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Urban Flooding in Ljungby Municipality

the Effectiveness of Blue-green Mitigation Measures Using the Software SCALGO Live

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Abstract

One of the realized consequences of climate change is a shift in precipitation patterns and an increase in extreme rainfall events. In addition, the growing urbanization trend associated with population and wealth growth has led to an increase in impervious surfaces while reducing groundwater recharge. In Sweden, it is expected that by the end of this century, annual precipitation will continue to increase, thereby increasing the possibility of urban flooding risks.

Ljungby city suffered a heavy rain on August 10, 2020. The rain event was about 70 mm in one hour. The event was estimated to have a return period equivalent of about 120-140 years, which caused many floods in the basements of private houses and public places.

This is an important investigation, but it will be more interesting to look at measures to ensure that similar floods do not occur again. Due to climate change, heavy rain will become more common. The area's most severely affected by floods can be delineated. Environmental measures to prevent similar floods from happening again can be proposed. In the future, how will Ljungby City adapt certain areas of the city to avoid similar flooding?

The main purpose of this thesis is to provide decision support for the implementation of Ljungby climate change adaptation strategy to reduce the risk of urban flooding caused by extreme rainfall events in the study area and the ability of blue-green solutions to manage climate impacts, and create and support ecosystem services.

In addition, the work of this thesis also supports municipality in formulating and investigating strategies to adapt the climate change to reduce or eliminate urban flooding risks in the two research areas of Lagan and Torsgatan street.

According to Scalgo Live, there is a high risk of flooding in the study areas that mainly affect residences and residential streets. It is recommended to take appropriate blue-green measures to regulate the rainwater runoff in the upstream and downstream areas.

Flooding in basements mainly comes from the rainwater pipe system and the leakage of the sewage pipe system, which are vulnerable to the high-

water level in the condition of heavy downpour. If waste water is spilled into the environment, heavy rain and improperly designed rainwater systems may pose a threat to health and the environment due to floods.
Flooding often occurs, so it is recommended to change the current drainage system layout and check the old pipes of the sewer system and rainwater system.

Key words: blue-green solutions, climate change, hydraulic modelling, urban flooding.

Sammanfattning

En av konsekvenserna av klimatförändringen är en ökning av extrema regn. Kraftigt regn har blivit vanligare de senaste åren, troligen kommer nederbörden fortsätta att öka under kommande åren, säger forskarna.
Den 10 augusti 2020, föll ett kraftigt regn i Ljungby stad som orsakade många översvämningar i privata och publika områden.
Huvudsyftet med denna avhandling är att stötta de som jobbar med konsekvenser av klimatförändringar i Ljungby kommun och att ge nya effektiva strategier. De nya strategierna skulle kunna hjälpa anpassningen mot klimatförändringar för att minska risken för översvämningar i staden. Syftet med denna artikeln att föreslå blågröna lösningar till drabbade egendomar och försäkra att översvämningar inte händer i framtiden. Dessutom stöder arbetet kommunerna att utforma och undersöka strategier för anpassning till klimatförändringar i särskilda stadsområde som Lagan och Torsgatan. Översvämningar i källare kommer framför allt från regnvattenledningssystemet och avloppsledningssystemets läckage, de här systemen bruka ligga i högre vattennivå.
Bland annat ett stort hot mot hälsan och miljön kan uppstå när regnvatten i ett felaktigt regnvattensystem blandas ihop med avloppsvatten.
Rekommendationer i så fall är att byta ut närvarande ledningsnät och kontrollera de gamla rören i avloppsystem och regnvattensystemet.

Nyckelord: blågröna lösningar, klimatförändringar, hydraulisk modellering, översvämningar.

Table OF Contests

1- Introduction

Pluvial flooding refers to the accidental inundation of land caused by heavy rain that causes damage. When rainfall exceeds the drainage capacity of natural and artificial systems, low-lying areas will be flooded. Rainfall is the main reason of flooding. In urban areas, small floods can either be controlled or not controlled through the transportation and retention of rainwater in major and minor systems.

Pluvial flooding acts on a different scale than fluvial flooding (Sörensen & Mobini, 2017). In the present study in Ljungby City the percentage of impermeable surfaces such as asphalt, sidewalks, and buildings increases, so floods in the city are urban floods. Compared with natural land, the land use and drainage conditions in urban areas have undergone great changes. Due to widespread urban and suburban growths (Boelee et al., 2017), inadequate sewer systems (Naturvårdsverket, 2008) and climate change (Semadeni-Davies et al., 2008) floods may increase in the future.

Extremely heavy rains in a short period of time may cause flash floods and cause serious problems in cities and towns (SMHI, 2020).

Global statistics registered in EM-DAT show that floods can cause huge damage. It is the second natural cause of economic loss paid after storms, and it accounted for 47% of all weather-related disasters between 1995 and 2015 (CRED, 2015).

Sweden has been affected by downpours, although they were more common in the southern regions. There are a lot of evidences that the future downpour will become more serious. In warm climates, the atmosphere can hold more water, which creates conditions for more extreme precipitation. However, just like today's climate, the downpour will naturally vary (Swedish Portal for Climate Change Adaptation, 2021). A humid climate in turn increases the risk of flooding, landslides and erosion (Ljungby Kommun, 13.8.2020).

Further climate change leads to extreme weather conditions, and cities need to adapt and prepare for the disposal of heat waves, rainwater and other rainwater to make it sustainable, safe and resilient (SMHI, 2020). Climate adaptation usually means that cities can solve climate related issues without damaging infrastructure, buildings or people (Wamsler et al., 2020)

On August 10, 2020, Ljungby suffered a heavy downpour, equivalent to approximately 120-140 years of rainfall, with about storm event (70 mm) in an hour. This heavy rainfall has caused high flow and high-water levels in the county's waterways. This rainfall event caused a great damage in the city where SMHI has issued a Class 2 warning for high traffic in most parts of the county. And Class 3 warning has been issued to the lower part of Lagan. This means that the flow in these waterways is extremely high (updated on 2020/23/2, 12:10) (SMHI,2020).

In this rainfall event the water level outside the electric power plant in Ljungby reached up to the windows (SVT Nyheter, 2020).

A warning of Class 3 indicates an extremely high flow: On average, a high flow that occurs every 50 years, which can cause serious flooding problems.

A Class 2 warning indicates a high flow rate: On average, there will be a very high flow rate every 10 to 50 years. It causes flooding problems in vulnerable places (SMHI,2020).

Since conventional pipelines cannot handle rainwater management during rainy days or when rainy days are too long, they can be supplemented with blue-green solutions to create long-term sustainable rainwater management (Egerer et al., 2021). Climate adaptation to cities through sustainable rainwater management can also create ecosystem services for the benefit of plants, animals and humans (Wamsler et al., 2020).

