and the Kingdom of Sweden support a 2D- hydrodynamic and numerical surface model for the simulation of pluvial flooding. The approaches show fundamental differences in the basic set-ups of the models. In BW the rain load is not assigned to a statistical return period due to the specified assessment of precipitation and soil properties in order to consider effects like capping. In Sweden, the rain load is classified by the return periods in the same manner as for fluvial flooding or pluvial flooding and the soil properties like infiltration capacity are respected separately. Those discrepancies should be assessed further to verify the application for pluvial flooding for both methods. Moreover, the type of modelling like assessed in the present thesis with the programs SCALGO, MIKE 21 and MIKE FLOOD featuring different types of pluvial flood modelling should be assessed on a legal basis. A legal basis could classify and determine the pre-requisites for when which tool must be applied to produce a flood map with legal consequences. According to the current recommendation of the state BW and Sweden simulations with coupled models of a 1D sewer system and a 2D surface model like MIKE FLOOD are not recommended, even though MSB defines the coupled model as state of the art (MSB, 2014). Yet a coupled model was assessed to be more accurate and for the modelling of measures linked to stormwater management a coupled model is required to fully investigate and analyze the effects of the measures. Several guidelines and recommendations suggest a staged assessment with a topographical, hydrological and hydraulic analysis for the municipalities based on risk assessments. But without a legal basis, simulations with less advanced programs like SCALGO could assumed to be suitable leading to the lack of the understanding of the hydraulics. On the other hand, SCALGO partially showed conform results to the more advanced programs MIKE 21 and MIKE FLOOD thus can be considered a useful tool, but as the recommendations are a 2D-surface model the opportunity of the application of programs like SCALGO might be missed.

Another issue in pluvial flood modelling linked to the lack of jurisdiction is the financing of measures and actions. If there are no explicit legal consequences and defined responsibilities the financing remains unclear. As the obligation is mostly assigned to the municipalities that lack of expertise, e.g. in modelling, the need for financial aid and manpower depending on the state of the municipalities can lead to an insufficient pluvial flood risk management with severe adverse consequences.

Despite the advantages of local knowledge, a uniform legal basis could support the municipalities and additionally provide a base for information and experience exchange. Especially in the field of forecasting and data acquisition for torrential rain or GIS data, municipalities do not have the same potential as national institutions or institutions within the EU.

Concluding an obligation to act for all involved authority levels is only given with a legal basis. With regard to pluvial flood modelling, further research on which type of modelling is suitable and recommended for a legally binding basis is suggested.

5.2. Risk assessment

In the present report, the risk assessment was used prior to the simulations of the software programs to identify areas of high potential risk for which measures should be implemented. The risk assessment was done with a risk analysis and evaluation. The approach applied in this thesis was a qualitative assessment. In a further investigation a holistic approach including all aspects of the water management and urban planning could be considered for a more detailed assessment. The approach did not consider aspects of water quality or fluvial or coastal flooding. As previously described pluvial flooding with torrential rain and urban flash floods was regarded and treated as an explicit hazard.

The approach chosen in this thesis reviewed the damage potential and flooding probability for the catchment Linnéstaden. In the flooding probability the results of previous studies were considered. However, the aim was to apply a new risk assessment with the current state of the catchment and an independent risk assessment in the scope of this thesis. The risk assessment was done in a general manner independent of the software programs and provides a starting position for further investigations in the software programs.

For a final evaluation or further investigations, one could investigate the risk based on the results of each software program. However, in this thesis this was done by reviewing the flood maps and the investigation with the FloodMan tool. Therefore, there was no need for an additional risk assessment after the simulations of each software program with and without measures.

In a detailed planning process, it is recommended to include several stakeholders for the risk assessment of an urban area and to fulfill the requirements of a holistic approach in water management in general. The risk assessment of this thesis was solely done by the author and the objective was a qualitative assessment, however one must consider that the focus was on pluvial flooding and that a certain degree of subjectivity is unavoidable for a further application of the present risk assessment.

5.3. SOFTWARE PROGRAMS

In this section the software programs and respective simulations and analysis are discussed.

5.3.1. BASIC COMPARISON

Different results with regard to flood propagation, water depth and volumes were expected when developing this thesis solely based on the scientific background of the investigated software programs SCALGO, MIKE 21 and MIKE FLOOD. Each software program represents a kind of pluvial flood modelling from more approximate to very detailed planning. In SCALGO the pivotal input data is the precipitation height. In MIKE 21 and MIKE FLOOD data acquisition and the model set-up itself are far more complex and require more knowledge to set-up and apply the software programs than SCALGO. The stages represented by the software programs in this thesis are SCALGO as a combination of a geographical and mathematical model allowing a topographical analysis, MIKE 21 as a 2D hydrodynamic numerical surface runoff model and MIKE FLOOD as a coupled hydrodynamic numerical 1D sewer system and 2D surface model.

Thus, from a first assessment SCALGO is the least advanced and MIKE FLOOD the most advanced software program. With regard to the possible output data this first assessment is confirmed. However, SCALGO still provides output data for water depth and flow accumulation. In the MIKE ZERO software programs the output data range from the water depth and flood propagation to volumes and fluxes and generally can be evaluated with respect of a time factor, which is not possible for SCALGO. In SCALGO the flow accumulation can only be assessed with regard to the runoff volume at that point and does not include the water depth at this point, unless the flow path correlates with a depression. Additionally, one must consider that the distribution of the flow is based on the principle of water flowing from the highest point of elevation to the lowest point in the elevation being stored in one depression until overflow occurs. In the MIKE ZERO software programs the water depth is displayed as the maximum water depth throughout the event. The water depth of the flooding displayed in depressions in SCALGO should also be considered as a snapshot of the water depth not describing the water depth over time. Meaning unlike in the MIKE ZERO programs the maximum depth of the event is not shown with the water depth displayed in SCALGO or not necessarily as correlations can occur. Therefore, the water depths displayed might lead to over- or underestimations of the actual risk in certain areas.

As discussed above the only input data apart from the DEM in SCALGO is the precipitation height. One of the objectives of this thesis was the development of a general approach to determine the precipitation height in SCALGO. This was done by two assessments the visual and the holistic approach. The visual approach was neglected, due to the large difference in water depth and precipitation height to the calculated precipitation height with the holistic approach and the *Structure Plan* in MIKE FLOOD.

The holistic approach on the other hand showed reasonable results for the precipitation height. The values were the same as the literature values of *Dahlström 2010* (Svenskt Vatten, 2011a) assuring a faultless calculation. The calculation highlighted the need to consider a climate factor in SCALGO for reasonable results based on the respective state of the art and legal basis for the *City of Gothenburg*. In addition, the calculation was validated with the precipitation heights of the previous studies *Cloudburst Modelling* and *Structure Plan*. The investigation showed that the simulation in SCALGO should be done for the peak precipitation, but the values still correlate for the total duration of the simulation in the respective programs.

A general deduction for the consideration of the sewer system capacity should not be done for the peak duration, as done for the model in MIKE 21. A deduction of solely the peak rain would be mathematically incorrect. In comparison the deduction of the sewer system capacity in MIKE 21 considers the complex rain load distribution with regard to the effects of e.g. the pre-rain and after-rain. A calculation of the rain load for the sewer system capacity with the assigned return period could done for SCALGO as well, but would lead to difficulties in application of the holistic approach of this thesis as only the peak rain is considered.

Infiltration for both of the programs in terms of the pre-rain but also the distribution of the rain load between MIKE 21 and MIKE URBAN in MIKE FLOOD due to the coupling cannot be easily simplified and applied in SCALGO by a general deduction of the rain load. However, one has the possibility to compare the rain load by using the *Dahlström 2010* equation (Svenskt Vatten, 2011a) for SCALGO, MIKE 21 and MIKE FLOOD and to assess a theoretical capacity. This method was validated by the present report.

Concluding, the holistic approach of the present report provides a basis for a general application of SCALGO for specific return periods and durations. The application still requires several assumption and simplifications, but the return period and duration are parameters which are determined on a regular basis in a planning process, thus do not require additional work. The consideration of a climate factor by a simple multiplication proved to be successful and necessary. For the application of the approach one must respect that the values are mean values and that equation of *Dahlström 2010* (Svenskt Vatten, 2011a) is limited to certain return periods. However, the limitations did not affect the results for pluvial flooding in this thesis. It would be interesting to investigate the effect of other regional rainfall intensity relations like *Dahlström 2010* (Svenskt Vatten, 2011a) in SCALGO for other countries. Another aspect that could be investigated further is the deduction in a general manner of the infiltration like done for the sewer system in the present report.

When comparing the basic features of the model in the different software programs a unexpected result was the better resolution in SCALGO with a more detailed raster set as standard, which is 2x2 m raster, opposed to the 4x4 m raster for both models in MIKE ZERO. According to MSB (2014) a raster of 4x4 m is the minimum detailed degree that is recommended for modelling in urban areas. The difference of the DEM raster was further investigated with regard to implementation of the measures and is discussed in the subsequent section. However, as SCALGO has the priority set on the topographical features it is expected that the model has the most accurate DEM. In addition, the software program has the least input data, thus general smallest computational time and can process a more accurate DEM faster and easier, as the data linked to each cell in the grid is way smaller than in the MIKE ZERO software programs which consider hydraulics and hydrology and a discretization over time and space. Generally, a higher resolution should be aimed for in more detailed planning stages. Despite this aim it might not be possible for a large area to model a smaller raster like in SCALGO in raster in MIKE ZERO, as previous attempts according to the expertise of *Sweco Environment AB* and the *City of Gothenburg* were not successful. With SCALGO having a more accurate raster the effects of smaller flow obstacles could be considered in a more detailed manner.

Another aspect of the general comparison of the software programs was the assessment of the sewer system. In the model set-up SCALGO cannot consider a sewer system, even though the holistic approach investigated the consideration of a general deduction with the sewer system as described above. In MIKE 21 the sewer system cannot be modelled but considered over a reduction of the rain load with regard to the capacity of the sewer system.

When applying a general deduction, one must consider that with this approach the dynamics within the pipe system, e.g. the effects of roughness or structure changes like inlets, outlets or intersections cannot be considered. The capacity of the model in MIKE 21 in this thesis were 2-year and 5-year return periods, but the capacity assigned to the sewer system in MIKE FLOOD was a 10-year return period. This difference was reviewed when evaluating the results of the simulation. The first assumption would be that MIKE FLOOD would show less flooding than MIKE 21 due to the larger capacity assigned to the sewer system. For both assigned capacities it is crucial to evaluate the uncertainties of over- and underestimating of the capacities throughout the catchment. With regard to the legal basis and the state of the art of pluvial flood modelling a modelling of the sewer system is not recommended or stated as a necessity.

For events like pluvial flooding the recommendation of a general deduction of the sewer system capacity or even neglecting that capacity is due to the assumption of clogging and the exceedance of the capacity due to the extreme rain load of torrential rain and flash floods on the system. Concluding the consideration and modelling of the sewer system is a controversial topic. It obviously requires more knowledge but presumably provides a better and more accurate analysis, which can be provided with an increased input data and the coupling of the 2D and 1D models. With a detailed modelling of the sewer system the over-and underestimating despite the assumed capacity can be further assessed. Based on such assessment flows can be redirected or parts of the system used as storage. The downside of including a coupling like for MIKE FLOOD are the large computational time but also the higher uncertainties and sensitivities of the model to errors. Therefore, the time to edit the possible occurring errors in a coupled model should be added to the computational time.

When comparing all three software programs the ability to model the hydraulic properties of the surface including the surface roughness and infiltration are restricted to the software programs of MIKE ZERO and cannot be regarded in SCALGO. The effects of those two properties were investigated with the hydraulic comparison in the present report. According to the legal basis as described in the literature section the infiltration could be considered with a general deduction like the sewer system capacity. Such a deduction would be interesting to assess further with regard to SCALGO, however a mean deduction over the whole catchment assuming a general deduction seems to be a rough estimation and might only be suitable for smaller investigated catchment mostly consisting of green areas with similar soil properties. Therefore, a general deduction of the infiltration for an urban area with various soil properties is questionable and should be matter for further investigations before applying as planning tool.

Additional features in general could be investigated with the MIKE ZERO software programs, which is not possible by solely applying the SCALGO software. MIKE ZERO by DHI (Hørsholm, Denmark) offers several adaptive modules for MIKE 21 and MIKE FLOOD with regard to the water quality or to the soil transport. A more detailed modelling of the soil behavior with erosion and flotsam could be a helpful tool to assess the effects of pluvial flooding in an urban environment. With regard to the water quality pollution sources and the spread of contaminants with the stormwater could be included in MIKE ZERO software programs and combined with the flood modelling to fully assess the damage of a flood in an urban environment as pollution can lead to large adverse consequences.

All investigated software programs are updated in a frequent manner. For SCALGO Live the support and interaction with the user are more frequent and allow small adjustments for specific applications. However, one must consider the complexity of the MIKE ZERO software by DHI (Hørsholm, Denmark) opposed to a web interface software program like SCALGO. With this consideration the frequency of updates to the state of the art should be considered equal for all three programs.

Apart from the obvious differences and similarities due to the scientific background the results of the simulations of the present report showed some discrepancies with the first assumption and are discussed in the subsequent section.

The first simulations were done in each software program for a 100-year return period including a climate factor of 1.2. The first obvious finding when displaying the flood map for SCALGO was the relatively small flood propagation. This can be explained as SCALGO only shows the flooding in depressions and the flooding can be seen as a snapshot not representative for the depths occurring over the whole flood event. Through the catchment the map shows small depressions filled, which can be used to illustrate the flow path in addition to the flood map from SCALGO. The map itself does not show the flow paths and the depths occurring on flow paths over the event. In addition, the flow accumulation could be illustrated in SCALGO itself but can only be displayed as lines in ArcMap without describing the water depth. In comparison to the results in SCALGO the results in MIKE 21 show a larger flood propagation for the water depth. The reason is that MIKE 21 can consider the time factor and presents the maximum water depth for the whole simulation period of 3 h. Therefore, it was expected that MIKE 21 will have a larger flow propagation than SCALGO. The same accounts generally speaking for the results of MIKE FLOOD displaying a larger flood propagation for the same reasons. With MIKE 21 the flow paths are also illustrated and can be mapped with the corresponding maximum water depth of the event. The flood map for MIKE FLOOD corresponds for the most part of the flood propagation with MIKE 21, especially the flow paths. The water depth in the main flooded areas is higher than in the simulation from MIKE 21. The water depth in the northern and downstream part of the catchment is lower in MIKE FLOOD than in MIKE 21. Despite the difference in the flood propagation the main flooded areas correlated for all three software programs. The lack of the display of the flood accumulation with the water depth shows a deficit of SCALGO. As it only displays a snapshot of the event one could come to false conclusion that only the depressions displayed with water depths are flooded for the rain event chosen in the set-up. Concluding the first impression of the smaller required knowledge for the application of SCALGO is reviewed. For a full understanding and evaluation of the results a deeper knowledge is highly recommended. In the risk assessment structural risk was identified as a very high risk for human health and life and such structures might not be displayed with a large water depth in SCALGO or not flooded at all but still pose a risk, which might not be identified without further knowledge.

