Stormwater measures and urban fabrics

A case study of Hovinbyen, Oslo.

Norwegian Institute for Water Research

WAGENINGEN UNIVERSITY & RESEARCH

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Abstract

Oslo, like many cities around the world, faces the challenges of global climate change. It will see an increase in population, impermeable surfaces and precipitation. For future adaptations, a large casestudy area called Hovinbyen is available in Oslo. This thesis seeks to answer the following research question: What are the effects of climate adaptation measures in the different urban fabrics of Hovinbyen? A GIS analyses creates three types of urban fabric based on their local climate zones; Low residential, High residential and Industrial. The estimated precipitation that these areas have to deal with, is based on the municipality of Oslo's three-step stormwater management program. The focus is on the second step, retain and infiltrate. It has been determined that 48.6 mm/h rainfall events has been the precipitation criteria for the measures. The two types of adaptation measures analyzed in this thesis are green roofs and vegetated measures. Measures in industrial areas can reduce stormwater runoff up to 29.9 percent. The lowest impact can be found in Low residential areas with a maximum reduction of 15.5 percent. This thesis concludes that for the case of Hovinbyen the largest impact of the measures has been in the industrial areas.

Key words: Urban fabrics, Climate change adaptation, Local climate zones, Green roofs, Vegetated measures, Oslo Hovinbyen.

Glossary

Bokmål (Norwegian) terms are written in italic, with the English translation between brackets.

Term	*Definition*
FKB	*Felles KartdataBase* (Norwegian Mapping Authority)
GeoNorge	GeoNorge is a database that contains openly accessible and restricted access GIS data for Norway.
IDF-Curves	Intensity, Duration and Frequency curves. Term used to describe rainfall events displayed in a graph. Showing the intensity (mm) the duration (minutes or hours) and the return period or frequency (in probability per year).
LID	Low impact development. Small measures to reduce stormwater runoff.
MET	*Meteorologisk institutt* (Norwegian metrological institute)
N/A	Not Applicable, used in tables when the units on the X and Y axle do not have corresponding values for that specific element.
NCCS	Norwegian Center for Climate Studies
KSS	*Norsk klimaservicesenter* (Norwegian center for climate services) The Norwegian abbreviation of NCCS
NINA	*Norsk Institutt for Naturforskning* (Norwegian institute for Nature research)
NIVA	*Norsk Institutt for Vannforskning* (Norwegian institute for water research)
Norsk Vann	A cooperation of all Norwegian municipalities.
Oslo kommune	The municipality of Oslo.
Raingarden	Raingardens are small deeper parts of a private garden. Connected to this is usually the drain of a roof and sometimes paved areas. In this study, raingardens are considered small disconnected vegetated areas on private property.
Rational method	The rational method is a calculation standard used in civil engineering when calculating peak discharge.
SUDS	Sustainable Drainage Systems, sometimes referred to as Sustainable Urban Drainage Systems. A difference system of sustainable stormwater measures.
Swale	A swale is a depression in the landscape which naturally holds up water. Usually a system of dry swales leads to a river. In this study, a swale is a system that can

	retain and drain water in a vegetated area in a public space.
Wadi	A wadi is originally an Arabic word used for valley, but now revers to a river system that only holds water after intense (dessert) rainfall. In this study, a Wadi is regarded the same as a swale.
WMO	World Metrological organization
WUR	Wageningen University and Research

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Section 1 - Introduction and background

1.1. Introduction

An increasingly larger part of the world population lives in cities. With current statistics showing that 55 percent of the total world population lives in urban areas. Which in turn is expected to increase to 68 percent by 2050 (UN Department of Economic & Social affairs, 2018). As a result, an increasing number of cities around the world are facing many different socio-economic and even physical and engineering challenges. One of the major challenges that cities have to deal with, are the effects of climate change. More weather extremes will occur, ranging from hotter summers and longer drought periods to more extreme rainfall events (IPCC,2007).

The capital city of Norway, Oslo, will have to face these challenges as well. The municipality recognizes the challenges posed by climate change for the city. This is expressed in their policy document called: "Climate Change Adaptation Strategy for the City of Oslo" (Municipality of Oslo, 2014). In this document, the municipality acknowledges that stormwater is, and has been, the biggest challenge for the city. Stormwater is currently already a problem which causes increasing amounts of damage (Lier et al. 2011). Further urbanization is one of the causes of this increase. Oslo currently has a population of around 660 000 people and is expected to grow to approximately 800 000 people (Tønnesen, Leknes & Syse, 2016). The increase in built-up areas reduces the permeable surfaces in urban areas which leads to higher peak flow rates. This combined with more intense rainfall events, make urban areas more vulnerable to flooding. The NCCS (Norwegian Centre for Climate Services) estimates that extreme precipitation events are 19% more likely to happen by 2100 (Hans-Bauer, et al.,2017).

An increase in pluvial floods in the city of Oslo may have serious economic impacts. Therefore, the municipality developed a stormwater management plan. (Municipality of Oslo,2014b). With the implementation of this plan, the municipality aims to retain stormwater as much as possible, by using open and multifunctional retention networks to reduce the risk of flooding. An important condition to be met is that the recipient of the stormwater will receive water of acceptable water quality. The strategy contains three steps: infiltration of stormwater, retention of stormwater and the drainage of stormwater. The steps are illustrated in figure 1.

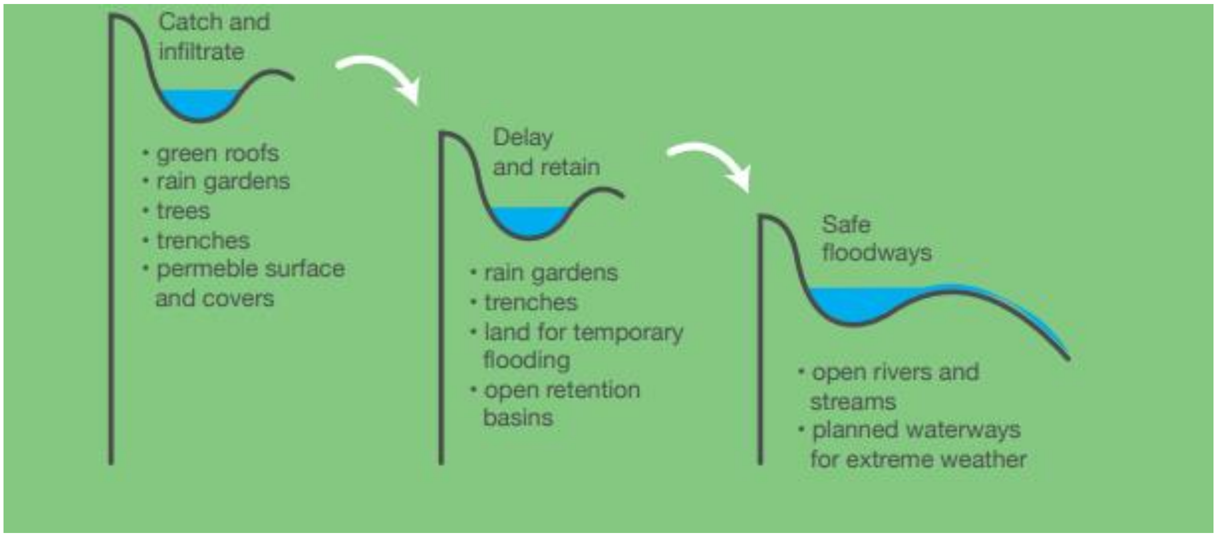

FIGURE 1: THREE STEPS IN THE PROPOSED STORMWATER MANAGEMENT PROGRAM OF THE MUNICIPALITY OF OSLO. (SOURCE: MUNICIPALITY OF OSLO,2014)

To effectively implement these steps, adaptations of the current infrastructure has to be done. City governments are required to adapt to climate change for its obligation to protect the city's, or national, important economic areas and the livelihood of its citizens (Neil-Adger, Arnell & Tompkins, 2005). Yet one of the major barriers to adaptation are the costs of the measures. These costs can be so high that they become a limitation to the possibilities for adaptation in a region (Moser & Ekstrom,2010). A way to make the implementation of adaptation measures economically feasible, is by implementing them during large maintenance or during area (re-) development (Dutch Climate Adaptation Services, 2018).

A place where the municipality of Oslo could combine redevelopment with climate change adaptation measures is Hovinbyen. This city district, which covers a surface area of roughly 1100, hectares consists of multiple neighborhoods, northeast of the historic city center of Oslo. Hovinbyen superposed over a map of the greater Oslo region can be seen in figure 2.

Figure 2: Location of Hovinbyen relative to Oslo city center (Source: Strategisk plan for Hovinbyen)

Hovinbyen has been redeveloped with regard to infrastructure, housing, public parks and socio-economic structure (Municipality of Oslo,2016). The district will also have to become more climate change resilient, with a focus on stormwater management. This is one of the reasons why NIVA is interested in this area. NIVA (Norsk Institutt for Vannforskning) is the Norwegian institute for water research, founded in 1958 by the Norwegian ministry of climate and environment (NIVA,2017). NIVA together with its partners in the New Water Ways project are looking to make Norwegian cities front runners in urban water management (New Water Ways,2018). They aim to use Oslo as a case study area for more sustainable urban water management.

1.2. Research objective and questions

The objective of this research is to provide an improved insight into the effectiveness of different types of stormwater measures in different types of urban fabric. The effectiveness has been judged based on their hydrological performance and their abilities to remove pollutants. The last of which is considered a co-benefit of these type of measures. In this study, there is one main research question that has been answered:

What are the effects of stormwater adaptation measures in the different urban fabrics of Hovinbyen?

For this the following sub-questions will have to be answered:

1. What different types of urban fabric can be identified?
2. What precipitation can be expected?
3. What measures can be implemented and what are their effects on water storage, peak discharge reduction and pollutant removal?
4. What are the dimensions of these measures?

1.3. Research outline

This research will consists out of five main sections. After this first introduction section, the second section consists of the methodology. It is subdivided in four sub-sections following the research questions. The third section is the result section, following the same sub-section buildup as the methodology. The fourth section is the discussion which will discuss the weaknesses of the research and alternatives. The final section is the conclusion and recommendations.

Section 2 - Methodology

This section describes the methodology of this research and contains a description of the project area. The methodology follows the flow of the research question. Starting with the sub-questions to conclude the main questions. First, the urban fabrics and the GIS analyses has been explained. Secondly, the climatological analyses, and lastly the evaluation of the measures and finally the calculation of the measures. The four sub-questions, and their individual steps, have been visualized in figure 3.

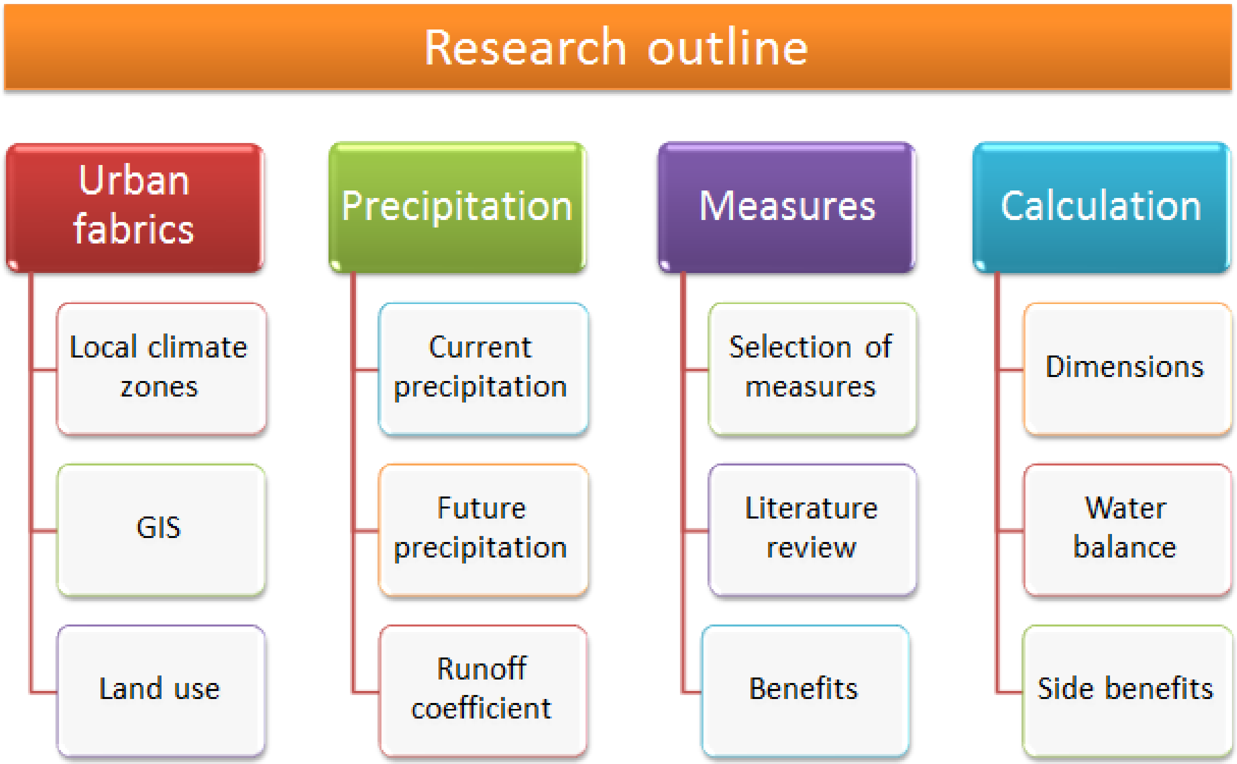

FIGURE 3: VISUALIZATION OF THE METHODOLOGY. WITH THE METHODOLOGY OF SUB-QUESTION 1 IN RED, SUB-QUESTION 2 IN GREEN, SUB-QUESTION 3 IN PURPLE AND SUB-QUESTION 4 IN BLUE.

2.1. Urban fabrics

Urban fabrics describes the physical aspects of buildup urban areas (Artibise,2012). Urban fabrics do not have a precise meaning or scientific definition. For this study, the urban fabrics have been based on the concept of Local Climate Zones (LCZ). The LCZ's were created through GIS (Geographical Information System) analyses. This turned out not to be accurate enough, because areas with an industrial or office characterization would be put in the same LCZ as dense residential areas. Because of this the land use of the project area has also been taken into account, adding the industrial LCZ.

Local climate zones

The areas have been classified based on their local climate zone (sometimes referred to as urban climate zone). This has been done through a method based on a paper of Stewart and Oke (2012). This method has been adjusted to fit this research better. They define ten local climate zones and seven types of additional land cover. Land cover will not be taken into account, since the land cover of the project area is completely homogeneous, thus it does not give any added value in the determination of the different urban areas. Land use has been taken into consideration because else there would be no difference between dense residential areas and industrial areas.

The local climate zones are based on seven factors. Factors that only contribute to urban heat have been removed from this study (Alexander, Mills & Fealy,2015). This leaves us with three factors related to water. These are: The percentage of roof surfaces, percentage of impervious surfaces and percentage of pervious surfaces. The last adaption of Stewart and Oke's paper is to reduce the amount of climate zones from seven to three major ones. This is because the seven zones contain details, like building height or building material, which are not considered in this study. The three major zones are: Compact urban areas, Open urban areas and Sparsely build areas. To better fit the type of urban area that each zone represents, new names for them have been added for this study. An added area is the industrial area, because for the industrial area in this case study, different measures have been used. All areas that are characterized beside these zones are considered exceptional. The three factors, the four major climate zones and their corresponding values can be seen in table 1.

TABLE 1: LOCAL CLIMATE ZONES WITH FACTOR VALUES ADAPTED FROM STEWART AND OKE (2012). THE LCZ AND THE CORRESPONDING LCZ ARE THE ORIGINAL TERMS AND NUMBERS USED IN THE SOURCE PAPER.

