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MASTER'S THESIS

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Preface

This master thesis is the conclusion of a two-year long master's degree program in city planning at the University of Stavanger. The master thesis is about improving the stormwater system to prevent flooding at the underpass at Danmarksplass in Bergen. The thesis is selected based on my own interest, personal experiences with the study area and the need for more research within a field which has grown in importance lately.

Working on the thesis has been very educational, challenging, and interesting. The thesis has helped me gain a better understanding of the complexity of the challenges which planners face, and the importance of great cooperation between different planning fields.

I would like to say thank you to my supervisor Ari Krisna Mawira Tarigan at the University of Stavanger, for great feedback and guidance on the work on the thesis.

Due to the corona virus pandemic, all guidance sessions have been done by using Zoom. This has been slightly challenging since I find it easier to explain information in person, but we made the best out of the situation and it has gone fine. The pandemic also led to the university closing, and therefore I did not have access to the software which are on the computers. Therefore, I used Autocad instead of Adobe Illustrator to make illustrations for this thesis.

Finally, I want to thank my family and friends who have been great supporters throughout the education and the master thesis.

Abstract

Stormwater management has increasingly become more important in recent times in urban planning. One of the reasons for this is climate change. More rainfall is occurring in form of more frequent, intense rainfall, and research say this trend will continue. This is especially true for western Norway and northern Norway, which will experience the greatest increase in rainfall. Something else, which has also made stormwater management more important, is the desire to densify along central areas and public transport axes due to the population growth. As a result, green permeable areas have been replaced with dense impermeable surfaces. Dense impermeable surfaces lead to less infiltration and a higher runoff velocity. When densification and climate change occur simultaneously without upgrading the stormwater infrastructure, problems often arise. This has particularly significant consequences when the piping infrastructure is shared by stormwater and sewage.

The underpass at Danmarksplass in Bergen is one of the areas which are struggling with floods following major rainfall events. The piping infrastructure is mostly shared by stormwater and sewage, and the infrastructure is not well enough equipped for neither today's nor future's rainfall events. During the night before 26.09.2018, a heavy rainfall occurred, and the underpass was once again filled

with water. This rainfall is considered as an event that statistically occurs every 5 years. The rainfall was much less intense than the type of rainfall the underpass in theory should be dimensioned for. Since the underpass is so important and highly trafficked by pedestrians and cyclists, measures should be made to improve the stormwater management at Danmarksplass.

To find the answer to why the underpass is struggling with floods and what solves the problem best, there has been done a literature study, an inspection of the area, an analysis with calculations, and finally a discussion. There has been made research on planning methods in the field of stormwater management, types of infrastructure which are available on the market and sought inspiration in other innovative projects which have previously been planned. Furthermore, 3 scenarios were established, where scenario 1 solely used traditional grey infrastructure, scenario 2 solely used blue-green infrastructure and scenario 3 had a combination of traditional grey infrastructure and blue-green infrastructure. The scenarios were further assessed on 5 different topics: costs, how well they manage stormwater, their impact on the urban environment and biodiversity and the amount of maintenance required. Finally, it was concluded that scenario 3 was the best solution to solve the stormwater problem at Danmarksplass

Sammendrag

Overvannshåndtering har i nyere tider blitt viktigere innen planlegging. En av grunnene til dette er at klimaet er i endring. Det oppstår mer nedbør i form av hyppige, intense regnskyll, og forskning sier at denne trenden vil fortsette. Dette gjelder spesielt på Vestlandet og Nord-Norge som vil oppleve den største nedbørsøkningen. Noe annet som også har gjort at overvannshåndtering blir viktigere er befolkningsvekst og et ønske om å fortette langs sentrale områder og kollektiv akser. Dette har ført til at grønne permeable områder har blitt erstattet med tette flater. Resultatet av dette er mindre infiltrasjon og høyere avrenningshastighet. Når fortetting og klimaendringer foregår samtidig uten at overvannshåndteringen oppgraderes, oppstår det ofte problemer. Dette får spesielt store konsekvenser når rørinfrastrukturen deles med avløpsvann.

Undergangen på Danmarksplass i Bergen er en av områdene som er utsatt for flom etter store nedbørshendelser. Rørinfrastrukturen deles stort sett av overvann og avløpsvann, og infrastrukturen er ikke godt nok rustet for hverken dagens eller fremtidens nedbørshendelser. Natt til 26.09.2018 kom det store mengder nedbør og undergangen ble nok en gang fylt med vann. Denne hendelsen er vurdert som en hendelse som statistisk sett vil kunne inntreffe hvert 5. år. Nedbøren var mye mildere enn den type nedbørshendelse undergangen i teorien skal være dimensjonert for. Siden undergangen er så viktig og svært trafikkert av gående og syklende, bør tiltak bli gjort for å forbedre overvannshåndteringen.

For å undersøke hvorfor gangtunnelen er utsatt for flommer, og hva som løser problemet best, har det blitt gjort en litteratur studie, en befaring av området, en analyse med beregninger, og til slutt en diskusjon. Det har blitt forsket på ulike planleggingsmetoder innen overvannshåndtering, typer infrastruktur som finnes på markedet og søkt inspirasjon i noen andre innovative prosjekt som tidligere har blitt planlagt. 3 scenarioer ble videre dannet, hvor scenario 1 kun brukte tradisjonelle grå løsninger, scenario 2 kun brukte blå-grønne løsninger og scenario 3 brukte en kombinasjon av tradisjonelle grå løsninger og blå-grønn infrastruktur. Scenariene ble videre vurdert innen 4 tema: kostnad, deres påvirkning på det urbane miljø og det biologiske mangfold og mengden vedlikehold som kreves. Til slutt ble det konkludert med at scenario 3 var den beste løsningen for å løse problemet på Danmarksplass.

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1 Introduction

1.1 Problem statement

Cities all over the world are more frequent than before experiencing floods after heavy rainfalls, and stormwater planning has now increased in importance. This is partly due to urban densification, but also a climate which is changing. Bergen, which is known for being the “rain city” of Norway, experiences a lot of heavy rainfalls every year, which sometimes results in floods in certain areas. The pedestrian underpass at Danmarksplass, Bergen is one of those areas which experiences floods after heavy rainfalls. There exist various types of infrastructure for dealing with stormwater on the market, but which infrastructure that is the optimal will vary from project to project. It is therefore interesting to investigate which solution that solves the stormwater problem the underpass at Danmarksplass in the best way. The problem statement is therefore defined as:

«How can the stormwater management at Danmarksplass be improved to be best equipped for future floods at the underpass at Danmarksplass?”

To answer the problem statement in the best manner possible, two research questions have been established.

- Why does the underpass struggle with floods after major rainfall events?
- Which type of stormwater infrastructure is the best considering the topics: management of stormwater, costs, biodiversity, urban environment and maintenance?

Furthermore, research will be conducted on what types of planning methods and infrastructures that are on the market. It will also look at other recent innovative projects which have been completed in the past. The problem statement and the research questions will form the basis for the task's registrations, analysis and discussion part. There will be made 3 scenarios with different stormwater infrastructures which will be discussed. The discussion of the scenarios will eventually help providing a good recommendation for how to improve the stormwater management at Danmarksplass.

1.2 Area demarcation

Figure 1 - The study area at Danmarksplass (Norge i bilder, 2020)
Edited by Eirik Instanes

The demarcation of the study area at Danmarksplass is defined by the dotted line in figure 1. The underpass is situated on the north-west part of the marked area and crosses under the highway called E39. The demarcation of the study area was made based on an inspection of the area where it was assumed which area that contributes to the floods in the underpass.

2 Method

The method which has been used to answer the problem statement and to answer the research questions is presented below:

Figure 2 – Method diagram

2.1 Literature study

A literature study has been made to find information and research which has been conducted in the past about stormwater management. The literature study has been done by researching online and studying relevant articles and reports about stormwater management and the study area. It has also been important to study textbooks about stormwater management. The literature study has resulted in a theory chapter which introduced the most important theory within stormwater management. It has also provided information which has been used in the analysis of the study area.

2.2 Inspection

After deciding which area was the suitable study area for the thesis, an inspection was made of Danmarksplass. The inspection was made to take pictures and get a hands-on perspective of the area. The inspection helped to gain a better understanding of the area, to make it easier to give a good and informed recommendation. Pictures from the internet may also sometimes not show the current situation accurately, and it was therefore important to inspect the area to properly map the current situation.

2.3 Analysis

The literature study and the inspection provided information which was used to analyse the study area. The analysis helped gain an understanding of the study area in order to answer the problem statement and the research questions in the best way. The analysis for instance looked at the slope of the area, the soil and its infiltration capacity, the surface area, plans which were of importance for planning in the area, etc. There was also developed scenarios which were individually analysed with calculations.

2.4 Discussion

In the discussion chapter, the scenarios will be discussed based on the theory and the analysis which has been done. Topics which played a part in the discussion are the scenarios effect on the urban environment and the biodiversity, the costs, how well they manage stormwater and the required maintenance. The discussion led to a final recommendation.

3 Theory

3.1 Stormwater runoff

Stormwater runoff is a result of rainfall and melted snow or ice. Some of the rainwater is infiltrated in the ground, and the rest which is not infiltrated is running on surfaces. It is this water, which is not infiltrated, that we call runoff water. The runoff water may come from roofs, roads and hills with different permeability. Runoff water may cause floods in urban areas. Floods can cause damage to property values and put roads and pavements out of play, which may lead to large socio-economic costs.

The runoff water may sometimes be polluted. While the water runs on surfaces it can pick up nutrients, particles and chemical substances such as salt and toxins. Therefore, it is important that the runoff water is cleansed before it reaches its recipient. (Miljødirektoratet, 2016)

Stormwater management has increasingly become more important in cities since the conditions which affect the stormwater runoff has changed since the old infrastructure was built. The conditions which has changed are the climate and the amount of developed areas due to densification.

3.1.1 Climate change

Climate change is a phenomenon which is resulting in great challenges for cities these days. The climate is defined as the average temperature, wind and rainfall measured over decades. It is assumed that climate change has natural and manmade causes. The manmade contribution to climate change is the emission of climate gases such as CO_2. Climate gases lead to an increase in the greenhouse effect which result in higher temperatures in the atmosphere (Lallanila, 2018).

Climate change may lead to an increase in the amount of total rainfall in certain parts of the world. Norway is one of those countries which according to research will receive more extreme rainfall due to climate change. The amount of rainfall in Norway has increased with 18 % from 1900 to 2015 as possible to see in figure 3. If we continue emitting greenhouse gases as before, it is predicted that the amount of rainfall will increase with an additional 18 % within 2100 (NCCS, 2015). Rainfall which previously had a likelihood of happening every 50 years (also called 50-year rainfall) may in the future happen every 10 years (NOU, 2015, s. 30). The west coast and the north of Norway are predicted to have the greatest increase in amount of rainfall due to climate change. (NRK, 2019).

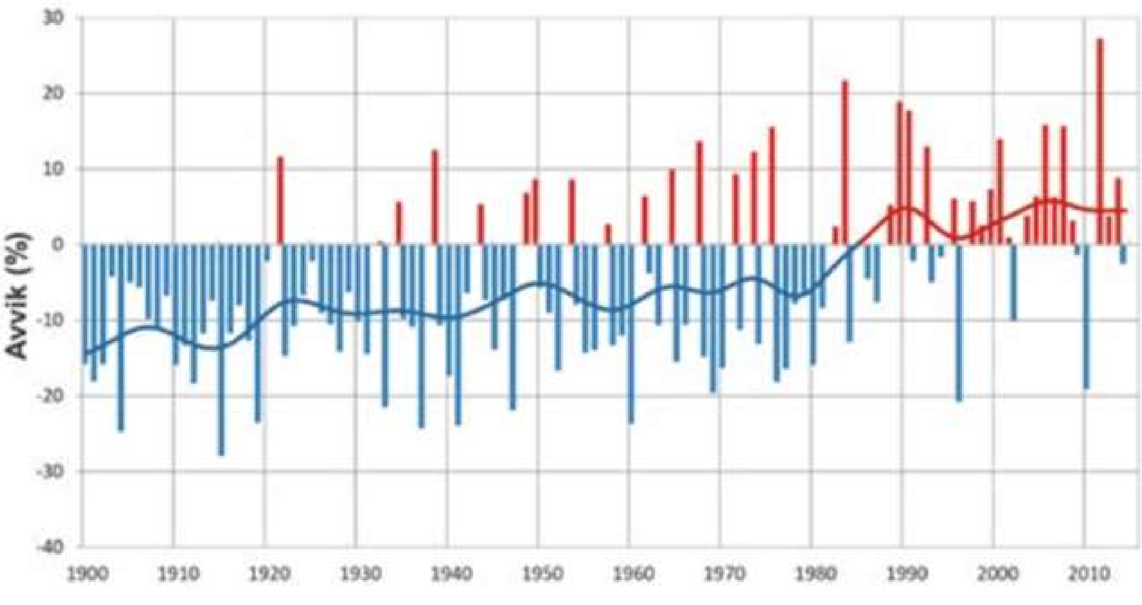

Figure 3 - Rainfall since 1900 (NCCS, 2015)

The UN's climate panel have created 4 emission-scenarios for year 2100. The scenarios are called RCP2.6, RCP4.5, and RCP8.5. RCP2.6 has the greatest amount of greenhouse gas reductions, and RCP8.5 is considered as a worst-case scenario, where the increase in emissions continue as before. Stormwater management infrastructure is normally planned for the worst-case scenario. Scientists claim that RCP8.5 seems unlikely nowadays due to the increased focus on emission cuts globally (Hausfather, 2019). Although scientist find the scenario unlikely, RCP8.5 remains as the most relevant climate scenario to focus on in this thesis because it is considered as the worst-case scenario. To consider climate change in planning, it is normal to multiply the dimensioning runoff with a climate factor to be equipped for the future RCP 8.5 climate.

3.1.2 Densification

In the national guidelines for urban development there is a major focus on densification (Kommunal- og moderniseringsdepartementet, 2019). The reasons for the focus on densification are population growth in the cities, the wish for less development on open green areas and reducing car use. There is a special focus on densification along the public transport axis so that public transport becomes more accessible and popular. However, densification and urban growth have led to replacement of green spaces with solid impermeable surfaces such as asphalt and concrete. Permeable surfaces are essential to allow the water to infiltrate in the ground. Replacing permeable surfaces with impermeable surfaces lead to water running faster and gathering in certain areas. The increase in water runoff intensity due to densification is shown in figure 4. The figure shows the change from natural unbuilt area on the top, to dense urban area in the bottom, where the runoff intensity increases with the density. The dotted line shows the runoff intensity with the additional effect of the future climate change.

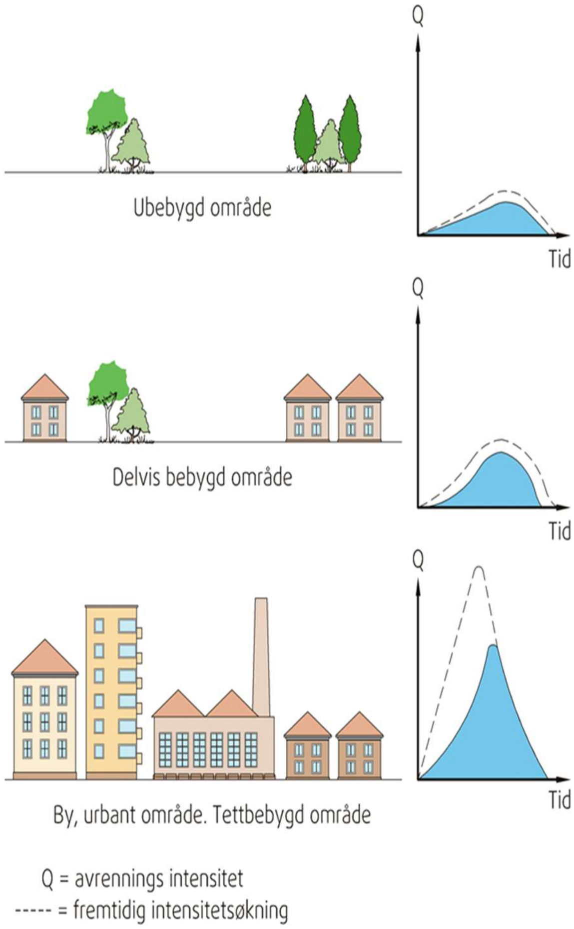

Figure 4 - Densification and runoff (Byggforsk, 2012)

Figure 6 show the natural water cycle where water is infiltrated into lots of green areas as well as vegetation transpiring water from the soil. Figure 5 shows the urban water cycle with much more water runoff, much less infiltration and no evapotranspiration from the trees. Evapotranspiration is the sum of evaporation from the vegetation and the vegetation's transpiration from the soil to the atmosphere. When vegetation is removed from the water cycle, a major part of the natural stormwater management is removed. For example, a medium large birchwood tree can transpire 100 litres per day (Berner, 2018). If permeable areas are replaced with impermeable surfaces, less water will be infiltrated to the groundwater. It is important to maintain the natural water balance in an area to avoid loss of local biodiversity as well as reducing risk of settlements in buildings (Ødegaard, 2014, s. 344)

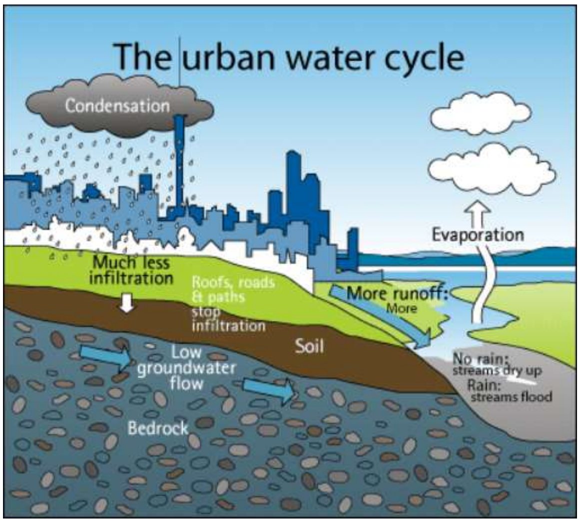

Figure 5 - Urban watercycle (blue planet, u.d.)

