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Can blue-green infrastructure help adaptation to climate change by preventing flooding?

A study on blue-green infrastructure and its effects on pluvial flooding in the town of Häljarp by using the TFM-DYN model

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Kan blå-grön infrastruktur underlätta klimatanpassning genom att förebygga översvämningar?
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Bachelor thesis, 15 credits, in *Physical Geography and Ecosystem Science*

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Abstract

The risk of pluvial flooding is going to increase as climate change causes an increase in intense precipitation along with urbanisation leading to an increase in impermeable surfaces. In the last decade, cities such as Malmö and Copenhagen have already experienced severe pluvial flooding that has caused extensive damage. Adapting to climate change by creating flood resilient urban areas is therefore important and blue-green infrastructure (BGI) may be one measure to accomplish this.

This thesis has used a hydrological model called TFM-DYN to investigate whether BGI can aid the mitigation of pluvial flooding. A GIS-based urban flood model (e.g. TFM-DYN) can also assist in selecting the best locations to construct BGI. The investigation was performed in the town of Häljarp located in south-eastern Sweden. The model was set-up with two different hyetographs simulating two different scenarios, both scenarios are based on rain events that have occurred only a few kilometres from the study area in Malmö respectively Copenhagen. The first scenario modelled represented a current scenario of a 100-year rain occurring in the year 2020, the second scenario represented future 100-year rain, calculated with a climate factor so that it is representable for the year 2100. Analysing the result from the two rainfall scenarios, one can conclude that Häljarp is at risk for flooding, especially for the future scenario.

After BGI was retrofitted to the area, the simulation showed that BGI significantly lowered the water depth after both rain scenarios as well as reducing the areal extent for several water depth-classes. The decrease in water depth was greater for the 100-year rain in the year 2020 where the average reduction in water depth was 7,1 centimetres. Based on this result, as well as a literature study performed, the conclusion is that BGI can be an effective way for municipalities to adapt to climate change by increasing their flood resilience.

Sammanfattning

Klimatförändringarna i kombination med den pågående urbaniseringen är förutspådda att öka risken för pluviala översvämningar i Sverige. Klimatförändringarna kommer att innebära en ökad nederbördsmängd i Sverige och det är framför allt kraftiga regn som kommer att bli allt vanligare. Detta i en kombination av urbanisering, som orsakar en ökning av ogenomsläppliga ytor så som hustak eller vägar, innebär att översvämningar kommer bli allt vanligare. Blå-grön infrastruktur (BGI) kan vara en lösning på detta problem.

Denna uppsats har använt en hydrologisk modell kallad TFM-DYN för att ta reda på huruvida det finns bevis för att BGI är en effektiv lösning för att minska översvämningsrisken i urbana områden. En GIS baserad hydrologisk modell, så som TFM-DYN, kan dessutom underlätta att identifiera den mest effektiva placeringen av BGI. Studien har genomförts i Häljarp, en stad i Landskrona kommun som ligger i Skåne i sydvästra Sverige. Två olika regnscenarios för 100-års regn har blivit modellerade, ett för nuläget och ett för framtiden. Båda regnscenarios är baserade på regnhändelser som skett i närområdet, i Malmö respektive Köpenhamn. Resultatet av simuleringen visade att det finns en översvämningsrisk i Häljarp samt att denna är mer signifikant i framtiden. BGI var sedan implementerat och simulationen genomfördes igen. Resultatet visade att vattendjupet i de översvämmade områdena minskade, för nulägesscenariot så var genomsnittet en 7,1 centimeters minskning. Detta resultat, i kombination med en litteraturstudie, visar att BGI kan vara en effektiv lösning för att klimatanpassa städer i kommuner genom att öka resiliensen mot översvämningar.

Contents

1. Introduction

1.1 A wet forecast

Global warming is causing an increased global mean surface temperature and thereby, climate change. An average increase in global temperature of 1,5 or 2 degrees is going to have significant consequences, both for ecosystems and human society. Sweden and northern Europe are highly likely to experience a large increase in heavy precipitation events (IPCC 2018). At the end of this decade, Sweden can expect a 20% increase in precipitation for the RPC4.5 emission scenario and a 40% increase in precipitation for the RPC8.5 emission scenario (Olsson et al. 2017).

The increase in heavy precipitation events in combination with urbanisation increases the risk of pluvial flooding. Urbanisation has been increasing in Sweden since the start of the 1900s and 85% of the population now lives in urban areas (Svanström 2015). One of the issues with urbanisation and densification of urban areas is that the flood risk may significantly increase. This is as the increase of impermeable surfaces like roads or roofs leads to an increase in runoff water and rapid overland flow. As the water cannot infiltrate the soil, the natural storage of stormwater is disturbed. Thus, if the rain intensity exceeds the ground infiltration capacity, the increase of impermeable surfaces can result in pluvial flooding (Wheater 2006). Flooding can cause a lot of damage and have a high cost for municipalities and cities. The exceptional 1000-year rain in Copenhagen in July 2011 is estimated to have ended up costing around 8,7 billion SEK (Beredskabsstyrelsen 2012). In August 2014, a 100-year rain caused flooding in Malmö and the cost of the damage it caused was 0.6 billion SEK (Malmö Stad and VA SYD 2016). Mitigation of pluvial flooding should, therefore, be of high priority. Especially as the risk most likely will increase in the future. Factors relating to the decrease of impermeable surfaces often have a high manageability level, meaning that municipalities or city planners easily can reduce the flood risk by changing the physical environment. One way to achieve this could be by for example retrofitting the area with blue-green infrastructure (BGI) (Berndtsson et al. 2019).

To mitigate the risks of flooding, engineer solutions such as stormwater drainage systems are commonly used. Stormwater systems in Sweden can be open or closed and are designed to be able to handle a 10-year rain event (a rain event with an intensity that is estimated to happen only once every decade). If the rain intensity exceeds the capacity of the stormwater system, flooding can occur (Hernebring and Mårtensson 2013). This thesis is using 10 centimetres water depth as a definition of flooding. If the water depth is above 10 centimetres, there is a danger for flooding and damage or disruptions to society can occur (Lunds Kommun and VA SYD 2018). As the stormwater system does not have the capacity to process a rain event with a higher intensity than a 10-year rain, it is important to implement measurements to delay the water or create areas that can be flooded in the case of extreme rain. One way to do this is by using BGI or so-called multipurpose solutions (Malmö Stad and VA SYD 2016). Copenhagen is one of the cities that focuses on these types of solutions. To delay the runoff water from precipitation, Copenhagen municipality is using green roofs, infiltration trenches and green infrastructure on town squares. Furthermore, Copenhagen uses for example parks as detention basins where the water can aggregate after a heavy precipitation event as well as designing roads to transport the run-off water to the sea or canals (COWI et al. 2012). BGI has also been successfully implemented in Augustenborg, Malmö with a decrease in flood damage as a result (Sörensen and Emilsson 2019).

The use of green infrastructure is also a step towards goal 11 of the United Nations Agenda 2030 for Sustainable Development, Sustainable cities and communities. To achieve sustainable cities, some of the criteria are access to green and public spaces, mitigation and adaption to climate change as well as increasing resilience to disasters (United Nations 2019).

This thesis aim was to investigate if BGI can be used to mitigate flooding in the town of Häljarp, situated in Landskrona municipality in southwestern Sweden. The investigation was performed by using a hydrological model called the triangular form-based multiple flow algorithm (TFM-DYN) (Pilesjö and Hasan 2014) to map the flood depth, to identify where new areas of BGI can be established as well as to simulate the effect of adding BGI on flood depth. To map these locations in the study area, a geographical information system (GIS) programme was used. The result is going to be provided to Landskrona municipality so it can be used for city planning and thereby hopefully prevent serious flooding in Häljarp in the future.

Hydrological modelling is an important aspect of adapting urban areas to climate change. To be able to adapt to or mitigate flood risk, one needs to understand where it can occur. Hydrological modelling indicates what areas are going to be flooded and how deep the flooding is going to be. There is a lot of different aspects one can include to a hydrological model and there is a lot of different models (MSB 2017). Apart from getting the water depth and calculate the flood risk for an urban area, a model such as the TFM-DYN algorithm is superior when retrofitting an area with BGI. The TFM-DYN model allows the user to try out retrofitting different types of BGI for different locations and different magnitudes of precipitation. Furthermore, it is easy to run the model several times and therefore carry out a trial-and-error method until the result of implementing BGI is performing as desired. One can after that construct BGI in the town based on where it performed as desired in the model. This makes the TFM-DYN model an easy and cost-effective way to retrofit BGI that increases the flood resilience and mitigates flooding in a town.

1.2 Aim and research questions

The aim of this bachelor thesis is to investigate the possibility of using blue-green infrastructure to mitigate the risk of flooding and increase flood resilience in the town of Häljarp situated in Landskrona Municipality. The thesis is going to test the hypothesis that blue-green infrastructure is believed to decrease the risk of flooding.

The research questions for this bachelor thesis are as follows:

- What is the potential danger for flooding above 10 centimetres in Häljarp, both at current and future circumstances?
- How efficient is green infrastructure or blue-green infrastructure in preventing flood risk?

1.3 Delineations and limitations

This is a bachelor thesis so because of time limitations certain delineations and limitations have been done. The area studied is limited to cover the town centre of Häljarp.

The focus for this thesis is on pluvial flooding, that is on flooding caused by precipitation. Fluvial flooding, flooding caused by upstream activity in the river, is therefore not considered in this thesis. Because of the way the digital elevation model is built, flooding caused by precipitation that increases the water volume in already existing bodies of water is not considered. The digital elevation model may as well not completely show the real ground surface conditions as it is based on a scanning performed in 2014.

