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Abstract

Climate change brings many challenges to cities of the world. One of them is an increase in precipitation, especially in the areas where it is already high. One example is the city of Stavanger, a case study for this project. Most cities are covered in asphalt, concrete and other impermeable materials, preventing stormwater from absorbing into the ground. Nature-based solutions (NBS) allow the retention process and, at the same time, bring many other benefits. The primary motivation behind this project is to investigate the role of green infrastructure (GI) in stormwater management and flood reduction. This study is critical because many large cities in Europe are already affected by high precipitation or will be in the near future. The results can be used as a part of stormwater management policymaking. The efficiency of the different types of GI was examined in two drainage basins in Stavanger using Rational method calculations, hydrological modelling with HEC-RAS software and scenario development. The calculations show the possible change in runoff volumes up to 9.4% of the initial amount. The hydrological modelling showed visible changes in flood reduction compared to the existing flood situation in the 100-year event. GI appear to be a good and multifunctional stormwater management tool, which should be a part of every city. Nevertheless, from the results, it is clear that GI, despite its undeniable benefits, can be used only in combination with the traditional flood measures in order to provide sufficient protection for the cities facing climate change.

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Abbreviations

GI – Green Infrastructure

GYI – Grey infrastructure

BGF – Blue-Green Factor

NBS -Nature-based Solutions

1 Introduction

The natural hydrologic cycle connects the atmosphere, lithosphere and biosphere by such processes as evapotranspiration, evaporation, condensation, precipitation, infiltration and runoff (Yang, Yang, & Xia, 2021). (See Figure 1 and 2) From these processes, it is reasonable to highlight infiltration, runoff and precipitation for this work. Infiltration is the process of water entering the soil through the pores, and it depends on many factors, such as soil type and depth, precipitation and climate (Smith, Smettem, Broadbridge, & Woolhiser, 2002) (Science Daily, 2019). Runoff is the water which did not infiltrate into the soil when the absorption capacity is exceeded. Therefore runoff volume can be defined as a difference in the volume of precipitation and the volume of possible infiltration (Betson, 1964). Precipitation is any water forming in the atmosphere that falls to the Earth afterwards (National Geographic, n.d.).

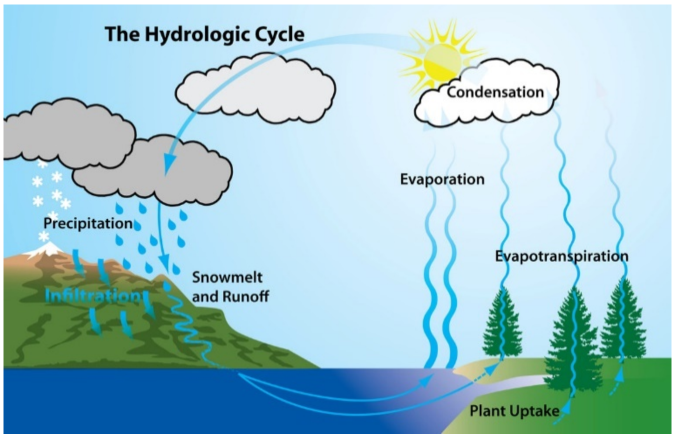

Figure 1 Natural hydrologic cycle OFFICIAL SITE OF THE STATE OF NEW JERSEY. (n.d.).

The natural hydrologic cycle is essential to secure access to the water supply for humans and animals (Oki, 2006). Water is one of the most vital resources and plays a significant role in sustainable development and the environment (Mekonnen & Hoekstra, 2016). Nevertheless, human activity interferes with the natural water cycle in urban areas by changing the Land Use and by making new synthetic barriers for water (Niemczynowicz, 1999) (Yang, Yang, & Xia, 2021).

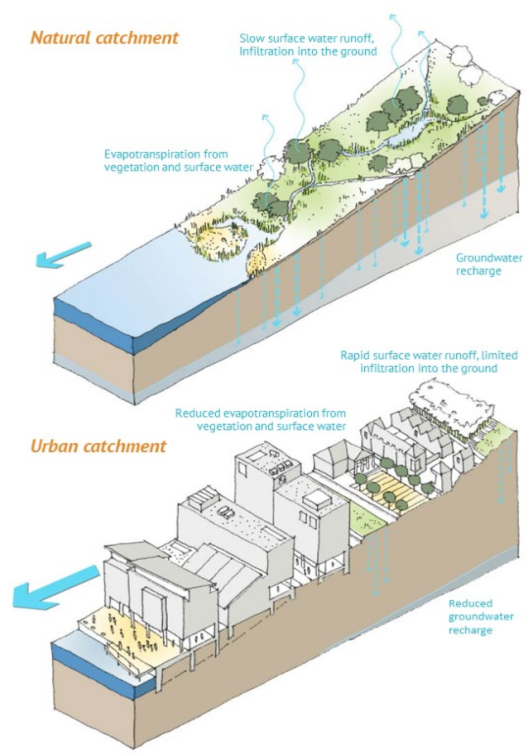

Figure 2 Natural and Urban catchment (Gunson, A., Morgan, C., & Guest, K. (2010))

The number of impervious surfaces in cities constantly grows to accommodate our needs. Asphalt roads, housing, and parking lots are built every day. These surfaces have a minimal allowance for water infiltration due to covering the underlying soil (Kjelgren & Clark, 1994). Therefore, urbanisation increases the peak flow intensity and quantity during rainfall events (Konijnendijk, 2010).

Impervious surfaces lead to higher surface runoff volumes. During extreme precipitation events, the amount of runoff is even more significant. Traditionally in cities, a Grey Infrastructure (GYI) is used to facilitate all of the runoff. GYI is mainly built from such materials as concrete or steel (Dong, Guo, & Zeng, 2017) (Tavakol-Davani, Burian, Devkota, & Apul, 2016). GIY for stormwater management is represented by pipes, ditches, swales and culverts connected into one network working to collect the runoff from the surface and transport it further (Duke Nicholas Institute, n.d.). In many cities worldwide, these networks consist of combined sewage systems, where runoff from precipitation and untreated wastewater is transported simultaneously to the water treatment plant or discharged into receiving water (if the plant's capacity is exceeded) (Phillips et al., 2012). Combined sewage is considered outdated and ineffective in high precipitation events, as it can easily overflow into the surroundings, and the excess water pollutes the water where it is discharged (Lucas & Sample, 2015).

Green Infrastructure (GI) is a sustainable alternative to traditional GYI. GI is a stormwater management tool that imitates parts of the natural hydrological cycle by employing vegetation. Examples of GI include Street Trees, Bioswales, Rain gardens, and Permeable Pavement. It is proven that GI is highly effective in runoff volume reduction by infiltrating the stormwater through leaves and soil. It is also described as a multifunctional tool due to its many positive impacts on the surroundings. Additional benefits of GI can include stormwater filtration, support for biodiversity, and air filtration. Overall, green infrastructure can be defined as a network of different green spaces beneficial for resilient cities, human health, and the preservation of nature (American Rivers, 2016) (Konijnendijk, 2010) (Mguni, Herslund, & Jensen, 2016) (Jayasooriya, Ng, Muthukumaran, & Perera, 2020).

The GI benefits have a very diverse nature; however, from the literature review related to the topic, it seems that the most discussed and significant advantage is the stormwater management ability of the GI. This work aims to investigate the efficiency of GI in stormwater infiltration and runoff reduction in an urban environment. This goal will be achieved through studying the existing literature, hydrological modelling and calculations, scenario development, SWOT analysis and Blue-Green factor analysis.

2 Motivation

Urbanisation and climate change bring challenges to the cities of the world. Urban fluvial flooding poses potential economic problems and can no longer be ignored. New solutions must be found in order to cope with the steadily increasing precipitation, and GI is one of those solutions. GI is still a new and less studied discipline. Nevertheless, when carefully planned and applied adequately, GI can be an alternative to traditional GIY.

The motivation for this work is to learn more about the sustainable city planning strategies regarding GI, understand the underlying problems and challenges connected to it, and see the possibility of the policymaking process toward those solutions. For the policymaking process, it is essential to investigate to what extent is it possible to substitute the GYI with GI in an urban context and how to do so.

3 Research questions

In this Master's thesis, several questions were posed to be answered through the proposed analysis. The main question of this research is

• What is the possible impact of green infrastructure on flood reduction in the urban environment of Stavanger?

The secondary questions are

• How can this infrastructure be implemented in the existing cities without significant changes?

• How can the existing GI handle the event of extreme precipitation?

4 Area description

The case study for this project is the City of Stavanger in Norway. The analysis will be conducted in two drainage basins located in several administrative parts of the city.