In the future, climate change is expected to increase the risk of extreme weather, combined with both heavy rainfall and drought. When the storm water systems cannot face the water, they can cause landslides, avalanches and floods that cause injuries to buildings, roads, which is the worst-case scenario.

Due to climate change, heavy rains will become more common. The thesis studies the causes of flooding in the basement and studies the measures to ensure that such floods do not happen again. The area’s most severely affected by floods can be delineated.

Heavy rains together with improperly designed rainwater systems may pose a risk to health and the environment if waste water is spilled into the environment (Ljungby kommun, 2014). How can Ljungby city adapt certain parts of the city to handle similar heavy rains in the future?
The main purpose of the thesis is to provide decision support for the implementation of climate change adaptation strategies for Ljungby City to reduce the risk of urban flooding caused by extreme rainfall events in the study area.

1-1 Aim of the study

This work focuses on the ability of blue-green solutions to manage climate impacts and create and support ecosystem services. Planning by proposing blue-green solutions to help houses damaged by rainwater leakage in the basement and ensure that similar floods will not occur again in the future.
To achieve this goal, the following steps were considered:
-Develop rainfall and land use plans.
-Propose appropriate blue-green solutions in the study area.
-Proposed solutions based on existing science and engineering.
-Use the computer model (SCALGO Live) to study the effectiveness of the blue-green solution for selected extreme rainfall events.
-Test the resilience of the solution to more extreme rainfall events.

1-2 Limitations of the study

-Only overland flow is considered in the model, the pipeline or drainage capacity of the entire study area remains unchanged.

-The study only focuses on assessing the amount of water submerged; water quality considerations are outside the scope of this paper.

-The precipitation included in the hydraulic model is a representation of a 120-140 year rainfall events based on historical extreme rainfall events.

-Ljungby Municipality has restrictions, municipality cannot work to solve the flood problem in private property areas. Therefore, there is more than one proposed solution for many problems.

The main focuse is to study the characteristics of floods, namely, the upstream and downstream of the flood, the amount of water collected, and the speed of the flood are essential to reduce the risk of urban flooding.

2- Background

2-1 Climate change, urbanization, and urban floods

Rapid urbanization combined with climate change creates a mixture of still inseparable challenges (Alexander et al, 2019). Rising global temperatures due to climate change are expected to increase the intensity and frequency of extreme storm events (Seneviratne et al, 2012). In Sweden, precipitation is expected to increase during autumn, winter, and spring (Climate ADAPT,2007). This includes the area of western and south Sweden, according to the RCA4 regional climate model developed by the Swedish Metrology and Hydrology Institute, precipitation patterns are expected to increase over the centuries (SMHI, 2020,Climate Scenarios). Figure 1 shows the calculated change in annual precipitation in Kronoberg county compared to normal between 1961-2100. The bars show historical data from observations. Green bars show above-normal precipitation and yellow bars show below-normal precipitation. The black line shows the cumulative average of nine climate models for the RCP4.5 scenario. The gray area shows the range of variation between the highest and lowest value for community members.

Climate scenarios are generated using the RCA4 regional model, which is used with initial conditions from different global climate models (SMHI, 2020,Climate Scenarios).

It is assumed that the trend for change in the annual precipitation will increase the frequency of precipitation. These extreme precipitation events are marked by their return period. For example, an event of a 100-year return period is one of a magnitude that has 1% risk of happening within a year.

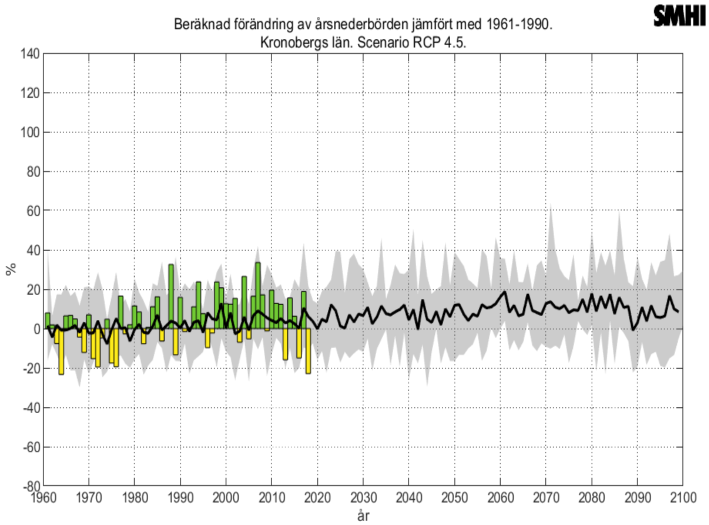

Figure 1 Estimated change in annual precipitation in the County Kronoberg until 2100 in comparison to reference period 1961-1990 (Image Source: SMHI).

Similarly, rapid urbanization leads to an increase in impermeable surfaces, such as sidewalks, roads, or roofs in urban areas, to a reduction in soil infiltration capacity and groundwater recharge. As a result, most of the water flows through the earth's surface, increasing the risk of inland flooding in the urban environment (T.I. Eldho, A.T. Kulkarni, 2018). In Sweden, most people live in urban areas at around 87% and the country is expanding rapidly, especially in the region of western Sweden, which accounts for 15% of the country's total development (SCB, 2018). This growing urbanization trend leads to the development of a denser urban space, which exerts high pressure on the urban environment and its rainwater drainage system (Wihlborg et al, 2019).

On the other hand, population growth and rapid urbanization are some causes of increasing floodplains in urban areas (Ligtenberg, 2017). In addition, climate change has major impacts on the water cycle and extreme precipitation patterns, and can thus directly affect surface runoff and flood frequency and the flood extent (Seneviratne et al, 2012). Therefore, with the increase in urbanization, which is further exacerbated by climate change, studies of flood mitigation measures are becoming more important as a form of adaptation to offset the risk of urban floods.

In a tropical monsoon climate, the normal amount of rainfall is considered extreme in a temperate or arid climate. Since the focus of this work is the flooding in Ljungby which is in southern Sweden, extreme precipitation is related to the climate of this region. According to the Koben-Geiger climate classification (Kottek et al., 2006) this region has a temperate climate with completely humid and warm summers (Cfb), also known as marine climate. For extreme rainfall, there must be enough moisture to generate convective thunderstorms by solar heating, or the moisture must be advective to the area and released through an uplift mechanism (Gustafsson et al., 2010). Advection causes the daily extreme rainfall in summer in Sweden to be controlled by the atmospheric circulation, which is characterized by the accumulation of water from the European continent and the Baltic Sea (Gustafsson et al., 2010).