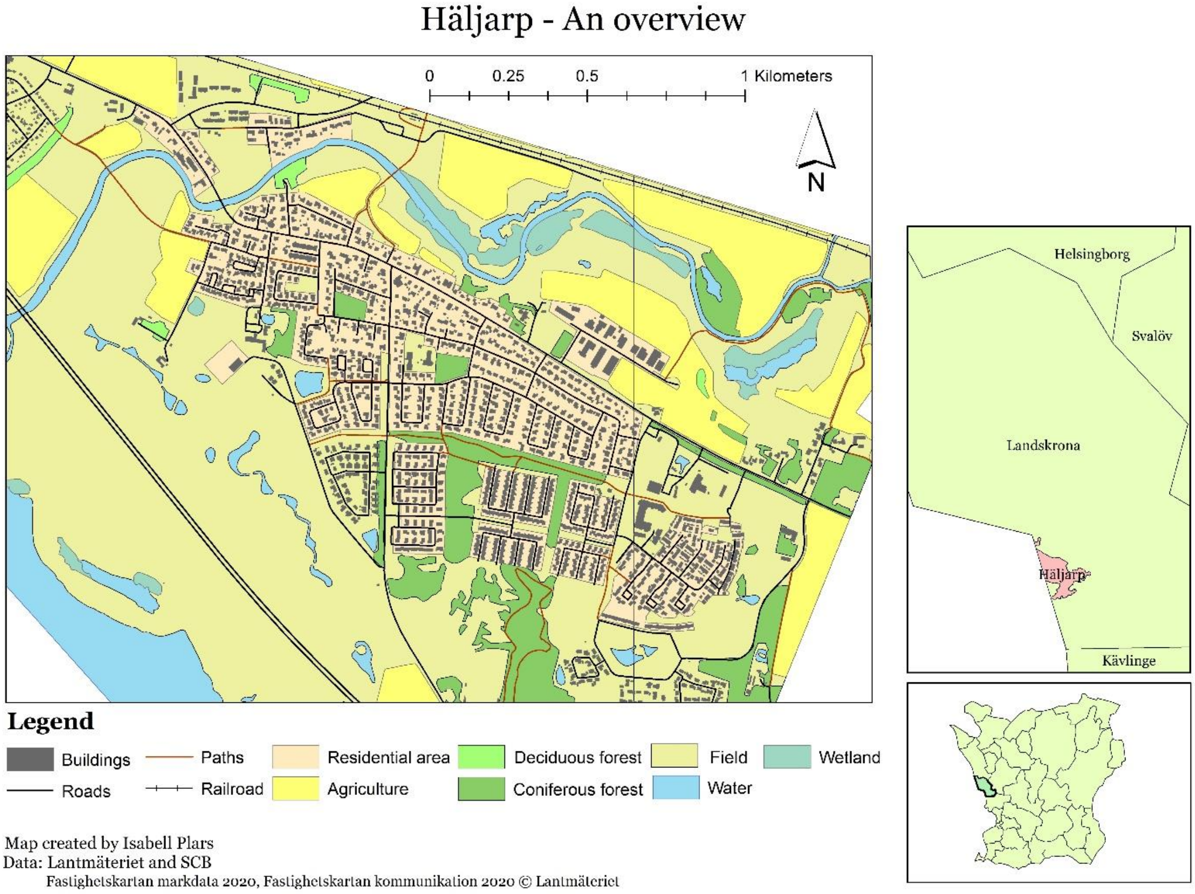
Regarding the stormwater system, it is only the capacity of the inlets, not the capacity for the entire stormwater system (inlets and pipes), that are included in the calculations. An inlet is an opening in the streets where the stormwater gets collected. Inlets are connected through pipes to outlets where the water is released. The average capacity for stormwater inlets is based on a calculation done for an urban area in Lund and may, therefore, differ from the actual capacity of the inlets in Häljarp.

Infiltration and friction coefficients are estimated based on soil maps respectively land use maps. The coefficients are assumed to be homogenous within the limits off different land use areas and for the different soil types. The coefficients have not been validated on-site and may therefore not represent the reality perfectly. Infiltration capacity varies a lot with the vegetation but in this thesis, it is only the soil data that has been used to calculate the infiltration rate. The soil layer may be highly altered because of urbanisation but for this study, it is only the original or natural soil layer that is used for estimating the infiltration rate. Furthermore, infiltration rates are assumed to be constant for the duration of the simulation.

2. Background

2.1 Study Area

The study area for this thesis is the small town of Häljarp, situated in Landskrona municipality, southern Sweden. The size of Häljarp is 221 hectares and the population is 3553 inhabitants (SCB 2020). Häljarp is one of four urban areas in Landskrona municipality. Landskrona municipality is currently developing each of the four urban areas in different ways so they can complement each other for it to be a wide variety of activities and recreation areas in the municipality. Landskrona municipality has identified 9 areas in Häljarp that can be further developed. Three of those areas are identified for further development of infrastructure, both for residential areas and commercial areas. The development of infrastructure would further increase the area of impermeable surfaces in Häljarp and lead to further urbanisation (Landskrona Stad 2016).



Map created by Isabell Plars
Data: Lantmäteriet and SCB
Fastighetskartan markdata 2020, Fastighetskartan kommunikation 2020 © Lantmäteriet

Figure 1: Map over the town of Häljarp showing the location as well as land use classes for the area.

Häljarp is situated in the south of Landskrona municipality, located between the strait Öresund and the river Saxån. Häljarp was chosen as a study area in consensus with Landskrona municipality. The town is prone to future issues with sea level rising and fluvial flooding because of its location between the river and the sea. However, a flood risk analysis on fluvial flooding was done in 2013 and it showed no significant flood risk from the river for the urban area itself (DHI and Landskrona Kommun 2013). Furthermore, Häljarp has issues with a shallow groundwater table that occasionally rises to the level that it occurs in the stormwater system. If a shallow groundwater table would coincide with a heavy rain event, the risk for pluvial flooding increases. Additionally, Häljarp is a low-lying town with some areas lower than the sea level. To conclude, Häljarp is vulnerable to flooding and is an interesting area for further development of flood mitigation methods (Gullin, pers. comm.).

2.2 Pluvial flooding, risk of flooding and cloudbursts

Pluvial flooding most commonly occurs after short intense cloudbursts when the precipitation exceeds the infiltration capacity of the ground. This causes runoff water and that is what tends to cause flooding. Depending on the surface, pluvial flooding is often caused by precipitation events that are less than three hours long but with a rainfall rate that exceeds 20-25 mm per hour or low intense rainfalls that occur for a longer time with a rainfall rate that exceeds 10 mm per hour. Pluvial flooding can occur even at places that are not prone to flooding e.g. in local depressions, where the runoff water accumulates, or on impermeable surfaces, where it cannot infiltrate the ground. Therefore, pluvial flooding is sometimes called an 'invisible hazard'. Pluvial flooding may cause a lot of damage if people cannot predict the flood and are taken by surprise (Houston et al. 2011). When mapping and modelling flooding, the max depth of accumulated water is used in this study. The consequences of different max depths are described in Table 1 (Lunds Kommun and VA SYD 2018).

Table 1: A description of the consequences for society for three different water depth classes (Lunds Kommun and VA SYD 2018).

Max depth (m)	**Consequences**
0.1-0.3	Difficult to navigate for vehicles
0.3-0.5	Very challenging to navigate for vehicles, a big risk for damage on structures
>0.5	Severe damage on structures and risk for people's safety

The risk of flooding is defined as a product of the flood hazard for a specific place, the exposed values at that place and their vulnerability (Kron 2005). This thesis investigates the flood hazard or danger of flood, so the possible flooding level, for the town of Häljarp. However, for the span of this thesis, flood hazard is going to be referred to as the flood risk even though the vulnerability of the town is not directly considered.

When discussing precipitation or when doing hydrological modelling, return periods are often mentioned. The return period of a rain event is the likelihood of the number of years between rain events of the same magnitude. In Sweden, one definition of a rain event with a return time of 10 years is that it should have a precipitation rate of 21 mm in 30 minutes. For a rain event with a return time of 100 years, the precipitation rate should be 44 mm in 30 minutes (MSB 2017). Even if there is uncertainty about the future and how climate change is going to affect the global precipitation pattern, it is highly likely that the number of short intense rainfall or downpours in Sweden are going to increase. This indicates that the return period of rain events is going to be shorter in the future. Short and intense rain events are most likely going to increase with between 20-40% by the end of this century depending on what RCP scenario (emission scenario) one uses (Olsson et al. 2017). When designing new stormwater drainage systems, the standard recommendation is that the stormwater drainage system should be dimensioned for a 20% increase in precipitation (Svenskt Vatten 2016).

2.3 Blue-green infrastructure and sustainable urban drainage

Stormwater drainage systems are an important aspect when planning for and designing a flood resilient town. Traditionally, before the 1970s, closed “grey” drainage systems were commonly used. Closed drainage systems aimed to get rid of the stormwater as quickly as possible, consequently often followed by water pollution and other environmental issues. Since the 1970s, sustainable urban drainage systems have been increasing in popularity (Stahre 2008). Sustainable urban drainage system focuses on both the quantity and quality of the runoff as well as the social aspects such as an increase in well-being for residentials or increased biodiversity of the area. To manage rainwater in nature’s way, open or partly open drainage systems are often used. One important aspect of sustainable urban drainage systems is blue-green infrastructure. Blue-green infrastructure allows for infiltration (increased permeability), slow drainage, and detention in ponds for the stormwater, leading to an increasingly natural hydrologic cycle (Woods-Ballard et al. 2007; Stahre 2008). Figure 1 shows the different categories of usage for blue-green infrastructure and where each type can be used according to Stahre (2008). The primary category is source control or on-site control, the second category is slow transport and the final category is downstream control,

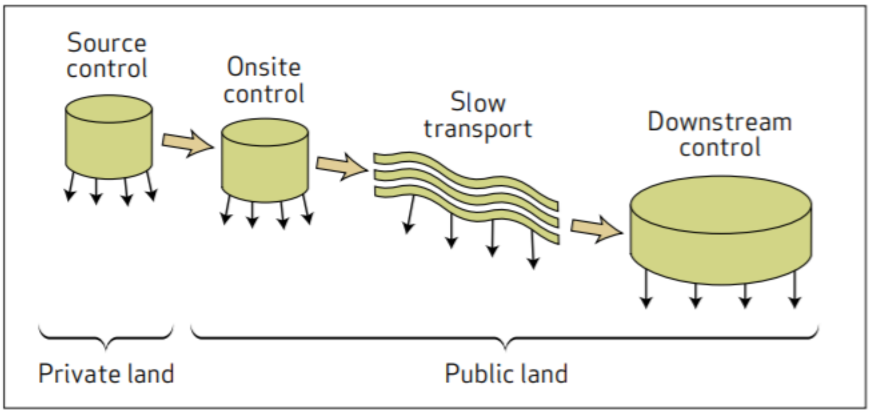


Figure 2: The four different categories of usage for sustainable urban drainage systems and where they can be implemented (Stahre 2008)

Green infrastructure (GI) can be defined as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings.” (European Commission 2013). In this study, the term GI also includes or has the same meaning as blue-green infrastructure (BGI) and green solutions. When discussing retrofitting of BGI in this thesis, it means implementing or creating new areas of BGI in an already existing urban area.

GI is an important aspect of socio-hydrology. Socio-hydrology acknowledges that humans play an important role in and effect the hydro cycle. GI can play an important role both for communities, ecosystems and the stormwater drainage system. To achieve as many benefits as possible, the efforts to implement GI must be connected. Different organisations and stakeholders need to cooperate for GI to have a bigger impact on both the hydrological aspect as well as the social aspect (Schifman et al. 2017). Drivers for implementing or retrofitting GI in an urban area are most often recognised as prevention of flooding as well as adaption to climate change. Furthermore, the delay and treatment of stormwater is an important driver. However, there are barriers when implementing GI. There is a lack of support for GI in the structure for planning and in the current management for stormwater in Sweden. Thus, there is a big need for both legal support and cooperation when implementing green solutions and transferring to a sustainable urban drainage system (Wihlborg et al. 2019).

2.3.1 Types of BGI

As mentioned, one of the drivers when implementing GI is the prevention of flooding. Green solutions such as GI and BGI can be used to mitigate flooding or increase flood resilience in urban areas. GI can be implemented in the planning stage but it can also be retrofitted to already established urban areas (Sörensen 2018). The most important aspect of GI is that it regulates the stormwater runoff (Pappalardo et al. 2017). The aim should therefore always be to implement GI in a way that causes a reduction in peak flows and total runoff volumes. This can be done by retrofitting urban areas with for example detention ponds, concave green spaces, swales or rain gardens (Sörensen 2018).

Copenhagen and Malmö are two cities very close to the study area that has experienced extreme rain events within the last 10 years. BGI has been retrofitted to both cities in order to mitigate flooding and increase flood resilience. Methods that have been applied to both Copenhagen and Malmö are solutions that focus on the detention of stormwater such as concave green spaces like dry basins in multifunctional places, swales, or ponds. Efforts to implement BGI focusing on infiltration and conveyance are undergoing, both in Copenhagen and in Malmö (Stahre 2008; COWI et al. 2012; Sörensen 2018). After the flood that occurred in Copenhagen 2011, a lot of time and effort has gone into creating a new strategic plan to manage extreme rain. This plan identifies that BGI is an important factor to achieve a flood resilient Copenhagen. However, creating paths that the runoff water can use without generating damage is important as well. This is being done in Copenhagen by so-called “cloud-burst roads”. These roads will convey the runoff water to chosen destinations such as the sea, storage ponds, canals, or retention basins in parks. The research that has been going on in Copenhagen shows once again the importance of cooperation between different methods and stakeholders (COWI et al. 2012).