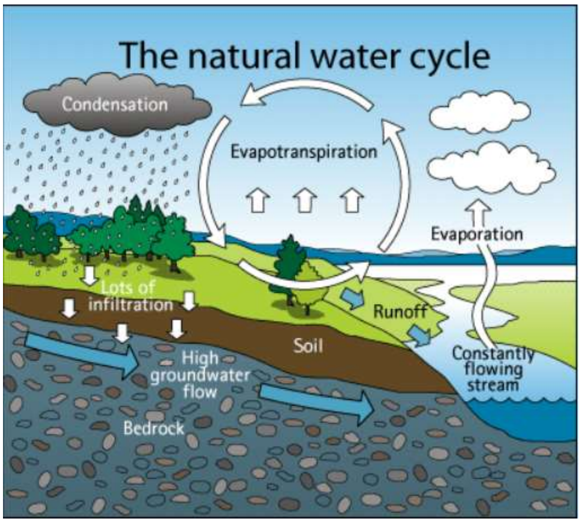

Figure 6 – Natural watercycle (blue planet, u.d.)

3.2 Planning theory in stormwater management

3.2.1 The three-link strategy

The three-link strategy is a strategy which has been developed in recent times, which explains how to handle stormwater locally in three parts. The first part is about infiltrating all rainfalls up to 20 mm. Permeable surfaces or greenery are popular and effective to use in this part. The second part is about managing rainfalls between 20 – 40 mm and involves slowing down and storing the runoff water. The third part is for rainfalls of over 40 mm and comes into play when the two previous parts no longer can control the runoff water. This part is about planning for safe flood ways, which the runoff water can use to reach its recipient. The process is also illustrated in figure 7. It is likely that stormwater is managed well if these parts are successfully implemented in the planning of an area.

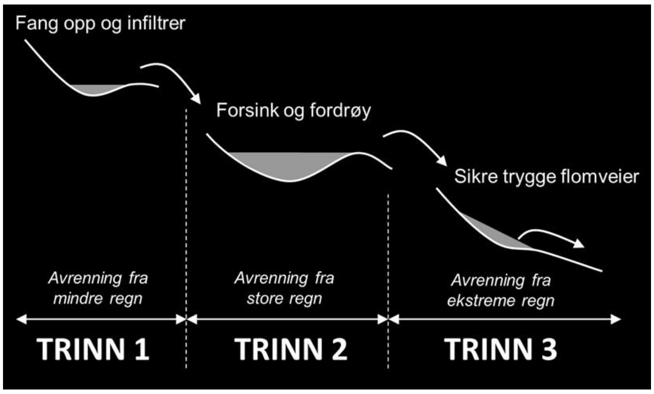

Figure 7 - Three-link strategy (Lørenskog kommune, 2017)

3.2.2 Catchment area based planning

A catchment area is an area which has a common runoff to a recipient (Rosvold, 2019). When regulatory plans are made, the catchment area often crosses multiple regulatory boundaries. The result of one implemented regulatory plan could affect other areas in the catchment area in a negative way.

Therefore, it is important to consider the entire catchment area when planning so the stormwater management will be more holistic.

A method developed for the catchment area based planning is presented in figure 8. The first part is about identifying areas which have been damaged by stormwater and areas which have been flooded in the past. Part 2 is about identifying the catchment area and create an overview of local climate data like rainfall, temperature and sea level. It is important to find information about the present situation as well as a prognosis for future climate data. Part 3 is divided into 4 parts. Part A is about finding information about areas which are relevant for infiltration. Examples of things to examine are the soil, the surface area, the slope of the surface area, and the bedrock of the area. Part B is about identifying areas which are important for the outdoor activity. Part C is about finding areas which are important for biodiversity and culture. Part D is about identifying areas which are good for housing development. The fourth and final part of this planning method has two alternatives. Alternative one is about identifying suitable areas for blue-green infrastructure. Alternative two is about identifying areas which are suitable for new housing and areas which are suitable for blue-green infrastructure when the cites are densified (Thorén, 2016).

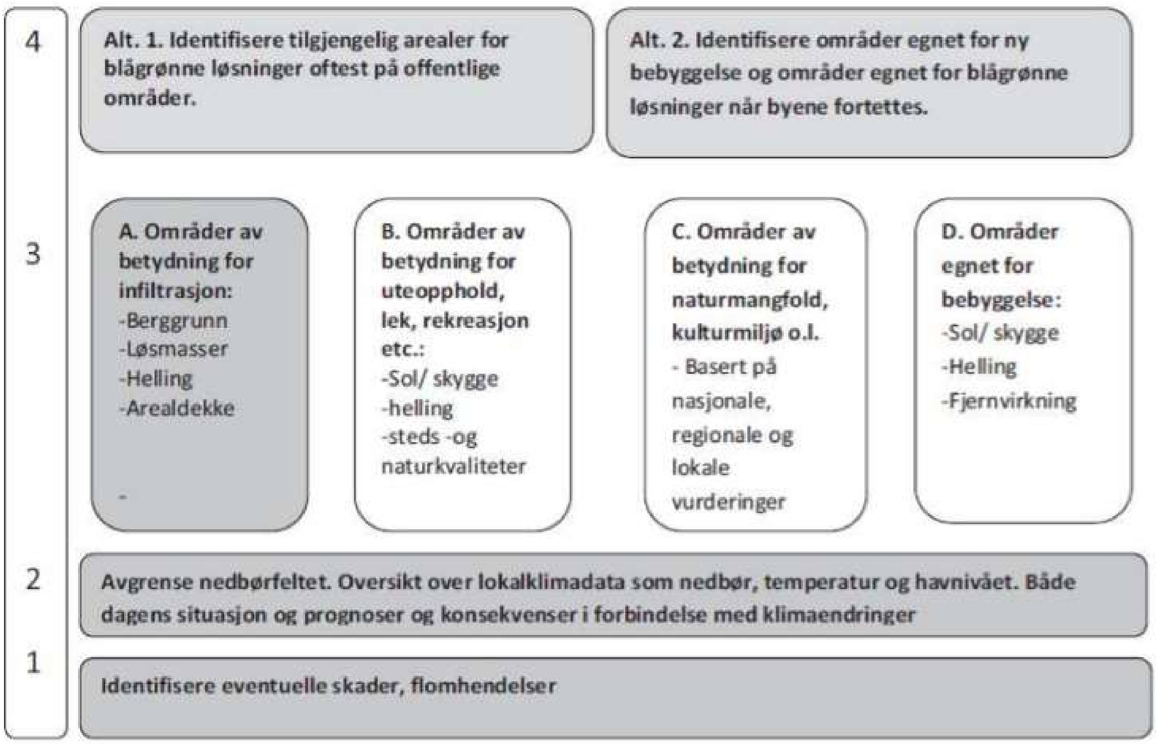

Figure 8 – Catchment area based planning (Thorén, 2016)

3.2.4 Local stormwater management

Local stormwater management is a concept which is about managing stormwater locally. The goal of local stormwater management is to prevent runoff to other areas which could cause overloads downstream. The concept is highly linked to utilizing blue-green infrastructure to infiltrate and detain the water in the local area, instead of using pipes to lead the runoff water away (Ødegaard, 2014, s. 345). Local stormwater management is based on using stormwater infrastructure which maintains the natural water balance of the area and uses the water as a resource in urban areas. The concept of managing stormwater locally with blue-green infrastructure is regarded as the most sustainable planning method. Blue-green infrastructures are considered as beneficial for the environment. They are also often considered aesthetically pleasing which attracts people for social interaction. Successful local stormwater management lead to less property damages due to floods, which may make them socioeconomically cheaper to invest in.

Runoff is a major source to polluting recipients. Runoff water is very effective in picking up litter, chemicals, toxic substances and fertilizers while running along surfaces (National Geographic, 2011). This can be quite harmful for the biodiversity. Some blue-green infrastructures can be quite effective in cleansing the stormwater. If the local stormwater management lead to less water in the pipes, there will also be less overflow of stormwater during heavy rainstorms. Overflow water is discharged directly out to the recipient without being purified. Overflow water can therefore be a major cause to recipient pollution when the overflow water originates from pipes which shares both sewage and stormwater.

3.2.5 The separation strategy

In conventional older stormwater infrastructures, it is common that manholes are used by both stormwater and sewage. This is called the “shared system” and is illustrated in figure 9 as the thick red lines. This has caused some issues during heavy rainfalls since the combination of both runoff water and sewage in one manhole has led to overloads and thus an overflow of water leading to the recipient. This overflow water is a combination of runoff water and sewage which end up polluting recipients. Sometimes the overload of the pipes of shared systems may lead to polluted water backing up through the manholes or through the sinks and toilets in basements. Shared systems have not been common to build since the 60’s, but they still exist in cities today.

Nowadays it is more common to build separate systems. This means that there is one pipe for sewage which is illustrated as the green line and one pipe for stormwater which is illustrated as the black dotted line in figure 9. Building a separated system results in a lot less overflows due to overloads. It also leads to less overloads in the sewage treatment plants.

The separation strategy is a strategy for separating existing “shared systems” to avoid the issues related to the shared system. Separating the shared systems is an expensive procedure, and the costs depend on how much the digging procedure affects other infrastructure and buildings. Different areas will have different benefits of separation. Some systems have a higher capacity than others, the conditions of the recipients vary and the amount of runoff water which is added to the shared systems also vary. Therefore, stormwater shall only be separated from shared systems where it is expedient (Bergen Kommune, 2018). This is an assessment which municipalities must make in each case.

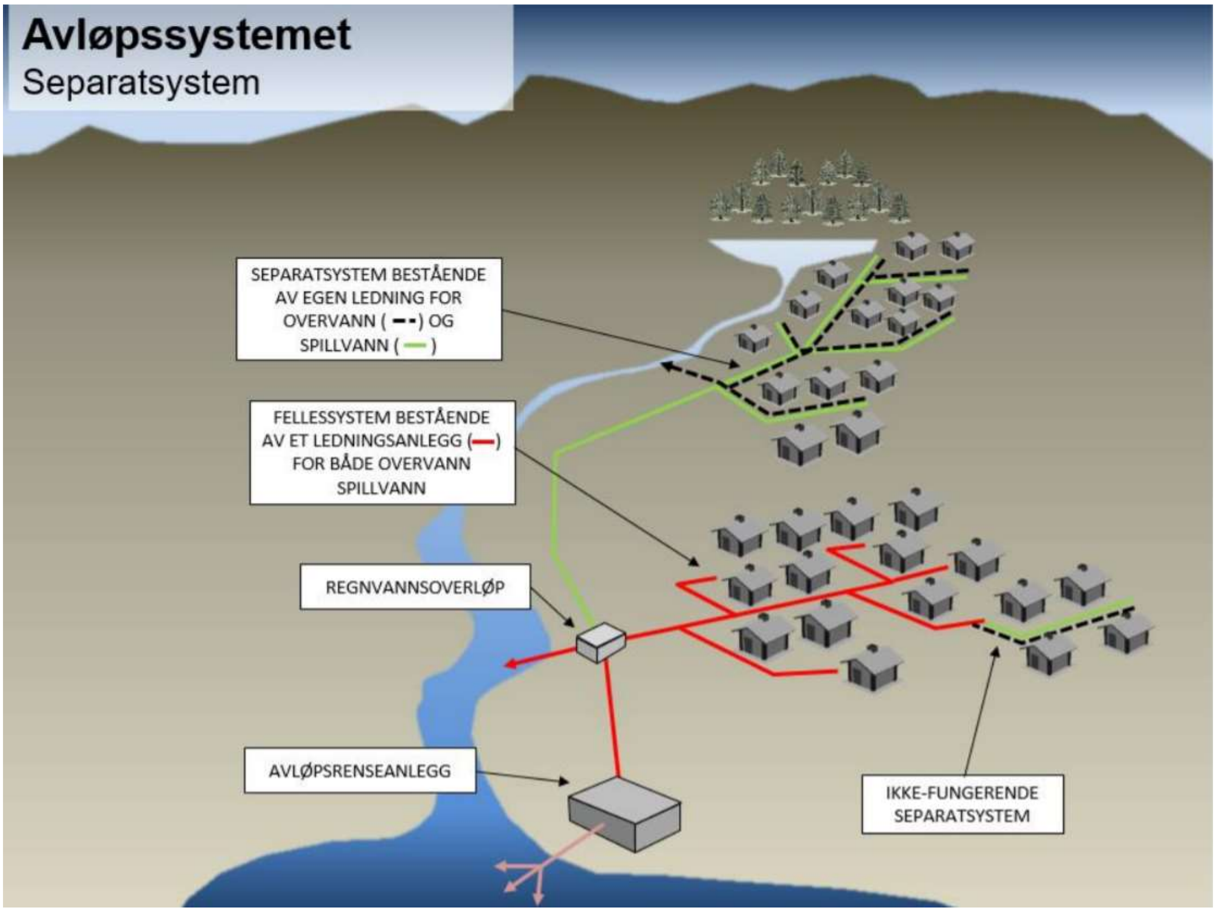

Figure 9 – Piping systems (Vannforeningen, 2017)

3.3 Stormwater management solutions

3.3.1 Raingarden

Raingardens, which is shown in figure 10, are flower beds which are designed to infiltrate and delay rainwater. They are made with multiple layers to infiltrate and delay water which reduces flood peaks and replenish the groundwater where the local masses have adequate infiltration capacity. Raingardens also have a cleansing effect on the water. The raingardens contribute mostly to the first part in the "three link strategy". They also contribute in the second part by delaying the runoff water (Miljødirektoratet, 2018). If the soil does not have the ability to infiltrate all the water, it can be convenient to add a perforated drainage pipe in the bottom part of the raingarden (Ødegaard, 2014, s. 367). During some periods, the raingarden may experience floods due to heavy rainfalls and other times there may be dry periods. Therefore, only certain plants, which are durable enough to handle different weather conditions, are suitable to use in a raingarden.

Raingardens are great to use for local stormwater management. They are suitable to use in most urban areas to manage stormwater as well as acting as an aesthetic element in cities. The placement of the raingarden is an important factor in planning. The raingarden cannot be placed in the shadow because the sunlight is essential for the vegetation to grow. The raingarden should also not be placed close to buildings with basements due to the risk of water damages on the buildings (Ødegaard, 2014, s. 368). It is also important to not place raingarden in areas which are steeper than 20 % because of the risk of erosion in the soil of the raingarden. The size of a raingarden should be 5-10 % of the catchment area but will depend on how much area is available to use. (Miljødirektoratet, 2018)

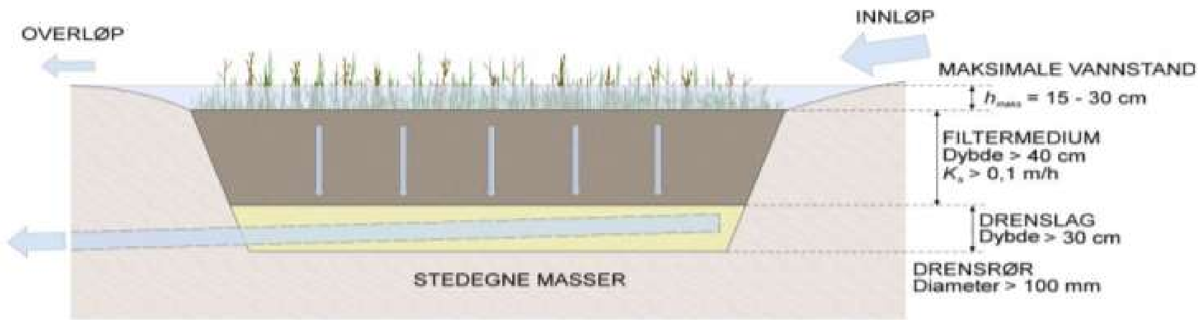

Figure 10 – Raingarden
(Oslo kommune, 2016)

3.3.2 Permeable surfaces

An alternative to impervious surfaces like concrete and asphalt is permeable surfaces. Permeable surfaces can be used for squares, sidewalks, roads and parking facilities. Examples of permeable surfaces used in urban areas are cobble stones, paving stones and porous asphalt. The porous asphalt consists of a pore system which has the ability to infiltrate water to underlying soil. Porous asphalt can infiltrate up to 1000 l/min/m^2 (Teknisk Ukeblad, 2015). Permeable surfaces are a great contribution to local stormwater management and contributes to the first part in the three-link strategy. They are also great at cleansing the runoff water since most pollution will remain on the surface. Permeable surfaces usually do not require a lot of maintenance. Some require more maintenance than others. The porous asphalt will for example have an impaired ability to infiltrate water if particles gather in the pores of the asphalt. It is crucial for the function of the permeable surfaces that the underlying soil have an adequate infiltration capacity (Interpave, 2012).

3.3.3 Green roofs

Planting green roofs, like shown in figure 11, is a popular measure to manage stormwater nowadays. Green roofs are roofs covered with vegetation which can infiltrate, delay and cleanse the stormwater before it reaches the ground. Therefore, they contribute in part 1 and 2 in the three-link strategy. The amount of runoff which is reduced from roofs by adding greenery depends on how much greenery is added as well as what type of greenery. It also depends on how saturated the vegetation is. A study on green roofs showed that green roofs had 63 % less runoff than the conventional roof during growing season (Seters, Rocha, Smith, & MacMillan, 2008). They can be built on roofs which are not too steep, and which can endure the additional load of the wet vegetation. There are three different types of green roofs:

Figure 11 - Green roof (Infobeck, 2011)

- Extensive green roofs
- Semi Intensive green roofs
- Intensive Green roofs

Green roofs can be distinguished by the vegetation type and substrate thickness.