Local Climate Zone	Name used for this thesis	Corresponding climate zone LCZ	Fraction Roofs [%]	Impermeable surface[i] [%]	Permeable surface [%]
Compact urban area	Very high residential	LCZ 1-3	40-70	>60	<30
Open urban area	High residential	LCZ 4-6	20-40	20-60	30-60
Sparsely build area	Low residential	LCZ 7-9	<20	<20	>60
Industrial	Industrial	Industrial LCZ is only determined by the land use.			
Non classified	-	N/A	N/A	N/A	N/A

GIS

To determine what areas fall in which category of LCZ, first smaller areas have to be created. The areas themselves have been created based on the watershed area. These watershed areas are sometimes referred to as catchment area or drainage basin. A watershed area is a basin where precipitation ends up in the same water outlet. This can be done on global, delta, tributary or sub-basin scale. For this study sub-basins have been used, due to the scale of the case study area. By using a digital elevation model (DEM), precise areas can be created. For the project area a DEM with a precision of half a meter (0.5 m) was available and has been used. A hillshade map of the used DEM can be seen in appendix 1. Because buildings, flyovers and other types of construction can change the direction of discharge, an unfiltered DEM has been used. This means that large constructions, bigger than 0.5 m, are visible on the map and

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[i] Impermeable surfaces are roofs, plus any other types of impermeable surfaces.

have been taken into account with the analyses. To create the areas based on watershed, first an area size has to be defined. After a discussion with the commissioner, it was determined that a size of 200 000 m2 would be used. This is not a grid size, but a polygon shape of this size. Further argumentation for this size is that it is the maximum advised size for the rational runoff method (Grønlund Magnussen, Et.Al. , 2015). This creates areas large enough to work with and prevents the creation of too many areas. If the areas would be much bigger, detailed information would be diluted and the accuracy of the results would suffer.

The program used to analyze the DEM and create the watershed areas, is called GRASS GIS, commonly referred to as just GRASS. GRASS is an open source GIS program, originally developed by the army of the United States of America (GRASS development team, 2015). The program provides modules based on the type of analysis the user wants to perform. For the creation of the watershed basins GRASS GIS, R.Watershed has been used. R.Watershed is the fundamental module for creating flow patterns, drainage lines and watershed areas. It calculates drainage areas based on a threshold value for the preferred surface area and the DEM. Next to a raster map of the watershed areas, it also creates an accumulation map and a flowline map. The accumulation map shows where water would concentrate within one of the areas, which can later be used to find feasible locations for measures.

After these areas are created, information about their road density, paved and unpaved areas is needed. For this a detailed map of the roof surfaces and road surfaces is required. Together they create the amount of impermeable surfaces. Combined with the size of one watershed area, the fractions can be determined and the areas can be classified. The roof surfaces and road surfaces have been obtained from Geonorge[ii], a website that provides access to all data from the Norwegian mapping authority (FKB). The roads are inventoried in the FKB-veg (road) database, this includes all public roads, parking lots and other road infrastructure. The roofs are inventoried in the FKB-Bygning (Building) database and includes all roofs of private and public permanent buildings. A map with the roads and buildings in the project area can be seen in figure 4. The full sized image can be found in appendix 2.

[ii] https://www.geonorge.no/

FIGURE 4: MAP OF THE PROJECT AREA WITH ALL ROADS AND ROOFS

On this map it is already visible that the center and bottom-left regions of the project area have a greater urban density. Something that is confirmed later on through the GIS analyses.

Land use

The way local climate zones are created in this study does not allow for a distinction between different types of land use. Dense residential areas would be classified as the same class as industrial areas in this case. For this reason, an extra criteria was added. Based on the land use, an area has been either classified as residential or industrial. This has been done based on the land use map of the municipality of Oslo (Oslo kommune, 2018). The municipality distinguishes seven areas: residential areas, recreational areas, roads, industries, offices, public buildings and a final class for areas that do not fall in the other classes. To determine the residential areas, the residential class has been used. Industrial areas include the offices and industrial areas. Added to this is the municipal waste management facility in the center of Hovinbyen, in the neighborhood of Økern, which is indicated as a public building.

Final project areas

The final project areas are created based on the following three reasons. The first reason being to reduce the amount of areas used to a more workable number. The second reason is to better scale the amount of areas to the type of measures that are considered. If areas with too small surfaces are not integrated into larger areas, they could be displayed as 100% building area, if they only contain a single roof for example. This would create a false sense of a very dense urban area. The final reason is that these areas should fit a certain urban typology, defined by their LCZ. Areas with the same typology in the same area can be clustered. Measures in these areas should have the same effect on the larger areas, since it contains the same type of LCZ. This is how the areas have been clustered, creating seven larger project areas. To allocate areas which would fall between these larger areas, a nearest neighbor principle has been used. This means that the area will copy the LCZ of one of its neighbors. To decide which area it will copy, the selection has been based upon what area lies downstream of the unassigned area. This principle is schematically displayed in figure 5.

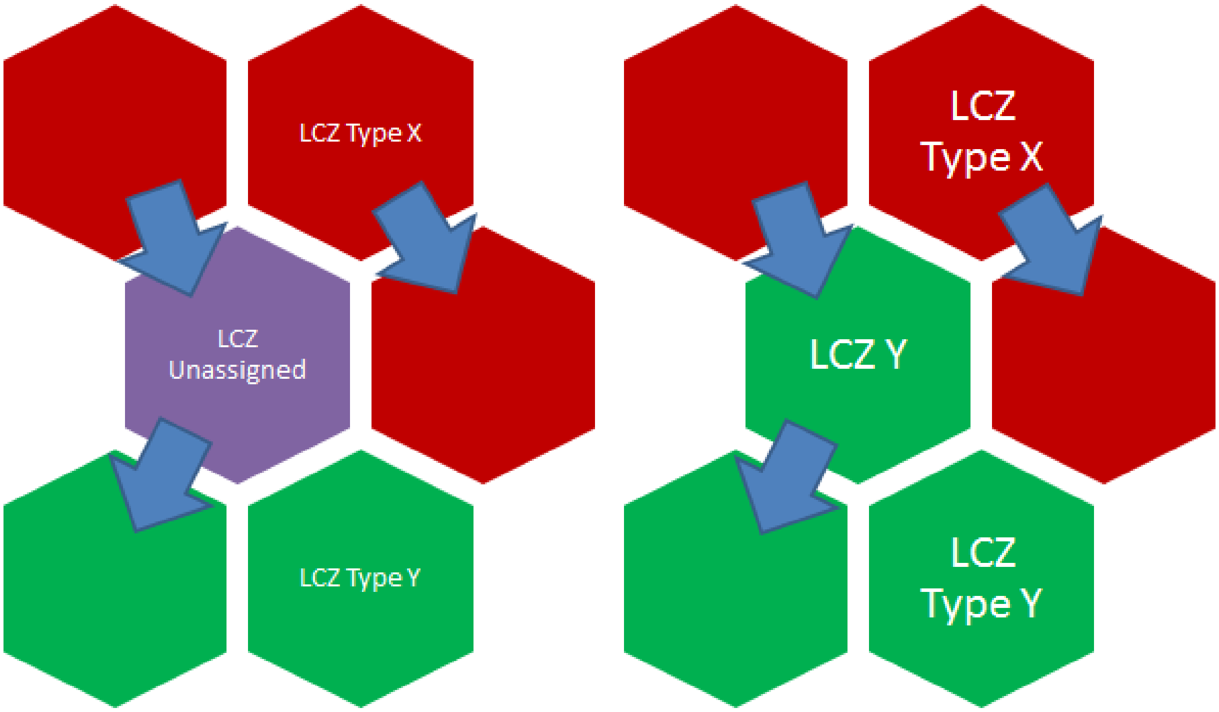


FIGURE 5: NEAREST NEIGHBOR PRINCIPLE USED FOR THIS STUDY. THE LEFT SIDE SHOWS THE UNASSIGNED SITUATION WITH THE FLOW DIRECTION INDICATED BY THE BLUE ARROWS. THE RIGHT SIDE SHOWS THE FINAL DISTRIBUTION, WITH IN RED A HYPOTHETICAL LCZ TYPE X AND IN GREEN LCZ TYPE Y.

2.2. Precipitation

Because this research focuses on measures against pluvial flooding, precipitation is an essential part. First the current precipitation standard has been analyzed, based on the information provided by the Norwegian Metrological Institute. The Meteorologisk institutt (MET). Secondly, climate change has been researched and finally the runoff coefficient has been determined.

Current precipitation

The current design precipitation is based on the IDF (Intensity, Duration and Frequency) statistics of the MET. IDF curves are defined by Oraevskiy (2009) as: *"…A graphical representation of the probability that a given average rainfall intensity event will occur"*. In these graphs, the duration, usually up to an hour for engineering purposes, in minutes and the amount of rain in mm can be seen. Plotted on this, are the probability curves for possibilities, per *N*-years. Where N is the design period for the probability of exceedance. The IDF curves for this research has been taken from the closest weather station in the vicinity of Hovinbyen, with a long enough measurement history. To get values from the IDF-curves of this station a design value was needed. For this the design values for the second step of Oslo's three-step water management program have been analyzed. This step is the delay-and-retain step. This has been evaluated based on rapports of the municipality of Oslo and Norsk Vann (Municipality of Oslo,2014; Norsk Vann,2008).

Future precipitation

To study the effects of climate change on precipitation in Oslo, the data of the Norwegian Center for Climate Services (NCCS) has been used. They provide a data portal with maps and tables related to climate change elements. The NCCS is a cooperation between the MET, NORCE, The Norwegian Water Resources and Energy Directorate and the Bjerkness center (KSS,2019). Through this service, two scenarios were presented. The scenarios used are two of the Representative Concentration Pathways (RCP) scenarios. Meinshausen, et. al. (2011) defines RCP's as following:" *A set of scenarios […]to provide a range of possible futures for the evolution of atmospheric composition*". The scenarios provided by the NCCS are the RCP 4.5 and the RCP 8.5 scenarios. Where 8.5 is a These two scenarios are analyzed and linked to a climate factor, used by the municipality of Oslo. Since there was no mandatory climate factor, multiple reports concerning this climate factor were considered. These reports were summarized by Kvalevåg, Et, Al. (2014).

Run off coefficient

In a natural situation, fields or other flat areas slow down the peak discharge of an area. The more urbanized an area gets the higher peak discharge gets. This effect is visualized in figure 6. Showing a theoretical representation of the peak discharge for the natural situation, the light urbanized and the heavy urbanized situation.

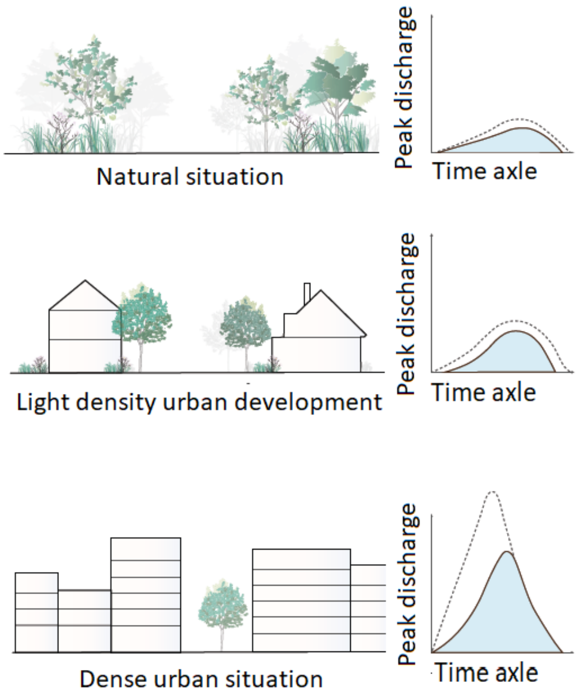


FIGURE 6: THEORETICAL REPRESENTATION OF THE PEAK DISCHARGE IN DIFFERENT LAND USE SITUATIONS. ADAPTED (TRANSLATED) FROM EIKELUND & JOHANSEN (2017).

The calculations for the water balance of the areas has been done based on the rational method. The rational method is an internationally common method for peak discharge calculation with the following definition:

EQUATION 1: THE RATIONAL METHOD FOR RUNOFF CALCULATION.

$$\boldsymbol{Q = C \cdot i \cdot A}$$

Where Q is the discharge in m^3/h, C the run off coefficient, i the rainfall intensity in m/h, A is the surface area in m^2. The rainfall intensity has been determined through the IDF-curves. Normally, precipitation is displayed in mm/h. However, this would cause a conflict of units considering the end unit of the equation is m^3/h. The surface area is equal to the surface area of the urban climate zones. The coefficient depends on the type of surface of the area. For example, paved areas have a high coefficient and grasslands have a low coefficient. Indicating how much water would be delayed by the surface. For this research an average coefficient has been used per area. First a small literature review has been done to identify the coefficients for each surface type, sloped roof, flat roof, paved and unpaved surfaces. Thereafter, per area the percentage of each type has been calculated and based on this percentage, the coefficient per area has been used. The calculation of this coefficient can be summarized as following:

EQUATION 2: METHOD OF RUNOFF COEFFICIENT CALCULATION.

$$c_{total} = c_{roof} \cdot \%_{roof\ area} + c_{road} \cdot \%_{road} + c_{unpaved} \cdot \%_{unpaved\ area}$$

This creates one coefficient for the entire area. While more detailed modeling studies would use a coefficient for each different surface area, this study only uses this average. This has been done because the aim is to evaluate different measures for different areas, which have a shared urban fabric. This way, the effectiveness for the water balance will be more generally applicable for similar urban areas.

2.3. Measures

The measures that are considered for this research first had to be selected, since there is a wide array of measures. After the selection the review for the two types of measures can be done.

Selection

At the moment of publication, a Dutch database consisting of urban climate adaptation measures counts over 110 different types of measures that can be implemented (Pötz, Sjauw, Windhorst & van Someren,2018). This also includes measures with multifunctional abilities to reduce the effects of climate change in a city. To make a selection from all of these measures which could be considered, three selection steps were made. This research focuses on the project area of Hovinbyen. This area sees urban renewal for both existing buildings and green areas. The first round of selection was to focus on two subjects, being implementation in public green and implementation in or on existing buildings. The second selection process was to filter out measures that cannot be implemented in Oslo's cold winters, land climate. For example, roads where water can be stored, but once frozen would damage the road. The last step consisted of a discussion with the commissioner to narrow the remaining measures down to, two categories of measures. These categories are green roofs and vegetated measures.

Literature review

The literature review consist of colleting five review papers for each of the two categories of measures. Based on these review papers, ranges have been set for the different parameters characterizing these measures. Parameters considered for this thesis are: Water storage, peak discharge delay, cost effectiveness, water quality and side benefits like urban heat reduction, biodiversity stimulation or isolation for buildings. The papers have been selected based on the following criteria: The first criteria of a review paper is relevance to the measures. Making sure that the paper evaluates a measure similar to the ones that can be implemented in Hovinbyen. Second criteria is that the paper preferably should review the measures under similar climate conditions like Oslo. Ranging around a continental climate, with warm summers (Peel, Finlayson & McMahon,2007). If possible with a test location the Nordic countries. If a paper complies to both criteria, the last criteria is the amount of citations. The papers with most citations have been used.

Co-benefits

One of the major advantages of using the previously mentioned measures is that they also affect their environment in other positive ways. These positive co-benefits have been identified from previous research done by Schaik (2018), commissioned by NIVA, and a paper of Francis and Jensen (2017). The first rapport has been used for the vegetated measures, the second paper has been used for the green roofs. The values from these two papers has been averaged for a low potential pollutant removal and a high potential pollutant removal. These pollutant removal values are not comparable with each other since the vegetated measures remove pollutants from stormwater, while green roofs improve air quality.

2.4. Calculation

In the end, all values have been summarized in a excel tool and their effects have been analyzed. This has been done in three consecutive steps. First the dimensions of the measures has been determined. Secondly a water balance has been calculated, comparing a situation without the stormwater measures, the current situation, to a situation with stormwater measures. Because all values are given as ranges at the end three scenarios should be clear. Hovinbyen with future precipitation without any stormwater measures and two scenarios worst and best estimated performance scenarios. And finally the benefits have been projected as well creating an overview of the created local climate zones, their values, the measures, the costs and the potential benefits.

Dimensions

The sizes of the measures are determined different for each of the two measures. For the green roofs data of a previous study has been used. This study has been done by the Oslo municipality planning and building agency. The purpose of the data was to map potential places for green roofs, for the municipality's green roof strategy. This data has been transformed to a GIS map.

