CHALMERS
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The importance of sustainable stormwater management in urban areas

A case study on current and future development in Lerum, Sweden

Master's thesis in Infrastructure and Environmental Engineering

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Cover: Depression in the ground by the school Torpskolan in Lerum, which is subject to large flooding depths in the case of a flash flood event (Authors' own image).

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Abstract

The risks of pluvial flooding in urban areas are expected to increase due to climate change leading to heavier rainfall events in the future. In addition, urbanisation contributes to impermeable surfaces which further increases the risk of flooding. Sustainable stormwater management that mimics nature based solutions is considered a favourable way to treat urban flooding. The use of sustainable stormwater management also enables incorporation of ecological and social services whilst reducing the impacts of urban flooding. Infiltration and surface roughness are two key parameters in assessing how efficient these sustainable stormwater solutions are. Infiltration has been established to have a large impact on flooding, while more recent studies have shown that surface roughness impacts runoff to a large extent. This project aims to further investigate the impact of infiltration and surface roughness on sustainable stormwater management. To achieve the aim, a case study is performed in the municipality of Lerum, Sweden. The softwares SCALGO Live and MIKE 21 are used to identify current and future infrastructure at risk for flooding in Lerum. Stormwater solutions to manage floods in the area are then implemented in suitable locations into the software SCALGO Live. The model is then imported into MIKE 21 where the solutions' properties are altered to correspond to permeable or impermeable surfaces to study the effect of infiltration and surface roughness. Thereafter simulations are performed to obtain results on flow speeds and water depths to assess risk levels stemming from the flooding, as well as investigating the impact of the alterations in infiltration and surface roughness. The results are compared and show that stormwater solutions with high surface roughness lowers flow speed and solutions with high infiltration capacity lowers water depths. Both parameters contribute to lower risk levels, which leads to the conclusion that both parameters are important to manage the runoff by affecting separate aspects of a flooding event.

Keywords: flood risk levels, infiltration, multifunctionality, pluvial flooding, surface roughness, sustainable stormwater management

Vikten av hållbar dagvattenhantering i urbana områden
En fallstudie av nuvarande och framtida exploatering i Lerum, Sverige
Examensarbete inom masterprogrammet Infrastruktur och Miljöteknik
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Sammanfattning

Risken för pluviala översvämningar i stadsområden förväntas öka på grund av att klimatförändringar leder till ökade regnmängder. Tillsammans med att urbanisering bidrar till hårdgjorda ytor ökar risken ytterligare för översvämning. Hållbar dagvattenhantering, vilken efterliknar naturlig dagvattenhantering, anses vara ett fördelaktigt sätt att motverka översvämningar i städer. Användningen av hållbar dagvattenhantering innefattar också möjlighet till ekologiska och sociala tjänster samtidigt som effekterna av översvämningar i städer minskar. Infiltration och ytråhet är två viktiga parametrar för att avgöra hur effektiva dessa hållbara dagvattenlösningar är. Infiltration har bekräftats ha stor inverkan på översvämningar, medan nyare studier har visat att ytråheten påverkar ytavrinning i stor utsträckning. Detta projekt syftar till att ytterligare undersöka effekterna av infiltration och ytråhet på hållbar dagvattenhantering. För att uppnå målet genomförs en fallstudie i Lerums kommun, Sverige. Programvarorna SCALGO Live och MIKE 21 används för att identifiera nuvarande och framtida infrastruktur med risk för översvämning i Lerum. Dagvattenlösningar för att hantera översvämningar i området implementeras sedan på lämpliga platser, genom programvaran SCALGO Live. Modellen importeras till MIKE 21 där indatan ändras så att de motsvarar permeabla eller hårdgjorda ytor för att studera effekten av infiltration och ytråhet. Därefter utförs simuleringar för att uppnå resultat för flödeshastigheter och vattendjup. Detta för att bedöma risknivåer av översvämningen, samt undersöka effekterna av förändringar i infiltration och ytråhet. Resultaten jämförs sedan och visar att dagvattenlösningar med hög ytråhet sänker flödeshastigheten och lösningar med hög infiltrationskapacitet sänker vattendjupet. Båda parametrarna bidrar till lägre risknivåer, vilket leder till slutsatsen att båda parametrarna är viktiga för att minska avrinningen genom att påverka separata aspekter av en översvämning.

Nyckelord: hållbar dagvattenhantering, infiltration, multifunktionalitet, pluviala översvämningar, ytråhet, översvämningsrisk

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Karl Norlén and Linda Oscarsson, Gothenburg, June 2021

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Terminology

Blue-green infrastructure Infrastructure with a variety of solutions incorporating vegetation and water to mimic the ways water is managed in nature.

Evapotranspiration The total amount of water leaving soil, bodies of water, and vegetation through vapour into the air.

Hydrological cycle The total sum of all water moving from the land and ocean into the atmosphere and back in the form of precipitation.

Hyetograph A graphical representation of the distribution of rainfall intensity over time.

Impermeable surface A surface without the ability to infiltrate water, such as roofs and roads.

MIKE 21 Hydrodynamic module found in the software MIKE Powered by DHI, used to model stormwater.

Permeable surface A surface with the ability to infiltrate water, such as grass covered areas.

Pluvial flood Heavy rainfall too large in volume for the local drainage system to handle.

Return time Describes the probability of a specified rain event to occur within a given time span.

Runoff Runoff = precipitation - evapotranspiration - infiltration - change in storage.

SCALGO Live Software developed by SCALGO, used to model stormwater.

Stormwater Water flowing as runoff on an impermeable surface.

Stormwater management Treatment, facilitation, and transportation of stormwater.

Sustainable stormwater management The use of stormwater solutions that mimics natural stormwater management.

Watershed Area of precipitation that contributes to a downstream point.

1

Introduction

Flooding has become more prominent globally over the past 20 years and is an increasing challenge (Jha et al., 2012). Large flows of stormwater in urban settings can result in flooded areas and have large impacts on society. The combination of increased precipitation and an increase in permeable surfaces due to urbanisation leads to challenges in managing the stormwater to avoid major floods. Climate change is one of the leading factors of increased pluvial flooding in urban areas, due to the increase in precipitation. Precipitation affects urban spaces more than natural settings due to its permeable surfaces and complexity of the water systems.

Stormwater in an urban setting is often subject to transportation of contaminants (Niemczynowicz, 1999). The contaminants present can be of organic or inorganic matter. Common contaminants studied in stormwater are nutrients, organic matter and heavy metals (Fletcher et al., 2013). Other contaminants found to be present in the stormwater system are synthetic compounds and chemicals such as pesticides or hormones. The composition of the pollutants present in the stormwater varies depending on location (Müller et al., 2020).

There are various practices to manage stormwater in urban areas. There is the option of collecting the stormwater in drainage systems and diverting it from the surface to a recipient (Zhang et al., 2017). This practice is not preferred and instead the use of stormwater management solutions that better mimic nature is preferred to be implemented. The terms used for these stormwater management practices differs between countries and are for example called; sustainable stormwater management (Stahre, 2004), LID - Low Impact Development, SUDS - Sustainable Urban Drainage Systems, blue-green infrastructure or solely green infrastructure (Chan et al., 2018; Liao et al., 2017). The main objective for using these practices is to mimic nature's management of stormwater and have additional benefits from the stormwater solutions. In this report, the term sustainable stormwater management is used.

The possibility of implementing flooding areas as multifunctional surfaces is an additional benefit of sustainable stormwater solutions. The multifunctional surfaces have other uses than stormwater retention during dry periods. Another benefit of using open, blue-green or only green solutions is ecosystem services. Ecosystem services stem from the nature and are resources and services utilised by people (Millennium

Ecosystem Assessment, 2005). The services are of varying forms and can be regulating, provisioning, supporting and cultural (Millennium Ecosystem Assessment, 2005; Naturvårdsverket, 2018). An example of a regulating ecosystem service is the lowered temperature that vegetated areas provide in an urban setting.

Sustainable stormwater solutions that include vegetation often contribute to stormwater management by infiltrating the initial volume of the rain event and lowering the peak flow (Chan et al., 2018; Svenskt Vatten, 2011b, 2016; S. Wang & Wang, 2018; J. L. Yang & Zhang, 2011). This suggests that infiltration has a large role in stormwater management and flood prevention, while some recent research found that infiltration has a minor impact and that surface roughness has a larger impact on the flood and flow speed (Herrmann, 2019). Y. Yang et al. (2015) identified a lack of studies on the effect of surface roughness on urban stormwater management and concluded in their research that surface roughness impacts peak runoff.

Urban development increases, and with it an increase in impermeable surfaces, all while there is an increased risk of flooding due to climate change (Liao et al., 2017). Infiltration is an extensively researched factor in stormwater management while surface roughness is not researched to the same extent (Y. Yang et al., 2015). Therefore an aim to investigate the impact of these parameters is formed.

1.1 Aim and objectives

Aim

The aim of this thesis is to investigate the importance of using sustainable stormwater management in urban areas. The study is performed through the assessment of the impact of infiltration and surface roughness for proposed solutions in a development project in Lerum, Sweden.

Objectives

The objectives set to achieve the aim are listed below.

- Identify areas sensitive to flooding.
- Identify vital infrastructure.
- Identify locations with high risk levels for people in case of flooding.
- Propose sustainable stormwater management solutions in suitable locations.
- Consider multifunctionality in the proposed stormwater solutions.
- Study the effect of infiltration and surface roughness in proposed stormwater solutions.

1.2 Limitations

- The only type of flooding considered in the project is pluvial flooding.
- Anything outside of the study area in Lerum is not considered in the evaluation.
- The proposed solutions are only implemented in areas owned by the municipality.
- The study does not consider the location of existing subsurface infrastructure
- The report does not focus on remediation aspects of stormwater, but rather only on flow and flood.
- The report does not consider which stakeholders are included in the process, and does not include economical aspects of various solutions.

2

Background

This chapter provides insight on the urban water cycle and how rainfall can affect urban areas. It also gives some examples of sustainable stormwater management solutions as well as information regarding climate change and the impact it can have on future rain events. Some information regarding modelling and its use in the topic is presented, and last is a description of the case study area in the municipality of Lerum.

2.1 Urban water systems

Water in urban areas differs from how water behaves in nature. In the natural hydrological setting, the ground consists of a natural ground cover and the processes included in the hydrological cycle after a rain event is infiltration, both deep and shallow, evapotranspiration and runoff (USEPA, 2003). Stormwater is water flowing as runoff on an impermeable surface (Mansell & Rollet, 2006). The precipitation can be present in a variety of amounts and forms such as rain, snow or hail. Evapotranspiration is the act of transpiration and evaporation of water by plants, and infiltration is seen as the part of the precipitated water seeping down to the groundwater. The change in storage can refer to storage in the groundwater, or in various storage above ground. Examples of storage above ground are depressions able to hold water, plants holding water temporarily and water attaching to the surfaces of various pavements. According to Mansell and Rollet (2006), the change in storage evens out over periods of time and is therefore negligible in the long term.

In an urban setting, as compared to the natural setting, many components connected to water infrastructure are present such as raw water, water treatment, distribution network and collection networks (Marsalek et al., 2014). Sewers for stormwater and sanitary purposes in urban areas can be of either a combined or separate system (Fletcher et al., 2013). In a separate system the wastewater is transported to the wastewater treatment plant in separate pipes from the stormwater (Field & Struzeski, 1972). The wastewater then goes to a wastewater treatment plant, and the collected stormwater goes directly to a recipient, or to a stormwater treatment facility. In a combined system, the stormwater is conveyed through the same pipes as the wastewater. Thus during dryer periods, when the capacity is sufficient, both types of water are treated at a wastewater treatment plant. However, in the event of heavier rainfall the addition of stormwater exceeds the pipes' capacity and a CSO (Combined System Overflow) can occur. A CSO entails a release of the combined stormwater and wastewater directly into a recipient, without foregoing treatment. The use of underground drainage systems for stormwater entails a limited capacity and the reduction of underground drainage is part of the aim for a sustainable stormwater management (Bohman et al., 2020).

Flooding occurs when large amounts of water fail to infiltrate to the ground, usually in an area that is dry most of the time (Jha et al., 2012). The flood can originate from raised water level from either the sea or a nearby river, heavy precipitation, or large amounts of snowmelt. The main source of flooding in urban areas is caused by heavy rain over the course of a short time span, usually referred to as a flash flood (Gruntfest & Handmer, 2001). A flood scenario where only rain is taken into consideration is called pluvial flood, and is defined as heavy rainfall that is too large in volume for the local drainage system to handle (Lin et al., 2021). The main issue with urban flooding lies in the water's inability to infiltrate properly, resulting in increased amounts of water gathering in a certain area (Zhang et al., 2017). A large contributor to this comes from the many impermeable surfaces in a city, caused by the rapid urbanisation (Xu et al., 2013). Flash floods and pluvial floods are floods of greater magnitude and often only problems in urban areas due to the area often being a living space or the area having a certain value to the residents, and any flash flood related events will only be more devastating as a direct consequence of human activities (Gruntfest & Handmer, 2001; Lin et al., 2021).

2.1.1 The hydrological cycle

The urban hydrological cycle differs from the natural hydrological cycle in terms of runoff, evapotranspiration and infiltration (Niemczynowicz, 1999). The difference affects the fate of precipitation falling on an urban area. The results of increased permeability are an increased runoff and lower infiltration due to the lack of permeable surfaces. Peak flows increase and the additional impermeable surface also leads to higher speeds of the flow. Studies have proven that an increase in impermeable surfaces also lead to additional runoff volumes (Chormanski et al., 2008; Olivera & Defee, 2007; Yao et al., 2016). Additionally, as mentioned by Niemczynowicz (1999), a change in the surface of a small area of a city can have large effects on a downstream location.

The impact on runoff due to an addition of impermeable surfaces is that the flow increases and the peak flow occurs earlier in the rain event (Wen et al., 2014). This is illustrated with the hydrograph in Figure 2.1 where the green line shows the natural runoff of an area, and the red line shows the urban, impermeable response, both for the same rain event. The goal of implementing sustainable stormwater management is to achieve a curve similar to the green one.

According to the United States Environmental Protection Agency (USEPA, 2003) the runoff in a natural setting is approximately 10%, and in an urban area runoff can be up to 55% of the downfall depending on how much of the area has an

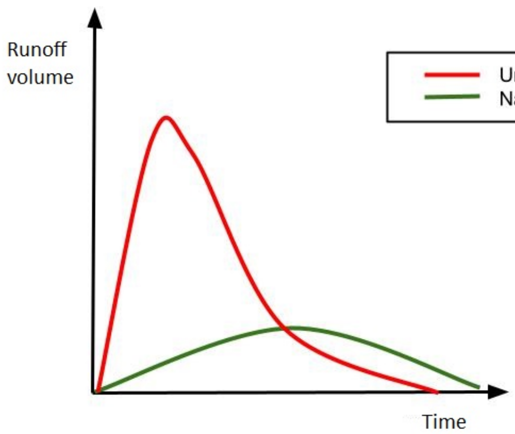


Figure 2.1: Schematic figure of urban and natural hydrograph, adapted from (Marsalek et al., 2014).

impermeable cover. The increase in runoff is due to a loss of evapotranspiration in urban areas, as well as lower infiltration. All of these effects together with the continuing densification of cities put great strain on the existing stormwater drainage system (Wihlborg et al., 2019).

2.1.2 Impacts of flooding

Stormwater management for flash floods is based on what the consequences might be in the case of a heavy rainfall (MSB, 2017). Buildings and infrastructure can be damaged which has economical consequences. Floods can also impact the functionality of a society by affecting vital infrastructure, which means that a loss of this infrastructure's function can lead to severe consequences in society (Håkanson et al., 2019). The functionality or facilities can also be lost by inaccessibility, caused by flooded roads and access points. A flood map shows the areas at risk of flooding, however the critical infrastructure at risk should also be identified and put in reference to the flooded areas (MSB, 2017). While buildings and infrastructure functions are most sensitive to the water depth of the flooded areas, more factors need to be taken into consideration when it comes to protecting people from flooding.

MSB (2017) has created an equation for calculating the risk level for people regarding flood events. The equation includes both water level and flow speed, with both higher flow speed and deeper water leading to higher risks. The equation can be seen below in equation 2.1 and is based on calculations for flood hazards made by

Defra (2006), which takes into consideration multiple other factors as well.

$$\text{Flood risk level} = (V + C) \times D \tag{2.1}$$

- C - constant coefficient of 0.5
- V - maximum velocity [m/s]
- D - water depth [m]

The equation results in various limits presented in MSB (2017), varying from <0.75 posing no risk, the intermediate levels of risk for some (0.75-1.25) and risk for most people (1.25-2.5) up to >2.50 posing a risk for everyone. These results can vary on an individual level, where a higher water level is more dangerous to some while others are more susceptible to higher flow speeds.

2.2 Stormwater management

Stormwater management is the prevention of floods by minimising the excess water flowing on impermeable surfaces. Because of the rampant increase of urbanisation, cities need to incorporate more sustainable solutions to lower the percentage of impermeable surfaces as these contribute to high stormwater flows (Xu et al., 2013). These sustainable solutions incorporate a variety of vegetation and methods inspired by the ways water is handled in nature (L. Liu et al., 2019). Wright (1996) states that by using this as a starting point, stormwater can be seen as a resource rather than an issue. According to European Environment Agency (n.d.) and Svenskt Vatten (2016), sustainable stormwater management aims to mimic nature's stormwater management, meaning not using subsurface stormwater solutions. Stormwater solutions with open surfaces are also more sustainable than subsurface ones. Examples of these open surface solutions are green roofs, rain gardens, swales and ponds. The goal of sustainable stormwater management is to delay and decrease the amount and flow of stormwater in an urban area. Additionally, L. Wang et al. (2001) mentions how detention ponds are efficient in reducing urban flooding caused by urbanisation.

2.2.1 Multifunctionality

Stormwater solutions can have other purposes, in addition to delaying water. This is especially important to consider when designing solutions for large rains with a low probability to occur frequently as the multifunctionality provides a use during dry weather (Keyvanfar et al., 2021). Using these multifunctional aspects, sustainable stormwater management can be of an ecosystem service nature and also have social value (Mell, 2009). Urban areas have been described to have a strong symbiosis between both social and ecological systems (Pickett et al., 2011). Therefore it is important to take into consideration the aspect of the multifunctional properties when designing a solution, to ensure usability of the space when not fulfilling the water delaying purpose (Keyvanfar et al., 2021).

Some benefits to sustainable stormwater management are environmentally related, such as; energy saving by having green roofs (Pfoser et al., 2014), increased biodiversity (Ghofrani et al., 2017), reduction of pollutants in the air (Berardi et al., 2014), and flood mitigation (Cristiano Id et al., 2021). Other benefits are social values, such as offering places for people to gather for recreational purposes and improving the scenic quality (Nurmi et al., 2016).

Large stormwater retention facilities are suitable for implementing social areas. An example of a facility is Enghaveparken in Copenhagen, which is a large park that also serves as a stormwater retention pond (Tredje Natur Architects, n.d.). Enghaveparken's plans show various examples of how the space can be utilised during dry periods, including having sporting areas, flowerbeds, park benches and more. The various activities that can be performed during the dry periods can be beneficial both in social aspects and with respect to ecosystem services.

Ecosystem services is a concept describing how ecosystems impact human wellbeing and are often presented in four different categories: provisioning, regulating, cultural, and supporting (Alcamo et al., 2005; Prudencio & Null, 2018). These services stem from nature and they highlight humans' dependency on it. Examples of services include food production, providing oxygen, binding of pollutants, providing shelter, reducing stress, and noise reduction. Urbanisation removes many of these services and they have to subsequently be replaced by other means, often man made. Using sustainable stormwater management is a way cities can incorporate more ecosystem services into a city. Some examples given by Elmqvist et al. (2015) are increased biodiversity, health benefits, and the inclusion of many cultural services. A body of water or a green area in an urban area could also attract animals that normally do not live in the city (Mottaghi et al., 2020).

Vegetation has proven to be beneficial to human wellbeing (Nghiem et al., 2021). During the start of the COVID-19 pandemic in 2020, a study was conducted in Chengdu, China to assess the wellbeing of its residents (Xie et al., 2020). The survey indicated that the residents felt a lack of social interaction and their health status being negatively affected by the restrictions in place. According to Xie et al. (2020), a visit to a local urban park would be beneficial to a person's wellbeing, both in terms of social needs and overall health, even if only once a week. Xie et al. (2020) also states that most of the correspondents preferred to visit a park close to their homes to minimise travelling.

2.2.2 Infiltration and surface roughness

Infiltration is the act of water entering the soil via gravitational forces (Kirkham, 2014). The amount of water able to infiltrate in a soil depends on a number of factors, ranging from type of soil, porosity, vegetation, and land use (Blackburn, 1975). Coarse soil such as gravel or sand has a greater infiltration capacity than finer soils such as clay or silt (MSB, 2017). Sand can infiltrate up to 100 mm/h whilst clay can only reach a few mm/h. In urban areas the soil is often replaced by an impermeable cover as described in section 2.1, which makes infiltration in these areas difficult and in turn generates excess amounts of runoff. During heavy rain events, a large amount of water can enter the soil and make it over-saturated, making it more vulnerable to erosion (MSB, 2017). Extreme rains generally occur in the summer in Sweden, making the soil more susceptible to infiltration due to dry weather before the rain event (Olsson et al., 2017).

Infiltration takes part in stormwater management by infiltrating the water from smaller rain events (Stahre, 2004). Therefore, in the case of a heavier rain event, the initial volume can be managed and infiltrated by the porous media, until the soil is saturated and the remaining rain flows on the surface as runoff (Wagener et al., 2007). The type of soil also has an effect on the infiltration capacity (J. Bai et al., 2019).

Surface roughness is a measurement describing the unevenness of a surface. In many cases it is described with Manning's number, M, (MSB, 2014) and has a vital role when calculating the surface runoff volume. Manning's M, is in turn based on an empirically derived Manning's roughness coefficient, n. Values of n ranges from 0.01-0.013 [s/m$^{1/3}$] for asphalt and 0.39-0.63 [s/m$^{1/3}$] for grass (Engman, 1986). The higher the value of n the more uneven the surface is, in turn making Manning's M small as a result of their inverse relationship, see equation 2.2.

$$M = 1/n \ [m^{1/3}/s] \tag{2.2}$$

Consequently, surfaces with high values of Manning's M, such as smooth asphalt, can convey water more efficiently than coarser surfaces (Lau & Afshar, 2013). This in turn leads to more stormwater runoff with a higher flow and flow speeds from areas with large amounts of impermeable surfaces that usually have a high Manning's M. If the surface on the other hand is for example a grass covered area it is likely that both surface roughness and infiltration values are high.

2.2.3 Stormwater management solutions

There are various solutions for managing stormwater and avoiding flooding. In the following sections, structures for stormwater management are described. The stormwater structures have two main objectives; retention of stormwater to delay the water, and to divert it from objects at risk from being flooded (Stahre, 2004).

2.2.3.1 Green roofs

Green roofs consist of a small layer of vegetation placed on the asphalt board of the roof (Parizotto & Lamberts, 2011). The layer of vegetation delays water and enables evapotranspiration. According to the US Department of Energy (2004) green roofs are able to retain up to 75% of annual precipitation. The ability to retain precipitation in an individual rain event depends on the size of the rain, where small rains can be retained up 100% producing zero runoff from the roof, while large rains create more runoff and smaller volumes infiltrate (VanWoert et al., 2005). Some benefits with green roofs are isolation, increased lifespan of roofs (Teemusk & Mander, 2009), improved air quality (Rowe, 2011), and noise reduction (Van Renterghem & Botteldooren, 2011). Other benefits are their ability to be implemented to existing buildings in addition to planned buildings (Stahre, 2004). However, using green roofs increases the weight of the roof significantly and if implemented on an already built roof, the building has to be able to manage the added weight (Stahre, 2004). Stahre (2004) emphasises the inclination of the roof, since it has to be minimal to allow the construction of green roofs.

2.2.3.2 Swales

Swales are large patches of grass with a slight inclination with the objective of collecting, diverting, and allowing runoff to infiltrate into the soil (Stahre, 2004). Because of its simplistic and linear design, swales are often a preferred choice of stormwater management alongside roadways (Davis et al., 2011). Swales are also preferred in areas with limited space (Yu et al., 2013). At the lowest point a well is often located to collect excess water to the stormwater network (Stahre, 2004). Stahre (2004) further explains to avoid erosion of the swale it is important that the steepness of the downward slope does not exceed 2 degrees inclination. Several studies have shown that swales performance can vary, reducing peak runoff rates from anywhere between 4% to 87% (Deletic & Fletcher, 2006; Rujner et al., 2018). Rujner et al. (2018) further describes the varying performance to possibly be related to initial soil moisture and infiltration capabilities. The height and density of the grass plays a role in the performance (Deletic & Fletcher, 2006), as does the characteristics of the soil (Rujner et al., 2016). Despite its variance in performance, swales have proven to be efficient in reducing local urban flooding and flash floods (Shafique et al., 2018).

2.2.3.3 Ditches

A ditch's main function is to convey water (Sustainable Technologies Evaluation Program, 2019). Ditches, by comparison to swales, are often both steeper and deeper and are naturally vegetated (J.F. Sabourin and Associates Inc., 2000). Some advantages of ditches, with or without culverts, are their ability to increase the concentration time of runoff leading to better design flows, some amount of filtration for ditches with grass bottoms, and lowering the risk of water gathering on the road during intense storms. A ditch can be formed to a serpentine shape using berms to prolong the flow route (Ontario Ministry of Environment, 2003). The same formation can be achieved by adding berms to a pond or dry pond. According to Larm and Blecken (2019) the slope perpendicular to the flow path of a ditch should not exceed 1:3, or roughly 18 degrees inclination. Drawbacks related to the construction of ditches are potential vegetation and the excavated soil. Trees and their roots might be in the way of excavation, and the excavated soil has to be attended to (Q. Bai et al., 2021). The ditch could also be subject to soil erosion from large volumes of flowing water.

2.2.3.4 Ponds

Stormwater ponds are man made structures with the main purpose to collect runoff thus reducing peak runoff and risks of flooding, as well as providing recreational and aesthetic services (Tixier et al., 2011). The ponds contain water permanently (Stahre, 2004) and also provide a degree of biodiversity, since the areas where they are integrated are often dominated by urban landscapes (Céréghino et al., 2014). Some studies have now identified that due to being so closely located to roads, the ponds accumulate pollutants and can become harmful to wildlife. (Meland et al., 2020). The design of the pond should prevent accidents by for example having fences around larger ponds (Stahre, 2004). For smaller and more shallow ponds it can be sufficient to enclose the pond using vegetation to ensure safety. The preferred design standards for slopes on the edges of the pond is to not exceed 1:7, or roughly 8 degrees inclination, from the permanent surface, but it can be steeper if necessary (Ontario Ministry of Environment, 2003).

2.2.3.5 Flooding areas and dry ponds

Flooding areas, also known as dry ponds, are often a large, lowered grassy area designed to be flooded in the event of a large storm, whilst being dry during times of no precipitation (Sinclair et al., 2020). After a storm event the water is either diverted through a ditch or left to infiltrate into the soil where usually a drainage pipe is located (Stockholm Vatten och Avfall, 2017). During dry periods when there is no water collected the area can be utilised as a park or playground (Shammaa et al., 2002). In recent times, during the COVID-19 pandemic, both Xie et al. (2020) and Jenkins (2020) put emphasis on urban parks and other large outdoor open spaces, describing how they have been crucial to maintaining a good mental wellbeing with humans. The area should only have an inclination of a few degrees to ensure maintenance can be performed (Stockholm Vatten och Avfall, 2017). According to Ontario Ministry of Environment (2003) guidelines, the side slope in a dry pond should not be steeper than 1:4, or 14 degrees inclination. Furthermore, the area should receive equal maintenance compared to a park in a similar area (Stahre, 2004). It is important to make sure that the area is fully drained to prevent a constant water table, which could affect the multifunctional purpose of the solution. These types of areas generally require a large area to be useful (Stockholm Vatten och Avfall, 2017). Another factor to take into consideration is related to soil compression when draining groundwater, as the settlements could have a negative impact on nearby buildings (Shen et al., 2006).

2.2.3.6 Permeable surfaces

Permeable surfaces consist of a permeable layer allowing water to infiltrate into the soil beneath (Eisenberg et al., 2015). These can either be natural such as grassy areas, or man made such as permeable asphalt or gravel with a storage tank placed beneath it (Lewis et al., 2019). From there the water can either be diverted to the natural soil layers or drained (Stahre, 2004). Solutions consisting of permeable surfaces have proven to lessen the impact of runoff entering the drainage system, and therefore lowering the risk of flooding (Lewis et al., 2019). As such they are often placed where there is a great amount of impermeable areas, such as parking lots and driveways. Additional benefits of this solution include recharging of the groundwater table, improved water quality, and reduction of infrastructure costs related to drainage systems (Eisenberg et al., 2015). One common disadvantage related to permeable surfaces arises when they are clogged and no longer can operate sufficiently (Bean et al., 2007). If these are not cleared and maintained regularly the surface can be completely clogged, in turn making the surface unable to perform and in need to be replaced entirely (Scholz & Grabowiecki, 2007).

2.2.3.7 Stormwater terraces

A series of terraces located on different height levels along a path can be used to collect and slow down water. The design is similar to dry flooding areas connected in a series, making them flood subsequently. According to research made by J. Bai et al. (2019), terraces are effective in reducing runoff rates when comparing the amount of vegetated areas of a terrace system to a simple slope. The terracing also increases infiltration rate compared to a constant slope since infiltration rates decrease with increased inclination (Morbidelli et al., 2018).

2.3 Precipitation and climate change

Climate change affects multiple aspects regarding flooding and precipitation. Some of the effects stemming from climate change are; an increase in global temperature, increased global sea levels, and an increased number of heavy rain events (Wolff et al., 2020). From The Fourth Assessment Report from the IPCC (the Intergovernmental Panel on Climate Change), it is clear that the biggest contributor to the global rise in temperature stems from the increase in greenhouse gas emissions, which in turn can lead to altered precipitation patterns (Solomon & Intergovernmental Panel on Climate Change, 2007). According to SMHI (Swedish Meteorological and Hydrological Institute), the amount of precipitation in Sweden has increased since 1980, and will by the end of this century have increased between 20-60% (SMHI, 2020a).