A study (Wern, 2012) found that most of the extreme precipitation events in Sweden occurred in July and August, and the correlation between summer high temperature and daily precipitation days was weak. In Sweden, about 70% (range 52-81%, but most often within 70-80%) of events which has a type of cyclonic weather occurred in 1961-2000, while only 45% of non-extreme events has happened. An event is defined as a daily rainfall exceeding 40 mm, and a non-extreme event is defined as a daily rainfall of 1 to 40 mm (Hellström, 2005). SMHI defines a downpour (Swedish: skyfall) as at least 50 mm in an hour or at least 1 mm in a minute (Wern 2012). The return period for such incidents is 2 to 5 years (Wern, 2012). Climatic factors describe the projected percentage increase in rainfall intensity, usually between 10% and 50%.

There are three classification of flood reasons: via drainage system, overland flow into the building, and groundwater intrusion (Sörensen & Mobini, 2017). When it rains constantly for a long time made the ground is wet and the groundwater level rise, and for smaller events, the floods are more evenly distributed over the city. Continuous rain in the previous weeks before the downpour that happened in the 10th of August (which was about 70 mm in one hour) saturated the ground with water.

The soil type within the Ljungby city differs, but except the areas close to river Lagan it’s mainly moraine. Moraine is the most common soil type in Sweden. Moraine is mostly hard and firm. On sandy silty moraine slopes, landslides can be triggered if the soil type is saturated with water (SGU, 2005). Moraine is Sweden's most common soil type and covers about 75% of the country's surface area. The groundwater surface in Moraine is generally close to the ground due to the low hydraulic conductivity of the soil type. In this groundwater environment, fine soil thicknesses and generally low porosity provide a short residence time (Naturvårdsverket, 2021).

2-2 Urban storm water system

Quantitative assessment of floods is done using flood models to understand the source and sink of urban floods. The next step will be to implement solutions that reduce the risk of flooding. But before applying flood control measures, it is important to understand the urban rainwater network system: its functioning, capacity, and limitations. This will provide the necessary technical assistance during the feasibility study to determine the best solution. Traditionally, rainwater systems have been constructed using structural measures such as rainwater drains, curb intakes, manholes, small drains, roadside ditches, and culverts to transfer rainwater from somewhere as quickly as possible.(Brears, 2018)

The urban drainage network includes two types of sewer systems: combined and separated. In a combined system, wastewater and rainwater are collected in a pipe network, while in a separate system, each unit has its pipe network. A schematic diagram of the two sewage system types is shown in Figure 2 below, which shows the operation of the two rainwater network systems. Urban drainage can be divided into main and secondary systems, where the smaller system reflects the underground drainage system built, while the main system reflects the flow in the streets, canals, and streams, as well as the holding tanks above ground. (Bengtsson and Milloti, 2010).

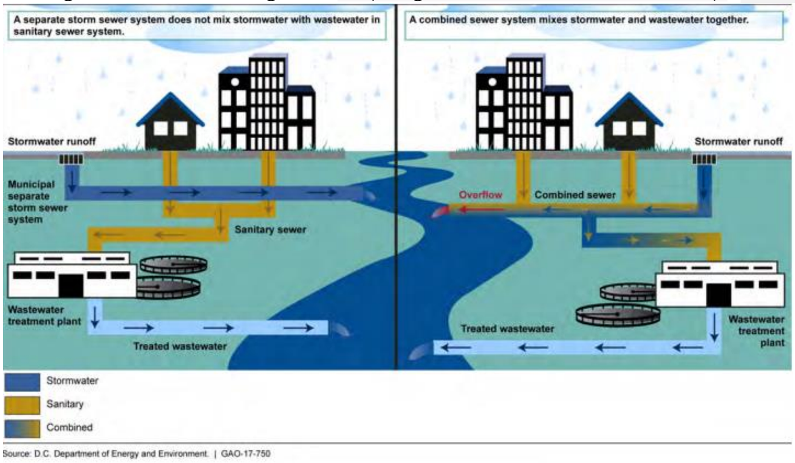

Figure 2 Schematic diagram of separate and combined sewer systems (Image source: Senate, 2017).

The sewer system in Ljungby city is separate. But there are several parts of the wastewater system that is affected by rainwater due to leaky pipes and wells as well as houses and other surfaces that are incorrectly connected to the main system.

Wastewater in a combined system poses a higher health risk than flooding from separate rainwater pipes. For example, an infection of rats while cleaning a flooded cellar led to the death of a man in Copenhagen after a severe flood in 2011,(Sörensen & Mobini, 2017). Urbanization and climate change would exacerbate the current problems with combined sewerage. The sewer system is the infrastructure that transports domestic, commercial, and industrial sewage to wastewater treatment facilities. As the population and industry increase, the capacity of the system becomes limited and may eventually fail. Many factors can also cause this failure. The structural defects of the sewer system are usually caused by natural aging, corrosion of the hydrogen sulfide (H2S) crown corrosion, design and construction of excessive overburden, and soil compaction.

Broken pipes, clogged gutters, and broken sewers are surprisingly common causes of flooding problems, which can affect the property (Mainmark, 2019).Many other external causes can cause pipe ruptures and leaks, such as tree roots infiltrating, rainwater overflow during heavy or prolonged rainfall, or the presence of old clay pipes and rainwater overflow (Mainmark, 2019). When the weather is wet, rainwater can flood the rainwater network and overflow into the sewer system, which can overload wastewater, backflow, and potentially overflow into the ground. Overcrowded rain drainage system overload can also cause land loss and water accumulation in low-lying areas, which may concentrate water on the foundation soil and cause structural problems. There are many connections between storm water or sewer pipes and every one of these connections has a possibility to leak. In the underground pipes, as much water can leak through connections as through faults in the rest of the pipeline (Paper, 2019). To avoid floods and save residential health, Storm water should be in separate pipes than wastewater pipes.

2-3 Blue-green solutions

There are a huge number of concepts to describe decentralized and sustainable rainwater runoff through vegetation measures, such as soil and water conservation measures. Best Management Practices (BMP), Low Impact Development (LID), Sustainable Urban Drainage Systems (SuDS/SUDS), Green Infrastructure (GI), and Water Sensitive Urban Design (WSUD) (Fletcher et al, 2013).

Water obviously follows the path of natural or man-made flow, but from an ecological perspective, urban ecological networks and connectivity are also important (Ahern, 2011). The European Commission defines green infrastructure as "a strategic planning network of high-quality natural and semi-natural areas with additional environmental characteristics, designed and managed to provide a wide range of ecosystem services and protect biodiversity in rural and urban environments." (Garmendia et al., 2016). The definition does not explicitly include water. The blue-green solution is a combination of LID (Low Impact Development) and BMP (Best Management Practices) to control urban runoff in the most natural way (Naeimi and Safavi, 2019). The term low-impact development (LID) refers to systems and practices that use or imitate natural processes that cause the infiltration, evapotranspiration or rainwater use to protect water quality and related aquatic habitats (US EPA, 2018).