For the vegetated measures two factors have been used. The first concerns the raingardens. NIVA has done a study to analyze the willingness of people to take a rain garden. The percentage ,78%, from this study has been taken and multiplied by the households in the area. For the size of a single rain garden, the proposed size of the NIVA study has been taken. Which was an average size of 7.5 m^2. For the size of swales a percentage of the total roofed area per zone has been used. This percentage has been advised by the commissioner to be 15%. These two areas together form the total areas for the vegetated measures.

Water balance

A water balance has been created using the previously mentioned rational method. For this the entire area will have one run off coefficient. This will create a water balance of the amount of water that has to be dealt with. For the second water balance, that includes the measures, the same method has been used, minus the storage capacity of the measures. This gives the potential reduction of discharge by the measures for the areas. This has been displayed together with the peak discharge reduction, which is taken from the earlier literature review. To make an approximation of the peak discharge reduction per zone, the percentages from the literature review have to be adjusted to the sizes of the measures in the zones. This has been done by multiplying the fraction that each measure covers by its peak discharge reduction.

Overview

The overview consists of all the final results, displayed by the Excel-tool. It consists of all the potential benefits, the effects on stormwater discharge reduction and a conclusion to the main research question. The analyses of the effectiveness per measure per urban fabric type has been done by calculating what percentage each measure storages. The effects of the green roofs on air pollution removal are displayed by considering their effectiveness per square meter of their total zone. This figure has been achieved by dividing the total removed pollution by the surface area of the zone.

Section 3 - Results

The results section follows the same build up as the methodology section. First addressing the urban fabrics of the area. Followed by the analyses of the precipitation data for the IDF-curves. The third sub-section contains the measures and literature review. This section is finalized by the application of the measures.

3.1. Urban fabrics

As has been described in the methodology, GRASS GIS was used for the creation of the areas. The first step resulted in the creation of roughly 800 areas. After filtering out areas that are too small, 600 areas still remain. The watershed areas created by the module can be seen in figure 7. Each differently colored area represents a different watershed area. The large areas around the project area are created because the DEM used in the analyses is cut to the shape of the project area and GRASS GIS only uses square map data.

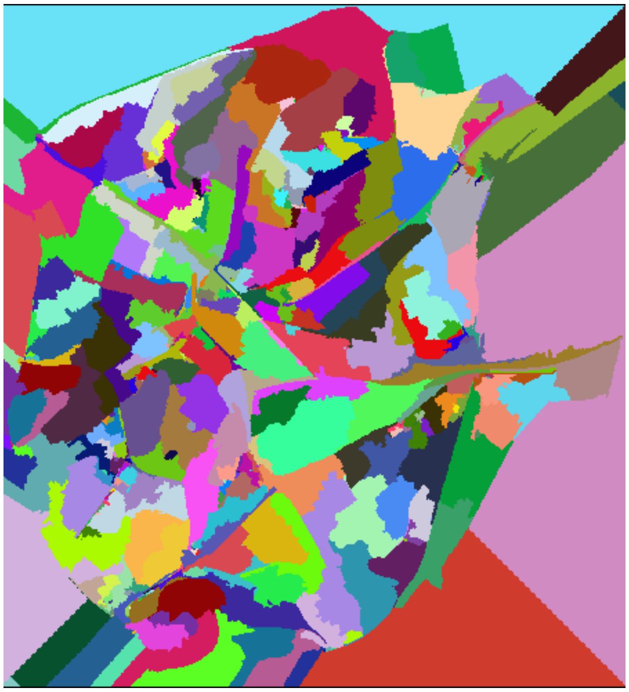


FIGURE 7: THE DRAINAGE BASINS, WATERSHED AREAS, OF HOVINBYEN. DISPLAYED ARE WATERSHED AREAS WITH A MAXIMUM SIZE OF 200000 M^2. THE AREAS ARE CREATED BASED ON A DEM MAP, ANALYZED WITH GRASS-GIS WATERSHED MODULE.

Smaller areas would show the outlines of highways, railroads and a stadium in the north. The areas with the size of 200000m^2 still show some larger highways, but most structures are now integrated into the other zones. The next step is combining these created areas with other GIS information.

Build up area

The layer with areas has been merged with the layers that contain the detailed data of the roads and roofs. To classify the different areas into LCZ's, the surface areas had to be transferred to percentages. The total amount of areas in each LCZ class can be seen in table 2. The results of each of the three parameters of all 800 areas can be found in appendix 3 and 4.

TABLE 2: AMOUNT OF AREAS PER LCZ IN HOVINBYEN.

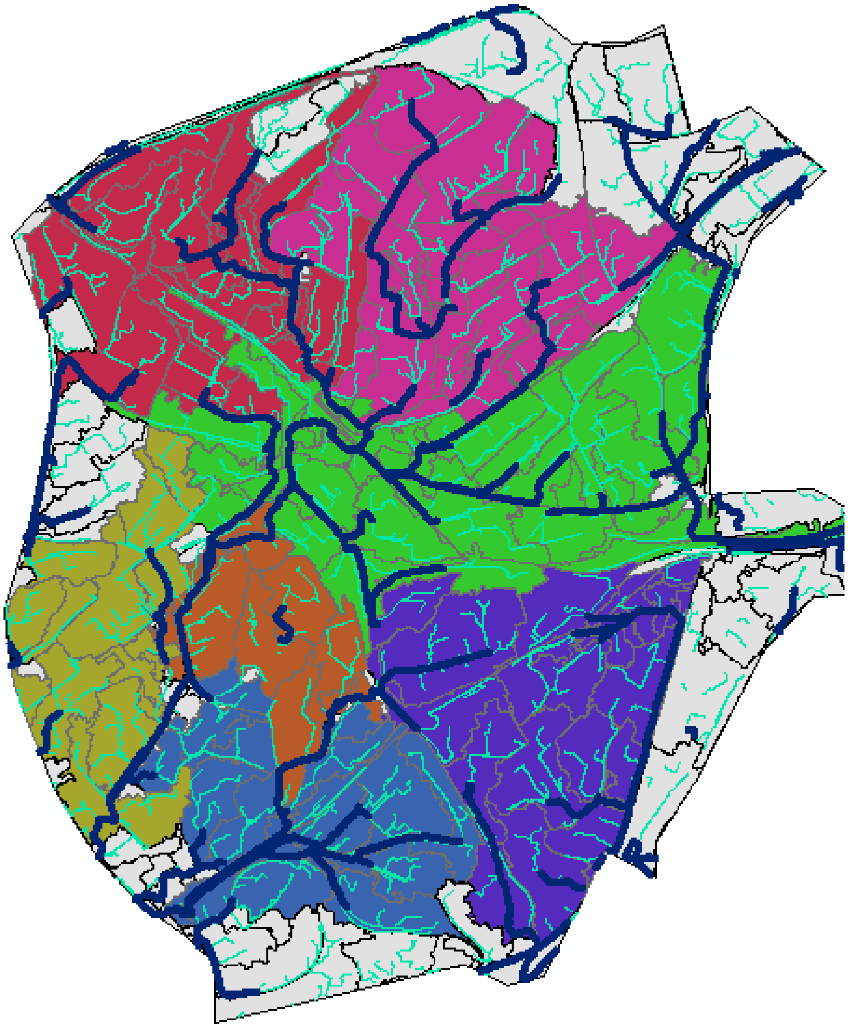
LCZ	**Number of areas classified**
Compact urban area	2
Open urban area	314
Sparsely build area	502

As can be seen in the results of the first GIS step, the amount of compact urban areas is minimal. The two compact urban areas have been integrated with the open urban areas.. As can be seen in the results, there is only a clear subdivision between open urban area and sparsely build urban area. Only some smaller areas can be considered densely build up urban area.

Considering the GIS data is not detailed enough to distinguish between industrial and denser urban areas, the land use map has to be overlaid with the areas. A simplified land use map of Hovinbyen has been used, based on the categories defined in the methodology. The watershed areas divided between industrial and nonindustrial (residential) can be seen in Appendix 5. With this step done, all areas are assigned to one of the four LCZ's used in this research.

Project areas

The final areas are clustered together based on shared climate zones and shared drainage paths. The final areas and the drainage paths can be seen in figure 8. The gray areas on the map are areas which will not be added to one of the areas. This because either they are a different LCZ, are at the edge of the project area and drain outwards, or because they could not have been classified due to the fact that they were too small.



	Zone name	**Type**
🟪	Hovinbekken	Low residential
🟥	Løren	High residential
🟩	Økern	Industrial
🟧	Hovin	Low residential
🟩	Hasle	High residential
🟪	Ulven	High residential
🟦	Helsfyre	Industrial
⬛	Other	-

FIGURE 8: ALL PROJECT AREAS AND DRAINAGE PATHS. DIFFERENT COLORS INDICATE DIFFERENT LCZ'S. THE THICKER DARK BLUE LINES INDICATE LARGER DRAINAGE PATHS, THE SMALLER LIGHT BLUE ONES SUPPLY INTO THE LARGER ONES.

This final step in creating the project areas leaves us with 7 zones. The zones, their given name, their color and their type are summarized in the next table.

TABLE 3: ALL ZONES, THEIR URBAN FABRIC AND SURFACE AREA. COLORS ARE DISPLAYED IN FIGURE 8.

Zone number	Zone name	Zone color	Type (LCZ)	Surface area [x1000 m^2]
Zone 1	Hovinbekken	Pink	Low residential	1477
Zone 2	Løren	Red	High residential	1269
Zone 3	Økern	Green	Industrial	1917
Zone 4	Hovin	Orange	Low residential	545
Zone 5	Hasle	Olive	High residential	838
Zone 6	Ulven	Purple	High residential	1405
Zone 7	Helsfyre	Blue	Industrial	1022
Other	-	Gray	-	2716

Something that stands out straight away is the large gray area that does not belong to any of the other zones. For the top range of the area this is because it shares many types of LCZ's and contains a racing stadium (Bjerkebanen), which distorts the GIS analyses. The areas towards the East, South and West, are not included for they are a different LCZ from their neighboring area and drain outwards.

3.2. Precipitation

Precipitation in the form of rainfall is the main focus point of the climatological chapter of this study. As discussed in the introduction precipitation is the biggest concern of the municipality of Oslo with regard to climate change. In this chapter first the current precipitation patterns are discussed. Then the expected changes due to climate change. Last the runoff calculation has been set up. Including the determination of the runoff factor. The reason for this set up is because the eventual discharge calculation has been done along the rational method. For this the area is needed, derived from the watershed areas. This surface area multiplied by the precipitation and a runoff factor provide the discharge.

Current precipitation

The metropolitan area of Oslo experiences the most intense rainfall of all of Norway (Hanssen-Bauer, 2015). These measurements are generated at official weather stations of the MET (Norwegian Metrological Institute). Accurate precipitation measurements for Hovinbyen can be generated by weather stations in or around Oslo. As of January 2019, there are five officially registered stations in the Oslo urban area. One of these stations, the Hovin station, is directly located in the project area. However, this station has a measurement history since 1998, which is too short for accurate climate projections. The World Metrological Organization (WMO) requires 30 years of measurements to draw up climate normals (WMO, 2017). Roughly five kilometers to the west, the Blindern weather station is located. Blindern weather station, officially station SN18701, has a measurement history since 1968 and is the longest running weather station of Oslo. The five weather stations can be seen in figure 9, the Blindern and Hovin stations are highlighted.

Figure 9: The five weather stations within Oslo. Highlighted in blue is Hovin station, directly in the project area. Highlighted in red is Blindern station, the station used for this study. (Source: Klimaservicecenter.no)

The other three stations that are located between Blindern and Hovin, either have a too short measurement period or are no longer active. With the measurement station established the climate data can be retrieved from the MET. The data that has been used consists of Intensity Duration and Frequency curves, better known as IDF curves. IDF curves are one of the most used methods in water management and water resource engineering (Koutsoyiannis, Kozonis & Manetas, 1998). The frequency of a rain event is derived from its yearly exceedance interpolated over the recorded measurements. To illustrate this the IDF curve of Blinder station can be seen in figure 10.

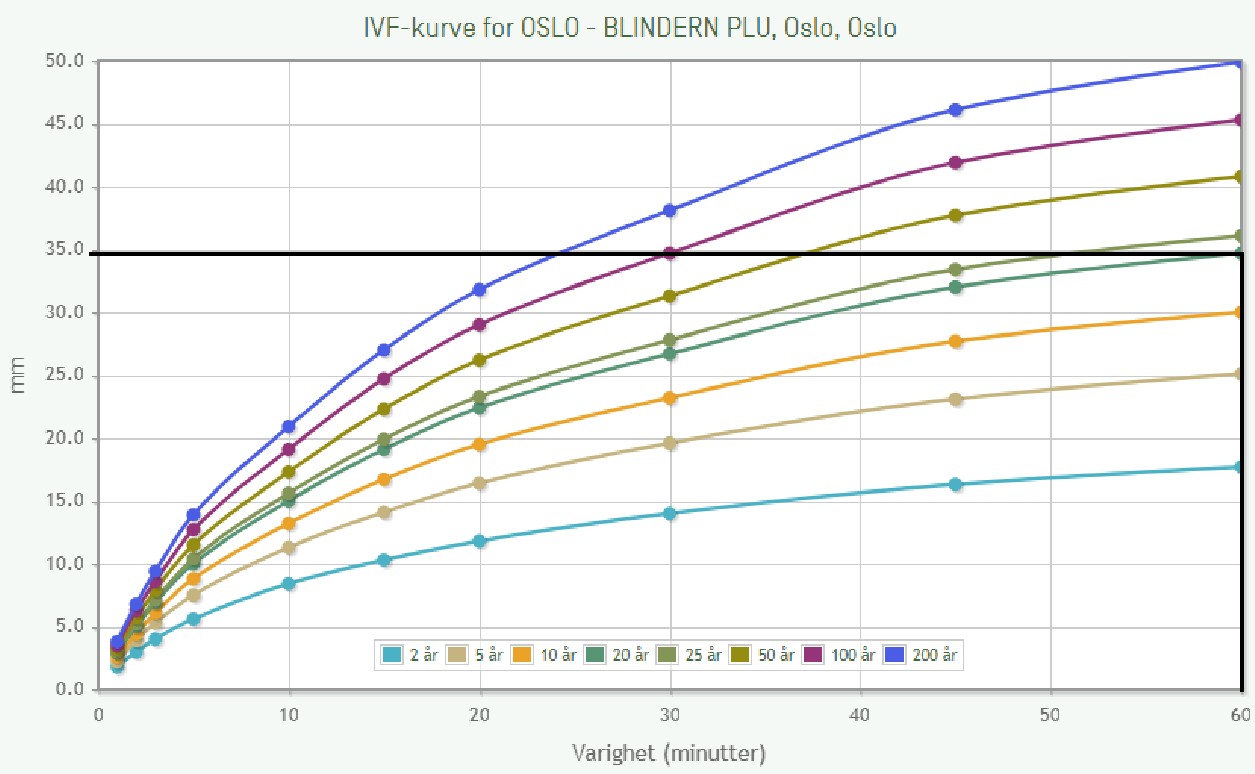


Figure 10: The IDF-curves (IVF-Kurve) for Blindern station. Showing the duration (Varighet) in minutes, the frequency in years (År) and the intensity in mm. With the design criteria for urban areas highlighted with the black lines, once in twenty years [1/20]. As provided by Norks Vann.

To retrieve the design criteria in millimeters for the climate adaption measures, a return period and duration has to be given. The municipality of Oslo follows the Norwegian national criteria when it comes to designing for pluvial flooding. This criteria have been developed by Norsk Vann, the Norwegian national institute for water industry. It is mainly represented by Norwegian municipalities and other public bodies. In their 2008 rapport on minimum design criteria for flood management, they established a table which shows the frequency at which certain types of areas are allowed to flood (Norsk Vann, 2008). The translated and adapted form of this pluvial flood data can be found in table 4.

TABLE 4: RETURN PERIOD FOR PLUVIAL FLOODING FOR DIFFERENT TYPES OF AREAS. ADAPTED FROM NORSK VANN RAPPORT 162/2008.