An unforeseeable result from the simulations was the display of some areas solely flooded in SCALGO. This could be caused by the more accurate display of the flow path with the smaller raster in SCALGO illustrating flow obstacles or slight depressions. For MIKE 21 and MIKE FLOOD most flow paths correlate. A remarkable result was that some areas were only flooded in MIKE FLOOD. Based on the higher capacity assigned to the sewer system with a 10-year capacity in MIKE FLOOD than the 2 and 5-year capacity for MIKE 21, which led to the assumption of less flooding in MIKE FLOOD than in MIKE 21. This occurred one time around the Sahlgrenska University Hospital and further downstream below the residential area Annedal towards the river Göta Älv. Some areas only displayed flooding in MIKE 21 which was as described expected. If one assumes a higher accuracy for MIKE FLOOD a flooding occurring just in MIKE 21 refers to an underestimation of the sewer system capacity. The flooding in MIKE FLOOD could be explained by the overflow of the sewer system in that area, which cannot be displayed in MIKE 21. For that area the system in MIKE 21 overestimates the capacity displaying the water depth not to its full extent.

For further investigation of MIKE 21 and MIKE FLOOD the time at the maximum water depth and the current speed were displayed as well. By assessing the time at which the maximum water depth occurs one has the possibility to investigate at which time the water depth is reached but also the accuracy of the individual simulation. If the area is flooded in the end of the time step a larger simulation period might be recommended as the water depth might increase if the simulation period were longer. One of the high-risk areas Magretebergsmotet was flooded at the end of the simulation period and as it is a high-risk structure a longer simulation period could lead to new results and show a larger water depth. When comparing both programs, the time steps for the flooding are similar, as one must consider the longer time of simulation for MIKE FLOOD with 6 hours and the short time of simulation for MIKE 21 with 3 hours. Most of the areas were flooded in the same range of time steps, only small differences occurred for two areas, for which MIKE FLOOD displayed the water depth much earlier than MIKE 21. Both areas are residential areas thus the different water depth might be a result of the sewer system interactions and capacities.

The current speed difference corresponds with the difference of water depth in MIKE 21 and MIKE FLOOD. The current speed was higher in the downstream areas in MIKE 21, where the program showed a larger water depth in MIKE 21 than in MIKE FLOOD. Vice versa occurred for the area around Annedal showing a severely higher speed in MIKE FLOOD and no flooding in MIKE 21 but flooding in MIKE FLOOD. The higher current speed around the area in Annedal supports the assumption of an overflow from the sewer system to the surface model as stated above in MIKE FLOOD.

From the simulation of the 100-year event with a climate factor for all three software programs the advantages of using a hydrodynamic model illustrating the flow paths with water depths is very obvious. The simulations showed the differences due the scientific background mostly as expected. However, the general correlation of the water depth for the main flooded areas supports the application of all tools including SCALGO for pluvial flood modelling. The disadvantage opposed to MIKE 21 and MIKE FLOOD lacking the ability to display the time at the maximum water depth and the current speed were also shown. With regard to risk assessments based on the water depth and velocity SCALGO is limited to the display of the water depth, whereas MIKE 21 and MIKE FLOOD would allow the risk assessment considering both factors relevant in the further process. The deduction with different capacities for MIKE 21 and MIKE FLOOD partially showed some unexpected results throughout the catchment, which support the need for explicit modelling of the sewer system for detailed planning. In a general manner and in earlier planning stages the deduction leading to similar results for most of the catchment with regard to the current speed, water depth, flood propagation and time at the maximum water depth are sufficient.

The simulation period for the three software programs increased from SCALGO to MIKE 21 and MIKE FLOOD. In SCALGO the simulation period can be approximated with a couple of minutes. In MIKE 21 the simulation period was 9 hours and in MIKE FLOOD 15 hours for the simulation for a 100-year event with a climate factor. The simulation period decreased with simplifications in the hydraulic comparison in MIKE FLOOD to 11 and 9 hours.

5.3.2. Hydraulic comparison

As SCALGO cannot consider infiltration and surface roughness an investigation of those parameters in MIKE 21 and MIKE FLOOD was done in this thesis to evaluate the effects of those parameters on the pluvial flooding. For those analysis the Manning number was adapted in MIKE 21 and MIKE FLOOD and set to a constant value. In a first step the highest Manning number assuming the least roughness presumably leading to more discharge was considered. In a second step the roughness was set to the lowest Manning number causing the vice versa effect. Besides the simulations were done with and without the constant infiltration. The first assumption was that the flooding should be more similar to SCALGO due to the simplifications of the software programs.

The hydraulic comparison showed that changes of the surface roughness in terms of changes to the Manning number had very severe effect on the results opposed to the infiltration, with a very small effect on the flood propagation. The results were mostly as expected showing a larger flood propagation for a smaller Manning number with a higher resistance and a smaller flood propagation for a higher Manning number with a smaller resistance. In comparison to the simulation with resistance files the flooding correlated in the upstream and green areas for a lower Manning number and in the downstream more urban areas with the higher Manning number as expected.

The difference of the flooding in MIKE 21 and MIKE FLOOD is presumed to be caused by capacity of the sewer system determined and modelled differently within the programs. For a very low Manning number there is no inflow into the sewer system in MIKE FLOOD, this was proven by the volume balance. In MIKE 21 the general deduction is done without considerations of the adaption of the surface roughness. Based on this finding the general deduction in MIKE 21 should be assessed in the model set-up with regard to the surface roughness but also possible changes of the surface roughness that might affect the deduction. Still the differential flow behavior also illustrates the sensitivities of the complex program MIKE FLOOD, for which low Manning number like applied in that simulation can lead to instabilities. The changes of the Manning number and its effects on the flooding and the interaction with the sewer system show that a thorough investigation including the sewer system should be considered. The changes of the surface roughness also had the highest impact on the volume balance.

Another cause for the disparity between the flooding in MIKE 21 and MIKE FLOOD without infiltration could be the division of the rain load. In MIKE 21 the pre-rain is solely diverted to the infiltration. In MIKE FLOOD the pre-rain is diverted to the sewer system with MIKE URBAN and the infiltration with MIKE 21. In virtue of this difference in rain load distribution MIKE FLOOD has a higher rain load than just MIKE 21 without infiltration. This explanation can be argued with an overall small effect of the infiltration on the difference between the simulations.

The simulations without infiltration were expected to cause a higher flood propagation compared to the first simulations. It was unforeseeable that the difference of the infiltration is much smaller than the flow resistance. The higher flood inundation was the same for the simulations with infiltration thus the cause was presumed to be the surface roughness instead. The comparison of flooding in SCALGO without infiltration and the highest and lowest Manning number did not show any obvious differences to the previous results, which supported the assumption. Areas solely flooded in SCALGO were flooded for the minimum Manning number as well. Concluding, the inability of SCALGO to display the infiltration should be considered as a smaller disadvantage than expected, but the surface roughness proved to be a very important parameter even for extreme rain event like torrential rain leading to flash floods.

The assessment of the hydraulic parameters identified the surface roughness investigated with various Manning numbers as the most crucial parameter. The infiltration did not affect the results in the same manner. The simplifications in the hydrodynamic software programs MIKE 21 and MIKE FLOOD did not lead to the expected commonalities with SCALGO in comparison to the original set-up. The flooding should the highest conformity for the lowest Manning number and SCALGO regardless of the infiltration.

5.3.3. MEASURES

In the scope of this thesis the focus of modelling measures was on the determined potentially high-risk areas classified by the risk assessment of the present report. The modelling of object-related measures for specific properties and buildings as well as the modelling of central measures was beyond the scope of this thesis. Besides non-structural measures were not evaluated as they cannot be modelled and compared in pluvial flood modelling. However, central measures could be modelled in Änggården in the form of retention or detention basins. As the priority of the measures was given to implement measures to prevent flooding in the high-risk areas of the risk assessment there were no measures taken in Änggården.

With regard to the modelling of measures the software program SCALGO has the easiest and most user-friendly interface. A clear advantage is the very accurate DEM, which eases the design of the measures. However, the program is restricted to changes of the topography and measures with an unlimited capacity. The application of measures with an unlimited capacity especially for the pipe design are not feasible for a detailed planning and even for a rough estimation does measures could provide a false assumption for the risk reduction in certain areas. The subsurface basin tool and the query tool are useful for the determination of runoff volume entering certain points in the catchment. The tools can be used for the design of surface retention basins or areas. As previously mentioned it is not possible to map the flow accumulation in SCALGO with regard to the water depth in the flow paths. When modelling a system with unlimited capacity discharging the water to another location in the catchment one must assume a severe increase of the water depth in the closer surroundings of the outlet of the pipe. Unless the close surroundings include depressions those changes of the water depth cannot be shown, but must be considered when evaluating the results to avoid an increase of downstream flooding or emergency roads. Furthermore, MIKE 21 and MIKE FLOOD both showed changes to the current speed with and without measures. Especially due to the rough planning, meaning that the elevation was not smoothened to avoid hydraulic jumps or an increased current speed in the scope of this thesis. If those areas with an increasing current speed are not identified they present an increased risk for human health and life. Thus, a presumably sufficient and accurate planning in SCALGO might not be suitable. Therefore, a detailed planning with solely using SCALGO is not recommended especially for urban areas with a high population density.

In MIKE 21 and MIKE FLOOD the interface requires a deeper knowledge about the software programs and the general hydrological and hydraulic background of pluvial flooding, as discussed in the previous section. This applies for the modelling of measures in the same manner. Despite 2D-surface modeling software programs like MIKE 21 being described as the recommended software. The program actually did not provide many advantages compared to SCALGO or MIKE FLOOD. Modelling structures in MIKE 21 instead of modelling them in a coupled program like MIKE FLOOD was not considered as state of the art and does not provide advantages in comparison. As it is possible and more accurate to model just small pipe systems in MIKE URBAN and couple them in MIKE FLOOD to MIKE 21 without including the whole sewer system this approach was considered as more feasible than modelling measures in just MIKE 21. Concluding the main advantages of MIKE 21 with regard to the measure implementation is the smaller computational time of the program than MIKE FLOOD. In addition, MIKE 21 allows the modelling of the explicit surface runoff including infiltration and surface roughness. Especially with the surface roughness being crucial according to the results of this thesis in the hydraulic comparison.

A more detailed design of the measures is to coupled 1D-sewerage and 2D-surface model, which is only suitable in MIKE FLOOD. With MIKE URBAN and the coupling the interaction between the sewer system and the surface can be modelled in detail. This is advantageous but also requires a longer computational time. With a more accurate modelling and more coupled nodes not only the computational time increases but also the possible sources for errors. The complexity of MIKE FLOOD is the highest but also complicates the user friendliness. Even for small additional structures modelled in MIKE URBAN several pre-requisites need to be considered and must correlate with the boundary conditions.

Despite the disadvantages of the increased computational time and a lower user-friendliness and a higher source for uncertainties and errors MIKE FLOOD is the only program which allows the investigation of the interaction with the sewer system and surface modelling. Even though one can assume clogging and a decreased efficiency for torrential rain and urban flash floods of the sewer system the simulations showed a difference in the results with and without the sewer system, which were not expected to this extent.

Besides the modelling of decentralized measures and an integrated approach for measures of torrential rain and stormwater management a modelling of the sewer system is necessary. From the evaluated software programs only, MIKE FLOOD offers the possibility for this kind of investigation. An average deduction of the sewerage capacity for the whole catchment is not sufficient to model the effects of structures, e.g. inlet and outlet. Thus, if the aim to model decentralized and integrated measures in the future should be achieved a coupled model at least for certain areas is an unavoidable requirement.

For a detailed modelling with a coupled 1D sewerage and 2D surface model it might be of interest for further investigation to examine the uncertainties linked to different types of couplings in MIKE FLOOD.

Further research on the applicability of the programs should be carried out for smaller study areas with a more detailed design of one measure. The results of simulations of such further investigations could specify the application of the investigated software programs for the different type of measures, e.g. green areas. The degree of details for which the software programs show sufficient results could be further assessed simplifying the planning process.

Another interesting aspect for further investigation could be the modelling of temporary and demountable measures to assess the efficiency of such measures instead of permanent measures as in the scope of this thesis. This type of investigation would require the consideration of a time factor. This approach is not possible for a software program like SCALGO. In MIKE 21 and MIKE FLOOD the simulation can include a time-factor. Nevertheless, one must consider the limited possibilities for forecasting at the current state, which lower the efficiency of temporary or demountable measures.

Concluding, the study showed no beneficial application of MIKE 21 with regard to the implementation of measures. SCALGO is recommended to be applied in the early planning stages and in the design process of the implementation of the measures. For an explicit modelling of the measures MIKE FLOOD is the recommended and based on the previous results most suitable software program.

5.4. FloodMan and FME

As previously described FloodMan was applied in an innovative manner and was still in the pilot phase. Therefore, a certain degree of errors and uncertainties was expected when evaluating the results.

The application of the tool for pluvial flooding was a sufficient and generally easily applicable tool for the study area. However, the source of possible errors and uncertainties related to FME at the current state are very large. Especially the effects of the raster resolution for the risk classification in FME and the difference of the classification of the water depth for high and low flood risk in FME and FloodMan need further investigation. On this account, the application of the FloodMan tool, as applied in this thesis, is critical and the effects on the risk classification in FME due to the uncertainties are hard to estimate without further investigations.

Nevertheless, FloodMan allowed a quantitative assessment of the three software programs SCALGO, MIKE 21 and MIKE FLOOD especially with regard to the uncertainties in the economic consequences.

As the measures were implemented in a general and not very detailed manner the effects of Step 7 and Step 8 of the FloodMan tool in the present report must be considered as subjective assessment by the author. Even though a qualitative approach was applied and aimed for, a certain subjectivity by applying an MCA from the perspective of one stakeholder should be critically assessed. As FloodMan aims to include and involve all stakeholders this should be regarded in the environmental and social analysis.

At the present time of this report the tool was applied within the full scope possible. The application of the tool highlighted uncertainties depending on several economic factors like the interest rate. However, it also illustrated the differences in the risk costs indicating different damages caused by the programs. The risk costs were the lowest for SCALGO, which illustrates the downsides of lower flood propagations and shallower water depths in the program for most of the areas as shown in the comparison of the simulations. However, the range between the risk costs of MIKE 21 and MIKE FLOOD only differs slightly indicating higher risks for MIKE FLOOD. MIKE FLOOD including the accurate modelling of the sewer system shows a slightly higher risk costs than MIKE 21, which is not expected and could be caused by the different assessment of the sewer system capacity with regard to the over- and underestimation. The range of the action costs was as expected. The risk reduction was equivalent to the risk costs with a slightly higher risk reduction in MIKE 21 than in MIKE FLOOD which was unexpected. With more detailed measures in Slottsskogen a higher risk reduction would be assumed. SCALGO with the most measures implemented showed the highest risk reduction as anticipated.