In Malmö, a project between a housing company, MKB, and the city of Malmö has been done in Augustenborg. The idea of the project was to retrofit Augustenborg with BGI to manage stormwater directly at the source as well as dealing with all the excess water in open drainage systems. To increase the permeability in the area, green roofs were implemented. The runoff water from the green roofs goes into a concrete canal with wetland weeds in the canal as well as a mini-wetland. The water from the canal leads into two different sets of storage ponds. Furthermore, there is both a swale and a third pond in the area as well (Stahre 2008). The project in Augustenborg has proven to be very successful. In 2014 when Malmö experienced a 100-year rain event, based on insurance claims, Augustenborg had less flood damage because of basement flooding compared to the surrounding areas (Sörensen and Emilsson 2019). Even if Augustenborg has a lot of green roofs, the reduction of damage is likely to mainly be due to the many areas that function as runoff detention. A study made in Augustenborg indicates that the green roofs used there can retain 9 mm of water before the runoff water from the roof equals the precipitation rate. One can, therefore, conclude that green roofs may be highly efficient at the case of a smaller rain event but may not significantly contribute to runoff reduction at the case of a severe rain event (Bengtsson et al. 2005). Woods-Ballard et al. (2007) concluded the same thing, that at a major rain event, green roofs may not perform better at reducing runoff than a normal roof. Permeable pavement is another option to reduce stormwater runoff. However, Sörensen and Emilsson (2019) conclude that it most likely would have a small effect in Augustenborg, mostly because of the underlying soil. Furthermore, Pappalardo et al. (2017) performed a study in southern Italy that indicates that green roofs perform better than permeable pavement.

As previously mentioned, the importance of connectivity and cooperation also affect the hydrological effectiveness of GI. One study shows that one single GI has a limited effect on urban runoff and that for GI to influence urban runoff in a significant way, integrated GI is required. When planning GI, it is therefore important to integrate multiple kinds of GI as well as carefully consider suitable locations for GI (Liu et al. 2014).

3. Method

3.1 TFM-DYN model

Hydrological modelling is commonly used to model and visualise flood risk. There are a lot of types of hydrological models with various functions that require different types of input data. MSB (2017) recommends municipalities to use a hydrological model based on solely elevation to only be used as a guide when identifying roughly what areas that are at risk for flooding. Models based on solely elevations are simple models to run but the result does not give a realistic view nor understanding to identify all areas that could be at risk. This simple type of model goes under the name elevation based flow routing (EFR) models (Nilsson 2017). When doing a more accurate flood risk mapping that can be used for urban planning, MSB (2017) recommends using a hydrological model with more parameters than elevation such as infiltration coefficients, friction coefficients and the stormwater drainage system. This type of model is called a physically-based hydrological (PHB) model. It is more advanced than the EFR but will give a more accurate result (Nilsson 2017).

For this thesis, a hydrological model called triangular form-based multiple flow dynamics (TFM-DYN) model was used (Pilesjö and Hasan 2014). The TFM algorithm is a type of PHB model with input parameters such as elevation, infiltration, friction, stormwater drainage systems and precipitation. The input data for the model is raster data generated by different cells. The TFM-DYN estimates overland flow over one raster cell by dividing the cell into eight triangular facets. From the original cell, the overland flow is distributed to one or more of the eight neighbouring cells. The result is an accurate estimation of an overland flow path. The TFM model is less complicated and better performing compared to other commonly used models (Pilesjö and Hasan 2014). The TFM-model uses data that often is easily available or easy to compute. The model used in this thesis is dynamic because one can with such a model analyse each time dimension or time step for the model. This means that the model creates a result for each decided time step (Nilsson 2017). One can, therefore, analyse the water depth over time.

The input data for the model is limited to raster data, commonly processed in a geographical information system (GIS). The different datasets used in this thesis are described in the next part of the thesis called ‘3.2 Input to TFM-DYN model’ as well as being visualised in Figure 3. The output from the model is raster data of water depths or velocity, it therefore requires the use of GIS for being visualised. Thus, as both the input and output are in the form of GIS data, the TFM-DYN model is user friendly. GIS data makes it is easier to visualise and analyse the data (Nilsson 2017). For this thesis, the data layers were prepared in ArcGIS Desktop 10.5 using the application ArcMap (Esri 2016). To run the model, the software Python has been used for this thesis (Python Software Foundation, 2020). However, the TFM-DYN model has several codes for different programming languages available.

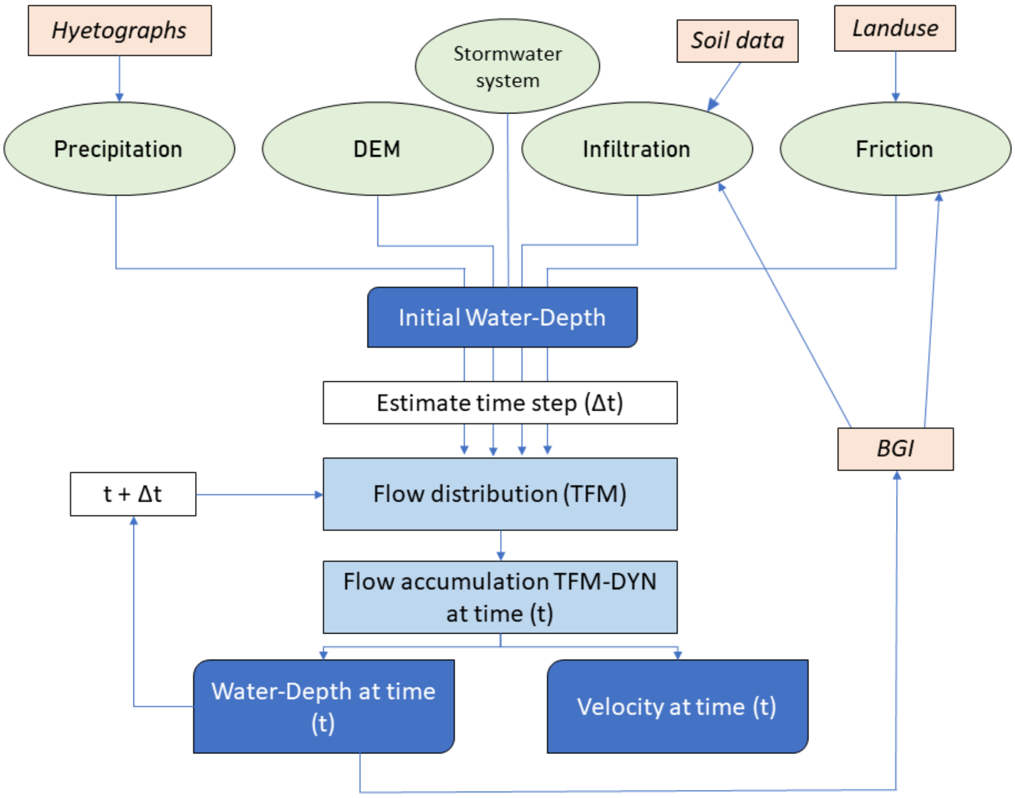
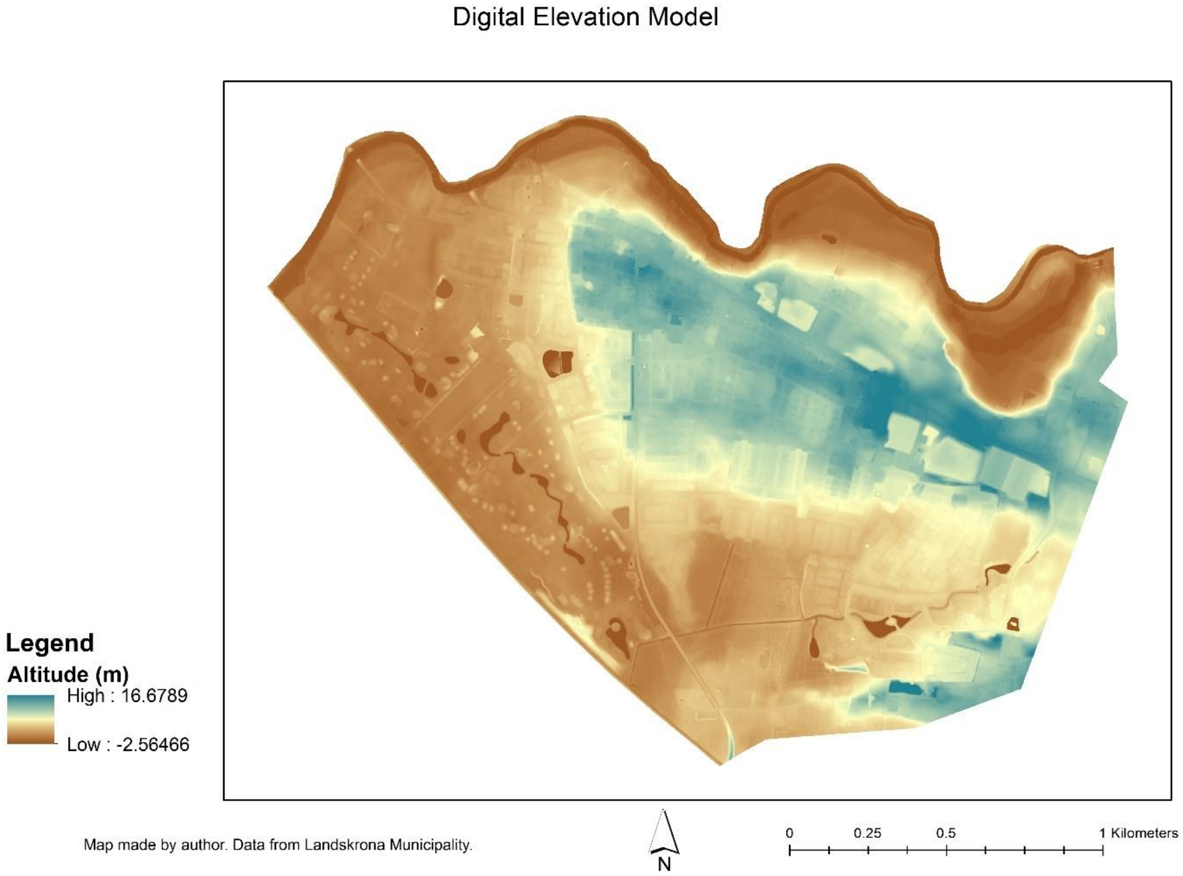


Figure 3: A visualised process of the input and output layers of the TFM-DYN model as well as the implementation of BGI. Adapted from Pilesjö and Hasan (2014).

3.2 Input to TFM-DYN model

3.2.1 Digital Elevation Model

The digital elevation model (DEM) used in this model was provided by Landskrona municipality. The DEM was created by using Light Detection and Ranging (LiDAR) technique. The scanning took place in 2014 and resulted in a DEM with a 1x1 meter resolution as shown in Figure 4. The format of the DEM was an ASCII-file, the height system was RH 2000 and the projection SWEREF 99 13 30 (Gullin, pers. comm). The DEM is crucial for the TFM-DYN algorithm as it determines the surface elevation for each of the cells. The slope and aspect in each facet in the DEM are what determines the overland runoff flow paths thus what areas are going to be flooded (Nilsson 2017).