Extensive green roof is the roof type with the thinnest soil and uses vegetation which does not have deep roots. It is normal to use grasses, sedum or mosses for this type of roof. Extensive roofs are the cheapest green roof type and requires the least amount of maintenance. This type of green roof is usually not suitable for the use of people since the vegetation is quite fragile (Archtoolbox, 2020).

Semi Intensive green roofs have a deeper layer of soil than the extensive green roofs. The semi intensive roof can have planting such as herbs, taller grasses, flowering plants and small shrubs. This roof is heavier, more expensive and requires more maintenance, but can handle more rainwater than the extensive roof. Semi intensive roof is more suitable to be occupied by people (Archtoolbox, 2020).

Intensive green roofs have the deepest soil and can have planting with very deep roots. This roof type is more suitable for large roofs, where the designer can create a parklike design to the rooftop for people to use. It is the most expensive roof type and require a lot of maintenance. Intensive green roofs can have all types of vegetation from regular plants to trees and is the most effective roof type for stormwater management (Archtoolbox, 2020).

3.3.4 Flood ways

As mentioned earlier, there must be planned flood paths for rain events where it rains 40 mm or more. When the first and the second part of the three-link strategy are no longer able to handle the stormwater, the water will run on the surface and follow the slope of the terrain. Where the water gathers and runs along the terrain is called drainage lines (Oslo kommune, u.d.). Drainage lines are often created by municipalities or planners by using terrain models in for example GIS. They can be used in the planning of flood ways. It is important to check if the drainage lines lead the water into areas where the water could potentially do damage on property or infrastructure. Flood ways should be planned so that the water is led to the recipient or an area where it can be temporarily stored in a manner where it will do the least amount of damage. Dimensional recurrence period for flood ways will depend on the consequences of floods (Paus K. H., 2017). Figure 12 shows a diagram which explains the theory of how the optimal recurrence interval is chosen. The optimal recurrence interval is illustrated by the black dotted line, which is where the function of repair costs of potential flood events crosses the function of preventative measures. Flood ways can for example be roads, reopened streams or rivers, canals, etc.

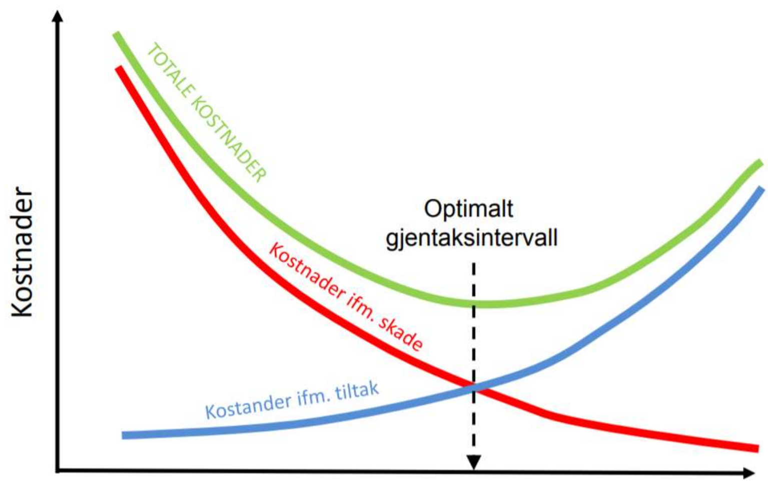

Figure 12 – The theory behind choosing the optimal recurrence interval. The black dotted line indicates the optimal recurrence interval.
(Paus K. H., 2017)

3.3.5 Stormwater detention vault

A stormwater detention vault is a vault which detain stormwater during rain events to prevent floods. These vaults are placed underground and is very effective in the second part of the three-link strategy. The detention vaults can be large pipes or cassettes which stores water and releases it through a small outlet in a controlled manner. Stormwater detention vaults are suitable to use if the area has limited space or has terrain constraints which doesn't allow to use other open infrastructures (Gosney, 2018). Figure 13 shows a detention vault which is connected to a manhole.

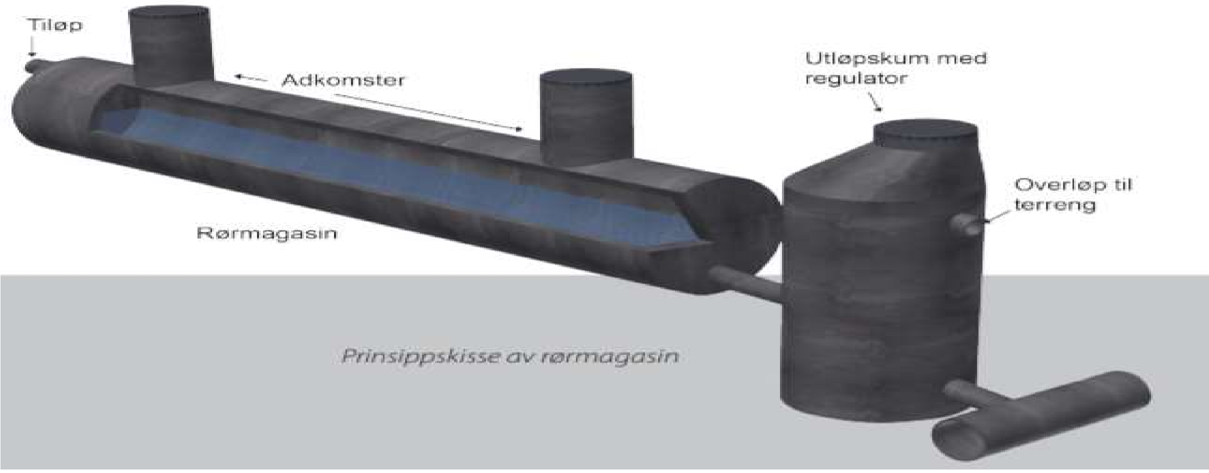

Figure 13 – Stormwater detention vault (Basal)

3.3.6 Ponds

Ponds are infrastructures which are frequently used to detain stormwater during rain events. There are two different types of ponds within stormwater management:

- Retention ponds
- Detention ponds

A detention pond has an orifice level at the bottom of the basin to drain the water, and therefore does not have a permanent pool of water (Leber, 2015). Detention ponds are known for being suitable for the second and third part of the three-link strategy because they can both detain water as well as being used as a temporary flood area. Areas which could be used as detention ponds could be anything from skateparks to lawns which could hold a temporary basin of water.

A retention pond, like shown in figure 14 and 15, is a pond with a permanent basin of water. They are designed to have a minimum and maximum water level. The water which is above the minimum water level is the water which is being detained in the basin, and which will slowly run out through an outlet to

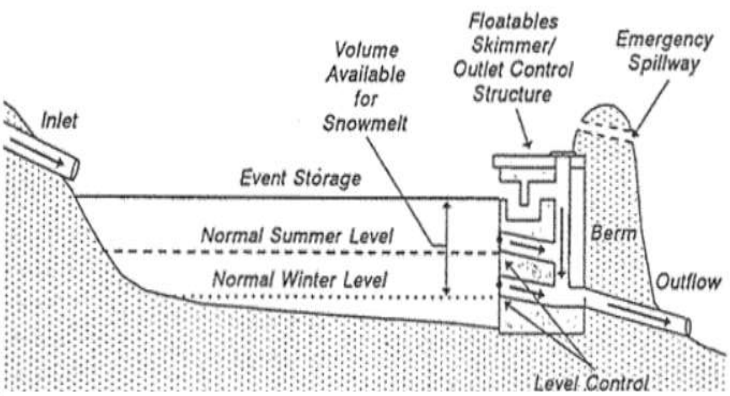

Figure 14 - Retention pool principle design (Stormwater PCA, u.d.)

the recipient. The dimension of the outlet is dimensioned to suit the recipient's capacity (Ødegaard, 2014). Since retention ponds have a permanent basin of water they are considered as an aesthetic element in urban areas. To prevent algae growth, it is popular to install fountains which keeps the water moving. It is important that the slope around the retention pond is gentle to prevent accidents (Ødegaard, 2014, s. 359). Ponds which are deeper than 20 cm must also be secured to prevent people falling into them (Plan- og bygningsloven, 2009, § 28-6).

Figure 15 - Retention pool (Lapinservices, 2015)

3.4 Reference projects

3.4.1 Deichmans street

Deichmans street is an urban street in Oslo which previously had a lot of issues with stormwater because of runoff from other streets and the street design. Flooded basements and overloaded manholes were frequently reported, and something had to be done. The buildings in the area were also built on fleets, which could rot if the groundwater became too low. Lower groundwater could also lead to settlements in building as previously mentioned. To solve the problems, it was decided to implement local stormwater management infrastructures like raingardens, open chutes and water sculptures (Klima Oslo, 2017).

The street became a pilot project for local stormwater management in Norway and there was installed measurement devices to measure the effect of the raingardens. There was installed 9 raingardens in the street which are all designed differently to measure which design works best (Asplan Viak, 2017). In total the raingardens have the capacity of detaining 60 m^3 of water and can hold a temporary water level of 25 cm (Klima Oslo, 2017). The raingardens were dimensioned for 20-year rain events. The street was also installed with permeable surfaces (Arkitektur skaper verdi, u.d.). Deichmans street is illustrated in figure 14.

The result of the project was:

- The street felt safer and was more often used as a social meeting place
- The access to greenery reduced stress
- The risk for floods was reduced
- The maintenance costs for the raingardens were low (Arkitektur skaper verdi, u.d.)

Figure 16 - Deichmans Street
(Arkitektur skaper verdi, u.d.)

3.4.2 Copenhagen

Copenhagen has been experiencing a lot of extreme rainfalls in the summers over the past years. The city experienced its most extreme rainfall in 2011 when 150 mm fell in 2 hours. This is the same amount of rain which normally falls in 2 months. This was a clear sign of climate change for the municipality of Copenhagen, and they needed to adapt. After this incident they prepared the “Cloudburst plan”. The plan was prepared with the precautionary principle in mind. By this they mean to invest in preventative measures rather than paying the costs after a rain event (Oslo Kommune Vann- og avløpsetaten, 2016).

Figure 17 - Detention Pond
(Oslo Kommune Vann- og avløpsetaten, 2016)

The plan emphasises investing in local open infrastructure rather than conventional closed infrastructure. Copenhagen municipality decided to invest 11 billion NOK in preventative measures for 20-year rain events. About 300 projects are planned to secure roads and buildings from floods and prevent harbour pollution. The "cloudburst plan" is often considered as a good role model in stormwater planning for the future climate. Many of the projects have now been completed. Examples of measures which have been done are sealing stormwater drains (to prevent overloaded shared sewage systems), transforming vulnerable impermeable areas into blue-green areas, developing local stormwater treatment networks and building multifunctional stormwater detention pools as in figure 17 and figure 18.

Figure 18 - Multifunctional detention pool (Oslo Kommune Vann- og avløpsetaten, 2016)

3.4.3 Augustenborg

Augustenborg is a large neighbourhood in Malmø, Sweden, which was built in the 50's. At this time, the stormwater system consisted of conventional shared piping system. The stormwater system was eventually frequently overloaded due to densification in other places in the catchment area. Basements were often flooded, and the area quickly became less attractive (Oslo Kommune Vann- og avløpsetaten, 2016).

Figure 19 – Stormwater chute (Oslo Kommune Vann- og avløpsetaten, 2016)
The chute has small blocks which slows the runoff water down.

Malmø initiated a blue-green initiative in 1998. It was chosen to handle the stormwater locally instead of installing separate pipes for stormwater and sewage. There was a focus on keeping the water visible in the area by for example using ditches, chutes and open detention ponds. Some of the new infrastructures had clever designs, as possible to see in figure 19 and figure 20. The new stormwater system was dimensioned for a 25-year rainstorm. Augustenborg also became the home of Scandinavian Green Roof Institute which works with research on green roofs. The area had a lot less issues after the upgrades and became an area which increased in popularity (Oslo Kommune Vann- og avløpsetaten, 2016).

Figure 20 – Stormwater chute (Oslo Kommune Vann- og avløpsetaten, 2016)
The chutes have small bumps to slow down the water and increase oxygen level in the water

4.3.4 Reference projects summary

The reference projects have shown how stormwater infrastructure is planned in modern times. The different cities are all somehow linked to the major rain event which happened in Copenhagen in 2011, and the cloudburst plan which was developed because of it. Something which is in common for all three cities is the focus on planning open and blue-green infrastructure. In Deichmans street in Oslo, the use of raingardens as an aesthetic and effective element in urban areas was shown. Copenhagen showed how open stormwater retention ponds can be used as a multifunctional infrastructure for either recreation and/or social interaction. Copenhagen also chose to close the stormwater drains in some cases rather than planning new stormwater pipes. Augustenborg had a similar approach to stormwater planning as Copenhagen, where the focus was often on installing open blue-green infrastructure rather than new stormwater pipes. Augustenborg is also the home of the "Scandinavian green roof institute", which has showed the great effect of green roofs through research.

4 Study area

The chosen study area is an area at Danmarksplass in Bergen which is marked as a yellow square in figure 21. The underpass at Danmarksplass, which is marked with a yellow circle in figure 21, crosses under E39 Fjøsangerveien and connects Danmarksplass to Solheimsviken on the west side of E39. Danmarksplass is considered a downtown area in Bergen and is situated in Årstad district which is south of the city centre of Bergen.

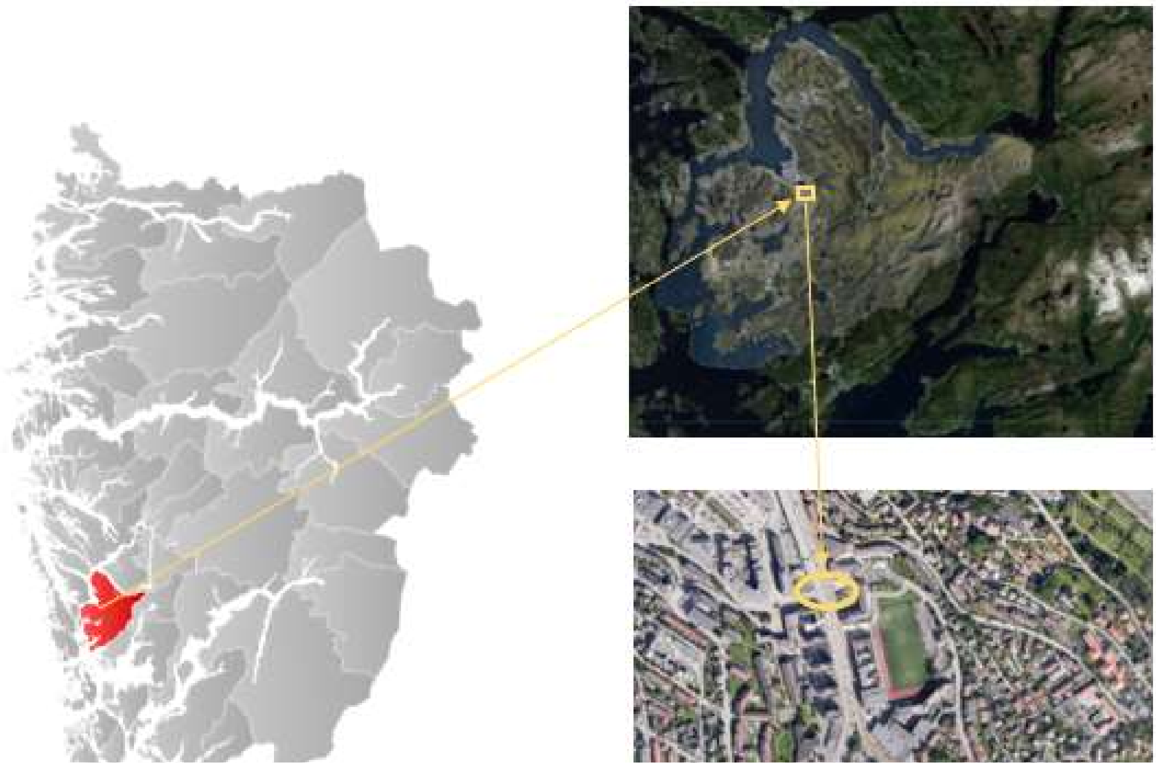

Figure 21 - Location of the study area. From (Wikipedia, 2020) and google maps
Edited by Eirik Instanes

4.1 Background for choice of study area

The background for choice of study area was a wish for writing about stormwater management in Bergen. Bergen is interesting in the topic of stormwater management because Bergen is known for being the "rain city" of Norway and will, as previously mentioned, according to research have a severe increase in rainfall in the coming future due to climate change. The average annual rainfall in Bergen is 2 511 mm. It was important that the study area had a lot of impermeable surfaces, little greenery, and an old stormwater infrastructure. It was also important that there had been reported a lot of floods which had serious consequences for the area.

The underpass at Danmarksplass is an area which fit those study area criterions which are mentioned above. As possible to see in figure 23 and figure 24, the stormwater issue at Danmarksplass can be severe and hinders pedestrian access to western side of E39 Fjøsangerveien. The water can in some areas of the underpass reach to chest height. In cases like these, the fire department must pump the water out of the underpass, so it can regain its function for the pedestrians. This unfortunately often take time, and the pedestrians, like the girl in figure 23, must find other ways to cross to the other side of E39.