The final assessment of the sustainability index mostly influenced by the environmental and social analysis shows the difference between the CBA and MCA part of FloodMan and its effects on the results in this thesis. The lowest sustainability index was achieved for SCALGO, followed by MIKE FLOOD and with the best index for MIKE 21. MIKE 21 had the least measures taken thus the least negative effects on the environment and costs for measures, but also the lowest risk reduction. Even though the economic consequences were rated with the highest weight for the calculation of the sustainability index one could assume the best outcome for MIKE 21. However, the smaller possibilities and state of the art of modelling measures is the main reason for the lower action costs opposed to the other programs. Therefore, this positive result in terms of the sustainability index needs to be critically assessed, as it is due to the limits of the software program MIKE 21. Meaning that despite MIKE 21 being the most sustainable solution according to the FloodMan assessment it still leads to a low risk reduction.

All in all, the application of FloodMan was a supportive tool for the evaluation of the software programs in a quantitative manner. The CBA aspects of the FloodMan tool are considered as the more reliable results opposed to the MCA section in the frame of this thesis.

For a further utilization of the tool to compare the effects of the program the improvement of the FME interface is recommended. Moreover, the investigation of one detailed measure for a smaller catchment could be subject of further investigations.

5.5. Final conclusion

The main goal of the present report was to determine the applicability and accuracy of the three investigated software programs SCALGO, MIKE 21 and MIKE FLOOD. The study aimed to develop a final recommendation including the explicit application of the software programs. The results of this thesis showed that the application of the software programs cannot be limited to the topographical and hydrodynamic analysis with regard to their applicability.

The application of a simply mathematical and geographical program like SCALGO was not recommended according to the legal basis investigated. Despite that, the simulations showed the applicability of SCALGO beyond its expected scope. With the successful development of an individual approach to use SCALGO with regard to return periods the tool can be applied for specific design events. Thus, the flow paths and water depths can be assessed for a pluvial flood event e.g. of a 100-year return period with a climate factor instead of only investigating the flow paths and depressions in a general simply topographical manner. In addition, implementing measures in SCALGO showed a high potential and its application for terrain adaptions was better than the more advanced programs due to the higher raster resolution. The very easy application of SCALGO and short computational time allow fast changes and modelling of different measures. In order to apply SCALGO in a detailed planning stage or only use SCALGO as a software program one would need to manually assess the flow accumulation even though water depths not located in depressions cannot be displayed. Therefore, a detailed planning which should include the possibilities to display the maximum water depths of the event and the velocity is not recommended to be done with SCALGO. Additional manual calculations of the water depths in those flow paths might be possible, but would be very time consuming and have a high vulnerability to errors and uncertainties. For that reason, more, advanced programs should be applied to display those properties.

With MIKE 21 a 2D hydrodynamic numerical surface model was investigated. The 2D modelling of the surface without the sewer system is suggested for pluvial flood modelling by the current legal basis. Despite the very promising application of this program the simulations showed some disadvantages. A deduction of the sewer system was feasible for the main parts of the area yet is vulnerable to over- and underestimations of the capacity. In addition, the deduction showed to be sensitive to changes of the surface properties as they cannot be considered. The modelling of measures with the structures available in MIKE 21 is no longer considered as state of the art, as a coupling of simple structure with MIKE FLOOD or modelling terrain editions with less advanced programs like SCALGO were more promising. With regard to the present report MIKE 21 still proved to be a reliable ad feasible tool for the general application especially as it displays the water depth over time, flow paths and if required flow velocities. As a conclusion, MIKE 21 could be applied for a general assessment of the area without the implementation of measures and serve as basis for emergency planning or risk assessments for a catchment area. In order to support a broader application of MIKE 21 the improvement of the user friendliness and the generation of structures would be considered as advantageous.

MIKE FLOOD was the most complex but also advanced program in the present report. The simulations and analysis supported the suggestion of a 2D and 1D coupled model as state of the art for pluvial flooding. Even though there are several disadvantages like a very long computational time and the high vulnerability to instabilities and errors for running the models especially after changes to the model set-up, e.g. by implementing measures, the results showed a higher accuracy. A major source of error was the coupling of MIKE 21 and MIKE URBAN, for this study, and further improvement of the uncertainties and vulnerability of the coupling would support the user friendliness. A simple improvement of the used hardware to improve the computational time is not considered as a suitable solution, as issues were identified to be caused by the complexity of the model set-ups. That is why at the current state a large computational time and an intensive process for the application combined with a thorough knowledge of the program features have to be accepted to achieve the accuracy for a detailed planning provided by the coupled model in MIKE FLOOD. The modelling of the sewer system with MIKE URBAN showed the most accurate results and is recommended for detailed planning. With regard to the implementation of measures MIKE FLOOD supports the modelling of any kind of measure like adaptions to the terrain model, storage facilities with a controlled outlet, adaptions to the sewer system etc. Thus, for detailed planning stages the program is recommended.

The main advantage of the hydrodynamic programs is the simulation over time and in consideration of the surface roughness. The application of the FloodMan tool supported the previous findings especially with regard to the economic analysis. However, a further investigation of the uncertainties in FME serving as input data for FloodMan should be done to assure the reliability of the results in FloodMan for the software programs.

In the following chapter, the final recommendation for SCALGO, MIKE 21 and MIKE FLOOD is presented based on the present report. The recommendation is considered as applicable for urban areas as Linnéstaden covers all aspects of an urban area with green areas, residential areas and commercial areas. The investigation of the present report covered the scientific background, legal basis and various simulations with the respective software programs and is considered as a suitable basis for a recommendation. It is beyond the scope of this thesis to develop a guideline as further investigations and the involvement of different stakeholders in pluvial flood management would be required. The recommendation is based on the current state of the art. With regard to pluvial flood modelling the accuracy of all programs would increase with the possibility of a calibration based on historic events. As described in the literature studies the lack of data acquisition does not support such a process. Therefore, a recommendation on the application of the different tools is considered as a supportive tool in the planning process of pluvial flood management.

6. RECOMMENDATION

This final section of the present master thesis is a summarized recommendation based on the findings and results of this thesis. In general, the whole thesis can be read as a recommendation, but this chapter presents the most important findings and aims to provide an overview. As discussed in the previous chapters, the scope of this thesis does not allow the development of a guideline therefore this thesis must be seen as a recommendation and not guideline based on the current state of the art. The recommendation was developed to be applied in a general manner, however simplifications and assumptions have been made and should be reviewed when applying the recommendation.

In the scope of this thesis all computational operations were done with the system: Windows 7 (64-bit operating system) and Intel® CoreTM i7 processor with 16 GB installed memory (RAM), provided by *Sweco Environment AB*. The software program versions of the MIKE ZERO software by DHI (Hørsholm, Denmark) used for MIKE 21 and MIKE FLOOD models was the MIKE 2017 Service Pack 2 - Version 16.0.0.12105, with the MOUSE HD Computation Engine x64 v2017 Release Version (16.0.0.12105) for MIKE URBAN. At time of the creation of the present report this version of MIKE ZERO by DHI (Hørsholm, Denmark) was the latest updated version (DHI, 2018d).For SCALGO Live the web interface is continuously updated but the latest major changes used in the scope of this thesis were the updates in March 2018 and the introduction of sub-surface tools like subsurface basins and sewage drains in the workspace in the beginning of September 2018 (SCALGO ApS, 2018h).

The recommendation consists of two parts. The first part is a general overview of the findings and results in this thesis presented in Table 6-1 including an illustration, which shows the runoff generation for SCALGO, MIKE 21 and MIKE FLOOD. The second part is a short description of the application of the tools for specific simulations and modelling aspects for pluvial flooding. It includes the advantages and disadvantages of the programs based on the present report.

6.1. Recommendation – Part 1 - General overview

The general overview is presented in Table 6-1.

Table 6-1: Recommendation of present master thesis (ACEX30-19-14)- general overview

Features	SCALGO Live	MIKE 21	MIKE FLOOD
General properties			
Type of Modelling	Mathematical	Numerical hydrodynamic	Numerical hydrodynamic
Possibility for adaptive features	None	Yes	Yes
Topography			
DEM raster	2x2 m	4x4 m	4x4 m
Structure level	10 m buildings	2-3 m buildings	2-3 m buildings
Sewer System			
Modelling	Not possible	Not possible	MIKE URBAN
Surface parameters			
Hydraulic transmittance	Impermeable	Impermeable and permeable	Impermeable and permeable
Infiltration	None	Defined	Defined
Surface Resistance	None	Defined	Defined
Precipitation			
Indata of precipitation	Precipitation height	Rainfall statistics CDS Rain	Rainfall statistics CDS Rain
Precipitation	Peak Rain	Pre and peak rain	Whole duration
Evaporation	None	Possible	Possible
Time of event	Not considered	Simulation period	Simulation period
Others			
Sensitivity to instabilities	Almost none	Vulnerable	Very vulnerable
User Friendliness	High	Medium	Low
Computation period	Very short	Long	Very long
Required level of knowledge	Low	Medium	High

In a simplified manner the runoff generation for all three software programs is compared in Figure 6-1. The programs are labelled with in the following manner: (a) SCALGO, (b) MIKE 21, (c) MIKE FLOOD. The red arrows illustrate the runoff generation. The clouds illustrate the precipitation. The same illustration of the precipitation does not imply the exact same input data. Between the three software programs, the input data for the precipitation varies in the distribution (spatial and temporal) and the quantity of the rain load. Impermeable surfaces are colored in grey and permeable surfaces are colored in green. Figure 6-1 provides the main characteristics of stormwater runoff and stresses the increasing complexity from SCALGO to MIKE 21 and MIKE FLOOD. Further details information about the similarities and differences are given in the explicit model set-up for the investigated catchment of the present report.

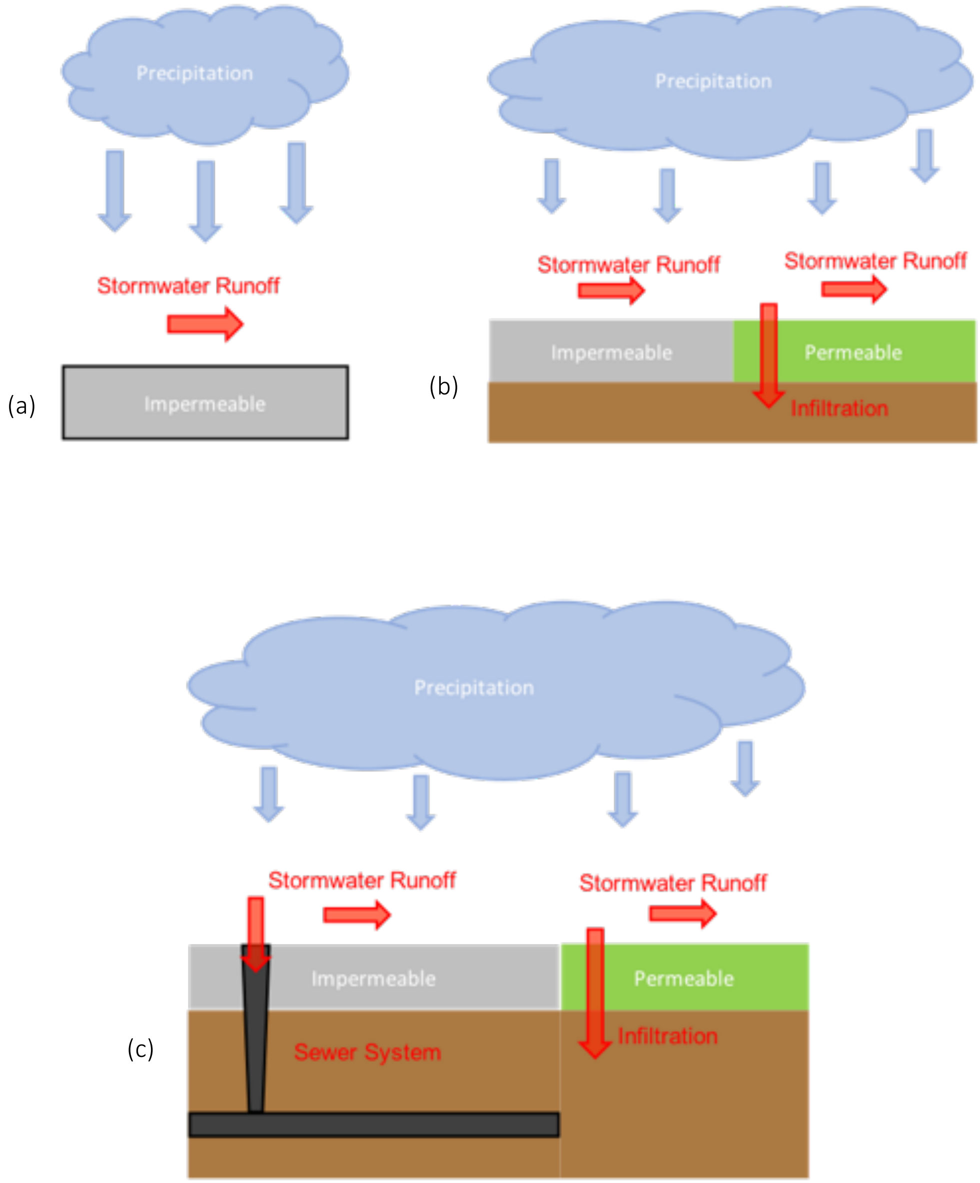


Figure 6-1: Illustration of stormwater runoff distribution in investigated software programs with SCALGO labelled with (a), MIKE 21 as (b) and MIKE FLOOD as (c). (created by author)

6.2. RECOMMENDATION – PART 2 – APPLICABILITY OF PROGRAMS

In the following the applicability of the software programs is briefly summarized with regard to the results of this thesis.

6.2.1. SCALGO

In SCALGO the only input data is the precipitation height. With the holistic approach developed in the present report, SCALGO can be applied for Sweden in an individual manner without previous knowledge of the study area. The required data for the holistic approach with the calculation of the mean precipitation height according to the regional distribution by *Dahlström 2010* (Svenskt Vatten, 2011a) are the return periods of the event and the peak duration. The application should be limited to the peak duration and general deductions for the capacity of the sewer system should be neglected. It is not recommended to solely visually assess and determine the precipitation height when studies for the comparison are available at least not with just using SCALGO. A comparison with software programs like ArcGIS however can be used in a supportive manner.

A large advantage of SCALGO is the very accurate DEM and the small raster of 2x2 m. This accuracy supports the planning process of measures and the assessment of the catchment. It can also help to possibility identify flow obstacles. The thorough investigation of the area with regard to implementing measures is very good in SCALGO. The modelling of terrain changes is especially easy in SCALGO and recommended. When implementing measures, the tools for subsurface structures or basins should be carefully considered and do not supplement a detailed modelling of the measures with more advanced programs. The tool for subsurface basins is supportive for the identification of upstream volumes in the watershed for the determined event and can be applied to design retention or detention basins. If solely SCALGO is applied, the basins are recommended to be modelled with the terrain changes and on the surface.

Even though SCALGO shows several advantages and seems to be applicable for more features than expected from a software program, which does not consider hydraulics or hydrology like hydrodynamic models, there are some downsides of its application.

The main disadvantage is the lack of the illustration of the water depth in the flow paths of the event. The flow accumulation is a visible in SCALGO but cannot be exported and one has not the option to present the water depth unless the flow accumulation overlaps with a depression, for which the water depth is presented in SCALGO. Concluding, the flow accumulation in SCALGO is not suitable for risk mapping or detailed planning.