The first drainage basin will be referred to as Ullandhaug-Hillevåg or basin no.1 (see Figure 3) due to being located in those two administrative parts of Stavanger. The area of the basin is 335.4 ha. The average elevation is 53.9 m.a.s.l. The site includes part of the E39 road. Stavanger University Hospital is situated northeast of the Ullandhaug-Hillevåg basin. On the southern part, by the E39 road, Sørmarka Arena - the indoor ice venue, could be found.

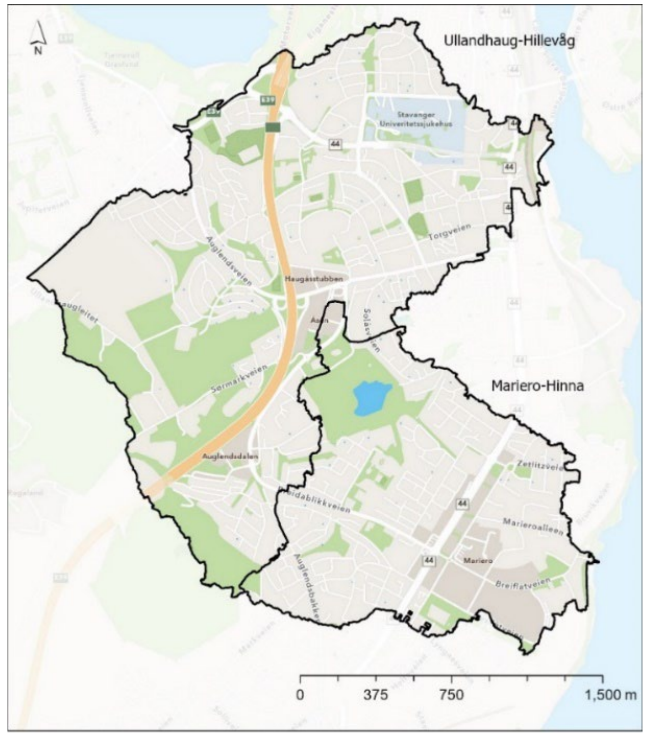

Figure 3 Drainage basins analysed in the project

The second drainage basin will be referred to as Mariero-Hinna or basin no.2. The area of the basin is 172.9 ha. The average elevation is 33.6 m.a.s.l.

Several reasons behind choosing these two drainage basins in this particular City could be identified. As mentioned above in the Introduction part of this work, one of the objectives of this work is to investigate the positive effect of GI in marine climate zone, and Stavanger, as an urban area with coastal climate conditions, is an example of such an environment.

Hydrological catchments were chosen over an administrative part of the city in this thesis to better understand the GI's hydrological impact on the total runoff in the drainage basin.

By SSB population of Rogaland is growing steadily, and by 2050 it is expected to grow by 12,5% compared to 2020 (Statistisk sentralbyrå, 2020). With population growth, the requirements for urban areas change. More housing units and more parking spaces are needed in order to fulfil the demand. Most modern parking lots are represented by entirely unporous surfaces, leading to the increase in artificial runoff in these areas. Runoff coefficients (C) can vary depending on the housing type. For instance, according to E. Zimmermann et al., the C coefficient for the multi-housing units with more than four floors is 0.75, whereas, for the multi-housing units with green sidewalks and green roofs, it is 0.48. Those numbers show that even the "green" housing still does not absorb as much stormwater as forests (C=0.13) or pastures (C=0.30), let alone unporous surfaces such as parking lots and traditional roofs. (Zimmermann, Bracalenti, Piacentini, & Inostroza, 2016). Thus, the increase in the number of residential and parking areas means more significant surface runoff and higher strains on the sewage systems.

5 Problems' description

The two catchments shown in Figure 3 are chosen to represent and examine the diverse nature of the urban setting. Areas have "problematic" locations defined by unporous surfaces, lack of greenery and outdated (combined) sewage systems (See Appendix 1 and 2).

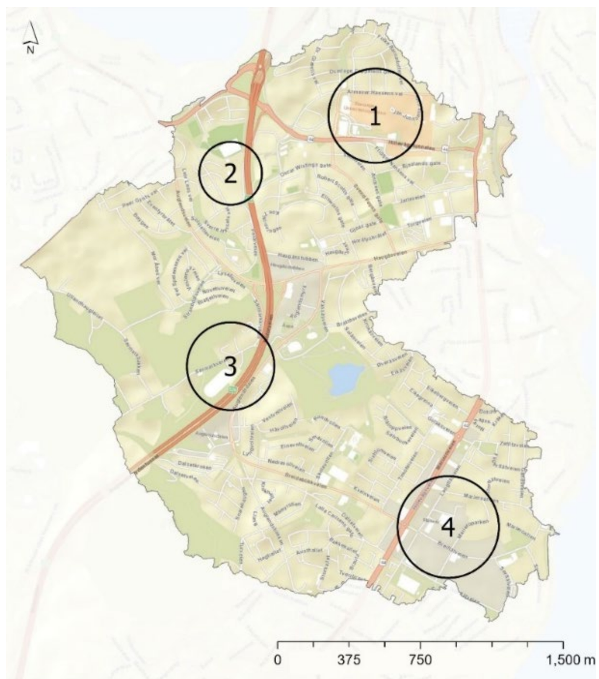

Figure 4 Main locations for the analysis

Unporous surfaces are represented by asphalt, concrete, roof surface, and similar materials. In urban areas, such surfaces constantly increase, disturbing the natural hydrological cycle by restricting stormwater infiltration (Kjelgren & Clark, 1994) (Mullaney, Lucke, & Trueman, 2015). In Stavanger, specifically in the studied drainage basins, the proportion of unporous surfaces is 70-71% (See Table 5 and).

Figure 4 shows the four areas with the most concentration of the unporous surface, which at the same time indicates a flooding problem shown in Figure 19. These areas will be the main zones for further analysis with the most proposed GI. The lack of greenery is directly related to the number of unporous surfaces. These two factors lead to flooding, especially in flatter areas shown in Figure 5.

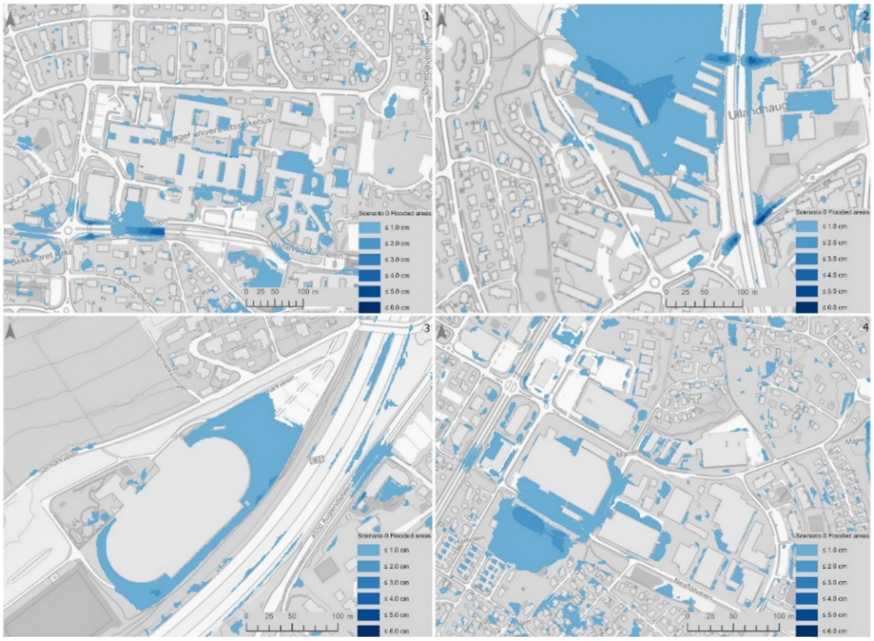

Figure 5 Flooded areas in the selected drainage basins

Another problem that can be highlighted in the area regarding stormwater management is the runoff quality. Most of the surface runoff in the area comes from unporous surfaces, including roads and parking lots, washing the pollutants down to sewage and loading the treating plants.

6 Methodology

6.1 History of Green Infrastructure in an Urban setting

The majority of the global population is living in an urban environment nowadays. This fact changes the appearance of our cities, creating a more hostile habitat consisting of concrete and asphalt to be able to facilitate the residents. Climate change brings even more challenges to the metropolitan areas. Urban floods are not a rare sight these days, and the traditional way of managing the extreme weather conditions is still by using Grey infrastructure. Those conventional methods strain the natural resources, as they need materials to be built from and are proven not sustainable. The grey infrastructure is an unnatural feature in a hydrological cycle; it does not allow deep drainage as well as groundwater recession flow, which impacts the water supply for wildlife and people. It also affects the water quality by letting untreated runoff into the sewage systems (Barnett & Beasley, 2015) (Brears, 2019).