Figure 25 - Birdseye view of Danmarksplass
Picture taken from Google maps

Figure 25 - Flood at the underpass at Danmarksplass
(Bergens tidene, 2018)

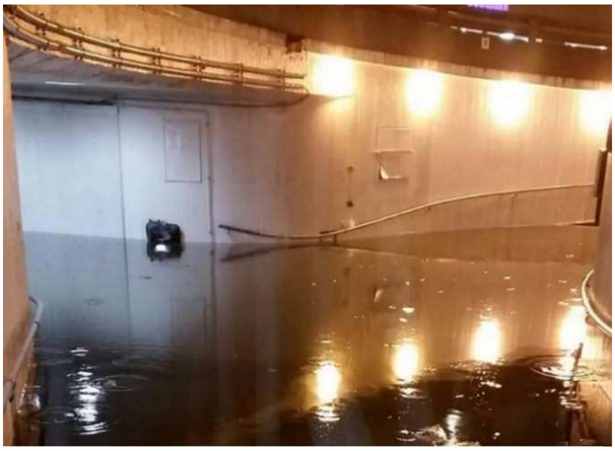

Figure 25 - Another flood event at Danmarksplass
(BA, 2015)

Figure 25 - Danmarksplass underpass before flood
(Den, 2010)

In figure 22 there is a bird's eye view of Danmarksplass where it is possible to see that the area is quite urban and buildings and impermeable surfaces dominate the area. Figure 25 shows the inside of the underpass when it is not flooded. The surface here is also impermeable, so if the stormwater system is overloaded, the water will gather and flood the underpass.

4.2 Overall plans, strategies and legislation

This subchapter deals with plans, strategies and legislation which are relevant for stormwater planning at Danmarksplass. The municipal plans must be in line with the national and regional plans, strategies, and legislation, and are therefore the most detailed.

Laws and acts:

- Planning and building act (PBL) (Kommunal- og moderniseringsdepartementet, 2008)
- Water and sewerage act (Klima- og miljødepartementet, 2012)
- Technical building act (TEK17) (Kommunal- og moderniseringsdepartementet, 2017)
- The pollution act (Klima- og miljødepartementet, 2004)
- Regulations on the framework for water management (Miljøverndepartementet, 2006)

National guidelines

- «NOU 2015:16 Overvann i byer og tettsteder»
- «NOU 2013:10 Naturens goder – om verdier av økosystemtjenester»
- «NOU 2010:10 Tilpassing til eit klima i endring»
- "Klimatilpasningsmeldingen, Stortingsmelding 33"

Regional guidelines

- Regional plan for water region Hordaland with additional action program. (Hordaland fylkeskommune, 2015)
- Measure plan for water region Hordaland (Hordaland fylkeskommune, 2015)

Municipal guidelines

- Bergen municipal plan (the societal part) (Bergen municipality, 2015)
- Bergen municipal plan (the area part) (Bergen Kommune, 2018)
- Municipal subplan for blue green infrastructure in Bergen (Bergen Kommune, 2014)
- Main plan for sewage and water environment 2019-2028 (Bergen Kommune, 2019)
- Bergen municipality Water and sewage norm ("VA-norm") (Bergen Kommune, 2020)
- Bergen municipality climate and energy action plan (Bergen Kommune, 2016)
- Guidelines for stormwater management in Bergen municipality (Bergen Kommune, 2005)

Some of the relevant guidelines for Danmarksplass from the “Guidelines for stormwater management in Bergen municipality” document are listed below:

- Stormwater planning should always be carried out in catchment area based and cover the entire planning area (Bergen Kommune, 2005)
- The stormwater system should divert rainfall (rainwater and snow) in a safe, environmentally friendly and cost-effective manner to safeguard the health, safety and financial interests of the inhabitants. (Bergen Kommune, 2005)
- All stormwater should preferably be taken care of locally, that is through infiltration, leading water to the recipient, or otherwise utilized as a resource so that the water cycle is maintained, and nature's self-cleaning ability is utilized. Leading stormwater to public sewage system should be minimized. (Bergen Kommune, 2005)
- Open floodway’s must be indicated on maps. New measures must also not hinder the existing flood paths (Bergen Kommune, 2005)
- Climate change must always be considered in planning (Bergen Kommune, 2005)
- The natural water balance is to be maintained within the plan area. (Bergen Kommune, 2005)
- Stormwater should be made more visible and accessible in built-up areas / urban areas. (Bergen Kommune, 2005)
- Blue-green infrastructure should be prioritized. (Bergen Kommune, 2005)
- Existing closed streams should be considered reopened (Bergen Kommune, 2005)
- If possible, runoff coefficient should be reduced. This can be achieved, among other things, by facilitating good infiltration, attachment of permeable surfaces and disconnection of dense surfaces. (Bergen Kommune, 2005)
- Stormwater should not affect the water quality in the recipient negatively. (Bergen Kommune, 2005)
- Stormwater management should, if possible and expedient, be planned so that the area can also be used for play, recreation and park-like elements in built-up areas. (Bergen Kommune, 2005)

Danmarksplass is in the area part of the municipal plan regulated as a district downtown area.

The only existing regulatory plan for the area is from 2007 which is illustrated in figure 26. In this plan the area was regulated as offices/public area and facility for sport and athletics (Bergen kommune, 2020).

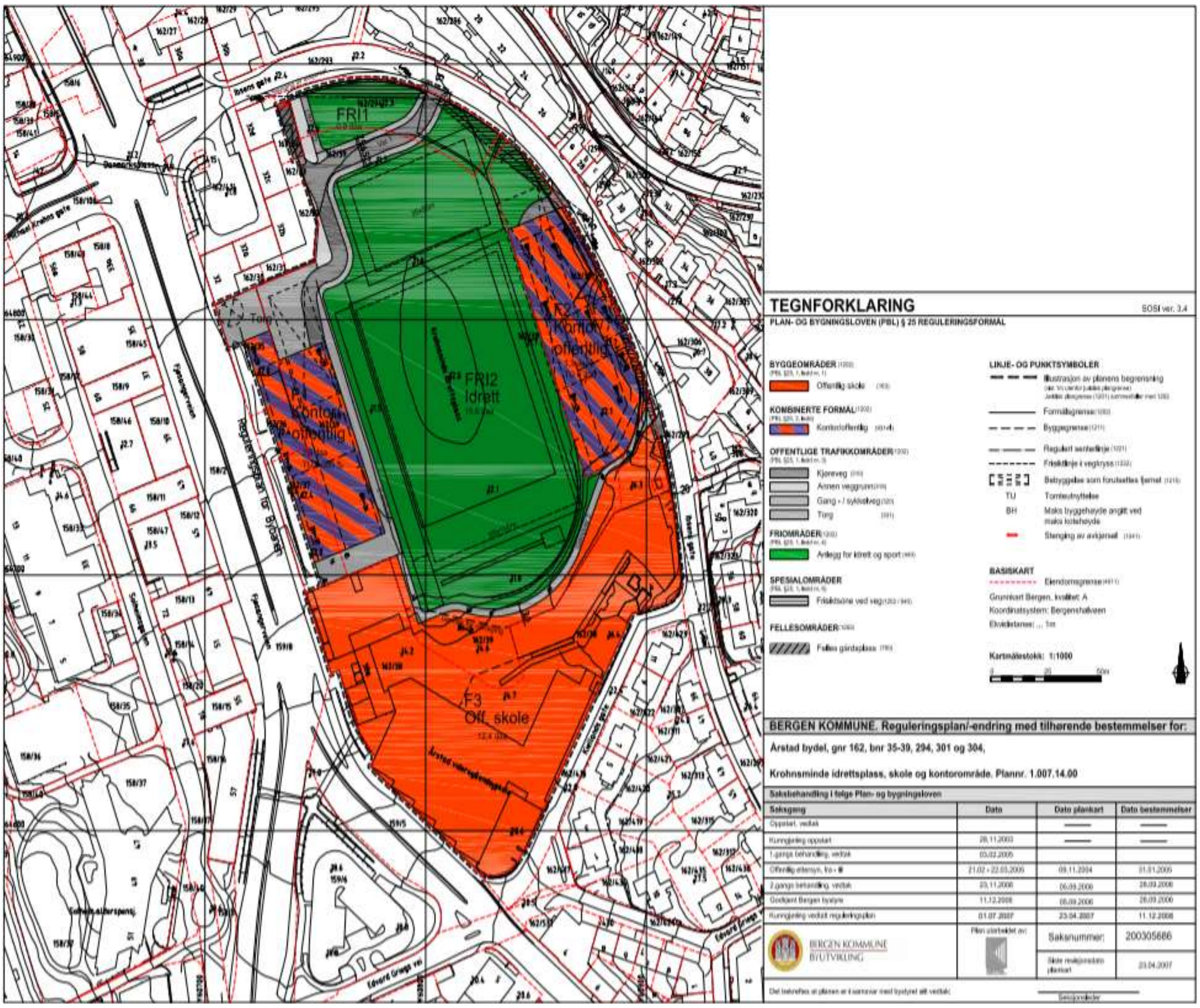

Figure 26 - Old regulatory plan at Danmarksplass (Bergen kommune, 2020)

4.3 Registrations

4.3.1 Stormwater system

The existing stormwater system at Danmarksplass is illustrated in the map in figure 27 and was made by Vann- og avløpsetaten in Bergen. The map is quite difficult to read as there is a lot of different types of pipes in the area. According to the legend, the red pipes are "shared system" pipes, and the black lines are stormwater pipes. After studying the map, it seems like the study area is connected to shared system pipes. There is no stormwater detaining system marked in the area on the map.

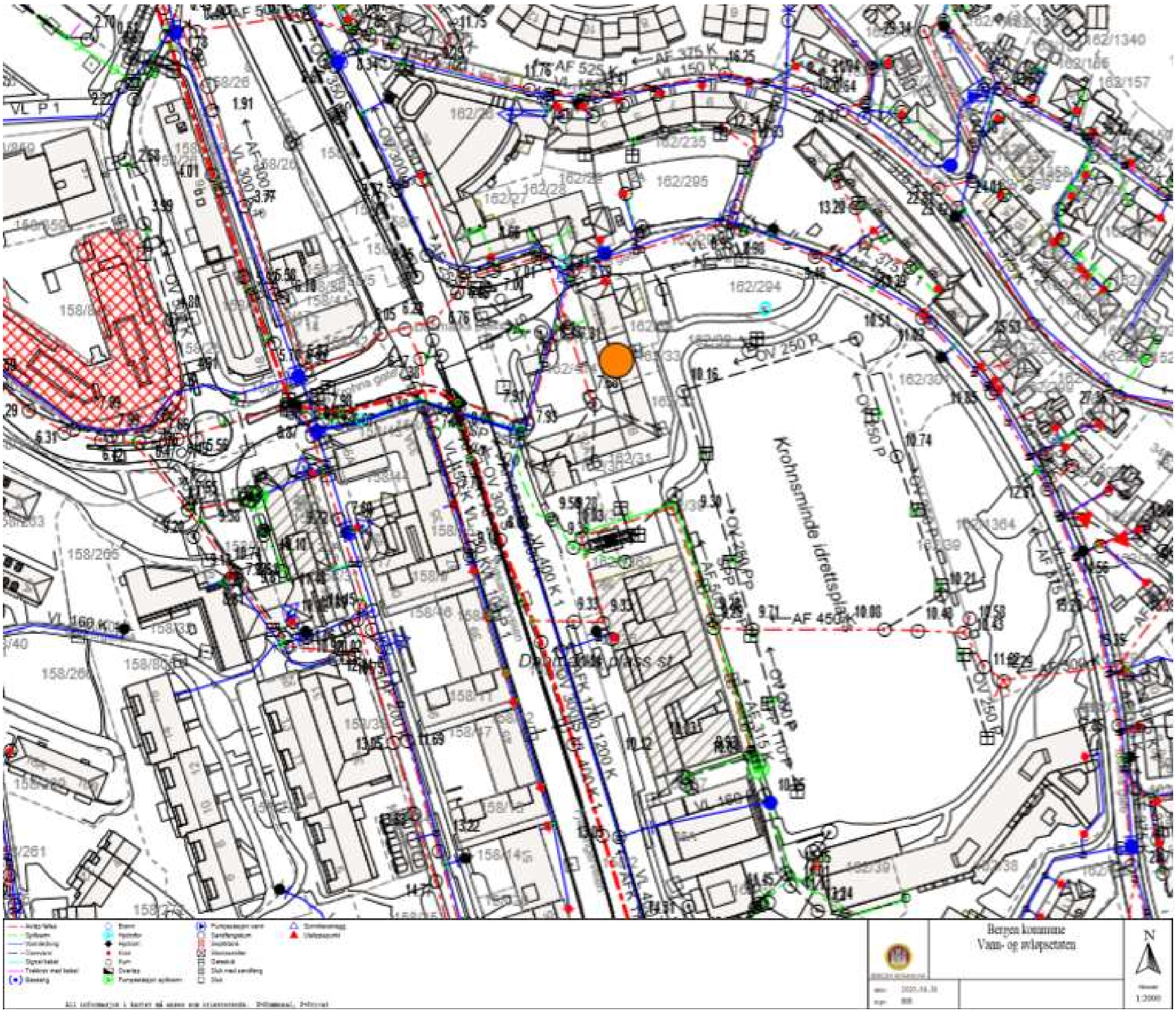

Figure 27 - Piping infrastructure at Danmarksplass
Created by Vann- og avløpsetaten in Bergen municipality

There was noted 5 drains in the underpass at Danmarksplass, like shown in the picture in figure 28. There is 1 drain in front of every entrance to the underpass which is illustrated with circles in figure 29.

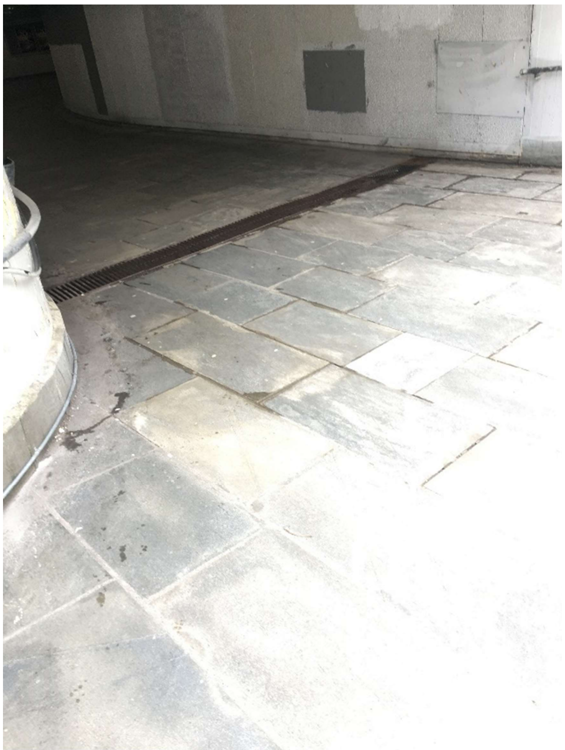

Figure 28 - Stormwater drain in the underpass
Picture taken by Eirik Instanes

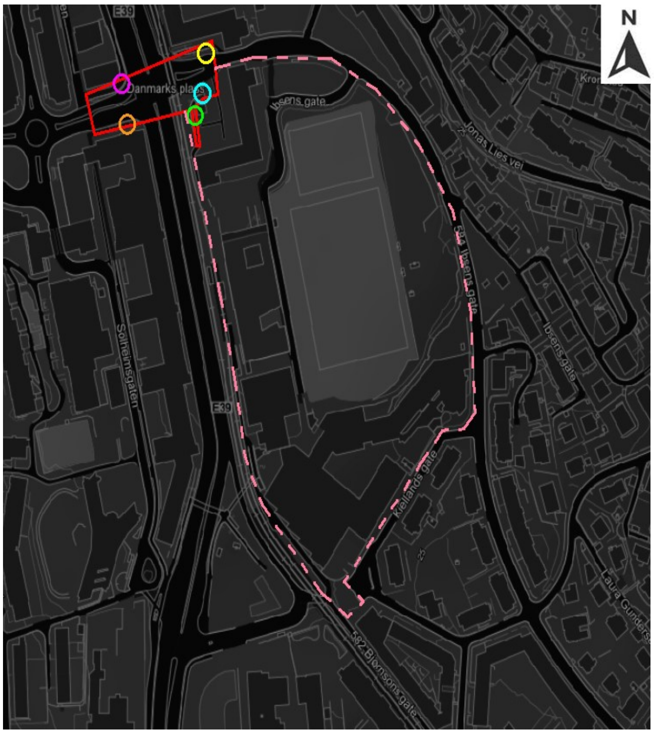

Figure 29 - Illustration of the 5 entrances with their associated drains
Created by Eirik Instanes in Autocad

4.3.2 Topography and soil conditions

Danmarksplass is situated in a rather flat area next to mount Løvstakken. The surface of the study area has a slight slope of 2,5 % leading north west as illustrated in figure 30. The highest point of the study area is 20m and the lowest is 11m.