Type of area	Return period for pluvial flooding.
Low damage areas, agricultural land, peripheral areas.	Once every 5 years [1/5 year]
Residential areas	Once every 10 years [1/10 year]
Urban centers, Industrial areas, Business districts.	Once every 20 years [1/20]
Areas with very high potential damage	Once every 50 year [1/50]

Hovinbyen contains both residential areas, urban centers, industrial areas and business districts. Since most of the project area can be considered to fall in the third category, a return period of once every 20 years has been used for all measures. The last element needed for the determination of the precipitation based on historic data, is the designed duration of a rain event. The selected multipurpose stormwater measures apply to the first two steps of the municipalities plan, being infiltration or delay of discharge. These first two steps apply to normal conditions. Weather extremes like a rain event of once in the 200 years belong to the last step of controlled discharge. For these first two steps, or normal rain events, the MET uses a precipitation duration of 60 minutes.

Looking back at the diagram created by the historic data (figure 10) of the Blindern weather station, a duration of 60 minutes for a once in 20 year precipitation event can be determined. This leads to a precipitation of 34.7 mm/h. This number is based, however, on the historic data of the weather station. The effects of climate change will be discussed in the next section.

Future precipitation

There is a broad consensus that normal precipitation and extreme precipitation patterns will change under the influence of climate change. World climate precipitation models and the MET projects an increase of yearly precipitation ranging from 7% to up to 21% for the Nordic countries in 2100 (Dore, 2005; Trenberth, 2011; Hanssen-Bauer, Et. Al., 2011; MET, 2011). The two aspects that matter the most in these projections is the location and the RCP scenario. For the location, the region Østlandet has been used. As can be seen in figure 11, Oslo is one of the areas with the largest increase in yearly precipitation.

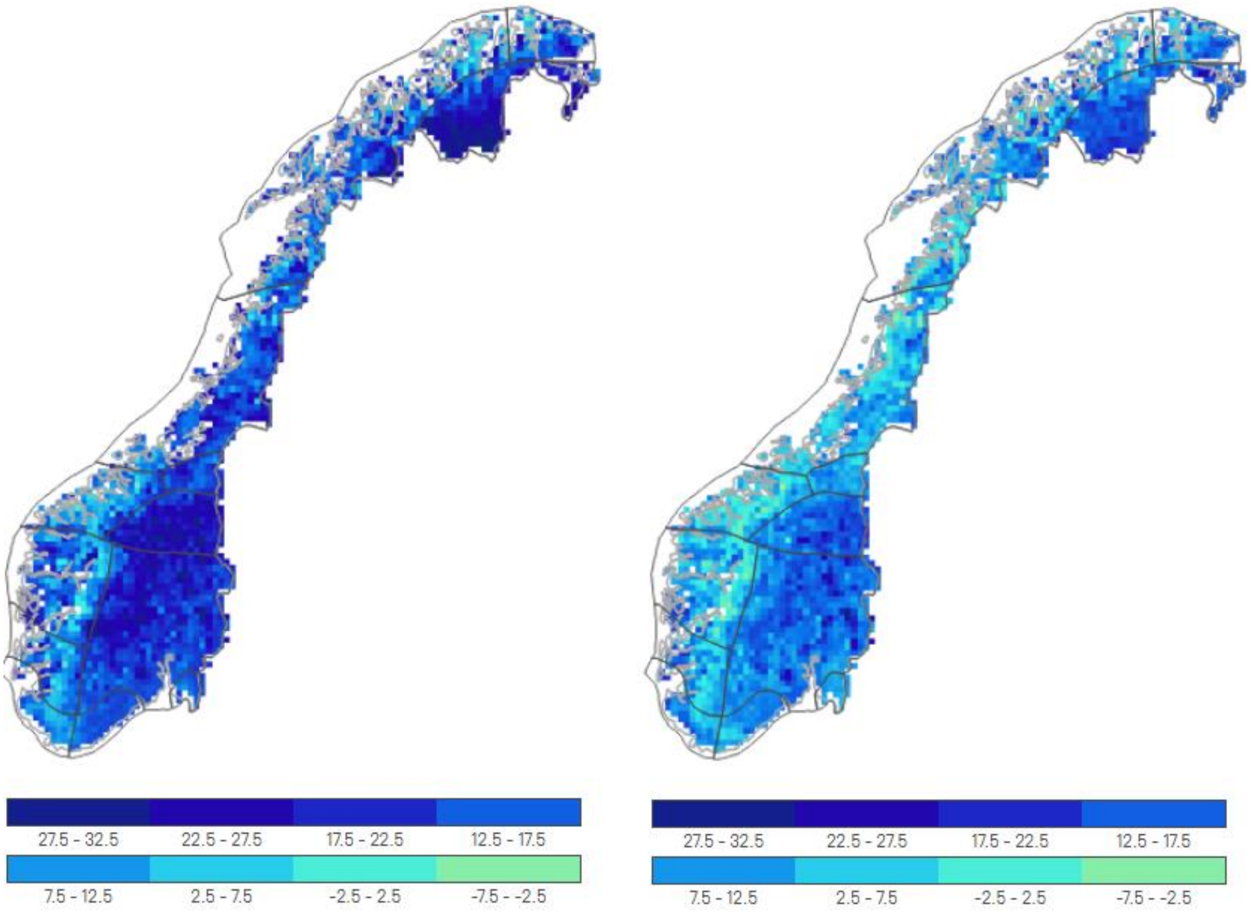


Figure 11: Precipitation change maps of Norway. With the changes in % relative to the climate normal measured between 1971 and 2000. The left side of the images indicates the changes in the year 2100 according to a RCP 8.5 scenario. The right side shows the RCP 4.5 scenario.

For the RCP scenarios, two scenarios are considered for the models. The moderate scenario RCP 4.5 and the high scenario of RCP 8.5. Most of Norway will see an increase in precipitation, based on these regional climate models (RCM). These RCM's have been run on 12x12 km grids. The list of RCM's and their global variants can be found in appendix 6. For a more detailed projection of the Oslo area, the region of Østlandet has been selected. The uncertainty of the projections would increase if the selected area is scaled down too much. The projections for both scenarios can be seen in figure 12.

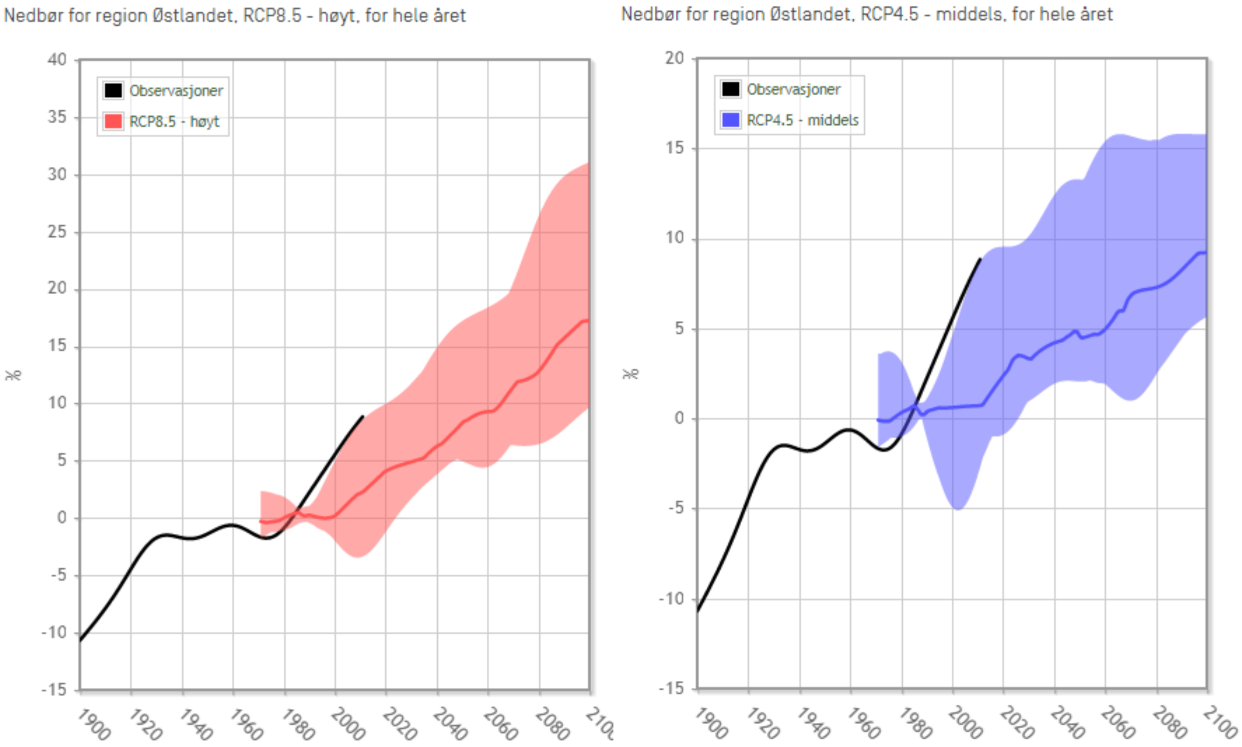


FIGURE 12: PROJECTIONS OF THE YEARLY PRECIPITATION DEVIATION OF THE MEDIAN. IN BLACK THE MEASURED PRECIPITATION CHANGE RELATIVE TO THE HISTORIC MEASUREMENTS. THE RED PROJECTION SHOWS THE CHANGES UNDER A RCP8.5 SCENARIO. THE BLUE PROJECTION SHOWS THE CHANGES UNDER A RCP 4.5 SCENARIO. (SOURCE: KLIMASERVICESENTER.NO)

When looking at the two scenarios two things stand out: There is an obvious increase in both scenarios in 2100. The second thing is that the scenarios do not seem to be following the trend of the measured precipitation. Based on personal communication[iii], two main reasons have been given for this abnormality. The first, the models are not based on historical measurements, so they are actually independent from each other. Secondly, the models provide long term projections within a set climate regime and climate forcings. In the worst case scenario the yearly increase in precipitation can be up to 30%. However, the increase in more intense hourly precipitation can become even greater.

Because of these different scenarios and the uncertainty of short duration high intensity precipitation events, new stormwater measures should be over dimensioned. Therefore, the municipality of Oslo requires all new structures to apply a “climate factor” regarding the drainage of precipitation (Municipality of Oslo: Department of Water and Wastewater services, 2017). The way this climate factor works is by taking the current design precipitation and multiplying it with the factor to estimate future precipitation. The climate factor can be summarized as following:

EQUATION 3: CLIMATE FACTOR APPLICATION PRINCIPLE.

$$P_f = P_c \cdot C$$

[iii] Personal communication through e-mail with: Inger Hanssen-Bauer, Head of the Norwegian Centre for Climate Services. Contacted on: 05-03-2019.

Where P_f is the future precipitation under climate change, P_c is the current design precipitation and C is the climate factor. This climate factor depends on the type of structure that is build. The Norwegian Environment Agency (Miljødirektoratet) has summarized the calculation of this climate factor and the standards established by other government bodies (Kvalevåg, Et, Al., 2014). These factors range from 1.05 to 1.50. For rainwater sewage and drainage Norsk Vann advices a climate factor of 1.3 for low impact structures with a life expectancy of 10 years and and a factor of 1.5 for high impact structures with a life expectancy of longer than 100 years(Norsk Vann, 2012). Low or high impact in this sense references to the impact a flooding would have on society. Where low impact, is for example, a shed and high impact a hospital. The factor that has been used for this research is based on the advice of the NCCS. For the region of Oslo and Akershus, they advise a climate factor of 1.4 (Hisdal, Et. Al., 2017). This climate factor is only applicable for short duration precipitation events, which are defined as lasting less than three hours in total.

This climate factor applied to the design precipitation of 34.7 mm/h gives a precipitation of 48.6 mm/h. This value has been used to determine the effectiveness of the measures in coping with stormwater.

Runoff factor

The runoff factor is needed to finalize the discharge calculations. One of the issues with this is that smaller areas are easier to calculate using the rational method. Some studies advice areas up to 40 000 m^2 for the rational method(Thompson,2006). Other studies use areas of 600 000m^2 and everything in between (Schaake, Geyer & Knapp, 1967). None of the areas used in this study exceed the 200 000 m2 advised by Grønlan, Et. Al. (2015). As has been described in the methodology, first the percentage of each surface type has been inventoried per zone. Each zone and their percentages can be seen in table 5.

TABLE 5: ALL ZONES AND THEIR PERCENTAGES OF SURFACE TYPES.

Zone	Zone name	Roof [%]	Road [%]	Unpaved [%]
Zone 1	Hovinbekken	9.4	7.5	83.1
Zone 2	Løren	13.9	9.0	77.0
Zone 3	Økern	15.2	14.3	70.6
Zone 4	Hovin	7.4	8.7	83.9
Zone 5	Hasle	14.2	8.7	77.1
Zone 6	Ulven	10.6	11.8	77.6
Zone 7	Helsfyre	12.9	12.4	74.7

For this rapport, the coefficient values has been based on a rapport of Norsk Vann (2012). The values of the coefficient values can be seen in table 6.

TABLE 6: SURFACE TYPES AND THEIR CORRESPONDING COEFFICIENT RANGES. ADAPTED FROM NORSK VANN (2012)

Surface type	Coefficient range [C]	Values used [C]
Roads, asphalt	0.85-0.95	0.95
Rooftops	0.7-0.9	0.8
Unpaved roads, gravel	0.5-0.8	N/A
Lawns/ fields	0.3-0.5	0.5

The exact value of the coefficient depends on three factors (Thompson,2006): the land cover, the slope and soil type. The land cover has been determined in the previous step, but the soil type of the area is unknown. The area has slopes in multiple directions, so no single factor can be assigned for the slopes. The slopes and soil type only affect the roads and fields in the area. Therefore it has been decided to take the worst case scenario values for these areas. Roofs are only dependent on their slope. Where flat roofs have a lower coefficient than sloped roofs. It is impossible within this study to determine which roofs are sloped or not and at which gradient. Because of this a median value has been used for roofs.

Next up is the calculation of a single C-value per zone. As been described in the methodology, this has been done by multiplying the C-values by the percentage of surface type in one zone. The results of this calculation can be seen in table 7.

TABLE 7: COEFFICIENT VALUES FOR ALL ZONES THAT HAVE BEEN USED FOR THE RUNOFF CALCULATION

Zone	Zone name	Coefficient used for entire zone [C]
Zone 1	Hovinbekken	0.56
Zone 2	Løren	0.58
Zone 3	Økern	0.61
Zone 4	Hovin	0.56
Zone 5	Hasle	0.58
Zone 6	Ulven	0.58
Zone 7	Helsfyre	0.59

Though the differences between these zones might look small, it is wise to keep in mind that the scale of the C-factor only goes up to 1. A last reason why a small change can be significant is because the factor has been applied to large surface areas. Consequently a small difference can still have a significant impact.

3.3. Measures

For this thesis, two types of measures have been selected. Which are green roofs and vegetated measures. In this sub-section, the two measures have been defined. Then the evaluation of the measures has been done, by analyzing five scientific papers. A third type of measure that could have been considered would be gray measures. Gray measures are more conventional engineering solutions to handle peak discharges, infiltration and storage.. They consists of, but are not limited to: Combined sewer systems, separate sewer systems, storm water channels and constructed retention basins(Madden,2010; Wang, Eckelman and Zimmerman, 2013). Gray measures are not featured in this study. For the reason that this thesis was assigned as part of the Norwegian New Water Ways project, which focuses on implementing integrated green measures(Seifert, 2018).

Green roofs

Green roofs can be divided in three main categories: intensive green roofs, extensive green roofs and blue roofs. A general buildup of a green roof can be seen in figure 13.

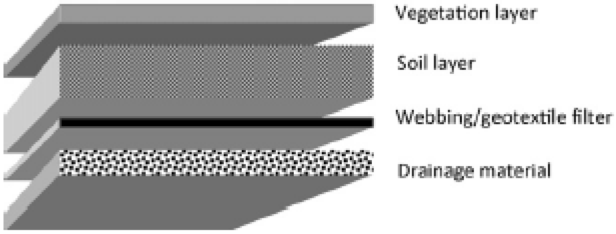


FIGURE 13: SCHEMATIC REPRESENTATION OF A GREEN ROOF. (SOURCE: BERNDTSSON, 2010)

Intensive green roofs, sometimes referred to as roof gardens, are green roofs with a deep layer of soil(Breuning, 2019). This allows the roofs to grow a wider variety of vegetation, absorb more water and extend its biodiversity purposes. A disadvantage of an intensive green roof is that the implementation costs and weight of the roof are much greater than an extensive green roof. Implementing an intensive green roof might require an adjustment of the roof and load bearing walls (Salter, 2018), making it more suitable for new constructions.