The US Environmental Protection Agency is the opposite and uses green infrastructure as a narrower, water-centric concept to describe plant-based rainwater technology. They claim that “green infrastructure is a cost-effective and resilient way to manage the impact of wet weather, which can bring many benefits to the community” and examples of technologies such as rain gardens, bioswales, downstream disconnection, urban tree canopies, green streets, and rainwater harvesting. And other technologies as an example (US EPA, 2018). Green roofs and other green surfaces cause intense evaporation-sweating from the surface by delaying the flow. Permeable sidewalks and seepage channels provide seepage from the soil. The canopies of trees will prevent rain, and their tree pits will seep rainwater. Retention ponds and detention ponds store rainwater and reduce the discharge to downstream recipients. Wetlands retain water, which then evaporates, infiltrates or discharges. Rain gardens function similarly, but on a smaller scale, but in contrast to wetlands, they usually dry out after each rain. Channels and streams transport surface water. The assembly line and the biological assembly line ensure slow transportation and certain penetration. Temporarily flooded surfaces (such as sunken green spaces) maintain surface runoff during heavy rains. Since no one solution is not optimal for all different rainfall intensities, it is better to combine them in so-called processing procedures. For a detailed description of the different solutions, see, for example, the SuDS manual. (Woods Ballard et al,2015). In contrast, blue-green solutions are a collective term for sustainable multi-functional measures that can reduce the negative effects of urbanization and adapt to climate change (Wihlborg et al., 2019).

The blue-green solution avoids flooding and damage to public and private property by allowing runoff to pass, while also treating rainwater to support the rainwater system. The main goals of the blue green solution are:

(1) Maintain or improve the natural, social and economic value of the downstream environment.

(2) Reduce the frequency, length and quantity of rainwater runoff to reduce flood hazards and limit the flow into watercourses and rivers after development.

(3) Improve urban environmental facilities (Brears, 2018).

Many people realize that bringing nature-based solutions to cities is a powerful means to alleviate urban pressures and build resistance to climate change. The benefits of proven nature-based solutions have been shown by(Maksimovic et al., 2017). Among the traditional and nature-based measures available, rainwater harvesting systems and green roofs (GRs) are the most popular and effective blue-green solutions for collecting and storing water from roofs to reduce and delayed flooding (Cristiano et al., 2021). Systems and green roofs (GRs) are sustainable tools that can store part of the rainfall in the soil layer, which is then absorbed by vegetation roots and returned to the atmosphere through evapotranspiration (Rosasco & Perini, 2019). The retained rainfall depends on the size of the roof, the type and thickness of the soil, and the type of vegetation. GRs have multiple benefits: In addition to mitigating floods, they can also ensure biodiversity and help reduce the temperature of buildings and surroundings (Cristiano et al., 2021)

2-4 SCALGO Live

Scalgo Live is a web-based flood modeling tool that maps the flood risk from sea, depressions or streams to get an overview of the combined flood risk of a property, a neighborhood or an entire municipality (SCALGO Live, 2020).

Scalgo Live is a web-based program, so it can be used by an Internet browser to do all combinations and analyses.

Scalgo is a Danish company, the program is developed for the analysis of the elevation data basically from a surface water point of view, it can be used to analyze two different kinds of flooding, flooding from rainfall and flooding from high seawater levels, only flooding from rainfall is used in this study. The advantage of Scalgo Live which makes it very useful is that it can use it to analyze very large amounts of elevation data in a very short time and makes rapid changes and analyses very quickly it can analyze very different scenarios at the same time, making it very useful.

In Scalgo Live there is the elevation model of Sweden, the basic data that is already in Scalgo is the national elevation model which has a resolution of (2 x 2 m), it is also possible to work in a project that has access to its own elevation data, it can import this elevation data and make analyses on this data.

Scalgo live uses a simplified method to calculate the flooded areas, it uses a static method which means that it is not a time-dependent scenario, it gives an instant response. For an example of a rainfall event, Scalgo shows what happened when all the rain has flown over the terrain and found its way to the lowest points.

In addition, there is no way to identify the real-time for water to reach the flooded areas, it’s very good it’s a very simple method but if it can't give a correct solution in all study areas that this method is good enough.

In this study, it is used for flash flood maps, which means that it shows the depth of water that floods accumulated during the selected rainfall event. During the flood risk analysis, Scalgo Live will use both terrain data and water volume to determine the area that is flooded under a given volume of water.

The water quantity is first filled into a depression, When the depression is saturated, the flow will drop to the lowest point until it reaches its threshold level, and the water flows to the next low point area. The greater the amount of precipitation used for the terrain, the greater the catchment area at the downstream point. Likewise, a catchment area or watershed that supplies water to the lowest enclosed area. The Scalgo Live tool considers the total water available in each depression, calculates the water depth and the propagation of selected precipitation events.

The flood analysis process in Scalgo Live provides the amount of water collected at different low points of the terrain under different rainfall events, so it can be used to identify risk areas under a given extreme rainfall event. In addition, the tool allows filtering of flood depths, so it can only display flood depths that pose a serious risk to people and infrastructure.

3- Methodology

With the help of Ljungby municipality, the buildings that were exposed to a rainwater leakage into the basement were identified during the stormwater that occurred in August 2020.

Ljungby Municipality provided me with information about the flood through shapefiles and dwg files with information about flooded properties. Both shape and dwg can be used in Scalgo. The Shapefile also contains information about the type of flood that occurred on various properties; if water enters through the floor drain in the basement or if there is flooding on the ground. I have used this information in my work, but in the completed report or other published documentation, it is important that it is not clear which properties were affected by the flooding. According to the municipality restrictions during the study work (Ljungby Kommun, 2020).

The information, in the files, used in Scalgo, appears as points over affected areas by flood.

3-1 Study areas

Ljungby municipality is in Kronoberg County, in the south-west of Sweden.

3.1.1. Lagan

Lagan is the second largest city in Ljungby, Kronoberg County, Sweden, located in the northern part of the municipal district with 1,744 residents in 2010 (Statistics Sweden 2011). The elevation is 139 meters (459 feet). Its name is taken from the nearby Lagan River.

Lagan River is one of the four major coastal rivers in southwestern Sweden, it is 244 kilometers long and is one of the longest rivers in southern Sweden. The area includes general buildings; namely residential, commercial and industrial, and a school in the center.

The city is located on Lagan river, where is the topographic elevation of the city grades descending from the E4 road to the river which is considered as the downstream point of the city. The flood depth varies from 0.5 to 1.5 m, and exceeds 2 m in some places during extreme rainfall events. Especially in areas far from the river or have high terrain in front of the downstream points.

3.1.2 Torsgatan

Torsgatan is a residential and industrial street in the Ljungby center.
Located in the center of Ljungby. In this street it has more than 10 private properties which have water in the basements in addition to the nearby hospital, therefore this area of Ljungby was used as a study area.