Another aspect one should consider is the flood propagation in SCALGO. The water depth illustrated can be compared to a snapshot of the final water depth of the event. SCALGO does not show the flooding in a depression if the water did overflow into the next depression. Thus, the maximum depth of the event is not shown with the water depth displayed in SCALGO or not necessarily as correlations can occur. Therefore, the water depths displayed might lead to over- or underestimations of the actual risk in certain areas. Concluding SCALGO should not be used for detailed planning without further investigation of the maximum water depth throughout the whole simulation.

With regard to the hydraulics the lack of the consideration of the surface roughness is one major disadvantage. The thesis showed that the surface roughness is a crucial parameter for the flow behavior. The infiltration on the other hand was not identified as a very important parameter based on the hydraulic comparison in this study. Therefore, the lack of modelling the infiltration does not seem to be a downside for pluvial flooding in SCALGO. Concluding SCALGO is considered as a good and very accurate tool for early planning stages including the modelling of terrain changes. For a detailed risk assessment, more advanced programs are recommended.

The water flow in SCALGO is illustrated with Figure 6-2, Figure 6-3 and Figure 6-4, created by the author. The grey area represents the DEM. The red arrows show the direction of the stormwater runoff. The blue arrows symbolize the rain load in terms of the precipitation height. Figure 6-2 shows the runoff for the flash flood map tool in SCALGO. Figure 6-3 illustrates the impermeability of the DEM in SCALGO. Figure 6-4 presents the different stages of a dynamic flow process for a flash flood.

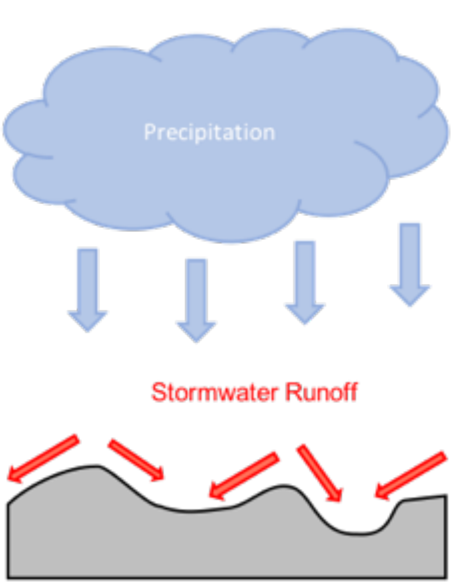


Figure 6-2: Illustration of stormwater runoff in flash flood map for SCALGO (created by author)

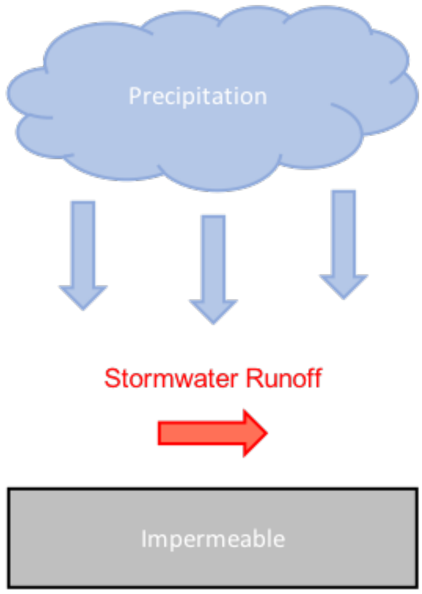


Figure 6-3: Illustration of runoff and soil behavior in SCALGO (created by author)

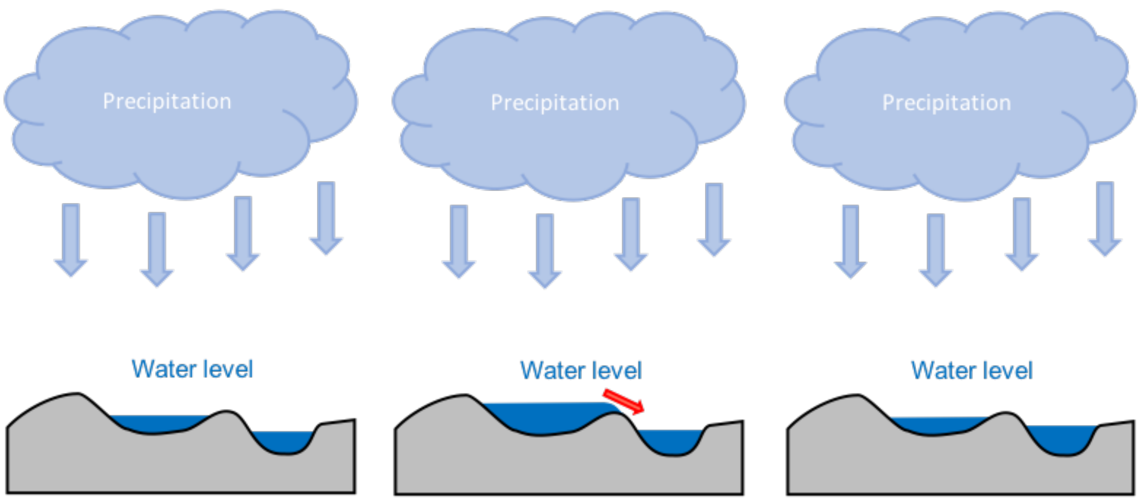


Figure 6-4: Illustration of flow behavior and mathematical distribution of flow for dynamic flash flood events in SCALGO including its effect on the water level in depressions. (created by author)

6.2.2. MIKE 21

MIKE 21 is a 2D hydrodynamic numerical model and is the recommended type of software program for pluvial flood modelling based on the legal basis assessed in the present report. Despite the recommendation of previous guidelines, the software program did not show the expected advantages in comparison to the other two software programs.

The main advantage is the possibility of MIKE 21 to consider the hydraulics especially the surface roughness, which was determined as a crucial factor of the runoff.

With regard to the modelling of measures in MIKE 21 the structures possible to be modelled are not considered as state of the art. However, a coupling for just a structure with the application of MIKE FLOOD is recommended and more feasible.

The general deduction of the sewer system is sufficient for a general and early planning stage. For a detailed planning a more accurate modelling of the sewer system is recommended. The deduction does not consider inlet and outlet structures.

The possible options of considering the water quality with the MIKE ZERO software are an advantage if all aspects of the water management are aimed to be considered.

The raster applied in the present report of 4x4 m fulfills the least requirements for modelling in urban areas. However, a modelling with a smaller raster showed to cause issues with the computation and leads to larger computational time. Concluding the applied raster is recommended for further applications but a detailed modelling of smaller model areas would be suggested for a smaller raster.

Concluding, MIKE 21 is considered as a suitable program for pluvial flood modelling. However, with regard to the computational time and the low technical feasibility of the implementation of measures with MIKE 21 its application is not as suitable as assumed in the first place and based on the recommendations of applying such a modeling software program. With regard to the benefits provided by using MIKE 21 a first assessment with SCALGO and implementing measures with SCALGO outweighs the primary application of MIKE 21 based on the results of the present report.

6.2.3. MIKE FLOOD

MIKE FLOOD in the present report was applied in the scope of 2D hydrodynamic numerical surface model MIKE 21 and a 1D hydrodynamic numerical sewer system model MIKE URBAN.

Based on the results of this thesis MIKE FLOOD is considered as the best software program for detailed planning. The detailed modelling of the sewer system and the interactions with the surface model are crucial for the implementation of detailed measures e.g. decentral stormwater management measures. With MIKE 21 the surface flow can be accurately modelled including infiltration and especially the surface roughness.

The major disadvantage of using MIKE FLOOD is the very high computational time and the high vulnerability to errors and instabilities leading to issues in running the model.

MIKE FLOOD has the opportunity for further investigations with the MIKE ZERO software programs like MIKE 21 e.g. to assess the water quality which should be considered as advantageous. Besides it is also possible to investigate fluvial flooding.

As MIKE FLOOD has the same raster size as MIKE 21 the same accounts for MIKE FLOOD. However, the high complexity of MIKE FLOOD does not support simulations with a smaller raster.

Concluding MIKE FLOOD is the recommended software program for any kind of pluvial flood modelling. The difference between the computational times in MIKE 21 and MIKE FLOOD with regard to the possibilities to model measures and the more accurate results with MIKE FLOOD should be accepted as the advantages of MIKE FLOOD outweigh the time factor.

I. REFERENCES

Becker, P. et al., 2016. *Die Entwicklung von Starkregenniederschlägen in Deutschland - Plädoyder für eine differenziere Betrachtung,* Germany: DWD.

Biondi, D. et al., 2011. Validation of hydrological models: Conceptual basis, methodological approaches and a proposal for a code of pratice. *Physics and Cehmistry of the Earth*, 05 08, pp. 70-76.

Blomgren, S., 2018. *Email correspondence with DHI* [Interview] (5 12 2018).

Braasch, A. et al., 2013. *Starkregen - Was können Kommunen tun?,* Mainz: Informations- und Beratungszentrum Hochwasservorsorge Rheinland-Pfalz und WBW Fortbildungsgesellschaft für Gewässerentwicklung mbH.

Bronstert, A. et al., 2017. *The Braunsbach Flashflood of Mai 29th - Origin, Pathways and Impacts of an Extreme Hydro - Metorological Event. Part 1: Meteorological and Hydrological Analysis,* Potsdam: Hydrologie und Wasserbewirtschaftung - 61.

Canadian Centre for Occupational Health & Safety, 2018a. *https://www.ccohs.ca/oshanswers/hsprograms/risk_assessment.html.* [Online] [Accessed 25 10 2018].

Canadian Centre for Occupational Health and Safety, 2018b. *https://www.ccohs.ca/oshanswers/hsprograms/hazard_risk.html.* [Online] [Accessed 25 10 2018].

Deutscher Wetterdienst, 2018a. *https://www.dwd.de/DE/service/lexikon/lexikon_node.html.* [Online] [Accessed 30 11 2018].

Deutscher Wetterdienst, 2018b. *https://www.dwd.de/DE/wetter/warnungen_aktuell/kriterien/warnkriterien.html.* [Online] [Accessed 30 11 2018].

Deutscher Wetterdienst, 2018c. *https://www.dwd.de/DE/service/lexikon/Functions/glossar.html?lv2=100932&lv3=621778.* [Online] [Accessed 5 12 2018].

DHI, 2017a. *MIKE 21 Flow Model - Hydrodynamic Module - User Guide,* s.l.: DHI Hørsholm Denmark.

DHI, 2017b. *MIKE FLOOD - 1D-2D Modelling - User Manual,* s.l.: DHI Hørsholm Denmark.

DHI, 2018a. *https://www.mikepoweredbydhi.com/products.* [Online] [Accessed 5 12 2018].

DHI, 2018b. *https://www.mikepoweredbydhi.com/products/mike-21.* [Online] [Accessed 5 12 2018].

DHI, 2018c. *https://www.mikepoweredbydhi.com/products/mike-flood.* [Online] [Accessed 5 12 2018].

DHI, 2018d. *https://www.mikepoweredbydhi.com/products/new-features.* [Online]
[Accessed 6 1 2019].

DHI, 2018. *https://www.mikepoweredbydhi.com/products/mike-21.* [Online]
[Accessed 5 12 2018].

DWA/ BWK, 2013. *DWA T1/2013 Starkregen und urbane Sturzfluten - Praxisleitfaden zur Überflutungsvorsorge,* Hennef: DWA.

DWA, 2012. *DWA - A 531, Starkregen in Abhängigkeit von Wiederkehrzeit und Dauer,* Hennef: DWA - Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Wasser e.V..

DWA, 2015. *DWA - M 550, Dezentrale Maßnahmen zur Hochwasserminderung,* Hennef: DWA.

DWA, 2016a. *DWA - M553, Hochwasserangepasstes Planen und Bauen,* Hennef: DWA.

DWA, 2016b. *Merkblatt DWA - M 119 Risikomanagement in der kommunalen Überflutungsvorsorfe - Entwässerungssysteme bei Starkregen,* Hennef: DWA.

DWA, 2016. *DWA - M 119, Risikomanagement in der kommunalen Überflutungsvorsorge für Entwässerungssystme bei Starkregen,* Hennef: DWA Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V..

DWA, 2017a. Warum technische Regeln? 60 Jahre DWA-Regelwerk. *Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V.*, September.

DWA, 2018a.
https://en.dwa.de/files/_media/content/PDFs/Stabsstelle_Forschung_und_Innovation/dm/DWA-Forschung_Innovation_Englisch.pdf. [Online]
[Accessed 14 10 2018a].

DWA, 2018b. *https://de.dwa.de/de/ueber-uns.html.* [Online]
[Zugriff am 12 10 2018].

DWD - Deutscher Wetterdienst, 2018.
https://www.dwd.de/DE/service/lexikon/Functions/glossar.html?lv2=100932&lv3=621778. [Online]
[Accessed 5 12 2018].

Esri, 2018. *https://pro.arcgis.com/de/pro-app/tool-reference/spatial-analyst/flow-direction.htm.*
[Online]
[Accessed 4 12 2018].

EU, 2007. Directive 2007/60/EC of the European Parliament and of the council of 23 October 2007 on the assessment and management of flood risk. *Journal of the European Union*, 6 11.

European Union, 2018a. *https://europa.eu/european-union/about-eu/countries/member-countries/germany_en.* [Online]
[Accessed 12 10 2018].

European Union, 2018b. *https://europa.eu/european-union/about-eu/countries/member-countries/sweden_en.* [Online]
[Accessed 12 10 2018].

European Union, 2018c. *https://europa.eu/european-union/index_en.* [Online]
[Accessed 12 10 2018].

Göteborg & Co, 2018a. *https://www.goteborg.com/en/linne/.* [Online]
[Accessed 30 11 2018].

Göteborg & Co, 2018b. *https://www.goteborg.com/en/anggardsbergen/.* [Online]
[Accessed 22 12 2018].

Göteborg Stad, 2015a. *Skyfallsmodellering för Göteborg - Avrinningsanalys med 2-dimensionell hydraulisk modell som beskriver vattenansammling och avrinningsvägar I stora delar av göteborgs kommun vid 100- och 500 årsregn,* Göteborg: s.n.

Göteborg Stad, 2017a. *Förslag till Översiktsplan för Göteborg - Tillägg för översvämmningsrisker,* Gothenburg: Göteborg Stad.

Göteborg Stad, 2017b. *Strukturplan för hantering av översvämningsrisker - Metodsbeskrivining ,* Göteborg: s.n.

Göteborg Stad, 2017c. *https://www.goteborg.se/wps/portal/enhetssida/statistik-och-analys/geografi/kartor/!ut/p/z1/04_Sj9CPykssy0xPLMnMz0vMAfIjo8ziTYzcDQy9TAy9_T3MDQwCvYMtXXzcXQ08Awz0w8EKAgxdHA1NgAoMPAzdDBwDXc38g1xNDAx8TPWjiNFvgAIcDZyCjJyMDQzc_Y2I049HQRSG8cgW6RfkhoaGOioqAgBcp3N.* [Online]
[Accessed 22 12 2018].

Göteborg Stad, 2017d. *Strukturplan för hantering av översvämningsrisker - Linnéstaden avrinningsområde,* Göteborg: Göteborg Stad.