Map made by author. Data from Landskrona Municipality.

Figure 4: A map with the DEM used for the model showing the altitude in Häljarp

3.2.2 Infiltration

The grounds infiltration capacity is an important aspect as it decides how much water is going to accumulate after a downpour. It is the soil that contributes the most to the infiltration capacity on permeable surfaces as the infiltration rate depends on the soil texture (MSB 2017). A soil map was downloaded from SLU’s Geodata extraction tool. The digital soil map was created by Sveriges Geologiska Undersökning (SGU) and is called “Jordarter 1:25 000-1:100 00” (SGU 2014). A vector layer of buildings in Häljarp was provided by Landskrona Municipality (Gullin, pers. comm). SLU’s Geodata extraction tool was used to download a vector layer of roads and other thoroughfares made by Lantmäteriet (Lantmäteriet 2020).

Infiltration values were assigned to each of the soil types in ArcMap. The final layer includes the addition of impermeable surfaces such as roads and buildings with an infiltration rate of null. In consultation with my supervisor, 20% of the infiltration rate was deducted from the final values to account for the decrease in infiltration intensity over time. The values used for the infiltration layer is seen in Table 2. The final layer used in the TFM-DYN model is shown in Figure 5.

Table 2: The infiltration values used to model the infiltration rate.

Type	**Infiltration rates (mm/hr)** (Larsson 2002; Savva and Frenken 2002; Aziz et al. 2017)	**Final values** (mm/hr)
Sand – different types	30	24
Fine sand	25	20
Clay loam	10	8
Sandy clay loam	7	6
Fine clay cloam	5	4
Peat	56	45

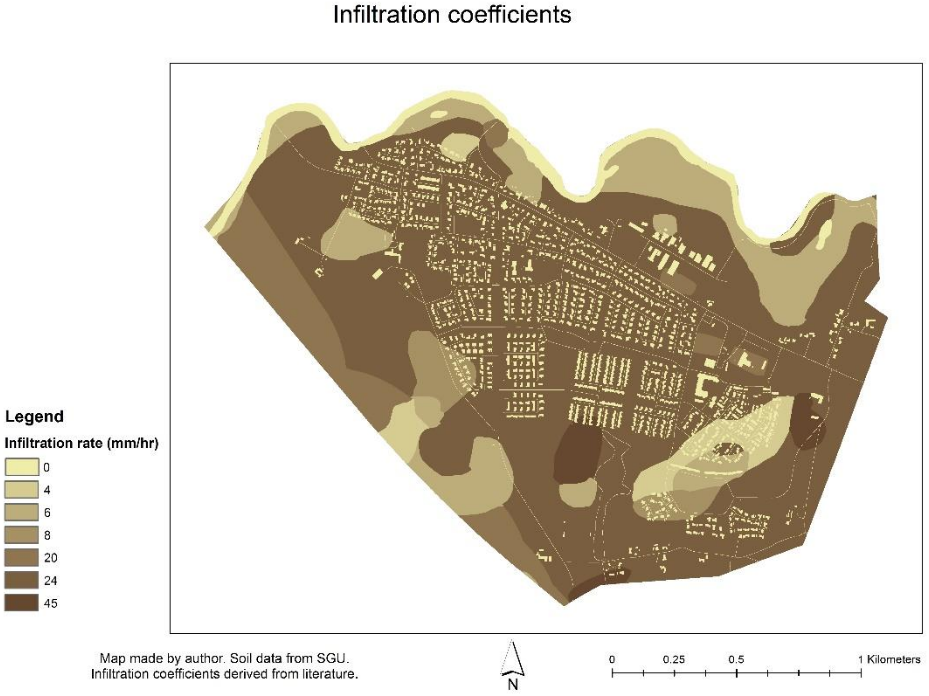


Figure 5: A map showing the final infiltration values used in the model

3.2.3 Manning's coefficient

Manning's coefficient is a measurement of friction. The friction value depends on the surface roughness and therefore on land cover. The surface roughness, or the friction, determines how fast water flows over a surface. Manning's coefficient is calculated by using Manning's equation (Risberg 2015). The friction values for different land cover types used in this thesis are based upon two different publications Risberg (2015) and McCuen (1989). The average of these two publications is used, see Table 3.

To create a friction layer, the land cover map was downloaded from SLU's Geodata extraction tool. The land cover map, GSD Fastighetskartan Vektor – Markdata, is made by Lantmäteriet and is continuously updated (Lantmäteriet 2020). Previously mentioned vector layers of buildings and roads were overlayed with the land use data. The average friction values were assigned to the different types of land cover in ArcMap as seen in Figure 6.

Table 3: The average Mannings coefficient is used to model the friction rate and was derived from two different publications.

Land cover	Trafikverket/WSP (Risberg 2015)	(McCuen 1989)	**Average used**
Buildings:	0.02	0.01	0.015
Roads:	0.02	0.01	0.015
Gardens/grass:	0.025	0.15	0.07
Wetlands:	0.05	-	0.05
Agriculture:	0.05	0.15	0.1
Coniferous:	0.2	0.4	0.3
Deciduous:	0.2	0.4	0.3
Field:	0.05	0.2	0.1
Water:	0.025	-	0.025

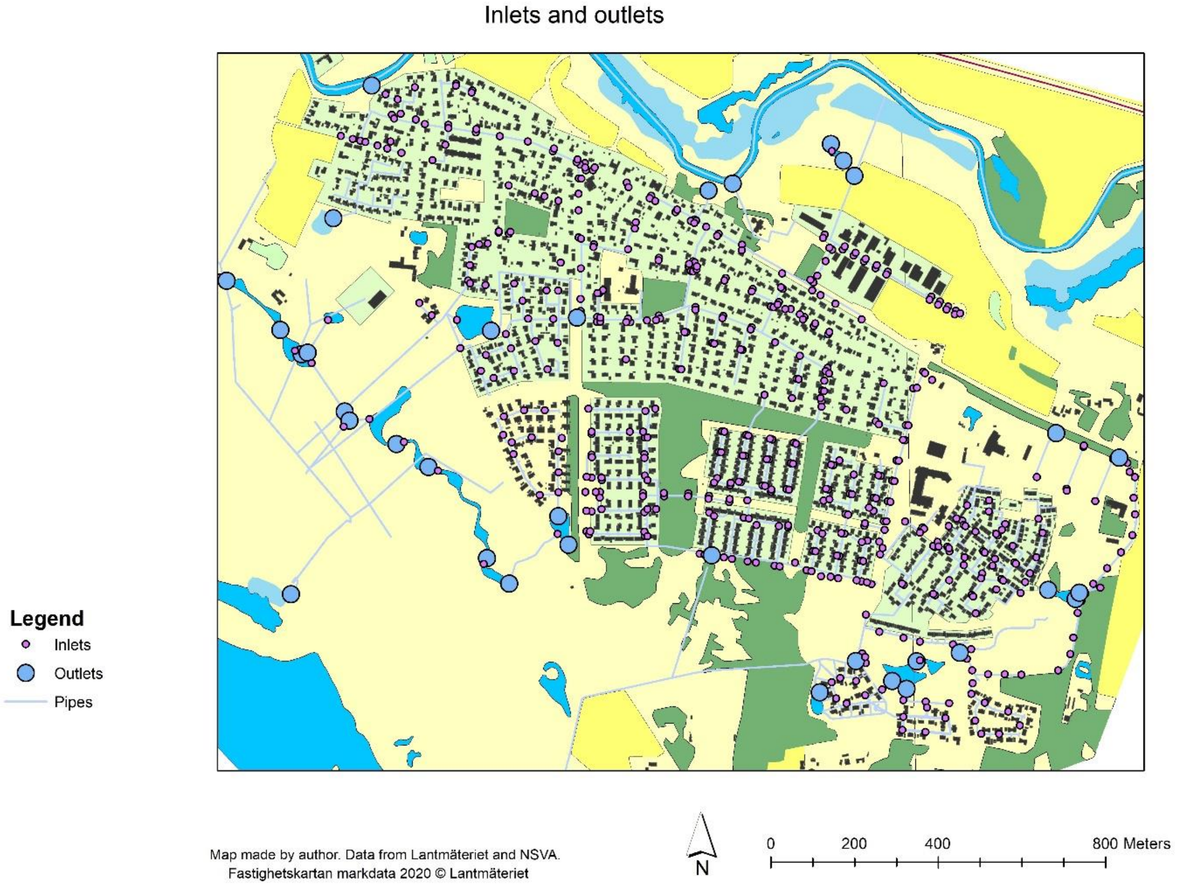
Figure 6: A map showing the friction values used for input to the model.

3.2.4 Inlets and outlets

Data for the stormwater drainage system in Häljarp was supplied by Nordvästra Skånes Vatten och Avlopp (NSVA). NSVA is also responsible for the stormwater drainage system in Landskrona municipality. The data received from NSVA was shapefiles of pipes, inlets and outlets. Most of these are owned by NSVA but some have other owners (Helmin, pers. comm.).

The data was processed in ArcMap 10.5.1. As there were excess data with no function for this thesis in the data set, this was removed and only the inlets and outlets with a purpose suitable for this thesis were left in the dataset. By looking at the pipes, each of the inlets connecting to an outlet via the pipes was assigned to the outlet as the inlet’s destination. The final layer with inlets, outlets and the pipes connecting inlets to outlets are shown in Figure 7.

The inlets were assigned an average capacity. This capacity is based on a calculation from a study made in a residential area in Lund. In the calculation, the total impervious area, rain intensity and the number of inlets are used. Based on this, the constant inlet capacity was calculated to be roughly 3.64 litres per second (Nilsson 2017).



Map made by author. Data from Lantmäteriet and NSVA.
Fastighetskartan markdata 2020 © Lantmäteriet

Figure 7: A map showing the stormwater drainage system in Häljarp.

3.2.5 Hyetographs

The precipitation input to the model was based on two different rain events: The downpour in Malmö 2014 and the downpour in Copenhagen 2011. For both scenarios, the model runs for an additional 30 minutes after the precipitation originally has stopped. This is done in order to see how water accumulates after the rain event.

The first scenario used was based on the rain that occurred in Malmö August 31st, 2014. In 24 hours, a total amount of 100,1 mm rain fell over Malmö. In this model, the total input is 73,5 mm over 135 minutes. The hyetograph is slightly altered to only have one peak, this to get a shorter rain event as this gives a more efficient run for the model. The rain event that occurred in Malmö 2014 is calculated to be a rain event with a 100-year return period (SMHI 2014). This rain event is therefore modelled as a 100-year rain that could occur in 2020 for the TFM-DYN model.

The second scenario is the rain in Copenhagen that caused vast pluvial floods on July 2nd, 2011. Copenhagen got a total amount of 135 mm of rain within two hours. For the model, the total level of input is 97 mm with the data is collected from a hyetograph (DMI 2011). The rain in Copenhagen is estimated to have a return period of 1000 years, it is, therefore, an extreme rain. It is common to use this rain when modelling pluvial flooding for municipalities in Sweden

(MSB 2017). In addition, the Malmö 2014-rain with a climate factor of 1.3 is very similar to the Copenhagen 2011-rain. Thus, this rain event is used for modelling a 100-year rain event year 2100.

Figure 8 visualises precipitation intensities that were used to model one scenario for the year 2020 and one scenario for the year 2100.