Extensive green roofs are like a light-weight version of the intensive green roofs. The cover of an extensive green roof usual consists of smaller vegetation, like short grasses or sedum. They are more drought resistance and usually do not exceed a thickness of 10 cm (Gregoire & Clausen , 2011). Green roofs that are thicker than that are considered intensive green roofs. Extensive green roofs are regarded to be easier applied to already existing structures for, there is little to no adjustment needed of the supporting structure (Gagliano, Detommaso, Nocera, Patania & Aneli, 2014). The last type is the blue roof. A blue roof is a roof which is created like a basin with the function to retain water. They usually contain little to no vegetation (New York City Department of Environmental Protection, 2016). Blue roofs can be extended with a weir system to further delay peak discharge or with a green roof. They do however require reconstruction of the load bearing constructions (Rangarajan, Pankani, Henning & Quigley, 2008).

Since most of the green roofs in Hovinbyen will have to be applied to already existing structures, only extensive green roofs has been used for the literature review. Five review papers have been selected and are displayed in table 8. For both parameters minimum and maximum values derived from the paper are shown. At the bottom, the numbers are averaged for both the low and high values found in all papers. The storage capacity is expressed in m^3 of water stored per square meter of green roof. The peak discharge is presented as percentage reduction of the highest peak discharge of a precipitation event.

TABLE 8: STORAGE CAPACITY AND PEAK DISCHARGE REDUCTION FOR GREEN ROOFS, AS FOUND IN THE LITERATURE.

Paper	Storage[iv] [m^3/m^2] Low- High	Peak discharge reduction [%] MIN - MAX	Other benefits mentioned
Berndtsson, 2010	0.013-0.026	33% - 70%	*Isolation of buildings*
Burszta-Adamiak, 2012	0.004-0.010	23%-73%	*Stimulation of biodiversity*
Li & Babcock[v], 2014	0.009-0.016	22%-93%	*Cooling of buildings*
Li & Babcock, 2014	0.016-0.017	40%-86%	*Cooling of buildings*
Johannessen, Hanslin & Muthanna (2017)	0.025-0.040	Not Mentioned	*Isolation of buildings*
Average	Low: **0,013** High: **0,022**	Min: **30%** Max: **81%**	N/A

[iv] Usually storage is expressed in mm, so it corresponds to the measurement unit of precipitation. For this research cubic meters has been chosen, since it is the unit that will be used for the discharge calculations.

[v] Li & Babcock has two entries because their paper consists of two parts. The first being measured discharges from field locations. The second part is a collection of results from different models (SWMM, SWAP, (SWATRE), SWMS-2D, HYDRUS)

To summarize this table, the end values for the low potential situation will be: A storage capacity of 0.013 m^3/m^2 (13mm of precipitation) and a reduction of 30%. For the high estimation a storage of 0.022 m^3/m^2 has been used and a reduction of 81%.

Vegetated measures

The second set of measures consists of vegetated measures. The term vegetated measures describes measures which seek to retrain and infiltrate water in shallow green areas. For this, study raingardens and swales will all be summarized as vegetated measures. The data for these measures will mostly come from papers about raingardens and swales (wadi's),

Raingardens, sometimes referred to as a bio retention area or rain beds, is shallow manmade depression in the landscape (Dietz & Clausen, 2005). They are decentralized stormwater management systems on private property. The raingarden is meant to compensate for the impervious surfaces (roofs) around it. Often the roofs are disconnected and led to the raingarden by a small gutter. This principle is depicted in figure 14.

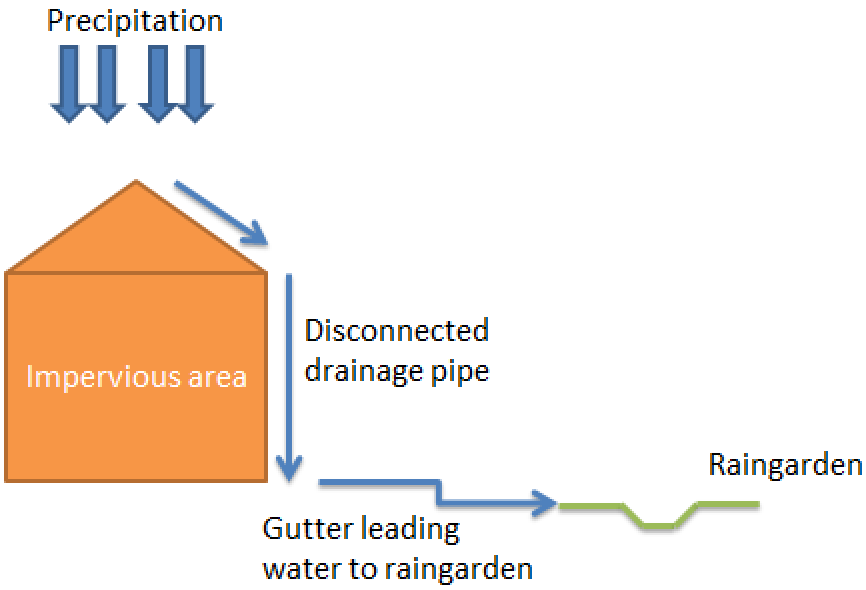


FIGURE 14: DEPICTION OF DISCONNECTED ROOF AREA, REDIRECTED TO A RAINGARDEN.

Most raingardens consist of cover layer of mulch or soil, which allows deep rooting plants to grow (Dietz & Clausen, 2005). If the soil in which the raingarden is placed is not permeable enough, a more permeable soil might have the be put into place. Unlike traditional stormwater measures, they do not drain into a sewage system. However, in less permeable soils raingardens can be constructed with a drainage-transport-and-infiltration-pipe, which is connected to the sewer. The raingardens are small scaled, meant to compensate roofed areas.

Swales and wadi's are often used as interchangeable terms for the same thing. In this study, the term swale has been used to cover all measures which can store and drain water in public green areas. A swale is a single, potentially disconnected, depression in the landscape. In a natural situation, it is created by the drainage path of precipitation and stores or discharges the water. In urban environments, swales can be manmade to serve this purpose. Swales can retain pollutants and be configured to increase biodiversity (Read, Wevill, Fletcher & Deletic, 2007). Thus the reason why they are sometimes referred to as bioswales. The main reason, however for the construction of swales, is stormwater management. As a paper by Scharenbroch, Morgenroth & Maule (2015) puts it: "*Their flexibility in size and configuration allows them to be located in an array of urban landscapes*". Indicating the wide use and potential of swales for urban stormwater management.

The literature study has been conducted over 5 articles, of which 2 were about raingardens and 3 were about swales.

TABLE 9: STORAGE CAPACITY AND PEAK DISCHARGE REDUCTION FOR VEGETATED MEASURES, AS FOUND IN THE LITERATURE.

Paper	Storage [m^3/m^2] Low- High	Peak discharge reduction [%] MIN - MAX	Other benefits mentioned
Dietz 2007	0.025-0.060	38%-70%	*Pollutant removal*
Ahiablame, Engel & Indrajeet[vi] 2012	Not mentioned	48%-74%	*Multifunctional area*
Boogaard, Bruins & Wentink[vii] 2006	0.23-0.65	Not mentioned	*Not mentioned*
Charlesworth 2012	0.30-0.60	10%-54%	*Pollutant removal*
Semadeni-Davies, et al.[viii] 2008	0.03-0.069	Not Mentioned	*Discharge reduction (mentioned not quantified)*
Average	MIN: **0.15** MAX: **0.34**	MIN: **32**% MAX: **66**%	

[vi] This paper has been included, because it has an extensive review of peak discharge reduction. Something that was not the case for some of the other papers.

[vii] This is a publication about a case study in the Netherlands, published by RIONED foundation.

[viii] This paper reviews a case study in Malmö, Sweden. In it a calculation for rain retention in vegetated areas is used for a simulation. These values have been converted to useable values for this research .

The values between the papers differ widely. This can be mostly contributed to two factors. The first is that for this research different sized measures have been combined to create the vegetated measures class. The second factor is that for both measures storage and reduction is completely depending on the dimensions of the measure. Where roofs have an average depth due to weight restrictions, are vegetated measures only limited by the space available and the possible depth of the measure. The figures from the studies are based on case studies which gives the following numbers: For the low potential storage a value of 0.15 m^3/m^2 has been used and a peak discharge reduction of 32%. For the high potential a storage of 0.34 m^3/m^2 has been used and a reduction of 66%.

Benefits

As described in the methodology, two papers have been used to compare the benefits. While it is impossible to directly calculate the effects of these measures, the values from these papers should be seen as potential removal values. First, air quality and green roofs have been analyzed based on the paper of Francis and Jensen (2017). Then pollutant removal by vegetated measures have been analyzed by the rapport of Schaik (2018).

Green roofs have other benefits next to stormwater management, like building isolation, environmental heat reduction and air quality improvement (Clark, Ardiaens & Talbot, 2008). For this research, the only benefit that has been looked at was air quality improvement. For the simple reason that this has been the easiest to estimate using the values mentioned in the paper and the values that have been collected in this research. For heat reduction, the height of buildings and the density of the green roofs has to be known. For the isolation of a building, the size of the building and its temperature requirements throughout the year has to be known. Because these factors are unknown, only the air quality measures have been studied. The way this is displayed in the paper of Francis and Jensen (2017) is in grams per square meter (g/m2). The pollutants researched in this paper are: PM_{10}, NO_2, SO_2 and O_3. They review values from four different papers providing a range for the pollutant removal. For this research, the low average of these four papers and the high average have been used. A complete image would be created by analyzing concentrations in the air before a after implementation in Hovinbyen, but unfortunately this is outside the scope of this research. The adopted values of the table represented in the paper of Francis and Jensen can be seen in table 10.

TABLE 10: LOW AND HIGH POTENTIAL AIR POLLUTION REMOVAL OF AN EXTENSIVE GREEN ROOF ON A YEARLY BASE.

Pollutant	Low potential removal	High potential removal
PM_{10}	0.99 g/m^2/year	4.03 g/m^2/year
NO_2.	1.10 g/m^2/year	2.16 g/m^2/year
SO_2	0.30 g/m^2/year	0.65 g/m^2/year
O_3	2.31 g/m^2/year	4.00 g/m^2/year

For the vegetated measures, a study of Schaik (2018) has been used. This rapport was written in commission of NIVA. It consists of a review of scientific literature on the capabilities of vegetated measures to remove pollutants. It also looks at other measures like permeable pavement, but for this study only the part about vegetated measures has been used. Stormwater runoff can contain a range of pollutants, from nutrients to heavy metals, oils and plastics (Bäckström,2003). In the rapport of Schaik four papers have been taken into account to analyze how much of a certain pollutant has been removed by the vegetated measures. The study Schaik (2018) indicates what percentage of the pollutant has been removed after it went through the measure. This serves as an indicator, since actual removal rates also depends on the concentration of the pollutant and other factors. The study creates an average removal percentage and displays the standard deviation. The low and high potential removal values used for this research has been based on the four papers analyzed for heavy metals. The pollutants and their removal rate can be found in table 11. From the study, only the heavy metal pollutants have been used. Heavy metals are focused, because they are among the most harmful water pollutants in urban areas(Pan, et. al., 2018). The three pollutants are: Copper (Cu), Lead (Pb) and Zinc (Zn). The removal rate is displayed as percentages of total pollution per volume of water, usually one cubic meter.

TABLE 11: LOW AND HIGH POTENTIAL HEAVY METALS POLLUTION REMOVAL OF VEGETATED MEASURES. THE PERCENTAGES INDICATE THE REMOVAL OF A TOTAL INCOMING VOLUME OF WATER.

Pollutant	Low potential removal	High potential removal
Cu	34%	83%
Pb[ix]	82%	89%
Zn	66%	92%

[ix] Not mentioned in the study used for the low estimate of the other heavy metals. The next lowest value has been used.

3.4. Calculation

This sub-chapter contains the final calculations through which the main research question has been answered. All previously collected data is also available in a simple Excel tool. For this first, the dimensions of the measures had to be determined, which is addressed in the next subchapter. Thereafter the water balance, based on the rational method, has been calculated and finally the overview of all the effects of the measures per zone.

Dimensions

Eventually the dimensions of the measures, both the green roofs as the vegetated measures, would have to be precisely calculated per location. This would require detailed plans of buildings, parks and other public and private areas. This information is not yet available, nor would it be possible to process all this information in a single master thesis. Therefore assumptions for the measures have been made. These assumptions are based upon literature reviews, data provided by the commissioner or by expert judgement.

The total surface area of green roofs has been taken from a previous study done by the municipality of Oslo. The total amount of roof surface area per zone can be seen in table 12.

TABLE 12: ROOF AREA AND GREEN ROOF POTENTIAL

Zone number	Zone name	Total roof area [m2]	Potential green roof area [m2]
Zone 1	Hovinbekken	138838	31715
Zone 2	Løren	176391	128453
Zone 3	Økern	291384	268073
Zone 4	Hovin	40330	27869
Zone 5	Hasle	118996	103234
Zone 6	Ulven	148930	142152
Zone 7	Helsfyre	131838	111139

In this table, a few characteristics catch the eye. For example, that zone three and seven have a very large amount of roofed area, which is suitable for green roofs. This is linked to the fact that these are the industrial areas of Hovinbyen. Percentage wise do the high residential zones also have an large amount of area for green roofs. They have plenty of flat roofs of offices and warehouse buildings. Following these areas up, are the areas which are identified as high residential, with many apartment buildings with flat roofs. The zones with low amounts of suitable roofs are the low residential zones Hovinbekken and Hovin, corresponding to zone one and four. For Hovinbekken, this is mostly due to the fact that these area consists mostly of detached housing with sharp angled rooftops. Hovin already has a much smaller roofed area, but also a low amount of suitable roofs. This is mostly due to the fact that the apartment buildings that are in the zone also have angled roofs, making them unsuitable for green roofs.

For the vegetated measures, two key figures are needed: The estimated number of raingardens and the total area of the swales. The values for these measures have been taken from an article provided by the commissioner (Furuseth, Seifert-Dähnn, Braskerud, 2018). The article researched different SODS and the people's willingness to take these measures. The research was carried out in Oslo and thus perfectly fits with this study. The raingardens discussed in this rapport were 5 to 10 m^2 per garden. For this study, an average value of 7.5 m^2 has been used. In this same rapport, the results for the willingness for people to have a raingarden or other low impact developments (LID) was 78%. To determine the total amount of raingarden per area, the amount of buildings has been multiplied by the willingness percentage and the average raingarden size.

For the swales, a different estimation has been used. Since this can be tailored to any size, an estimation has to be made for the total size of all swales. According to expert judgement[x], it is aspired to have an area the size of 15% of the total roofed area per zone as swale. The values for raingardens, swales and total vegetated area per zone can be seen in table 13.

TABLE 13: SURFACE AREA PER MEASURE PER ZONE AND TOTAL VEGETATED MEASURE SURFACE AREA.

Zone number	Zone name	Raingardens area [m²]	Swales [m²]	Total [m²]
Zone 1	Hovinbekken	3662	13884	17546
Zone 2	Løren	2768	17639	20407
Zone 3	Økern	N/A	29138	29138
Zone 4	Hovin	386	4033	4419
Zone 5	Hasle	1422	11900	13322
Zone 6	Ulven	2170	14893	17063
Zone 7	Helsfyre	N/A	13184	13184

The first thing that stands out are the industrial zones three and seven. They do not contain any values for raingardens for it is impossible to make a proper assumption for these zones. This is due to two factors. The first is because the GIS data displays single buildings as multiple buildings. This does not matter for the surface area of the roofs, but it does influence the total amount of raingarden. Making it less accurate. The second reason has to do with the land use of the area. All buildings in those zones are for offices or industrial usage. These types of buildings usually have asphalt surfaces around them for facilitating parking or shunting. This leaves little to no room for raingardens.

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[x] This is the value that the municipality of Oslo strives for. Advised by Bent Braskerud senior adviser, Oslo municipality

A second thing that is highly noticeable is the large difference in swale size and rain bed size for zone one and four. This is mostly due to the fact that zone four, Hovin, has a large park. This park counts towards the swales, but does not contain buildings to be connected with rain gardens. With all sizes of the green roofs and the vegetated measures determined, the water balance can be made.