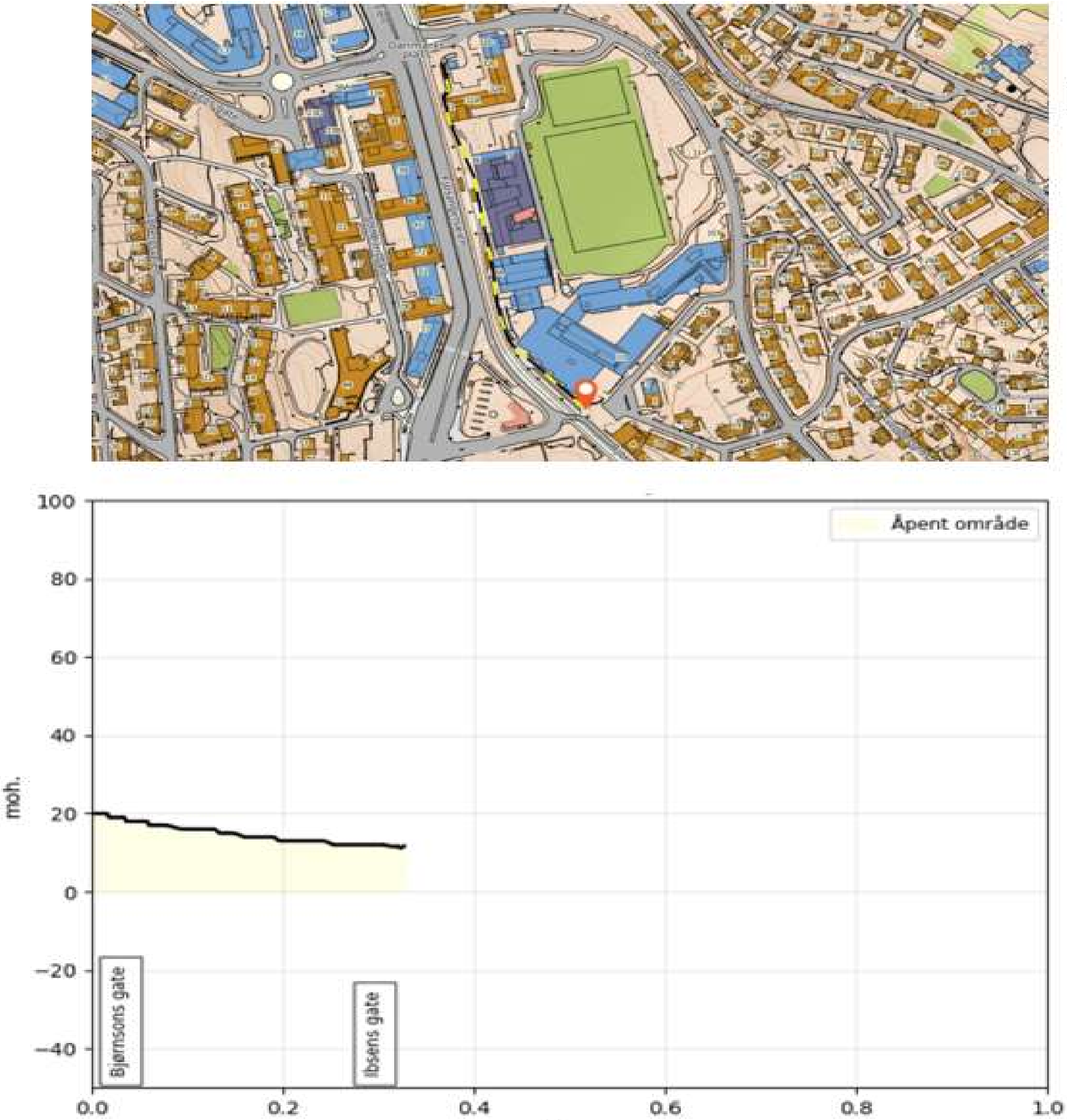

Figure 30 - Slope of study area. The black and yellow line illustrates the distance measured
The illustration was created by Eirik Instanes with the use of the map function at Norgeskart.no

The surface area outside the underpass consists of mostly impermeable surfaces such as concrete and asphalt. There are some trees and planting as possible to see in figure 31, but the impermeable surfaces dominate the area. There is a small fountain in the area which is marked as the small blue square.

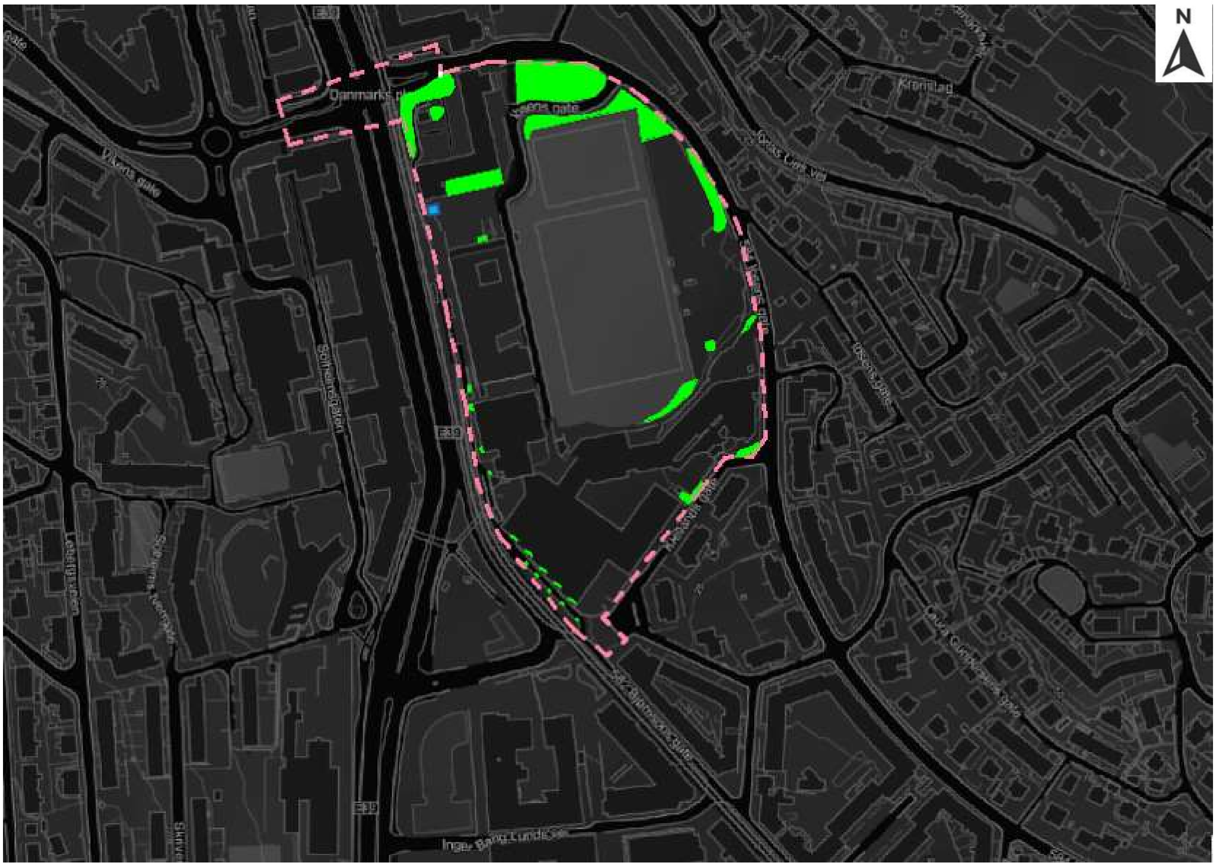

Figure 31 - Existing greenery
Created by Eirik Instanes in Autocad

Danmarksplass is an urban area with a lot of tall buildings. One of the roofs is green, and the rest have standard impermeable roofs. The buildings at Danmarksplass are commercial and residential. Some of the important buildings at Danmarksplass are for instance Årstad high school, Danmarksplass district psychiatric centre, and Forum cinema. The surrounding area of Danmarksplass is mostly residential with a lot of single and semi-detached housing. Solheimsviken business park is also next to Danmarksplass where "Legevakten" and large businesses like GC Rieber and DNB take place.

There is major infrastructure dominating the area at Danmarksplass such as E39 and the city light rail. Danmarksplass is one of the heavy trafficked light rail stops in Bergen. The light rail stop serves a lot of residents in the nearby area, as well as the businesses, and therefore generates a lot of pedestrian traffic through the underpass. Figure 32 shows the buildings and the infrastructure in the area.

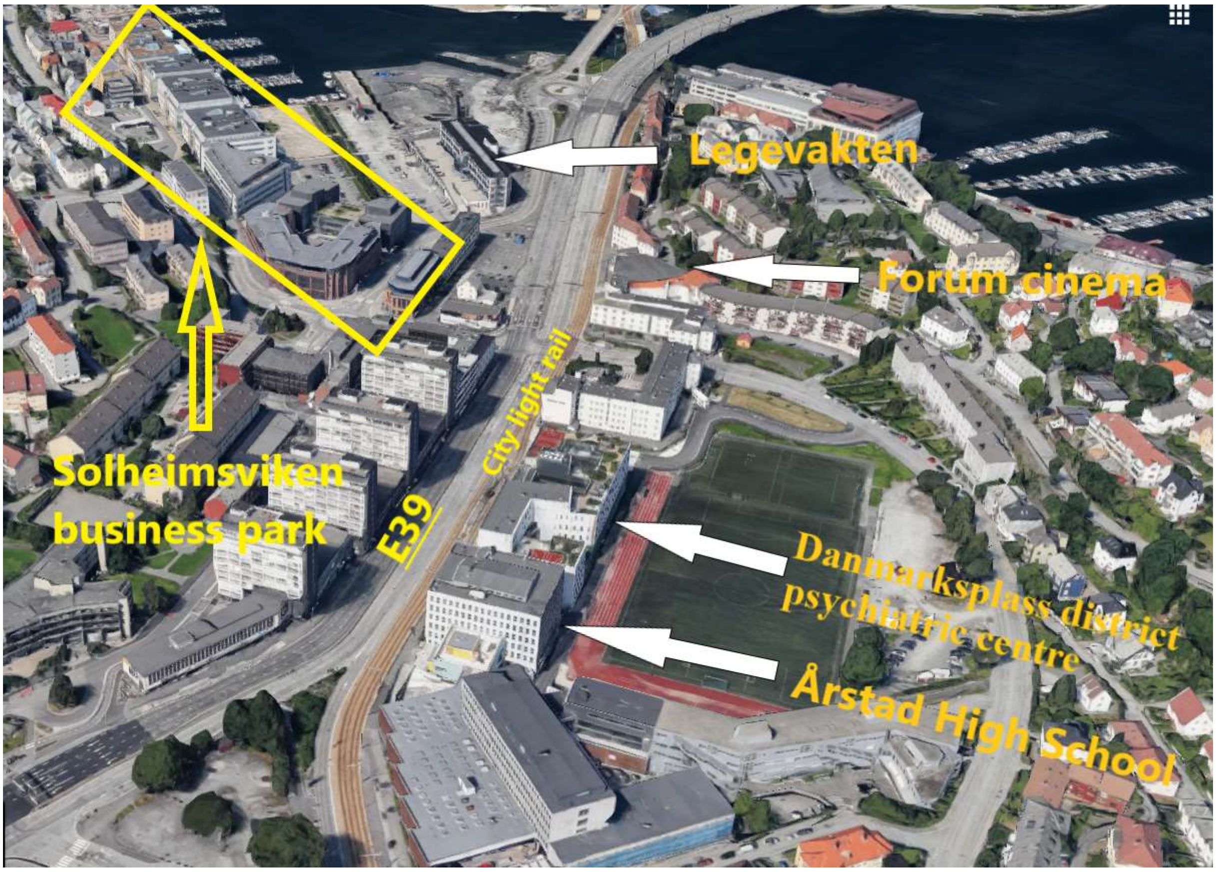

Figure 32 - Buildings and infrastructure at Danmarksplass

Map retrieved from Google Maps and edited by Eirik Instanes

The soil condition of the area is illustrated in soil map in figure 33. Danmarksplass is marked as a yellow rectangle. As possible to see in the soil map, Danmarksplass is dominated by "filler mass", which is defined as anthropogenic material that is "supplied or strongly influenced by human activity" (NGU, 1991). It is already known, after the inspection of the area, that not all the areas which are marked as filler mass, is actually filler mass in reality. The map is not very detailed and a bit generalized, where dense urban areas have been classified as filler mass, even though there is greenery in the area. It is hard to determine what kind of soil is underneath this filler mass without doing soil tests. It can be assumed that the soil at Danmarksplass is "thin moraine soil" since this soil type exists in the nearby area close to Minde. Both Minde and Danmarksplass are also situated in the bottom of a valley and it is therefore likely that there is moraine soil in the area since moraine soil are usually found in valleys.

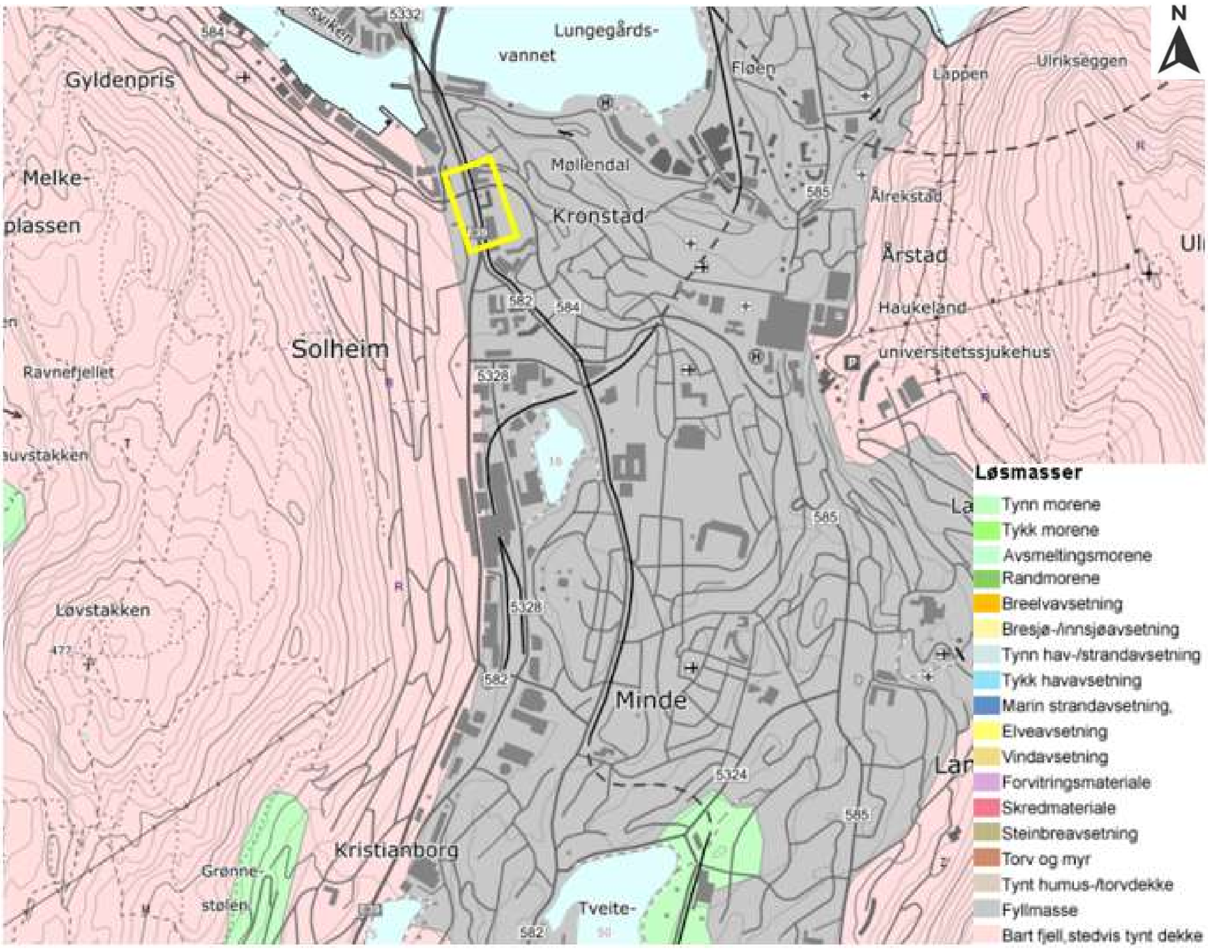

Figure 33 - Soil conditions at Danmarksplass. The yellow square is Danmarksplass. (NGU, u.d.)

The different soil types have different infiltration capacities. The thin moraine soil has, according to the infiltration capacity map in figure 34, a low infiltration capacity.

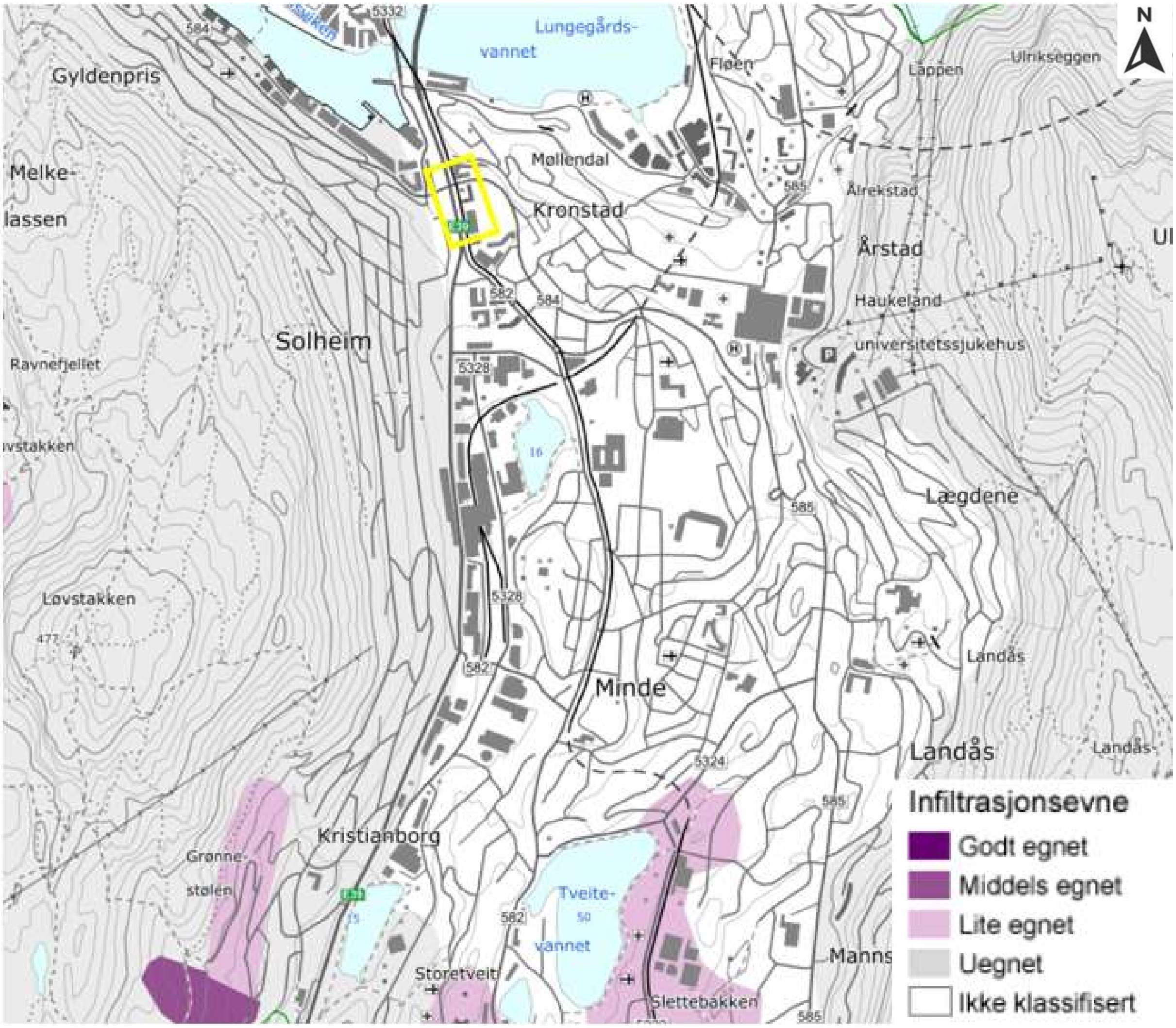

Figure 34 - Infiltration capacity map. Danmarksplass is located in the yellow square. (NGU, u.d.)