Green Infrastructure (GI) is a non-traditional sustainable, economically beneficial multifunctional tool for stormwater management. It has many other ecological benefits such as air quality improvement, temperature reduction, a better environment for higher biodiversity and overall climate adaptation. GI has become increasingly popular in the last couple of decades due to its undeniable advantages (European Commission, 2016) (Barnett & Beasley, 2015) (Brears, 2019).

The concept of "Green Infrastructure" was adopted fairly recently. However, the actual implementation of GI started around 150 years ago with simple nature preservation as a primary goal. This measure was necessary to improve the life quality in rapidly densifying cities, especially in America, where people had no access to clean water and proper healthcare. Parks and other green spaces were thus mainly designed to be a feature with primarily social benefits, not ecological (Benedict & Mcmahon, 2006) (Sinnett, Smith, & Burgess, 2015) (Ward Thompson, 2011).

During the 1900-1950 period, the vision of urban planning changed, and with it, the purpose of the green infrastructure shifted. More architects and planners started to see the connection between ecology and design, and consequently, new regulations, policies and ideas were born. For instance, greenbelt towns were a part of the New Deal program, which aimed to improve the life of the American population after the Great Depression. New greenbelt cities not only provided many with a workplace but created a much better environment for the new residents compared to old urban areas (Benedict & Mcmahon, 2006) (Dictionary of American History, n.d.) (Howard, 1902).

During the next two decades, the city planners pushed the concept of connection between people and nature even further. Land use has been studied closely, and Geographic information systems (GIS) have been developed as a tool in spatial planning. Green corridors and Greenways were constructed and promoted as a nature conservation method as well as a recreational space for people. However, at the end of the 1980-s, planners started to understand that the current green infrastructure was not enough to preserve biodiversity and the natural ecological progress (Benedict & Mcmahon, 2006) (Davies, McGloin, Roe, & Macfarlane, n.d.).

Starting from the 1990-s, planning communities around the world emphasised the importance of green spaces in an urban context. A new vision of green infrastructure emerged, shaping the policies and planning approaches. Now, greenery is seen as a multifunctional tool for sustainable urban development and preserving nature (Benedict & Mcmahon, 2006).

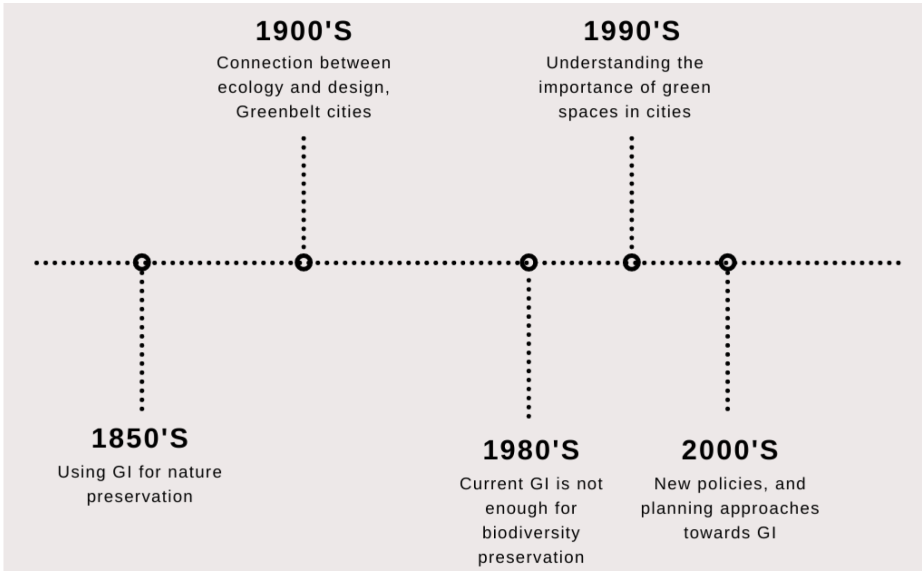

Figure 6 Timeline of GI development through the years

6.2 Green Infrastructure in a Planning Process

With Green Infrastructure becoming more popular, it is essential to discuss the inclusion of the NBS into the planning process.

Spatial planning is considered one of the most effective methods of adopting GI. This allows for studying interactions between diverse land uses across a vast geographical region. Strategic-level spatial planning can help identify the best locations for the NBS projects to "reconnect healthy ecosystems, improve landscape permeability or improve connectivity between protected areas, guide infrastructure developments away from sensitive natural areas to more robust areas" (Brears, 2019).

Changing societal norms and environmental regulations in many countries makes it difficult for cities to control floods while simultaneously restoring urban waterway ecosystems and their environmental and cultural assets. The Endangered Species Act is an example of a regulation in the US that compels developers to consider "the needs of endangered aquatic species". Another example of an environmentally-conscious policy is the Federal Clean Water Act, within which new developments or renovated developments are obligated to install separate stormwater sewers to minimise a post-construction runoff volume from the site. As a result, as part of these standards, several cities are implementing Blue-Green Infrastructure (BGI) into municipal stormwater laws (Bears,2019).

One of the modern approaches to sustainable development is Water Sensitive Urban Design (WSUD). WSUD is defined as "the integration of urban planning with the management, protection and conservation of the urban water cycle, ensuring that urban water management is sensitive to natural hydrological and ecological processes" (Council of Australian Governments, 2004). The concept of WSUD is quite broad, meaning that it can be executed on different levels, from local to regional. The notion serves as the foundation for a comprehensive strategy for flood control that employs methods capable of generating a wide range of good results at both levels (Wong & Eadie, 2000).

Climate Adaptation Plan (CAP) is another example of integrating GI into the planning process. In 2013 the European Commission came to an agreement to promote the financing of the GI in order to "restore the health of ecosystems, ensure that natural areas remain connected together, and allow species to thrive across their entire natural habitat, so that nature keeps on delivering its many benefits to us.". The agreement should cover the development of the GI across the whole of Europe (European Commission, n.d.).

In Stavanger, for several years, continuous green corridors were developed as recreational spaces as well as habitats for biodiversity. Stavanger Municipality recognises the loss of green areas and biodiversity in the city due to densification and new development. The government also highlights the consequences of lack of greenery, such as poorer air quality and flooding problems. Therefore one of the many objectives of the Green Plan for 2018-2030 is "protecting and creating new blue and green structures that can help to capture increased precipitation and other effects of climate change" (Stavanger City Council, 2018).

6.3 State of Art

In this sub-chapter, several examples of GI implementation from different places worldwide are presented to prove the efficiency of these stormwater measures. Types of the GI are chosen based on which GI is analysed later in Chapter 7 of this thesis.

6.4 Green Roof Program, Chicago

Location – Chicago, Illinois

Date – 2007

Type of Development – Retrofit

Type of GI – Green roofs

Chicago, like many other older cities across the world, has a combined sewage infrastructure. Untreated waste and stormwater are dumped into the Chicago river when major storms surpass the capacity of Chicago's wastewater treatment plants, deteriorating water quality in the nearby rivers and lakes. Despite spending billions on grey infrastructure systems to increase capacity during floods, Chicago is augmenting its conventional infrastructure strategy with green infrastructure. Chicago is promoting landscape-based solutions to build a more resilient system (EPA (United States Environmental Protection Agency), 2010).

Examples of such initiatives were The Green Roof Grant Program and the Green Roof Improvement Fund in Chicago, which provide financial incentives for constructing green roofs. The Green Roof Grant Program offered $5,000 grants to 72 vegetated rooftop projects on housing or small office buildings in 2005, 2006, and 2007. The Chicago City Council appropriated $500,000 for the Green Roof Improvement Fund in 2007. The Department of Planning and Development was given authority to award grants of up to $100,000 to green roof projects in the Central Loop District. Although neither grant programme is operational in the current economic climate, the City expects to

Figure 7 Building in Chicago features a green roof, permeable paver and bioswales (EPA Office of Wetlands, Oceans and Watersheds. (2010))

reinstate both once the City's budget has recovered (EPA (United States Environmental Protection Agency), 2010).

According to City Hall's green roof data, the roof cuts stormwater runoff by half, considerably reduces energy usage, and saves the City around $5,500 in heating and cooling costs per year (EPA (United States Environmental Protection Agency), 2010).

6.5 Mountain Equipment Co-op Head Office, Vancouver, BC

Location – City of Vancouver, BC

Date – 2014

Type of Development – Redevelopment

Type of GI – Rainwater harvesting and reuse, rain garden, green roof and bioswale

The Mountain Equipment Co-op (MEC) Head Office (Figure 8), which opened in 2014 on the outskirts of Vancouver's False Creek Flats industrial region, is situated on a former industrial site. The property has a variety of GI elements to regulate stormwater on the property. It was certified as the first urban site in British Columbia to be Salmon-Safe (Fraser Basin Council, 2016). Salmon-Safe is a third-party certification standard that acknowledges and rewards responsible, environmentally friendly management methods on agricultural and urban properties that conserve Pacific salmon habitat and improve water quality (Salmon-Safe BC, 2022).