Water balance

The water balance has been made according to the rational method. First this has been done by calculating the total volume of rainfall per zone. Then the storage of all measures has been calculated to create a second water balance, which takes these measures in to account. The results of the water balance without measures, the current situation, can be seen in table 14.

TABLE 14: RUNOFF VOLUME PER ZONE IN THE CURRENT SITUATION, WITHOUT MEASURES.

Zone number	Zone name	Runoff volume [m^3]
Zone 1	Hovinbekken	40198
Zone 2	Løren	41634
Zone 3	Økern	43787
Zone 4	Hovin	14833
Zone 5	Hasle	23622
Zone 6	Ulven	39604
Zone 7	Helsfyre	29305

Now this same water balance has been calculated, minus the storage of the green roofs and vegetated measures. The runoff in the improved situation, the total storage and the storage per type of measure can be seen in table 15 With the low estimation at the top and the high estimation at the bottom.

TABLE 15: RUNOFF VOLUME AND STORAGE CAPACITY IN AN IMPROVED SITUATION. RESULTS FOR BOTH LOW AND HIGH POTENTIAL ARE SHOWN.

Zone number	Zone name	Green roof storage [m^3]	Vegetated measures storage [m^3]	Runoff volume with measures [m^3]
Zone 1	Hovinbekken	412 698	2632 5966	37154 33535
Zone 2	Løren	1670 2826	3061 6938	36903 31869
Zone 3	Økern	3485 5898	4371 9907	35931 27983
Zone 4	Hovin	362 613	663 1502	13808 12717
Zone 5	Hasle	1342 2271	1998 4529	20281 16821
Zone 6	Ulven	1848 3127	2559 5801	35197 30675
Zone 7	Helsfyre	1145 2445	1978 4483	25882 22377

Obvious is that the vegetated measures provide a much larger effect than the green roofs. This is directly linked to the fact that they are larger in size and store more water per square meter. For the industrial zones (3 & 7) the green roofs have a much larger effect. This is because they have a more roofed area suitable for green roofs. The effects become more evident in figure 15.

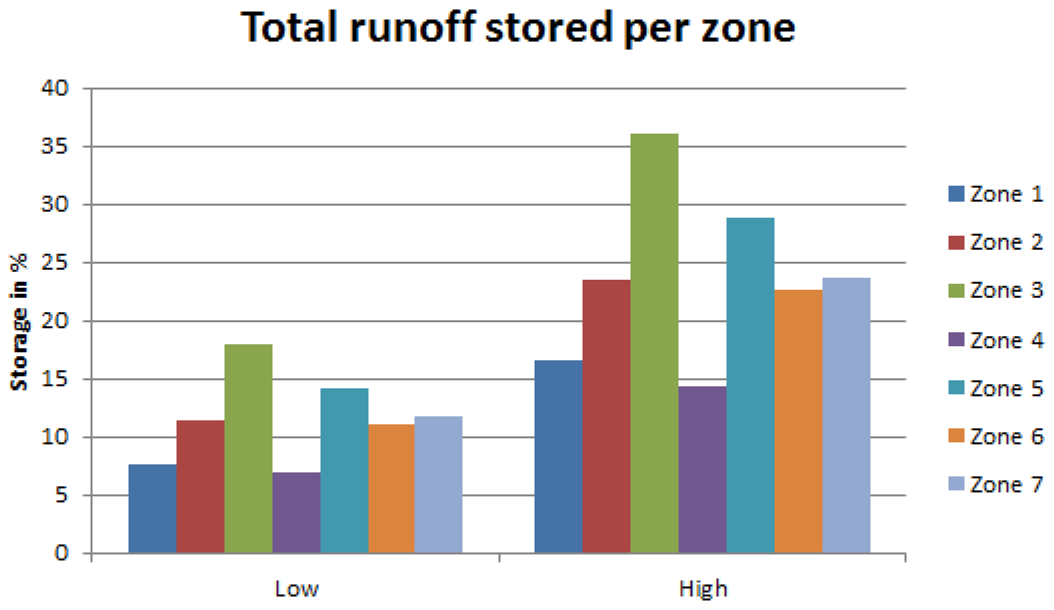

FIGURE 15: RESULTS OF WATER STORED PER ZONE FOR LOW AND HIGH ESTIMATIONS.

It is clear that the highest effects are achieved in the zones with a larger impermeable surface area, like zones 3 and 5. The lowest effect can be seen in zone 1 and 4, these are the low residential zones. These areas are generally already greener meaning the runoff is already less. Next to this they do not contain a lot of roofed area to connect to swales or use as green roofs. The only positive aspect in relation to water storage is that the area can harbor larger amounts of rain beds, due to the fact that this has been linked to the amount of buildings in an area. The effects of this, however, seems to be minimal.

The peak discharge reduction has been estimated based on the percentage the measures cover in an area. The fragmentation of all zones and their peak discharge reduction can be seen in table 16:

TABLE 16: FRAGMENTATION OF THE SURFACE AREAS PER MEASURES PER ZONE. DERIVED FROM THIS ARE THE HIGH AND LOW PEAK DISCHARGE REDUCTION.

Zone number	Zone name	Fragment green roofs [%]	Fragmentation Vegetated measures [%]	Peak discharge reduction Low [%]	Peak discharge reduction High [%]
Zone 1	Hovinbekken	2.1	1.2	1.0	2.5
Zone 2	Løren	10.1	1.6	3.6	9.3
Zone 3	Økern	14.0	1.5	4.7	12.3
Zone 4	Hovin	5.1	0.8	1.8	4.7
Zone 5	Hasle	12.3	1.6	4.2	11.0

Zone 6	Ulven	10.1	1.2	3.4	9.0
Zone 7	Helsfyre	10.9	1.3	3.7	9.7

At first glance, the measures seem to be having a small impact. However, it is important to keep in mind that this is just the discharge reduction of the runoff that directly falls onto the measures. Taking this in consideration, it is interesting to see that the densest areas, Økern and Hasle, have the largest discharge reduction. The smallest discharge reduction is in the least dense areas. Based on the GIS data and field observation it can also be argued that these areas require a smaller discharge reduction, since they are already greener giving them a lower peak discharge in general. However, to fully support this claim a simulation of the peak discharge would have to be made.

Overview

The overview is created by displaying and analyzing the results per factor. The water balance has been previously discussed. In the overview, this is further looked into with the effectiveness per measure for the different zones. After that, the side effects have been looked into, together with the costs.

Measurements effectiveness

To see what type of measures function best in what type of urban fabric, the stored water per type of measure has been looked into. The diagram of these results can be seen in figure 16.

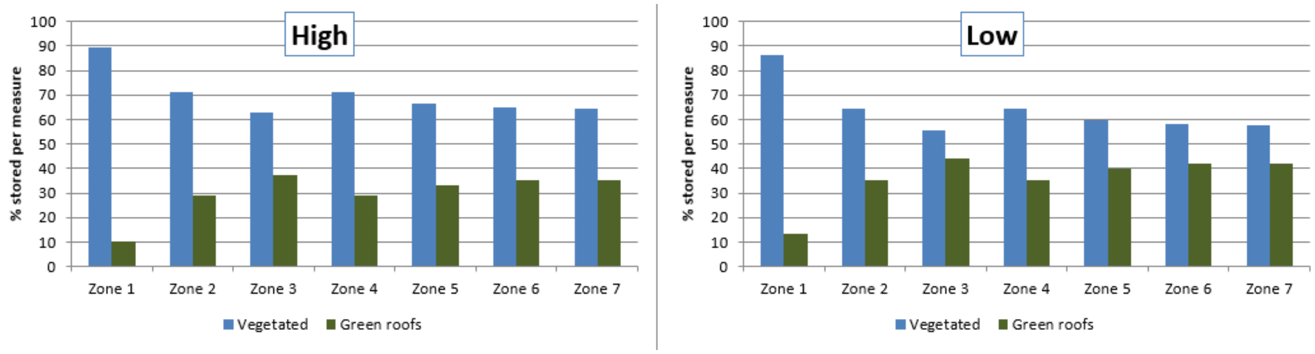

FIGURE 16: RESULTS FOR THE EFFECTIVENESS, BOTH HIGH AND LOW ESTIMATION, PER CONSIDERED MEASURE PER ZONE. INDICATED IN PERCENTAGE OF THE TOTAL STORED WATER.

Obvious for both scenarios is that the vegetated measures store most water. This comes as no surprise since they cover a larger area and can store more water per square meter. The three zones that stand out are once more the two industrial zones 3 and 7 and zone 4. The industrial zones have large surface areas for green roofs and smaller vegetated areas. This causes the green roofs to be more effective there in comparison to other zones. The reason why zone 4 stands out is because it should look similar to zone 1, result wise. They are both low residential areas, which should have similar characteristics. Upon closer inspection of zone 4 it becomes clear that there might be a mismatch in the way the LCZ have been determined. This zone is largely classified as low residential because it has a large park. The buildup area around the park, however, consists of apartment buildings with suitable roofs for green roofs. So, while the building density is low, the roofed area with high green roof potential is high.

The second aspect that can be seen through the results is the estimated effectiveness of green roofs to remove air pollution. The pollutants that have been looked into are PM_{10}, NO_2 SO_2 and O_3. The following table displays the seven zones and their effectiveness per square meter of the total zone to remove pollutants. The reason that this has been analyzed per square meter and not for total removal of pollutants is to make a better base for comparison. If it would not be translated per square meter of the total zone, the bigger zones would automatically be the most efficient. Simply because they are bigger.

TABLE 17: ALL ZONES AND THEIR YEARLY AIR POLLUTANT REMOVAL PER SQUARE METER, AVERAGED OVER THE ENTIRE AREA OF A ZONE. THE COLOR CODING RANKS THE ZONES BASED ON THEIR PERFORMANCE. THE DARKER GREEN, THE BETTER THE PERFORMANCE. THE DARKER ORANGE THE WORST THE PERFORMANCE.

Zone	Zone name	PM_{10} Removal [g/m²/y] Low - High	NO_2 Removal [g/m²/y] Low - High	SO_2 Removal [g/m²/y] Low - High	O_3 Removal [g/m²/y] Low - High
Zone 1	Hovinbekken	0.021 - 0.087	0.024 - 0.046	0.006 - 0.014	0.050 - 0.086
Zone 2	Løren	0.100 - 0.408	0.111-0.219	0.030 - 0.066	0.234 - 0.405
Zone 3	Økern	0.138 - 0.564	0.154 - 0.302	0.042 - 0.091	0.323 - 0.559
Zone 4	Hovin	0.051 - 0.206	0.056 - 0.110	0.015 - 0.033	0.118 - 0.205
Zone 5	Hasle	0.122- 0.496	0.136 - 0.266	0.037 - 0.080	0.285 - 0.493
Zone 6	Ulven	0.100 - 0.408	0.111 - 0.219	0.030 - 0.066	0.234 - 0.405
Zone 7	Helsfyre	0.108 - 0.438	0.120 - 0.235	0.033 - 0.071	0.251 - 0.435

Table 17 shows the low and high estimation of the pollutant removal by green roofs in the different zones. The color ranking shows that the best performing zones are zone 3 and 5. This basically means that these zones have the highest percentage of green roof area of all the zones. From this table, it is obvious that low residential zones, Hovinbekken and Hovin, perform the worst on the pollutant removal factor. This makes sense considering that these zones have a large surface area with a low density of buildings. Added to this, is that the roofed area that is available in the area is often not suitable for green roofs.

The second pollution aspect is the removal of heavy metals by the vegetated measures. In chapter 3.3. the values for the heavy metal removal rate are displayed in percentages, based on a previous study. This percentage indicates the removal rate for normal rain water and snow melt events in Nordic countries. This figure however cannot be transferred to individual values for each zone. The reasoning behind them is that the same amount of surface area is connected to the same ratio of vegetated measures. So if the surface area becomes twice as large, the connected vegetated area should be twice as big as well. What is possible, is to make an approximation based on what zones make most use of the vegetated measures. Based on the assumption that the more water passes through these measures, the more heavy metals have been removed. This can then directly be linked to the graphs of figure 16, mentioned earlier.

On request of the commissioner, a simple cost estimation has also been done. This cost estimation is based on a previous study done by a student at the municipality of Oslo (Hernes,2018). In this study, different projects with green roofs, raingardens or swales have been looked into. Based on these projects, constructed in Norway, a cost estimation for the measures has been made. This gives an estimation based on the size of the measure. The overview of the investment costs per square meter can be seen in table X. The reason that this has been transferred to costs per square meter of a zone is because it makes a more reasonable base for comparison. The total costs per zone can be found in appendix 7.

TABLE 18: INVESTMENT COSTS PER SQUARE METER FOR ALL MEASURES PER ZONE.

Zone	Zone Name	Costs [NOK/m^2] Low - High	Costs [€/m^2][xi] Low - High
Zone 1	Hovinbekken	31 - 138	3.1 – 13.8
Zone 2	Løren	69 - 245	6.9 – 24.5
Zone 3	Økern	83 - 267	8.3 – 26.7
Zone 4	Hovin	35 - 123	3.5 – 12.3
Zone 5	Hasle	77 - 260	7.7 – 26.0
Zone 6	Ulven	61 – 204	6,1 – 20.0
Zone 7	Helsfyre	67 - 219	6.7 – 22.0

The highest costs can be found for the industrial zone Økern, which is also the most effective zone for water storage and air pollutant removal. The second highest costs can be found for zone 5, Hasle. It is no surprise that Hasle is in the higher end, since it also has the second largest water storage capabilities. It is, however, remarkable that it has the highest investment costs, even higher than the industrial areas where green roofs can be widely implemented. The lowest costs are with the Low residential zones, zone 1 and 4, these also have the smallest effects. The industrial zones both have high investment costs, but also the highest results for all factors.

[xi] Exchange rate as of 28-5-2019: 1 NOK equals 0,10 Euro.

Section 4 - Discussion

The discussion consists of five parts following the research questions and adding a comparison to other cities. It strives to critically review the methods used in this research and provide and analyze alternatives.

Urban fabrics

The method used for determining the urban fabrics revolved around the theory of local climate zones. The first issue that rises with this is the detail of data of the GIS analyses. This study made use of the FKB data for the impermeable surface areas. This data consists of all public roads and all buildings. The level of detail is, however, not so specific that it accurately takes sidewalks into account. Over an area the size of Hovinbyen this detail can still account for a large amount of runoff. The second thing is, that the FKB data does not display is the amount of paved surface on private property. For the residential zones in Hovinbyen this might be negligible, but especially for industrial areas the amounts of paved areas can be large. Industrial areas have their own roads between warehouses or have asphalt covered shunting and parking areas.

A second subject for this part of the discussion is the way the areas are created. This has been done based on a GIS analyses of the relief map, creating watershed areas of the project area. The problem with this is that there is no fixed method to decide the size of a watershed area. A watershed area can be infinitely made smaller. This affects the LCZ categorization, since smaller areas are more likely to create extremer values. For example, in the methodology there is also a category called Very High residential areas. If the size of the watershed areas would have been smaller, there would have been more of this type of area.

A potential different way of classifying urban areas is by using satellite data, such as Landsat. This method requires high detail full spectrum images and an algorithm to classify the areas (Lu & Weng, 2005). The benefit of this method is that a large area can be swiftly classified. The downside of this method is that the imagery is sensitive to distortion.

Precipitation

Precipitation runoff management is the central theme of this research, since the municipality focuses on this in their climate adaptation strategy. The way the current precipitation has been determined in this research is by looking at flooding regulations for buildup areas and crossing this with the IDF-curves. However, storm events can take many forms duration and intensity wise. Long low intensity precipitation might have the same total volume of runoff, but might not cause flooding. While short high intensity events will cause flooding. This has not been taken into account in this study. Also scenarios of heavy rainfall in combination with snow melt have not been looked into. An alternative method to establish the design precipitation event would have been through modeling. An example for more detailed hydrological modelling is currently being carried out by the University of Oslo[xii]. This model seeks to create a 2D pluvial flooding model for Hovinbyen. A second option would be to downscale and

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[xii] Personal communication with Hong Li, Post doctorate at the UiO and Jan Olsman Msc student and intern for 2D Hydrologic modelling of Oslo.

refine the regional precipitation projections as has been described by Engen-Skaugen (2007) for example.