5 Scenarios

5.1 Scenario 0 – Existing situation

Scenario 0 is a scenario which shows the current runoff situation at Danmarksplass. As mentioned earlier, there is a lot of impermeable surfaces and little greenery in the area. This cause very little water to infiltrate into the soil and a lot of water running on the surface. The water then runs into drains and manholes which is further led away in a shared piping system going north towards the sea.

Sometimes during heavy rainfalls, the capacity of the stormwater system is exceeded, and water may be pushed up through manholes and run/gather on the surface. In these cases, the runoff water will run towards the underpass as illustrated in figure 35. The capacity the existing shared piping system has for stormwater is difficult to determine as a shared piping system will contain an uncertain amount of sewage water at different times of the day. On the other hand, the capacity of the piping system was exceeded on the 26.09.2018, which resulted in a huge flood as shown in figure 23 earlier. In this incident it rained 37,1mm in 3 hours (Meteorologisk institutt, 2020), which according to the IVF table, for Florida in Bergen, equals a 5-year rainfall, as shown in table 1.

Table 1 - IVF table showing rainfall in mm
(Norsk klimaservice senter, 2020)

	VARIGHET [MINUTTER]						
RETURPERIODE [ÅR]	60	90	120	180	360	720	1440
2	17.2	20.6	23.8	30.0	43.6	63.9	88.1
5	19.9	23.3	28.2	36.9	56.6	86.0	119.2
10	21.8	25.1	31.0	41.5	65.2	100.7	140.0
20	23.5	26.8	33.7	45.9	73.4	114.5	159.8
25	24.0	27.3	34.6	47.2	76.0	119.2	165.9
50	25.8	29.0	37.2	51.5	84.2	132.6	184.9
100	27.5	30.7	39.9	55.7	92.2	146.4	203.9
200	29.1	32.3	42.5	59.9	100.2	159.8	223.8

The calculation for the water flow of the study area during this incident is done by using the "rational formula" which is shown below:

$$Q = I * C * A$$

I is the intensity of the rain in L/s*ha and can be found in the IVF table if the duration of the rain and the recurrence interval is known. By using the IVF table in table 2, it is possible to see that I = 27,8L/s*ha after a 5-year rain event with a duration of 3 hours, has occurred.

*Table 2 – IVF table showing rainfall in L/s*ha and a duration up to 1440 minutes (Norsk klimaservice senter, 2020)*

	VARIGHET [MINUTTER]						
RETURPERIODE [ÅR]	**60**	**90**	**120**	**180**	**360**	**720**	**1440**
2	47.8	38.2	33.1	27.8	20.2	14.8	10.2
5	55.4	43.2	39.1	34.2	26.2	19.9	13.8
10	60.5	46.5	43.0	38.4	30.2	23.3	16.2
20	65.3	49.6	46.8	42.5	34.0	26.5	18.5
25	66.8	50.6	48.0	43.7	35.2	27.6	19.2
50	71.6	53.7	51.7	47.7	39.0	30.7	21.4
100	76.3	56.8	55.4	51.6	42.7	33.9	23.6
200	80.9	59.8	59.0	55.5	46.4	37.0	25.9

C is the runoff coefficient of the area and shows the infiltration capacity of the surface which is dependent on the surface's and the soil's permeability and the slope of the surface. The coefficient is dimensionless and is between 0 to 1, where 1 indicates zero infiltration and 0 indicates full infiltration.

Table 3 - Runoff coefficient (Bergen Kommune, 2005)

Tette flater (tak, asfalterte plasser/veger o.l.)	0,85 - 0,95
Bykjerne	0,70 - 0,90
Rekkehus-/leilighetsområder	0,60 - 0,80
Eneboligområder	0,50 - 0,70
Grusveier/-plasser	0,50 - 0,80
Industriområder	0,50 – 0,90
Plen, park, eng, skog, dyrket mark	0,30 - 0,50
Fjellområde uten lyng og skog	0,50 - 0,80
Fjellområde med lyng og skog, steinet og sandholdig grunn	0,30 - 0,50

Table 3 can be used to find the runoff coefficient of an area. This table gives an indication of what the coefficient might be, but it is always a matter of assessment of how the underlying soil's ability to infiltrate water is and the slope of the area to determine the correct coefficient. As a catchment area has many different surface types, the average runoff coefficient must be determined to calculate the waterflow. The runoff coefficients for Danmarksplass is shown in table 4.

Table 4 - Runoff coefficients at Danmarksplass

	Area	Coefficient
Football field	2,057ha	0,5
Green roof	0,36ha	0,65
Grass	0,2ha	0,4
Roof	1,543ha	0,95
Asphalt	1,08ha	0,9
Gravel	0,23ha	0,7
Total	5,1438ha	0,77

Since the underlying soil does not have a great infiltration capacity, the area types which usually has a high infiltration capacity (grass for instance) have been given higher coefficients than usual. The football field consists of artificial grass which is designed to be permeable and infiltrate water to the underlying soil. It is not as permeable as natural grass, and the field has a stormwater piping system surrounding the field to handle the water which is not infiltrated. Therefore, the football field has been given a runoff coefficient of 0,5.

$$Cavg = \frac{\sum An * Cn}{\sum A} = 0{,}77$$

The water flow Q after the rain event in 2018 can now be calculated as:

$$Q = I * C * A = \frac{27{,}8l}{s * ha} * 0{,}77 * 5{,}1438ha = 110{,}1l/s$$

To calculate what water flow the stormwater system should be dimensioned for to be equipped for today's rain events, a suitable recurrence interval and the time of concentration must be determined. The time of concentration is the time it takes for a water droplet to travel from the most remote part of the catchment area, to the outlet of the catchment area. There are no drainage line maps available of the study area, so the runoff path had to be assumed based on the inspection and the slope of the area.

This travel distance is illustrated as a blue line in figure 35 and is 36m.

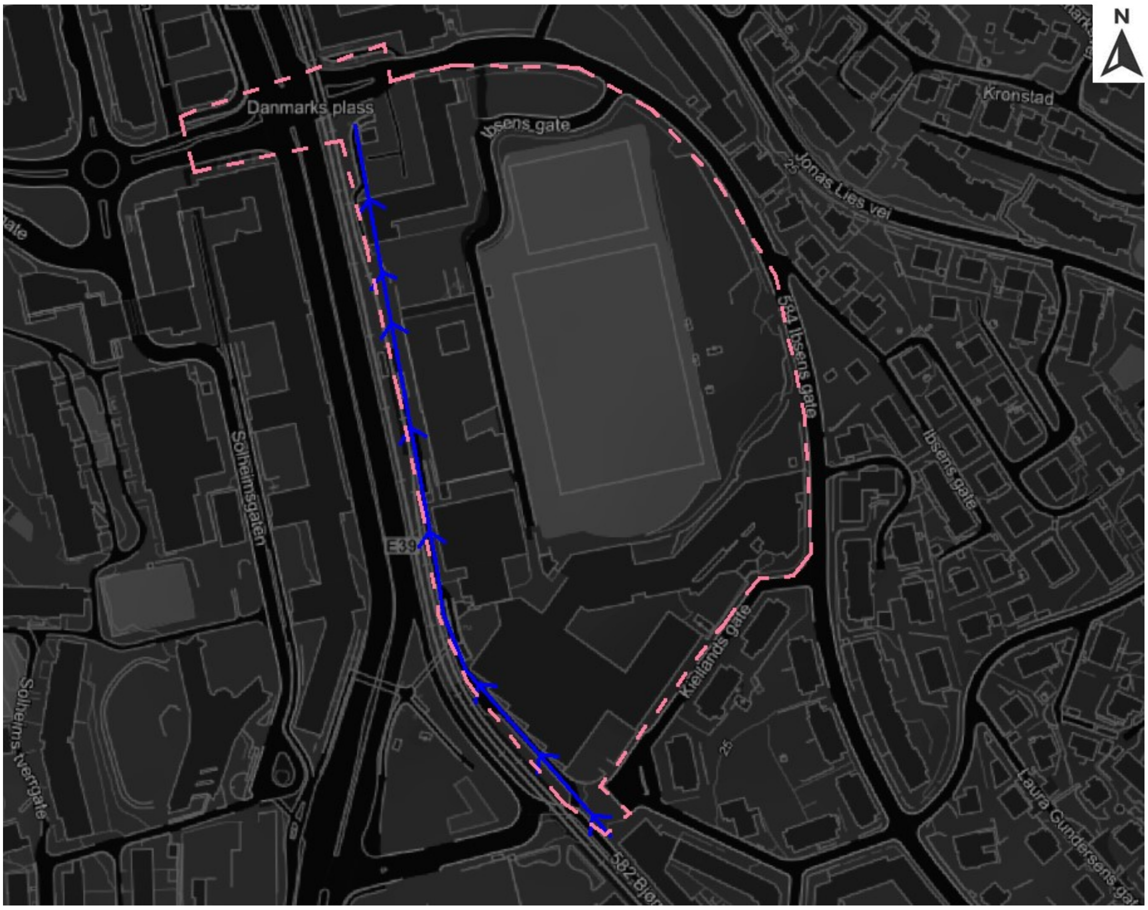

Figure 35 - Runoff distance toward the underpass. The dotted pink line shows the catchment area. Created by Eirik Instanes in Autocad

There are two different formulas which exist for calculating the time of concentration for water running on surfaces. The formula which has been the most normal to use the past years for urban areas is:

$$Tc = 0{,}02 * L^{1{,}15} * H^{-0{,}39}$$

L is the length the water runs in the catchment area and H is the height difference of the catchment area.

This formula originates from Statens Vegvesen N200 2014 but does not exist in the newer 2018 version. Statens Vegvesen has on the other hand created a textbook for stormwater management where a new proposed formula was stated:

$$t = K * \left(\frac{L}{I}\right)^{0{,}5}$$

K is a coefficient which depends on the area type, L is the length the water travels in the catchment area, and I is the slope of the surface the water runs on (Statens Vegvesen, 2018)

Under the formula it is written that in urban conditions with surfaces like asphalt and concrete, this formula will give a similar value as the formula from the 2014 version of N200. Therefore, the formula from the 2014 version of N200 was used to find the time of concentration for the focus area.

$Tc = 0{,}02 * 360^{1{,}15} * 9^{-0{,}39} = 7\ minutes\ and\ 23\ seconds$

The recurrence interval for the area was decided as 50 years by using table 5. Critical underpasses may sometimes be dimensioned for 100 years, but since there is another underpass which can be used to cross the road nearby, it has been decided that the underpass is not critical enough for a 100 year recurrence interval.

Table 5 - Dimensioning recurrence interval (Bergen Kommune, 2005)

Dimensjonerende regnskyllhyppighet (gjentaksintervall) [1] (1 i løpet av *n* år)	**Områdetype**	**Dimensjonerende oversvømmelseshyppighet (gjentaksintervall)** [2] (1 i løpet av *n* år)
2 år	Ubebygd område (åpent)	10 år
10 år 20 år	Boligområde - Åpent - Lukket	20 år 30 år
20 år 30 år	By-/sentrumsområde - Åpent - Lukket	30 år 50 år

The rain intensity can now be decided as 290l/s*ha by using the IVF table in table 6. The water flow Q can now be calculated:

$Q = I * C * A = \frac{290l}{s*ha} * 0{,}77 * 5{,}1438ha = 1148.6l/s$

*Table 6 - IVF table in l/s*ha*
(Norsk klimaservice senter, 2020)

	VARIGHET (MINUTTER)									
RETURPERIODE (ÅR)	1	2	3	5	10	15	20	30	45	60
2	322.7	263.3	226.9	186.7	129.7	106.6	92.1	71.3	55.6	47.8
5	543.0	388.9	309.1	238.2	159.9	128.8	109.1	85.0	66.9	55.4
10	688.8	472.0	363.5	272.3	179.9	143.5	120.4	94.1	74.4	60.5
20	828.6	551.8	415.7	305.0	199.1	157.6	131.2	102.9	81.6	65.3
25	873.0	577.1	432.3	315.4	205.2	162.0	134.6	105.6	83.9	66.8
50	1009.7	655.0	483.3	347.4	224.0	175.8	145.2	114.2	91.0	71.6
100	1145.4	732.4	533.9	379.1	242.6	189.5	155.7	122.6	98.0	76.3
200	1280.9	809.6	584.4	410.8	261.2	203.1	166.1	131.1	104.9	80.9

This water flow generated by a 50-year storm with a duration of 7 minutes and 23 seconds is what the stormwater system should be dimensioned for to handle today's climate according to the standards of Bergen municipality. 1148,6l/s is a 10,4 times larger water flow than the incident which happened in 2018.

When dimensioning new stormwater systems, they are always dimensioned for the future climate. According to Statens Vegvesen, the water flow in Vestland county should be multiplied with a climate factor of 1,4 in order to be dimensioned for the future RCP8.5 climate scenario (Statens Vegvesen, 2018). The stormwater system at Danmarksplass therefore has to be dimensioned for $\frac{1148{,}6l}{s} * 1{,}4 = 1608l/s$, which is a 14,6 times larger waterflow than the waterflow of the rain event in 2018. The stormwater system at Danmarksplass is thus far from being equipped for future rain events, which will probably be much more intense.

Statens Vegvesen has a safety factor for stormwater management infrastructure which the dimensioning runoff should be multiplied with. This safety factor is from 1,0 – 1,2 and depend on the consequences floods may have for the area (Statens Vegvesen, 2018, s. 83). Since the dimensioning recurrence period is decided as 50 years, and there is a possible detour route to cross the road, it has been decided that the floods are not critical enough to use a safety factor higher than 1,0. The dimensioning runoff thus remains as 1608l/s.

5.2 Scenario 1 – Traditional grey infrastructure

The traditional way of planning stormwater systems would be upgrading the piping capacity and/or planning stormwater detention vaults. As the area consists of a «shared piping systems", it would be expedient to follow the separation strategy of Bergen municipality and install a separate piping system for stormwater. It is common to use the «Colebrook diagram», in figure 36, to find the suitable dimension of the pipes. The minimum slope for pipes is according to the norm of Bergen municipality 0,5 %. The norm also specifies that there is no need to document the self-cleaning ability of the stormwater pipes which are placed in a steeper slope than 1 % (Bergen Kommune, 2020). The pipes will follow the slope of the terrain and therefore have a slope of 2,5 % which is in accordance with the norm of Bergen municipality. By using the Colebrook diagram, it is possible to see that the suitable diameter for 2,5 % slope and a water flow of 1608l/s is between 750mm and 800mm. To ensure that the capacity of the pipes is satisfactory, the dimension is rounded up to 800mm. The pipes will be of concrete since concrete is the standard to use for stormwater management in Bergen.