3-2 Reassessment in SCALGO Live

The proposed solution was pre-evaluated within the tool SCALGO Live. First, use the flow accumulation tool to see the downstream points of the 2 study areas. Next, define the rainfall appreciate the 100-year rainfall event by adjusting the rainfall slider option. Then, use the watershed tool to seek out the geographical area at the center and lower reaches of the 120-year rainfall event. After that, create a separate work area for every study area, the extent of which corresponds to the geographic area, to supply a separate editable terrain model. Shape files for the scope and placement of the proposed solutions for all study areas are imported into their respective workspaces.
Similarly, within the work area, in step with the look, the acceptable terrain editing function was employed in the corresponding position to form a suggested solution. As an example, to keep up an even vertical slope, an interpolation tool is employed for a given width. Similarly, when designing the detention pond and the canal, the "Reduce Path and Flatness" tool was accustomed lower the terrain from all-time low point, and so level it at the desired depth. The lower path and flattening tools also contain functions for creating side slopes, which are accustomed create slopes as designed. the answer to the flood meandering involves twisting and turning, additionally as intensive excavation and filling, so in several locations, filling materials also are added to level the terrain and simplify the flow path. SCALGO Live also contains different tools to facilitate these processes. Calculate the filling amount and excavation amount of every solution separately and it's shown in Table A1.

4- Results

1- Vulnerability of the Study Area to Urban Floods

I studied the characteristics of floods in upstream and downstream areas, and make use of feasible land space as much as possible, by using the water collection tool in SCALGO Live to discover the downstream point and its water collection area. Based on the storm event (70 mm) in August 2020, the rainfall event in 120-140 years was evaluated for the present land use scenario.
Rainwater is collected and directed to water sources. Sometimes it flows through some form of rainwater system to filter the water, but usually it just flows straight out (Ljungby kommun, 2014).
In the Ljungby urban area, most of the rain is directed to Lagan river. For other urban areas, rainwater is directed to the water sources the closest downstream. The downstream point is the river that passes Ljungby; however, all the study areas suffer from rainwater gathering in some places relatively far from the river or downstream point.
There are two methods to solve the flood's problem using Scalgo live software, either by (a) solving the flood problem directly in the study area using drainage canal, detention ponds and digging paths, etc., or (b) by following the flow accumulations and editing the terrain to prevent this flow accumulation from moving water and gathering making floods in the study areas. In this thesis, a comparison will be made between these two methods.

4-1. Lagan:

Lagan is marked as four different hot spots zones starts from the E4 road towards the river (see figure 3) where the downstream point for all the city.

Figure 3 Marking of flood hotspot zones and flow direction in the Lagan study area.

Zone 1: Located in the area furthest from the estuary and at the highest elevation of the city. The depth of the flood exceeded 1.3 m.

The first proposed solution is to dig a detention pond in an open area near the city entrance. The detention pond collects rainwater from all nearby areas

with a slope of 45° and is connected to 4 underground pipelines to move water under roads and terrain.
These pipes are drains and do not change any elevation of the terrain, but can transport water between the endpoints without affecting the terrain between them. The underground structure will transport an unlimited amount of water, but it does not store any water itself, so the volume is zero.
The detention pond elevation should be less than the elevation of all areas submerged in it to collect water, so the depth of the detention pond is about 6 m. Because of this pond, water was prevented from flooding the basement or ground floor of buildings in the area (marked with black points in the figure). Figure 4 shows before and after of applying the green and blue solutions, the red spots are flooded areas; the blue spots are the water after applying solutions.

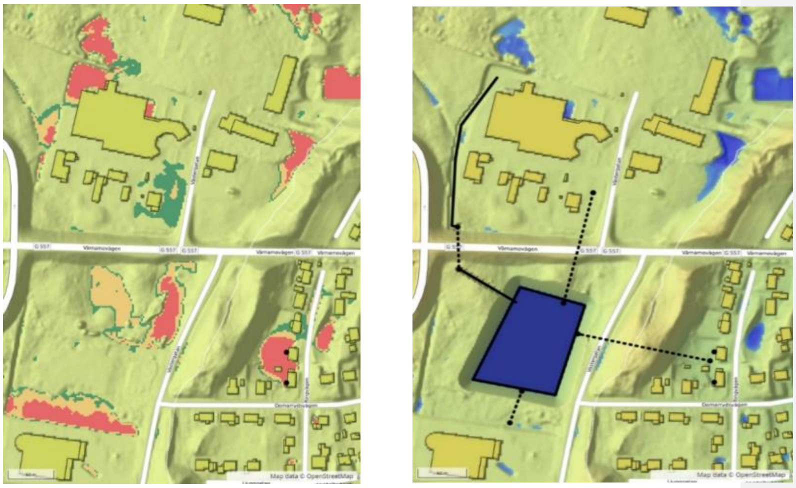

Figure 4 shows SCALGO Live output on the extent of flood depth during rain event obtained before and after implementing blue-green solutions

The second proposed solution is to follow the flow accumulation and change its ways by editing terrain to prevent water from gathering in the private property, causing floods. By increasing the elevation near the road to change the flow accumulation that comes from higher elevation (see figure 5 for the edited terrain). This solution reduced the flood depth from 1.26 m to 0.92 m in zone 1 of the study area (see figure 6 for the profile section of the flood).

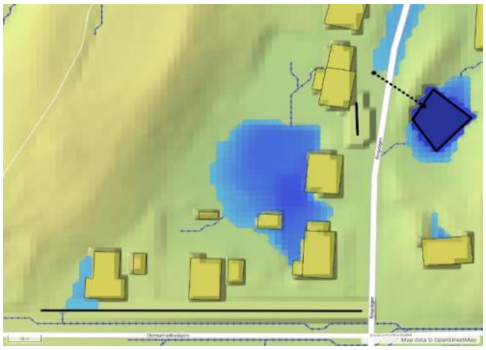

Figure 5 shows SCALGO Live after edit terrains elevations.

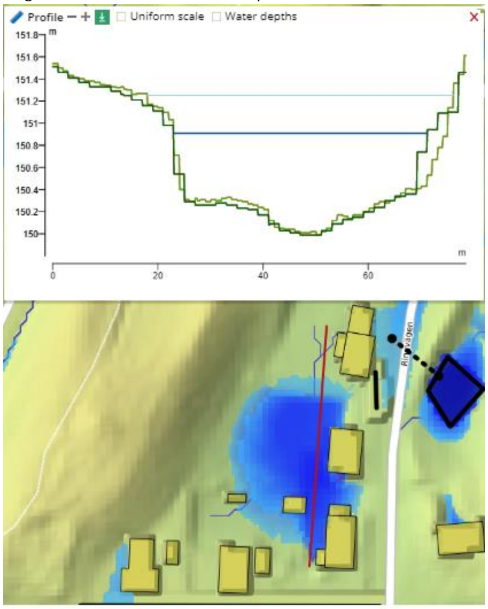

Figure 6 shows a profile section of the flood after implementing blue-green solutions

Zone 2:

2.1. Residential houses with a flood depth of 0.8 m located at an altitude of 150 m. The proposed solution is to make a drainage canal to the nearby area, which has an altitude of 143 m. This pipe diverts water from the confined areas (see figure 7).