There are a number of potential consequences with climate change related to stormwater. One potential consequence is an increased risk of extreme rain events and flash-floods. Furthermore, an increase in precipitation will increase the amount of water coming from the increased number of impermeable areas (Alamdari et al., 2017). All of the events listed will put great strain on society unless adequate preparations are made before they occur.

2.3.1 Return times

Return times are used to describe the intensity of a rain event. SMHI has defined a cloudburst as a rain event of at least 50 mm in an hour, or a minimum of 1 mm per minute (SMHI, 2017). The definition by SMHI is very specific, and another way of describing the size of rain events is return times. Using return times, the rain event is classified by the magnitude of rain which falls on a surface for a period of time (Svenskt Vatten, 2016). If the same volume falls during one longer and one shorter time period, the shorter time period will have a higher intensity and thus be classified as a higher return time, meaning it is a more rare event with a possibility of more extreme consequences.

The intensity and return times are a way of describing how likely it is that an event will occur each year. For example a rain with a 100-year return time has a 1% chance of occurring each year, independently of when the last 100-year rain event occurred (Svenskt Vatten, 2016). On average, a 100-year rain would occur 10 times in 1,000 years. Rain events of different magnitudes have various chances of occurring each year. For example a 5-year rain has a 67% chance of occurring in 5 years, and 100% in 50 years, while a rain of a 1,000-year magnitude has less than 1% chance of occurring in a 5-year period, and 10% in 1,000 years. These figures of return times are what societal functions are designed to withstand in the case of a flood event, now and in the future.

2.3.2 RCP scenarios

Representative Concentration Pathways (RCP) are scenarios describing how the effect of global warming will impact the world in the future. These were projected by IPCC in 2014 and are updated versions of their former projections called Special Report on Emissions Scenarios (IPCC, 2019). The scenarios are based on the possible radiative forcing value reached by the year 2100, these being RCP2.6, RCP4.5, RCP6.0 and RCP8.5. All scenarios are possible outcomes, however which path will become reality depends on how much greenhouse gases will be emitted in the future (Moss & Intergovernmental Panel on Climate Change., 2008). For the lowest scenario, RCP2.6, the highest emissions of carbon dioxide are comparable to present day values and will have peaked around the year 2020 (SMHI, 2018). For RCP4.5 it is predicted that the emissions will peak close to 2040, and for RCP6.0 it will peak in 2060. RCP8.5, which is the highest scenario, predicts the carbon dioxide emissions are three times higher than today by the year 2100, with the world having little to no environmental action plans whilst using fossil fuels to great extents. The RCP-scenarios are the foundation to the climate adaptation of stormwater management.

2.3.3 Climate factors

To account for climate change when selecting design precipitation, a climate factor is added to the selected rain (SMHI, 2020b). The climate factor is based on the RCP-scenarios and reflects the possible increase in precipitation at the end of the century, based on the followed scenario as discussed in section 2.3.2. The climate factors reflect an increase, in percent, of the precipitation. According to SMHI (2020b), a trend in precipitation points towards an increase of 30-40% by the year 2100, if the worst case scenario of RCP8.5 is followed. The 30-40% increase corresponds to an addition of a climate factor of 1.3 or 1.4 for design precipitation. The addition of

1.4 as climate factor is recommended by Länsstyrelserna (2018). However, Svenskt Vatten recommends the use of climate factors 1.25 for rain shorter than 60 minutes, and 1.2 for rain events lasting longer than an hour (Svenskt Vatten, 2016). The same recommendation is given by SMHI for events that might occur in the coming 50 years, but at the end of the century it is more likely that the factors 1.3-1.4 will be accurate (Olsson et al., 2017). This means that the selection of a higher climate factor gives a higher safety for a longer period of time when designing solutions to manage flash floods.

2.4 Modelling

Stormwater modelling is used to predict and simulate scenarios related to stormwater, such as flooding or elevated sea levels. The earliest versions of modelling in this area derive from the US in the 1970s and were created by government agencies (Zoppou, 2001). Today the range of softwares has expanded and cover a variety of areas and provide varying degrees of difficulty and depth, while they have various advantages and disadvantages (Viklander et al., 2019). When choosing a software for a project it is important to consider what kind of parameters are studied and what results should be obtained. Another important factor to consider is the complexity of the model, where the complexity should correspond to the studied phenomena (Rauch et al., 2002). A more complex model might not be the most suitable, since it could leave room for more errors.

Modelling can assist in predicting where water will gather in the case of a large rain event when the drainage system is unable to operate efficiently. This can in turn aid in the decision of where to place measures to counter the risk of flooding (Svenskt Vatten, 2016). Certain parameters are able to be studied using modelling as well. The impact of infiltration has been studied previously using softwares such as SWMM (Lee, 2011) and MIKE 21 (Gunnarsson, 2015). SCALGO Live can be used to study flow paths and water volumes in an easy manner (Eriksson & Wilkås, 2018). Surface roughness has been studied as well, however not to the same extent (Z. Liu et al., 2018).

As described in section 2.3, the ever changing nature of stormwater related events can be difficult to prepare for. Therefore, use of modelling softwares for predicting these events have become increasingly important. In this project, two softwares are used to assess the impact of the proposed solutions, these being SCALGO Live and MIKE 21. These are described in more detail below. SCALGO Live is used to assess proposed stormwater solutions in a fast and effective manner, while MIKE 21 is used to assess the hydrodynamics as well as impacts of infiltration and surface roughness.

2.4.1 SCALGO Live

SCALGO Live is a web based software with high resolution terrain data for flooding simulations developed by SCALGO (SCALGO, n.d.-a). The software allows the user to analyse the terrain data with different tools, such as Flash Flood Scenario and Sea-Level Rise. The flash flood scenario, used in this report, simulates flooded areas and flow paths caused by extreme rain events (SCALGO, 2021a).

When using the flash flood scenario the user can manually set the amount of rain to be analysed and the software then visually shows how the land would be affected by the conditions set. Other functions of the software include altering the terrain, flood pathways, and flooded areas (SCALGO, n.d.-b). It should be noted that SCALGO Live only shows the final outcome of a flash-flood or raised sea level and not a continuous event. Additionally, SCALGO Live does not take soil properties into account for its simulations, such as infiltration or surface roughness. This makes the results somewhat overestimated when compared to the real life scenario. As soil properties are not defined in SCALGO Live, buildings and other structures are simply altered elevations with no unique properties to differentiate them from the ground.

The terrain model of Sweden used in SCALGO Live is based on data from Lantmäteriet and consisted, at the time of the project, of a 2x2 meter resolution grid that covers most of Sweden (SCALGO, 2021b). As of April 2021 the resolution has been increased, to have a 1x1 meter grid available (SCALGO, 2021c). In SCALGO Live, water is collected in depressions with a specific volume capacity. When a depression has reached its capacity, water will flow to other depressions downstream. When the total rain amount increases, so does the size of the area that contributes to the lowest located depression (SCALGO, 2021a).

2.4.2 MIKE 21 Flow Model FM

MIKE Powered by DHI is a 2D modelling software developed by DHI used to analyse, model, and simulate various water related properties and scenarios (DHI, n.d.-a). The scenarios can be of varying sizes and types; from a flooded parking lot, to a river and up to the ocean and estuaries. The model can include various parameters such as waves, flows, sediments, and precipitation (DHI, n.d.-c). There are a variety of options available for different research topics, called modules, where these aforementioned parameters can be specified before simulation.

MIKE 21 Flow Model FM, henceforth referred to as *MIKE 21*, is a 2D tool designed for simulating processes in coastal, oceanic and estuarine settings, which can also be used to model inland flooding (DHI, n.d.-b). Some of the processes available as modules for modelling are oil spill, ecology, and hydrodynamics. The tool is based on a flexible mesh (FM) consisting of linear triangular elements (DHI, 2017). In the tool, the user defines conditions such as; boundary, bathymetry, simulation period, and choice of module. There are six modules available in the tool, the one being used for this thesis is the hydrodynamic module.

The hydrodynamic module allows the user to specify a number of input features related to stormwater such as; precipitation, wind conditions, surface roughness, infiltration capacity, and evaporation (DHI, n.d.-b). Furthermore, the module allows the user to include different structures and sources of pollutants if desired.

Precipitation in MIKE 21 can be defined in three ways; no precipitation, net precipitation, and specified precipitation (DHI, 2017). The first choice includes no precipitation and the second one simply calculates the difference between the precipitation and evaporation. The third option uses a time series to describe the varying precipitation over time in the domain that can either be constant, varying in time but constant in domain, or varying in both time and domain.

MIKE 21 uses an input feature called Flood and Dry to visualise flooding (DHI, 2017). The user has to specify two parameters called the drying depth, h_{dry}, and wetting depth, h_{wet}, a value written in meters. A third value, called h_{flood}, is used to define if a cell is flooded. MIKE 21 determines a certain cell in the mesh to be flooded if two conditions are met; the water depth, h, at the cell is lower than h_{dry} on one side of the cell and larger than h_{flood} on the other side, and the sum of the depth lower than h_{dry} and elevation on the other side is greater than 0. If h is greater than h_{wet} in a cell, then the cell is considered wet. A cell is dry if h is less than h_{dry}, and partially dry if h is greater than h_{dry} but lower than h_{wet}. The default values set in MIKE 21 for h_{wet} and h_{dry} are 0.05 m and 0.005 m respectively.

The precipitation pattern used for a series that varies in time is called a hyetograph (Svenskt Vatten, 2011a). The hyetograph consists of three main parts; a pre-rain, a rain intensity peak and a post-peak duration. The hyetograph is based on IDF curves, Intensity Duration Frequency, to create a simulated rain that is representative to the modelled area. One such standard design hyetograph is called CDS-rain, which stands for Chicago Design Storm. In the hyetograph for the CDS-rain, the pre-rain is usually shorter than the post-rain, meaning that the peak is not located in the middle.

2.5 Case study area

The case study area for this project is located within the urban area of Lerum, the largest urban area in the municipality of Leurm. The municipality of Lerum is located in western Sweden, approximately 20 km northeast of Gothenburg. The municipality has an area of 260 km^2, and approximately 43,000 inhabitants (Regionfakta, 2021a, 2021b). The urban area of Lerum has an area of 25 km^2 (SCB, 2019) and 20,000 inhabitants (Gustafsson, 2020). Henceforth '*Lerum*' will indicate the urban area of Lerum. If the municipality is implied, it will be distinguished. Through Lerum runs the river Säveån, which runs through the lake Aspen in the western part before continuing to Gothenburg. The lake Aspen is adjacent to Lerum and can be a possible flood risk for areas near the lake. The flood risk from the lake is outside the scope of this study, as this project only relates to pluvial flooding.

2.5.1 Topography and geology

According to the available soil information at the site, the soil in Lerum consists mainly of postglacial or glacial clay, with some elements of crystalline rock, till/sandy till and postglacial sand (SGU, n.d.-a). Lerum is situated in an area with presence of quick clay, as is the case for some locations in Lerum including the central parts (Håkanson et al., 2019; SGI, 2017). The presence of quick clay can affect the possibility for implementations to manage flash floods.

The river Säveån that runs through Lerum, from east to west, is sensitive to climate change driven impacts (SGI, 2017). Parts of the river flowing through Lerum are also sensitive to slope failure which is a consequence of for example flow and flow speed in the river. Säveån can be subject to flooding in some parts of the river, as can be seen by using SCALGO Live with flooding predictions by MSB (2018). The flooding predictions by MSB can be examined for both 100-year and 200-year return times, with an additional climate factor. The water quality status according to VISS (n.d.-b) is good in most aspects, with traffic and stormwater being part of the contribution to pollution of the river. Säveån connects to the lake Aspen, which has a generally good ecological status, with some possible eutrophication (VISS, n.d.-a).

2.5.2 Sensitive infrastructure in Lerum

Sensitive infrastructure and facilities that are of societal importance are services that have negative effects on society should they fail (Håkanson et al., 2019). Examples are healthcare facilities, power grid networks and drinking water distribution. Sensitive infrastructure and facilities which can be identified using a map are used in this project. The identified facilities are shown in Figure 2.2 and are found through Lantmäteriet and Lerums kommun (2019), Svenska Kyrkan (n.d.) and Google (n.d.). Vital infrastructure included in the figure is healthcare facilities and a fire department. The facilities identified to be more sensitive to flooding in terms of livability are grocery stores, and risk for people are preschools and senior homes. Elementary schools are also included in the map as young children can be at risk in a flooding event, while higher education is not included. As mentioned, other sensitive or vital infrastructure relates to for example IT-services, power supply and drinking water supply (Håkanson et al., 2019). However, these are not included due to the information being classified.

Other than protecting facilities for livability, it can also be of interest to investigate how a flood can affect historically and culturally significant locations (MSB, 2015). Significant buildings are listed in the database on built heritage, a database created by the Swedish National Heritage Board (Riksantikvarieämbetet, n.d.). In Lerum, there are several buildings that are included in the list. However, most of the listed buildings are located south of Säveån, and are not affected by the catchment area. Two churches listed in the database are located on the north side of Säveån and are therefore included in the map.

Figure 2.2: Identified critical infrastructure where flooding should be avoided. Map is created by the authors with information obtained from Lantmäteriet and Lerums kommun (2019), Svenska Kyrkan (n.d.) and Google (n.d.) .

2.5.3 Stormwater management in Lerum

There are multiple reports and documents that relate to the subject of stormwater management in Lerum, including, but not limited to; the comprehensive plan (Lerums kommun, 2008), stormwater strategy (Lerums kommun, 2015a), stormwater management handbook (Lerums kommun, 2015b) and a climate adaptation plan (Lerums kommun, 2015c). Adding to this list are the regional and national plans and recommendations that affect stormwater management (Länsstyrelserna, 2018; SMHI & Svenskt Vatten, 2020). The municipality of Lerum has a comprehensive plan, valid from 2008 (Lerums kommun, 2008) with another one under development. The comprehensive plan describes goals and operations for different parts of the society. In the most recent comprehensive plan, it is mentioned that the goal for stormwater management is to be ecologically sustainable and that management should mainly aim to be local. Included in the stormwater strategy is a goal to prioritise sustainable stormwater management (Lerums kommun, 2015a).

In Lerum's comprehensive plan, it is also mentioned that at the time, in 2008, the sewage system was local and the sewage was treated in Lerum (Lerums kommun, 2008). However the goal for the municipality was to connect to Ryaverket in Gothenburg. According to the website of Gryyab, the company running Ryaverket, this has been achieved and Lerum's sewage system is connected to Gothenburg through a large wastewater tunnel (Gryyab AB, n.d.).

In the stormwater strategy, information is provided on what types of rain should be the design standards. It is stated that rains of the size with 100-year return time should be design standard when the rain risks damaging buildings, and a 400-year rain is design standard for the risk of damaging or affecting important functions in society (Lerums kommun, 2015a). These can for example be healthcare facilities or fire stations. The stormwater strategy brings up a municipal goal for Lerum, which is that the stormwater management should be sustainably adjusted to climate change in the year 2025, with respect to quality, quantity and design (Lerums kommun, 2015a). These parameters are based on the design standards for sustainable stormwater management as stated in the publication P110 by Svenskt Vatten (2016).

2.5.4 Development

The municipality of Lerum is an expanding municipality, and the expansion is likely to lead to an increase in impermeable surfaces in its urban areas (Björkman et al., 2019). The municipality of Lerum is planning to build two new schools in the area. The one furthest in planning is an elementary school in the area Norra Hallsås (Lerums kommun, 2021a), which is the starting point for the catchment area examined in this project. The school is planned to have a capacity of between 800-1000 students and will also include a school for children with special requirements, as well as a sports hall. The area is currently a forested area with rocky terrain mixed with lower vegetated areas containing water, as well as water in springs. A parking lot will also be constructed together with the school. The road leading up to the area is heavily sloped. This new development has a possibility to affect the flow to downstream areas by having an increased amount of impermeable surfaces.

The second planned school is a preschool that will be located at Kring Alles Road in Lerum (Lerums kommun, 2017b). It is still early in its development process. The area where the preschool is planned to be located is sloping steeply towards Kring Alles Road and is mainly covered in grass. The suggested location by the municipality of Lerum for the preschool is in the south-west corner of the currently grass covered area. There are also plans for a parking space in the south-east part. The location and suggestion of the design made by the architects at AL Studio can be seen in Appendix A. The road Kring Alles is part of the course the water takes from Norra Hallsås.

To obtain the watershed related to the case study area in Lerum, the watershed connected to Torpskolan is used. Torpskolan then becomes the downstream point of the watershed that is studied. Torpskolan is located in the centre of Lerum, north of the river Säveån. The watershed can be seen in Figure 2.3. The watershed corresponds to an area where high flows and flow speeds have been identified as a challenge when it rains, along with floods by Torpskolan. The area is also subject to developments upstream, downstream and along the way which can affect the stormwater situation (Lerums kommun, 2017a, 2017b, 2021a).

Within the examined area in the project is a stormwater flow path, identified by the

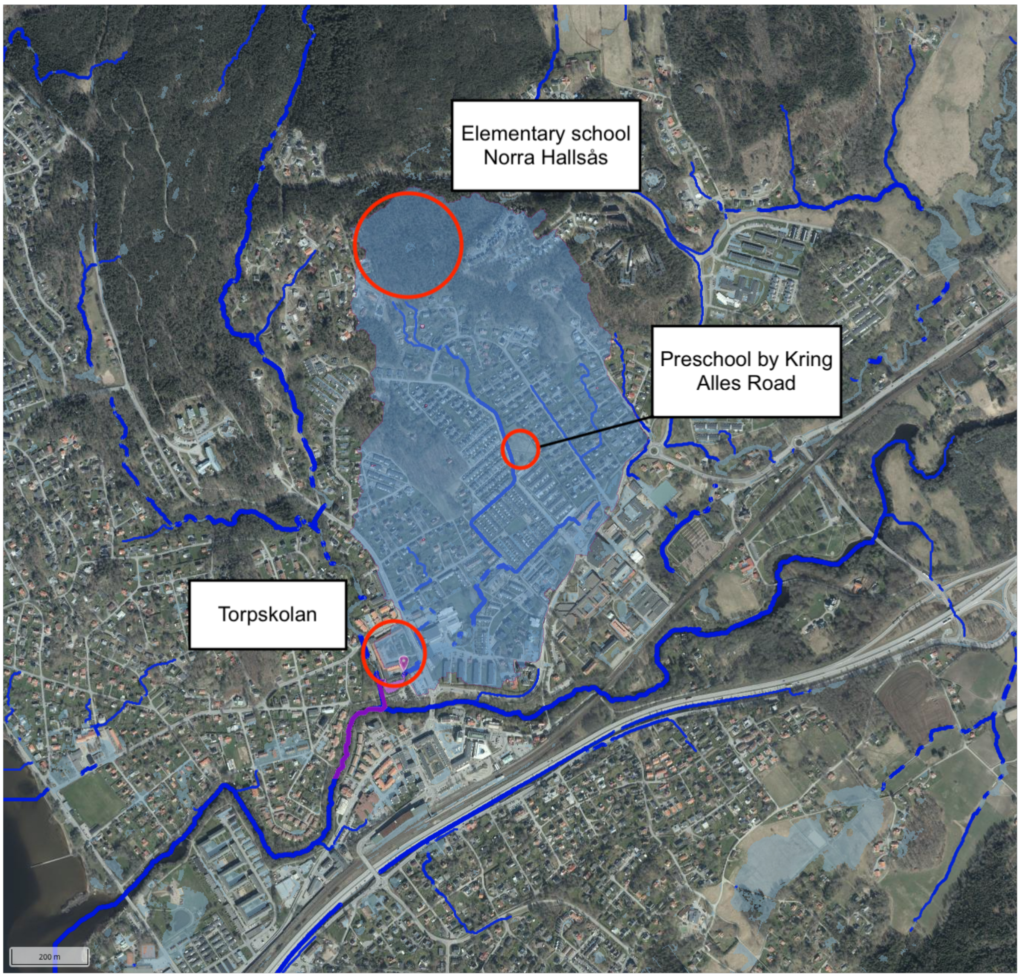


Figure 2.3: The watershed in the case study area in Lerum.

municipality and studied in SCALGO Live. The flow path can be seen in Figure 2.3 and starts in an elevated area in the northeast, and ends by the school Torpskolan. The water flows from the elevated area where the planned elementary school in Norra Hallsås will be located, down to Kring Alles Road. Then it follows Kring Alles Road past the location for a new preschool. After the location for the planned preschool there is a natural depression in the roadway, where the water is diverted into a residential area and flows evenly through the area, down to a park. Before the water reaches the park it passes through a developed lot for housing currently occupied by temporary buildings. The park is an open, green field with trees and a social area. When the water exits the park area it flows via a bicycle lane running in between residential houses and a water park, Vattenpalatset. The flow path, along with the mentioned schools, can be seen in Figure 2.3. The downstream point of the water flowing on this course is the school Torpskolan, which is at risk of flooding due to its location and elevation. Torpskolan is a school currently attended by children ages 12-15 (Lerums kommun, n.d.).

A current facility in Lerum is the swimming centre Vattenpalatset. It is located just upstream from Torpskolan and has been in use for almost 30 years (Lerums kommun, 2020). Due to the long usage time the future of Vattenpalatset is under evaluation (Lindblom, 2020). The location is deemed suitable in this project to be evaluated for a larger stormwater retention system with a multifunctional focus.

By the downstream location Torpskolan in the watershed, which can be seen in Figure 2.3, a residential area with apartments is planned to be built (Lerums kommun, 2017a). At the time of the project the final decision on the detailed development plan has yet to be decided on. The relevance of the area for this project is the fact that half of the current parking lot is part of the watershed contributing to the flood at Torpskolan.

3

Methodology

To fulfil the aim and objectives of finding sustainable solutions to the flood management in Lerum and investigate the effects of infiltration and surface roughness on the implemented solutions, various methods are applied. The methods are based on Swedish standards and guidelines, where applicable, as the case study area is located in Sweden.

3.1 Flood vulnerability

As mentioned in section 2.1.2, both water depth and flow speed impact different aspects of society such as people or sensitive infrastructure. Therefore it is of interest to identify what areas pose a hazard. This is conducted using flood maps for water depth, and a 2D-model for flow in combination with the previously presented risk level equation 2.1. In this project, SCALGO Live is used to create a flood map showing areas with high flood, and MIKE 21 to show areas with high water flow speed.

In addition to the risk for flooding of buildings and for people's safety, there is also a risk that roads become flooded and emergency vehicles are stalled as a result. In research conducted by Pregnolato et al. (2017), it was concluded that the water depth where most vehicles can still operate safely is 30 cm. However, this depth varies with the size of the vehicles, where smaller cars can be affected by a water depth of 15 cm and larger cars have the possibility to be operated safely in depths up to 45 cm. In planning documents obtained from the City of Gothenburg it is concluded that the guidelines for flooding on roads is a maximum of 20 cm to ensure access for ambulances and police cars (Blomquist, 2015a, 2015b).

To identify which facilities are subject to risk of flooding, the map of critical infrastructure is combined with the flooded areas within the watershed for the case study area. This is to exclude the facilities located outside of the watershed, which can be seen in Figure 2.3, and only take into consideration the ones affected by the water depth in the study area. Flooding can also be a danger to people through water depth or flow speed, as is seen in equation 2.1. Using equation 2.1 and a simulation in MIKE 21, the initial conditions where high flow speed, or a combination of flow speed and water depth is high can be found.

3.2 Rainfall events

The flood scenario used for this project is called pluvial flood. To calculate the amount of rain to test the solutions for, and base the design on, the recommendation by SMHI and Svenskt Vatten is to use Dahlström's formula (2010) (SMHI & Svenskt Vatten, 2020). The formula is a reworked version of a formula developed in (2006), and the science of predicting rain events is an ongoing process. According to SMHI there is currently a process to develop the formula by Dahlström (2010) to an improved formula called Dahlström (2018). However the recommendation by SMHI and Svenskt Vatten is currently to use Dahlström (2010), and the formula can be seen in equation 3.1.

$$i_{\text{Å}} = 190 \times \sqrt[3]{\text{Å}}\frac{\ln T_R}{T_R^{0.98}} + 2 \tag{3.1}$$

- $i_{\text{Å}}$ = intensity for a specified return time [mm/h]
- Å = return time [months]
- T_R = rain event duration [min]

The return times chosen for investigation are based on the stormwater management guidelines from the municipality of Lerum (Lerums kommun, 2015a). The investigated return times are 100 years and 400 years as these return times are the current guidelines of the municipality of Lerum on withstanding floods. According to the demands, facilities should withstand a flood corresponding to a 100-year rain event, and vital infrastructure should withstand a 400-year rain event. For both the 100- and 400-year events, two different durations are investigated to enable comparison between a longer and a shorter rain event. The chosen durations are 10 minutes and 4 hours and are chosen since a shorter duration of maximum a few hours is usually of higher interest in urban areas (MSB, 2017; Svenskt Vatten, 2016). The duration of 10 minutes is of interest since it is predicted that short durations will increase the most in a future climate. The 4 hour duration is chosen as it is still in the range of a short duration, while also differing from the 10 minutes as to ease a comparison to investigate the different effects of precipitation. A climate factor of 1.4 is added to the precipitation volume, as per recommendation by Länsstyrelserna (2018).

Neither of the modelling programmes include drainage systems, as is further discussed in sections 3.3.2 and 3.3.4. Therefore, a deduction is made on the entire rain event of an amount corresponding to the rain that is collected in the drainage pipes. The drainage system manages the initial volume in a rain event. Lerum's stormwater system is designed to manage a 2 year rain with respect to filled pipes, and 10 year return time with respect to overflows onto the surface (Björkman et al., 2019), both for a duration of 10 minutes (A. Kalm, personal communication, February 24, 2021). New pipes should be designed to collect this precipitation, including a climate factor, but since the concept of an additional climate factor has not always been standard, it cannot be expected that older pipes can manage the same amounts. The presence of a drainage system can not always be assumed, as the inlets can be clogged with debris (Svenskt Vatten, 2011b). With the drainage in consideration, the deduction made to account for the stormwater drainage system is a rain with a 2 year return time, and 10 minute duration, resulting in an amount of 8 mm to be deducted. The corresponding intensity is calculated using formula 3.1.

SCALGO Live does not account for soil properties in it's simulations, and thus does not have an infiltration capacity. To account for infiltration in simulations in SCALGO Live, the infiltration capacity is deducted from the total amount of rain to the area, similar to the deduction of the drainage system. In this project, there is no deduction of infiltration capacity, since the capacity varies to a large extent over the case study area (SGU, n.d.-b).

The calculated precipitation volumes used in the modelling are presented in Table 3.1. Initially the precipitation intensity for the different rain scenarios are calculated using the formula by Dahlström (2010), formula 3.1, which corresponds to the first row. Certain units are preferred when calculating runoff, and to convert the intensity from [l/s × ha] to [mm/h] a factor of 0.36 is multiplied with the values in the first row to create the values in the second row (Svenskt Vatten, 2016). To account for the climate factor the values are then multiplied by 1.4, as seen in the third row. The fourth row is the amount of precipitation for the selected duration, for example 10 minutes in the first column. Lastly the deduction is made for the drainage system, which then gives the rounded off values that are used to investigate results from the simulations.

Table 3.1: Calculated precipitation volumes.

	100 years 10 min	100 years 4 h	400 years 10 min	400 years 4 h
Intensity [l/s×ha]	488.81	53.45	774.77	83.67
Intensity [mm/h]	175.97	19.24	278.92	30.12
Intensity×Climate factor [mm/h]	146.36	26.94	390.48	42.17
Amount of precipitation [mm]	41.06	107.75	65.08	168.68
Deduction of 8 mm [mm]	33.06	99.75	57.08	160.68
Design precipitation [mm]	33	100	58	160

The figures calculated in Table 3.1 are used in the simulations to investigate how the stormwater solutions perform during different rain events. When designing stormwater solutions it is of interest to consider various rain events as to not have an underdimensioned or overdimensioned system. MSB (2014) states that it is of most interest to study short and intense rain events in an urban setting. However, it is also of interest to study a variation in rainfall events and precipitation volumes as the requirements regarding flooding differ between facilities, as discussed in section 3.1, and the various rain events contribute with different properties to the floods and flows.

For the modelling in MIKE 21, another rain event scenario is used, and thus not the values presented in Table 3.1. In MIKE 21, a predetermined CDS-rain created by Tyréns AB is used (Björkman et al., 2019). The CDS-rain used in this project consists of a rain event with a 100 year return time and an added climate factor of 1.4, as specified by Lerum in the municipal stormwater management guidelines (Lerums kommun, 2015a). The peak rain volume is modelled to last for 10 minutes, and begins about 2 hours into the simulated 6-hour period (Björkman et al., 2019). The precipitation volume used for the 100 year, climate adapted rain event is 118.3 mm, with a deduction made on impermeable surfaces that connect to a drainage system. The deduction is made for a rain with a 2-year return time and the volume deducted is 26.1 mm. This is implemented in MIKE 21 as a precipitation file that is varying in time and domain.

3.3 Model setup

The modelling starts with elevation edits and simulations in SCALGO Live corresponding to the implementation of the schools and the stormwater solutions, and then proceeds to MIKE 21. In the modelling, the solutions will only be placed on land owned by the municipality, where the available land is shown on the map in Appendix B. The larger solutions will be placed in areas identified as suitable for stormwater delay and collection. The locations are identified during a study visit to the case study area. These areas and their labels are shown in Figure 3.1. Areas that can be seen as unsuitable for stormwater management, in addition to privately owned land, are on contaminated soil. The occurrence of contaminated soil is investigated using SCALGO Live and the built-in function to see contaminated soil.

The facilities that are future development in the case study area, the elementary school in Norra Hallsås and the preschool by Kring Alles Road, do not exist yet. Therefore they are not automatically included in the elevation models of the modelling programmes SCALGO Live and MIKE 21. To investigate how these areas can affect future stormwater flow, the areas are implemented manually in the programmes.