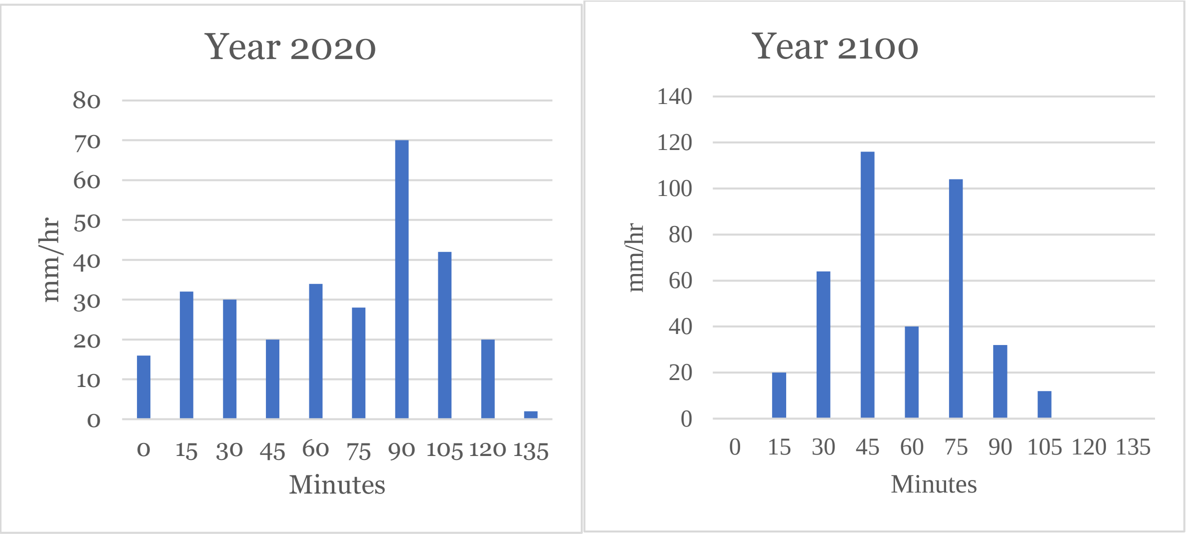


Figure 8: Hyetographs showing the precipitation rate used for input to the mode based on the weather events that occurred in Malmö 2014 and Copenhagen 2011.

3.3 Retrofitting of blue-green infrastructure

To evaluate the effectiveness of using BGI to mitigate flooding in Häljarp, BGI was incorporated in the infiltration layer. To find the most effective way to implement BGI, two different methods were used.

3.3.1 Retrofitting BGI in specific areas

The first method used was that BGI was incorporated at specific areas in the community. These areas were chosen as the focus was on implementing BGI at places that would be easy to access and would be cost-efficient for the municipality. BGI was therefore implemented on areas such as in parks, on the side of roads and open fields within the urban area. 14 areas in total were retrofitted with BGI and ArcMap 10.5 was used to do so, see figure 9 for the first location and figure 10 for the second location.

Two different types of BGI was implemented as they were judged as being efficient, cost-effective, and easy to retrofit into already existing urban areas. Rain gardens were implemented with an infiltration rate of 100 mm/hr. A rain garden can both retain the water as well as clean it from pollution. Rain gardens are also aesthetically pleasing and increase biodiversity (Stockholm Vatten och Avfall 2017b). Furthermore, infiltration trenches were implemented with an infiltration rate of 50 mm/hr. Infiltration trenches functions equally to rain gardens but are easier to implement closer to roads and in smaller spaces (Stockholm Vatten och Avfall 2017a). The final layer with the two locations where the changes to the infiltration layer were made is shown in Figure 9 and 10. As previously mentioned, the location was chosen because of it being public land that would be easy to alter, such as parks. The shape and size of the BGI are supposed to represent rain gardens and infiltration trenches. Rain gardens were implemented in spacious areas, infiltration trenches were implemented in areas where space was limited for example by the side of roads.

When analysing the result, five random points were chosen from where BGI has been implemented and the average mean water depth was calculated and analysed.

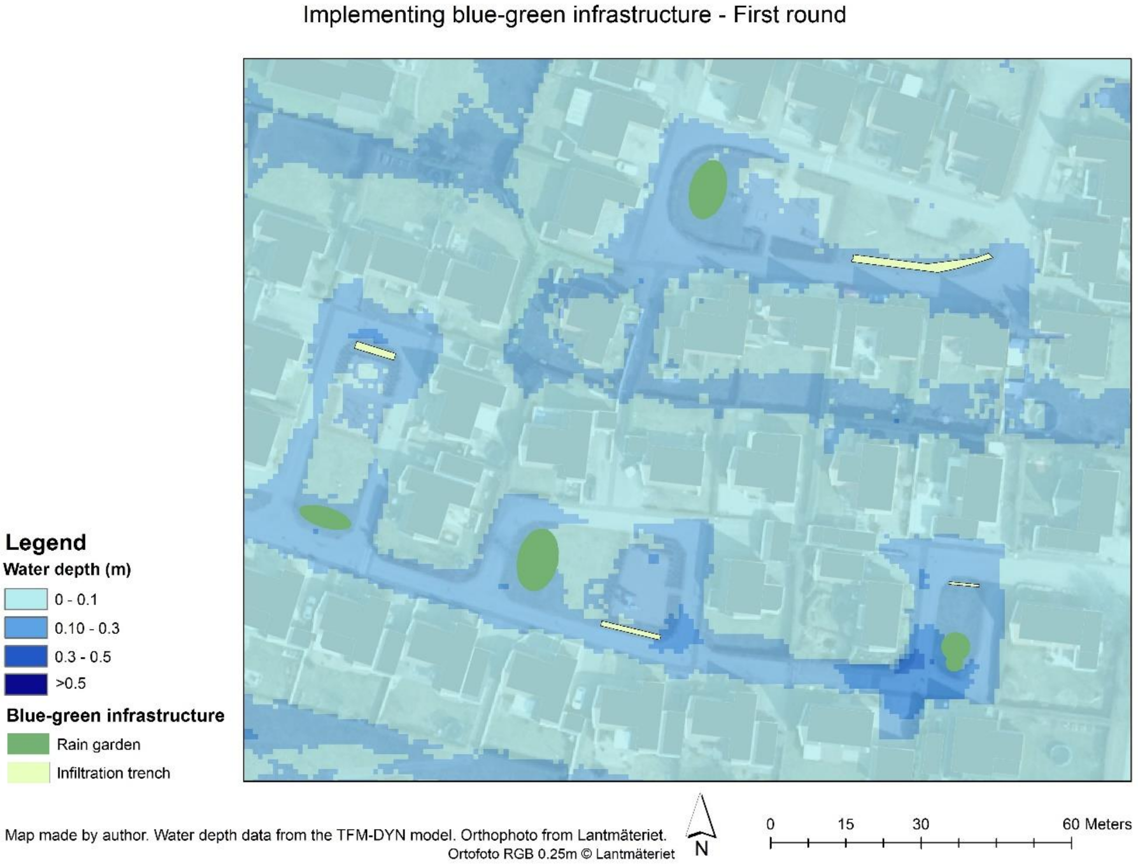


Figure 9: A map showing the water depth after a future 100-year rain and the location of BGI retrofitted.

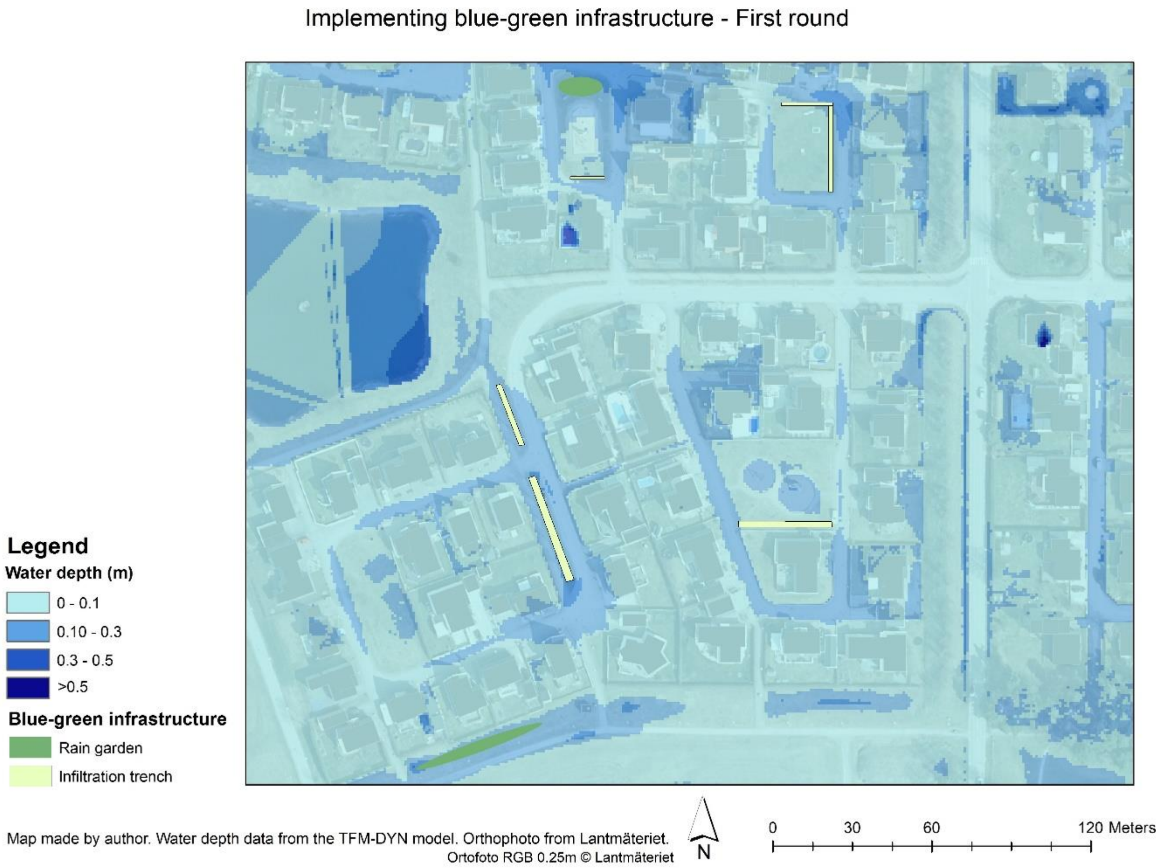


Figure 10: A map showing the water depth after a future 100-year rain and the second location where BGI was retrofitted.

3.3.2 Retrofitting BGI in areas with >30 cm flooding

The second method to retrofit BGI was to identify all locations with a water depth of more than 30 centimetres and an area bigger than 25 m^2. BGI was decided to be most effective in bigger areas with higher water depth. Areas smaller than 25 m^2 was excluded both because of the small area but also because they were judged often be outliers due to errors in the DEM. To choose all areas reaching the criteria in the study area, ArcMap 10.5 was used. After every area was identified, the infiltration rate was changed to 100 mm/hr, corresponding the infiltration rate of a rain garden. Some of the areas where changes to the infiltration layer occurred are visualised in Figure 11.

When analysing the result, nineteen random points were chosen from where BGI has been implemented and the average mean water depth was calculated and analysed.