Göteborg Stad, 2017e. *Bilaga - Förslag till Översiktsplan för Göteborg Tillägg för översvämningsrisker,* Gothenburg: Göteborg Stad.

Göteborg Stad, 2017-M. *Strukturplan för hantering av översvämningsrisker - Metodsbeskrivning,* Gothenburg: Göteborg Stad.

Göteborg Stad, 2018a. *http://international.goteborg.se/facts-figures.* [Online]
[Accessed 1 12 2018].

Göteborg Stad, 2018b. *http://statistik.goteborg.se/Demografi/GBG-bef/Befolkningsutveckling-2017/.* [Online]
[Accessed 26 10 2018].

Göteborg Stad, 2018c. *http://statistik.goteborg.se/Demografi/Demografirapporter-och-analyser/Kommunprognos/.* [Online]
[Accessed 26 10 2018].

Gothenburg Botanical Garden, 2017. *http://www.botaniska.se/en/garden--greenhouses/anggardsbergen/.* [Online]
[Accessed 22 12 2018].

Gothenburg Botanical Garden, 2018. *http://www.botaniska.se/en/.* [Online]
[Accessed 22 12 2018].

Hedelin, B., 2017. The EU floods directive in Sweden: opportunities for integrated and participatory flood risk planning. *The Journal of Flood Risk Management,* 10(2), pp. 226-237.

Kärna, A. C. et al., 2008. *Linnéstaden - Beskrivining av stadsdelen,* Göteborg: Göteborg Stad.

Karlsson, D., 2018 . *Email correspondence* [Interview] (5 11 2018).

Koch, P. D. r. n. M., 2003. *https://www.smhi.se/en/research/research-news/higher-temperatures-affect-intensive-rain-showers-1.28948,* Kassel: Universität Kassel.

Löwe, R. et al., 2017. Assessment of urban pluvial flood risk and efficiency of adaption options through simulations - A new generation of urban planning tools. *Journal of Hydrology,* Journal of Hydrology(550), pp. 355-367.

Landmäteriet, 2017. *Product description: Plans, Regulations and Rights (Version: 4.0),* Sweden: s.n.

Lantmäteriet, 2016a. *Product description: GSD-Elevtion data, Grid 2+ (Version 2.3),* Sweden: s.n.

Lantmäteriet, 2016b. *Quality description of National Elevation Model,* Sweden: Lantmäteriet.

LAWA, 2018a. *http://www.lawa.de/index.php?a=2.* [Online]
[Accessed 22 12 2018].

LAWA, 2018b. *LAWA-Strategie für ein effektives Starkregenrisikiomanagement,* Erfurt: LAWA.

LUBW, 2016a. *Leitfaden Kommunales Starkregenrisikomanagement in Baden-Württemberg,* Karlsruhe: LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg.

LUBW, 2018a. *https://www.lubw.baden-wuerttemberg.de/organisation.* [Online]
[Accessed 14 10 2018].

Müller, U., 2010. *Hochwasserrisikomanagement - Theorie und Praxis.* 1. Auflage Hrsg. Wiesbaden: VIEWEG + TEUBNER Verlag; Springer Fachmedien Wiesbaden GmbH 2010.

Maddox, I., 2014. *https://www.intermap.com/risks-of-hazard-blog/three-common-types-of-flood-explained.* [Online]
[Accessed 5 12 2018].

Mark, O. et al., 2004. Potential and limitations of 1D modelling of urban flooding. *Journal of Hydrology,* Journal of Hydrology(299), pp. 284-299.

MSB, 2013. *Pluviala översvämningar - Konsekvenser vid skyfall över tätorter - En kunskapsöversikt,* Göteborg och Lund: MSB - Myndigheten för samhällsskydd och beredskap.

MSB, 2014. - *Kartläggning av skyfalls påverkan på samhällsviktig verksamhet - Framtagande av metodik för utredning på kommunal nivå,* Malmö: MSB - Myndigheten för samhällsskydd och beredskap.

MSB, 2014. *Kartläggning av skyfalls påverkan på samhällsviktig verksamhet,* Sweden: Myndigheten för samhällsskydd och beredskap.

MSB, 2015a. *https://www.msb.se/en/About-MSB/Crisis-Management-in-Sweden/.* [Online]
[Accessed 10 2018].

MSB, 2017a. *Vägledning för skyfallskartering - Tips för genömförande och exempel på använding,* Sweden: MSB - Myndigheten för samhällsskydd och beredskap.

MSB, 2017. *Vägledning för skyfallskartering - Tips för genomförande och exampel på användning,* Sweden: MSB - Myndigheten för samhällsskydd och beredskapp.

Olsson, J. & Foster, K., 2013. *Extrem korttidsnederbörd i klimatprojektiner för Sverige - Klimatologi Nr 6, 2013,* Sweden: SMHI Klmatolog.

Open Street Map, 2018. *https://www.openstreetmap.org/#map=9/57.7804/12.1591.* [Online]
[Zugriff am 30 11 2018].

Paquier, A., Mignot, E. & Bazin, P.-H., 2015. Symposim From hydraulic modelling to urban flood risk. *Procedia Engieering - ScienceDirect,* Issue Procedia Engieering 115, pp. 37-44.

Philipps Unversität Marburg - Fachbereich Geographie, 2011. *http://gisbsc.gis-ma.org/GISBScL7/de/html/VL7a_V_lo4.html.* [Online]
[Accessed 4 12 2018].

Rosén, L., 2018. *conversation about FloodMan application* [Interview] (16 11 2018).

Rosén, L. & Nimmermark, J., 2018. *FloodMan - Sustainable Flood Management Assessment Tool; Ett verktyg för samhällsekonomisk analys och hållbarhetsanalys av översvämningsskydd,* Göteborg: Göteborg Stad.

Safe Software Inc, 2018. *https://www.safe.com/fme/fme-desktop/.* [Online]
[Zugriff am 11 11 2018].

Sahlqvist, C., 2018. *Interview with Västra Götalandsregionen* [Interview] (18 09 2018).

SCALGO ApS, 2018a. *https://scalgo.com/en-US/about.* [Online]
[Accessed 4 12 2018].

SCALGO ApS, 2018b. *https://scalgo.com/doc/live-flood-risk/?id=basicStyles.* [Online]
[Accessed 4 12 2018].

SCALGO ApS, 2018c. *https://scalgo.com/doc/live-flood-risk/?id=hydroFlashFloodMapping.* [Online]
[Accessed 4 12 2018].

SCALGO ApS, 2018d. *https://scalgo.com/doc/live-flood-risk/?id=liveAboutSweden.* [Online]
[Accessed 4 12 2018].

SCALGO ApS, 2018e. *https://scalgo.com/doc/live-flood-risk/?id=workspacesEdit.* [Online]
[Accessed 14 11 2018].

SCALGO ApS, 2018f.
https://scalgo.com/live/sweden?ll=11.953704%2C57.687931&res=4.777314267823516&tool=query&lrs=mapbox_basic%2Cw20558%3Aboundary&query=11.948833%2C57.687634. [Online]
[Accessed 11 11 2018].

SCALGO ApS, 2018g. *https://scalgo.com/doc/live-flood-risk/?id=liveIntroduction.* [Online]
[Accessed 11 11 2018].

SCALGO ApS, 2018h. *http://scalgo.com/doc/live-flood-risk/?id=liveWhatsNew.* [Online]
[Accessed 22 12 2018].

SMHI, 2014a. *https://www.smhi.se/en/research/research-news/higher-temperatures-affect-intensive-rain-showers-1.28948.* [Online]
[Accessed 6 12 2018].

SMHI, 2014b. *https://www.smhi.se/en/research/research-news/higher-temperatures-affect-intensive-rain-showers-1.28948.* [Online]
[Accessed 12 2018].

Stadsbyggnadskontoret Göteborg, 2017. *Strukturplan för hantering av översvämingsrisker - Linnéstadens avrinningområde,* Gothenburg: Göteborg Stad.

Starkregen, Sturzflut, Sintflut – sieht so der Sommer der Zukunft aus?. 2016. [Film] Directed by Peter Krachten. Deutschland: © WDR 2016.

Svenskt Vatten, 2011a. *P 104 - Nederbrödsdata vid dimensionering och analysis av avloppssystem,* Sweden: s.n.

Svenskt Vatten, 2011b. *P 105 - Hållbar dag- och dränvattenhantering – Råd vid planering och utformning,* Sweden: Svenskt Vatten.

Svenskt Vatten, 2015a. *http://www.svensktvatten.se/om-oss/in-english/.* [Online]
[Accessed 12 10 2018].

Svenskt Vatten, 2016a. *P 110 - Avledning av dag-, drän- och spillvatten - Funktionskrav, hydraulisk dimensionering och utformning av allmänna avloppssystem,* s.l.: Svenskt Vatten.

Sveriges meteorologiska och hydrologiska institut, 2012.
http://www.smhi.se/kunskapsbanken/meteorologi/extrem-nederbord-1.23060. [Online]
[Accessed 30 11 2018].

The Government Offices of Sweden, 2015a. *https://www.government.se/how-sweden-is-governed/the-swedish-model-of-government-administration/.* [Online]
[Accessed 14 10 2018].

The Government Offices of Sweden, 2015b. *https://www.government.se/government-of-sweden/ministry-of-the-environment/organisation/.* [Online]
[Accessed 14 10 2018].

The Government Offices of Sweden, 2015b. *https://www.government.se/how-sweden-is-governed/public-agencies-and-how-they-are-governed/.* [Online]
[Accessed 14 10 2018].

The Government Offices of Sweden, 2015c. *https://www.government.se/government-agencies/swedish-civil-contingencies-agency/.* [Online]
[Accessed 15 10 2018].

The Government Offices of Sweden, 2017. *https://www.government.se/government-of-sweden/ministry-of-justice/organisation/.* [Online]
[Accessed 14 10 2018].

United Nations Office for Disaster and Risk Reduction, 2017 a. *4. Flood Hazard and Risk Assessment,* s.l.: s.n.

United Nations Office for Disaster Risk Reduction , 2017 . *4. Flood Hazard and Risk Assessment ,* s.l.: s.n.

United Nations, 2018 a. *https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.* [Online]
[Accessed 10 2018].

Västra Götalands Län, 2018. *https://www.lansstyrelsen.se/vastra-gotaland/privat.html.* [Online]
[Accessed 1 12 2018].

Västtrafik, 2018. *https://www.vasttrafik.se.* [Online]
[Accessed 30 11 2018].

Walderveen, F. v., 2018. *Email correspondence* [Interview] (29 10 2018).

Wern, L., 2012. *Extrem nederbörd i Sverige under 1 till 30 dygn, 1900 - 2011,* Sweden: SMHI.

Yin, J. et al., 2018. Large increase in global storm runoff extremes driven by climate and anthropogenic change. *nature communications ,* 22 10.Volume DOI: 10.1038/s41467-018-06765-2.

II. List of tables

Tables in Appendix

III. LIST OF FIGURES

IV. APPENDICES

A. RISK ANALYSIS – DAMAGE POTENTIAL

In this appendix the detailed decision-making process for damage potential of the risk analysis as shown in Table 3-2 and Table 3-3.

(1) Risk for human life and health

This category is rated with the highest risk and the grade 1. It is the only category allocated to the highest damage potential as the vulnerability of the human livelihood and health is the most significant threat. The group is assigned to non-monetary damage. Only the exemplified area and object 'shopping malls' is additionally marked as monetary damage, as the damage potential for economic damage is considered as well. Within this superior risk group, the classifications 'particularly vulnerable groups' and 'structural high-risk zones' are both assigned to the highest risk "++". The classification 'areas with high passenger volumes' are assigned to medium risk "+".

(2) Risk of damage and loss of cultural heritage

The risk for this category was rated with the lowest risk and the grade 3. The type of damage is non-monetary as well as monetary. Even though the loss and damage to cultural heritage might be of radical extent and lead to unrecoverable losses, it can by no means lead to consequential damage for human life and health. In the scope of the danger of a catastrophe like a flooding caused by torrential rain the risk of damage and loss of cultural heritage is considered as low damage potential in the scope of this thesis. Therefore, the sub-categories are also rated with low risk "o".

(3) Environmental risk

Environmental risk is rated with medium risk and the grade 2. The sub-categories are rated with medium risk "++". The damage potential within this category is categorized with a medium risk, as it has very high likelihood for consequential damages, e.g. contamination due to oil or biochemical hazards. The damage in this group can be monetary and non-monetary, whereby the consequential damages are considered as non-monetary.

(4) Economic and industrial risk

This superior risk group is graded with low risk and the grade 3. It is assigned to monetary damage. The aspect of industries, which are a possible source for environmental damage are included in category three. For this reason, only the industries, agriculture and forestry itself are graded in this group. The monetary harm for both categories is rated with "o", the lowest risk, in relation to the other categories.

(5) Risk to relevant infrastructure

The damage potential of this group is assigned to the grade 2 with a medium risk. The medium grade was given, as the infrastructure is a crucial sector for the coordination of the flood management during a hazardous event. All objectives within the sub-categories are rated with medium risk "++", because the coordination and the supply and evacuation access are rated equally.

B. SCALGO – PRECIPITATION CALCULATION

This section presents tables of the calculation of the precipitation height in the holistic approach and the respective validation.