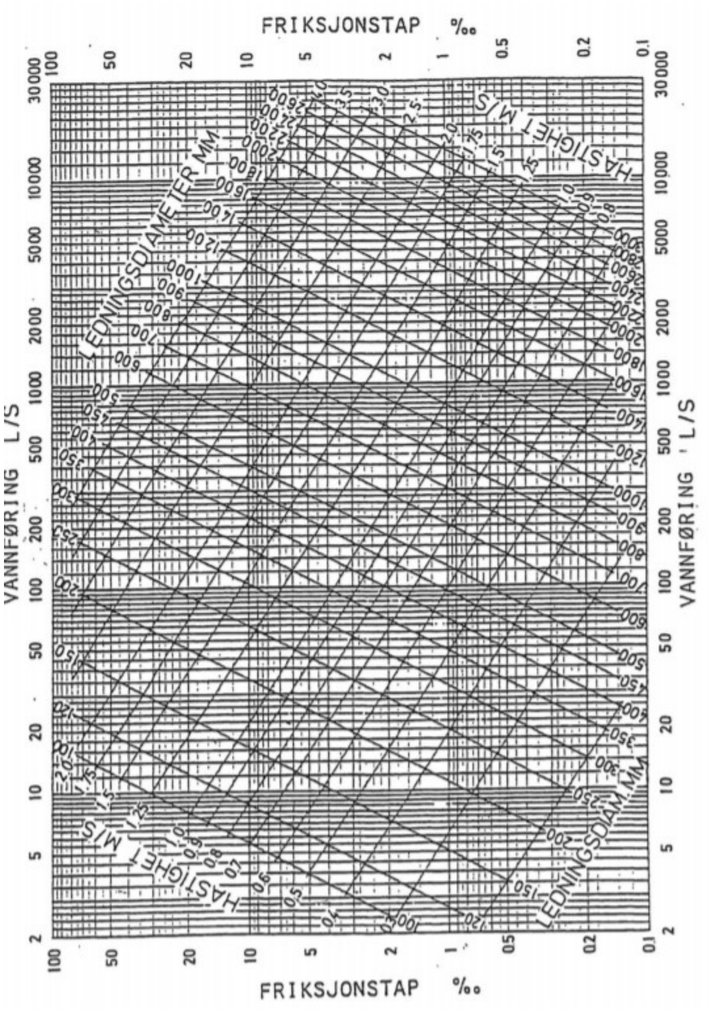

Figure 36 - Colebrook diagram (Høgskolen i østfold, 2019)

There already exists stormwater pipes around the football field as possible to see in figure 27. These stormwater pipes will remain unchanged since they were installed in more recent times and therefore have a sufficient capacity to handle the stormwater from the football field. It also would not be critical if the stormwater pipes from the football field would be overloaded since the water won't do any damage there. The stormwater pipes from the football field connects in a manhole where the stormwater will be led west by a 300mm stormwater pipe which further connects to the 800mm pipe which handles all the water from the study area. The 800mm pipe leads the water north to the underpass and then northwest toward the sea. An illustration of the new proposed stormwater system is illustrated in figure 37

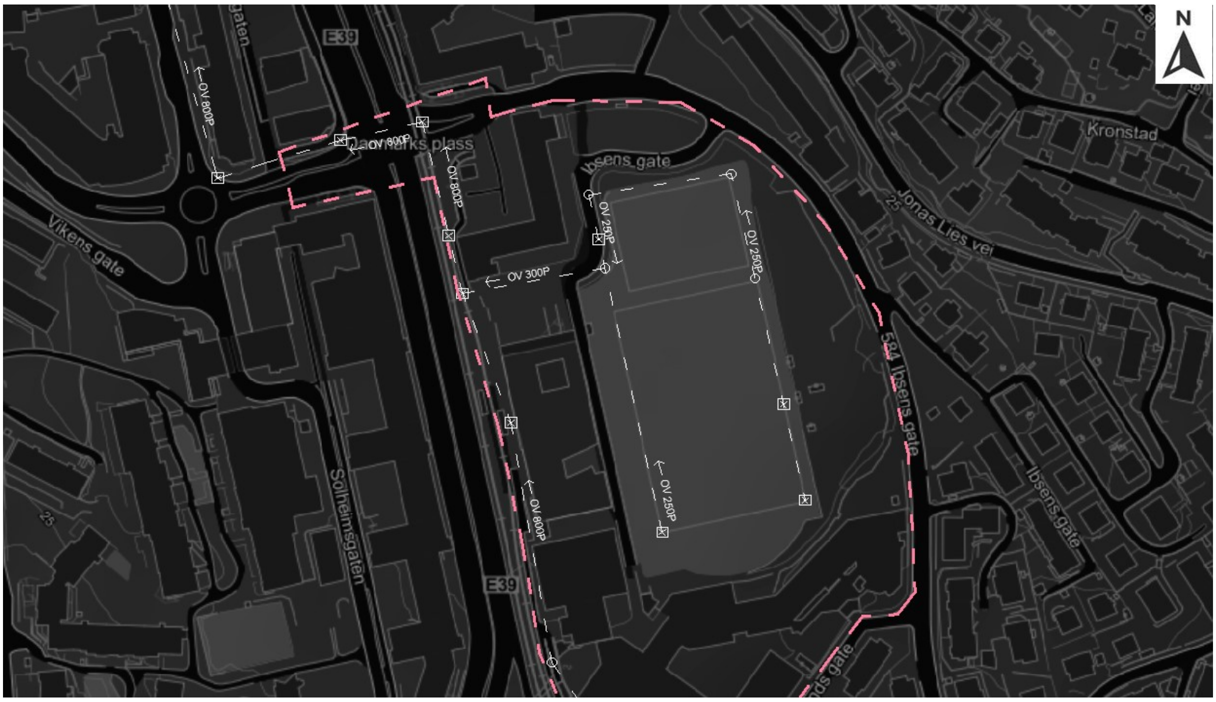

Figure 37 - New stormwater pipes
Created by Eirik Instanes in Autocad

After the new stormwater pipes have been installed there is no longer a need for a stormwater detention vault as the new pipes will be able to handle the water flow it was dimensioned for. An alternative could be installing a stormwater detention vault instead of the new stormwater pipes. The vault would then have an outlet to the existing system with a water flow which the existing system could handle without being overloaded. This solution would require less digging, but it is more expedient to install a separate piping system for stormwater since overflows from shared systems may pollute recipients.

5.3 Scenario 2 – Blue-green infrastructure

Scenario 2, which is illustrated in figure 38, will focus on only planning green measures to handle the stormwater of the area. The three-link strategy which was mentioned in the theory chapter forms the basis for this plan. The first part of the plan is increasing the permeability of the surfaces in the area. All previously impermeable surfaces will be replaced with permeable surfaces. In Bergen it has been normal to use cobble stone on streets to ensure permeability. Cobble stones are on the other hand not good to walk on and therefore do not result a universal design for everyone. Paving stones are better to use in urban areas like Danmarksplass. In some cases, paving stones may have a similar runoff coefficient to regular grass (Sintef, 2018). The runoff coefficient for the permeable surface has been given a runoff coefficient of 0,65 since the infiltration capacity of the underlying soil is not great.

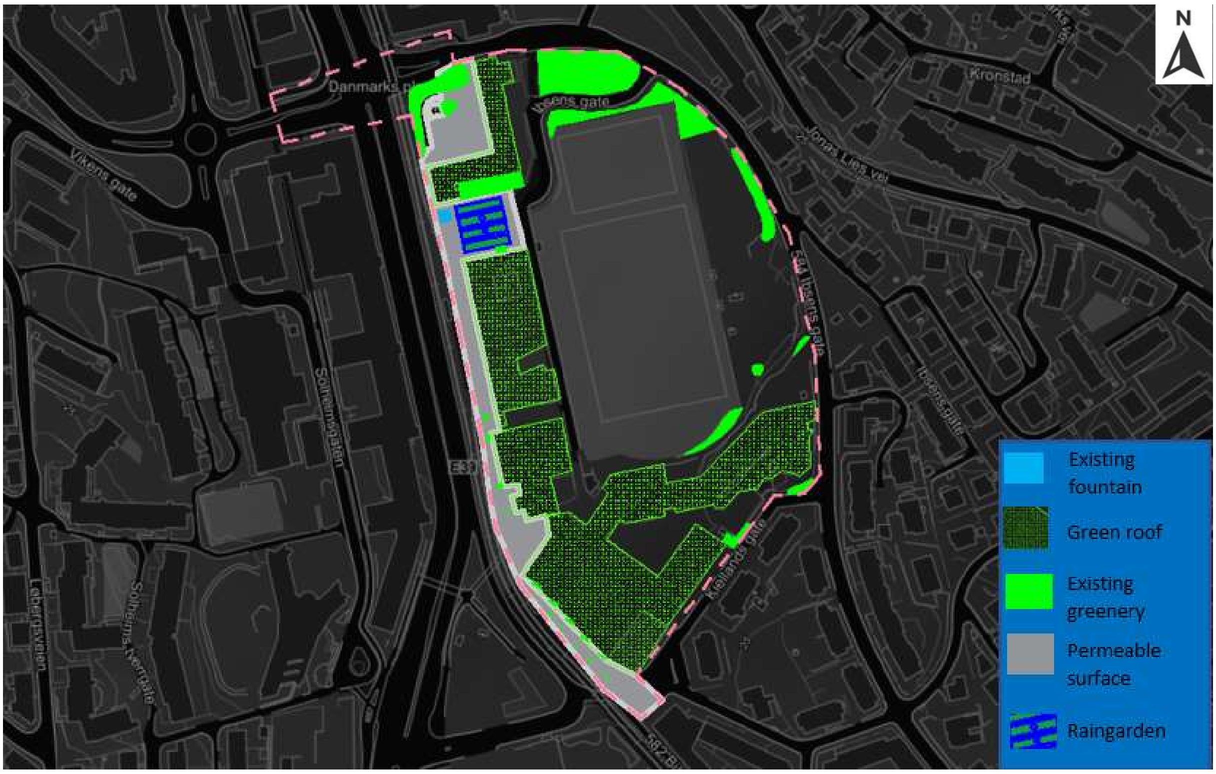

Figure 38 - Scenario 2
Created by Eirik Instanes in Autocad

The roofs of the area will be changed to green roofs. The roof of the Danmarksplass district psychiatric centre is already a semi-intensive green roof. The other roofs will be transformed to extensive green roofs. It has been concluded that there is not enough space on the roofs to install semi-intensive or intensive roofs. Green roofs may according to research have a runoff coefficient of 0,55 (Braskerud, 2014). A new runoff coefficient with the new surfaces may now be calculated for the area:

Table 7 - New runoff coefficient for scenario 2

	Area	Coefficient
Football field	2,057ha	0,5
Green roof	1,543ha	0,55
Grass	0,2ha	0,4
Permeable surface	0,92ha	0,65
Asphalt	0,1543ha	0,9
Gravel	0,25ha	0,7
Total	5,1438ha	0,55

$$Cavg = \frac{\sum An * Cn}{\sum A} = 0{,}55$$

As possible to see in table 7, the new total runoff coefficient is 0,55. With a new greener surface with a lower runoff coefficient, a new time of concentration must be calculated. In this case, the previous formula will not be correct since the area does not consist of just impermeable surfaces anymore. The new formula from the textbook of Statens Vegvesen, which was mentioned above, is more suitable to use for this kind of calculation. A suitable K value for this scenario is considered to be close to 0,25 (grass). The K value is then decided as 0,20.

$$t = K * \left(\frac{L}{I}\right)^{0{,}5} = 0{,}20 * \left(\frac{360}{0{,}025}\right)^{0{,}5} = 24\,min$$

By using the IVF table in table 6 and using the same recurrence interval, the new rain intensity was decided as 130l/s*ha. The dimensioning water flow Q can now be calculated:

$$Q = I * C * A = \frac{130l}{s * ha} * 0{,}55 * 5{,}1438ha * 1{,}4 = 514l/s$$

To handle this water flow there will be planted raingardens. The new permeable surface will have a slight slope of 3 % towards the location of the raingardens. This is done to make sure that the runoff water which does not infiltrate into the permeable surface, is handled by the raingardens. The raingarden will infiltrate a lot of the stormwater, until the soil is fully saturated. When the soil is saturated, the water will be detained in the raingarden, where the maximum water depth is decided as 0,25m. The filter medium’s infiltration capacity is decided as 0,006m/min or 0,37m/hr which has been previously used in Oslo in 2009 (Paus & Braskerud, 2013, s. 3).

The dimensioning of the raingarden is shown in the table 8. The largest area in the table is the dimensioning area, which in this case is $576m^2$.

Table 8 - Raingarden calculation
The final calculation for Araingarden is calculated with "tr" in minutes and not seconds

					Vin = A*C*I*Kf*tr			Araingarden = (Vin)/(hmax + Kh*tr)
t_r (sec)	I (l/s*ha)	A (ha)	C	Kf	Vin (m^3)	Kh (m/min)	hmax (m)	Araingarden
60	1009,7	1,57	0,55	1,4	73,0043391	0,006	0,25	285,1731996
120	655	1,57	0,55	1,4	94,71693	0,006	0,25	361,515
180	483,3	1,57	0,55	1,4	104,8321197	0,006	0,25	391,1646257
300	347,4	1,57	0,55	1,4	125,590311	0,006	0,25	448,536825
600	224	1,57	0,55	1,4	161,95872	0,006	0,25	522,4474839
900	175,8	1,57	0,55	1,4	190,663011	0,006	0,25	560,7735618
1200	145,2	1,57	0,55	1,4	209,967912	0,006	0,25	567,4808432
1800	114,2	1,57	0,55	1,4	247,710078	0,006	0,25	576,0699488
2700	91	1,57	0,55	1,4	296,080785	0,006	0,25	569,386125
3600	71,6	1,57	0,55	1,4	310,613688	0,006	0,25	509,2027672
5400	53,7	1,57	0,55	1,4	349,440399	0,006	0,25	442,329619
7200	51,7	1,57	0,55	1,4	448,567812	0,006	0,25	462,4410433
10800	47,7	1,57	0,55	1,4	620,793558	0,006	0,25	466,7620737
21600	39	1,57	0,55	1,4	1015,13412	0,006	0,25	421,2174772
43200	30,7	1,57	0,55	1,4	1598,185512	0,006	0,25	349,7123659
86400	21,4	1,57	0,55	1,4	2228,089248	0,006	0,25	250,6287118

The maximum volume the raingarden can detain is $576m^2 *0,25m = 144m^3$. When it rains more than the dimensioning water flow, the water detained in the raingarden will overflow. The raingarden is designed so the overflow water will run out on the east side of the raingarden. There is a slight slope leading the water towards the football field as illustrated in figure 39. The runoff water will run into the stormwater pipes which handle the stormwater from the football field. If the stormwater pipes are overloaded, the stormwater will gather, and the sides of the football field will function as a detention pool until the overload passes and water will start draining into the pipes again.

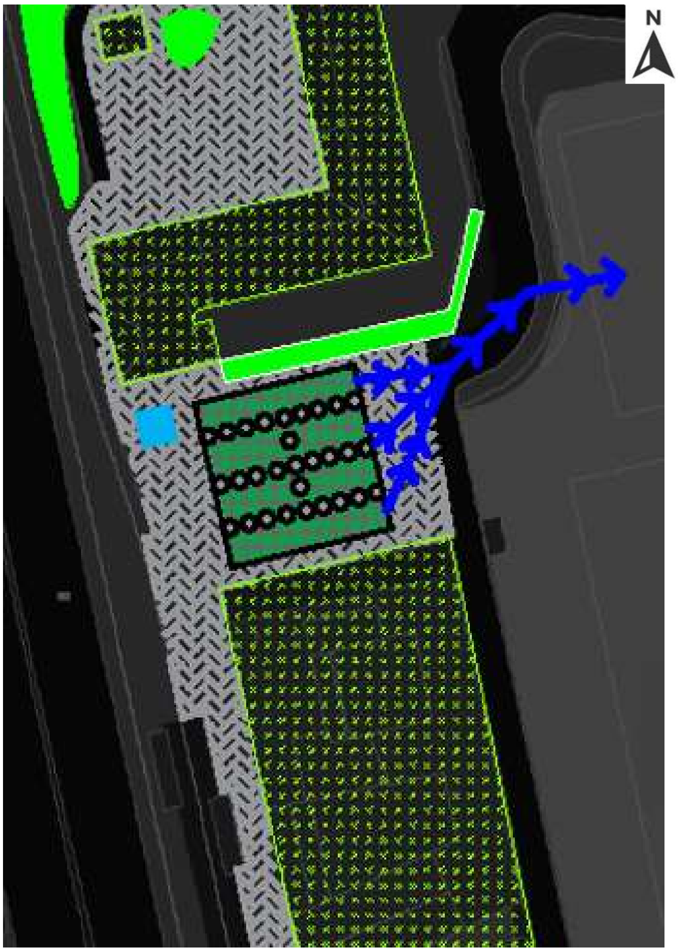

Figure 39 - Detailed illustration of the raingarden with flood path
Created in Autocad by Eirik Instanes

The raingarden can be considered a blue-green infrastructure since it will, during heavy rainfalls, have a temporary basin of stormwater. There are placed large stones, which are crossing the raingarden, which can used by kids to play with when there is a basin of water. The use of stones like this is inspired by the pond in figure 40 at “Lille Ole bulls plass” in the city centre of Bergen. Kids are frequently playing by jumping from stone to stone in this pond. Using stones like this is a great measure for inviting play with blue-green stormwater planning.

Figure 40 - Pond with large stones in the city centre of Bergen (Mapio, u.d.)

5.4 Scenario 3 – Combination scenario

The two beforementioned scenarios both improve the stormwater system. They both manage the stormwater for the dimensioning runoff, as well as offer different qualities. The traditional grey infrastructure scenario separates the sewage from the stormwater, which as mentioned in the theory chapter, has a lot of great benefits. The green measure scenario does not include a separation of the shared piping system but offers a lot of good qualities for the local environment as mentioned in the theory chapter.

A combination of the two would result in a stormwater system which is green, and which does not discharge a combination of sewage and stormwater when an overload occurs. In this scenario some of the green infrastructure has been removed or reduced in size. There has also been planned a new stormwater piping system. Since stormwater systems should not be over dimensioned, the piping system will have a smaller diameter than in scenario 1. To over dimension stormwater systems is more expensive than necessary and should be avoided. When it rains more than the green roofs, permeable surface, and the raingarden can handle, the overflow runoff water will run into the stormwater pipes.

It has been decided that the raingarden will be reduced from 576m^2 to 391 m^2. When the dimensioning rainfall event occurs, the raingarden will have an overflow after 3 minutes, where the stormwater pipes will have to handle an extra waterflow load of 87,5 l/s. The time it takes for the overload to occur is found by reusing table 8. A suitable diameter for 87,5l/s would be 250mm in this case, according to the Colebrook diagram. The existing stormwater pipes which surround the football field has a 250mm dimension. The new pipes which handle the waterflow from the football field and the overflow from the raingarden area should therefore be 250mm + 250mm = 500mm.

In this scenario there has been planned an overflow pipe in the underpass which is illustrated as the dotted blue line in figure 41. It has been placed there to prevent floods in the underpass during rainfalls which are more intense than the dimensioning rainfall event. The overflow pipe leads the water to an existing channel, where the water flows directly to the sea to the north-west. The overflow pipe which has a 250mm dimension can drain approximately 90l/s from the underpass when an overflow occurs.