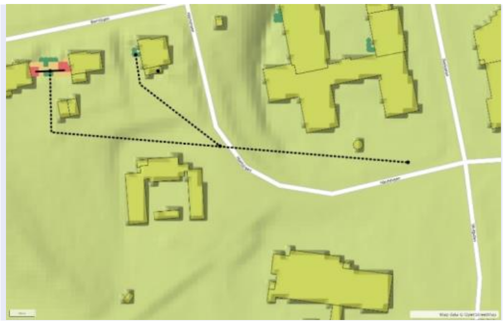

Figure 7 shows SCALGO Live after implementing blue-green solutions

2.2. The same goes for the residential area below, where water gathers in the highland area and the solution is to dig a path and drain canal to the lower area below in the football yard from altitude 145 m to 143 m above sea level. These solutions prevent water from leaking into the basement of three buildings (see figure 8).

Figure 8 shows SCALGO Live after implementing blue-green solutions

Zone 3:1: This is a residential area near the river, where a lot of water gathered, causing flooding of 1.25 m. The flood's depth between the houses, the entrance and the first floor and in the yard, is about 0.7 m.

The proposed solution is to dig a path on the south side of the road, which is lower than the area with 1 m and width of 1 m and a slope of -6.5% like it shown in Figure 9. This path transfers water to wood at a lower altitude, and then to the river through a drain.

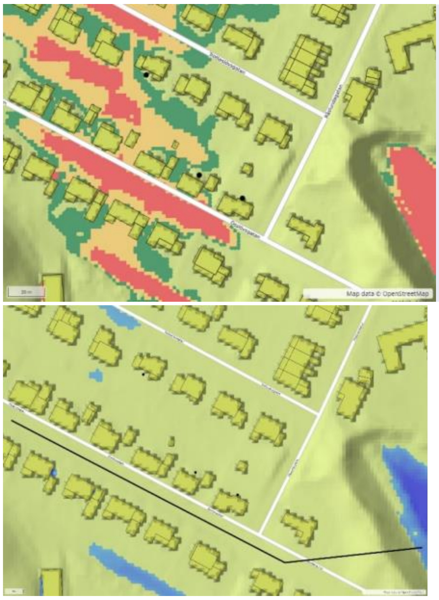

Figure 9 shows SCALGO Live output on the extent of flood depth during rain event obtained before and after implementing blue-green solutions

3.2. To the north between the houses, the flood depth reaches 1.5 m. To solve this problem, for the 8 houses on the street, the best solution is to dig a 100 m long and 1 m deep path. There are many drainage ditches from the house to the trail, then a 190-m long trail, from the trail to the river (see figure 10 for before and after applying solutions the black line is the path).

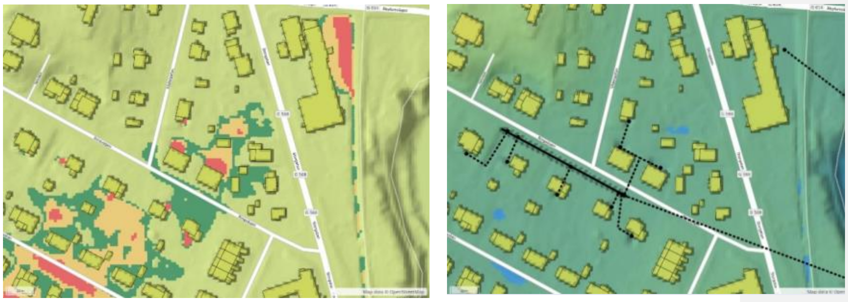

Figure 10 shows SCALGO Live output on the extent of flood depth during rain event obtained before and after implementing blue-green solutions

Zone 4: In the city center and near the church, there are many houses reaching flood depths of 2.25 m, and the nearby square can be used as a reservoir to transport water from all houses through 4 drainage ditches. The water flows from the detention pond to the river through a 190-m outlet. The water that leaks into the houses' basement (the black points in the figure) during the rainstorms events can be solved through a drain that moves water to a lower altitude, see figure 11.

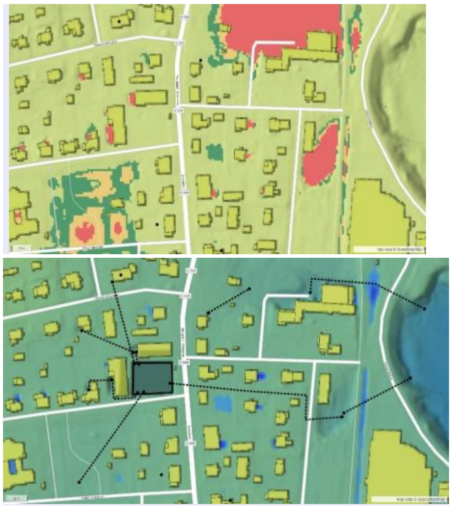

Figure 11 shows SCALGO Live output on the extent of flood depth during rain event obtained before and after implementing blue-green solutions.

Many houses complained about rainwater seeping into the first floor, and the problem of 9 houses in low-lying areas was solved. Rainwater is collected and transferred downstream through drainage canals. The blue-green solution in Lagan City requires 22.62 square kilometers and requires the removal of 84779.10 cubic meters of soil.

4-2. Torsgatan

In the event of rain, water collection caused flooding near houses, factories and squares. The flood occurred in an area with a lower altitude than the surrounding area, where the flood depth reached 1.5 m. These depressions can be avoided by increasing the height of the terrain near the house and in the garden or by establishing a subsurface drainage network connected to the main drainage channel to solve the problem of flooding around Torsgatan Street, Hospital and houses.

A drainage canal was proposed for the area from the hospital through Torsgatan to the south towards the downstream point in the detention pond, the length of the drainage canal is 750 m, and from the house to the main canal is connected to 9 smaller drainage canals that terminate in a detention pond near Helsingborgsvägen Street.
The main drainage canal passes through a section of Torsgatan street near 9 of the houses where rainwater leaks into the basement, using this proposed solution solves the flood problem of 10 houses including the hospital. The purple points in figure 8 are the houses that rainwater leaks into the basement in the rainstorm, the dashed line in figure 12 is the main subsurface drainage canal.

Figure 12 shows SCALGO Live output on the extent of flood depth during rain event obtained after implementing blue-green solutions.