3.3.1 Adjustment of the elevation model in SCALGO Live

Before modelling the possible stormwater management solutions, the available elevation model in SCALGO Live is compared to maps of the area and information from the study visit. SCALGO Live has some terrain edits already implemented in the interface, which should be controlled before use. An area where the model and reality do not correlate is by the school Torpskolan, which is the downstream point of the case study area. On the west side of the school, a creek runs from the north and down to the river Säveån. In reality, it contains culverts to direct the flow under the road Frödings Allé north of the school, and another culvert under the bike lane south of the school to connect with Säveån. Maps from SCALGO Live showing the area and the culverts can be found in Appendix C. To amend this in the SCALGO Live model, the original model contains a culvert going straight from Frödings Allé to Säveån, which does not correlate with reality. Before implementing the stormwa-

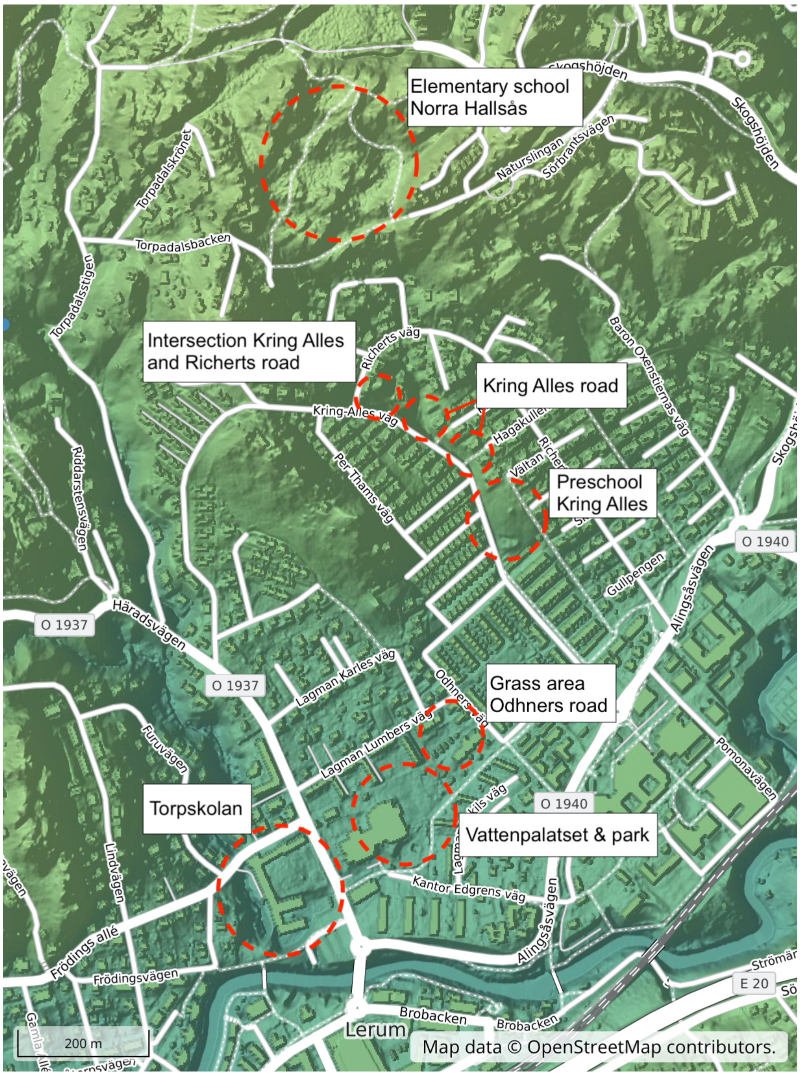


Figure 3.1: The red circles show the areas where stormwater solutions are implemented and the areas' respective labels. The reference labels will be used throughout the report to refer to the locations of the solutions.

ter solutions, the culvert is altered to represent the two culverts diverting the water to the river Säveån while running through the creek west of the school.

3.3.2 SCALGO Live model setup

In this project, simulations are performed in SCALGO Live using the flash-flood tool with a set precipitation based on Table 3.1. A workspace covering the whole area can be seen in Figure 2.3. This is the area that SCALGO Live will take into consideration when calculating the stormwater flow. The locations where the elementary school and preschool will be built are marked in the figure. To understand how the buildings will affect the stormwater, representations of the buildings were created by raising the terrain a minimum of 3 meters above the ground. The shape of the building is based on development plans from Lerum (Lerums kommun, 2021b). As mentioned in the background about SCALGO Live, in section 2.4.1, the grid resolution was improved in April of 2021 to be 1x1 m instead of 2x2 m. However this was done after the modelling in SCALGO Live was completed for this project, meaning that the surface elevation edits in SCALGO Live are based on a 2x2 m grid.

First, the initial conditions showing what the flooding impacts would be if it occurred today is simulated in SCALGO Live. The simulation of the initial conditions is used to show the conditions of the study area without any modifications, neither stormwater solutions nor the addition of the planned new developments.

The next step is to add the planned buildings, the school and preschool, to identify the flooding risks they are exposed to, as well as how the flood and flow is altered because of the development. Both schools are initially implemented directly on the terrain without any alterations of the terrain around the schools. After the schools are implemented into the model, the option of flattening the ground around the elementary school is examined. After the examination, some of the ground around the school is flattened, along with measures to avoid flooding in the proximity of the building as it is deemed of more interest to study the impact of the water downstream. It is also deemed likely that the surface around the school will be flattened in reality, which could divert the water from the school.

By the preschool, there is a parking lot which is added according to design plans that can be seen in Appendix A. The parking lot is added to enable investigations on how the surface can be used as a stormwater management solution in addition to serving as a parking lot. Both the elementary school model and the preschool model are based on the available zoning plans at the time of investigation and might therefore not correspond to the final design.

Another new development mentioned in section 2.5.4 is the residential buildings in the current parking lot by Torpskolan. Future alterations to the area could affect the stormwater flow and possibly infiltration depending on the design. The buildings in this area are however not added to the SCALGO Live main model. This is since the studied floods are unlikely to be affected by these buildings due to the minor contribution of this downstream parking lot area. The flow speeds are also unlikely to be altered into a higher flow speed since the parking lot is currently an impermeable asphalt surface.

3.3.3 Selection and design of stormwater solutions using SCALGO Live

In the following sections, the different stormwater management solutions are simulated in different scenarios using SCALGO Live. The scenarios are based on the solutions mentioned in Chapter 2.2.3 and simulated one by one. Locations of the solutions are presented in Figure 3.1 above. The aim is to find the most appropriate and effective solutions and move on with further analyses. The further analysis in SCALGO Live is an evaluation of the solutions' performance for the rain events calculated in Table 3.1. Further analyses in MIKE 21 entail an investigation of infiltration and surface roughness on the solutions. The stormwater management solutions presented below are simulated in SCALGO Live.

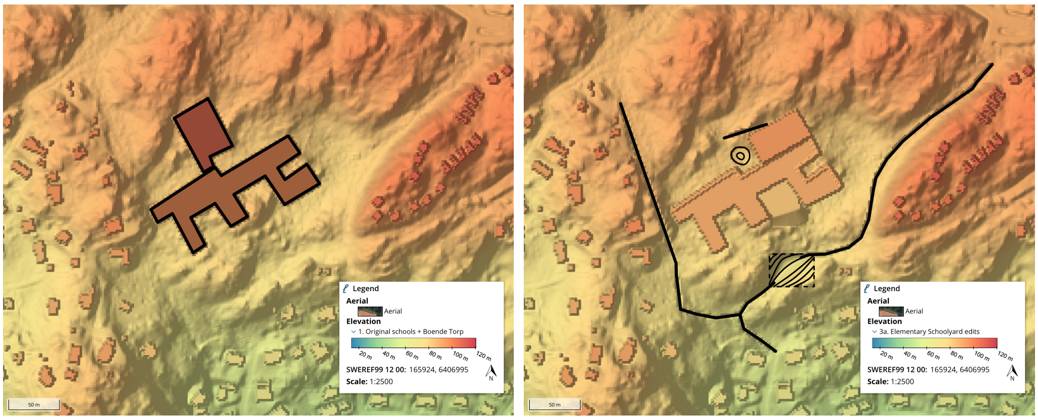
The stormwater management solutions are designed following design standards related to safety based on standards set by Larm and Blecken (2019), Stahre (2004) and Ontario Ministry of Environment (2003). Stahre (2004) mentions that one way to include safety aspects is by planting high grass by pond sides, which could also be part of a multifunctional aspect. Vegetation in the solutions can assist in providing ecosystem services (Elmqvist et al., 2015).

The solutions and the location of the aforementioned are also based on availability of municipally owned areas. The solutions are solely designed as open surfaced solutions, and not as subsurface drainage systems as the open solutions have a larger capacity than a closed subsurface system (Shukri, 2010; Svenskt Vatten, 2016). Furthermore, open stormwater solutions comply with sustainable stormwater management practices (Svenskt Vatten, 2016).

Solution 1 - Edited Schools In the original model of the elementary school, based on the detailed development plan which can be seen in Appendix D, there is a risk for large amounts of water to gather by the north side of the building where the sports hall and the rest of the school connects. The proposed layout of the sports hall is changed to allow water to flow past it more effectively and thereby provide a more accurate flow of stormwater downstream. The new, edited design is conceptual for stormwater flow, while in reality there are multiple other aspects to consider which are not addressed in this project. The difference between the design as proposed in the detailed development plan (Lerums kommun, 2021a) and the suggested altered design can be seen in Figure 3.2. The figure also shows the proposed stormwater solutions for the school area, which are further described in section 3.3.3. The change entails moving the sports hall and rotating it 90° and having it connect to the northern corner of the school to avoid a flood by the north-eastern wall. To prevent flooding on the southern side of the school, between the middle and right wing where there is a slight elevation sloping towards the school wall, the ground is flattened to allow water to flow away from the building.

No major edits are done to the preschool as the layout is in its initial stages. The area is not a location where a lot of water is collected, but rather flows past so there is no need for flood conveying measures. Therefore the preschool is only added to SCALGO Live as an elevated rectangle according to the plans presented in Appendix A.

Solution 2 - Pond and ditches by the elementary school As is mentioned in section 3.3.3 above, there are stormwater management solutions implemented in the school area. The solutions can be seen in the figure above, Figure 3.2, subfigure (b). Starting at the top left hand of the figure, to the west of the school, along the mountain, a swale or smaller ditch with the dimensions 0.25 m deep and 2 m wide is created to avoid flooding from the elevated area to the west. On the northern side of the school, the elevation is also higher than the school ground. Therefore, to avoid flooding on the north side of the school, a small area is lowered directly to



(a) The original elementary school. (b) The altered elementary school.

Figure 3.2: Solution 1. Figure (a) depicts the elementary school when implemented into SCALGO Live according to the design in the detailed development plan. Figure (b) shows how the school is altered to avoid flooding in the direct proximity, and the implemented solutions connected to the schoolyard. The stormwater solutions are marked in black.

the west of the sports hall. The water is led to this spot from the north side of the hall before being led further west, away from the school. The design of this lowering should be so that the area can have a multifunctional purpose of gathering water in rain events, while in dry periods it could be used as a playground.

Running along the south-east part of the figure is a ditch, with dimensions 1 m deep and 6 m wide. It starts in the north-east corner of the area and runs along the elementary school area boundary down to the south of the school, as can be seen in subfigure (b) in Figure 3.2. A pond, 15 m wide, 50 m long, and 1.7 m at its deepest, is created along the ditch to delay the water collected from the ditch. The water in the pond is conveyed further downstream in the ditch with the same dimensions as the previous when the pond overflows. This ditch is then merged with the water coming from the swale or smaller ditch on the western side and subsequently diverted to the Gatekullen Road. For a pond located near a school, it is important to consider safety aspects such as slope rate and other measures. Examples of safety measures are presented in section 2.2.3.4.

Solution 3 - Terraces Kring Alles Road A large dry pond is constructed by the intersection Kring Alles and Richerts Road. It measures 46 m in length, 13 m in width, and is approximately 80 cm deep. Water will gather there before being led further down past an existing playground to a second dry pond. From this dry pond the water crosses a small path before reaching a series of connected flooding areas, named terraces from this point. Figure 3.3 shows the two dry ponds and the 7 terraces. The second dry pond is 16.6 m long and 11 m wide. Each terrace is set to be 1 m deep and large enough to not exceed the maximum slope for a dry pond of 1:4 (Ontario Ministry of Environment, 2003).

(a) The terraces and dry ponds as seen in SCALGO Live.

(b) Photograph taken from the last terrace, showing the available grass area. (Authors' own picture, 2021).

Figure 3.3: Solution 3. Figure (a) depicts the terraces and dry pond as seen in SCALGO Live. The yellow arrow in the bottom right corner indicates where the photograph in Figure (b) is taken. Figure (b) is a photograph taken to illustrate the area where the terraces can be implemented.

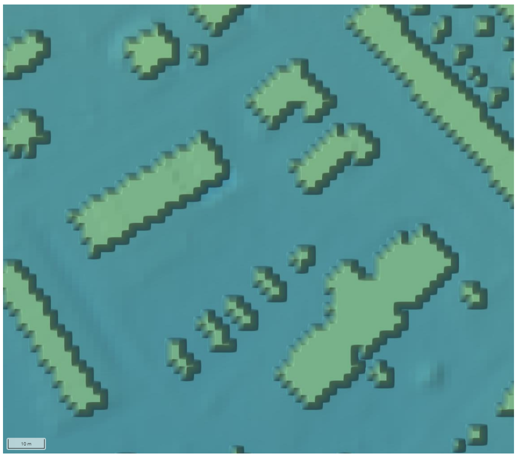
Solution 4 - Ditch Kring Alles Road This solution incorporates a large ditch instead of the previously mentioned terraces. The ditch is 5 m wide with a depth of 25 cm, putting its slope within the requirement compiled by Larm and Blecken (2019), where the maximum slope should be less than 1:3 for ditches. The solution covers the same length as the second dry pond and terraces mentioned in the previous paragraph. The shallow depth is chosen as to not interfere with two bike paths running perpendicular to the ditch.

Solution 5 - Ditch in grass area by Odhners Road To achieve comparable values for flow speed from the simulations with stormwater solutions in the area, the temporary buildings in Odhners Road are removed in the elevation parameter of the model.

The first solution implemented in this area uses a serpentine formed ditch with a depth of 1 m and a total length of 21 m, shown in Figure 3.4. The water comes from Odhners Road and is conveyed into the ditch where it infiltrates into the soil. If the soil reaches maximum saturation the water will travel in the ditch and out at the end to the next area.

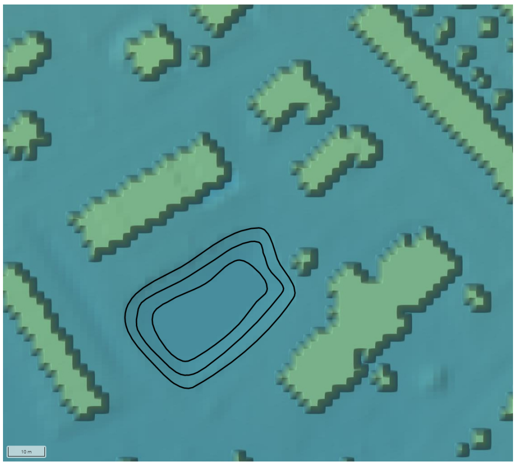
Solution 6 - Flooding area in grass area by Odhners Road The second solution in this area implements the use of a dry pond in favour of a ditch. The pond, which can be seen in subfigure (c) in Figure 3.4 is roughly 46x28 m and covers an area of 1,300 m^2 with a maximum depth of 1 m.

Solution 7 - Flooding area in the park by Vattenpalatset This solution utilises the large field east of Vattenpalatset as seen in Figure 3.5. The field is lowered to a maximum depth of 1.5 m over an area of 37,000 m^2. This area contains a pétanque (Swedish: boule) court as well, 30 m long and 13 m wide. The court is lowered by 10 cm to allow a smaller quantity of water to gather and infiltrate.



(a) The area by Odhners Road without edits.

(b) Solution 5 - The area by Odhners Road with the serpentine ditch.

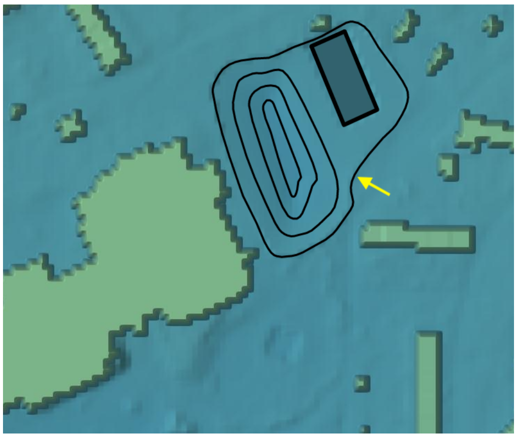


(c) Solution 6 - The area by Odhners Road with flooding area.

Figure 3.4: Figure (a) depicts the area by Odhners Road as it is today. Figure (b) depicts how the area would look if the serpentine ditch is implemented. The black circle surrounding the serpentine shape depicts the removal of the buildings shown in Figure (a). Figure (c) depicts the implementation of a flooding area instead of a serpentine ditch.

When it is dry, the area can be used as a park or developed into a field for sport related activities.

Solution 8 - Removal of Vattenpalatset Vattenpalatset takes up a large area with the potential to be used as a stormwater retention area, something of interest to investigate as the future of Vattenpalatset is under evaluation as described in section 2.5.4. The evaluation does in reality rather correspond to renovation or repurposing of the facility, and who should own and run it, but in this project the option of completely removing it is also studied as an extreme measure for retaining stormwater. Removing the building corresponding to the swimming hall part could facilitate a flooding area with an area of roughly 8,600 m^2. The deepest point is located 1.5 m below the surface giving it a slope of 1:11, which fulfils the safety



(a) The flooding area as seen in SCALGO Live.

(b) Photograph of the area as taken from the yellow arrow in (a). (Authors' own picture, 2021).

Figure 3.5: Figure (a) depicts the flooding area by Vattenpalatset and the pétanque court in the upper right corner. Figure (b) shows a photo of the area. Vattenpalatset is located to the left and the pétanque court is outside the picture to the right.

limits (Ontario Ministry of Environment, 2003).

If the entire building is removed, including gym, bowling and cinema, the available area is 12,400 m^2 and the depth can be expanded to 3 m. The available area can be seen in Figure 3.6. To utilise the whole area to be more than just a retention pond for large rain events, the design should be multifunctional to be useful in dry weather too. The multifunctional purpose of using the area as for example a park is the reason the slope is rather flat, with a slope of approximately 1:12, which is well below the dry pond limits (Ontario Ministry of Environment, 2003). The straight line in Figure 3.6 is a path that collects the water to the retention area.

Solution 9 - Ditch to Säveån In the case that none of the above solutions are sufficient, the implementation of a ditch to divert the flow before it reaches Torpskolan is investigated. As is shown in Figure 3.7, two ditches are evaluated, one following the road Häradsvägen in subfigure (a) and one following the parking lot south of Torpskolan in subfigure (b) before reaching Säveån. The ditch along Häradsvägen (a) is set to be 50 cm deep and 1 m wide for the simulations. The ditch starts at the low point leading into the school, and then gradually slopes towards the river Säveån, going alongside the road Häradsvägen. The maximum depth for the ditch along the road towards Säveån is 1.7 m, as the inclination is not constantly sloping towards the river.

The ditch going along the parking lot (b) is also set to a 50 cm depth and a width of 1 m and obtains a maximum depth of 1.3 m. Close to the starting point of the ditches is a bike rack, which is interpreted by SCALGO Live as a building. The bike rack is removed for this solution as to not interfere with the water collection in the ditch. In all other solutions the bike rack is not removed due to a lack of impact on the flow. In order to assist in directing the water towards the ditch, an elevated

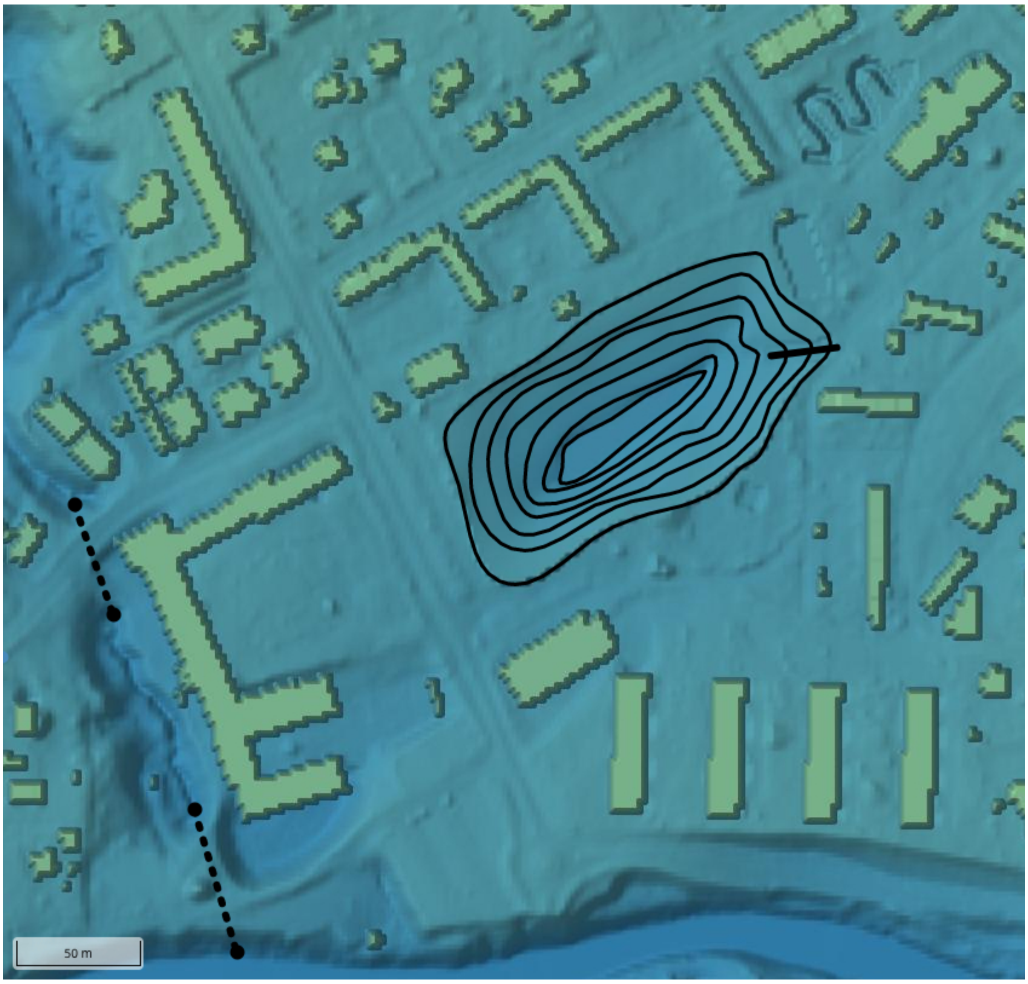
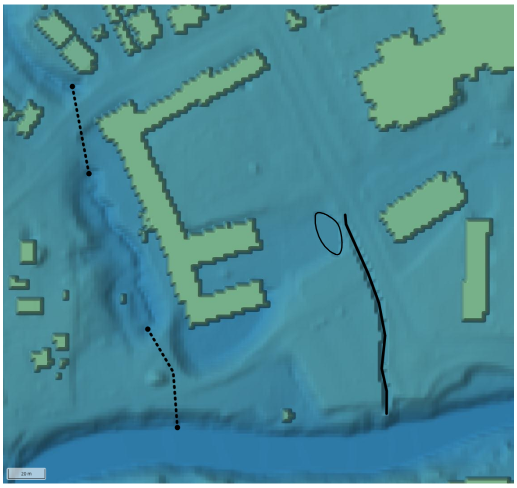


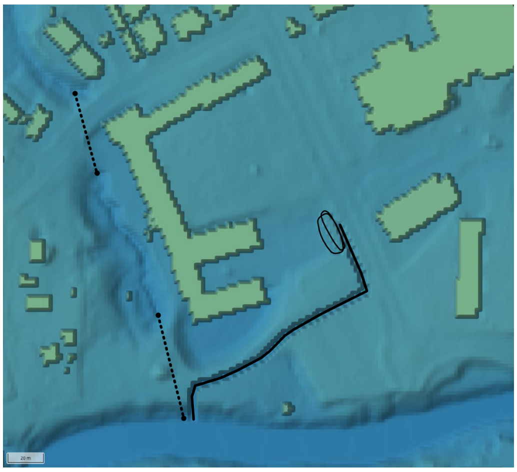
Figure 3.6: The available flooding area when Vattenpalatset is removed and used as a retention area.

structure is implemented at the starting point of the ditch. The structure's objective is to stop the water from flowing to the depression at Torpskolan, and instead collect in the ditch and be diverted to Säveån. An example of a structure that can be used is a flowerbed, or a slightly elevated, grass covered slope or something else deemed suitable for the location.

Solution 10 - Downstream solutions at Torpskolan Since there is a risk for a flood of a high magnitude by Torpskolan, the downstream point in this study, it can be of interest to find solutions that not only delay the water upstream but also divert the water by the school. The area most sensitive to flooding is the southern part where there is a depression along the wall and the entire area is surrounded by elevated bike paths. There is a creek running on the western side of the school, which then connects to Säveån through a culvert. The flood susceptible area can be connected to the creek by using a 2 m wide "ditch" going through the bike path that currently divides the school from the creek. The setup can be seen in Figure 3.8. To enable the use of a ditch in the location while fulfilling the use of a bike path, the ditch would need to be covered by a bridge, which can not be implemented in



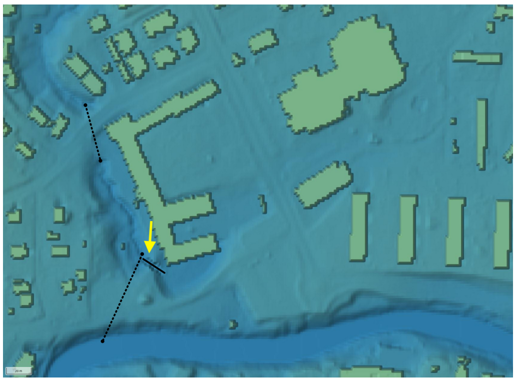
(a) The ditch along Häradsvägen.



(b) The ditch along the parking lot.

Figure 3.7: Subfigure (a) shows the path for the ditch leading to Säveån along the road Häradsvägen. Also shown to the left in subfigure (a) are culverts to the west of Torpskolan. The circle at the northern part of the ditches depicts the removal of the current bike rack with a roof. Subfigure (b) shows the ditch following the parking lot instead of the road.

the SCALGO Live model at the same time as simulating the ditch.



(a) Ditch and culverts by Torpskolan.

(b) Photograph of the area as taken from the yellow arrow in (a). (Authors' own picture, 2021).

Figure 3.8: Solution 10. Subfigure (a) depicts the SCALGO Live model with the ditch as the solid black line at the bottom left corner of Torpskolan. The flooded area is to the right of the ditch, and the creek is to the left. The dotted lines are culverts which ultimately connect to Säveån at the bottom of the figure. Subfigure (b) shows a photo of the location where the ditch can be implemented and the bridge would cross the ditch.

3.3.4 MIKE 21 model setup

In this project the software MIKE 21 is used to simulate the flow of the flood, as SCALGO Live only shows flood paths and not flow or flow speed. Furthermore, MIKE 21 is also used to simulate the impact of infiltration and surface roughness, two parameters set to different values based on if the modelled scenarios are set to have stormwater solutions with impermeable or permeable surfaces. The initial conditions in the study area have been modelled in MIKE 21 by Tyréns AB for the municipality of Lerum as part of Lerum's stormwater strategy (Björkman et al., 2019). The model foundation used from Tyréns AB is part of a larger system of models covering several parts of the municipality of Lerum. The use of an already existing model leaves more room for investigating the impacts of the suggested stormwater solutions, as well as the effect of infiltration and surface roughness without spending time on setting up the base model.

The MIKE 21 module used in this project is the *hydrodynamic model* with the model created by Tyréns AB for the municipality of Lerum. This model is used as the foundation for the modelling with all initial parameters as determined by Tyréns. The MIKE 21 domain created by Tyréns is the foundation to which the alterations created in SCALGO Live are added, such as the new schools and the stormwater solutions. To model the alterations made to the study area, a domain covering the area of interest is created by importing the model from SCALGO Live. This aims to alter the elevation model according to the changes made in SCALGO Live, while still using the model created by Tyréns AB for all areas that remains unchanged. The model is downloaded from SCALGO Live as a ASCII-format and then converted using the MIKE Zero Toolbox and implemented into the MIKE 21 model.

Some alterations are made to the model in SCALGO Live before exporting to MIKE 21 to achieve an accurate transfer. The culverts by Torpskolan mentioned in section 3.3.1 are replaced by ditches with a 1 m width before importing the model from SCALGO to MIKE 21. This is because the culverts in SCALGO Live only transfer water from the starting point to the end point without altering the elevation model, and therefore the culverts are not taken into account in the elevation model imported into MIKE 21. There is an option in MIKE 21 to include structures such as culverts or weirs. This option is not used, as it is sufficient to implement a large ditch to obtain the same diverting capacity.

To edit the infiltration and surface roughness parameters, the MIKE 21 model created by Tyréns AB is the foundation. The original values remain unchanged in the locations not affected by the edits in the elevation model. To edit the infiltration and surface roughness parameters according to the locations of the solutions and new buildings in the study area, an ASCII file is exported from SCALGO Live. The ASCII file covers the study area, and includes all alterations made to the elevation model. The exported file is opened in ArcMap and the patterns for the edits are traced to create a template layer. The template is then added as a layer in MIKE 21 to aid in altering the infiltration rate and Manning's M in the edited domain in MIKE 21.

The precipitation input is set to a specified precipitation in the format of varying in time and domain. The file used is included in the original model created by Tyréns AB with a CDS-rain, as described in section 3.2 (Björkman et al., 2019). The simulation spans six hours, 09:00 to 15:00 for the date 2100-01-01, as is set in the original model and remains unchanged. Another parameter that is not changed from the original values set by Tyréns AB are the drying and wetting depths. The drying depth is set to 0.008 m and the wetting depth to 0.02 m and remain unchanged for all simulations.

Four points are chosen as reference points for the (maximum flow speed and total water depth) results, these being located in; Gatekullen Road below the elementary school, on Kring Alles Road next to where the terraces and ditch ends, on Kring Alles Road where the highest flow speed is obtained, and right outside the entrance to the parking lot by the preschool. The locations of these points are chosen to best show the solutions impact on flow speed and depth.