Figure 8 Mountain Equipment Coop Head Office (ED WHITE PHOTOGRAPHICS. (2022))

A system of landscape elements is combined to reduce stormwater runoff, improve water quality, and keep water on-site. The "blue roof," which covers 50 per cent of the building footprint, collects rainwater. This rainwater is contained in a 35 000-litre subterranean cistern and used for non-potable functions like toilet flushing and watering of the green roof, which fills the remaining rooftop space and is accessible to the employees. Rainwater gathering cuts non-potable water usage by nearly half, while drought-tolerant native plants minimise irrigation needs. The parking lot's stormwater is diverted into a central bioswale, which filters contaminants and minimises the amount of water entering the storm sewer system (Fraser Basin Council, 2016).

6.6 Mitigating the Effects of Bridge Deck Runoff

Location – Mango Creek, North Carolina

Date – 2010

Type of Development – Retrofit

Type of GI – Bioretention cells and a bioswale

In North Carolina, stormwater runoff from highways is a major cause of surface water contamination. For that reason, stormwater BMPs have been implemented beside linear roads by the North Carolina Department of Transportation (NCDOT). NCDOT was particularly interested in collecting runoff from bridge decks, frequently discharged straight into streams through drainage holes in the surface. NCDOT evaluated the best stormwater BMPs for retrofitting bridge decks. In the easement of a bridge deck on I-540 near Mango Creek, two bioretention cells and a bioswale were built (See Figures 9 and 10). According to current North Carolina design guidelines, one bioretention cell was sufficiently sized, while the other was half-sized. Because undersized Bioretention cells are frequently utilised in retrofit settings, it is critical to understand how a small Bioretention cell works in terms of hydrology and water quality. Both bioretention cells contained a 0.6 m internal water storage layer (IWS) and 0.9 m of fill medium. The swale has a surface area to length ratio of 130 m2 /m and was designed to carry the 2-year storm event without overtopping. Runoff was routed to the bioretention cells and swale from the northbound and southbound lanes, respectively (Winston, Luell, & Hunt, 2010).

This investigation revealed that the typical bioretention cell significantly decreased runoff volumes from events smaller than 2.5cm (86 per cent versus 49 per cent). The bioswale, however, did not affect pollutant concentrations and did not lower runoff volumes. This result can be caused by the bioswale being placed on allow-infiltration soil (clay) (Winston, Luell, & Hunt, 2010).

Figure 9 Bioswale at Mango Creek (World Environmental and Water Resources Congress. (2010))

Figure 10 Water delivery system for bioretention and bioswale (World Environmental and Water Resources Congress. (2010))

6.7 Public gardens on a factory site

Location – Coventry, U.K

Date – 2006

Type of Development – Retrofit

Type of GI – Rain Garden, Stormwater Planter

This factory location suffered from flooding, especially in the places with newly built unporous surfaces. The traditional grey infrastructure could not handle the high precipitation in the summertime. The first solution the project designers agreed to implement was to expand the capacity of the existing piping at the location. This method would mean an extensive and very costly project. Before the works started, a new solution was proposed – green infrastructure, specifically Rain Garden and a Stormwater Planter. These two approaches allowed the necessary stormwater infiltration

Figure 11 Rain Garden beside the canteen (Mount, A. (2012))

and brought a new recreational environment for the factory workers and visitors (Charlesworth & Uncapher, 2012).

The Rain Garden was built beside the canteen and had 3m by 60 m dimensions(See Figure 11), and it replaced an existing asphalt coverage. The Planter had a similar construction to a Rain Garden. However, it is standing on a concrete foundation and has dimensions of 6 m by 15 m. Despite the structural difference, both bioretention units work well in stormwater retention and pollutants removal. Overall, the project was considered a successful one and was very appreciated by the public. Furthermore, the implementation of NBS was faster and less costly than the first proposed change of piping (Charlesworth & Uncapher, 2012).

6.8 Neighbourhood-Scaled Green-Infrastructure Retrofit in Abbot Circle

Location – Texas, Sugar Land, Abbot Circle

Date – 2018

Type of Development – Retrofit

Type of GI – Low-Impact Development (Different types of infrastructure)

The project by M. Thiagarajan et al. aimed to evaluate the possible impacts of retrofit GI in an established suburban community on a bigger scale regarding flood protection. The case study is located in the United States, Texas, Sugar Land. The proposed GI is constructed on a site scale for an average single-family house (See Figures 12 and 13). The Green Values National Stormwater Management Calculator was used to calculate the volume of rainfall that may be infiltrated on site owing to each included component (GI). The total volume of rainwater that could be retained if all residential areas in Sugar Land had equivalent facilities was calculated using this data (Thiagarajan, Newman, & Zandt, 2018).

According to the results of this study, Sugar Land has the ability to catch 56 billion litres of stormwater annually if all residential units adopt similar Low-Impact development GI. Findings also show that the "additional benefits of the use of GI include reduced heat (37%), improved aesthetics and property values (20%), increased recreational opportunities (18%), improved water quality (12%), improved air quality (5%), increased green-collar jobs (4%), reduced damage from harmful gas emissions (3%), and increased energy savings (1%), thereby surpassing conventional stormwater management techniques." (Thiagarajan, Newman, & Zandt, 2018).

Figure 12 Site plan before the development (Thiagarajan, M., Newman, G., & Van Zandt, S. (2018))

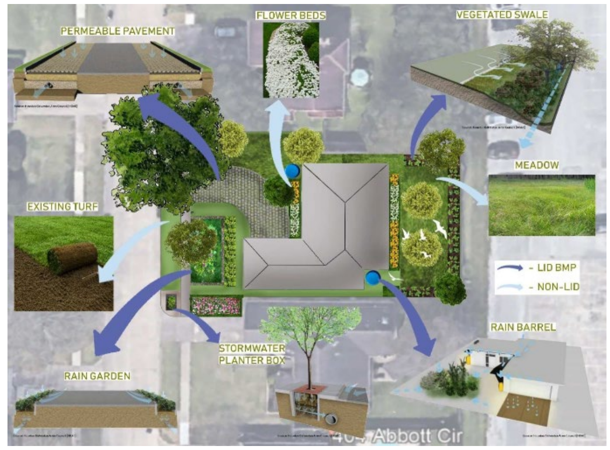

Figure 13 Site plan after proposed development (Thiagarajan, M., Newman, G., & Van Zandt, S. (2018))

6.9 Green infrastructures in stormwater management and their implementation

Green Infrastructure has different scale application possibilities, smaller- building level and more extensive- landscape level. (American Rivers, 2016) Only small-scale GI will be considered for calculations in this work, as these are more likely to be applied as a retrofit. Seven GI types are described in this chapter: Bioswales, Street Trees, Stormwater Planters, Green Roofs, Permeable Pavement Rainwater Harvesting and Rain Gardens.

6.9.1 Bioswales

Bioswale is a vegetated drainage course, swale, ditch, or depression that conveys stormwater and acts as the primary treatment and water capture system for surface runoff during storm events (See Figure 14). It slows water flow, settles sediments, and reduces nutrients, metals, and hydrocarbons in the runoff. Bioswale can absorb low flows or carry runoff from heavy rains to storm sewer inlets or directly to surface waters (Anderson et al., 2016), (Jurries, 2003), (Natural Resources Conservation Service, 2005).

Figure 14 Schematic image of vegetated bioswale (Zimmerman, A. (2017))

Bioswales designing. The four main parameters of the bioswale proposal include longitudinal slope, cross-section (shape of the future bioswale), length, and roughness. Roughness is a function of the vegetation coverage and type (Jurries, 2003).

The recommended slope for the bioswales is 1:3, which equals 33.3%. This slope ensures the proper function of the swale in terms of water infiltration and does not jeopardise its stability. The maximum recommended slope is 1:2 or 50%. However, this slope might be prone to erosions, depending on soil type, vegetation, and water flow in the swale (Jurries, 2003) (Sýkorová et al., 2021).

Four main cross-sectional shapes are commonly used for bioswale building: rectangular, triangular, trapezoidal, and parabolic. The trapezoidal shape is used the most often due to its practical characteristics such as easiness of construction, good hydraulic performance, maintenance and aesthetics (Jurries, 2003).

The length of a bioswale is determined by location and the expected precipitation. With the increase of the bioswale length time of the retention also increases because of the more prolonged contact of water with vegetation and soil. Therefore the longer the swale, the better results in retention can be achieved. The minimum requirement for the residence time is five minutes (Jurries, 2003).