This research has dealt with the effects of climate change by applying a climate change factor to the precipitation, as advised by the municipality of Oslo. This way of accounting for climate change is, however, a crude way to deal with future uncertainties. It facilitates over dimensioning and would require a more precise estimation for future projects.

Last on the hydrological part of this research, is the way the runoff coefficient has been utilized. Because one factor per classified zone was needed, the runoff coefficient was determined through analyzing the fragmentation of the buildup area. This does, however, leave out certain details which could be of importance to the functioning of the measures and the runoff volume in general. One of the details which can be of major importance is the elevation of the area. Sharp angled areas have larger runoff coefficient than flat areas. The second is the exact terrain roughness of an area has not been taken into account. For instance, not all areas that are unpaved are vegetated for example. Also different types of road surfaces and pavements have different runoff coefficients. More detailed modeling could help with adjusting for these details. This was, however, impossible for the current scale and time frame of the project.

Measures

The first point of the discussion for the measures would be the selected measures themselves. There are many possible measures that can be evaluated. One important example is permeable parking lots in combination with a water storage system underneath it. This form of multifunctional space use has not been explored for the required detail level was too high.

The effects of the measures are all quantified by either review papers or previous studies. However there can be major differences depending on the size of the measures and the exact conditions. A paper by Pugh, et. al. (2012) for example explains the effect of the location of clustered green roofs on the streets below it. The effects that a single roof has is almost nonexistent, however depending on the actual location multiple green roofs can have their effects.

Calculation

The refinedness of the rational method for the calculation of runoff volume is discussable. While it does take into account the runoff coefficient of different surfaces, it does it not take infiltration and evaporation into account. Since a simplified version has been used for this study, hill slopes and obstacles have also not been taken into account.

Another addition to the precision of the calculation would be more detailed information on the sites and location of the measures. That way a more precise look at the pollution could also be made. For example, a test location which would provide flux values would be very useful.

Other cities

Last on the discussion is the comparison with some other European cities. For this sources and the conclusion from a different thesis will be used. The thesis in question deals with nature based solutions in London and Rotterdam (Eijkelkamp, 2019). It is concluded in this research that the city of London focuses on collaboration with local stakeholders, to make the city more climate change resilient. Rotterdam meanwhile focuses on citizen involvement for climate change adaptation. Since Hovinbyen is quite a diverse area it can be wise to seek the best of both of these worlds. But also increasing the size of the involvement of external partners to that of Rotterdam or London, could be suggestable.

Section 5- Conclusions and recommendations

The final section of this thesis is the conclusion and recommendations. It is structured according to the research questions and will repeat the main findings. The main research question was:

What are the effects of climate adaptation measures in the different urban fabrics of Hovinbyen?

The main strength of this research lies in the combination of an urban classification and the effectiveness and side benefits of different stormwater management measures. The importance of these types of measures is increasing as traditional drainage systems cannot cope with more intense and frequent storms. Storms which are likely to increase due to effects of climate change.

The case study area consists of an array of urban typologies which required classification for this research. The first research question identifies the different urban fabrics of Hovinbyen. Based on classification for local climate zones three types where identified. Divided in seven larger zones throughout the project area. The types were named low residential, high residential and industrial.

The municipality of Oslo strives for improvement of its stormwater management by implementing a three step program. The measures considered in this thesis focusses on the second step and has been split up in two types. The first type being green roofs, focusing on extensive green roofs which can be implemented on existing buildings. The second type, named vegetated measures, consists of (bio) swales and raingardens. Implementation of these types of measures can be costly which makes it important to find the proper locations for this type of implementation. That is why the case study area of Hovinbyen in Oslo has been selected.

To what kind of storm event the measures should be tested has been determined by looking at what falls under the second step of three step program. For this a once-in-every-twenty-year (1/20) precipitation event was determined. To make an estimation on what this means for future precipitation, while taking climate change in account, a climate factor has been used. This gave a precipitation event of 48.6 mm per hour.

To answer the main research question of this study all urban fabrics has been discussed separately starting off with the Low residential zones. The Low residential zones have an average storage capacity of 7.3 % to 15.5% of the previously mentioned precipitation event. Next to this do they also have the smallest impacts with of side benefits of all zones. This is reflected in the fact that they also have the lowest average investment costs per square meter. For the low residential zones the vegetated measures can be up to nine times as effective as the green roof measures, when looking at stored water.

The High residential zones averaged a storage capacity of 12.2% for the low estimation. The high estimation assigns a storage capacity of 24.9% of the total runoff volume. The high residential zones can be considered to be fairly effective at removing pollution, since they employ both a large amount of vegetated measures and green roofs. Their investment costs are almost double that of the low residential zones, which does show in their effectiveness.

The measures that could be implemented in the industrial zones of Hovinbyen can be considered to have the largest impact of all urban fabrics. Measures in this type of urban fabric store an average between

14.8 % and 29.9%. They are also most effective at removing pollution where there effectiveness can be over six times as big as, for example, low residential zones. Their average investment costs per square meter is the highest of all urban fabrics. However, averaged out this is only slightly higher than the High residential zones.

Recommendations

Based on the results of this research and the experiences gained through the applied methodology a number of recommendations can be made:

- Comparing results from different types of urban fabrics can be beneficial since it allows to compare different areas from different cities. This allows decisionmakers to better understand what the effects of different measures can be in comparable areas. The LCZ method, based of Stewart and Oke (2012), lends itself to be used to develop the urban fabrics needed for this comparison. However, perhaps a more standardized or detailed tool should be used for this. Since many more factors like social or soil composition could influence the success of the measures. To create more detailed LCZ a potential tool could be WUDAPT, which is the World Urban Database Access Portal Tool. This can create an automatic LCZ characterization using a GIS program.
- Hydrologically, it is important to know two parts on this subject which could use as much improvement as possible. The first is further understanding what damages would be suffered by potential pluvial flooding events in Oslo. Further modelling is advised to gain better knowledge on what type of rain event should be treated by what step of the municipal three-step program. The second part consists of better implementing measures on location. By detailed modeling certain hotspots for pluvial flooding can be determined. Combining these hotspots with measures can help to justify the extra costs of implementing the measures.
- The involvement of citizens in climate adaptation measures can also be important. Green roofs and raingardens can help with storing stormwater. The municipality does not own enough land to manage all stormwater measures, so private actors are crucial. Citizens
- Further research could pay off for studying how industrial and office areas can contribute to strengthen these areas and contribute to the climate resilience of a city. This study underlines the argumentation that climate adaptation measures, with regard to pluvial flooding, would be most effective when implemented in these areas with a large fraction of impermeable surfaces. Especially looking at ways to reduce the costs in these areas could be interesting.

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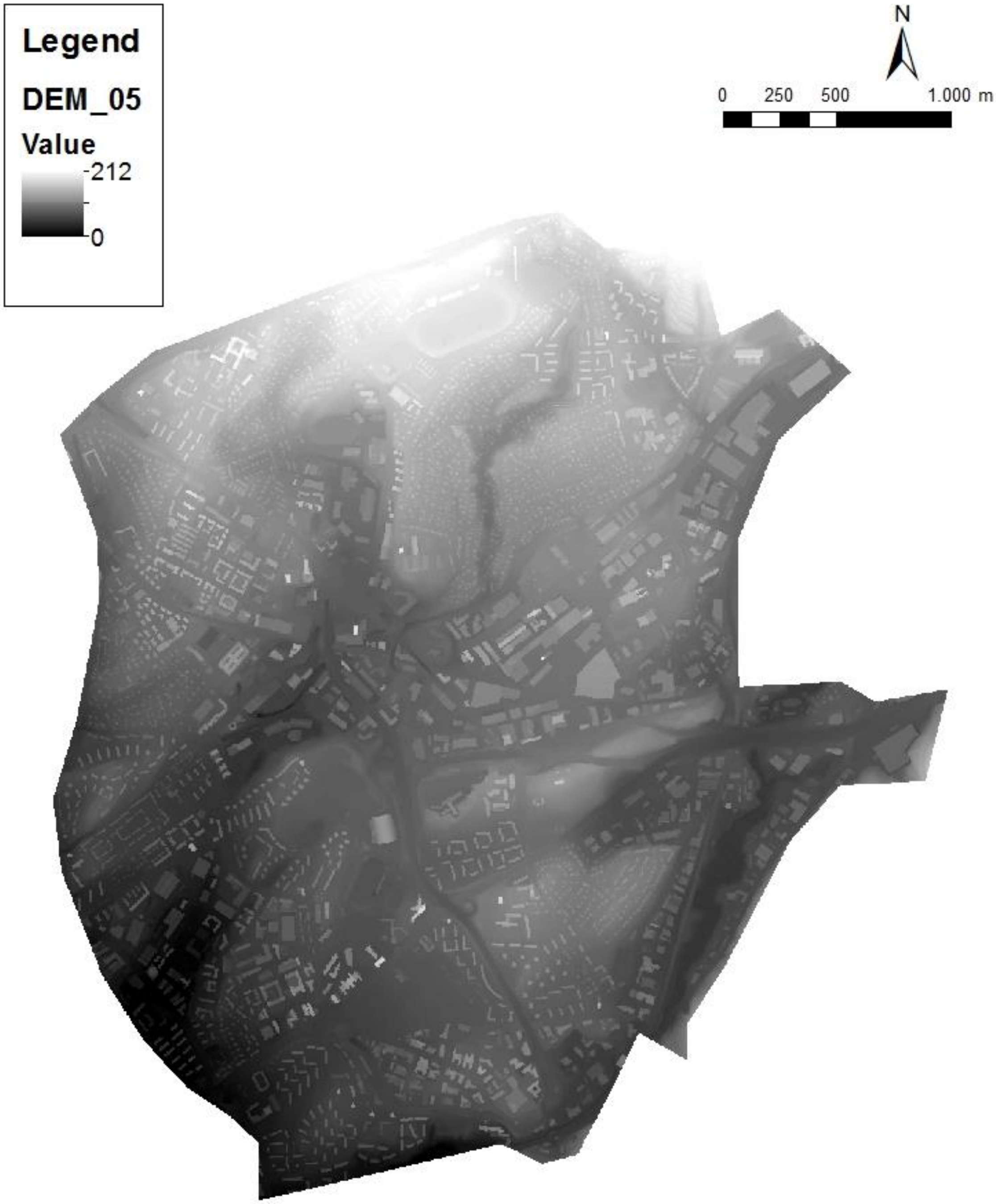
Appendixes

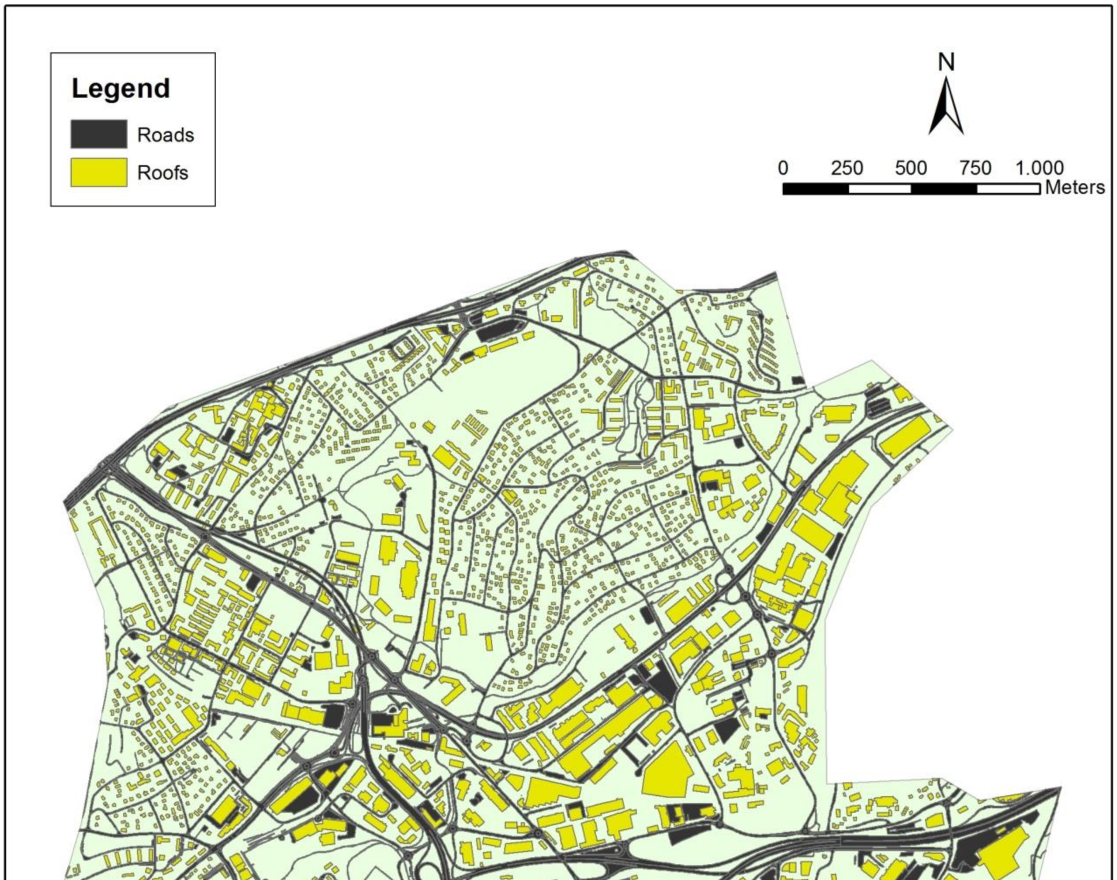
The following table will contain an inventory of all referenced appendixes.

Appendix	*Description*
1	Digital Elevation Map (DEM)
2	Buildup area of Hovinbyen
3	Percentages of roofed area
4	Percentages of Impermeable area
5	Land use map
6	Regional climate models
7	Total costs per zone