3.3.4.1 Infiltration

In MIKE 21, infiltration can be determined in two ways, either by *constant infiltration with capacity* or *net infiltration* (DHI, 2017). When using the first alternative the user first has to define the extent of the infiltration zone in means of depth or level as well as the initial volume of water in the zone. Afterwards the infiltration rate, porosity, and leakage rate also has to be defined. Using the second alternative the user chooses one of three ways the infiltration rate is specified: constant over the whole area, constant in time and varying in space, or varying in both time and space. The infiltration is applied horizontally and does not vary with the slope of the elevation (DHI, 2017, 2021).

For this project the selected method was the one previously defined by Tyréns AB which is constant infiltration with capacity (Björkman et al., 2019). The depth of the infiltration zone, the porosity, and the initial water volume are all predetermined to be 0.3 m, 40%, and 30% respectively. The leakage has three values based on the type of soil underneath the surface layer. For sand, gavel, and till the value is 36 mm/h. For clay, silt, and peat the value is set to 0.4 mm/h, and for bedrock the value is 0.04 mm/h.

As the infiltration zones vary depending on the surface and underlying material, the implemented schools and the stormwater solutions are given different values to define their respective infiltration rate. The original infiltration rates implemented from Tyréns AB are 36 mm/h where there are permeable surfaces, and 0.0001 mm/h for the impermeable surfaces such as buildings or roads (Björkman et al., 2019). To ease alterations of the values for the different modelled scenarios, the values chosen for the new implemented buildings and solutions differ slightly from the values set by Tyréns AB. This is to distinguish what has been added to the model and what was there originally, still keeping the values in the same range. The reason they are set to differ slightly from the original values is that if they were not, the values would have to be changed manually, tracing the template layer created in ArcMap, see section 3.3.4. If the values instead differ slightly, the user only has to ask the programme to select all cells with value x, and replace it with desired value y.

The selected values for the new implemented buildings and the solutions are in the same range as the original values, and based on the literature as shown in section 2.2.2. These values are also presented in Table 3.3. The infiltration rate for the new buildings is set to 0.0002 mm/h, which remains constant throughout the simulations. The stormwater solutions are set to have an infiltration rate of 40 mm/h when the solutions are permeable (P. Wang et al., 2018). When they are impermeable, the rate is set to 0.0003 mm/h as this is the same low range as the original values. An example of the infiltration rates used is shown in Figure 3.9. Again, the various solutions and the buildings are assigned slightly different values to ease the change between different scenarios. To include already established social areas as part of the stormwater management, the pétanque court located in the park by Vattenpalatset is given an infiltration rate of 35 mm/h when set to permeable (Luhr, 2016). When the pétanque court is set to impermeable, the infiltration rate is set to 0.0005 mm/h to correspond to the original impermeable values. The parking lot by the preschool, coloured red in Figure 3.9, is a similar situation where the surface can be either permeable or impermeable. Therefore the infiltration rates are set to 49 mm/h if a permeable surface, such as permeable asphalt, is used (Bean et al., 2007). When the asphalt is set to be impermeable, the infiltration rate is 0.0004 mm/h to be in the same range as the original values, but with a slight difference to enable edits.

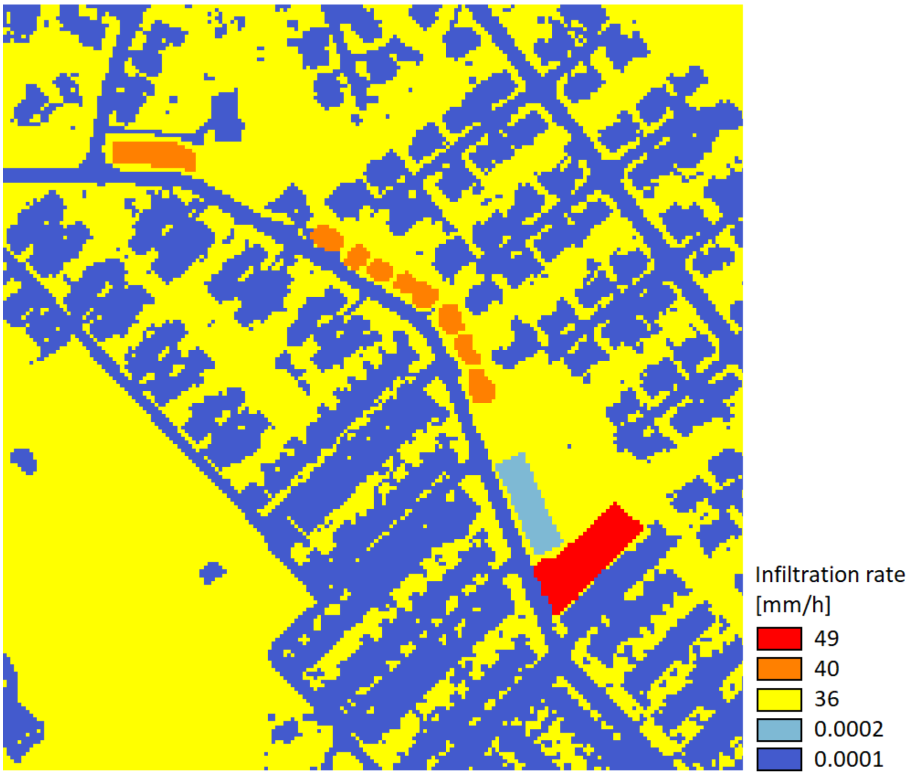


Figure 3.9: The infiltration rates for the solutions in a permeable scenario, located by Kring Alles Road.

3.3.4.2 Surface roughness

The surface roughness, known as bed resistance in MIKE, is defined in one of three ways: Manning's M, the Chezy number, or by wave induced bed resistance. The first two are either a constant value defined over the whole area or a data file with specific value determined for each grid point. The last option includes specifying the grain diameter, density of the material, as well as other resistance parameters (DHI, 2017).

Similarly to the infiltration values, Manning's M for impermeable surfaces and grass covered areas have been predefined in the already existing model by Tyréns AB, where the original values are 50 $m^{1/3}/s$ for impermeable surfaces and 2 $m^{1/3}/s$ for permeable surfaces (Björkman et al., 2019). The stormwater solutions and the implemented schools have different values depending on the scenario being simulated. Manning's M for the stormwater solutions are set to 90 $m^{1/3}/s$ when they are modelled to be constructed out of concrete or 2.5 $m^{1/3}/s$ when they are modelled to have a grass surface (Engman, 1986). For the new school buildings the values are either 51 $m^{1/3}/s$ or 4 $m^{1/3}/s$, where 51 $m^{1/3}/s$ represents a generic roof covering (Jung et al., 2011) and 4 $m^{1/3}/s$ represents green roofs (Engman, 1986) which has a higher surface roughness. The value for the pétanque court is set to 33 $m^{1/3}/s$ to represent the gravel used as cover for the court (Arcement & Schneider, 1989). The values are presented in Table 3.3. This value is based on an average value for gravel between 28.6 and 35.7, and then adjusted to the likely size of the grains used in a pétanque court. The cover of the pétanque court does not vary with the permeability of the court, hence the value is 33 $m^{1/3}/s$ for all scenarios. The value for the parking lot by the preschool is set to 48 $m^{1/3}/s$ for the case of using impermeable pavement (Jung et al., 2011) or 3 $m^{1/3}/s$ when using a permeable solution which also includes vegetation (Engman, 1986).

3.3.5 Modelling scenarios in MIKE 21 and SCALGO Live

The modelling in MIKE 21 is conducted to obtain flow speed values and flood for an impermeable scenario and a permeable scenario. Similarly to SCALGO Live, a scenario depicting the initial conditions is modelled to provide an overview of the current status of flood and flow in the study area before any alterations have been made. The flow result is also used to provide insight on the infrastructure vulnerability with respect to flow speeds according to the map of sensitive infrastructure in Figure 2.2 and the risk level equation 2.1.

After the initial scenario is simulated, the scenario with the new schools (Solution 1, section 3.3.3) is simulated. It is simulated to illustrate and investigate the possible impact of the new construction, and to model how the new buildings are affected by flooding. The next simulation is a system with a combination of stormwater measures that have been simulated one by one in SCALGO Live. Two systems with combinations of stormwater measures are used to identify differences in effect on flood and flow speed from the combinations of stormwater solutions, called System A and System B. The setup of the systems can be seen in Table 3.2. The two systems are then simulated as mainly impermeable solutions, and as mainly permeable. The systems are made with all investigated solutions from SCALGO Live, except the removal of Vattenpalatset. Both systems are simulated as there are two locations where it is of interest to investigate the difference in effects, Kring Alles Road and the grass area by Odhners Road. By Kring Alles Road the solution is either the terrace system or a ditch. In the grass area by Odhners Road the solution is either the serpentine ditch or a dry pond.

Table 3.2: The stormwater solutions included in System A and System B. The differences between the systems are marked in *italics*.

System A	System B
• New design of elementary school	• New design of elementary school
• Pond and ditches by the elementary school	• Pond and ditches by the elementary school
• Flooding area in the intersection Kring Alles Road and Richerts Road	• Flooding area in the intersection Kring Alles Road and Richerts Road
• *Terraces along Kring Alles Road*	• *Ditch by Kring Alles Road*
• *Serpentine ditch by Odhners Road*	• *Flooding area by Odhners Road*
• Flooding area in park by Vattenpalatset	• Flooding area in park by Vattenpalatset
• Ditch along Häradsvägen to Säveån	• Ditch along Häradsvägen to Säveån

The ditch along Häradsvägen to Säveån is selected to be included as to have a definite diversion of the water before it reaches Torpskolan. In addition to these systems A and B being evaluated for their impact on the flood by Torpskolan, simulations are also run in SCALGO Live where all solutions used in Systems A and B are included, except for the ditch to Säveån. This is performed to investigate whether the system's retaining capacity without the diversion is sufficient to avoid the flood by Torpskolan.

Both systems A and B are simulated as impermeable or permeable scenarios to investigate the effect of surface roughness and infiltration. In the impermeable scenario, the edited areas are seen as impermeable surfaces, including the new buildings and the stormwater solutions. This leads to high Manning's M and low infiltration rates. The parking lot by the preschool is considered paved with an impermeable asphalt, and the pétanque court lacks infiltration possibilities. Both the roofs of the schools and the solutions are set to be impermeable. The exact values for infiltration rate and Manning's M in the impermeable scenario are presented in Table 3.3. The values for Manning's M are calculated using equation 2.2.

Also shown in Table 3.3 is the permeable scenario. The infiltration rate in the stormwater solutions are given a higher value, signifying a slightly higher infiltration rate than the original. The original infiltration rate is in the lower range of infiltration values for permeable surfaces (Engman, 1986). Manning's M for the solutions are altered to be representative for a grass covered area, while still different from the original value to ease the alterations of the values. In the permeable scenario, the solution of green roofs is implemented on the preschool and the school Norra Hallsås. This is represented by a lower Manning's M, but without change in infiltration rate. The pétanque court is given a higher infiltration rate, as is the parking lot by the preschool.

Table 3.3: Infiltration rate and surface roughness represented by infiltration values and Manning's M for each edited surface. The table is divided into the original values set by Tyréns AB, the scenario with mainly impermeable surfaces and the scenario with mainly permeable surfaces.

Original values	**Infiltration rate [mm/h]**	**Manning's M [$m^{1/3}/s$]**
Impermeable surfaces	0.0001	50
Permeable surfaces	36	2
Impermeable scenario		
Preschool Kring Alles	0.0002	51
Parking lot preschool	0.0004	48
School Norra Hallsås	0.0002	51
Stormwater solutions	0.0003	90
Pétanque court	0.0005	33
Permeable scenario		
Preschool Kring Alles	0.0002	4
Parking lot preschool	49	3
School Norra Hallsås	0.0002	4
Stormwater solutions	40	2.5
Pétanque court	35	33

There are a total of 8 scenarios modelled in MIKE 21 to simulate flow speeds and flooding based on infiltration rate and surface roughness, as presented in the list below. In the first 6 scenarios all values are adapted at the same time, as an impermeable surface often also entails a lower surface roughness, for example concrete, and the permeable surfaces are seen as covered in grass or similar media, which infiltrate and lower current speeds.

To further examine the effect of infiltration and surface roughness as sole factors, two other simulations are run, number 7 and 8 on the list. These two simulations are run using System A as the elevation model, but with only the surface roughness parameter or infiltration parameter changed. The changes made to the infiltration rate is to be less infiltrating, as the areas used for the solutions are mainly made on areas that are grass covered in the original model. The same reasoning leads to the change in surface roughness being changed to the lower values as used in the impermeable scenario.

1. **Initial scenario**: Both infiltration rate and Manning's M are the original values as set by Tyréns AB in the original model.

2. **Solution 1, edited schools**: The infiltration rate and Manning's M are changed in the locations for the elementary school and the preschool to correspond to being impermeable.

3. **System A, impermeable**: The schools remain impermeable, and all stormwater solutions are set to be impermeable. This entails low infiltration rate and low surface roughness as set in the impermeable rows in Table 3.3.

4. **System A, permeable**: The schools' infiltration rate remains impermeable, but surface roughness is increased to simulate green roofs. The solutions are also set to being permeable, following the permeable rows in Table 3.3.

5. **System B, impermeable**: The schools remain impermeable, and all stormwater solutions are set to be impermeable.

6. **System B, permeable**: The schools' infiltration rate remains impermeable, but surface roughness is increased to simulate green roofs. The solutions are also set to being permeable.

7. **System A, lower infiltration**: The infiltration rates are altered to correspond to the impermeable scenario. The surface roughness remains set to the original values as set by Tyréns AB.

8. **System A, lower surface roughness**: The surface roughness is set to the impermeable values, while infiltration rate is set to the original values as set by Tyréns AB.

The two systems A and B are created in SCALGO Live as the elevation model is altered in SCALGO Live. The systems are also simulated in SCALGO Live, but without the last ditch implemented. It is simulated to investigate the retaining capacity of the entire system, and whether it affects the flood downstream.

3.4 Sensitivity analysis

All modelling contains an aspect of uncertainty. Therefore it is suitable to perform a sensitivity analysis to investigate how the results vary with varying input data. A sensitivity analysis is performed on the infiltration and surface roughness parameters in MIKE 21. The analysis is performed by increasing the infiltration rate values by 15%, as well as decreasing them by 15%. The same is done for the surface roughness, firstly all values are increased by 15% and then decreased by 15%. The simulations are then run using System A with the increased and decreased values, and evaluated in the reference point with the highest flow speed. The simulations performed are then; System A with the increased surface roughness and increased infiltration rate, and then System A with the decreased surface roughness and decreased infiltration rate. The results should then differ to the same extent in order to have a stable model. The results of the sensitivity analysis are then compared to the base scenario, which is when the original values as set in this project are used in System A and evaluated in the reference point for highest flow speed.

4

Results

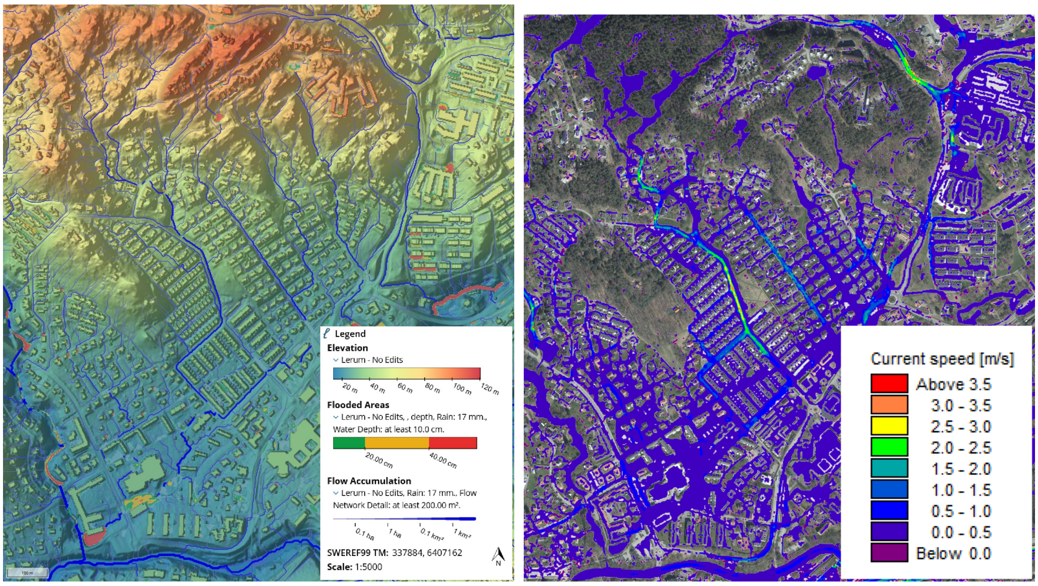
The results chapter presents the calculated and modelled results from SCALGO Live and MIKE 21. The generated results correspond to identifying locations where flooding proves a risk for facilities or people, finding a suitable solution for flood management in the case study area. The results also correlate to investigating the effect of infiltration and surface roughness on the solutions to validate the necessity of sustainable stormwater management.

4.1 Flood vulnerability

In section 3.1, it is stated that flooding can affect people by either flow, water depth or a combination of the two. The aspect of facilities sensitive to flooding from a societal perspective is also mentioned in section 2.5.2. To identify which facilities are subject to flooding and which locations pose a possible threat to people, the initial flood and flow conditions are combined with the map of sensitive infrastructure as seen in Figure 2.2.

4.1.1 Initial scenario

Firstly, the initial scenario of flood and flow are modelled in SCALGO Live and MIKE 21. The initial scenario shows how the area would be affected by a 100-year rain as the topography and development is today. The new developments of the elementary school in Norra Hallsås and the preschool by Kring Alles Road are not included in the flow and flood simulations of the initial scenario, but are included as sensitive infrastructure. The results of flooded areas from SCALGO Live and flow conditions from MIKE 21 can be seen in Figure 4.1 below. Subfigure (a) shows the topography, with red colours being higher ground and blue lower. It is clear that the general slope of the area is towards the south, to Säveån which is shown in the bottom of the figure. In subfigure (a) of SCALGO Live, the model shows the flood and flow path for a climate adjusted 100-year rain event with 4 hours duration. Subfigure (b) of MIKE 21 is created using a climate adjusted CDS-rain for a 100-year return time and a 6 hour duration. The 100-year rain event is selected as there is no vital infrastructure in the area, as can be seen from Figures 2.3 and 2.2 showing the watershed and the sensitive infrastructure.



(a) Initial scenario in SCALGO Live. **(b)** Initial conditions in MIKE 21.

Figure 4.1: Figures (a) and (b) show the flood and flow conditions before any alterations have been done to the area. Figure (a) shows the flood depth on the three colour scale, and large flow paths with bold blue lines. The topography is also shown, with red colours being higher ground and blue lower. Figure (b) shows the magnitude of the flow speed using a scale where red indicates a flow speed above 3.5 m/s.

4.1.2 Identified flood vulnerability

Figure 4.2 shows the facilities from Figure 2.2 that are located within the studied watershed, and additionally the new elementary school in Norra Hallsås and the new preschool by Kring Alles Road. As can be seen, none of the vital infrastructure such as the fire department or the healthcare facilities are located within the watershed. However, three preschools, two elementary schools and one grocery store are located within the watershed.

When comparing the map of sensitive infrastructure in Lerum, Figure 2.2, to the floods and high flow speeds for various rain events in the initial scenario it can be seen that there are facilities at risk for damages by high water depth. When using only flooding as a risk factor, Torpskolan, which is the downstream point of the watershed, will be flooded by 2 meters for only 20 mm of rain according to SCALGO Live. Using equation 2.1, a 2 m water depth gives the risk level *risk for some*. From MIKE 21 the maximum flood reaches over 3 m for the 100-year rain used in the CDS-rain. The 3 m water depth gives a risk level of 1.5, which means it is a risk for most people according to the risk levels presented in the background in section 2.1.2. The function for contaminated soil in SCALGO Live shows that there are areas with possible contaminated soil in Lerum, but not within the studied watershed.

In order to avoid a large flood in the downstream point by Torpskolan, it is necessary to remove a total of 2,101.57 m^3 of water in the system as this is how much water is gathered in the flooded point. Depending on how the water is diverted from the area, there will still be flooding of various magnitudes which is further presented in sections 4.2.2.9 and 4.2.2.10.

Using MIKE 21 to simulate the flow speed, and combining it with the map of sensitive infrastructure in Figure 2.2, shows three locations within the studied watershed where the flow speed can be considered high. The locations can be seen in Figure 4.2 where they are marked with red stars. Following the flow path from the upstream area where the new elementary school will be located, the first point of high flow speed is on the connecting road, Gatekullen. The peak flow speed at this point is 2.3 m/s. When using the equation for risk level, equation 2.1, by inserting the water depth in the same point and time a value of 0.25 is achieved, posing no risk for people in the location. The reason the risk is low is because of the water depth of barely 0.1 m.

Figure 4.2: Combination of high flow speed locations, sensitive infrastructure and the investigated watershed. The figure shows three preexisting preschools, one elementary school and a grocery store to be within the watershed. Also located in the watershed is the new elementary school in Norra Hallsås and the new preschool by Kring Alles Road.

The next location when following the flow downstream, is the location for highest flow speed in the watershed. The peak flow speed in this point is 3.4 m/s and occurs in the roadway on Kring Alles Road. Regarding the flood risk for people, the same applies in this point as in Gatekullen. The water depth in this point point is only

0.15 m, which leads to the risk value 0.57 and therefore poses no risk according to equation 2.1.

The last point identified to have a high flow speed is on the same road, at the bottom of the grass covered area where the preschool is planned to be built. There the flow speed reaches 2.3 m/s, and has a depth of 30 cm, leading to a risk level of 0.8 when using equation 2.1. The risk level corresponds to a risk for some people and is the only identified location within the watershed where the flow is a risk for people before any edits have been made.

4.2 Stormwater management solutions

In this section, the results from the different scenarios for implemented stormwater solutions are presented. To present the results of the stormwater solutions, 7 measuring points are used, 3 are used to study the effects on the flood vulnerability locations as presented in section 4.1.2, and an additional 4 are placed in locations where the effect from the investigated stormwater solutions can be evaluated. In Figure 4.3, the points of reference for measuring the effects of the solutions are shown. The red stars show where the locations are based mainly on flow speeds and the alteration thereof, and the green star shows the point based mainly on flood depth, even though both flow speed and depth are measured in all points. The exact coordinates for each location can be seen in Table E.1 in Appendix E.

4.2.1 Implementation and design of schools

After the initial scenario with its flood and flow speed is identified, the elementary school in Norra Hallsås and the preschool by Kring Alles Road are implemented in the model. A flood does not occur in the vicinity of the preschool when implemented according to the available plans at the time of investigation. The plan used can be seen in Appendix A.

The elementary school in Norra Hallsås is flooded in some locations when implemented according to contemporary available plans, available in Appendix D. This leads to a suggested alteration of the layout of the school buildings to avoid flooding, shown in Figure 4.5. The new, altered model of the school also includes a simulation of the roof sloping towards the south. This assists in diverting a possible flood on the north side of the school as the natural surface water flow is towards the south.

4.2.2 Effect of implementing stormwater solutions

In this section the effect of implementing the solutions for flood management are presented. The results follow the same pattern as the solutions are presented in the methodology in section 3.3.3. Presented in the results are, where applicable, the retained volumes and diverted flood using SCALGO Live and changes in peak flow speeds using MIKE 21. The results of the flows are based on a combination of measures set up in two different systems; System A and System B. The results

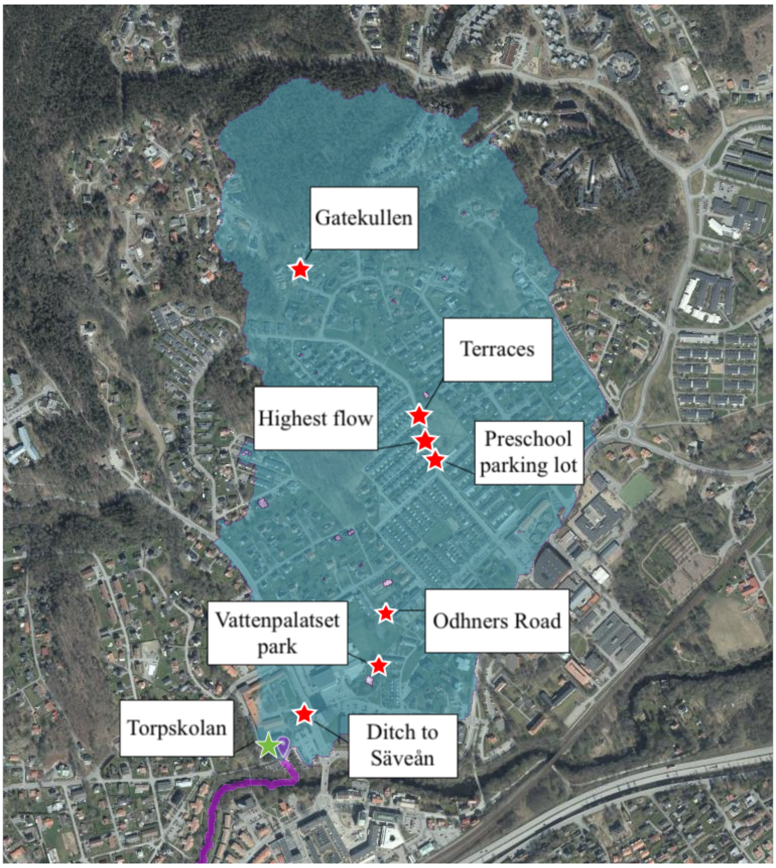


Figure 4.3: Measuring points for flow speed and depth, marked with stars.

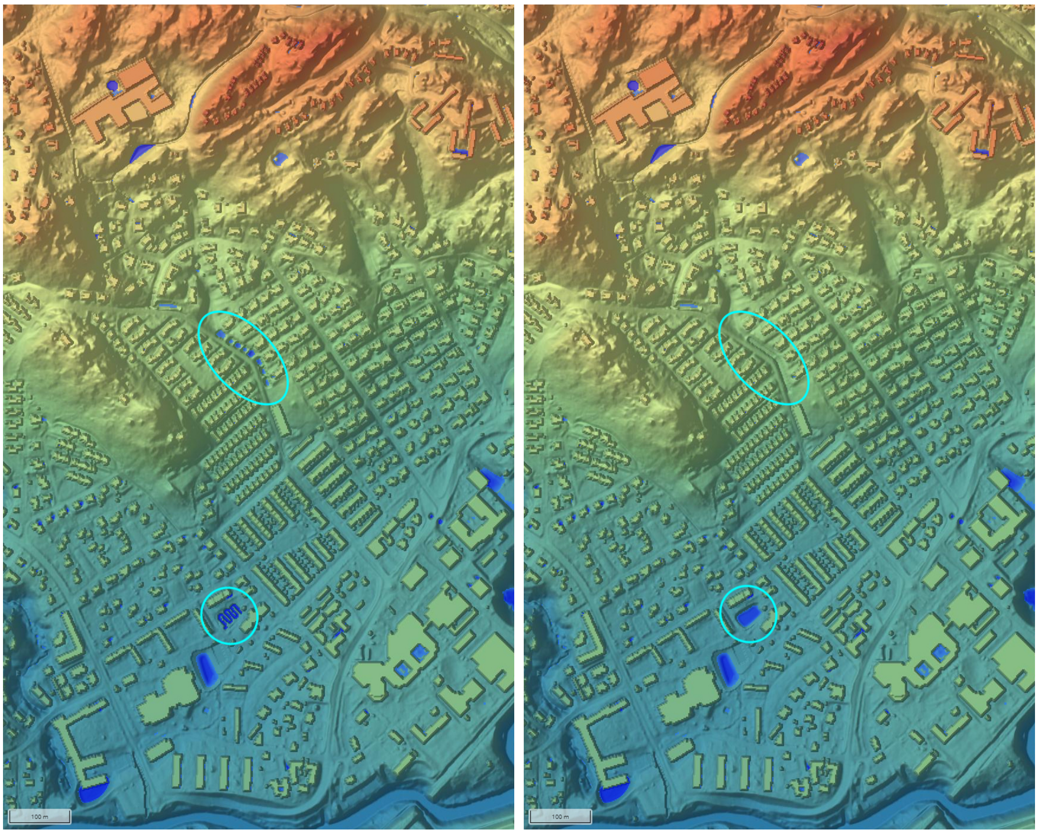
for the flooding by Torpskolan using the different rain events on all solutions are also presented. All results presented in section 4.2.2 are compared to the scenario where the new schools, as edited by the authors, have been implemented. The solutions are only implemented on land owned by the municipality. Additionally the investigation on possibly contaminated soil using SCALGO Live shows there are no areas necessary to avoid due to contamination or possibly harmful activities.

4.2.2.1 Combination of measures

To investigate the flow speeds in the system and the effects of infiltration and surface roughness on the selected stormwater management solutions, two systems of combinations of solutions are created. They are called System A and System B and differ in some aspects, while they are the same in others, which is presented in the methodology in Table 3.2. The setup of the systems are shown in Figure 4.4, which provides an overview of the individual solutions and their locations used in the combination scenarios.

Since both combinations of measures include the ditch to Säveån, they convey the water from Torpskolan and possibly prevent the major flood that would occur otherwise.

For both systems and variations in permeability on the solutions, the highest flow



(a) System A. **(b)** System B.

Figure 4.4: Subfigure (a) shows the solutions included in System A, and subfigure (b) shows the solutions included in System B. Ditches do not retain any water and are thus not marked as flooded. The light blue circles show the differences in the systems.

speed in the system is the same. It occurs in the point in Kring Alles Road that was identified in the initial scenario to have the highest peak flow speed. The point can be seen in Figure 4.3. The flow speed in the initial scenario is 3.4 m/s, and increases with the implementation of the schools to 3.9 m/s. When the different solutions are implemented, the maximum current speed remains at approximately 3.8 m/s, with some minor flux.

4.2.2.2 Results Solution 2 - Pond and ditches by the elementary school

The implemented stormwater solutions by the elementary school in Norra Hallsås can be seen in Figure 4.5. It is a dry pond north of the school building, a swale along the western side of the school and a larger ditch south of the school along with a larger pond. The ditch and the swale merge in the bottom left of Figure 4.5 and from that point it diverts the water from the school area to the Gatekullen Road. The pond south of the elementary school can hold a total volume of 731 m^3 with a maximum depth of 1.74 m, and the ditches divert the water to the Gatekullen Road.