Understanding the context in which green infrastructure will be built is critical to developing successful and beneficial green infrastructure. To avoid invasive species and maintain efficacy, green infrastructure that uses plants to filter water should only be constructed in locations where the plants are native. These plants subsequently serve as food sources for local species, increase environmental biodiversity, and efficiently clean up pollution and other contaminants in water supplies. At the moment, bioswales can not wholly replace grey infrastructure, but they can improve water filtration systems that are currently in use in metropolitan areas (Ganvir, Sayyed, Agrawal, Sawant, & Wayal, 2020).

6.9.2 Street Trees

Street trees are an essential feature in the green Factor of an urban environment. In the urban hydrological cycle, they play a critical role. According to several studies, urban tree cover is closely related to stormwater volumes and, as a result, to the costs of constructing designed stormwater control structures. Trees contribute to the urban hydrologic cycle by intercepting rain, removing water from the soil via transpiration, improving infiltration, and boosting the performance of other green infrastructure technologies (e.g. bioswales, rain gardens) (Stovin et al., 2008).

Nevertheless, many of these interactions are poorly understood, particularly at geographical and temporal dimensions essential to stormwater management. As a result, a better understanding of how and to what level trees interact with stormwater, as well as context-specific recognition of optimal arboricultural procedures and institutional frameworks to maximise the stormwater benefits trees can provide, are required for the reliable use of trees for stormwater control (Berland et al., 2017).

Urban trees, like any other green infrastructure, have many additional benefits besides stormwater management:

- **Noise reduction and air quality**. Trees along roads are able to reduce noise partially and remove harmful particles and pollutants from the air (Mullaney et al., 2015) (Salmond et al., 2016) (Tallis et al., 2011).

- **Temperature reduction**. Trees are proven to reduce temperatures by 5 ˚C to 10 ˚C in the daytime in the summertime (Burden, 2006) (Mullaney et al., 2015).
- **Traffic calming**. Trees along the road reduce traffic speeds by creating vertical walls, making a defined street edge and forcing drivers to slow down (Burden, 2006).
- **Mental benefits.** Greenery in the urban environment reduces stress and stimulates social cohesion (van Dillen et al., 2011) (Mullaney et al., 2015).

The trees in cities are usually long-living and change throughout the seasons (deciduous trees). Different types of trees imprint the specific character of the place and influence its perception by visitors changing the overall experience of the area. Trees are planted solitary, in groups, or linearly; they can be found in all types of public spaces (Sýkorová et al., 2021).

Planting and maintaining street trees is hard work that needs careful planning and support from the authorities. Different types of trees can be chosen based on the environment they will be grown in. The most significant physical limiting factors are a sufficiently large uprooting space and moisture provision. Other aspects to consider are the suitable sub-height under the treetops, especially in places such as streets and squares; tree species whose inflorescences or fruits will not pollute the environment and degrade the property of the population (Sýkorová et al., 2021).

Excess stormwater can be another critical factor for tree well-being. Therefore choosing tree location and design of surroundings is an integral part of the planning process. Sufficient drainage is necessary for places prone to have water stagnation (Roloff & Eckhard Auch, 2016).

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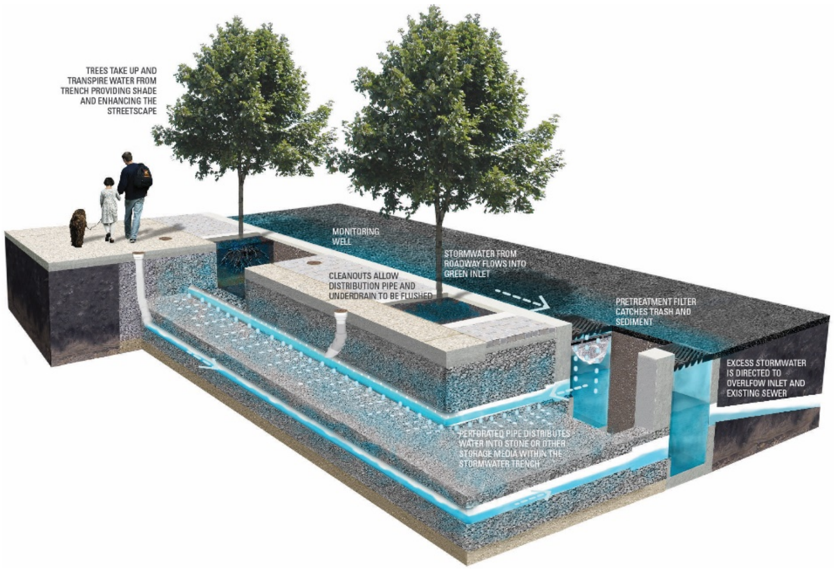

Figure 15 Typical tree trench design (Philadelphia Water Department. (2016))

Tree trenches work similarly to other types of Green Infrastructure such as dry wells or basins, additionally providing the benefits of a tree canopy (noise reduction, air quality, temperature reduction etc.) (Coder, 2011). An underground infiltration system connects trees in the tree trenches (See Figure 15) (Grohmann & Menconi, 2016), (Philadelphia Water Department, 2009).

6.9.3 Stormwater Planters

Stormwater Planters have similar to rain gardens construction; additionally, it has borders built from durable materials such as concrete, stone or bricks (See Figure 16 and 17). The purpose of

Figure 16 Stormwater Planter (BSU Alumnus. (n.d.))

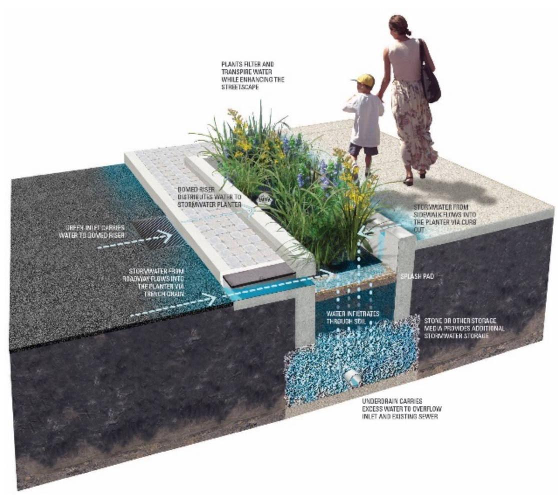

Figure 17 Stormwater Planter construction (Philadelphia Water Department. (2016))

the stormwater planter is to capture runoff and then either filtrate this water or infiltrate it, depending on the construction. Runoff can be directed to the planters by pipes, channels or by the particular design of the sidewalk. Stormwater planters are divided into two main types - infiltration and filtration, similarly to rain gardens. Filtration planters do not infiltrate rainwater; they only treat it and then release it through pipes off-site (Cahill et al., 2018). In this thesis, only infiltration stormwater planters are considered a stormwater management solution and will be included in the calculations.

The real benefit of planters over rain gardens is that the structure allows for more water storage, resulting in a smaller facility footprint. The most significant disadvantage is that the vertical sides must be made of concrete, wood, or another material, which increases the construction expense. Front and rear residential yards, parking lots, and roadways are excellent places for planters (Barr Engineering Company, 2009), (Cahill et al., 2018).

6.9.4 Green roofs

Green roofs are layered systems that use growth material and plants to cover traditional grey roof surfaces. The most basic (extensive) green roofs are shallow, with 3 to 4 inches of growing medium

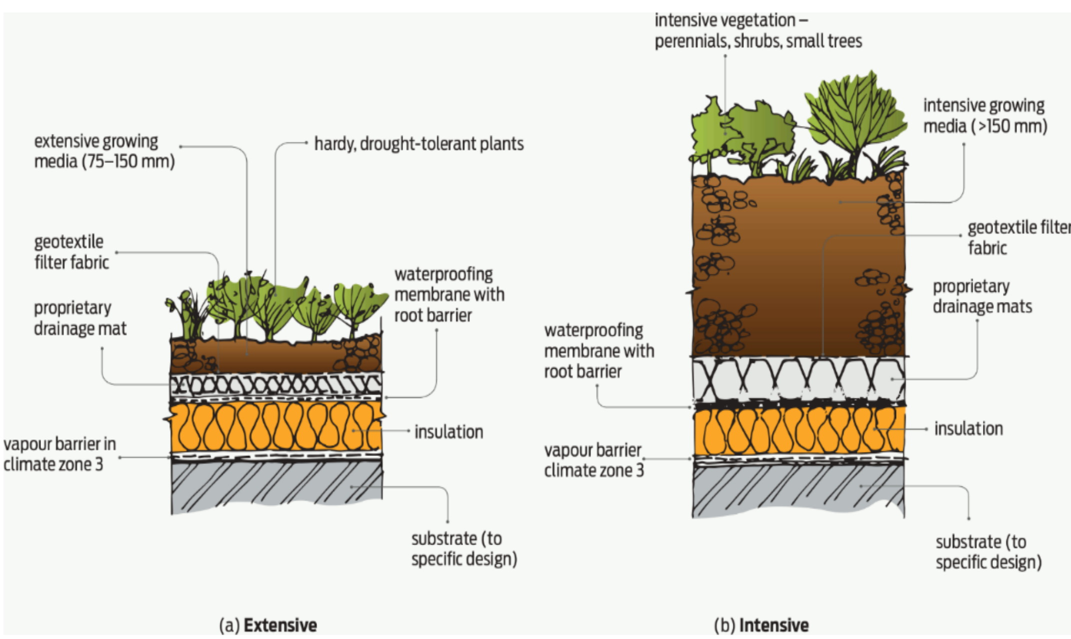

Figure 18 Extensive (left) and intensive (right) green roof layers (Elkink, A. (2017))

planted with drought-tolerant succulents or grasses and no upkeep. Green roofs that are deeper and more extensive (intensive) can be landscaped with flower and vegetable gardens and trees (See Figure 18) (Earth Pledge, 2005).