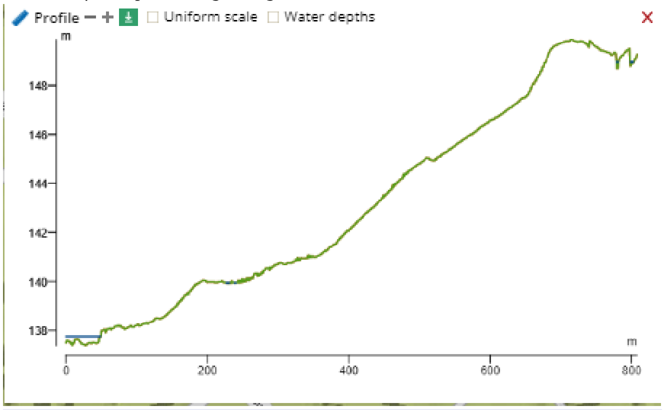

Figure 13 the profile section of the terrains elevation from the hospital to the downstream point.

Figure 13 shows the profile section of the terrains' elevation along the main drainage canal from the hospital to the right downstream to the left, the main drainage canal can be constructed directly under the ground according to the elevation gradation of the terrains. The water can be runs directly to the downstream point by the gravity force without any needs to pump.

To accommodate the amount of water that has been moved from the upstream point to the detention pond downstream, the proposed solution is to decrease the detention pond's elevation and removal the terrain between the two detention ponds on the side of the road, as it shows in figure 13.

In the same area there is many nearby houses that have floods with a depth about 0.5 m. The proposed solution is to increase the elevation of the terrains near this house, but this solution needs a field visit to find out the locations of the floods and the possibility of raising the terrains at these points.

A second solution was proposed for the hospital of only due to the municipality restrictions of not being able to work in private properties. This diverts the water from flooded by towards the garden of the hospital to avoid damage by the accumulation of water in the basement and around the building, if there is has no possibility to use pumps, the garden´s elevation should reduce to be less than rounding area of the building, which means about 6 m.

5- Discussion

5-1 Effectiveness of the proposed solutions

The main purpose of the thesis is to provide decision support for the implementation of climate change adaptation strategies for Ljungby City to reduce the risk of urban flooding caused by extreme rainfall events in the study area. Propose blue-green solutions to help houses damaged by rainwater leakage in the basement and ensure that similar floods will not occur again in the future.

In Lagan, many solutions have been proposed, such as transferring the water in Zone 1 from the affected houses to the detention pond in the open area through drainage pipes in the area. This method can ensure the natural leakage of water through the ground. And reduce the pressure of the water on the sewage pipe network. In addition, according to the recommendations of the Environmental and Construction Administration, Ljungby Municipality, Rainwater can infiltrate and replenish underground water. In this way, the ground subsidence that would affect the foundation of the house is avoided (Ljungby kommun, 2014). On the other hand, this solution cannot be done without study the condition of the drainage system from this area to the downstream point, because it is unreasonable to have a detention pond with a depth of 6 m, but this is the only overland possible solution using Scalgo Live.

It is proposed to dig natural ditches near the residential areas of zone 3, collect water and filter it in the soil layer, and transfer the excess water to the forest, and then to the river. This solution can remove a flood with 1m water depth. The ditches and weak ditches transport the storm water openly and have a certain storage capacity as well as an infiltration and purification effect.

In addition to using the public square in zone 4 as a detention pond to collect water from the houses around the square and transfer the water to the river, this method is used for heavy rains. The water is transported without treatment to the river to relieve pressure on the sewage water network because this area is urban and contain large areas of asphalt and land that increase surface runoff and reduce soil infiltration.

Using the Scalgo program, it was noticed that there are many floods in areas near the river due to the presence of high terrain, and with that the floods are due to reasons related to the saturation of the soil after long-term rains, and solutions can be proposed that transport the flood water through pipes to the river.

5-2 Possibility of implementing the proposed solutions

In this thesis, the difference between theoretical solutions to the flood problem and the application of these solutions in practice are discussed. Solutions are proposed theoretically in a way that prevents floods from occurring in the future in a way that preserves the balance of surface and ground water and prevents landslides environmentally, while in practice you may face many problems such as administrative and economic restrictions and conditions of the study area.

According to the Ljungby Municipal restrictions (Ljungby Kommun,2020), the municipality is not able to solve the flood problem in private property areas. Therefore, solutions to flooding must be proposed, such as changing the direction of flow accumulations by changing the terrain outside the private property areas.

In the Scalgo program, changing the flow paths in Zone 1 was implemented, and the terrain level was raised, as the water was transferred to other neighboring areas; therefor, the depth of the flood water decreased from 1.23 m to 0.9 m, which means that it still has a flood with a water depth of 0.9 m, and this indicates to the cause of the flood was the low elevation of the place where the property was built, or the current condition of the drainage system which needs to check to defend the real reason of the flood in this area. During heavy downpours, runoff is directed towards low-lying areas quickly, both through the pipe system and by overland flow (Sörensen & Mobini, 2017). This solution cannot be used in most areas because the flow accumulations often starts near the flood zone or from areas in privet proprieties.

The rest of the blue-green solutions were proposed in accordance with the municipal laws as possible. However, calibration of runoff processes in torrential rains is rarely possible, as there are often no rainfall measurements and observations of flood extent and water depth. In addition, extreme precipitation is often very local and the intensity of the rain can vary a lot in time and space (Sörensen & Mobini, 2017).

On Torsgatan Street, more than 9 private properties in addition to Ljungby Hospital complained of a water leakage in the basement in the rainstorms. There are several possible reasons to explain this. It could be a rise in the water table in the groundwater or the topography of the street, making these homes at lower points than neighboring areas, which leads to pooling of water in them, or the existing piping systems don’t cope with overflows during heavy storm water or snowmelt. And this area has a companied sewage system, which leads to a rise in the water level in the network during rainstorms. During periods of heavy rainfall, the areas close to the main sewers are most affected by floods (Sörensen & Mobini, 2017) .

In Scalgo, the topography of the place was checked and this reason was excluded from the causes of water leakage. As the topography of the city gradually progresses towards the river.

It has been proposed to have a rain drainage network separate from the sewage network, this drainage network extends from the hospital to the detention pond that collects water in the southern street, through pipes placed directly under the surface of the ground, because the topography of the area allows the pipelines to slop naturally.

From the practical point of view, the application of this proposal solution is limited, because there are enough pipes under this street to transport drinking water, sewage, electricity etc., so to construct a new rain drainage network needs a new place in the street. Therefore, a new solution was proposed that fits the hospital without solving the flood problems of private proprieties due to the municipality’s restrictions on working in private proprieties.

In addition to recommending the use of hospital gardens to reduce the depth of flooding in the area around the hospital, to move the water to the garden under gravity without the use of pumps, the water level of the garden must be reduced, which means reducing it by 6 m. This is an unreasonable solution for a hospital garden so the water must be transferred from the area around the hospital to the park through a pump.