The implementation of the schools affects the flow speed in the area. The initial

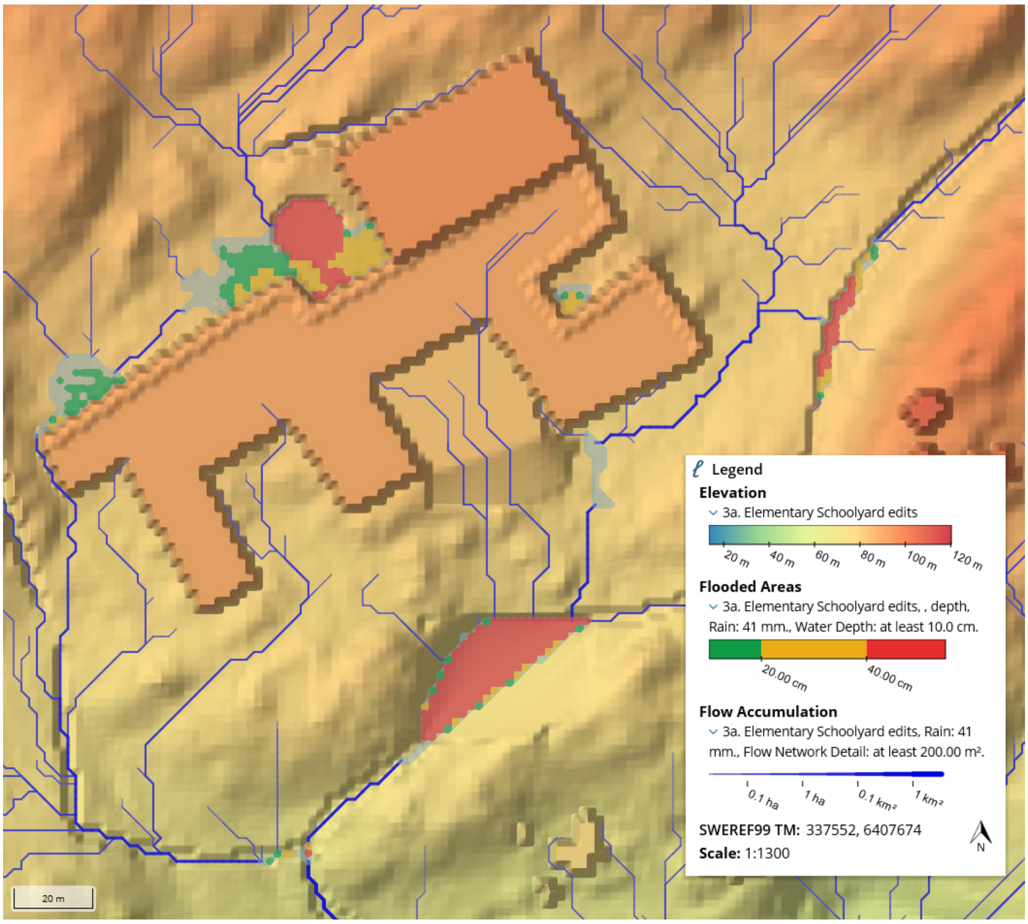


Figure 4.5: The elementary school with the altered design where the top building is moved. Also shown are the stormwater solutions in the direct proximity.

condition for Kring Alles Road, where the preschool is located, is that the flow speed is high on the road. Therefore the preschool does not have a high impact on the flow speed since the majority of the water collects upstream. The addition of the elementary school in Norra Hallsås has an impact on the flow speed on the Gatekullen Road below. The flow speed is increased in Gatekullen due to the increase in impermeable surfaces that the school entails, as well as the diversion of the additional stormwater. The peak flow speed on Gatekullen Road increases from 2.3 m/s to 2.9 m/s with the implementation of the school. Since the water level is relatively low on the road, approximately 0.1 m, the risk level according to the risk level equation 2.1 results in the level *risk for no one*, at a value of 0.3. The implementation of the elementary school also affects the flow downstream, as the flow speed increases along the general major flow path. The point with the highest peak flow speed is in Kring Alles Road. The increase is 0.5 m/s, from 3.4 m/s to 3.9 m/s, which can also be seen in Appendix E. The increased flow speed, in combination with the water depth of almost 0.2 m at the point, leads to a risk level of 0.8, meaning there is a risk for some. In another location shortly downstream, right after the preschool parking lot, where SCALGO Live indicates that all flow paths in Kring Alles Road merge, the flow speed is almost the same but the water level is increased. The increased water level leads to an increased risk level of 1.0, which is still in the span for *risk* *for some.*

4.2.2.3 Results Solution 3 - Flooding area in intersection and terraces by Kring Alles Road

The large, single dry pond by the intersection Kring Alles and Richerts Road holds 101 m^3 with a maximum depth of 52 cm. The second dry pond before the terraces start holds a volume of 91 m^3 with a maximum depth of 72 cm. The 7 terraces that follow are collectively holding a volume of 312 m^3 with a depth ranging from 57 cm to 1 m. A layout of the terraces and the second pond above them can be seen in Figure 4.6. The elevation in the figure is less extreme in reality since the elevation of the terraces ranges from 39 m above sea level for the pond by the playground, down to below 34 m for the last pond in series over a distance of 140 m.

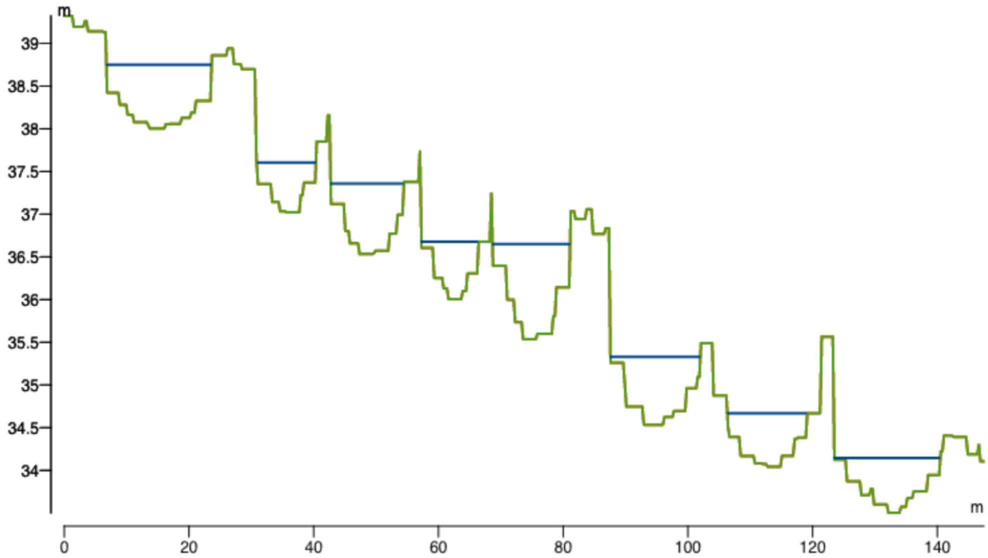


Figure 4.6: A profile showing the water depth of the 7 terraces and the second, larger, pond by the playground shown on the far left in the figure for a rain volume of 100 mm.

The terraces lower the flow speed of the water in the reference point in the road at the end of the terraces, see Figure 4.3. The lowering of the flow speed is 0.7 m/s since the peak flow speed is 3.2 m/s in Solution 1 (when only the schools are implemented), and goes down to 1.5 m/s when the terraces are permeable, i.e. grass covered and infiltrating. When the terraces are impermeable, meaning constructed out of concrete, the flow speed is 1.7 m/s.

4.2.2.4 Results Solution 4 - Ditch Kring Alles Road

The ditch diverts the water from Kring Alles Road, conveying the water to the side of the road instead of on the road. The ditch does not have a large retaining capacity due to the sloping surface, but aims to divert the flow from the road and lower the flow speed. Before the solution is implemented, the flow speed in the road is 3 m/s in the measuring point *terraces* from Figure 4.3. With the addition of the ditch the flow speed is 0.1 m/s when the surface of the ditch is impermeable, and 2.3 m/s with a permeable surface. The point of reference is the same as in the previous paragraph. The solution as seen in MIKE 21 can be seen in Figure 4.7.

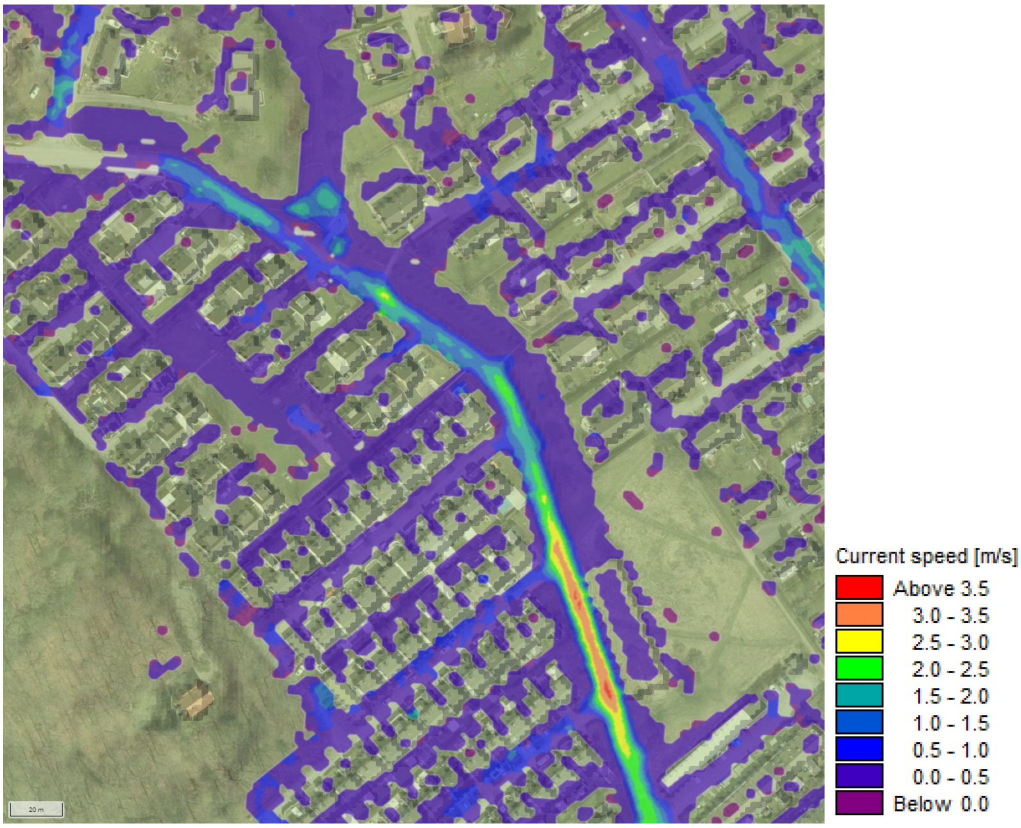


Figure 4.7: Flow speed results from MIKE 21 for the ditch by Kring Alles Road.

4.2.2.5 Results Solution 5 - Ditch in grass area by Odhners Road

The serpentine shaped ditch collects water from Odhners Road and holds a maximum volume of 579 m^3. Before the ditch is implemented in this area, the peak flow speed reaches 0.76 m/s in the reference point Odhners Road as presented in Figure 4.3. With the ditch in place the flow speed increases to 0.86 m/s for the impermeable surface and 0.85 m/s for the permeable surface. The increase in flow speed is likely due to a concentration of the flow. According to equation 2.1 there is no risk for people for this solution.

4.2.2.6 Results Solution 6 - Flooding area in grass area by Odhners Road

When using the same area in Odhners Road as a dry pond, a total water retaining volume of 708 m^3 is achieved with a depth of 88 cm. The flow speed increased from 0.76 m/s with no flooding area to 0.8 m/s with the flooding area implemented, both as impermeable and permeable. No risk for people is present for this solution according to equation 2.1.

4.2.2.7 Results Solution 7 - Flooding area in the park by Vattenpalatset

Including the pétanque court, the total volume of water reaches 1,314 m^3 with a maximum depth of approximately 1 m. The initial values of the flow speed in the point Vattenpalatset park, see Figure 4.3, are of a low range compared to the other points. It only reaches 0.4 m/s both for the permeable and impermeable solutions.

4.2.2.8 Results Solution 8 - Removal of Vattenpalatset

When the entire building with all facilities is removed, the maximum water depth can be up to approximately 3 m if there is no interference with groundwater levels. The volume retained in the pond is 12,347 m^3. The access path collects the water into the pond. The reference point for this solution is to the south east of the pond, Vattenpalatset park in Figure 4.3. In this location, the initial flow speed is 0.49 m/s when the new schools are implemented upstream, and is lowered in all other scenarios, both for impermeable and permeable solutions, to approximately 0.4 m/s.

4.2.2.9 Results Solution 9 - Ditch to Säveån

A ditch to Säveån diverts the water that flows into the Torpskolan area in the other scenarios. The solution of implementing either one of the proposed ditches lowers the flood moderately by Torpskolan, as can be seen in Table 4.1. The ditches in themselves do not hold a significant amount of water, but rather convey the water. Although the ditch diverts water and lowers the flood depth, the depth of the flood by Torpskolan is still relatively high according to simulations in SCALGO Live. The water depth is 50 cm for 33 mm of rain, and 1.3 m for 100 mm. For the 400 year and 4 hour rain scenario the water depth is the same as without any diverting stormwater solutions, which is 2 m. The peak flow speed in the flood by Torpskolan, see Figure 4.3, is 0.01 m/s, meaning it is the water depth that poses the largest risk. Using the risk level equation 2.1 it is only the 400 year rain event with a 4 hour duration that poses a risk for some. Then the risk level is the same as the initial scenario.

4.2.2.10 Results Solution 10 - Downstream solutions at Torpskolan

The largest flood is by Torpskolan, as can be seen in Figure 4.1. In SCALGO Live the maximum flood for Torpskolan is 2 m when no solutions have been implemented, while in MIKE 21 it reaches over 3 m for the same scenario. The solutions implemented at Torpskolan aim to convey the water from the depression where the water collects. The implementation of an opening towards the creek on the west side of Torpskolan diverts the water and lowers the flood in the downstream point by Torpskolan. For the highest rain amount of 160 mm (400 year rain, 4 hours), the flood in the reference point by Torpskolan, which can be seen in Figure 4.3, remains below 20 cm, the limit for accessibility, and poses no risk.

Results from SCALGO Live as presented in Table 4.1, show that the measures for delaying and collecting the water upstream does not affect the final flood by Torpskolan. Thus it is diversion of the flow that is of most essence to prevent

Table 4.1: Results on flooding from the various stormwater solutions. The table shows how the total water volume by Torpskolan varies in SCALGO Live for the different solutions and rain events.

Solution	**100 years 10 min** (33 mm)	**100 years 4 h** (100 mm)	**400 years 10 min** (58 mm)	**400 years 4 h** (160 mm)
Initial scenarios	2,101 m^3	2,101 m^3	2,101 m^3	2,101 m^3
Solution 1	2,101 m^3	2,101 m^3	2,101 m^3	2,101 m^3
Solution 2	2,101 m^3	2,101 m^3	2,101 m^3	2,101 m^3
Solution 3	2,101 m^3	2,101 m^3	2,101 m^3	2,101 m^3
Solution 4	2,101 m^3	2,101 m^3	2,101 m^3	2,101 m^3
Solution 5	2,101 m^3	2,101 m^3	2,101 m^3	2,101 m^3
Solution 6	2,101 m^3	2,101 m^3	2,101 m^3	2,101 m^3
Solution 7	2,101 m^3	2,101 m^3	2,101 m^3	2,101 m^3
Solution 8	2,101 m^3	2,101 m^3	2,101 m^3	2,101 m^3
Solution 9	371 m^3	1,211 m^3	685 m^3	1,960 m^3
Solution 10	67 m^3	67 m^3	67 m^3	67 m^3

flooding in that location. This can be seen in Solutions 9 and 10 in Table 4.1. Solution 9, which is the ditch to Säveån along Häradsvägen, gives a differing volume by Torpskolan depending on the rain amount. This is because the area by Torpskolan is also affected by flows from other areas, and not just the main flow path. The ditch still manages to lower the flood for all scenarios. Solution 10, a ditch to the creek behind Torpskolan, gives a consistent volume of the flood and lowers the risk level.

As mentioned in the methodology, in section 3.3.5, the scenarios where the upstream solutions in Systems A and B are included is also simulated. However, it shows the same results as the other, non-diverting solutions and results in a flooding volume of 2,101 m^3 by Torpskolan. The total area that all the implemented solutions take up is roughly 6600 m^2 for System A and 7200 m^2 for System B. These numbers include all ditches, all ponds, and the parking lot by the preschool.

4.3 Effect of infiltration and surface roughness

Some results of the flow speed simulations have been presented in connection to the stormwater management solutions. The flow speed is examined with respect to the impact of infiltration and surface roughness on the speed. Some simulations are performed with changes to the infiltration and surface roughness parameters simultaneously, to represent a permeable or impermeable cover.

To investigate which of the parameters infiltration and surface roughness has the most impact on the highest flow speed and flood, two simulations, simulations 7 and 8 from section 3.3.5, are performed where only one of the parameters is changed at a time. In simulation 7 infiltration is altered to represent an impermeable scenario, whilst the surface roughness values remain as the original values. These values can be seen in Table 3.3. In simulation 8 it is the other way around, meaning surface roughness (Manning's M) is altered to represent an impermeable scenario and the infiltration values remain as the original values. All other parameters remain unaltered, meaning they are set to the model's original values. The elevation model used is a combination of stormwater solutions, System A, which is further described in section 4.2.2.1. The two simulations consist of one simulation where the infiltration is lowered in the stormwater solutions, and one where Manning's M is increased, meaning there is less surface roughness. The parameters are altered solely in this order as the original values are of a relatively high infiltration and high surface roughness. This is since most solutions are implemented on what are currently mainly grass covered areas. Therefore it is deemed unnecessary to run simulations where only the infiltration and surface roughness are increased.

The results of these single parameter simulations are included in Appendix E, where they are named "Lower infiltration" and "Lower surface roughness" and the results are shown for all reference points of flow speed. They are also presented separately in Figure 4.8, where they are presented as a comparison to the scenario where the schools have been added to the model. What can be seen in these results is that the flow speed is affected by the infiltration and surface roughness parameters. The variation in flow speed and the incoherence between the results can be an effect of the various solutions and will be further addressed in the discussion chapter.

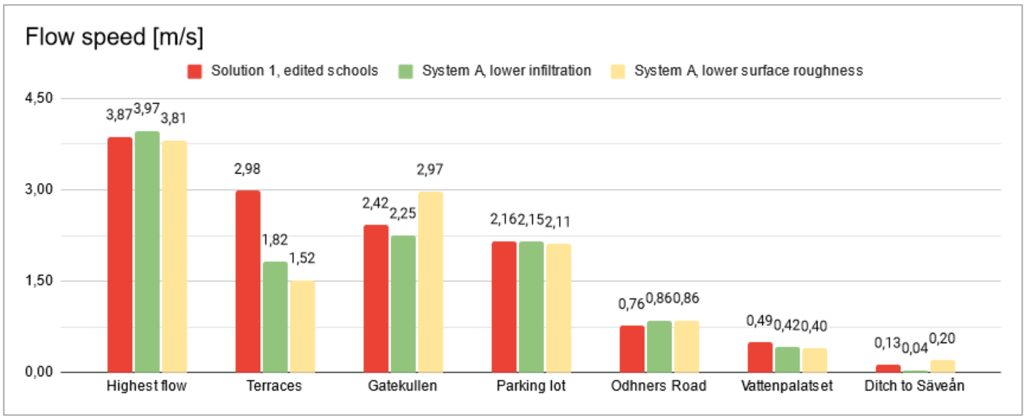


Figure 4.8: Flow speed results in the reference points for lower infiltration and lower surface roughness parameters.

Figure 4.8 shows the results of the scenario when only infiltration is lowered, but not Manning's M. Solution 1 - Edited schools is the reference scenario to which all results are compared as it includes an increase in impermeable surfaces. A location where the impact of infiltration and surface roughness is noticeable is in the Gatekullen Road. In the Gatekullen Road, the only upstream solutions are the ones implemented by the elementary school, which remain the same for all simulated scenarios. In the Gatekullen Road, the flow speed is increased slightly for all impermeable scenarios, including the scenario where only the surface roughness is decreased to simulate impermeable surfaces. This can be seen in Figure 4.9. For the permeable scenarios, where Manning's M is high, the flow speed is low. For the scenario where only infiltration is decreased and surface roughness remains the same, the flow speed is slightly higher than for the scenarios with both parameters representing a permeable scenario.

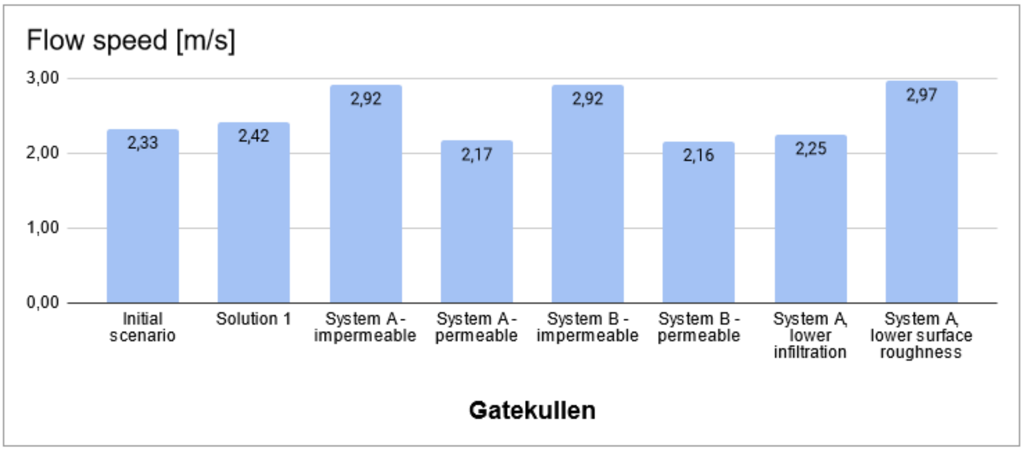


Figure 4.9: The maximum flow speeds in Gatekullen Road.

The time for the peak flow speed changes in the rain event with the various scenarios. In the initial scenario, before the schools are added, the peak flow speed in the Gatekullen location occurs at 11:30, which occurs at 11:28 when the schools are added without the stormwater solutions by the elementary school. When the stormwater solutions are added to the elementary school, the peak flow speed occurs at 11:18 for all scenarios, meaning it occurs earlier for every additional construction done to the upstream area. It does not vary with the permeable or impermeable scenarios. Figure 4.10 shows that the peak flow speed occurs earlier in the rain event in the point Gatekullen Road when alterations are made to the area, compared to the initial scenario when the upstream area has a natural, permeable cover. The graph for Solution 1 indicates a slight tilt towards a higher flow occurring earlier in the rain event. The figure also shows that in addition to the peak arriving early in the event for the systems with stormwater management solutions, Systems A impermeable and permeable, the speed is decreasing slower and the flow speed is still high one hour after the peak rain event (at 11:15). The permeable scenario follows the same shape as the impermeable scenario, however at a lower flow speed in general, indicating that sustainable stormwater solutions have an impact on the general flow speed.

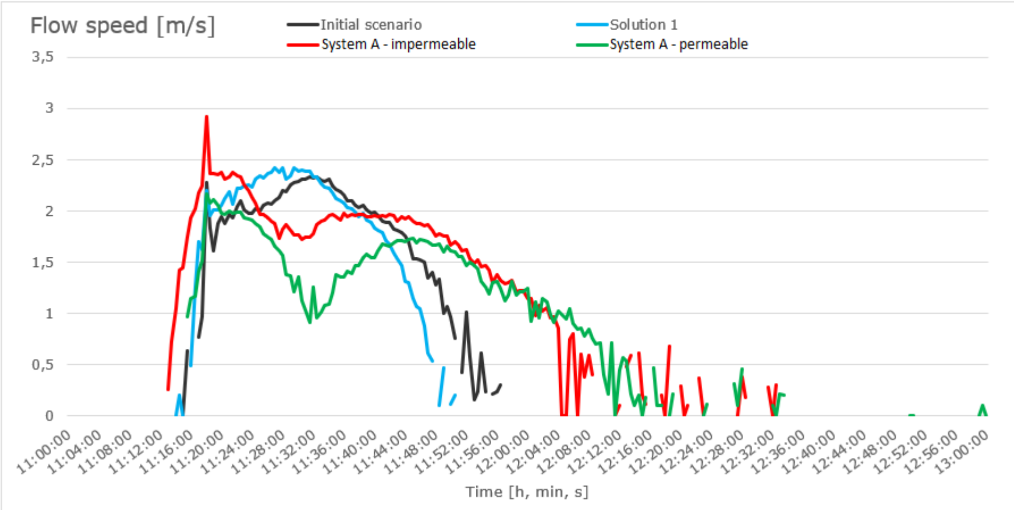


Figure 4.10: Flow speeds at Gatekullen Road from 11:00 to 13:00.

In the reference point by the terraces the results vary greatly between simulations. Overall the peak flow speed was reduced for both Systems A and B, most notably, for System B with impermeable solutions, reaching only 0.12 m/s, as can be seen by the blue bars in Figure 4.11. The time for the peak flow speeds occurs more or less within the same time span for all scenarios, around 11:26 to 11:27, except for System B with impermeable solutions. This peak was reached earlier at 11:23.

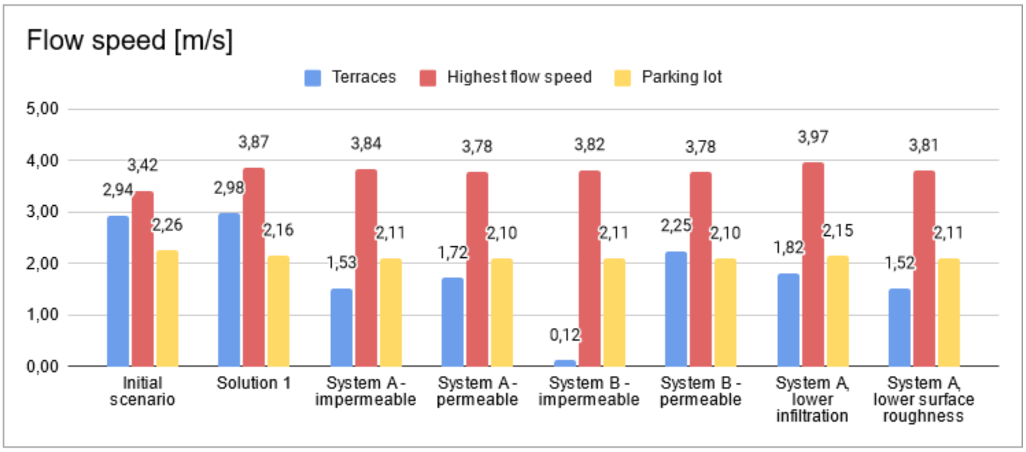


Figure 4.11: The maximum flow speeds for the points located in Kring Alles Road.

At the highest flow reference point, in Kring Alles Road, the flow speed increases slightly when the infiltration is decreased, and the flow speed decreases with an even lower magnitude when the surface roughness is decreased. The initial scenario is the only scenario in which the peak flow speed does not exceed 3.5 m/s. The times for the peak flow speeds occur all around 11:27, except for System B with impermeable solutions where the peak is reached at 11:26.

In the reference point by the preschool's parking lot the largest peak flow speed is achieved during the initial scenario with a value of 2.26 m/s. For the other scenarios the peak flow speed is lower by a small amount, and the difference between the scenarios even smaller. The peak flow speed is reached around 11:27 for all points except System B with impermeable solutions. The peak flow speed for that scenario is reached at 11:25.

Since infiltration is part of managing the stormwater in sustainable stormwater solutions, the infiltration curve is shown in Figure 4.12. The graph is shown for System A with both the initial conditions and the impermeable and permeable scenario.

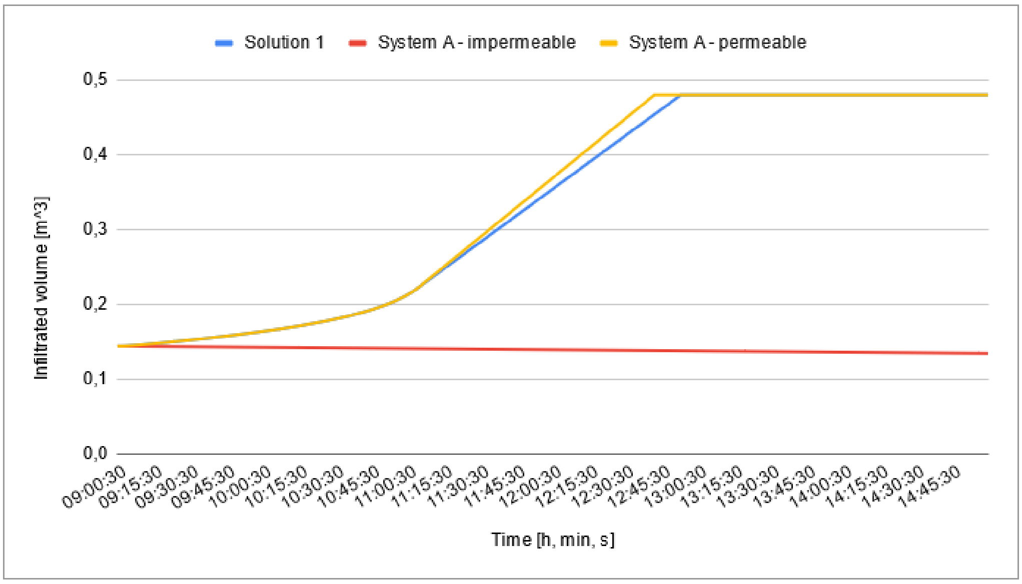


Figure 4.12: The infiltrated volume at the park by Vattenpalatset for Solutions 1 (Edited schools) and System A with permeable and impermeable surfaces.