Appendix - Table 1: Calculation rain intensity according to Dahlström 2010 (Svenskt Vatten, 2011a) for SCALGO

Scenario	Return period [year]	Return period [month]	Duration [min]	Intensity [l/s*ha]	Notes to Duration
1	100	1200	30	**247,01**	30min
	200	2400	30	**310,70**	30min
	50	600	30	**196,47**	30min
2	100	1200	60	**151,53**	60min
	200	2400	60	**190,40**	60min
	50	600	60	**120,68**	60min
3	100	1200	360	**39,13**	6h
	100	1200	180	**66,62**	3h

Appendix - Table 2: Calculation of mean precipitation with rain intensity according to Dahlström 2010 (Svenskt Vatten, 2011a)

Scenario	Average intensity [l/s*ha]	Duration [min]	Precipitation [mm]	Input Scalgo [mm]	Notes to Scenarios
1	247,01	30	**44,46**	44,5	*100 a; 30min; Cloudburst*
	310,70	30	**55,92**	55,9	*200 a; 30min; FME*
	196,47	30	**35,36**	35,4	*50 a; 30min; FME*
2	151,53	60	**54,55**	54,6	*100 a; 60min; Cloudburst*
	190,40	60	**68,54**	68,5	*200 a; 60min; FME*
	120,68	60	**43,44**	43,4	*50 a; 60min; FME*
3	39,13	360	**84,53**	84,5	*100 a; 6h; control with table 92 P104*
	66,62	180	**71,95**	72,0	*100a; 3h*

Appendix – Table 3: Calculation precipitation height in SCALGO according to Dahlström 2010 (Svenskt Vatten, 2011a) rainfall intensity with consideration of climate factor

Scenario	Average intensity [l/s*ha]	Intensity with climate factor [l/s*ha]	Rain duration [min]	Precipitation height [mm]	Input Scalgo [mm]
1	247,02	296,42	30	**53,35**	53,4
	310,71	372,85	30	**67,11**	67,1
	196,47	235,77	30	**42,43**	42,4
2	151,54	181,84	60	**65,46**	65,5
	190,40	228,48	60	**82,25**	82,3
	120,69	144,82	60	**52,136**	52,1
3	39,14	46,96	360	**101,44**	101,4
	66,62	79,95	180	**86,34**	86,3

Appendix - Table 4: Calculation precipitation height in MIKE ZERO software programs according to Software Program Setup from Cloudburst Modelling and Structure Plan

Mike 21	Precipitation height [mm]	Mike Flood	Mike 21 Precipitation height [mm]	Mike Urban Precipitation height [mm]
Total Duration	3h	Total	6h	6h
Peak Rain	30min	Peak Rain	30min	30min
Peak Rain	53	Peak Rain	53,4	20,84
Pre-Rain	24	Pre-Rain	0	23,7
After Rain	0	After Rain	23,7	23,7
Total	**77**	**Total**	**77,1**	**68,24**

Appendix - Table 5: Calculation of validation precipitation heights in SCALGO and respective software programs for holistic approach

Notes Duration	Software Program	return period	Duration	Precipitation
		[year]	[min]	[mm]
30 min	SCALGO	100	30	53,36
	MIKE 21	100	30	53,00
	MIKE FLOOD	100	30	53,40
3h	SCALGO	100	180	86,34
	MIKE 21	100	180	77,00
6h	SCALGO	100	360	101,44
	MIKE FLOOD	100	360	100,80
Sewer	SCALGO	100	360	94,91
	MIKE FLOOD	100	360	100,80
Sewer	SCALGO	100	180	77,84
	MIKE 21	100	180	77,00

C. SCALGO – VOLUME BALANCE FOR MEASURES

Appendix - Table 6: Volume balance for measure implementation in SCALGO

Final Overview	Precipitation Input Data	53,4 mm
Flash Flood Mapping Tool	Return Period	100 year event

Label	Volume w/o measures	Risk Area/ Location in Linnéstaden	Volume w measure	Measure to Area	Size	Tool	Storage
1	11.644,59	Magreteberg	4.278,00	Slottskogen Basin	*Area 2.99ha; Depth 30cm*	*Lower Path and Flatten Tool*	*11667,12 m^3*
	6.614,80	Magreteberg	2.518,84	Slottskogen; Path to Basin	*1m width; 20cm depth*	*Lower Path with Interpolation*	*none*
	18.259,39	Total Volume	**6.796,84**				
	11.462,55	Volume Difference (Storage)					
2	27.167,36	Sahlgrenska University Hospital	17145,93	Guldheden Basin, Dam	*Area 0,64ha; lowered by 2m*	*Flatten and Lower Area Tool*	*9876,57 m^3*
	439,80		439,80		*2m width; 5m rise*	*Rise Path and Flatten Tool*	*none*
	533,20		533,20				
	8.686,14		1.070,00	ParkingLot Area	*Area 0,68ha; lowered by 1m*	*Flatten and Lower Area Tool*	*7656,33 m^3*
	101,43		101,43				
	145,25		145,25				
	143,75		143,75				
	133,07		133,07				
	132,85		132,85				
	55,96		55,96				
	302,80		302,80				
	37.841,61	Total Volume	**20.204,04**				
	17.637,57	Volume Difference (Storage)					
3	6.677,29	Annedal	440	Pipe (unlimited capacity), Basin SLK	*Pipelenght; 364m; upstream*	*Subsurface Structure*	*none; unlimited*
	625,95		625,95		*0,62 ha Area; 30cm Depth*	*Flatten and Lower Area*	*1631,99m^3*
	7.303,24	Total Volume	**1065,95**				
	6.237,29	Volume Difference (Storage)					

D. Volume balance of simulations in MIKE 21 and MIKE FLOOD

Appendix - Table 7: Volume Balance MIKE 21

Comparison Volume Balance	0	1	2	3	4	5	6	7
Program	MIKE 21 - original	MIKE 21	MIKE 21					
Software Version	**PFS Type: Dec 16 2013 19:42:22**	Version: 16.0.0.12105						
Simulation	Skyfallsmodellering	Validation	Basic Comparison Scenario 1	Basic Comparison Scenario 1-1	Basic Comparison Scenario 2	Basic Comparison Scenario 2-1	Basic Comparison Scenario 3	With measures
Notes			No Inf/M 50	No Inf/ M2	Inf/ M50	Inf/ M2	No Inf/Res File	
Source	not available	16 Modell\Skyfallsmodell\New Version\GOTEBORG_VAST.html	22 Basic Comparison - Manning2+50\Mike 21 - Skyfallsmodelling\Scenario 1\1_SCENARIO_GOTEBORG_VAST.html	22 Basic Comparison - Manning2+50\Mike 21 - Skyfallsmodelling\Scenario 1 - 1\1_1SCENARIO_GOTEBORG_VAST.html	22 Basic Comparison - Manning2+50\Mike 21 - Skyfallsmodelling\Scenario 2\2_SCENARIO_GOTEBORG_VAST.html	22 Basic Comparison - Manning2+50\Mike 21 - Skyfallsmodelling\Scenario 2 - 1\2_1SCENARIO_GOTEBORG_VAST.html	22 Basic Comparison - Manning2+50\Mike 21 - Skyfallsmodelling\Scenario 3\3_SCENARIO_GOTEBORG_VAST.html	28 Modell Measures\Skyfallsmodell\1_100y\1_100Y_MIKE21.html
Volume Balance Summary								
Initial volume in model area		1222,95	1222,95	1222,95	1222,95	1222,95	1222,95	1222,95
Final volume in model area		264873,03	298424,95	294403,16	278846,21	263734,20	294586,35	265387,74
Inflow sources		0,00	0,00	0,00	0,00	0,00	0,00	0,00
Open boundaries inflow		0,00	0,00	0,00	0,00	0,00	0,00	0,00
Hydrology net precipiation		292773,26	292773,26	292773,26	292773,26	292773,26	292773,26	292773,26
water level correction		10481,76	4428,73	406,94	11428,30	10220,03	590,13	10914,03
Total inflow		303255,04	297202,00	293180,20	304201,56	302993,29	293363,40	303687,30
outflow sinks		0,00	0,00	0,00	0,00	0,00	0,00	0,00
open boundaries outflow		0,00	0,00	0,00	0,00	0,00	0,00	0,00
hydrology infiltration		39604,96	0,00	0,00	26578,31	40482,04	0,00	39522,51
Total outflow		39604,96	0,00	0,00	26578,31	40482,04	0,00	39522,51
Continuity balance		0,00	0,00	0,01	0,01	0,00	0,00	0,00
relative deficit		0,00	0,00	0,00	0,00	0,00	0,00	0,00

Appendix - Table 8: Volume Balance MIKE 21 of MIKE FLOOD

Comparison Volume Balance	0	2	4	5	6	7	9	11
Program	MIKE FLOOD - original	MIKE FLOOD						
Software Version	PFS Version: Nov 22 2015 02:58:09	Version: 16.0.0.12105						
Simulation	Strukturplan	Strukturplan	Basic Comparison Scenario 1	Basic Comparison Scenario 1-1	Basic Comparison Scenario 2	Basic Comparison Scenario 2-1	Basic Comparison Scenario 3	Measures
Notes	MIKE 21	MIKE 21	No Inf/M 50 Mike 21	No Inf/ M2 MIKE 21	Inf/ M50 MIKE 21	Inf/ M2 MIKE 21	No Inf/Res File MIKE 21	MIKE 21
Source	07 Underlag\Strukturplan\Linnegatan FLOOD\M21\Linnegatan_100y_kf.html	16 Modell\Strukturplan\2_Strukturplan wo additional rain files\M21\Linnegatan_100y_kf.html	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 1\1_Scenario_Linnegatan_100y_kf.html	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 1 - 1\1_1_Scenario_Linnegatan_100y_kf.html	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 2\2_Scenario_Linnegatan_100y_kf.html	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 2 - 1\2_1_Scenario_Linnegatan_100y_kf.html	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 3\3_SCENARIO_LINNEGATAN_100Y_KF.html	28 Modell Measures\Strukturplan\1_M21\1_100y_MF_m21\Linnegatan_100y_kf.html
Volume Balance Summary								
Initial volume in model area	1222,95	1222,95	1222,95	1222,95	1222,95	1222,95	1222,95	1222,95
Final volume in model area	316059,71	278277,84	277342,34	413509,11	256202,25	365650,50	313696,15	281561,06
MIKE URBAN CS inflow	93589,00	160790,63	196145,38	0,00	182834,03	0,00	168209,75	159356,55
Inflow sources	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Open boundaries inflow	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Hydrology net precipiation	364543,48	411895,12	411895,12	411895,12	411895,12	411895,12	411895,12	411895,12
water level correction	31281,38	112982,16	91370,21	391,05	112234,65	15437,88	93424,13	115653,06
Total inflow	489413.86	685667,91	699410,71	412286,16	706963,80	427333,00	673528,99	686904,72
MIKE URBAN CS outflow	123551,01	285564,23	371723,85	0,00	338326,73	0,00	303081,88	282510,15
outflow sinks	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
open boundaries outflow	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
hydrology infiltration	34639,00	348207,23	0,00	0,00	59409,10	62905,45	0,00	62574,46
Total outflow	158190,04	0,00	371723,85	0,00	397735,83	62905,45	303081,88	345085,61
Continuity balance	-16387,00	-60405,80	-51567,48	0,00	-54248,67	0,00	-57973,91	-61481,00
relative deficit	-0,03	-0,09	-0,07	0,00	-0,08	0,00	-0,09	-0,09
Notes								

Appendix - Table 9: Volume Balance MIKE URBAN of MIKE FLOOD

MOUSE Pipe Flow Simulation - Status Report - Dynamic Wave

Comparison Volume Balance	0	1	2	3	4	5	6	7
Software Program	MIKE FLOOD - original	MIKE FLOOD	MIKE FLOOD					
Software Version	MOUSE HD Computation Engine x64 v2016 Release Version (15.0.0.9324)	MOUSE HD Computation Engine x64 v2017 Release Version (16.0.0.12105)	MOUSE HD Computation Engine x64 v2017 Release Version (16.0.0.12105)	MOUSE HD Computation Engine x64 v2017 Release Version (16.0.0.12105)	MOUSE HD Computation Engine x64 v2017 Release Version (16.0.0.12105)	MOUSE HD Computation Engine x64 v2017 Release Version (16.0.0.12105)	MOUSE HD Computation Engine x64 v2017 Release Version (16.0.0.12105)	MOUSE HD Computation Engine x64 v2017 Release Version (16.0.0.12105)
Simulation	Strukturplan	Validation	Basic Comparison Scenario 1	Basic Comparison Scenario 1-1	Basic Comparison Scenario 2	Basic Comparison Scenario 2-1	Basic Comparison Scenario 3	With measures
Notes	MIKE URBAN not available; Simulation time in existing file false; html files not correlating with data	MIKE URBAN	No Inf/ M50	No Inf/ M2	Inf/ M50	Inf/ M2	No inf/ Res File	
Source	07 Underlag\Strukturplan\Linnegatan FLOOD\MU\Summary_HD_FLOOD_Linne_kopplad_basins_to_nodeBase.HTM	16 Modell\Strukturplan\2_Strukturplan wo additional rain files\180612\Summary_HD_FLOOD_Linne_kopplad_basins_to_nodeBase.HTM	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 1\Summary_HD_FLOOD_Linne_kopplad_basins_to_nodeBase.HTM	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 1 - 1\Summary_HD_FLOOD_Linne_kopplad_basins_to_nodeBase.HTM	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 2\Summary_HD_FLOOD_Linne_kopplad_basins_to_nodeBase.HTM	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 2 - 1\Summary_HD_FLOOD_Linne_kopplad_basins_to_nodeBase.HTM	22 Basic Comparison - Manning2+50\Mike Flood - Strukturplan\Scenario 3\Summary_HD_FLOOD_Linne_kopplad_basins_to_nodeBase.HTM	28 Modell Measures\Strukturplan\3_new Mike Urban\Created w Marie 27_11\Summary_HD_1_FINAl_new_measuresBase.HTM
Time Overview								
Simulation start date	2014-07-26; 17:45:00	2014-07-26; 17:45:00	2014-07-26; 17:45:00	2014-07-26; 17:45:00	2014-07-26; 17:45:00	2014-07-26; 17:45:00	2014-07-26; 17:45:00	2014-07-26; 17:45:00
Simulation end date	2014-07-26; 22:00:00	2014-07-26; 22:00:00	2014-07-26; 22:00:00	2014-07-26; 22:00:00	2014-07-26; 22:00:00	2014-07-26; 22:00:00	2014-07-26; 22:00:00	2014-07-26; 22:00:00
Save time step [hh:mm:ss]	0:01:00	0:01:00	0:01:00	0:01:00	0:01:00	0:01:00	0:01:00	0:01:00
Maximum time step [sec]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Minimum time step [sec]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Calculation started	2016-07-29; 12:56:38	2018-06-12; 14:40:50	2018-11-05; 15:10:32	2018-11-06; 09:45:38	2018-11-05; 15:17:02	2018-11-06; 09:55:33	2018-10-18; 08:53:34	2018-11-27; 17:13:30
Calculation ended	2016-07-29; 12:56:38	2018-06-13; 06:03:04	2018-11-06; 02:20:29	2018-11-06; 18:47:22	2018-11-06; 02:55:25	2018-11-06; 19:50:19	2018-10-18; 14:49:26	2018-11-27; 00:19:57
Calculation time [hh:mm:ss]	00:00:00	15:22:13	11:09:56	09:01:44	11:38:23	09:45:46	05:55:53	07:06:27
Hotstart start date [hh:mm:ss]	02:45:00	02:45:00	02:45:00	02:45:00	02:45:00	02:45:00	02:45:00	02:45:00
Input overview								
Number of Structures								
Number of Manholes	851	851	851	851	851	851	851	856
Number of Basins	0	0	0	0	0	0	0	0
Number of Outlets	20	20	20	20	20	20	20	21
Number of Storage Nodes	0	0	0	0	0	0	0	0
Number of Circular Pipes	780	780	780	780	780	780	780	785
Number of Rectangular Pipes	11	11	11	11	11	11	11	11
Number of CRS defined pipes	0	0	0	0	0	0	0	0
Number of Punps	0	0	0	0	0	0	0	0
Number of Conttrolled Pumps	0	0	0	0	0	0	0	0
Number of weirs/orifices	28	28	28	28	28	28	28	28
Number of controlled weirs/gates	0	0	0	0	0	0	0	0
Number of valves	0	0	0	0	0	0	0	0
Number of controlled valves	0	0	0	0	0	0	0	0
Nodes								
Total Manhole volume [m3]	7892,30	7892,30	7892,30	8495,30	7892,30	8495,30	7892,30	7908,10
Total basin volume [m3]	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Links								
Total Circular Volume [m3]	17996,40	17996,40	17996,40	17996,40	17996,40	17996,40	17996,40	18214,80
Total CRS Volume [m3]	3071,90	3071,90	3071,90	3071,90	3071,90	3071,90	3071,90	3071,90
Total Lenght [m]	33988,00	33988,00	33988,00	33988,00	33988,00	33988,00	33988,00	34266,00
Simulation Result Summary								
Continuity Balance [m3]								
1: Start volume in pipes, manholes and structures	15695,10	15695,10	15695,10	22671,40	15695,10	22671,40	15695,10	15695,80
2: End volume in pipes, manholes and structures	29038,50	14472,40	14341,10	35563,50	12810,00	35563,50	15341,60	13642,50
3: Total inflow volume	245241,80	451850,70	537841,30	187699,80	504666,30	187699,80	469175,60	449004,30
specified inflows								
runoff	119519,20	160578,60	160375,40	179063,50	160583,20	179063,50	160335,00	160764,90
DWF (dry weather flow)	2171,50	5710,10	5710,10	5710,10	5710,10	5710,10	5710,10	5710,10
No specified inflows								
Outlets (inflow)	1,00	0,60	34,70	2926,30	48,50	2926,30	51,90	21,70
Inflow from 2D overland	123551,00	285561,40	371721,10	0,00	338324,60	0,00	303078,60	282507,70
4: Total diverted volume	228094,40	445036,40	534213,60	169651,10	503001,10	169651,10	463945,40	437227,40
Operational, non-specified outflows								
Outlets	150524,00	302292,10	356110,20	169086,80	338001,00	169086,80	313825,10	297695,20
Weirs	637,40	636,60	644,10	3,7 E93	644,10	3,7 E93	637,30	636,60
Flow to 2D overland	76933,00	142307,70	177459,30	0,00	164356,00	0,00	149483,00	138895,60
5: Water generated in empty parts of the system	177,30	576,50	583,90	1236,80	584,40	1236,80	577,30	577,60
6: Continuity Balance	-3981,30	-8413,50	-5565,60	-6393,40	-5134,80	-6393,40	-6161,10	-14407,80
max. value	104,40	91,00	68,20	103,00	109,50	103,00	62,90	92,00
min. value	-4283,00	-8428,40	-5721,90	-11773,20	-5134,80	-11773,20	-6266,80	-14413,20
2D overland [m3]								
inflows from 2D overland								
Manholes/basins	123551,00	285561,40	371721,10	0,00	338324,60	0,00	303078,60	282507,70
outlets:	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
total	123551,00	285561,40	371721,10	0,00	338324,60	0,00	303078,60	282507,70
Outflows to 2D overland								
Manholes/basins	76933,00	142307,70	177459,30	0,00	164356,00	0,00	149483,00	138895,60
pumps	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
weirs	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
outlets	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2164,30
diverted runoff	16658,70	18484,90	18688,10	0,00	18480,30	0,00	18728,50	18298,60
total	93591,70	160792,60	196147,30	0,00	182836,30	0,00	168211,60	159358,60