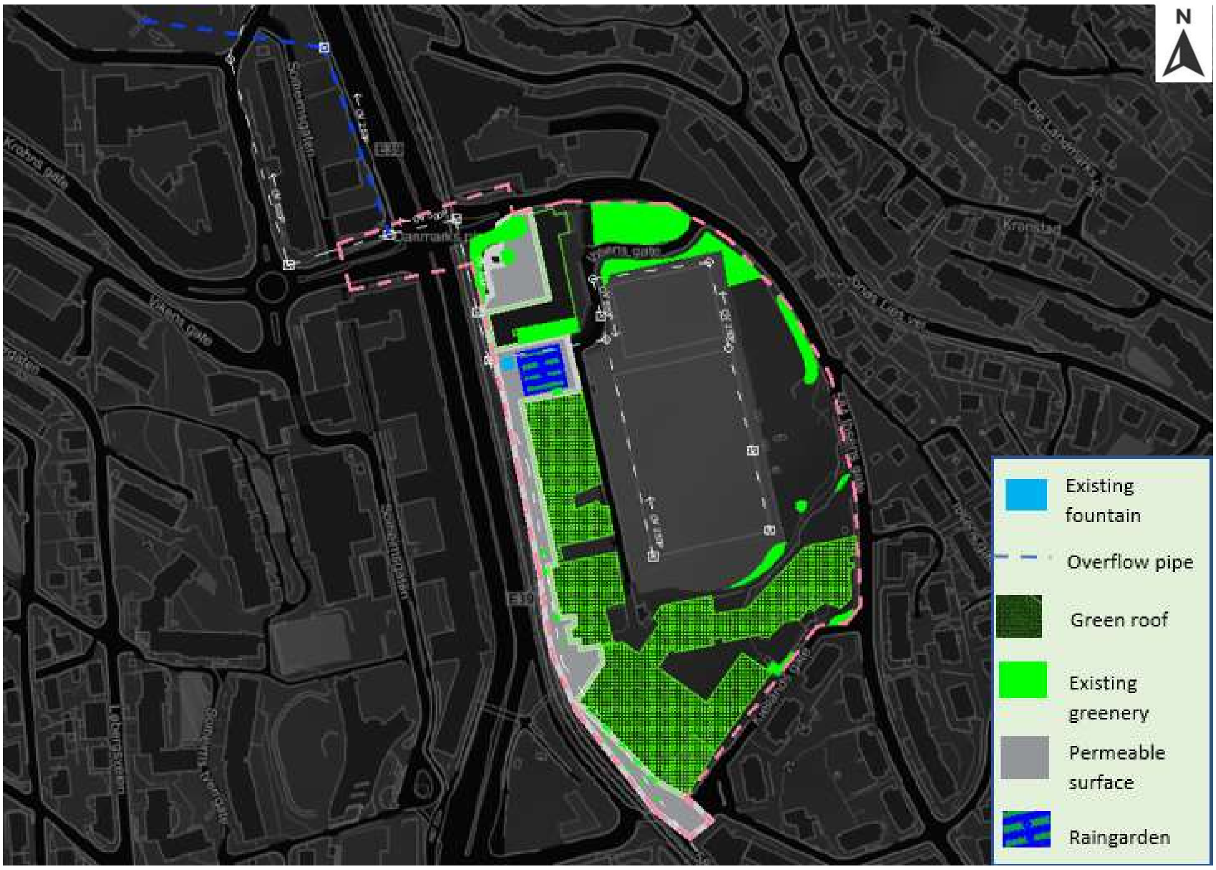

Figure 41 – Scenario 3: Combination scenario
Created in Autocad by Eirik Instanes

6 Discussion and recommendation

6.1 Discussion

There are some weaknesses in the method which has been used in this thesis. One of them is that evaporation has not been considered in the waterflow calculations. Evaporation can, especially during warm summer months, play a big role in waterflow calculations. Especially if it rains after the sun has heated up the asphalt. But this is not as relevant in Norway as it is in other warmer countries and won't play a big role in Bergen. Another thing which has not been discussed previously, is that the lifespan of pipes is a lot longer than open green solutions like raingardens. It is on the other hand a lot easier to renew green infrastructure than installing new pipes for instance.

There is also some inaccuracy in the dimensioning waterflow calculations for the underpass since catchment area for Danmarksplass is actually a lot larger than the one drawn in figure 35. It was on the other hand difficult to make accurate calculations for the entire catchment area for Danmarksplass. This is because the piping infrastructure map, which was received, did not include a large enough area of infrastructure. The map was also quite difficult to read since the area is quite complex. Therefore, it would have been impossible to accurately calculate the time of concentration since the piping information of the entire catchment area was lacking. It was then decided to calculate the runoff on the planning area of Danmarksplass and try to manage this runoff.

With the changing climate, stormwater planning must adapt all over the world. Copenhagen, Malmø and Oslo are great role models within stormwater planning. These cities have invested a lot in preventative stormwater planning, and work on inspirational and innovative solutions. It is usually expedient to invest in preventative measures rather than constantly spending money on repairs. To prepare for climate change, cities should seek inspiration from each other for how to plan stormwater infrastructures which are effective, cost-efficient and which results in a vivid, practical, and aesthetic urban environment. Since underpasses are often vulnerable to floods due to them being in a closed underground environment, it would be interesting to further research how stormwater could be used as a resource to improve the environment in underpasses

As previously shown in chapter 5.1, the existing situation is an urban area which is not prepared for future rainfall events related to climate change. If the area remains unchanged, the floods will continue to occur, and likely become worse. Scenario 1, 2 and 3 all provide solutions which solve the problem. Which scenario that is the best will further be discussed based on the costs, how well they manage stormwater, how they affect the urban environment and biodiversity and how much maintenance they require.

6.2 Scenario 1

6.2.1 Stormwater management

This scenario can handle the dimensioning runoff. Since the shared piping system now has been separated, overflows will never be of a combination of sewage and stormwater. Overflows will also less frequently occur since the pipes no longer have to handle the load from the sewage system and the stormwater. This scenario does on the other hand not handle the stormwater locally or accomplish any of the steps in the three-link strategy.

6.2.2 Urban Environment

Scenario 1 does not occupy any space on the ground level since the pipes are situated under the surface. This scenario therefore does not affect the aesthetics of the local environment. The scenario does improve the local environment in the sense that the area wont struggle as much with flooding. Also, an overflow of this piping system will not be of a mixture of waste and stormwater which may have a foul smell.

6.2.3 Costs

The material costs of the stormwater infrastructure from scenario 1 is shown in table 9 below. The unit costs for 800mm pipe is 4679kr per meter (Loe rørprodukter AS, 2018), the unit costs for 300mm pipe is 748kr per meter (Loe rørprodukter AS, 2018), and the cost per manhole is 20 000kr (Loe rørprodukter AS, 2018). The total cost for this scenario is 13 003 267 kr

Table 9 - Scenario 1 Costs

Description	Unit	Unitprice	Amount	Sum
Concrete pipe 800 mm	m	4679kr/m	593	2 774 647 kr
Concrete pipe 300 mm	m	748kr/m	65	48 620 kr
Manhole	apiece	20000kr apiece	9	180 000 kr
Sum				3 003 267 kr

The procedure of installing a separate stormwater system will in this case likely be expensive since this is a very complex area with lots of different pipes and infrastructure. The digging process could lead to a change in the traffic pattern in certain areas, which is expensive socioeconomically.

6.2.4 Biodiversity

Scenario 1 will have no effect for the local biodiversity since it will lead to no changes on ground level. It will on the other hand have positive effects for the recipient downstream since the overflows won't be of a combination of waste and stormwater. The sewage water pollutes recipients which may be bad for the biodiversity.

6.2.5 Maintenance

For stormwater pipes which are placed in a steeper slope than 1 %, there will be no need for cleaning the pipes. This is because the shear of the water is high enough for the pipes to clean themselves. If the pipes are never cleaned, and are not self-cleaning, they may eventually clog. Drains will occasionally need to be cleaned to prevent leaves and trash from clogging the drains. Also, the manholes must be emptied for sand every year, since manholes gathers a lot of sand, which may eventually clog the pipes in the manhole.

6.3 Scenario 2

6.3.1 Stormwater management

Scenario 2 has the capacity to manage the dimensioning runoff. The scenario has a lot of greenery and permeable surfaces which increases the amount of infiltration at Danmarksplass. This means that a lot of the stormwater is managed locally. The raingarden also has the ability to detain a lot of stormwater and has a flood path toward the football field. The existing shared piping system still remains a problem though, since an overload will be of a combination of sewage and stormwater. There is also no overflow pipe to ensure a safe flood path for potential floods in the underpass. This means that the flood problem may not be solved in this scenario. This scenario is considered as equally good for stormwater management as scenario 1, since they both have different and great qualities, but are both lacking some qualities which are very important in good stormwater management

6.3.2 Urban Environment

The raingarden is placed in an area which previously used to be quite empty and grey. Building a raingarden here makes the urban environment at Danmarksplass greener and more aesthetic. Especially in combination with the fountains which are in front of the raingarden. When it rains a lot, the raingarden will have a basin of water which increases the amount of blue elements in the area. The stones in the raingarden also invites for recreation for children. Scenario 2 has a more positive effect on the urban environment than scenario 1.

6.3.3 Costs

The costs for building scenario 1 are shown in table 10 below. The unit cost for the raingarden is 1400kr per m^2 (COWI, 2015), the unit cost for the green roof is 600kr per m^2 (Sintef, 2012), and the unit costs for the permeable surface is 800kr per m^2 (COWI, 2015).

Table 10 – Scenario 2 Costs

Description	Unit	Unitprice	Amount	Sum
Raingarden	m^2	1400 kr/m^2	576	806 400 kr
Green roof	m^2	600 kr/m^2	11830	7 098 000 kr
Permable surface	m^2	800 kr/m^2	9200	7 360 000 kr
Sum				15 264 400 kr

This scenario does not have expensive digging costs like in scenario 1. The construction process and the maintenance of open and green infrastructure is often cheaper than traditional closed infrastructure (Statens Vegvesen, 2019). The material cost for scenario 2 is 15 264 400 kr, which is significantly more expensive than scenario 1. But combined with construction costs, they may not differ much, but scenario 2 is still considered more expensive than scenario 1.

6.3.4 Biodiversity

Green infrastructure adds greenery to the area, which strengthens the ecosystem and the biodiversity. With added greenery on the roofs, the roofs may become more attractive for birds. Green roofs will also attract more insects such as bees. The type of green roofs which best facilitates for biodiversity is a green roof which has a varied substrate depth, and which is planted or seeded with a wide range of wildflowers (Livingroofs, u.d.).

This scenario does not offer a separation of the existing shared piping system, so overflows of the piping system will have a mixture of waste and stormwater. This is as mentioned before, not good for the biodiversity of the recipient. In total, scenario 2 is considered as better for the biodiversity than scenario 1.

6.3.5 Maintenance

The raingarden will require watering, fertilizing and protection during the growth period. After it is fully established it will be important to maintain it by watering during dry periods and occasional removal of weeds which may occur. The permeable surface must be cleaned occasionally to prevent the permeability from deteriorating. The green roofs will also require watering during very dry periods, fertilizing and removal of weeds. Cleaning of roof drains may occasionally be necessary to prevent clogging and ensure maximum drainage during heavy rainfall. In total, Scenario 2 requires more maintenance than scenario 1.

6.4 Scenario 3

6.4.1 Stormwater management

Scenario 3 covers all the steps in the three-link strategy well. The permeable surface, green roofs and the raingarden take care of both step one and two, and the overflow pipe ensures that the water has a safe flood path to the recipient when it rains more than step one and step two can handle. The football field may also work as a temporary detention basin if the pipes become overloaded. Scenario 3 is in line with Bergen's separation strategy, which was mentioned in the theory part. The overflow water is thus not contaminated with sewage water, and therefore will not pollute the recipient as much. It is also in line with multiple of the municipal guidelines which are mentioned in chapter 4.2, like for instance to prioritize blue-green infrastructure and to attempt to include play and recreation in stormwater planning. Scenario 3 is therefore the best scenario for stormwater management

6.4.2 Urban environment

In this scenario the urban environment will be improved since the area will be much less vulnerable to floods. The overflow pipe in the underpass will result in it being unlikely to experience floods in the underpass, and it will remain open for pedestrians to use. The green roofs and the raingarden will have the same effect for the urban environment as in scenario 2. The combination scenario is the best scenario in regard to improving the urban environment.

6.4.3 Costs

The costs of scenario 3 is presented in table 11. The unit price is the same as in scenario 1 and 2.

Table 11 - Scenario 3 costs

Description	Unit	Unitprice	Amount	Sum
Raingarden	m^2	1400kr/m^2	391	547 400 kr
Green roof	m^2	600kr/m^2	10400	6 240 000 kr
Permeable surface	m^2	800kr/m^2	9200	7 360 000 kr
Concrete pipe 500mm	m	1788kr/m	692	1 237 300 kr
Manhole	apiece	20000kr apiece	9	180 000 kr
Sum				15 564 700 kr

The construction costs for the green infrastructure will be slightly less since there is less area used for construction. The construction costs for the grey infrastructure will be the same as in scenario 1. Scenario 3 costs 15 564 700 kr and is the most expensive scenario.

6.4.4 Biodiversity

Scenario 3 has a combination of the effects mentioned in scenario 2 and scenario 1. The scenario has slightly less area of green roofs and raingarden, which leaves less area for the birds and insects to thrive on. Scenario 3 is considered the best scenario for improving the biodiversity of the area.

6.4.5 Maintenance

The required maintenance of this stormwater system is a combination of what was required for scenario 1 and 2. Scenario 3 is thus the scenario which requires the greatest amount of maintenance.

6.5 Recommendation

Bergen is a city which have many areas which struggle with floods nowadays. As shown in Scenario 0, the underpass at Danmarksplass is undoubtedly one of those areas, and the problems will likely worsen with the changing climate. If Danmarksplass is an area where measures should be made is a question which depend on whether the municipality values the benefit high enough to pay for the expenses of upgrading the stormwater system. Since Danmarksplass, with its associated underpass, is such an important and highly pedestrian trafficked area in Bergen, it should be prioritized for improvement.

Table 1 shows the evaluation of how the 4 scenarios affect on the selected topics mentioned above. The topics are rated from 1-4, where 1 is the worst value, 2 is the second worst, 3 is the second best and 4 is the best. As shown in the table, scenario 3 is the highest rated scenario.

Table 12 - Evaluation of the scenarios

Evaluation criterions	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Stormwater management	1	3	3	4
Costs	4	3	2	1
Biodiversity	1	2	3	4
Urban environment	1	2	3	4
Maintenance	4	3	2	1
Total	**11**	**12**	**12**	**14**

Scenario 3 is great at managing the stormwater and improving the urban environment. Scenario 3 is on the other hand lowest rated in maintenance and costs, so the recommended plan comes with a price. The costs of scenario 3 is not much more expensive than scenario 2 and is therefore considered as worth the extra investment. Scenario 3 is thus the recommended scenario for Danmarksplass.

7 Conclusion

Climate change is creating big challenges regarding floods for densified cities globally. Stormwater planning is in need for a change due to this development. Underpasses are one of those areas which are extra vulnerable for floods since they are underground in a closed environment. The underpass at Danmarksplass has proven to be one of these underpasses which are quite vulnerable to floods. One of the reasons for this is that there are no overflow pipes connected to the underpass. This means that water which gathers in the underpass, during the times when the stormwater system is overloaded, will eventually become a large basin of water as more stormwater runs into the underpass. Another reason is the slope of the impermeable area outside the underpass which allows water to run into the tunnel during heavy rains. It has therefore been important to not only stop the water from running into the underpass, but also install an overflow pipe for those cases the stormwater system becomes overloaded.

Which solution that works the best varies from project to project. In some projects there may for example not be enough space for certain solutions which worked well in previous projects. In these cases, it may be more suitable to place the infrastructure underground. In this thesis there has been done research on which type of infrastructure that is the optimal to solve the problem at Danmarksplass. The infiltration capacity of the soil was concluded to be low. This meant that the scenarios with blue-green infrastructure would be considered as less effective than their maximum effect. The three scenarios which was created was discussed regarding the 5 topics: cost, their ability to handle stormwater, their effect on the urban environment and biodiversity and maintenance. The combination scenario of stormwater pipes along with blue-green infrastructure was rated the best on these topics. This scenario was also the most expensive one but was still concluded as worth the investment since It was not much more expensive than the scenario which only had green infrastructure. One of the most important parts of this scenario was the overflow pipe, which was connected to the underpass. The overflow pipe ensured that the water had a flood path in the cases it might be needed. The blue-green infrastructure scenario was considered as the second-best scenario to handle the stormwater and was very close to being as good as the combination scenario. This shows what a great contribution blue-green infrastructure is to urban areas, since they have many other great qualities than just managing stormwater.

Malmø and Copenhagen are two cities which have been mentioned as role models within the use of open solutions in stormwater planning. In some cases, the cities even closed the drains to the manholes so stormwater would solely be handled by open solutions. If successfully done, it is a great alternative to creating separate pipes for stormwater since it would not require any digging and the water would be handled locally. But it is considered as unlikely to be successful in the long run since future rainfall events are likely be intense enough to even result in floods in natural unbuilt areas. It is therefore hard to avoid planning stormwater pipes, especially in urban areas. A combination of both blue-green infrastructure complimented by traditional stormwater piping system is therefore considered the best scenario for preparing Danmarksplass for future floods. Due to densification, cities now need to prepare their vulnerable urban areas for the changing climate. Blue-green infrastructure should always be considered and prioritized in the planning process.

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