The results show that the permeable scenario and the initial conditions are similar in the first two hours of the rain event, but when the peak in the hyetograph begins, the permeable scenario has a higher infiltration rate. This is due to the changes made for the stormwater solutions where the solutions are given a higher infiltration rate. Both curves reach the same maximum volume due to the infiltration limitation set in the model based on soil conditions.

4.4 Results of sensitivity analysis

The sensitivity analysis performed in MIKE 21 on the parameters' infiltration and surface roughness is evaluated at the point of highest flow speed in the model. The system used is System A and the parameters are changed to increase by 15% and decrease by 15%. The simulation is run for the impermeable scenario and the permeable scenario respectively. The results for the impermeable scenario are shown as a line chart in Figures 4.13 and 4.14. In the figures, the base value represents the values used in the modelling throughout the project, the +15% represents an increase in surface roughness values and infiltration values while the -15% represents a decrease of the same values.

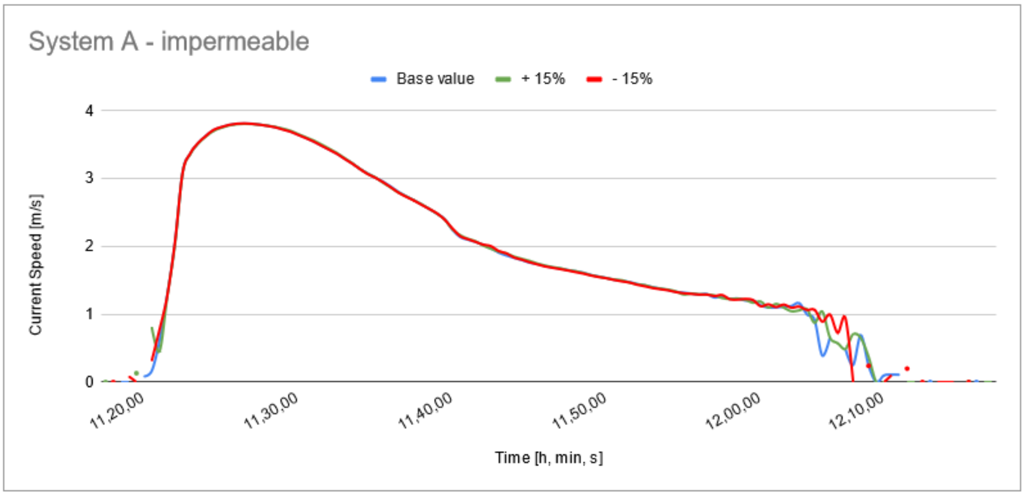


Figure 4.13: Line chart showing the sensitivity analysis performed in MIKE 21 on surface roughness and infiltration for System A with impermeable surfaces. The evaluated location is the highest flow reference point.

Figure 4.13 shows the results for the sensitivity analysis in the impermeable scenario, while Figure 4.14 shows the results for the sensitivity analysis in the permeable scenario. In both scenarios it is System A with its combination of solutions that is used.

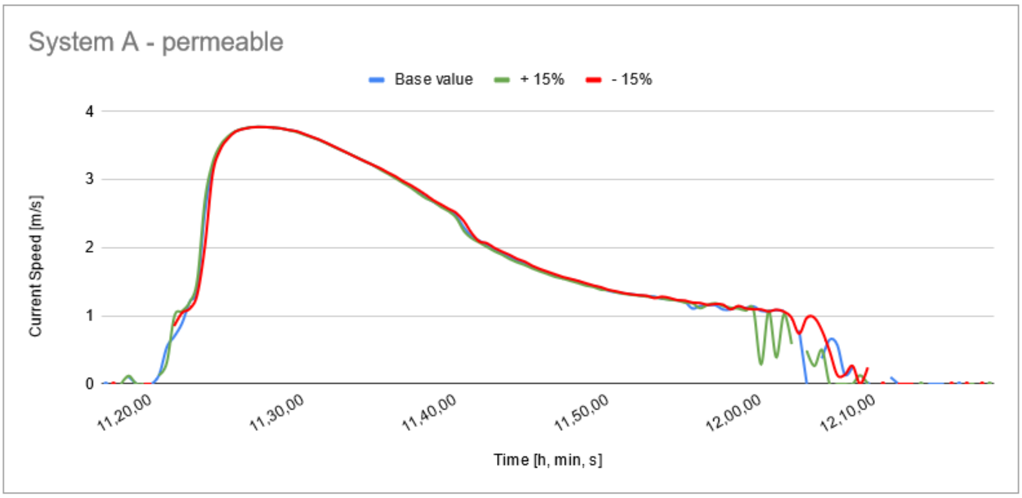


Figure 4.14: Line chart showing the sensitivity analysis performed in MIKE 21 on surface roughness and infiltration for System A with permeable surfaces. The evaluated location is the highest flow reference point.

As can be seen in both Figure 4.13 and 4.14, the results are following the same curve for the majority of the chart, with some variation at the start, and more variation at the end of the curves. The similarity in results between the simulations indicates that the model is not sensitive to changes in the altered parameters.

5

Discussion

In this chapter the results are discussed and evaluated. The uncertainties related to the project are presented, as well as reasoning related to the multifunctional purposes of the sustainable stormwater management solutions.

5.1 Discussion of results

The discussion of the results relate to the effect of infiltration and surface roughness on the achieved flow speeds and floods, as well as the effects of the implemented solutions on the flooding depths.

The results show that the implementation of the new elementary school in Norra Hallsås increases the flow speed downstream in almost all locations. It also increases the amount of locations where the risk level is *risk for some*. Generally the flow speed is lower when the solutions are simulated as a permeable surface and the speed is higher for when the surfaces are set to be impermeable. By the reference point of Gatekullen Road, the impermeable solutions increase the flow speed. The results are more inconclusive downstream, as they are also affected by upstream solutions. The values can still provide an insight to how the various solutions and the permeability affects the flow speed and flood.

The flooding depths are also affected by whether the surface is permeable or not, as well as the retaining capacity of the stormwater management solutions. The flood depth results from MIKE 21, as presented in the reference points, show a similar pattern as is shown for the flow speeds, meaning that the permeable surface contributes to lower flood depths. For the flood depths that in the reference points Odhners Road and Ditch to Säveån, the flood at the time of the maximum speed is lower than the maximum flood during the event. The maximum flood occurs later in the event, when the flow speed is lower. For the other reference points, the maximum flow speeds roughly coincide with the maximum flood depths.

The location where the effects of infiltration and surface roughness best coincide with the theory presented in section 2.2.2 is in the reference point by Gatekullen. In this location, it is easy to identify the impact of each change as it is not affected by a combination of upstream solutions, as the only upstream measure is the implementation of the elementary school and the solutions in the school area. The results are presented further in section 4.3, where it can be concluded that the use of permeable surfaces such as the green covers proposed for sustainable stormwater management successfully reduce flow speed and water depth. It also shows that it is beneficial and effective to retain stormwater and reduce flow early in the flow path.

Most of the results of the flow simulations presented in Figure 4.11 follow a similar pattern and remain in a similar range of values, except for in System B - impermeable for the Terraces reference point. The value is significantly lower than all other values in the same category, represented by the blue bars. The solutions in this scenario uses the ditch placed along Kring Alles Road in an attempt to divert the water away from the road. Comparing the value to System B - permeable, it becomes clear that the point of reference might have not been misplaced, because then the two results should have been within the same range, either both low or high. The result is therefore not deemed unreasonable. Worth noting is that the terraces and the ditch do not end in the exact same location, making exact comparisons between systems A and B for this specific reference point invalid.

Another result of the flow speeds from Figure 4.11 that might be considered unreasonable is the result for System A - impermeable in the reference point of the terraces. The peak value for this scenario is lower than for the permeable scenario, which according to Lau and Afshar (2013) is the opposite effect achieved by an uneven surface.

The flow speed results are somewhat inconclusive for some of the reference points. The flow speeds in the reference points, and the connected floods, presented in sections 4.2 and 4.3 are all created from a model that has multiple stormwater solutions implemented simultaneously. The reason for not running simulations for each solution by itself is due to time constraints in the project. If a simulation was performed for each solution by itself both the floods, and especially the flow speed results, could have been different than the ones achieved for this report. This is due to the fact that a downstream solution depends on the flows upstream, which could have been altered by an upstream solution. Since the flow speeds are also affected by the implementation of the solutions, there is no guarantee that the difference in flow speeds are solely impacted by the change in infiltration and surface roughness. There is also the possibility that the solutions do affect the flow speed, by delaying the flow until the upstream solutions are filled and start overflowing. The stormwater management can also contribute to the opposite, that the flow speed peak occurs earlier in the rain event, as is the case in the reference point by the preschool parking lot and the use of an impermeable ditch by Kring Alles Road. This solution makes the flow speed peak arrive approximately 2.5 min earlier than for Solution 2 - Edited schools. The flow speed at this point in time is however the same, and the water level slightly lower which is likely due to the retaining dry pond upstream by the intersection with Richerts Road. The lower water level leads to a slightly lower risk level, while it still remains in the category of *risk for some*. When using this reference point by the preschool parking lot, it is clear that the use of an impermeable ditch is not favourable, as all other solutions provide lower speeds, although the variation is low and all give the risk level of *risk for some*, and further investigations are likely to be necessary to lower the flood risk level.

The differences in flow speed and flood presented in section 4.2.1, when the solutions located around the elementary schools are added, likely stem from the collection of stormwater that the solutions contribute to. The implementation of the elementary school will most likely create more impermeable cover than the ones designed in SCALGO Live, such as a schoolyard and parking lot, possibly leading to even higher flow speeds on the Gatekullen Road. This change in impermeable cover would have an impact on the results derived from MIKE 21, since the model and simulations in that software are based on the elevation model created in SCALGO Live.

The flow speeds on Kring Alles Road are affected by the proposed solutions, the terraces and the ditch. However, there are still other, smaller flow paths from other roads that connect to the flow on Kring Alles Road and create a high flow speed in the reference points on the road. These smaller flow paths run through private properties and have therefore not been addressed in this project. An attempt to divert the flow paths further up in the path to the dry pond by the intersection with Richerts Road was tried by implementing what could be described as a speed bump in SCALGO Live. The attempt was unsuccessful, as the flow derives from multiple connecting roads. Each flow would need to be diverted to a ditch or terrace to lower the flow speed, which is something that could be evaluated in a future study.

The risk level by Torpskolan varies with the investigated rain events. It is determined that for the use of a flood diversion such as a ditch towards Säveån, only the maximum investigated rain event (400 year return time, 4 hour duration) poses a risk to people. However, for the rain event of 100 mm, the water depth by Torpskolan is at 1.3 m, which can be seen as rather deep considering it is located by a school, albeit with older students (Lerums kommun, n.d.). A water depth of 1.3 m is also likely to affect the building.

It can be concluded from the results of the flooding by Torpskolan that diversion of the stormwater is the most efficient and, according to the presented volumes in Table 4.1, the only solution to lowering the flood. The diversion can be performed either by using Solution 9 - Ditch to Säveån, with either ditch design, or Solution 10 - Solutions by Torpskolan which entails a ditch to the creek west of Torpskolan, where the creek connects to Säveån. This is because the solutions implemented in this project all are connected to the main flow path, while the flood at Torpskolan is affected by other flow paths as well. To lower the flood by Torpskolan, solutions in those flow paths would have to be investigated as well. The use of ditches for diversion contain the element of diverting the water directly into Säveån, without remediation. As is mentioned in the topology and geography of the case study area, section 2.5.1, Säveån is affected by pollution from stormwater (VISS, n.d.-b), which would increase if the diverting solutions are implemented. Not only for flash floods, the solutions could also divert rain events of lower magnitudes, which could contribute to higher levels of pollution during more frequent rain events. It is possible this could be avoided through design measures, however it is not investigated in this report.

5.2 Uncertainties

Uncertainties are part of every model and simulation, as they correspond with reality to a varying degree. Some uncertainties in the simulations in this project is the uncertainty in the prediction of climate change and its effect on precipitation, the likelihood that all rain falls simultaneously and of the same amount on the entire surface and the correlation with the drainage system.

Another uncertainty regarding the rainfall events in the simulations in this project is the fact that in SCALGO Live, the same rain is added to the entire area. In reality it varies over the domain, and the larger the area the larger the variation in precipitation. The simulated rain also differs between SCALGO Live and MIKE 21. As described in section 2.4.1, in SCALGO Live the rain is a set amount without variation in time, making SCALGO Live a static model. For MIKE 21, the rain can either be constant or varying over time and domain and thus creating a more dynamic model, as described in section 2.4.2. This difference in precipitation behaviour is deemed to have no significant impact due to rain being very difficult to accurately design, and it is therefore favourable in a larger perspective to have results for various storm events.

Further uncertainties when using SCALGO Live stem from the software's lack of ability to edit soil properties. As mentioned in 2.4.1 this makes results overestimated since the infiltration capacity is modelled as zero. This would correspond to modelling a scenario where the soil's infiltration capacity is already filled. However, it can also be considered a more conservative approach to assume that the infiltration capacity of the soil is filled at the time of the flash flood, as all precipitation then becomes runoff. Another aspect, stated by SMHI (2017), flash floods occur more frequently during the summers in Sweden, which means infiltration can impact the amount of runoff.

Further aspects regarding modelling compared to reality is that infiltration rate is affected by the slope of the surface, where an increased gradient decreases the infiltration rate (Morbidelli et al., 2018). This is not something included in MIKE 21, where the cells use the same rate of infiltration regardless of the slope rate (DHI, 2017, 2021). Morbidelli et al. (2018) also state that surface roughness has an impact on the infiltration rate for sloping surfaces, where an increased surface roughness increases the infiltration rate. The true effects of a sustainable stormwater solution on a sloping surface, such as along Kring Alles Road, is therefore difficult to assess and the downstream flooding and flow speeds might be underestimated. The infiltration method used in this project is constant infiltration with capacity, as mentioned in section 3.3.4.1. There are other infiltration methods available in MIKE 21, which could result in a different outcome.

The MIKE 21 model created by Tyréns AB had preset values for wetting depth

(h_{wet}) and drying depth (h_{dry}), these being 0.02 m and 0.008 m respectively. They are altered compared to the default values of 0.05 m and 0.005 m as described in the MIKE 21 FM User guide (DHI, 2017). The drying and wetting depth are parameters used by the software to decide of a cell should or should not be considered in calculations. This slight difference between the default values and the values set by Tyréns AB are considered to not have a significant impact on the final outcome of the simulations.

An uncertainty regarding hydrological evaluations is the future and the impact of climate change (Hernebring et al., 2018). The uncertainty implies that caution should be taken when interpreting the results. Hernebring et al. (2018) mentions that the uncertainty can be represented by presenting the variety which the results can lie within. In this project, the uncertainty has been addressed by using the higher climate factor of 1.4, following the higher RCP-scenario of RCP8.5 which is recommended by Länsstyrelserna (2018). The higher values lead to an aspect of safety, when the design is for higher volumes of rain than what may actually occur in the future. On the other hand, since the predictions on climate change are uncertain in themselves, the design volumes might be underestimated and the measures might not be sufficient. The use of multiple rain events also relates to the uncertainty, as it is not feasible to rely on one single rain scenario when designing stormwater measures. Investigating multiple rain events provides a higher aspect of safety for future rain amounts when designing capacities of stormwater solutions.

5.2.1 Discussion of implementation of solutions

The diversion of the flood to Säveån poses a possible risk in terms of flooding of the river itself. In SCALGO Live, it is possible to display a flood simulated by MSB for 100- and 200-year events for the year 2100, however it is uncertain for which RCP scenario this is evaluated (MSB, 2018). These simulations show that the river is likely to contain more water. The area is currently subject to high risk of slope failure (SGI, 2017) and the addition of the stormwater from the study area can further increase the risk of slope failure. The addition of stormwater can also increase the risk of flooding for areas downstream in Säveån.

The design of one of the ditches in Solution 9, the one running along Häradsvägen, is not compatible with the detailed development plan for the new residential buildings planned in the current parking lot (Lerums kommun, 2017a), which is mentioned in the case study section 2.5. The reason for choosing it as an inclusion in the combination systems A and B for flow speed studies is to simply have a solution that successfully diverts the water from the depression by Torpskolan. If a similar, diverting, solution is to be implemented in reality, the design would likely rather be similar to the ditch following the parking lot, see subfigure (b) in Figure 3.7.

When excavating the soil to make room for retention ponds, terraces, and ditches the soil type might change depending on the depth of the excavation. Different soil types have different properties which in turn could have an effect on the infiltration capacity (J. Bai et al., 2019). Another soil property to take into account is the groundwater table, as it is in theory possible to reach the groundwater table when excavating the soil for the solutions. The presence of groundwater could cause the stormwater solution to not function as efficiently due to water saturating the soil or creating a water surface in the solution which limits the retaining capacity. Although the proposed solutions are only implemented on land owned by the municipality, which can be concluded using Appendix B, groundwater drawdown can affect the stability of soil and lead to soil settlements, possibly affecting nearby buildings (Shen et al., 2006). The solutions can also affect soil stability in some cases for nearby houses by removing the resisting force that the soil contributed with, which would need to be further evaluated. Two locations in possible need of reinforcing are the dry pond located at the intersection of Richerts Road and Kring Alles Road, or the terraces/ditch along Kring Alles Road. These areas are especially interesting due to being closely located to residential buildings and bike paths.

The drainage system has not been thoroughly examined in this project and the assumptions made might not be representative of how it looks in reality. The assumed deduction made for the rain event calculations in section 3.2 might be larger or smaller depending on when the drainage system was implemented, since contemporary drainage systems have to take into account newly built areas and how the design standards have changed. Inlets to drainage systems can also be blocked if regular maintenance is not executed, which could further increase flooding. The drainage system and other, for this project, uninvestigated subsurface infrastructure can also affect the implementation of solutions. This is because some locations can be seen as unsuitable due to existing subsurface networks.

Similarly to the subsurface infrastructure, trees can also prove to be an issue for some of the proposed solutions. For the solutions proposed along Kring Alles Road, the terraces and the ditch, there is the risk of them being difficult to implement either in full size as proposed in this project. The trees, which can be seen in Figure 3.3 (b), and their root systems might hinder excavation in the terrace system, making it necessary to map the root system before further decision making.

The parking lot by the preschool is in this project evaluated as a possible stormwater retention facility by using a permeable cover and thereby facilitating infiltration. The surface has varying capabilities of infiltration depending on what kind of permeable cover is used and how well maintained the cover is (Bean et al., 2007). Providing proper maintenance can increase infiltration rates up to almost 90% compared to without maintenance.

An uncertainty that can have a large impact on the flooding by Torpskolan is the presence and capacity of culverts. Culverts in SCALGO Live, as described in section 3.3.4, are essentially two connected points with no dimensions where water is instantly conveyed from the upstream point to the downstream point. In MIKE 21, culverts can be designed to be more precise, but for this project it was deemed that the two softwares handles culverts too differently to enable a comparison between the simulation results. Therefore the culverts were represented in MIKE 21 as large ditches where it was controlled that they conveyed the water similarly to the culverts in SCALGO Live. Another aspect regarding the culverts is that in reality, culverts can get clogged which hinders them from conveying water efficiently. This can not be replicated in the softwares. As this aspect is not considered in neither SCALGO Live nor in MIKE 21, it is possible that the results are overestimated with respect to the culverts' capacities which is further described in Appendix C. Yet another aspect concerning the culverts is that there are culverts upstream the creek west of Torpskolan. These have not been investigated in this project as they are not included in the watershed. However, as the creek is one body of water connected by culverts, it can have effects downstream as well.

Something that can influence the amount of flow and flood locations is the layout of the new schools as the shape of the two schools in the softwares might not represent the final designs. The reason for this is because the designs in the softwares are entirely based on illustrations found on Lerum's website and personal contact. Furthermore they were created by hand directly into SCALGO Live, and might therefore not be accurately proportioned. The results might therefore not be representative if major changes are done to the buildings.

Further insecurities in SCALGO Live stem from the resolution. During the start of the project the resolution for Sweden in SCALGO Live was 2x2 meter. This resolution was later refined in April of 2021 to 1x1 meter (SCALGO, 2021c). By that point the model had already been created with the 2x2 resolution and there was no time to remake it with the finer resolution. The finer resolution could potentially have an impact on the overall flow paths and the designs of the schools in SCALGO Live, in turn potentially having an impact on the results in MIKE 21. The finer mesh could also make the modelling of infiltration and surface roughness described in 3.3.4 more precise.

5.3 Discussion of multifunctionality in proposed solutions

The implementation of stormwater solutions to manage rain events of the magnitudes investigated in this project tend to take up a lot of space, especially where the objective is to retain stormwater and not just convey it. Therefore it is of interest to design these solutions as to have other purposes than stormwater management for when it is not raining. In this project some of the solutions are evaluated to have multifunctional properties either as ecosystem services or societal functions.

5.3.1 Ecological aspects

The underlying cause of urban areas being subject to flood risks are alterations to the natural environment by construction of impermeable surfaces. Green and sustainable stormwater management solutions are a way to imitate nature's management of stormwater (European Environment Agency, n.d.). Sustainable stormwater management can also contribute to biodiversity by making conscious choices on materials and locations. Examples for this project are using grass covered dry ponds and preserving existing greenery such as trees in the park by Vattenpalatset or by Kring Alles Road. Although the end means is to protect urban areas from flooding, it is of interest to try and have as little impact as possible on nature while constructing the stormwater solutions. The material and energy use of construction is part of each stormwater management solution and contributes to whether the ecological aspects benefit from the proposed solution.

The solutions proposed in this project have varying impacts on nature, depending on the type of material used. If the solutions were to be designed as impermeable cover, using a material such as concrete, they would not be as beneficial to ecosystem services as if they were designed with permeable cover. The serpentine ditch located by Odhners Road could include different types of grass such as tall grass to further emphasise the function of slowing down the flow speed. A varying permeable cover on the stormwater solutions can also benefit biodiversity (Ghofrani et al., 2017). The use of sustainable stormwater management can also provide heat reduction in urban areas, most in larger urban areas with a lot of impermeable surfaces (Prudencio & Null, 2018). As Lerum is an expanding urban area, it is beneficial to include areas for sustainable stormwater management with multifunctional purposes such as ecosystem services early in the development to ensure there is sufficient space available for these purposes.

5.3.2 Societal aspects

In section 2.2, some of the sustainable stormwater management solutions incorporate temporary bodies of water, for example the park next to Vattenpalatset. According to Mottaghi et al. (2020) these could attract different kinds of animals to an urban setting where animals rarely gather, both those that are more commonly desirable, such as ducks and birds, and less desirable such as rats and certain insects. The presence of these animals could in turn have an impact on the number of people and the types of people visiting the area, such as bird watchers, possibly creating a frequently visited space. The water could also serve as a hub or living space for certain species of animals not commonly found in urban areas, depending on the necessary space, and as a result increase the local biodiversity. Using the area as a recreational hub when not in use to collect stormwater as well as providing a living space for animals could be beneficial for residents' wellbeing in the area.

The solutions proposed in this project all have the option to include some degree of vegetation and/or social function. The decision to keep the pétanque court in the proposed solution in the park was made with this in mind. During the study visit it was mentioned that it is utilised by the local residents as a meeting place, especially during the pandemic. The survey held by Xie et al. (2020) in China showed that recreational areas play a significant role in the wellbeing of humans, and the multifunctional nature of open stormwater solutions could play an important role in the future for providing citizens a place for social recreation. Having parks within a walking distance would also make citizens more willing to visit them. Another reason to have parks and recreational areas in close proximity to residential homes is related to public transportation. During the pandemic it was recommended to avoid large groups of people. By not using public transportation, one is able to avoid a group of people in a confined area. Thus, having parks within walking distance would still allow people to go there. Large areas for water retention could be developed to be used as a smaller field for sport related activities or a local park.

One of the proposed solutions for stormwater management is to remove the entire, or part of, the swimming pool facility Vattenpalatset and use the space for water retention. A figure obtained from the suggested solution in SCALGO Live can be seen in section 3.3.3. The solution entails a lowering of the ground by 3 m, with a side slope ratio of 1:12. The use of the space as a stormwater retention area can be given additional benefits. As mentioned in the background, the area can serve the purpose of a public park similar to Enghaveparken in Copenhagen (Tredje Natur Architects, n.d.). In the park there could be space made for various activities when the area is dry, as well as activities for when it is raining or recently has been. An access point to the area is added in the south east corner by constructing a path from the bike lane outside of the pond down to the bottom of the pond to ensure access to the area. The access path can additionally assist in collecting water into the pond during rain events. Although the benefits could be great in terms of flooding preparedness and possible social benefits, it is unfortunately not considered to be a plausible solution to remove Vattenpalatset.

6

Conclusion

The aim of this project is to investigate the importance of using sustainable stormwater management in urban areas. The study is performed through the assessment of the impact of infiltration and surface roughness for proposed solutions in a development project in Lerum, Sweden. Objectives are to identify vital infrastructure, areas sensitive to flooding and locations with high risk levels for people in case of flooding. It is also to propose sustainable stormwater management solutions and consider multifunctionality in the solutions. Lastly it is to study the effect of infiltration and surface roughness in the stormwater solutions, two parameters strongly connected to sustainable stormwater management.

Initially the identified sensitive and vital infrastructure or facilities are compared to areas with high flow speed in the initial conditions. This comparison shows that there is no vital infrastructure at risk in Lerum, based on non-classified information. There is a risk that people can get injured in the case of a flash flood for some locations, for example by the planned preschool and Torpskolan.

The implementation of the new development increases flow speed and flooding depth and leads to more locations with increased risk levels. The implementation of stormwater solutions manages to lower the risk levels in most locations, except for the location by the preschool where the risk level is *risk for some* in all scenarios. Regarding the flood by Torpskolan, the only solution that manages to lower the flood depth is the use of a ditch that diverts the water, as the delaying and retaining properties are insufficient. The lowering of risk levels when implementing solutions indicates that focus should be on retaining the water early in the flow path, which in this case study is by the new elementary school in Norra Hallsås.

One objective is to only suggest solutions on municipally owned land, which is accomplished. Some of the solutions are proposed to have multifunctional purposes for dry weather. These are investigated for both societal and ecological purposes in addition to flood prevention. The solutions proposed to be multifunctional in a societal and social aspect are the various designs of the flooding area by Vattenpalatset and the pétanque court. Regarding ecological aspects it is recommended that the proposed solutions include a permeable cover to contribute to ecosystem services.

In this project, the use of permeable covers contributes to lower flow speed by having high surface roughness, and lower flood depths by infiltrating parts of the precipitation. It can be concluded that the flow speed is lower for permeable surfaces, and that surface roughness has a higher impact on reducing flow speed than infiltration in the evaluated scenarios. It can also be concluded that infiltration impacts the flood depth more than the surface roughness by lowering the flood depth for increased infiltration rate in the evaluated scenarios. Depending on whether it is flow speed or flood depth that poses the highest risk, surface roughness and infiltration provide different impacts. Both aspects of lowering flow speed and flood depth by using sustainable stormwater management contribute to lower risk levels in flooding events and minimise consequences, both for people and infrastructure.

6.1 Future studies

Further studies that can be conducted based on this project is the effect of diverting a flood to Säveån, both in terms of an added pollution load and risks of slope failure.

Another future study can be to investigate how much a change in surface roughness can affect various amounts of flow speeds to provide guidance on which types of cover is recommended for sustainable stormwater management.

It can also be of interest to investigate how a sloping elevation and infiltration rate and capacity is managed in MIKE 21 compared to reality and what effects it has on flooding results, as the programme currently does not consider a decreased infiltration for sloping surfaces.

Reference list

Alamdari, N., Sample, D. J., Steinberg, P., Ross, A. C., & Easton, Z. M. (2017). Assessing the Effects of Climate Change on Water Quantity and Quality in an Urban Watershed Using a Calibrated Stormwater Model. https://doi.org/10.3390/w9070464

Alcamo, J., van Vuuren, D., Cramer Lead Authors, W., Alder, J., Bennett, E., Carpenter, S., Christensen, V., Foley, J., Maerker, M., Masui, T., Morita, T., Peterson, G., Ringler, C., Rosegrant, M., Schulze Contributing Authors, K., Bouwman, L., Eickhout, B., Floerke, M., Lal, R., . . . Field, C. (2005). *Changes in Ecosystem Services and Their Drivers across the Scenarios* (tech. rep.). Millennium Ecosystem Assessment. https://www.millenniumassessment.org/documents/document.333.aspx.pdf

Arcement, G. J., & Schneider, V. R. (1989). Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. *United States Geological Survey*. https://pubs.usgs.gov/wsp/2339/report.pdf

Bai, J., Yang, S., Zhang, Y., Liu, X., & Guan, Y. (2019). Assessing the impact of terraces and vegetation on runoffand sediment routing using the time-area method in the Chinese Loess Plateau. *Water*, *11*(4). https://doi.org/10.3390/w11040803

Bai, Q., Sun, J., Han, D., Zheng, T., & Huang, W. (2021). Structural Design of New Permeable Ecological Side Edge. *IOP Conference Series: Earth and Environmental Science*. https://doi.org/10.1088/1755-1315/651/4/042036

Bean, E. Z., Hunt, W. F., & Bidelspach, D. A. (2007). Field Survey of Permeable Pavement Surface Infiltration Rates. https://doi.org/10.1061/ASCE0733-94372007133:3249

Berardi, U., GhaffarianHoseini, A. H., & GhaffarianHoseini, A. (2014). State-of-the-art analysis of the environmental benefits of green roofs. https://doi.org/10.1016/j.apenergy.2013.10.047

Björkman, E., Vikingsson, H., Karlsson, A., & Svensson, G. (2019). *Skyfallskartering Lerums kommun* (tech. rep.). Tyréns AB. Göteborg. www.tyrens.se

Blackburn, W. H. (1975). *Factors Influencing Infiltration and Sediment Production of Semiarid Rangelands in Nevada* (tech. rep. No. 6). Water Resources Research. https://doi.org/10.1029

Blomquist, N. (2015a). *PM - Delområdesbeskrivning Klimatrisker Södra Älvstranden* (tech. rep.). City of Gothenburg - Stadsbyggnadskontoret. Gothenburg.

Blomquist, N. (2015b). *PM - Översvämningsrisker - framkomlighet inom detaljplan Haga station* (tech. rep.). City of Gothenburg - Stadsbyggnadskontoret. Gothenburg.