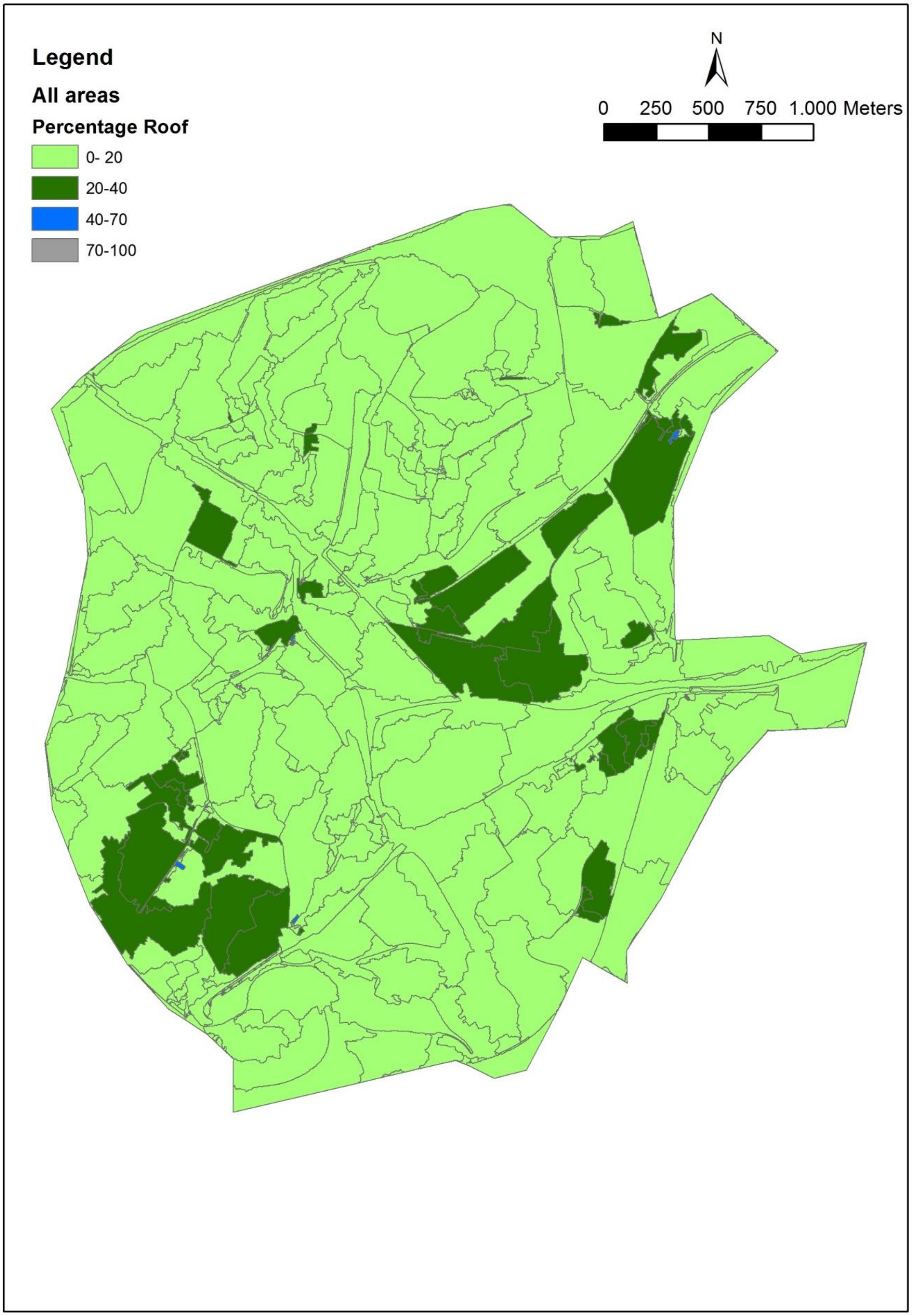
Appendix 1: DEM



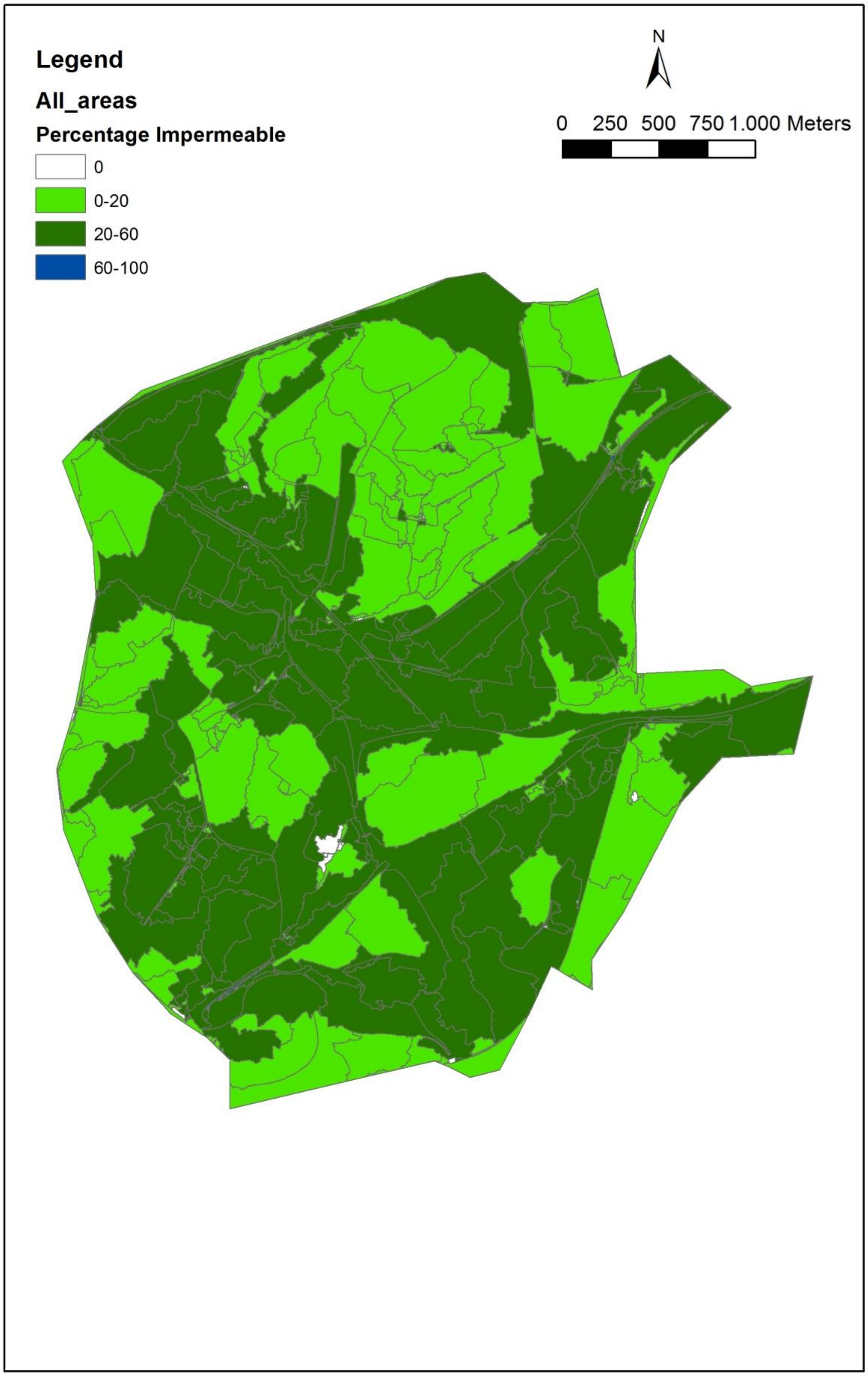
Appendix 2: Buildup area



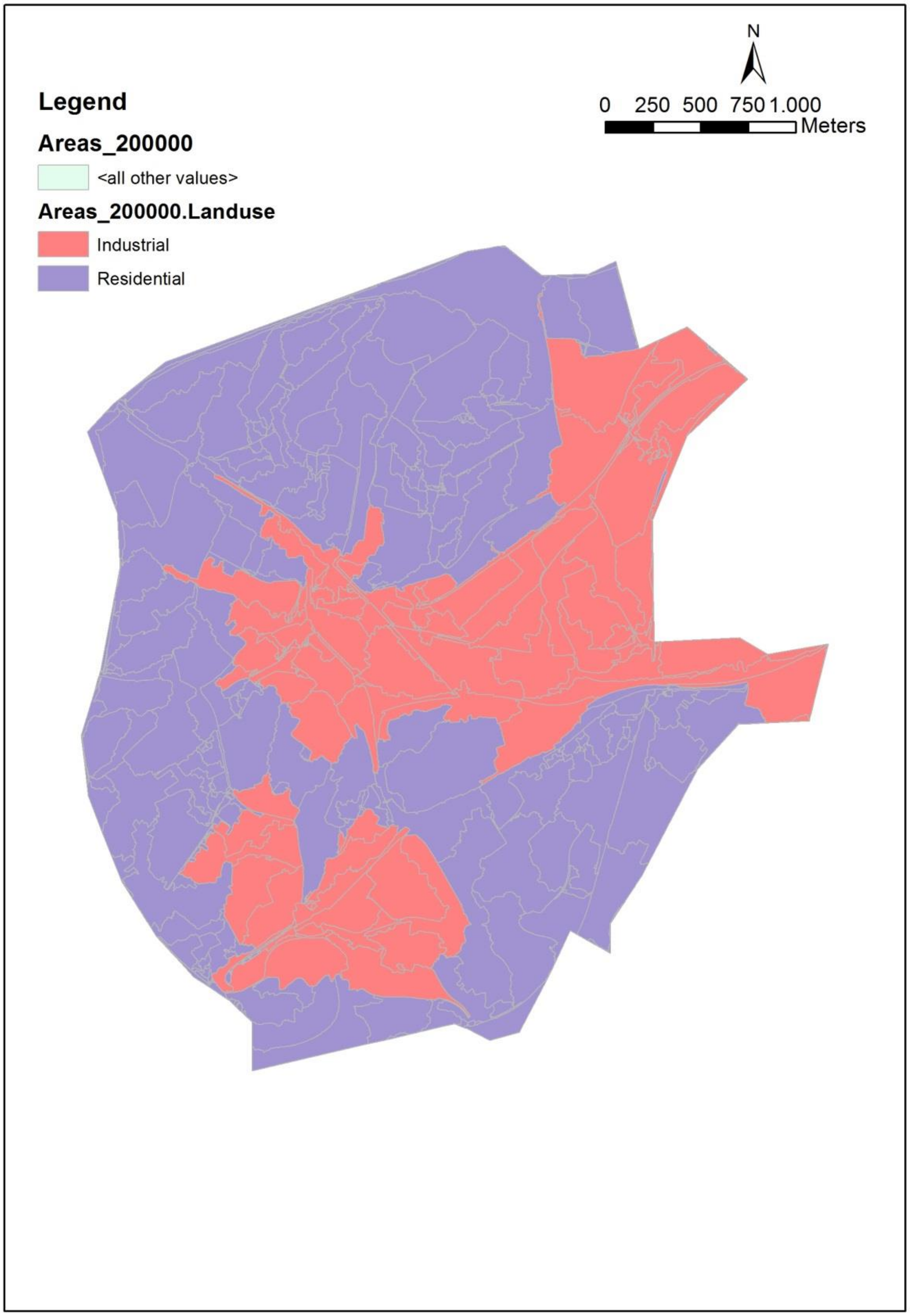
Appendix 3: Percentages of roofed area



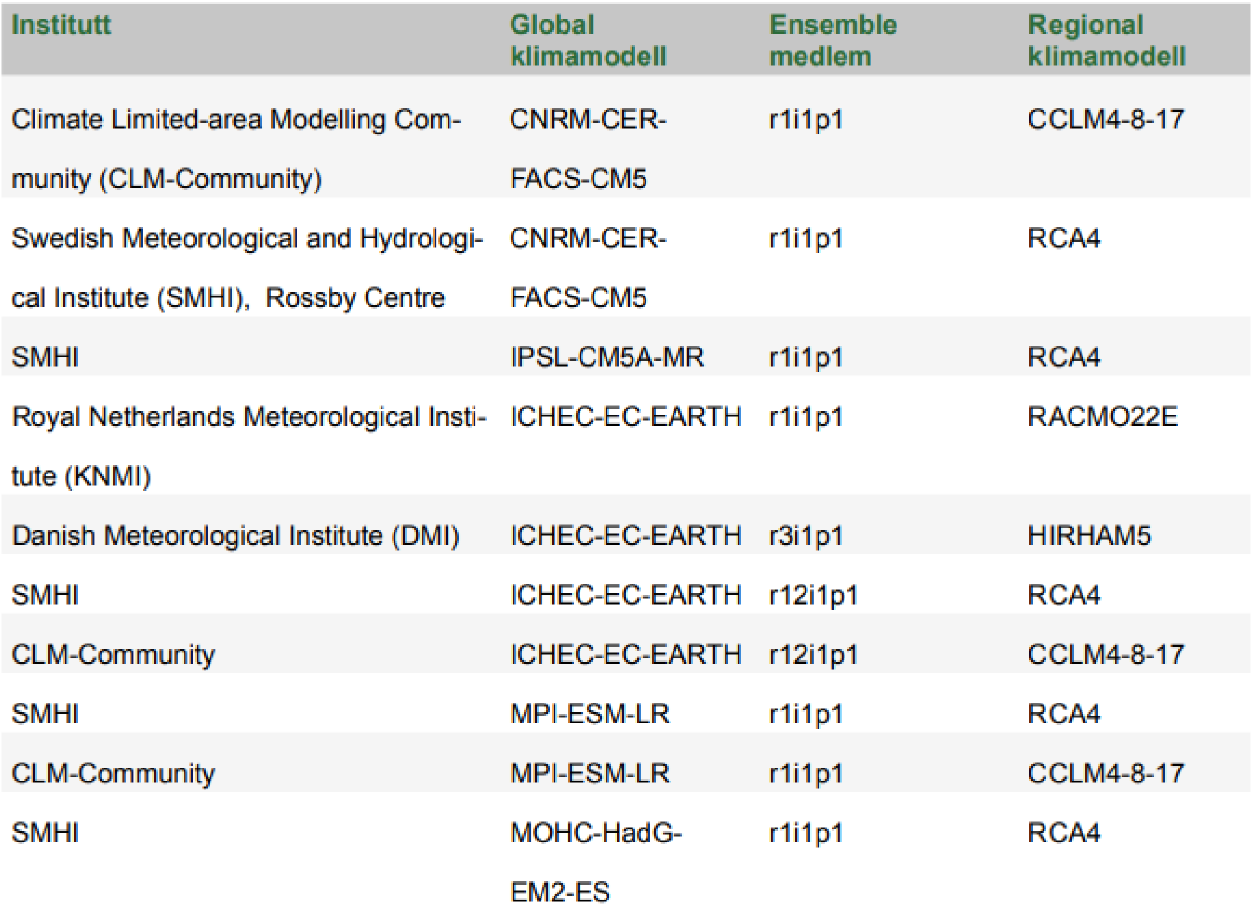
Appendix 4: Percentages of Impermeable area



Appendix 5: Land use



Appendix 6: Regional climate models



Institutt	Global klimamodell	Ensemble medlem	Regional klimamodell
Climate Limited-area Modelling Community (CLM-Community)	CNRM-CERFACS-CM5	r1i1p1	CCLM4-8-17
Swedish Meteorological and Hydrological Institute (SMHI), Rossby Centre	CNRM-CERFACS-CM5	r1i1p1	RCA4
SMHI	IPSL-CM5A-MR	r1i1p1	RCA4
Royal Netherlands Meteorological Institute (KNMI)	ICHEC-EC-EARTH	r1i1p1	RACMO22E
Danish Meteorological Institute (DMI)	ICHEC-EC-EARTH	r3i1p1	HIRHAM5
SMHI	ICHEC-EC-EARTH	r12i1p1	RCA4
CLM-Community	ICHEC-EC-EARTH	r12i1p1	CCLM4-8-17
SMHI	MPI-ESM-LR	r1i1p1	RCA4
CLM-Community	MPI-ESM-LR	r1i1p1	CCLM4-8-17
SMHI	MOHC-HadGEM2-ES	r1i1p1	RCA4

All local climate models used for the 12x12 km grid used for the calculation of the RCP scenarios of Norway. (source: Klima i Norge 2100). *Translation of the headers from left to right: Institute, Global climate model, ensemble member, Regional climate model.*

Appendix 7: Total costs per zone

TABLE 19: LOW COST ESTIMATION

Cost of Unit	Zone 1 Hovinbekken	Zone 2 Løren	Zone 3 Økern	Zone 4 Hovin	Zone 5 Hasle	Zone 6 Ulven	Zone 7 Helsfyre
Green roofs	NOK 11.100.250	NOK 44.958.550	NOK 93.825.550	NOK 9.754.150	NOK 36.131.900	NOK 49.753.200	NOK 38.898.650
Raingarden	NOK 3.662.000	NOK 2.768.000	NOK 0	NOK 386.000	NOK 1.422.000	NOK 2.170.000	NOK 0
Swales	NOK 31.238.550	NOK 39.687.750	NOK 65.560.500	NOK 9.074.250	NOK 26.775.000	NOK 33.509.250	NOK 29.664.000
Total NOK	NOK 46.000.800	NOK 87.414.300	NOK 159.386.050	NOK 19.214.400	NOK 64.328.900	NOK 85.432.450	NOK 68.562.650
Total Euro	€ 4.600.080	€ 8.741.430	€ 15.938.605	€ 1.921.440	€ 6.432.890	€ 8.543.245	€ 6.856.265

TABLE 20: HIGH COST ESTIMATION

Cost of Unit	Zone 1 Hovinbekken	Zone 2 Løren	Zone 3 Økern	Zone 4 Hovin	Zone 5 Hasle	Zone 6 Ulven	Zone 7 Helsfyre
Green roofs	NOK 25.372.000	NOK 102.762.400	NOK 214.458.400	NOK 22.295.200	NOK 82.587.200	NOK 113.721.600	NOK 88.911.200
Raingarden	NOK 36.620.000	NOK 27.680.000	NOK 0	NOK 3.860.000	NOK 14.220.000	NOK 21.700.000	NOK 0
Swales	NOK 141.614.760	NOK 179.917.800	NOK 297.207.600	NOK 41.136.600	NOK 121.380.000	NOK 151.908.600	NOK 134.476.800
Total NOK	NOK 203.606.760	NOK 310.360.200	NOK 511.666.000	NOK 67.291.800	NOK 218.187.200	NOK 287.330.200	NOK 223.388.000
Total Euro	€ 20.360.676	€ 31.036.020	€ 51.166.600	€ 6.729.180	€ 21.818.720	€ 28.733.020	€ 22.338.800