Nowadays, green roofs are based on German ideas from the 1970s and support plant growth with a lightweight, mineral-based growing material. Green roofs on a citywide or regional scale have the ability to alleviate some of the most critical environmental issues that cities are experiencing in this century (Earth Pledge, 2005).

Rainwater is retained and detained by vegetated rooftops, reducing runoff volume and decreasing the rate at which it enters the drainage system. Green roofs with considerable vegetation coverage can hold up to 70% of 1-inch rainfall and up to 50% of annual rainfall. Green roofs can slow runoff by forty-two to ninety-six per cent and postpone it by thirty minutes to four and a half hours (Earth Pledge, 2005, Moran et al., 2003). It is just as crucial to delay runoff as it is to reduce its amount; the initial rainwater flood causes overflows. Green roofs also serve as filters, lowering the amount of pollution that enters waterways. Airborne contaminants are trapped by plants and soil, and heavy metals bond to soil particles (Earth Pledge, 2005, Hosker & Lindberg, 1982).

Green roofs are a cost-effective stormwater management technology compared to traditional treatment and retention methods. Toronto has demonstrated that by greening 6% of available roof spaces for $45.5 million (CDN), the City can retain as much stormwater as a $60 million storage tank, saving $14.5 million (Earth Pledge, 2005).

Structural limitations and considerations of Green roofs

When constructing green roof systems, a number of factors influence the structural structure chosen, and it is essential to consider all of them:

- Project programmatic and design requirements
- Geotechnical considerations such as depth to bedrock or hydrostatic conditions
- Bearing capacity of the soil
- Material availability and choosing
- Material weights, such as:
  - Soil
  - Vegetation
  - Water
  - Paving
- Parts of other site elements like fountains, walls, or stairwells

- Costs (Weiler & Katrin Scholz-Barth, 2009)

It is critical to select appropriate waterproofing. A flood test is typically conducted before installing the green roof to choose the proper type of waterproof layer. The substrate layer thickness determines the variety of flora on the green rooftop. Because it must carry the weight of soil (dry and saturated) and perhaps humans, the roof-bearing architecture must be more robust (Poórová & Vranayová, 2020) (Sýkorová et al., 2021).

Vegetation roofs can be single-layer or multi-layer, with a drainage layer (e.g. studded foil) separated from the growing substrate in the case of a basic extensive or semi-intensive roof. Under the plant layer, there are also unique constructions (e.g., plastic grates) that, beyond the capabilities of the roof substrate, improve water retention and accumulation, therefore mitigating the consequences of heavy rain (see Figure 13) (Sýkorová et al., 2021).

6.9.5 Permeable Pavement

Permeable pavement is a stormwater management system which consists of two main layers, the outer through which the stormwater passes and the inner – the infiltration layer. This GI is highly effective in runoff reduction, up to 100% if planned successfully and water filtration. Permeable pavements are usually implemented on parking lots, roads with a speed limit under 55 km/h, lawns, driveways and pathways." Permeable sidewalks are also used in recreational and park-related applications, such as playground pools, fountain areas or permeable bumpers around flower beds and pots." (Eisenberg, Lindow, & Smith, 2015).

Permeable Pavements have an advantage over GI and GIY as they can serve a dual function – a surface for pedestrians and transportation and a stormwater management tool. Additionally, retrofitting a Permeable Pavement is considered affordable and feasible in space-limited locations. "Permeable pavements can be strategically placed to accept clean run-on from adjacent uses such as walkways or roofs." (Eisenberg, Lindow, & Smith, 2015).

Porous Pavement types

Porous asphalt

Porous asphalt is very similar to ordinary; however, the pores are hollow, allowing water to penetrate. Compounds and adhesives with larger grains are frequently employed to increase longevity and avoid the drain down of the asphalt binder (Eisenberg, Lindow, & Smith, 2015).

Pervious concrete

Pervious concrete is produced based on a similar principle as Porous asphalt by adding larger particles to a concrete mixture to increase the porosity. "As a result, it has a coarser appearance than standard concrete." (Eisenberg, Lindow, & Smith, 2015).

Permeable interlocking concrete pavement

This surface type consists of multiple pavement tiles with gravel or similar material filling in between. The pavers themselves are unporous, meaning stormwater is infiltrating through the gaps (Eisenberg, Lindow, & Smith, 2015).

Grid pavement systems (plastic or concrete)

Grid pavement systems are plastic or concrete interlocking panels filled with gravel or turf (Eisenberg, Lindow, & Smith, 2015).

Porous Pavement Design

Three main factors must be addressed before the Porous Pavement construction:

- Location on the site
- Subsurface materials with appropriate hydrological capacity
- Insulation layer or an additional drainage layer (Eisenberg, Lindow, & Smith, 2015).

The Grid pavement system with the concrete lattice and turf filling will be included in the Scenario development in this work.

6.9.6 Rainwater Harvesting

Rainwater harvesting is the process of collecting runoff from a building or other impermeable surface and storing it for later use (See Figure 19). Traditionally, this entails collecting rainwater from a roof. Rainwater will accumulate in gutters, which will route it into downspouts and eventually into a storage vessel. Rainwater collection systems may be as basic as collecting rainwater in a rain bucket or as complex as gathering rainwater into giant cisterns to meet the household's complete requirements. (Maxwell-Gaines, 2004)

Rainwater collecting is becoming a feasible option for providing water to our homes and businesses, and not only in rural areas. Rainwater collection is used and promoted by the government in several countries, especially in Europe. (Maxwell-Gaines, 2004)

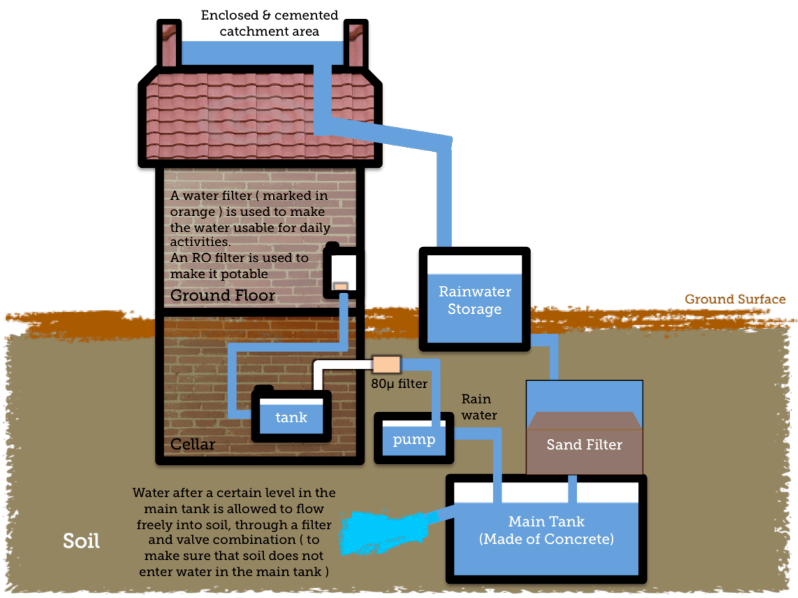

Figure 19 Rainwater harvesting schematic representation (Adityamail. (2010))

Local governments can fund and encourage low-impact development solutions for recycling rainwater, reducing and mitigating impermeable surfaces, and boosting natural drainage through programs in Europe, where scant open space necessitates careful and varied land use. The European initiatives are mostly aimed at individual households. They are designed to support them in their typically self-motivated efforts to conserve water and exercise environmental stewardship at home. For example, the City of Saarbrücken in Germany offers homeowners incentives ranging from $2,700 to $5,400. The grant amount is determined by the overall stormwater runoff reduction achieved by the proposed project (therefore lowering the municipality's infrastructure costs) and differs between various technologies. For example, the award pays around $0.75 per square foot of roof area gathered for rainwater collection in a cistern or barrel for reuse in toilet flushing or watering plants. The cost of "de-sealing" a driveway, which involves removing the impermeable surface cover and replacing it with pervious materials to improve natural infiltration, is $1.50 per square foot. Grants for their installation—

new or retrofit—pay $3 per square foot of vegetated roof area to acknowledge the wide-ranging advantages of living green roofs (Weiler & Katrin Scholz-Barth, 2009).