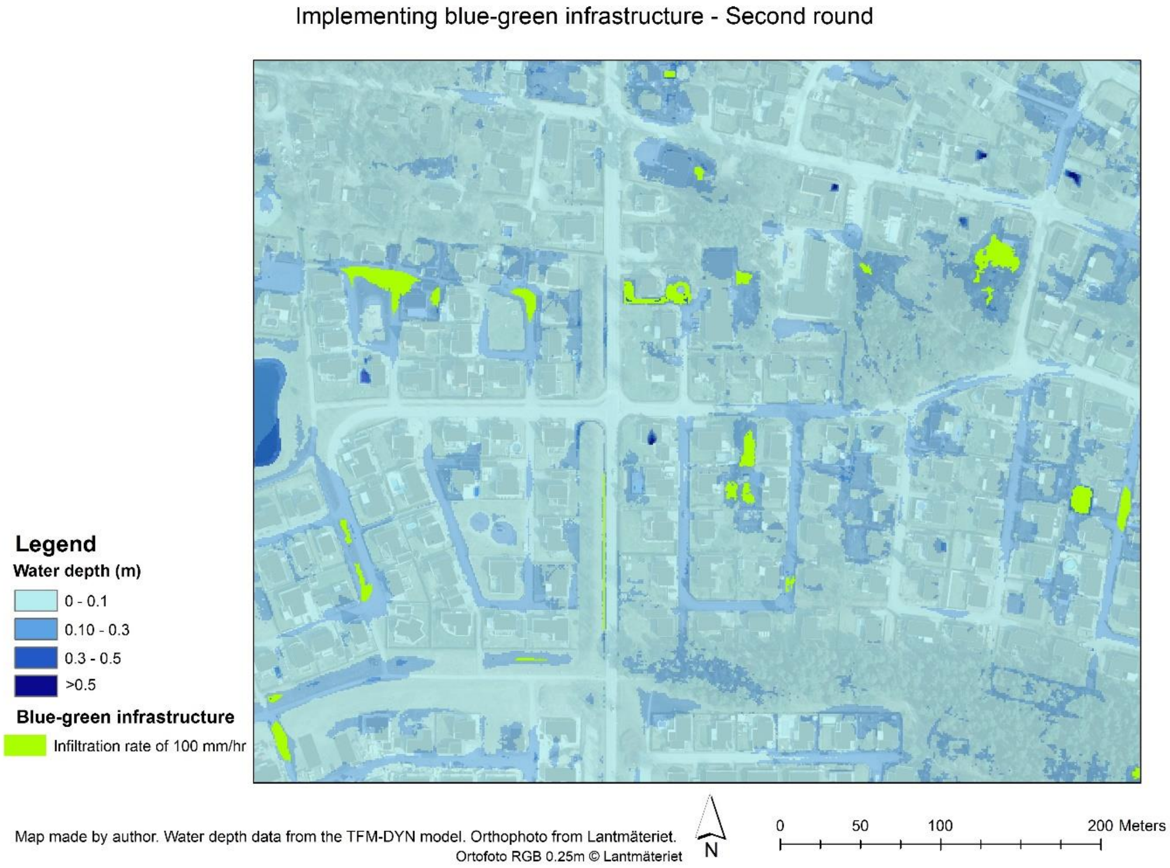


Figure 11: A map showing the water depth after a future 100-year rain and a part of the study area where BGI was retrofitted in areas with more than 30 cm flooding

4. Results

4.1 The flood risk in Häljarp

When using the TFM-DYN algorithm to model and visualise the flood risk in Häljarp, the results indicate that Häljarp is of risk for flooding, both at current circumstances and in future circumstances. Both private land and impermeable areas like roads are at risk for flooding. Analysis of modelling results was performed in Microsoft Excel (2003). The result for a 100-year rain occurring in the year 2020 shows that 10% of the total study area would be under more than 10 cm of water. For a 100-year rain year 2100, the same calculations show that 23% of the area would have flooding of 10 cm or more. When visualising the result, one can clearly see that a 100-year rain in 2100 likely would cause more damage because of the higher average water depth as seen in Figure 13. However, there is still substantial flooding for a 100-year rain that could occur at current circumstances, as seen in Figure 12 below.

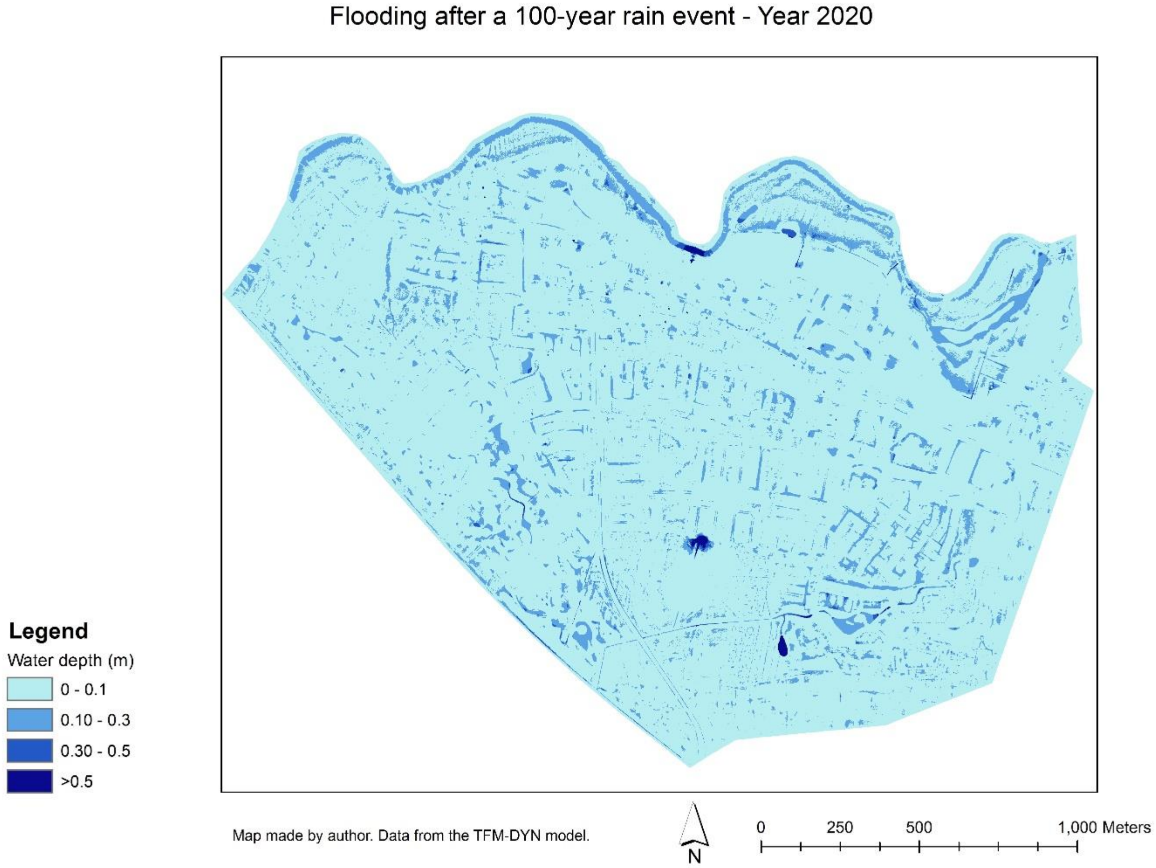


Figure 12: Map indicating the level of flooding in Häljarp at a 100-year rain event in current circumstances year 2020

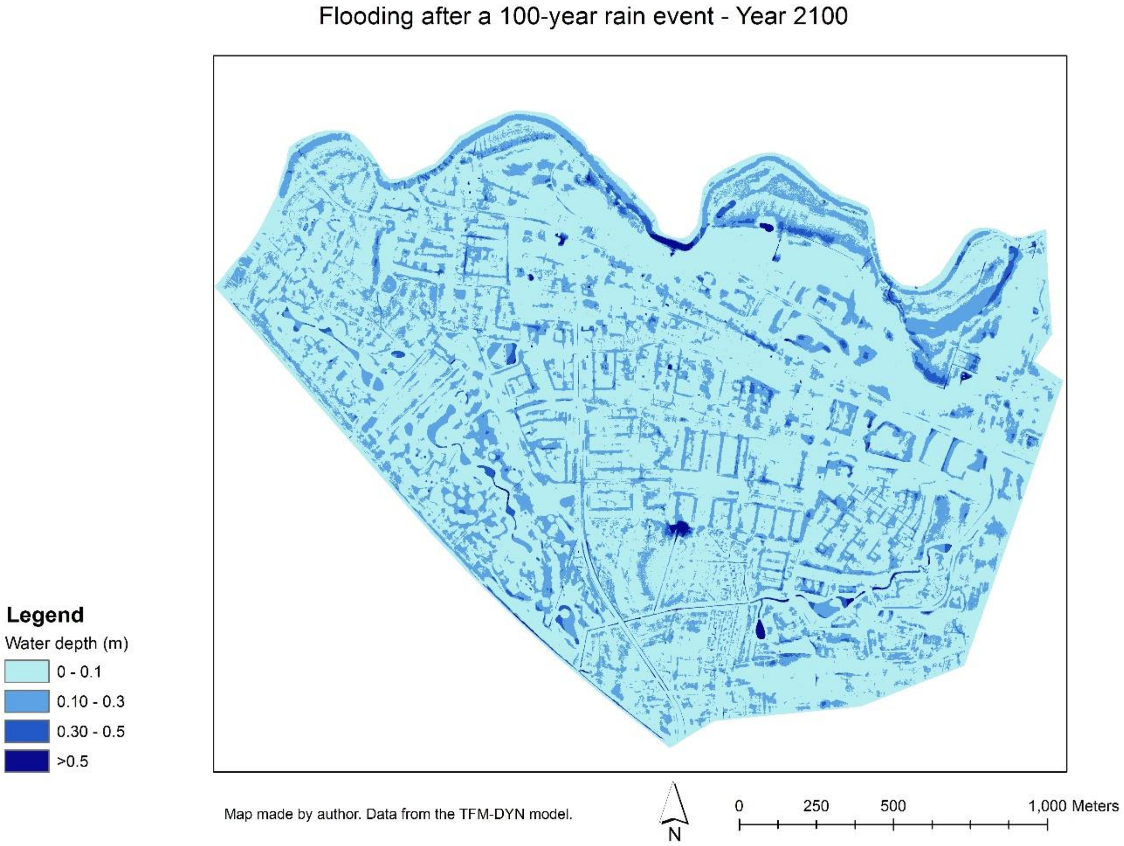


Figure 13: Map indicating the level of flooding in Häljarp at a 100-year rain event in the year 2100

4.2 The effect of using BGI

Two different ways to retrofit BGI in Häljarp were tested in this thesis, as described in section '3.3 Retrofitting of blue-green infrastructure'. Table 4 compares the flood depth before BGI versus after BGI has been retrofitted. It is calculated by using the change in the total number of raster cells within the specific categories of flood depth. As seen in Table 4, retrofitting BGI in small specific areas does not show a significant result. When using the result from the TFM-DYN to select locations, so when applying BGI to all areas with a water depth deeper than 30 centimetres, the result is considerably better with some categories having more than a 15% or even 20% reduction of areas flooded.

Table 4: The reduction of the number of flooded cells shown in percentage after BGI has been implemented.