Bohman, A., Glaas, E., & Karlson, M. (2020). Integrating sustainable stormwater management in urban planning: Ways forward towards institutional change and collaborative action. *Water (Switzerland)*, *12*(1). https://doi.org/10.3390/w12010203

Céréghino, R., Boix, D., Cauchie, H.-M., Martens, K., Oertli, B., Céréghino, R., Boix, D., Martens, K., & Oertli, B. (2014). The ecological role of ponds in a changing world. *Hydrobiologia*, *723*, 1–6. https://doi.org/10.1007/s10750-013-1719-y

Chan, F. K. S., Griffiths, J. A., Higgitt, D., Xu, S., Zhu, F., Tang, Y. T., Xu, Y., & Thorne, C. R. (2018). 'Sponge City' in China - A breakthrough of planning and flood risk management in the urban context. *Land Use Policy*, *76*, 772–778. https://doi.org/10.1016/j.landusepol.2018.03.005

Chormanski, J., Van De Voorde, T., De Roeck, T., Batelaan, O., & Canters, F. (2008). Improving Distributed Runoff Prediction in Urbanized Catchments with Remote Sensing based Estimates of Impervious Surface Cover. *Sensors*, *8*, 910–932. https://doi.org/https://doi.org/10.3390/s8020910

Cristiano Id, E., Farris, S., Deidda, R., & Viola, F. (2021). Comparison of blue-green solutions for urban flood mitigation: A multi-city large-scale analysis. https://doi.org/10.1371/journal.pone.0246429

Davis, A. P., Stagge, J. H., Jamil, E., & Kim, H. (2011). Hydraulic performance of grass swales for managing highway runoff. https://doi.org/10.1016/j.watres.2011.10.017

Defra. (2006). *Flood Risks to People Phase 2* (tech. rep.). Middlesex University.

Deletic, A., & Fletcher, T. D. (2006). Performance of grass filters used for stormwater treatment - A field and modelling study. *Journal of Hydrology*, *317*(3-4), 261–275. https://doi.org/10.1016/j.jhydrol.2005.05.021

DHI. (n.d.-a). About Us. https://www.dhigroup.com/about-us

DHI. (n.d.-b). *MIKE 21 & MIKE 3 Flow Model FM Hydrodynamic Module Short Description* (tech. rep.).

DHI. (n.d.-c). Our products. https://www.mikepoweredbydhi.com/products

DHI. (2017). *MIKE 21 Flow Model FM Hydrodynamic Module User Guide* (tech. rep.). https://manuals.mikepoweredbydhi.help/2017/Coast_and_Sea/MIKE_FM_HD_2D.pdf

DHI. (2021). MIKE 21 Flow Model & MIKE 21 Flood Screening Tool. https://manuals.mikepoweredbydhi.help/2021/Coast_and_Sea/M21HDFST_Scientific_Doc.pdf

Eisenberg, B., Lindow Collins, K., & Smith, D. R. (2015). Design Considerations Common To All Permeable Pavements. In B. E. Eisenberg, K. Collins Lindow, & D. R. Smith (Eds.), *Permeable pavements* (pp. 3–48). https://doi.org/https://doi.org/10.1061/9780784413784

Elmqvist, T., Setälä, H., Handel, S. N., van der Ploeg, S., Aronson, J., Blignaut, J. N., Gómez-Baggethun, E., Nowak, D. J., Kronenberg, J., & de Groot, R. (2015). Benefits of restoring ecosystem services in urban areas. *Current*

Opinion in Environmental Sustainability, *14*, 101–108. https://doi.org/10.1016/j.cosust.2015.05.001

Engman, E. T. (1986). Roughness Coefficients for Routing Surface Runoff. *Journal of Irrigation and Drainage Engineering*, *112*(1), 39–53. https://ascelibrary-org.eu1.proxy.openathens.net/doi/pdf/10.1061/%28ASCE%290733-9437%281986%29112%3A1%2839%29

Eriksson, J., & Wilkås, T. (2018). *Mapping, Evaluation and Improvements of Simple Stormwater Measures* (Doctoral dissertation). Water Environment Technology. Gothenburg.

European Environment Agency. (n.d.). What is European policy on green infrastructure? https://www.eea.europa.eu/themes/sustainability-transitions/urban-environment/urban-green-infrastructure/what-is-green-infrastructure

Field, R., & Struzeski, E. J. (1972). Management and Control of Combined Sewer Overflows. *Journal (Water Pollution Control Federation)*, *44*(7), 1393–1415. https://www.jstor.org/stable/pdf/25037548.pdf?refreqid=excelsior%3A55619da0685d481bc78def7b8a067e87

Fletcher, T. D., Andrieu, H., & Hamel, P. (2013). Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. *Advances in Water Resources*, *51*, 261–279. https://doi.org/10.1016/j.advwatres.2012.09.001

Ghofrani, Z., Sposito, V., & Faggian, R. (2017). *A Comprehensive Review of Blue-Green Infrastructure Concepts* (tech. rep. No. 1). https://www.sciencetarget.com/Journal/index.php/IJES/article/view/728/218

Google. (n.d.). Google Maps. https://www.google.se/maps/@57.7740736,12.2748025,2315m/data=!3m1!1e3

Gruntfest, E., & Handmer, J. (2001). *Coping With Flash Floods* (E. Gruntfest & J. Handmer, Eds.; 1st ed., Vol. 77). Springer. https://doi.org/https://doi-org.proxy.lib.chalmers.se/10.1007/978-94-010-0918-8

Gryyab AB. (n.d.). Kort om Gryyab. https://www.gryaab.se/vad-vi-gor/kort-om-gryaab/

Gunnarsson, K. (2015). *Two-dimensional hydrodynamic modeling of overland flow and infiltration in a sustainable drainage system* (Doctoral dissertation). Water Resources Engineering. Lund. https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=7758021&fileOId=7758032

Gustafsson, K. (2020). *Befolkningsprognos 2020* (tech. rep.). Lerum. https://www.lerum.se/globalassets/documents/forvaltningssidorna/kommun-och-politik/fakta-och-info/befolkningsprognos-2020_2029_rapport.pdf

Håkanson, B., Stål, J.-P., Marklund, M., & Zerpe, P. (2019). *Risk- och sårbarhetsanalys (RSA) för Lerums kommun* (tech. rep.). https://doi.org/https://doi.org/10.1016/S1364-8152(00)00084-0

Hernebring, C., Dahlström, B., & Kjellström, E. (2018). *Regnintensitet i ett förändrat klimat i Sverige med data tillgängliga för användare* (tech. rep.). Svenskt Vatten Utveckling, DHI. http://vav.griffel.net/filer/C_Regnintensitet_forandrat_klimat_Sverige.pdf

Herrmann, J. T. (2019). *Investigation and assessment of pluvial flood modelling tools in urban areas: A recommendation for flood management exemplified by the*

catchment area Linnéstaden in the City of Gothenburg in Sweden (Doctoral dissertation). Chalmers University of Technology. Gothenburg.
IPCC. (2019). Representative Concentration Pathways (RCPs). https://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/RCPs.html
Jenkins, A. (2020). Biotic systems as a critical urban infrastructure during crisis: learning from the COVID-19 pandemic. https://doi.org/10.1080/23748834.2020.1789821
J.F. Sabourin and Associates Inc. (2000). *An Evaluation of Roadside Ditches and Other Related Stormwater Management Practices* (tech. rep. No. 2). The Toronto and Region Conservation Authority. Ottawa.
Jha, A. K., Bloch, R., & Lamond, J. (2012). *Cities and Flooding. A Guide to Integrated Urban Flood Risk Management for the 21st Century* (tech. rep.). International Bank for Reconstruction and Development. Washington, D.C. https://doi.org/10.1596/978-0-8213-8866-2
Jung, I. K., Park, J. Y., Park, G. A., Lee, M. S., & Kim, S. J. (2011). A grid-based rainfall-runoff model for flood simulation including paddy fields. *Paddy and Water Environment*, *9*(3), 275–290. https://doi.org/10.1007/s10333-010-0232-4
Keyvanfar, A., Shafaghat, A., Ismail, N., Mohamad, S., & Ahmad, H. (2021). Multifunctional retention pond for stormwater management: A decision-support model using Analytical Network Process (ANP) and Global Sensitivity Analysis (GSA). *Ecological Indicators*, *124*. https://doi.org/10.1016/j.ecolind.2020.107317
Kirkham, M. (2014). Infiltration. *Principles of soil and plant water relations* (pp. 201–227). Elsevier. https://doi.org/10.1016/B978-0-12-420022-7.00013-6
Länsstyrelserna. (2018). *Rekommendationer för hantering av översvämning till följd av skyfall* (tech. rep.).
Lantmäteriet, & Lerums kommun. (2019). Lerumskartan. https://karta.lerum.se/mapserver2017/fusion/templates/mapguide/gsviewer2.0/index.html?ApplicationDefinition=Library%3a%2f%2fGSViewer2.0%2fLerumskartan.ApplicationDefinition
Larm, T., & Blecken, G. (2019). *Utformning och dimensionering av anläggningar för rening och flödesutjämning av dagvatten* (tech. rep.). https://www.svensktvatten.se/contentassets/c8abaf832f154888aa018c23752bf5a9/svu-920.pdf?fbclid=IwAR24-uflp65aZ_AudFcZ9Y4HSIoef5QZpq1-1Keh5-7zCGVkuzCMmVc3cSo
Lau, T. W., & Afshar, N. R. (2013). Effect of Roughness on Discharge. *UNIMAS e-Journal of Civil Engineering*, *4*(3). https://www.researchgate.net/publication/282292334
Lee, R. S. (2011). *Modeling infiltration in a stormwater control measure using modified Green and AMPT* (tech. rep.). Philadelphia. https://www1.villanova.edu/content/dam/villanova/engineering/vcase/vusp/Lee-Thesis-11f.pdf
Lerums kommun. (n.d.). Torpskolan. https://www.lerum.se/Utbildning-och-barnomsorg/Grundskola-och-forskoleklass/Grundskolor-i-lerums-kommun/Torpskolan/

Lerums kommun. (2008). *Lerums Framtidsplan ÖP 2008* (tech. rep.). Lerums kommun. Lerum. lerum.se/bygga-bo-och-miljo/kommunens-planarbete/oversiktsplan/
Lerums kommun. (2015a). *Dagvattenstrategi för Lerums kommun* (tech. rep.). Lerum. https://www.lerum.se/globalassets/documents/forvaltningssidorna/bygga-bo-och-miljo/va/strategi_dagvatten_150826.pdf
Lerums kommun. (2015b). *Handbok för dagvattenhantering i Lerums kommun* (tech. rep.). https://www.lerum.se/globalassets/documents/forvaltningssidorna/bygga-bo-och-miljo/va/handbok_dagvatten_171205-uppdaterad.pdf
Lerums kommun. (2015c). *Klimatanpassningsplan för Lerums kommun* (tech. rep.). https://alexanderabenius.se/wp-content/uploads/sites/50/2015/12/Klimatanpassningsplan_f%c3%b6r_Lerums_kommun_2015-10-06.pdf
Lerums kommun. (2017a). Detaljplan för del av fastigheten Torp 2:80, Säveå Park, i Lerums kommun. https://www.lerum.se/Bygga-bo-och-miljo/Kommunens-planarbete/pagaende-detaljplaner-och-program2/Lerum/Lerum-centrum/Detaljplan-for-bostader-vid-Saveapark/
Lerums kommun. (2017b). Detaljplan för ny förskola vid Kring Alles väg. https://www.lerum.se/Bygga-bo-och-miljo/Kommunens-planarbete/pagaende-detaljplaner-och-program2/Lerum/detaljplan-for-ny-forskola-vid-Kring-Alles-vag/
Lerums kommun. (2020). Vad händer med Vattenpalatset efter nyår? https://www.lerum.se/Kommun-och-politik/Nyhetsarkiv/vad-hander-med-vattenpalatset-efter-nyar/
Lerums kommun. (2021a). Detaljplan ny skola i Norra Hallsås. https://www.lerum.se/Bygga-bo-och-miljo/Kommunens-planarbete/pagaende-detaljplaner-och-program2/Lerum/detaljplan-ny-skola-norra-hallsas/
Lerums kommun. (2021b). Illustrationskarta - Detaljplan ny skola i Norra Hallsås. https://www.lerum.se/Bygga-bo-och-miljo/Kommunens-planarbete/pagaende-detaljplaner-och-program2/Lerum/detaljplan-ny-skola-norra-hallsas/
Lewis, K., Warner, D., & Tzilivakis, J. (2019). Applied Environmental Science and Engineering for a Sustainable Future: Urban Stormwater and Flood Management Enhancing the Liveability of Cities. *Applied Environmental Science and Engineering for a Sustainable Future*, 119–137. https://doi.org/10.1007/978-3-030-11818-1
Liao, K.-H., Deng, S., & Tan, P. Y. (2017). Blue-Green Infrastructure: New Frontier for Sustainable Urban Stormwater Management. *Greening cities* (pp. 203–226). https://doi.org/10.1007/978-981-10-4113-6_10
Lin, J., He, X., Lu, S., Liu, D., & He, P. (2021). Investigating the influence of three-dimensional building configuration on urban pluvial flooding using random forest algorithm. *Environmental Research*, *196*. https://doi.org/10.1016/j.envres.2020.110438
Lindblom, T. (2020). Vattenpalatset stängs vid årsskiftet för renovering. Därefter är framtiden oklar för anläggningen. https://lerumsnyheter.se/vattenpalatset-stangs-vid-arsskiftet-for-renovering-darefter-ar-framtiden-oklar-for-anlaggningen/

Liu, L., Fryd, O., & Zhang, S. (2019). Blue-green infrastructure for sustainable urban stormwater management-Lessons from six municipality-led pilot projects in Beijing and Copenhagen. *Water (Switzerland)*, *11*(10). https://doi.org/10.3390/w11102024

Liu, Z., Merwade, V., & Jafarzadegan, K. (2018). Investigating the role of model structure and surface roughness in generating flood inundation extents using one- and two-dimensional hydraulic models. *Journal of Flood Risk Management*, *12*(1). https://doi.org/10.1111/jfr3.12347

Luhr, K. (2016). Dagvattenhantering Riktlinjer för parkeringsytor. https://tinyurl.com/ndf7zne7

Mansell, M., & Rollet, F. (2006). Water balance and the behaviour of different paving surfaces. *Water and Environment Journal*, *20*(1), 7–10. https://doi.org/10.1111/j.1747-6593.2005.00015.x

Marsalek, J., Jiménez-Cisneros, B., Malmquist, P.-A., Karamouz, M., Goldenfum, J., & Chocat, B. (2014). *Urban Water Cycle Processes and Interactions*. CRC Press. https://doi.org/10.1201/9781482288544

Meland, S., Sun, Z., Sokolova, E., Rauch, S., & Brittain, J. E. (2020). A comparative study of macroinvertebrate biodiversity in highway stormwater ponds and natural ponds. *Science of the Total Environment*, *740*, 140029. https://doi.org/10.1016/j.scitotenv.2020.140029

Mell, I. C. (2009). Can green infrastructure promote urban sustainability? *Proceedings of the Institution of Civil Engineers - Engineering Sustainability*, *162*(1). https://doi.org/10.1680/ensu.2009.162.1.23

Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Synthesis*. Island Press. https://web.archive.org/web/20131203005715/http://www.unep.org/maweb/documents/document.356.aspx.pdf

Morbidelli, R., Saltalippi, C., Flammini, A., & Govindaraju, R. S. (2018). Role of slope on infiltration: A review. https://doi.org/10.1016/j.jhydrol.2018.01.019

Moss, R., & Intergovernmental Panel on Climate Change. (2008). *Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies: IPCC Expert Meeting report: 19-21 September, 2007, Noordwijkerhout, the Netherlands* (tech. rep.). Noordwijkerhout, Intergovernmental Panel on Climate Change. https://archive.ipcc.ch/pdf/supporting-material/expert-meeting-report-scenarios.pdf

Mottaghi, M., Kärrholm, M., & Sternudd, C. (2020). Blue-green solutions and everyday ethicalities: Affordances and matters of concern in Augustenborg, Malmö. *Urban Planning*, *5*(4), 132–142. https://doi.org/10.17645/up.v5i4.3286

MSB. (2014). *Kartläggning av skyfalls påverkan på samhällsviktig verksamhet: framtagande av metodik för utredning på kommunal nivå* (tech. rep.). MSB. https://rib.msb.se/filer/pdf/27365.pdf

MSB. (2015). *Vägledning för utredning av översvämningar* (tech. rep.).

MSB. (2017). *Vägledning för skyfallskartering: Tips för genomförande och exempel på användning* (tech. rep.). https://rib.msb.se/filer/pdf/28389.pdf

MSB. (2018). Översvämningsportalen - Avancerad Karta. https://gisapp.msb.se/apps/oversvamningsportal/avancerade-kartor/oversvamningskartering.html

Müller, A., Österlund, H., Marsalek, J., & Viklander, M. (2020). The pollution conveyed by urban runoff: A review of sources. *Science of The Total Environment*, *709*. https://doi.org/10.1016/j.scitotenv.2019.136125

Naturvårdsverket. (2018). *Guide to valuing ecosystem services* (tech. rep.). https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6854-7.pdf?pid=23788

Nghiem, T., Wong, K., Jeevanandam, L., Chang, C., Tan, L., Goh, Y., & Carrasco, L. (2021). Biodiverse urban forests, happy people: Experimental evidence linking perceived biodiversity, restoration, and emotional wellbeing. *Urban Forestry & Urban Greening*, *59*. https://doi.org/10.1016/j.ufug.2021.127030

Niemczynowicz, J. (1999). Urban hydrology and water management - present and future challenges. *Urban Water*, *1*(1), 1–14. https://doi.org/10.1016/s1462-0758(99)00009-6

Nurmi, V., Votsis, A., Perrels, A., & Lehvävirta, S. (2016). Green Roof Cost-Benefit Analysis: Special Emphasis on Scenic Benefits. *J. Benefit Cost Analysis*, *7*(3), 488–522. https://doi.org/10.1017/bca.2016.18

Olivera, F., & Defee, B. B. (2007). Urbanization and its effect on runoff in the Whiteoak Bayou Watershed, Texas. *Journal of the American Water Resources Association (JAWRA)*, *43*(1), 170–182. https://doi.org/10.1111/j.1752-1688.2007.00014.x

Olsson, J., Berg, P., Eronn, A., Simonsson, L., Södling, J., Wern, L., & Yang, W. (2017). Extremregn i nuvarande och framtida klimat - Analyser av observationer och framtidsscenarier. *Klimatologi*, *47*.

Ontario Ministry of Environment. (2003). Stormwater Management Planning and Design Manual. https://www.ontario.ca/document/stormwater-management-planning-and-design-manual/stormwater-management-plan-and-swmp-design

Parizotto, S., & Lamberts, R. (2011). Investigation of green roof thermal performance in temperate climate: A case study of an experimental building in Florianópolis city, Southern Brazil. *Energy and Buildings*, *43*(7), 1712–1722. https://doi.org/10.1016/j.enbuild.2011.03.014

Pfoser, N., Jenner, N., Henrich, J., Heusinger, J., & Weber, S. (2014). *Gebäude Begrünung Energie Potenziale und Wechselwirkungen* (tech. rep.). Institut für Geoökologie. Darmstadt. https://www.irbnet.de/daten/rswb/13109006683.pdf

Pickett, S., Cadenasso, M., Grove, J., Boone, C. G., Groffman, P. M., Irwin, E., Kaushal, S. S., Marshall, V., McGrath, B. P., Nilon, C., Pouyat, R., Szlavecz, K., Troy, A., & Warren, P. (2011). Urban ecological systems: Scientific foundations and a decade of progress. *Journal of Environmental Management*, *92*(3). https://doi.org/10.1016/j.jenvman.2010.08.022

Pregnolato, M., Ford, A., Wilkinson, S. M., & Dawson, R. J. (2017). The impact of flooding on road transport: A depth-disruption function. *Transportation Research Part D: Transport and Environment*, *55*, 67–81. https://doi.org/10.1016/j.trd.2017.06.020

Prudencio, L., & Null, S. E. (2018). Stormwater management and ecosystem services: A review. *Environmental Research Letters*, *13*(3). https://doi.org/10.1088/1748-9326/aaa81a

Rauch, W., Bertrand-Krajewski, J. L., Krebs, P., Mark, O., Schilling, W., Schütze, M., & Vanrolleghem, P. A. (2002). Deterministic modelling of integrated urban drainage systems. *Water Science & Technology*, *45*(3), 81–94. http://iwaponline.com/wst/article-pdf/45/3/81/425172/81.pdf

Regionfakta. (2021a). Areal och befolkningstäthet 2020-12-31, Västra Götalands län. https://www.regionfakta.com/vastra-gotalands-lan/geografi/areal-och-befolkningstathet/

Regionfakta. (2021b). Befolkningssiffror kvartalsvis. https://www.regionfakta.com/vastra-gotalands-lan/snabbstatistik/befolkningssiffror-kvartalsvis/

Riksantikvarieämbetet. (n.d.). Bebyggelseregistret. https://bebyggelseregistret.raa.se/bbr2/sok/search.raa

Rowe, D. B. (2011). Green roofs as a means of pollution abatement. *Environmental Pollution*, *159*(8-9), 2100–2110. https://doi.org/10.1016/j.envpol.2010.10.029

Rujner, H., Leonhardt, G., Marsalek, J., Perttu, A.-M., & Viklander, M. (2018). The effects of initial soil moisture conditions on swale flow hydrographs. https://doi.org/10.1002/hyp.11446

Rujner, H., Leonhardt, G., Perttu, A.-M., Marsalek, J., & Viklander, M. (2016). *Advancing green infrastructure design: Field evaluation of grassed urban drainage swales* (tech. rep.). Luleå.

SCALGO. (n.d.-a). About Us. https://scalgo.com/en-US/about

SCALGO. (n.d.-b). SCALGO Live Documentations, Workspaces - Creating and managing workspaces. https://scalgo.com/en-US/scalgo-live-documentation/workspaces/creation

SCALGO. (2021a). Analysis - Flash Flood Map. https://scalgo.com/en-US/scalgo-live-documentation/analysis/flash-flood-map

SCALGO. (2021b). Country Specific - Sweden. https://scalgo.com/en-US/scalgo-live-documentation/country-specific/sweden

SCALGO. (2021c). New Sweden high-resolution model. https://scalgo.com/en-US/scalgo-live-documentation/about/whats-new/new-high-resolution-model-for-sweden

SCB. (2019). Statistiska tätorter 2018; befolkning, landareal, befolkningstäthet. https://www.scb.se/MI0810

Scholz, M., & Grabowiecki, P. (2007). Review of permeable pavement systems. *Building and Environment*, *42*(11), 3830–3836. https://doi.org/10.1016/j.buildenv.2006.11.016

SGI. (2017). Skredrisker i ett förändrat klimat – Säveån. Del 1: Sammanfattning och kartredovisning. *Publikation 38-1*. www.swedgeo.se

SGU. (n.d.-a). Jordartskartan Lerum. https://apps.sgu.se/kartvisare/kartvisare-jordarter-25-100.html

SGU. (n.d.-b). Kartvisare genomsläpplighet. https://apps.sgu.se/kartvisare/kartvisare-genomslapplighet.html

Shafique, M., Kim, R., & Kyung-Ho, K. (2018). Evaluating the Capability of Grass Swale for the Rainfall Runoff Reduction from an Urban Parking Lot, Seoul, Korea. *International Journal of Environmental Research and Public Health Article*. https://doi.org/10.3390/ijerph15030537

Shammaa, Y., Zhu, D. Z., Gyũrék, L. L., & Labatiuk, C. W. (2002). Effectiveness of dry ponds for stormwater total suspended solids removal. *Canadian Journal of Civil Engineering*, *29*(2), 316–324. https://doi.org/10.1139/l02-008

Shen, S. L., Tang, C. P., Bai, Y., & Xu, Y. S. (2006). Analysis of Settlement Due to Withdrawal of Groundwater Around an Unexcavated Foundation Pit. *Geotechnical Special Publication*, 377–384. https://doi.org/10.1061/40867(199)47

Shukri, A. (2010). *Hydraulic Modeling of Open Stormwater System in Augustenborg, Sweden* (Doctoral dissertation). Water and Environmental Engineering. Lund. https://va-tekniksodra.se/wp-content/uploads/2016/10/Shukri-Aza-2010.pdf

Sinclair, J. S., Reisinger, A. J., Bean, E., Adams, C. R., Reisinger, L. S., & Iannone, B. V. (2020). Stormwater ponds: An overlooked but plentiful urban designer ecosystem provides invasive plant habitat in a subtropical region (Florida, USA). *Science of the Total Environment*, *711*, 135133. https://doi.org/10.1016/j.scitotenv.2019.135133

SMHI. (2017). Skyfall och rotblöta. https://www.smhi.se/kunskapsbanken/rotblota-1.17339

SMHI. (2018). Vad är RCP? https://www.smhi.se/klimat/framtidens-klimat/vagledning-klimatscenarier/vad-ar-rcp-1.80271

SMHI. (2020a). Klimatindikator - nederbörd. https://www.smhi.se/klimat/klimatet-da-och-nu/klimatindikatorer/klimatindikator-nederbord-1.2887

SMHI. (2020b). Statistik för extrem korttidsnederbörd. https://www.smhi.se/kunskapsbanken/meteorologi/statistik-for-extrem-korttidsnederbord-1.159736

SMHI, & Svenskt Vatten. (2020). *Nederbördsstatistik för dimensionering av dagvattensystem - "State of the Art"* (tech. rep.). https://www.smhi.se/polopoly_fs/1.159923!/State%20of%20the%20Art-2020-03-11_GS.pdf

Solomon, S., & Intergovernmental Panel on Climate Change. (2007). *Climate Change 2007 – Impacts, Adaptation and Vulnerability*. Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

Stahre, P. (2004). *En långsiktigt hållbar dagvattenhantering*. Svenskt Vatten.

Stockholm Vatten och Avfall. (2017). Överdämningsytor/torra dammar. https://tinyurl.com/4djmdupu

Sustainable Technologies Evaluation Program. (2019). Swales and Roadside Ditches. https://sustainabletechnologies.ca/home/urban-runoff-green-infrastructure/low-impact-development/swales-and-roadside-ditches/

Svenska Kyrkan. (n.d.). Lerums församling - Förskolan. https://www.svenskakyrkan.se/lerum/forskolan

Svenskt Vatten. (2011a). *Publikation P104 Nederbördsdata vid dimensionering och analys av avloppssystem* (Vol. 1). Svenskt Vatten.

Svenskt Vatten. (2011b). *Publikation P105 Hållbar dag- och dränvattenhantering: Råd vid planering och utformning* (1st ed.).
Svenskt Vatten. (2016). *Publikation P110 Avledning av dag-, drän-och spillvatten* (tech. rep.).
Teemusk, A., & Mander, Ü. (2009). Greenroof potential to reduce temperature fluctuations of a roof membrane: A case study from Estonia. *Building and Environment*, *44*(3), 643–650. https://doi.org/10.1016/j.buildenv.2008.05.011
Tixier, G., Lafont, M., Grapentine, L., Rochfort, Q., & Marsalek, J. (2011). Ecological risk assessment of urban stormwater ponds: Literature review and proposal of a new conceptual approach providing ecological quality goals and the associated bioassessment tools. *Ecological Indicators*, *11*(6), 1497–1506. https://doi.org/10.1016/j.ecolind.2011.03.027
Tredje Natur Architects. (n.d.). Enghaveparken – Climate Park. https://www.tredjenatur.dk/en/portfolio/enghaveparken-climate-park/
US Department of Energy. (2004). *Green Roofs* (tech. rep.). www.eere.energy.gov/femp/
USEPA. (2003). Protecting water quality from urban runoff. www.epa.gov/
Van Renterghem, T., & Botteldooren, D. (2011). In-situ measurements of sound propagating over extensive green roofs. *Building and Environment*, *46*(3), 729–738. https://doi.org/10.1016/j.buildenv.2010.10.006
VanWoert, N. D., Rowe, D. B., Andresen, J. A., Rugh, C. L., Fernandez, R. T., & Xiao, L. (2005). Green Roof Stormwater Retention. *Journal of Environmental Quality*, *34*(3), 1036–1044. https://doi.org/10.2134/jeq2004.0364
Viklander, M., Österlund, H., Müller, A., Marsalek, J., & Borris, M. (2019). *Kunskapssammanställning Dagvattenkvalitet* (tech. rep.). Svenskt Vatten Utveckling. https://tinyurl.com/zjhy6ws8
VISS. (n.d.-a). Aspen. https://viss.lansstyrelsen.se/Waters.aspx?waterMSCD=WA56167263
VISS. (n.d.-b). Säveån - mellan Aspen och Sävelången. https://viss.lansstyrelsen.se/Waters.aspx?waterMSCD=WA75019230
Wagener, T., Sivapalan, M., Troch, P., & Woods, R. (2007). Catchment Classification and Hydrologic Similarity. *Geography Compass*, *1*(4), 901–931. https://doi.org/10.1111/j.1749-8198.2007.00039.x
Wang, L., Lyons, J., Kanehl, P., & Bannerman, R. (2001). Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales. *Environmental Management*, *28*, 255–266. https://doi.org/https://doi.org/10.1007/s0026702409
Wang, P., Zheng, H., Ren, Z., Zhang, D., Zhai, C., Mao, Z., Tang, Z., & He, X. (2018). Effects of Urbanization, Soil Property and Vegetation Configuration on Soil Infiltration of Urban Forest in Changchun, Northeast China. *Chinese Geographical Science*, *28*(3). https://doi.org/10.1007/s11769-018-0953-7
Wang, S., & Wang, H. (2018). Extending the Rational Method for assessing and developing sustainable urban drainage systems. *Water Research*, *144*. https://doi.org/10.1016/j.watres.2018.07.022

Wen, J. c., Lee, Y. j., Cheng, S. j., & Lee, J. h. (2014). Changes of rural to urban areas in hydrograph characteristics on watershed divisions. *Natural Hazards*, *74*(2), 887–909. https://doi.org/10.1007/s11069-014-1220-6

Wihlborg, M., Sörensen, J., & Alkan Olsson, J. (2019). Assessment of barriers and drivers for implementation of blue-green solutions in Swedish municipalities. *Journal of Environmental Management*, *233*, 706–718. https://doi.org/10.1016/j.jenvman.2018.12.018

Wolff, E., Fung, I., Hoskins, B., Mitchell, J. F., Palmer, T., Santer, B., Shepherd, J., Shine, K., Solomon, S., Trenberth, K., Walsh, J., & Wuebbles, D. (2020). *Climate Change: Evidence & Causes 2020* (tech. rep.). The Royal Society and The US National Academy of Sciences. https://royalsociety.org/~/media/royal_society_content/policy/projects/climate-evidence-causes/climate-change-evidence-causes.pdf

Wright, A. (1996). Urban Stormwater, correctly managed, is a resource rahter than a nuisance. *Proceedings of the Water Institute of South Africa 1996 Biennial Conference & Exhibition.*, 1–8.