Rainwater harvesting methods and their construction

Barrels

The most popular and the cheapest way to harvest rainwater from the roofs is a barrel right under the gutters. (See Figure 20) This method is the easiest for installation and does not require extensive maintenance. Collected rainwater can be used in gardens for watering or partly in a household (e.g. automobile washing). Tanks for the water collection vary in size and volume. Generally market offers barrels from 50 l to 1000 l. The volume is chosen according to the rainfall intensity in the region (larger tanks are required in the locations with more precipitation) (GM8 Group, n.d.) (Maxwell-Gaines, 2004).

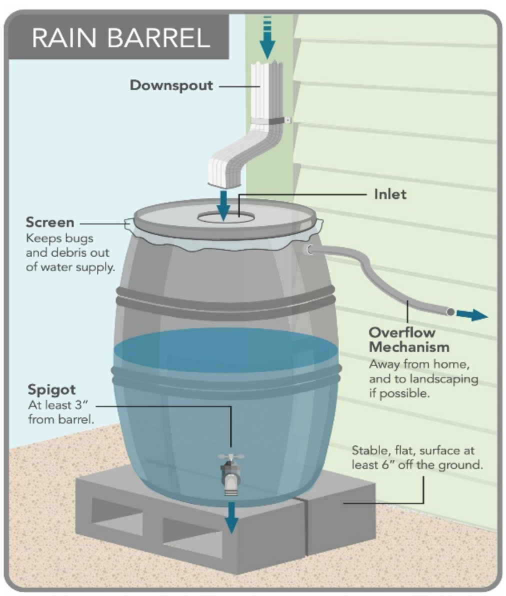

Figure 20 Rain Barrel (City of Palo Alto Stormwater Program. (n.d.))

Dry Method

This approach is similar to a rain barrel setup, except it requires a more significant storage volume. A larger container is installed adjacent to the property, with a higher storage capacity than a barrel, and the guttering is channelled to the tank's top. The method is called dry because the piping system has enough time to dry between rainfall events (Constro Facilitator, 2021) (Maxwell-Gaines, 2004).

Wet Method

In a "wet method," the pipes are located underground, and therefore water is always present inside. Several downspouts are connected to one gutter, and when the water level rises, stormwater will overflow into a tank. The tank intake must be lower than the lowest gutter on the house. In between the precipitation, the water level is static. Construction requires the underground tubes to be completely waterproof not to allow any leakage into the soil (Constro Facilitator, 2021) (Maxwell-Gaines, 2004).

Rain Harvesting retrofit

It is not usually feasible to retrofit older buildings with specialised water pipes for each end-use. It is often impractical to re-plumb the whole school or office building to create a devoted water system line to the toilets. It is costly to open up wall cavities and make the necessary plumbing changes to accommodate a rainwater harvesting system unless it is done as part of a major renovation. Consequently, outside irrigation is frequently selected as a low-cost technique for using rainwater in an existing facility (Novak, Van Giesen, & Debusk, 2014).

For that reason, in this thesis, simple rain barrels would be considered a rainwater harvesting system

6.9.7 Rain gardens

Rain Gardens are a type of bioretention space intended for stormwater collection, infiltration and treatment. These structures are usually represented by a depression in a landscape several centimetres deep, vegetated with native plants or shrubs. (See Figure 21) Rain gardens are highly effective in pollutants removal, making them desirable and practical in residential and industrial areas (Davis, 2005) (Shafique & Kim, 2015).

The construction of Rain Gardens allows stormwater to be infiltrated into the soil and the excess water to be evapotranspirated. Additionally, an optional subsurface drainage pipe can be installed to prevent overflow, generally in the depth of 75 cm. It is preferable to create irregular banks in the Rain Garden to avoid erosion and provide more smaller spaces for the fauna as a habitat (Davis, 2005) (Charlesworth & Uncapher, 2012).

There are not many structural limitations to be considered for a Rain Garden compared to other NBS. Rain Gardens can vary in size, shape, and location on a property. Perhaps the most important factors to be aware of before the installations are:

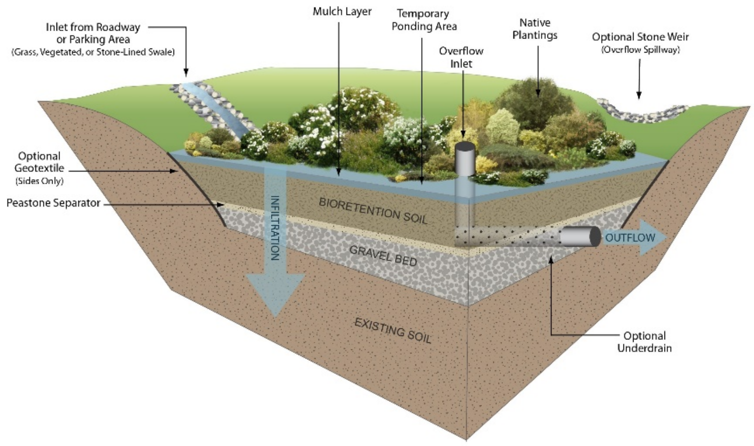

Figure 21 Rain Garden design (Massachusetts Celan Water Toolkit. (n.d.))

- Soil type (soils with a large percentage of clay have bad infiltration qualities, which can cause an overflow or vegetation damage)
- Flow direction (the water should be naturally or artificially directed to the Rain Garden from the ground or a roof)
- Slope (too steep slopes lead to erosion, too flat slopes could lead to overflow to a property) (Charlesworth & Uncapher, 2012).

A successful design of a bioretention unit such as a Rain Garden can promote biodiversity by creating a new suitable environment for species. Other benefits of Rain Gardens include:

- Aesthetics
- Improvement of a microclimate (better air quality, lower temperature)
- Water filtration
- Soil surface protection (Charlesworth & Uncapher, 2012) (Sýkorová et al., 2021).

6.10 Methods

In order to analyse the potential of the GI in the chosen drainage basins, several methods are used.

Scenarios' development

Analysis using scenarios is a standard method for forecasting the situation in future using the modified parameters (Kishita, Hara, Uwasu, & Umeda, 2015). This thesis will consider four designs to measure the efficiency of different-scale GI implemented in the area of interest. The scenarios differ in the initial costs, expanse, level of intervention and types of the proposed GI. Scenario 1 will be represented by the minor expanse area, whereas Scenario 3 is the costliest, and the proposed GI has the most significant spatial scale. The scenarios would be compared based on two methods, the Rational Method and the hydraulic modelling using HEC-RAS software.

Hydrological calculations and simulations

The Rational Method is a calculation method in hydrology that "expresses a relationship between rainfall intensity and catchment area as independent variables and the peak flood discharge resulting from the rainfall as the dependent variable" (Main Roads Western Australia, 2019). It is used to calculate the peak flow in a given drainage basin. To do that, a formula used **Q=CiA**, where **C** is a runoff coefficient, **i** is the rainfall intensity, and **A** is the drainage basin area (HydroCAD, 2020). This method has been used for almost two centuries and remains unchanged, proving its efficiency. The "Rational" part in the Method's name comes from the ratio of C to the rainfall rate being constant, considering that i is uniform during the rainfall event (Chin, 2019).

Runoff coefficient **C** values are dimensionless and are directly related to the land use type of the area, soil type, average permeability and gradient. Usually, a table with the C values for a particular kind of land is used for the calculations. A larger C value means higher runoff and lower infiltration chances (The Clean Water Team Guidance Compendium for Watershed Monitoring and Assessment State Water Resources Control Board, 2011). Table 1 was used in this work to determine the C value in the Rational Method calculations.

Table 1 Runoff Coefficient (Ministry of Education, Culture, Sports, Science and Technology, Japan. (n.d.))