Flood depth (m)	2020 – Specific BGI	2020 – BGI >30cm	2100 – Specific BGI	2100 – BGI >30cm
<0.1	0.18%	6.49%	0.06%	-0.08%
0.1-0.3	0.40%	23.29%	0.19%	16.51%
0.3-0.5	0.04%	8.09%	-0.03%	14.93%
>0.5	0.46%	21,23%	0.78%	8.09%

4.2.1 Result of retrofitting BGI in specific areas

As shown in Table 4 in the previous section, the result for applying BGI in specific areas was not significant. However, Figure 14 B below suggest that the average reduction of water depth after a 100-year rain occurring in 2100 was 1,3 centimetres for five separate locations where

BGI has been implemented. The average reduction of water depth meant that the average water depth for these five points where BGI had been implemented was reduced from 18,8 centimetres to 17,5 centimetres. The average reduction of water depth after a 100-year rain occurring in 2020 was 1,5 centimetres, from 10,3 centimetres to 8,8 centimetres as seen in Figure 14 A. The result is analysed and visualised by using Microsoft Excel (2003).

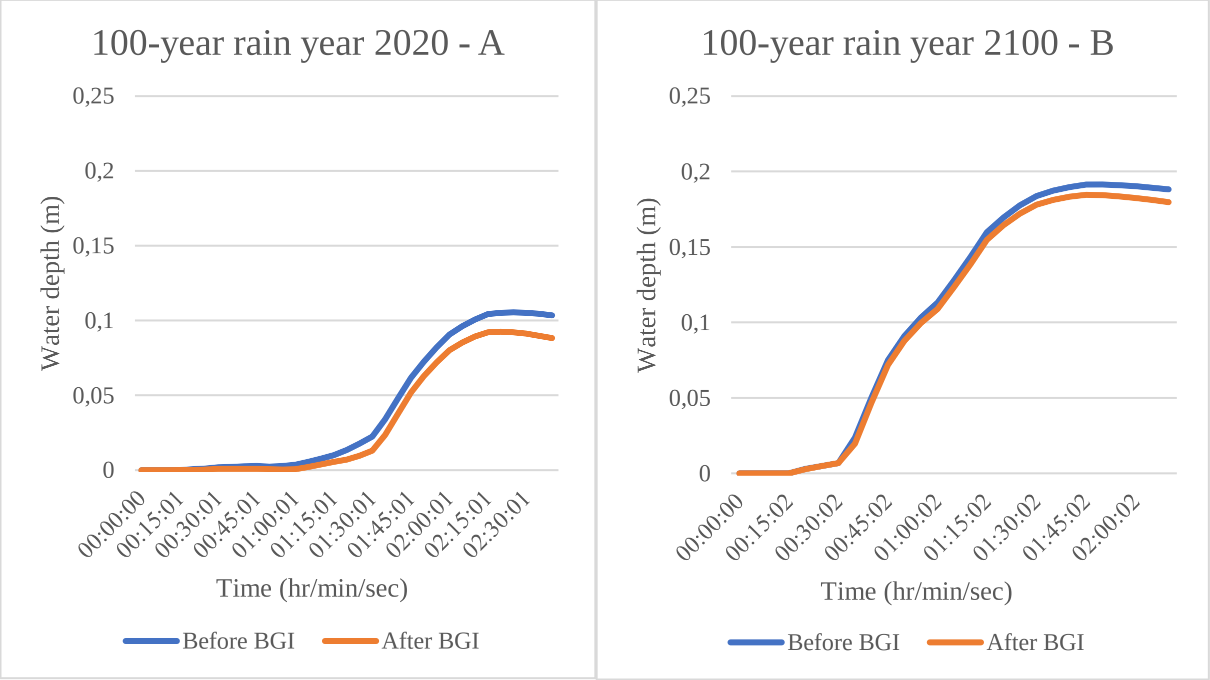


Figure 14 A and B: The average water depth for five different points before and after retrofitting BGI

4.2.2 Result of retrofitting BGI in areas with >30 cm flooding

When retrofitting BGI to all areas that fulfilled the criteria of being bigger than 25 m^2 and having flooding of deeper than 30 centimetres, flooding substantially decreased as seen in Table 4. The average water depth for 19 different points, with points selected where BGI has been implemented and with flooding above 30 centimetres after a 100-year rain in 2100, was 42,4 centimetres after a 100-year rain in 2100. After retrofitting BGI, the average water depth was 38,5 centimetres. The average reduction of flood depth for a future 100-year rain was therefore 3,9 centimetres as seen in Figure 15 B.

For a 100-year rain in 2020, the average water depth was 25,1 centimetres before retrofitting BGI. After the implementation of BGI, the average water depth was 18 centimetres. That is a 7,1-centimetre reduction in water depth. This is displayed in Figure 15 A as well as Figure 16.

The average water depths over time are displayed in Figure 15 A-B. Both calculations and visualisation are done in Microsoft Excel (2003). Figure 16 is visualised by using ArcMap 10.5.

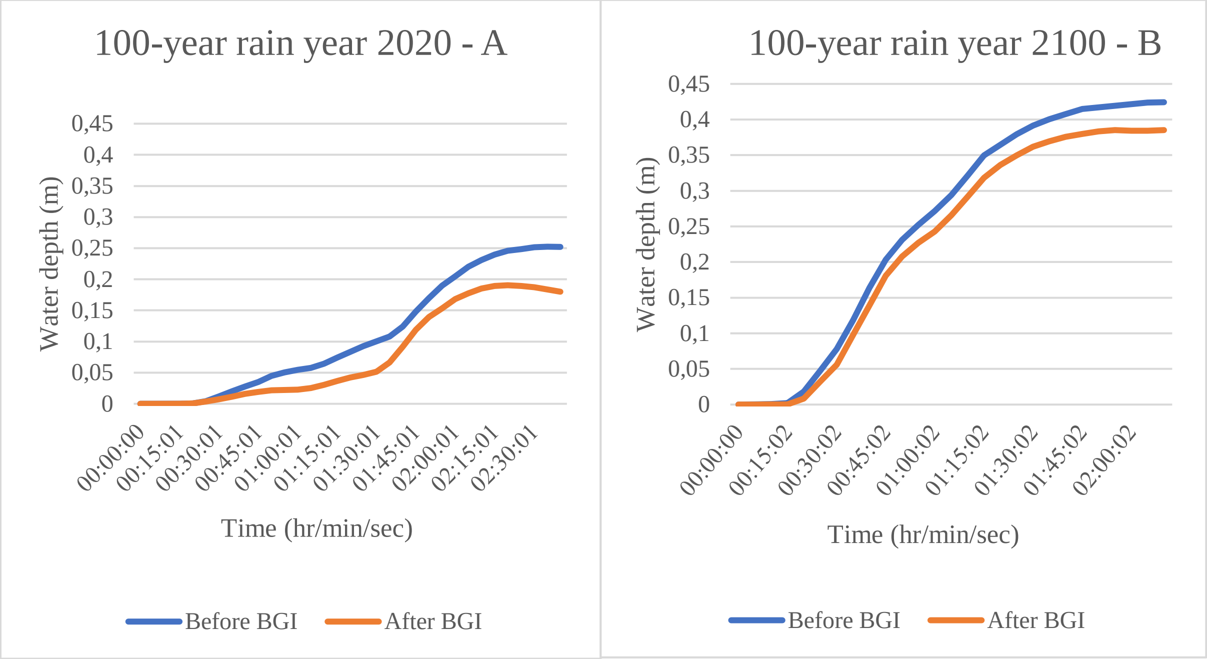


Figure 15 A and B: The average water depth for the nineteen different points before and after retrofitting BGI

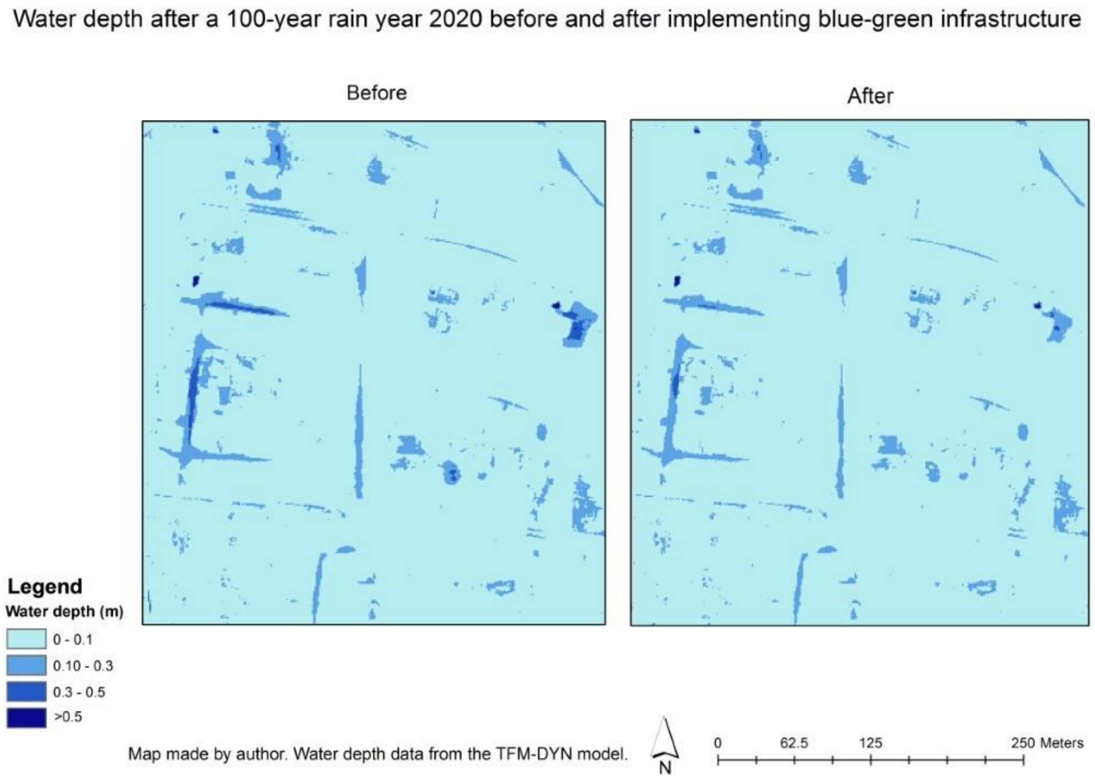


Figure 16: Two maps showing the water depth before and after BGI has been retrofitted for a rainfall occurring in 2020.

5. Discussion

5.1 The risk of flooding in Häljarp

The results from the hydrological modelling for Häljarp shows that there is a risk of flooding in Häljarp, both after a 100-year rain for the year 2020 and a 100-year rain with a climate factor of 1.3 applied, so the magnitude of a 100-year rain event occurring in the year 2100. As seen in Table 1, the water depth does not have to be deep for it to severely affect society. A water depth of 10 centimetres is enough to cause issues for the traffic as it can be difficult to drive through. A water depth of more than 30 centimetres is enough to cause severe risk for damage on infrastructure and buildings (Lunds Kommun and VA SYD 2018). For the rain in 2020, 10% of the area studied has a water depth of 10 cm or more. As seen in Figure 12, most likely parts of that flooding would occur on roads possibly causing issues for transportation in the area. For a 100-year rain occurring in 2100, the flooding would most likely cause severe issues for the traffic as well as potentially damaging buildings or infrastructure such as roads. Figure 13 shows how flooding is distributed over the area. One can see that the roads are where the deepest flooding would occur. The total area that is under more than 10 centimetres of water would be around 23%.

What is simulated to happen in Häljarp is not uncommon, infrastructure for transportation such as roads is often severely damaged after a major flood. After the flooding in Copenhagen 2011, it took three days until the roads could be used as regularly. The flooding in Copenhagen also severely affected other transportation systems such as public transport. However, the major damage made by the flooding in Copenhagen was done on buildings. Based on insurance claims, the flooding is calculated to be the most expensive weather event that has occurred in Europe (Beredskabsstyrelsen 2012).