5-3 SCALGO Live

The utility of SCALGO as it has been used in this thesis will be discussed. The method is static, unlike two-dimensional modelling techniques traditionally used by torrential mapping. This means that the method does not have these aspects. It was however considered as a useful tool to determine the navigable waterways and to better understand the water on the evaluated properties. This can additionally be used to determine the contributing to run off to retention systems and accompanying drainage systems. Therefore, I cannot identify the effects of inertia in the system.

In addition, SCALGO Live does not show the effect of ground, e.g. soil infiltration capacity of the model area, which leads to an overestimation in the flood depth compared to the reality. However, as the tool does not include seepage losses or losses through manholes and pipe networks, it was of limited help in estimating a suitable retention system volume. Since SCALGO is relatively new software, there is little literature on this subject, and therefore, most discussions of accuracy and potential issues based on the author's perception.

One of the problems with SCALGO is the lack of consideration of hydrological processes and the existence of a drainage system that is only helpful in determining flow accumulations over the proprieties. It shows the direction of surface runoff and the topography of the earth without knowing the capacity or the direction of the drainage system, so it was suggested to use the Mike Urban software to find out the condition of the subsurface sewage network or create a new storm water drainage network separate from the sewage network, to avoid the problem of future floods in conditions of climate change.

The use of the Mike Urban program to study the current drainage network and plan for a new storm water drainage network took a long time and was not used due to the limited time for the thesis. MIKE URBAN is the preferred urban water modelling software. It covers all water supply networks in the city, including water distribution systems, rainwater drainage systems, and sewer collection in separate and combined systems (MIKE URBAN,2019).

5-4 Suggestion

New planning areas need to be designed so that the diversion can also take place above ground via streets or ditches. It is also necessary to provide for the management of trapped low points (Ljungby kommun , 2014).

Pipes generally have a long lifespan, (100 years) and it would be a waste of money to remove something that works well to a large extent. In many places, especially in areas with a combined system, the blue-green infrastructure could rather be used as a supplement to reduce the storm water load, than to replace the pipes altogether, when it is possible to design new developments with blue-green infrastructure from the start. Different urban spaces also call for different solutions. Public places can, and must also, be built with other solutions than, for example, private gardens or large car parks. Public places such as green spaces and parks play an important role in water management of rain. Plated surfaces help divert rainwater and purify it by infiltration.

What matters most during extreme events, the large volumes of storage, preferably distributed in many places of the urban landscape, in large and ponds, rain gardens, wetlands, retention basins. New planning areas must be designed so that the diversion can also take place via streets or ditches.

It is sometimes claimed that retention in gardens, ditches and ponds might be ineffective during heavy rains if previous rains have already used up most of the storage capacity. However, in southern Sweden, most extreme events occur during the hot months when the weather is often sunny and dry.

Homeowners should be made aware of the benefits of local storm drainage and be encouraged to act about alterations and extension, rainwater should be delayed, reduced and treated using open rainwater systems, if possible. Homeowners should ensure that storm water pipes do not drain rainwater from roof gutters into the sewer system and that the storm drainage system is regularly maintained and cleaned to prevent damage. Being overloaded and overflowing. They should consult a licensed plumber to check the current health of pipes on their properties.

The safest way to prevent storm water from entering the drainage pipes around is to pump out the drainage water. In this way, the risk of damage caused by the basic construction of the building caused by dammed storm water disappears (Stad, 2001).

To mitigate climate change, the reduction of greenhouse gas emissions through changes in human life is essential. At the same time, households, cities and countries reduce their impacts of climate change by adapting to the projected future of their region.

6- CONCLUSION

This work mainly focuses on hydrology and is associated to reduce the risk of flooding, and less with management in the event of flooding. However, it is inevitable that unforeseen things will happen despite proper landscaping, significant area retention and other risk reduction measures. No system is perfect and works with and resilience must therefore go further and work on awareness, warning systems, vulnerability and other non-hydrological measures.

Following input data in Scalgo and the identification of floodplains and monitoring of flow accumulation, solutions have been proposed for water transfer or change of flow accumulation to open areas, such as forests, with the recommendation of the Environment and Construction Administration.

Both study areas were found to be highly vulnerable to the risk of urban flooding during the 120-year rain for the current land use scenario and many buildings are suffering from water leaks in the basement and streets, the water depth was greater than 1 m in some areas, Ljungby hospital was affected by water leaks in the basement in addition to flooding around the building causing serious impacts on the building and the patients. Other possibilities have been proposed to modify areas that contain flooding by using drainage pipes to carry water to the downstream area or using open trenches to take advantage of the natural infiltration and evaporation to reduce the volume of flood water. The ability of the proposed blue-green solution to divert water pods from the flood zone in the Lagan area was tested by Scalgo, and it was a poor solution compared to the water containment solution in a natural retention pond.

The results in Scalgo were imprecise because Scalgo did not have the ability to incorporate the soil infiltration property into the model. But it was very useful in determining the accumulations of flow and identifying the upstream and downstream points.

The use of the Mike Urban program was suggested to determine the condition of the existing sewer system in addition to the possibility of knowing the infiltration capacity of the soil, the roughness of the soil and the possibility of repairing or establishing a new rainwater system in the future. In addition to suggestions for future studies and measures using blue-green solutions to reduce the risk of flooding.

These proposed solutions will reduce or eliminate flooding however the most drawback for applying these solutions is that the drainage system should be checked by alternative programs like 'Mike Urban' to make sure the capability of the pipes then the blue-green solution can be applied.

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Formaterat: Engelska (USA)

8- Appendix:

Table A1 Design parameters used for proposed solution

Zone	Name	Size (average)			Water depth (m)	Volume of excavation (m^3)
		L (m)	B (m)	H (m)		
Lagan 1	Path	190	6	2.6	1.1	1664.2
	Detention Pond	110	70	6	1.6	30870
	Path2	70	2	3		2531.11
	Drainage canal	2.3			1.1	
	Drainage canal	133			0.4	
	Drainage canal	141			1.55	
	Drainage canal	40				
2	Path	200	1	0.2	0.3	1664.2
	Drainage canal	60				
	Drainage canal	170			0.8	
3:1	Path	250	1	1	1	1665
	Drainage canal	60				
3:2	Path	100	1	2	1.40	31400
	Drainage canal	190			2.25	
4:1	Detention Pond	30	36	2	2.25	2643
	Drainage canal	55			0.9	
	Drainage canal	13			1.3	
	Drainage canal	30			1	
	Drainage canal	44			2.2	
	Drainage canal	80			0.4	
	Drainage canal	70			2	
4:2	Drainage canal	130			2.8	
	Drainage canal	45			1.11	
Torsgatan	Drainage canal	750				
	Detention Pond	50	30	4	1.65	
	Detention Pond	250	14	1.6	1.6	10909.37