E. FLOODMAN

In this appendix additional information regarding the results and application of FloodMan in this thesis are presented.

1. REFERENCE SYSTEM

In this section the input data from FME for the reference option is presented in the interface of FloodMan.

Appendix - Table 10: FloodMan input from FME for reference system - MIKE FLOOD

Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
50	Ja	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK
50		Spårväg	4387	HÖG	TRANSFORMATOR	3	HÖG	Motorväg	282	HÖG	Spårväg	5484	HÖG	TRANSFORMATOR	4	HÖG	Motorväg	352	HÖG
50		Järnväg	14	HÖG	TRANSFORMATOR	2	LÅG	Motorväg	179	LÅG	Järnväg	17	HÖG	TRANSFORMATOR	3	LÅG	Motorväg	224	LÅG
50		Spårväg	608	LÅG	INDUSTRI	1	HÖG	Huvudled	7142	HÖG	Spårväg	760	LÅG	INDUSTRI	1	HÖG	Huvudled	8928	HÖG
50					FLERBOSTADSHUS	159	LÅG	Huvudled	512	LÅG				FLERBOSTADSHUS	199	LÅG	Huvudled	640	LÅG
50					FLERBOSTADSHUS	330	HÖG	Lokalväg	19110	HÖG				FLERBOSTADSHUS	413	HÖG	Lokalväg	23888	HÖG
50					OFFENTLIG	161	HÖG	Lokalväg	666	LÅG				OFFENTLIG	201	HÖG	Lokalväg	832	LÅG
50					HANDEL	8	LÅG							HANDEL	10	LÅG			
50					OFFENTLIG	65	LÅG							OFFENTLIG	81	LÅG			
50					HANDEL	18	HÖG							HANDEL	23	HÖG			
50					SMÅHUS	62	HÖG							SMÅHUS	78	HÖG			
50					SMÅHUS	54	LÅG							SMÅHUS	67	LÅG			
50					UTHUS	96	LÅG							UTHUS	120	LÅG			
50					UTHUS	186	HÖG							UTHUS	233	HÖG			
50					PARKERING	7	HÖG							PARKERING	9	HÖG			
50					PARKERING	10	LÅG							PARKERING	12	LÅG			
50																			
50																			
50																			
50																			
50																			
50																			
50																			
50																			
Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
100	Ja	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK
100		Spårväg	5938	HÖG	TRANSFORMATOR	5	HÖG	Motorväg	333	HÖG	Spårväg	7422	HÖG	TRANSFORMATOR	6	HÖG	Motorväg	416	HÖG
100		Järnväg	14	HÖG	TRANSFORMATOR	3	LÅG	Motorväg	166	LÅG	Järnväg	17	HÖG	TRANSFORMATOR	4	LÅG	Motorväg	208	LÅG
100		Spårväg	612	LÅG	INDUSTRI	1	LÅG	Huvudled	8883	HÖG	Spårväg	765	LÅG	INDUSTRI	1	LÅG	Huvudled	11104	HÖG
100					INDUSTRI	1	HÖG	Huvudled	1050	LÅG				INDUSTRI	1	HÖG	Huvudled	1312	LÅG
100					FLERBOSTADSHUS	132	LÅG	Lokalväg	25626	HÖG				FLERBOSTADSHUS	165	LÅG	Lokalväg	32032	HÖG
100					FLERBOSTADSHUS	398	HÖG	Lokalväg	870	LÅG				FLERBOSTADSHUS	498	HÖG	Lokalväg	1088	LÅG
100					OFFENTLIG	178	HÖG							OFFENTLIG	222	HÖG			
100					HANDEL	6	LÅG							HANDEL	8	LÅG			
100					OFFENTLIG	63	LÅG							OFFENTLIG	79	LÅG			
100					HANDEL	22	HÖG							HANDEL	28	HÖG			
100					SMÅHUS	75	HÖG							SMÅHUS	94	HÖG			
100					SMÅHUS	54	LÅG							SMÅHUS	68	LÅG			
100					UTHUS	102	LÅG							UTHUS	128	LÅG			
100					UTHUS	228	HÖG							UTHUS	285	HÖG			
100					PARKERING	11	HÖG							PARKERING	14	HÖG			
100					PARKERING	6	LÅG							PARKERING	8	LÅG			
100																			
100																			
100																			
100																			
100																			
100																			
100																			
100																			
Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
200	Ja	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK
200		Spårväg	7979	HÖG	TRANSFORMATOR	8	HÖG	Motorväg	563	HÖG	Spårväg	9974	HÖG	TRANSFORMATOR	10	HÖG	Motorväg	704	HÖG
200		Järnväg	14	HÖG	TRANSFORMATOR	2	LÅG	Motorväg	166	LÅG	Järnväg	17	HÖG	TRANSFORMATOR	3	LÅG	Motorväg	208	LÅG
200		Spårväg	354	LÅG	INDUSTRI	1	LÅG	Huvudled	16742	HÖG	Spårväg	442	LÅG	INDUSTRI	1	LÅG	Huvudled	20928	HÖG
200					INDUSTRI	1	HÖG	Huvudled	614	LÅG				INDUSTRI	1	HÖG	Huvudled	768	LÅG
200					FLERBOSTADSHUS	125	LÅG	Lokalväg	34432	HÖG				FLERBOSTADSHUS	156	LÅG	Lokalväg	43040	HÖG
200					FLERBOSTADSHUS	457	HÖG	Lokalväg	1011	LÅG				FLERBOSTADSHUS	571	HÖG	Lokalväg	1264	LÅG
200					OFFENTLIG	197	HÖG							OFFENTLIG	246	HÖG			
200					HANDEL	3	LÅG							HANDEL	4	LÅG			
200					OFFENTLIG	60	LÅG							OFFENTLIG	75	LÅG			
200					HANDEL	30	HÖG							HANDEL	37	HÖG			
200					SMÅHUS	89	HÖG							SMÅHUS	111	HÖG			
200					SMÅHUS	53	LÅG							SMÅHUS	66	LÅG			
200					UTHUS	98	LÅG							UTHUS	123	LÅG			
200					UTHUS	285	HÖG							UTHUS	356	HÖG			
200					PARKERING	15	HÖG							PARKERING	19	HÖG			
200					PARKERING	6	LÅG							PARKERING	8	LÅG			

2. ALTERNATIVE 1 – SCALGO

In this section the input data from FME for the alternative 1 is presented in the interface of FloodMan.

Appendix - Table 11: FloodMan input from FME for SCALGO (Alternative 1)

Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
50	Ja	TYP		RISK	TYP		RISK	TYP		RISK	TYP		RISK	TYP		RISK	TYP		RISK
50		Spårväg	1638	HÖG	TRANSFORMATOR	3	HÖG	Motorväg	1606	HÖG	Spårväg	2048	HÖG	TRANSFORMATOR	4	HÖG	Motorväg	2008	HÖG
50		Spårväg	161	LÅG	TRANSFORMATOR	6	LÅG	Huvudled	2437	HÖG	Spårväg	201	LÅG	TRANSFORMATOR	8	LÅG	Huvudled	3046	HÖG
50					INDUSTRI	1	HÖG	Lokalväg	6705	HÖG				INDUSTRI	1	HÖG	Lokalväg	8381	HÖG
50					FLERBOSTADSHUS	126	LÅG							FLERBOSTADSHUS	158	LÅG			
50					FLERBOSTADSHUS	278	HÖG							FLERBOSTADSHUS	348	HÖG			
50					OFFENTLIG	139	HÖG							OFFENTLIG	174	HÖG			
50					HANDEL	2	LÅG							HANDEL	3	LÅG			
50					OFFENTLIG	42	LÅG							OFFENTLIG	52	LÅG			
50					HANDEL	19	HÖG							HANDEL	24	HÖG			
50					SMÅHUS	18	HÖG							SMÅHUS	22	HÖG			
50					SMÅHUS	22	LÅG							SMÅHUS	28	LÅG			
50					UTHUS	37	LÅG							UTHUS	46	LÅG			
50					UTHUS	181	HÖG							UTHUS	226	HÖG			
50					PARKERING	13	HÖG							PARKERING	16	HÖG			
50					PARKERING	2	LÅG							PARKERING	2	LÅG			
50																			
50																			
50																			
50																			
50																			
50																			
50																			
50																			
Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
100	Ja	TYP		RISK	TYP		RISK	TYP		RISK	TYP		RISK	TYP		RISK	TYP		RISK
100		Spårväg	1671	HÖG	TRANSFORMATOR	3	HÖG	Motorväg	1725	HÖG	Spårväg	2089	HÖG	TRANSFORMATOR	4	HÖG	Motorväg	2157	HÖG
100		Spårväg	161	LÅG	TRANSFORMATOR	6	LÅG	Huvudled	2651	HÖG	Spårväg	201	LÅG	TRANSFORMATOR	8	LÅG	Huvudled	3314	HÖG
100					INDUSTRI	1	HÖG	Lokalväg	7578	HÖG				INDUSTRI	1	HÖG	Lokalväg	9472	HÖG
100					FLERBOSTADSHUS	111	LÅG							FLERBOSTADSHUS	139	LÅG			
100					FLERBOSTADSHUS	304	HÖG							FLERBOSTADSHUS	380	HÖG			
100					OFFENTLIG	146	HÖG							OFFENTLIG	182	HÖG			
100					HANDEL	2	LÅG							HANDEL	2	LÅG			
100					OFFENTLIG	41	LÅG							OFFENTLIG	51	LÅG			
100					HANDEL	21	HÖG							HANDEL	26	HÖG			
100					SMÅHUS	18	HÖG							SMÅHUS	22	HÖG			
100					SMÅHUS	23	LÅG							SMÅHUS	29	LÅG			
100					UTHUS	38	LÅG							UTHUS	48	LÅG			
100					UTHUS	197	HÖG							UTHUS	246	HÖG			
100					PARKERING	14	HÖG							PARKERING	17	HÖG			
100					PARKERING	2	LÅG							PARKERING	2	LÅG			
100																			
100																			
100																			
100																			
100																			
100																			
100																			
100																			
Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
200	Ja	TYP		RISK	TYP		RISK	TYP		RISK	TYP		RISK	TYP		RISK	TYP		RISK
200		Spårväg	1721	HÖG	TRANSFORMATOR	3	HÖG	Motorväg	1866	HÖG	Spårväg	2151	HÖG	TRANSFORMATOR	4	HÖG	Motorväg	2332	HÖG
200		Spårväg	161	LÅG	TRANSFORMATOR	6	LÅG	Huvudled	3033	HÖG	Spårväg	201	LÅG	TRANSFORMATOR	8	LÅG	Huvudled	3792	HÖG
200					INDUSTRI	1	HÖG	Lokalväg	8676	HÖG				INDUSTRI	1	HÖG	Lokalväg	10844	HÖG
200					FLERBOSTADSHUS	107	LÅG							FLERBOSTADSHUS	134	LÅG			
200					FLERBOSTADSHUS	314	HÖG							FLERBOSTADSHUS	393	HÖG			
200					OFFENTLIG	155	HÖG							OFFENTLIG	194	HÖG			
200					HANDEL	1	LÅG							HANDEL	1	LÅG			
200					OFFENTLIG	35	LÅG							OFFENTLIG	44	LÅG			
200					HANDEL	22	HÖG							HANDEL	27	HÖG			
200					SMÅHUS	18	HÖG							SMÅHUS	23	HÖG			
200					SMÅHUS	22	LÅG							SMÅHUS	28	LÅG			
200					UTHUS	29	LÅG							UTHUS	36	LÅG			
200					UTHUS	218	HÖG							UTHUS	273	HÖG			
200					PARKERING	14	HÖG							PARKERING	17	HÖG			
200					PARKERING	2	LÅG							PARKERING	2	LÅG			

3. ALTERNATIVE 2 – MIKE 21

In this section the input data from FME for the alternative 2 is presented in the interface of FloodMan.