The focus for this thesis is rain events with a return time of 100 years. However, even a rain event with a very short return time can cause a lot of damage if the rain is very intense. This is as the return times for rain events most commonly are based on how much precipitation has occurred in one day. An example of this is a rain event that occurred in Norrköping in 2011. 800 buildings got damaged because of basement flooding. If one looks at the return time for the Norrköping rain calculated on a 24-hour basis, the return time is only one year. Thus, return times on rain events are not necessarily directly in proportion to the damage they can cause (Hernebring and Mårtensson 2013). As these very short but intense rains are said to increase because of climate change, urban areas need to increase their flood resilience (Olsson et al. 2017).

5.2 Retrofitting of BGI, is it worth it?

Green solutions are an increasingly popular way to reduce flooding and BGI’s positive effects, both regarding flood reduction and social benefits, has been proven in many studies using different methods and seen from different aspects (Stahre 2008; Liu et al. 2014; Pappalardo et al. 2017; Schifman et al. 2017; Sörensen 2018; Sörensen and Emilsson 2019). A study done by Berndtsson et al. (2019) identifies that one of the drivers for increased urban flood risk is a decrease in permeability. This driver is viewed as highly manageable for cities and BGI is one way to counteract a decrease in permeability. Thus, BGI could be a key factor when urban areas need to adapt to climate change.

5.2.1 The results from the TFM-DYN model

This thesis aimed to see if there was hydrological proof that BGI could reduce the flood risk in Häljarp. This was done using two different methods. In the first method, BGI was implemented on selected areas that would be easy for a municipality to retrofit BGI on. Examples of areas could be for example green public spaces such as parks or on the side of roads. The result for this method was not substantial as there was only a slight reduction in flooding as seen in Table 4 and Figure 14 A and B. In Figure 14 A and B, it is shown that there is a slightly higher reduction of water depth for the 2020 rain, that is the rain with a lower precipitation rate. However, as previously mentioned, this result is not substantial, and one should therefore not draw conclusions from it. Furthermore, this supports a study made by Liu et al. (2014) where they concluded that in order for BGI to be effective, it is important that the BGIs are interconnected when being implemented. One single unit of BGI does not make a significant difference.

In the second method, all areas with flooding over 30 centimetres and with an area bigger than 5x5 metres were chosen. These criteria were chosen to make sure that BGI was implemented in the areas most significantly flooded and that the areas were big enough to test the effect of BGI. The criteria of the area also made sure that errors due to the DEM was eliminated. The errors eliminated could be for example smaller sinks in the DEM, such as swimming pools or house constructing at the time of the lidar scanning, that caused small areas of deep water depth in the model output. In reality, these are examples of areas that may not be flooded at all after a big rain event. The result for this method turned out to be much more efficient compared to the first method, see Table 4 and Figure 15 A and B. It is also likely that this method worked better as it was bigger areas that were implemented as BGI, as seen in Figure 11. This probably caused better connectivity between the areas of BGI allowing them to work more effectively.

Figure 16 shows the reduction in water depth after retrofitting BGI. As seen, it is primarily the water depth that is reduced, not the extent of the area flooded. As seen in Table 4 for the 2020 rain, the biggest reduction of water depth occurs in the category of more than 0.5 metres water depth and the category of 0.1-0.3 metres water depth, with a 23,29% respectively 21,23% reduction. This is especially interesting as BGI was not retrofitted to areas with a water depth of less than 0.3 metres so the areas within the category of 0.1-0.3 had no BGI directly implemented, but BGI still had a big impact in that category. The biggest reduction for that category likely occurred in areas close to where BGI had been implemented. As previously described, 19 locations were selected where BGI had been implemented. The average reduction of water depth for these 19 points in different areas was 7,1 centimetres for the 2020 rain as seen in Figure 15 A. The average reduction of water depth was calculated to visualise the effects of BGI.

When increasing the precipitation rate and amount of total rainfall, as done in the modelling for a future 100-year rain, the average reduction of water depth for the same 19 points in different areas, is reduced with an average of 3,9 centimetres compared to before BGI was implemented. This is visualised in Figure 15 B. When looking at the reduction in each category of water depth, see Table 4, most of the reduction of water depth, around 15%, occur in the 0.1-0.3- and 0.3-0.5 metre categories. The decrease in reduction rate compared to the 2020 rain is probably due to the intense rainfall in 2100 as the precipitation rate significantly exceeds the infiltration rate. This also causes a very high average water depth; the average water depth for the 19 points is 42,4 centimetres before BGI is retrofitted. The trend is therefore that BGI works better for less intense rain events, but it will still be the source for a noteworthy reduction in flood depth for more intense rainfalls.

5.2.2 The use of BGI in this thesis

BGI does not have a clear definition and there is, therefore, a lot of different ways of retrofitting green solutions to an area. What is common for all green solutions is that they strive to minimise runoff volumes and flow rates. BGI also tend to decrease pollution. Overland flow paths, land use, future management scenarios, requirements from stakeholders, risks and long-term effects should be considered when implementing BGI. However, the wide variety of solutions available provides a lot of options and opportunities for city planners (Woods-Ballard et al. 2007). The prime reason to retrofit BGI is to achieve a reduction of runoff water volumes (Pappalardo et al. 2017). This can be done in four different ways; infiltration, detention or attenuation, conveyance, and water harvesting (Woods-Ballard et al. 2007).

For this thesis, the focus was on rain gardens and infiltration trenches when retrofitting BGI to Häljarp. Rain gardens and infiltration trenches foremost focus on infiltration but to some parts detention as well. They are both easy to implement in an already urban area as they are space- and cost-effective as well as aesthetically pleasing. Rain gardens can with advantage be implemented in both public land as well as private land such as gardens. Infiltration trenches require less space and are cheaper than rain gardens. However, rain gardens are more effective both at reducing runoff water and decreasing pollution (Stockholm Vatten och Avfall 2017b, a). Methods that require a bigger effort to change the area and elevation, such as concave green spaces, were not considered in this thesis. They would also require more work to be implemented in the model as it would require changes to the DEM-layer. However, this can be done using the TFM-DYN model.

To conclude, there are a lot of different strategies to mitigate flooding by using BGI, the most efficient way is highly dependent on the urban area and its conditions. Thus, when retrofitting BGI to an urban area, municipalities would most likely benefit from investigating and invest in more than one option in order to find the most efficient way to increase flood resilience. The usage of hydrological models such as the TFM-DYN model is beneficial when testing different options. Furthermore, studies show that the best way to reduce flooding is by integrating many different types of green infrastructure (Liu et al. 2014; Sörensen and Emilsson 2019). Just evaluating two types, rain gardens and infiltration trenches, as done in this thesis does only give an indicator of the potential of BGI has to mitigate flooding and adapt to climate change.

5.3 Limitations and errors

All models are highly dependent on their input data, and the results are only as good as the data that was used to calculate them. For this model, parts of the input data have high uncertainty. This thesis has been strongly based on the recommendations given for hydrological modelling by the Swedish governmental department Myndigheten för samhällsskydd och beredskap (MSB) in a report called 'Vägledning för skyfallskartering' (2017).

As mentioned in the introduction, the DEM used for the model was made from scanning in 2014. There is a risk that the elevation in the urban area has changed since then. Houses may have been removed and new residential areas may have been built. The DEM also includes some sinks, local depressions where water accumulates. Some sinks could exist because of for example building sites at the time of the scanning. Furthermore, the DEM does not take already existing bodies of water into account. This makes it difficult to model how precipitation is going to accumulate in bodies of water and if these bodies of water could be a source of flooding as well. Furthermore, another major limitation is that for this thesis, the TFM-DYN model did not take into consideration any area outside the study area nor initial conditions regarding the river. Upstream activity outside the study area that could cause flooding in the study area was not considered. Fluvial flooding is a very possible issue and a combination of fluvial and pluvial flooding could have serious consequences for Häljarp.

For the infiltration layer and friction layer, no on-site measurements were made. The coefficients for the categories are solely based on maps of soil respectively land use. Assumptions of homogenous coefficients within each polygon in the data layers were made. Even if this is within the guidelines for how MSB (2017) recommends hydrological modelling to be performed, it is not an ideal representation of reality. Especially for the infiltration values, MSB is aware that they may differ severely within areas of the urban area. When preparing for the construction of new residential areas, the soil is heavily altered and affected. The original soil may be removed and new soil with completely different attributes may replace it. The infiltration capacity of soil also highly varies depending on the specific hydrological conditions at that moment. Depending on if the soil is dry or if it is water-filled, it may behave very differently. Infiltration values also vary with the land cover. Despite this, the recommendation in Sweden is to base the infiltration capacity on the original soil in the area by using a soil map (MSB 2017). The friction layer is based on land use but has similar problems as the infiltration layer. For discussion about the stormwater system capacity, see the introduction (1.3 Delineations and limitations) as well as the method (3.2.4 Inlets and outlets).

As previously mentioned in the discussion, BGI is dependent on inter-connectivity and a diversity of different types of green solutions. In this thesis, there are only two different types of BGI that are considered, and they are only retrofitted in locations where there already is a flood. Retrofitting concave green spaces in a combination with BGI may have produced a very different result.

5.3.1 Future studies

Apart from the error discussion above, where the complexity of the input layers could be improved as well as the integration of activity outside the study area such as fluvial flooding, it is also important to calibrate the model. When looking at more extreme rains, the most important factor for the model is the infiltration capacity. The model would, therefore, benefit from more accurate infiltration coefficients. To achieve this, on-site measurements have to be done. In the case of flooding, one can also calibrate the model by collecting precipitation data and water depth data. This was made for a model in Malmö in 2014 and it was concluded that the average error for water depth was 6 cm. In order to calibrate and verify the model, the network of precipitation gauges must be well developed as precipitation may be highly spatially variable (MSB 2017).

The TFM-DYN model could also be further developed to change the infiltration rates according to a predefined function depending on the water-depth existing in the cell. This function would make it easier for urban planners to see the effects of BGI.

6. Conclusion

This bachelor thesis aimed to investigate the possibility of using blue-green infrastructure to mitigate the risk of flooding and increase flood resilience in the town of Häljarp situated in Landskrona municipality. The investigation has been done by using the TFM-DYN model and through GIS analysis. Two different temporal scenarios have been considered in this thesis, a 100-year rain event in the year 2020 and a 100-year rain event in the year 2100.

By looking at the result, both for a current and a future 100-year rain event, one can conclude that there is a flood risk in Häljarp. For a 100-year rain scenario in 2020, 10% of the study area is going to have a flood depth of more than 10 centimetres. For a 100-year rain scenario in 2100, 23% of the study area is going to have a flood depth of more than 10 centimetres. Consequently, the municipality should act in order to avoid severe damage on infrastructure, to mitigate flooding and to increase flood resilience in Häljarp.

BGI has been retrofitted to areas with a flood depth deeper than 30 centimetres and as a result, the water depth was significantly lower in those areas. The result was more significant for the 2020 rain event and one can, therefore, conclude that BGI seems to be more efficient for reducing water depth after less extreme rain events. However, BGI is proven to be efficient to decrease flood risk at all magnitudes if carefully positioned and integrated into the urban area. Furthermore, the literature study showed that BGI has many positive effects for the community such as increasing citizen’s well-being and increasing the biodiversity in the area. BGI could, therefore, be an effective multi-purpose solution for municipalities wanting to mitigate flooding, increase flood resilience and adapt to climate change.

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