Xie, J., Luo, S., Furuya, K., & Sun, D. (2020). Urban parks as green buffers during the COVID-19 pandemic. *Sustainability*, *12*(17). https://doi.org/10.3390/SU12176751

Xu, H., Lin, D., & Tang, F. (2013). The impact of impervious surface development on land surface temperature in a subtropical city: Xiamen, China. *International Journal of Climatology*, *33*(8), 1873–1883. https://doi.org/10.1002/joc.3554

Yang, J. L., & Zhang, G. L. (2011). Water infiltration in urban soils and its effects on the quantity and quality of runoff. *Journal of Soils and Sediments*, *11*(5), 751–761. https://doi.org/10.1007/s11368-011-0356-1

Yang, Y., Endreny, T. A., & Nowak, D. J. (2015). Simulating the effect of flow path roughness to examine how green infrastructure restores urban runoff timing and magnitude. *Urban Forestry and Urban Greening*, *14*(2), 361–367. https://doi.org/10.1016/j.ufug.2015.03.004

Yao, L., Chen, L., & Wei, W. (2016). Assessing the effectiveness of imperviousness on stormwater runoff in micro urban catchments by model simulation. *Hydrological Processes*, *30*(12), 1836–1848. https://doi.org/10.1002/hyp.10758

Yu, J., Yu, H., & Xu, L. (2013). Performance evaluation of various stormwater best management practices. https://doi.org/10.1007/s11356-013-1655-4

Zhang, D., Gersberg, R. M., Ng, W. J., & Tan, S. K. (2017). Conventional and decentralized urban stormwater management: A comparison through case studies of Singapore and Berlin, Germany. *Urban Water Journal*, *14*(2), 113–124. https://doi.org/10.1080/1573062X.2015.1076488

Zoppou, C. (2001). Review of urban storm water models. *Environmental Modelling & Software*, *16*(3), 195–231. https://doi.org/10.1016/S1364-8152(00)00084-0

A

Map of preschool

The preschool location and design is mentioned in section 2.5.4 and 3.3.2. The location by Kring Alles Road for the preschool is shown below in Figure A.1. It is the foundation of how the preschool is implemented as a terrain edit in SCALGO Live, and a building in MIKE 21. The design of the preschool is a draft that was accessed through the municipality of Lerum in late February to be used in this project and might not represent the final design of the preschool (Lerums kommun, 2017b).

Figure A.1: Suggestion by the architect studio AL Studio for location and design of the preschool and the associated parking lot at Kring Alles Road.

B

Municipally owned land

In Figure B.1, a map is shown with the possible land to implement stormwater management solutions as to not impose on private property as described in section 3.3. The available land is marked in yellow in the map.

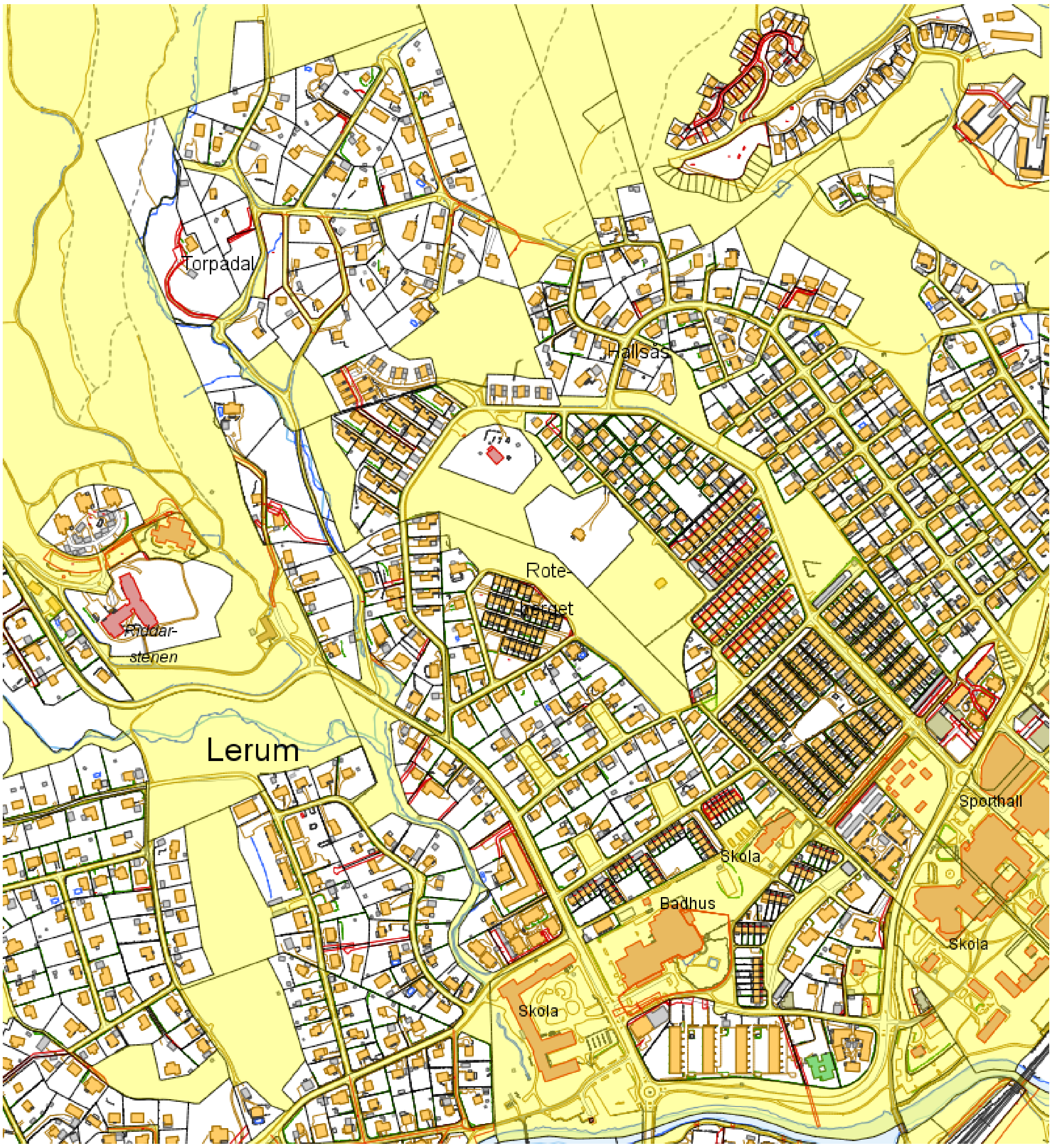


Figure B.1: Map of the study area in Lerum with land owned by the municipality marked in yellow.

C

Culverts at Torpskolan

The management of culverts in SCALGO Live is altered in this project to better correspond to reality, as described in section 3.3.1. When the study area is first examined in SCALGO Live, there is one long culvert stretching from north of Torpskolan, down to Säveån and completely avoiding the creek west of Torpskolan. This can be seen in Figure C.1 where the flow of water in the left part of the figure is from north to south.

The flood occurring by Torpskolan when the long culvert is in place is the same size as when there are no culverts, which is demonstrated in Figure C.2. It is therefore important to implement the culverts as they are located in reality to get a representative flow of stormwater.

In Figure C.3, two culverts have been implemented into SCALGO Live as to represent the real locations of the culverts. The culvert above Torpskolan conveys the water under the road Frödings Allé to enable the water's continuing flow in the creek, before it reaches the second culvert which diverts the water out to Säveån. As can be seen in the figure, this solution lowers the flood by Torpskolan significantly. However, the capacity of the culverts in SCALGO Live is likely to be overestimated since it solely conveys the water from a point A to a point B, without any dimensions of the culverts. This means that the reality of a flood by Torpskolan might well become close to what is simulated in Figures C.1 and C.2 if the capacity of the culverts are compromised.

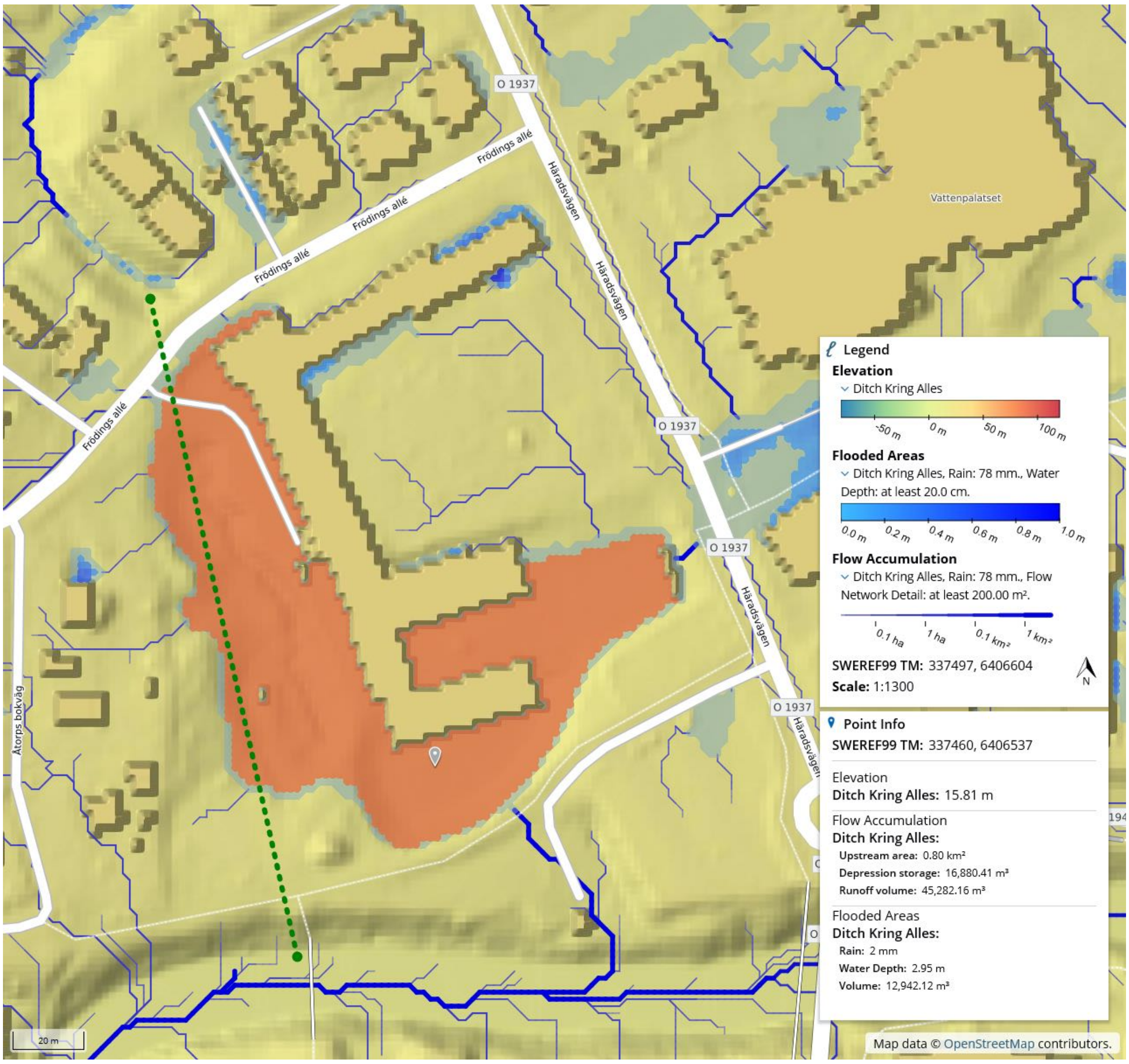


Figure C.1: The dotted green line shows the initial culvert implemented in SCALGO Live diverting water past the creek on the western side of Torpskolan.

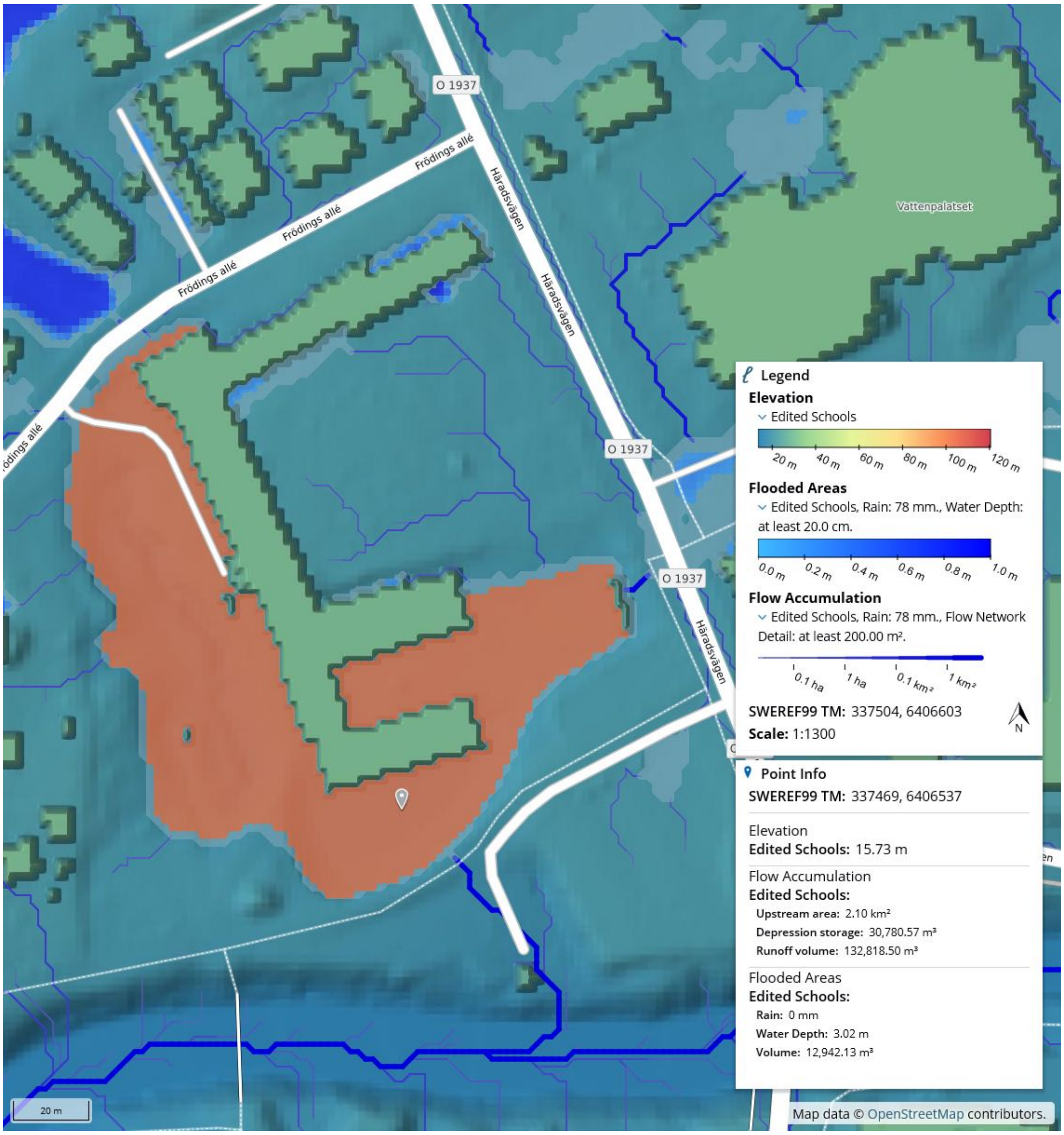


Figure C.2: The orange area shows the flooding by Torpskolan if there are no culverts diverting the water to the creek.

Figure C.3: The flooding with two culverts marked as black dotted lines. The flood by the school is significantly smaller.

D

Map of elementary school

The location and design as proposed in February of 2021 is shown in the figure below. In Figure D.1 the available ground where stormwater solutions can be implemented is marked in light green and the proposed location and design of the school is shown in red. The darker green area is part of the school area, but is not deemed suitable for construction due to its higher elevation than the rest of the school area (Lerums kommun, 2021a). The edits made in this project can be seen in section 3.3.3

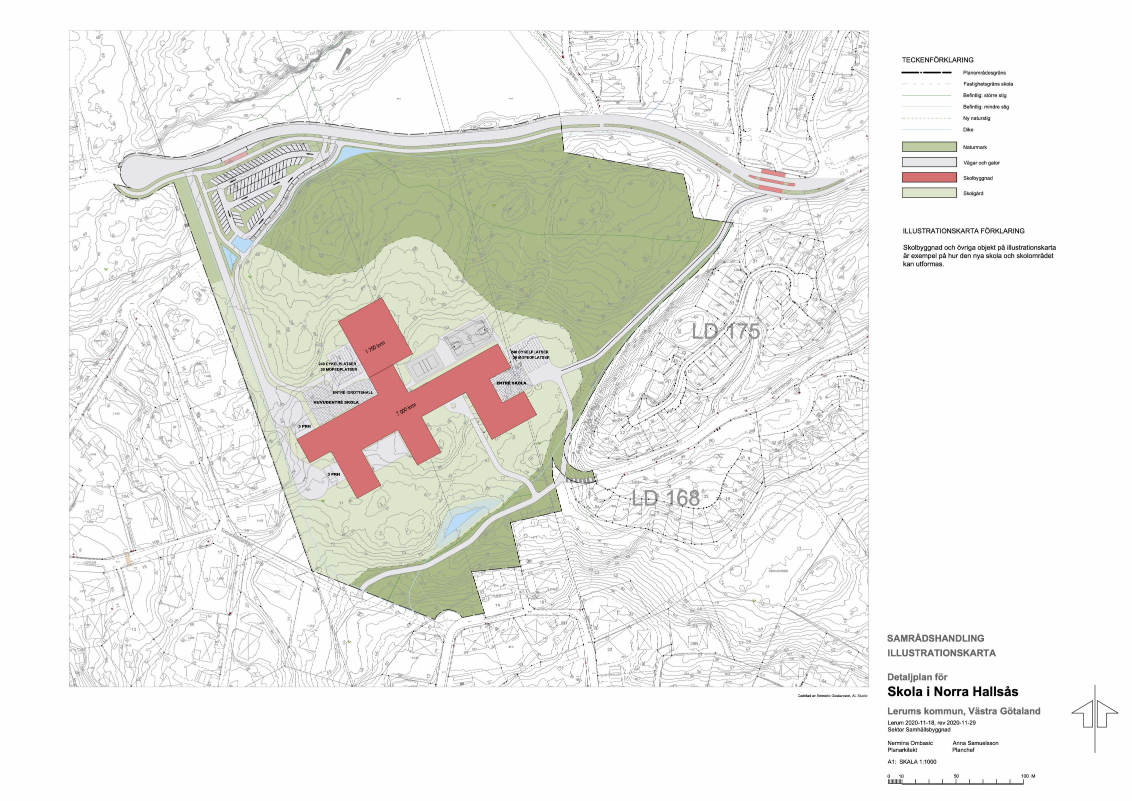


Figure D.1: Location and design of the elementary school in Norra Hallsås.

E

Result charts from MIKE 21

The results for the simulations performed in MIKE 21 as presented in section 4.3 are shown below, in four figures. The coordinates used for the points are shown in Table E.1. The label "No edits" is the initial scenario. The labels "Lower infiltration" and "Lower surface roughness" are the single parameter changes. Lower infiltration is a scenario using lower infiltration rate, while the Manning's M remains it's original values. The lower surface roughness is a scenario where Manning's M is lower, indicating a smoother surface. Meanwhile, the infiltration values remain the original values.

Table E.1: Easting and northing coordinates for the reference points.

Area	Easting coordinates [m]	Northing coordinates [m]
Gatekullen	165920	6406820
Terraces	166147	6406568
Highest flow	166186	6406469
Preschool parking lot	166200	6406437
Odhners Road	166113	6406127
Vattenpalatset park	166109	6406035
Ditch to Säveån	165971	6405917
Torpskolan	165906	6405850

Table E.1 provides the coordinates used for the reference points where the maximum flow speeds and the impact of the solutions on flooding are measured.

In Figure E.1, the maximum speed value for the flow in the various identified hot spots for high flow is shown. The bars are grouped on the x-axis based on the location, with the value for each simulation scenario shown on the y-axis.

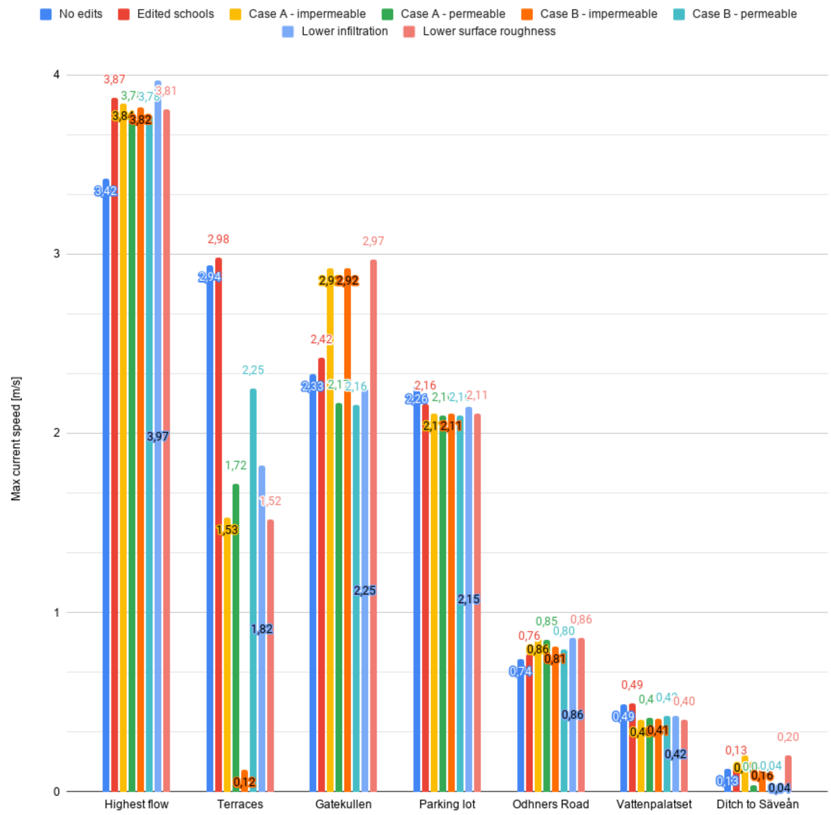


Figure E.1: Chart over the maximum speeds in the reference points in Figure 4.3.

Figure E.2 shows the depth in the reference points at the time of the maximum flow speed as presented in Figure E.1.

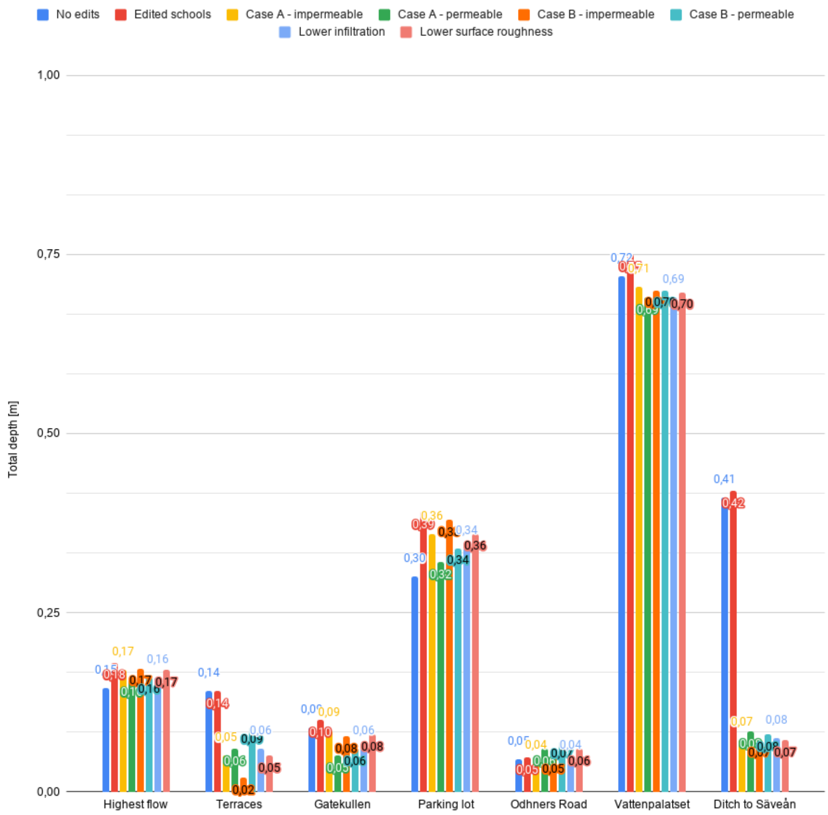


Figure E.2: Chart over the depth at the time of the maximum speeds in the reference points in Figure 4.3.

Figure E.3 shows the maximum depth in the reference points, which for Odhner's Road and the Ditch to Säveån occur later in the rain event than the depths corresponding to the maximum flow speeds.

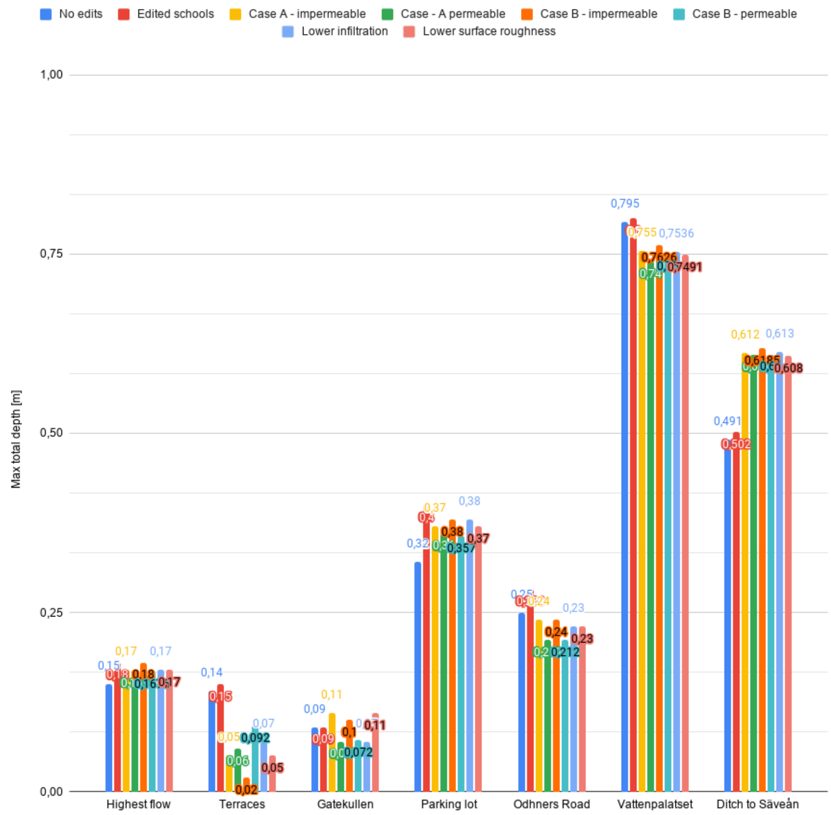


Figure E.3: Chart over the maximum depth in the reference points in Figure 4.3.

Figure E.4 shows the speed at the time of maximum depths as presented in Figure E.3. It is these combinations of results that are the input values in the flood risk level equation 2.1.

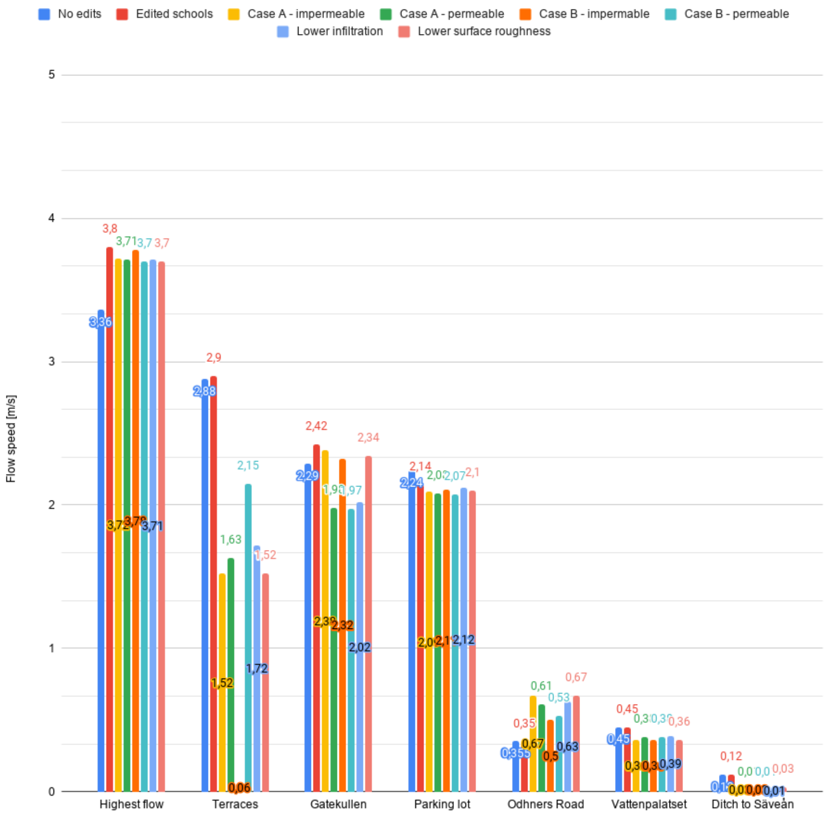


Figure E.4: Chart over the flow speeds in the reference points in Figure 4.3 at the time of the maximum depth.

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