Appendix - Table 12: FloodMan input data from FME for MIKE 21 (Alternative 2)

Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
50	Ja	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK
50		Spårväg	5474	HÖG	TRANSFORMATOR	3	HÖG	Motorväg	1114	HÖG	Spårväg	6842	HÖG	TRANSFORMATOR	4	HÖG	Motorväg	1392	HÖG
50		Jämväg	14	HÖG	TRANSFORMATOR	2	LÅG	Motorväg	102	LÅG	Jämväg	17	HÖG	TRANSFORMATOR	3	LÅG	Motorväg	128	LÅG
50		Spårväg	438	LÅG	INDUSTRI	2	HÖG	Huvudled	550	LÅG	Spårväg	548	LÅG	INDUSTRI	2	HÖG	Huvudled	688	LÅG
50					FLERBOSTADSHUS	166	LÅG	Huvudled	8653	HÖG				FLERBOSTADSHUS	208	LÅG	Huvudled	10816	HÖG
50					FLERBOSTADSHUS	290	HÖG	Lokalväg	18125	HÖG				FLERBOSTADSHUS	363	HÖG	Lokalväg	22656	HÖG
50					OFFENTLIG	128	HÖG	Lokalväg	230	LÅG				OFFENTLIG	160	HÖG	Lokalväg	288	LÅG
50					HANDEL	6	LÅG							HANDEL	8	LÅG			
50					OFFENTLIG	77	LÅG							OFFENTLIG	96	LÅG			
50					HANDEL	22	HÖG							HANDEL	28	HÖG			
50					SMÅHUS	55	HÖG							SMÅHUS	69	HÖG			
50					SMÅHUS	59	LÅG							SMÅHUS	74	LÅG			
50					UTHUS	102	LÅG							UTHUS	127	LÅG			
50					UTHUS	142	HÖG							UTHUS	178	HÖG			
50					PARKERING	12	HÖG							PARKERING	15	HÖG			
50					PARKERING	7	LÅG							PARKERING	9	LÅG			
50																			
50																			
50																			
50																			
50																			
50																			
50																			
50																			

Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
100	Ja	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK
100		Spårväg	6856	HÖG	TRANSFORMATOR	5	HÖG	Motorväg	858	HÖG	Spårväg	8570	HÖG	TRANSFORMATOR	6	HÖG	Motorväg	1072	HÖG
100		Jämväg	14	HÖG	TRANSFORMATOR	3	LÅG	Motorväg	614	LÅG	Jämväg	17	HÖG	TRANSFORMATOR	4	LÅG	Motorväg	768	LÅG
100		Spårväg	531	LÅG	INDUSTRI	2	HÖG	Huvudled	1101	LÅG	Spårväg	664	LÅG	INDUSTRI	2	HÖG	Huvudled	1376	LÅG
100					FLERBOSTADSHUS	159	LÅG	Huvudled	12122	HÖG				FLERBOSTADSHUS	199	LÅG	Huvudled	15152	HÖG
100					FLERBOSTADSHUS	360	HÖG	Lokalväg	27648	HÖG				FLERBOSTADSHUS	450	HÖG	Lokalväg	34560	HÖG
100					OFFENTLIG	158	HÖG	Lokalväg	269	LÅG				OFFENTLIG	197	HÖG	Lokalväg	336	LÅG
100					HANDEL	4	LÅG							HANDEL	5	LÅG			
100					OFFENTLIG	69	LÅG							OFFENTLIG	86	LÅG			
100					HANDEL	28	HÖG							HANDEL	35	HÖG			
100					SMÅHUS	74	HÖG							SMÅHUS	92	HÖG			
100					SMÅHUS	58	LÅG							SMÅHUS	72	LÅG			
100					UTHUS	108	LÅG							UTHUS	135	LÅG			
100					UTHUS	194	HÖG							UTHUS	243	HÖG			
100					PARKERING	15	HÖG							PARKERING	19	HÖG			
100					PARKERING	5	LÅG							PARKERING	6	LÅG			
100																			
100																			
100																			
100																			
100																			
100																			
100																			
100																			

Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
200	Ja	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK
200		Spårväg	7822	HÖG	TRANSFORMATOR	8	HÖG	Motorväg	2189	HÖG	Spårväg	9778	HÖG	TRANSFORMATOR	10	HÖG	Motorväg	2736	HÖG
200		Jämväg	14	HÖG	TRANSFORMATOR	2	LÅG	Motorväg	218	LÅG	Jämväg	17	HÖG	TRANSFORMATOR	3	LÅG	Motorväg	272	LÅG
200		Spårväg	406	LÅG	INDUSTRI	1	LÅG	Huvudled	20326	HÖG	Spårväg	508	LÅG	INDUSTRI	1	LÅG	Huvudled	25408	HÖG
200					INDUSTRI	2	HÖG	Huvudled	474	LÅG				INDUSTRI	2	HÖG	Huvudled	592	LÅG
200					FLERBOSTADSHUS	128	LÅG	Lokalväg	38118	HÖG				FLERBOSTADSHUS	160	LÅG	Lokalväg	47648	HÖG
200					FLERBOSTADSHUS	440	HÖG	Lokalväg	589	LÅG				FLERBOSTADSHUS	550	HÖG	Lokalväg	736	LÅG
200					OFFENTLIG	190	HÖG							OFFENTLIG	237	HÖG			
200					HANDEL	3	LÅG							HANDEL	4	LÅG			
200					OFFENTLIG	64	LÅG							OFFENTLIG	80	LÅG			
200					HANDEL	31	HÖG							HANDEL	39	HÖG			
200					SMÅHUS	90	HÖG							SMÅHUS	112	HÖG			
200					SMÅHUS	54	LÅG							SMÅHUS	68	LÅG			
200					UTHUS	102	LÅG							UTHUS	127	LÅG			
200					UTHUS	259	HÖG							UTHUS	324	HÖG			
200					PARKERING	16	HÖG							PARKERING	20	HÖG			
200					PARKERING	6	LÅG							PARKERING	8	LÅG			

4. ALTERNATIVE 3 – MIKE FLOOD

In this section the input data from FME for the alternative 3 is presented in the interface of FloodMan.

Appendix - Table 13: FloodMan input data from FME for MIKE FLOOD (Alternative 3)

Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
50	Ja	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK
50		Spårväg	3828	HÖG	TRANSFORMATOR	3	HÖG	Motorväg	282	HÖG	Spårväg	4784	HÖG	TRANSFORMATOR	4	HÖG	Motorväg	352	HÖG
50		Järnväg	14	HÖG	TRANSFORMATOR	2	LÅG	Motorväg	179	LÅG	Järnväg	17	HÖG	TRANSFORMATOR	3	LÅG	Motorväg	224	LÅG
50		Spårväg	536	LÅG	INDUSTRI	1	HÖG	Huvudled	282	LÅG	Spårväg	670	LÅG	INDUSTRI	1	HÖG	Huvudled	352	LÅG
50					FLERBOSTADSHUS	168	LÅG	Huvudled	6912	HÖG				FLERBOSTADSHUS	210	LÅG	Huvudled	8640	HÖG
50					FLERBOSTADSHUS	317	HÖG	Lokalväg	15104	HÖG				FLERBOSTADSHUS	396	HÖG	Lokalväg	18880	HÖG
50					OFFENTLIG	152	HÖG	Lokalväg	589	LÅG				OFFENTLIG	190	HÖG	Lokalväg	736	LÅG
50					HANDEL	7	LÅG							HANDEL	9	LÅG			
50					OFFENTLIG	66	LÅG							OFFENTLIG	83	LÅG			
50					HANDEL	18	HÖG							HANDEL	22	HÖG			
50					SMÅHUS	58	HÖG							SMÅHUS	73	HÖG			
50					SMÅHUS	56	LÅG							SMÅHUS	70	LÅG			
50					UTHUS	99	LÅG							UTHUS	124	LÅG			
50					UTHUS	182	HÖG							UTHUS	228	HÖG			
50					PARKERING	6	HÖG							PARKERING	8	HÖG			
50					PARKERING	10	LÅG							PARKERING	12	LÅG			
50																			
50																			
50																			
50																			
50																			
50																			
50																			
50																			
Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
100	Ja	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK
100		Spårväg	5643	HÖG	TRANSFORMATOR	5	HÖG	Motorväg	333	HÖG	Spårväg	7054	HÖG	TRANSFORMATOR	6	HÖG	Motorväg	416	HÖG
100		Järnväg	14	HÖG	TRANSFORMATOR	3	LÅG	Motorväg	243	LÅG	Järnväg	17	HÖG	TRANSFORMATOR	4	LÅG	Motorväg	304	LÅG
100		Spårväg	612	LÅG	INDUSTRI	1	LÅG	Huvudled	538	LÅG	Spårväg	765	LÅG	INDUSTRI	1	LÅG	Huvudled	672	LÅG
100					INDUSTRI	1	HÖG	Huvudled	9331	HÖG				INDUSTRI	1	HÖG	Huvudled	11664	HÖG
100					FLERBOSTADSHUS	132	LÅG	Lokalväg	23091	HÖG				FLERBOSTADSHUS	165	LÅG	Lokalväg	28864	HÖG
100					FLERBOSTADSHUS	398	HÖG	Lokalväg	627	LÅG				FLERBOSTADSHUS	498	HÖG	Lokalväg	784	LÅG
100					OFFENTLIG	172	HÖG							OFFENTLIG	215	HÖG			
100					HANDEL	6	LÅG							HANDEL	8	LÅG			
100					OFFENTLIG	66	LÅG							OFFENTLIG	82	LÅG			
100					HANDEL	22	HÖG							HANDEL	27	HÖG			
100					SMÅHUS	76	HÖG							SMÅHUS	95	HÖG			
100					SMÅHUS	54	LÅG							SMÅHUS	68	LÅG			
100					UTHUS	102	LÅG							UTHUS	128	LÅG			
100					UTHUS	230	HÖG							UTHUS	288	HÖG			
100					PARKERING	11	HÖG							PARKERING	14	HÖG			
100					PARKERING	6	LÅG							PARKERING	8	LÅG			
100																			
100																			
100																			
100																			
100																			
100																			
100																			
Återkomsttid (år)	Analysera nivå	Spår			Byggnader			Vägar			Spår			Byggnader			Vägar		
200	Ja	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK	TYP	LÄNGD	RISK	TYP	ANTAL	RISK	TYP	YTA	RISK
200		Spårväg	7821	HÖG	TRANSFORMATOR	8	HÖG	Motorväg	563	HÖG	Spårväg	9777	HÖG	TRANSFORMATOR	10	HÖG	Motorväg	704	HÖG
200		Järnväg	14	HÖG	TRANSFORMATOR	2	LÅG	Motorväg	179	LÅG	Järnväg	17	HÖG	TRANSFORMATOR	3	LÅG	Motorväg	224	LÅG
200		Spårväg	404	LÅG	INDUSTRI	1	LÅG	Huvudled	576	LÅG	Spårväg	505	LÅG	INDUSTRI	1	LÅG	Huvudled	720	LÅG
200					INDUSTRI	1	HÖG	Huvudled	15232	HÖG				INDUSTRI	1	HÖG	Huvudled	19040	HÖG
200					FLERBOSTADSHUS	125	LÅG	Lokalväg	35341	HÖG				FLERBOSTADSHUS	156	LÅG	Lokalväg	44176	HÖG
200					FLERBOSTADSHUS	456	HÖG	Lokalväg	819	LÅG				FLERBOSTADSHUS	570	HÖG	Lokalväg	1024	LÅG
200					OFFENTLIG	196	HÖG							OFFENTLIG	245	HÖG			
200					HANDEL	3	LÅG							HANDEL	4	LÅG			
200					OFFENTLIG	61	LÅG							OFFENTLIG	76	LÅG			
200					HANDEL	30	HÖG							HANDEL	37	HÖG			
200					SMÅHUS	89	HÖG							SMÅHUS	111	HÖG			
200					SMÅHUS	53	LÅG							SMÅHUS	66	LÅG			
200					UTHUS	98	LÅG							UTHUS	123	LÅG			
200					UTHUS	287	HÖG							UTHUS	359	HÖG			
200					PARKERING	15	HÖG							PARKERING	19	HÖG			
200					PARKERING	6	LÅG							PARKERING	8	LÅG			

5. OTHER FINANCIAL CONSEQUENCES – FLOODMAN INTERFACE

In this section the interface of the other financial consequences used as input data for the present report is shown.

Appendix - Tables 14: Alternative 1 - SCALGO; other financial consequences - FloodMan interface for present report

Övriga ekonomiska konsekvenser	Alternativ 1 – SCALGO - actions simulated in SCALGO							
	År		Värde					
	Från	Till och med	Antal	Förväntat värde (kr) per enhet	Osäkerhet (+/- %)	Förväntat värde (kr), fördelning	Nuvärde R1 (kr)	Nuvärde R2 (kr)
Markvärdesförändring	5	100	0	10.000 kr	20%	9.873 kr	0 kr	0 kr
Tillgång på ekosystemtjänster								
Rekreation	0	0	0	24 kr	25%	24 kr	0 kr	0 kr
Vattenrening	0	0	0	3,50 kr	50%	3 kr	0 kr	0 kr
Andra tjänster								
Buller	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Luftkvalitet	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Kulturella värden	0	0	0	1 kr	10%	1 kr		
Hälsoeffekter	0	0	0	16.000 kr	12%	15.927 kr	0 kr	0 kr
Övriga konsekvenser					0			
Konsekvens 1	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Konsekvens 2	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Konsekvens 3	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Summa							**0 kr**	**0 kr**

Appendix - Tables 15: Alternative 2 - MIKE 21; other financial consequences - FloodMan interface for present report

Övriga ekonomiska konsekvenser	Alternativ 2 – MIKE 21 - actions simulated in MIKE 21							
	År		Värde					
	Från	Till och med	Antal	Förväntat värde (kr) per enhet	Osäkerhet (+/- %)	Förväntat värde (kr), fördelning	Nuvärde R1 (kr)	Nuvärde R2 (kr)
Markvärdesförändring	5	100	0	10.000 kr	20%	9.873 kr	0 kr	0 kr
Tillgång på ekosystemtjänster								
Rekreation	0	0	0	24 kr	25%	24 kr	0 kr	0 kr
Vattenrening	0	0	0	3,50 kr	50%	3 kr	0 kr	0 kr
Andra tjänster								
Buller	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Luftkvalitet	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Kulturella värden	0	0	0	1 kr	10%	1 kr		
Hälsoeffekter	0	0	0	16.000 kr	12%	15.927 kr	0 kr	0 kr
Övriga konsekvenser								
Konsekvens 1	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Konsekvens 2	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Konsekvens 3	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Summa							**0 kr**	**0 kr**

Appendix - Tables 16: Alternative 3 - MIKE FLOOD; othe financial consequences - FloodMan interface for present report

Övriga ekonomiska konsekvenser	Alternativ 3 – MIKE FLOOD - actions simulated in MIKE FLOOD							
	År		Värde					
	Från	Till och med	Antal	Förväntat värde (kr) per enhet	Osäkerhet (+/- %)	Förväntat värde (kr), fördelning	Nuvärde R1 (kr)	Nuvärde R2 (kr)
Markvärdesförändring	5	100	0	10.000 kr	20%	9.873 kr	0 kr	0 kr
Tillgång på ekosystemtjänster								
Rekreation	0	0	0	24 kr	25%	24 kr	0 kr	0 kr
Vattenrening	0	0	0	3,50 kr	50%	3 kr	0 kr	0 kr
Andra tjänster								
Buller	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Luftkvalitet	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Kulturella värden	0	0	0	1 kr	10%	1 kr		
Hälsoeffekter	0	0	0	16.000 kr	12%	15.927 kr	0 kr	0 kr
Övriga konsekvenser								
Konsekvens 1	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Konsekvens 2	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Konsekvens 3	0	0	0	1 kr	10%	1 kr	0 kr	0 kr
Summa							**0 kr**	**0 kr**