Type of ground surface	Coefficient of surface runoff, $F_{i\infty}$
Road:	
Pavement	0.70–0.90
Permeable pavement	0.30–0.40
Gravel road	0.30–0.70
Shoulder or top of slope:	
Fine soil	0.40–0.65
Coarse soil	0.10–0.30
Hard rock	0.70–0.85
Soft rock	0.50–0.75
Grass plot of sand:	
Slope 0–2%	0.05–0.10
Slope 2–7%	0.10–0.15
Slope 7%	0.15–0.20
Grass plot of clay:	
Slope 0–2%	0.13–0.17
Slope 2–7%	0.18–0.22
Slope 7%	0.25–0.35
Roof	1.00
Unused bare land	0.20–0.40
Athletic field	0.40–0.80
Park with vegetation	0.10–0.25
Mountain with a gentle slope	0.30
Mountain with a steep slope	0.50
A paddy field or water	0.70–0.80
Farmland	0.10–0.30

Data for the rainfall intensity are borrowed from the Norwegian Climate Service Center website. IDF data are taken from Våland (SN44640) station, as it is the closest to the analysed area station. With the assumption of the 100 -year event with 200 minutes duration, the rainfall intensity is equal to 54.8 l/s.ha.

With climate changes, larger rainfall intensity and frequency are expected (IPCC, 2007) (Willems, Arnbjerg-Nielsen, Olsson, & Nguyen, 2012). Climate change allowance is estimated to provide a better overview for the predictions of peak flow in future. Table 2 was borrowed from the Norwegian Climate Service Center and used in the calculations.

Table 2 Climate change allowance for different durations and return periods (Klimaservicesenter (Norwegian Climate Service Center). (n.d.))

	Return period < 50 years	Return period ≥ 50 years
≤ 1 hour	40 %	50 %
>1–3 hours	40 %	40 %
>3–24 hours	30 %	30 %

HEC-RAS software

HEC-RAS software was developed by The U.S. Army Corps of Engineers (USACE). Its purpose is to "perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modelling." (US Army Corps of Engineers, n.d.). This thesis uses HEC-RAS to simulate the water depth during each Scenario's flooding events.

The input data used for the flood simulations:

Land Cover – is spatial information about a type of surface in a specific area on the Earth's surface. Land Cover examples are forests, lakes and wetlands (Copernicus Global Land Service, n.d.).

IDF Intensity-Duration-Frequency of the rainfall is a graphical visualisation of a probability "that a given average rainfall intensity will occur within a given period of time". IDF is used to estimate the return period of a precipitation event or, overwise, rainfall intensity based on the return period (Sun, Wendi, Kim, & Liong, 2019).

In this work for the hydrological modelling in HEC-RAS software, a synthetic hyetograph based on IDF data from the Norwegian Climate Service Center website was used (See Figure 22).

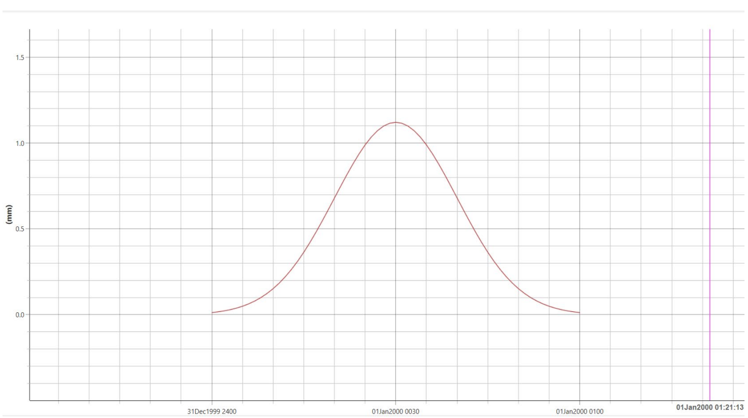

Figure 22 Hyetograph used for modelling

Boundary lines are located on the borders of different structures to mark a change from one construction to another, for instance, from a road to a building.

Manning's coefficient expresses the roughness of the material applied to the water flow. Usually, the values are taken from tables (The Engineering Tool Box, 2019).

Flow direction shows which way the water flows during the storm events. The data were borrowed from the SCALGO website (SCALGO, 2022).

The output data were the water depth in places prone to flooding. This output then was visualised by map using ArcGIS software.

Spatial analysis (using GIS)

Spatial Analysis is a geographical tool that helps find connections between a location and a particular characteristic or event taking place at this location (The ArcGIS Book, n.d.) (Mayhew, 2009).

Spatial Analysis was performed using ArcGIS Pro software and data from various sources, including the Norwegian Water Resources and Energy Directorate, The Norwegian Institute of Bioeconomy Research, and Scalgo.com (online software). Primarily the Spatial analysis was used to determine the Land Use type for the Rational Method calculations. Secondarily it was utilised for the data visualisation.

SWOT analysis

SWOT analysis is used as a planning tool to determine a realistic overview of a decision's Strengths, Weaknesses, Opportunities and Threats and conclude its compatibility and effectiveness. SWOT can be divided into two categories by the data type, internal and external, where Strengths and Weaknesses are based on internal data, and Opportunities and Threats on external (Kenton, 2021). SWOT analysis is a visual tool that can be used with stakeholders of different backgrounds to explain the decision-making process easier (Sarsby, 2016).

Blue-Green factor analysis

The Blue-Green Factor (BGF) is a policy instrument that uses factors to secure and maintain targeted amounts of green and blue zones in urban developments. It rates the relative value of distinct green or blue features at a specific site as a non-economic valuation approach by analysing the ecologically effective surface area ratio as a proportion of the total land area. This tool allows architects to choose how green or blue features should be integrated into their plans and serves as an assessment criterion in public procurement or land allocation (UnaLab, 2022).

Oslo Municipality Planning and Building Agency, Bærum Municipality, Dronninga Landskap AS, Cowi AS, and C. F. Møller partnered up for the Cities of the Future program to develop a 'blue-green factor' rating scale to move the latest housing estate to the Oslo Green Plan goals as close as possible (Barton, Stange, & Fongar, n.d.). Table in Appendix 3 was used for the calculations in this thesis.

Various case studies have been used to create and evaluate the BGF idea. However, the final idea has yet to be adopted into local construction standards or regulations. The BGF assigns a score to each construction based on performance parameters, primarily water infiltration and storage capacity. Scores are assigned to various blue-green surfaces based on their hydrological regulating impact. Extra credit is provided for water and vegetation elements that improve runoff control, as well as aesthetic aspects and biodiversity habitat (Barton, Stange, & Fongar, n.d).

7 Scenarios

In this chapter, the efficiency of the suggested infrastructure will be assessed separately to see how each method works according to the literature and previous similar studies. Later this information will be used to determine the effectiveness of the proposed approaches in the case study area.

It is important to note that all the proposed methods focus on retrofitting rather than being built from scratch. The retrofit allows GI to be as cost-effective as possible and the changes to be more desirable for authorities.

7.1 Scenario 0

Scenario 0 represents the current Land use situation in the area of interest without any applied changes.

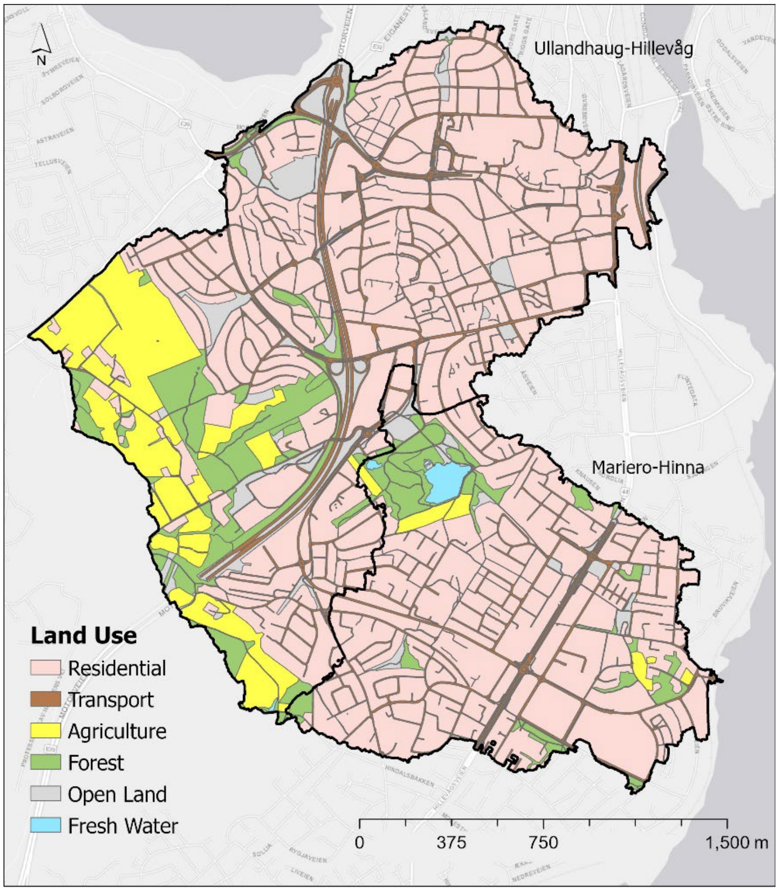

Figure 23 Current Land Use in the area

Current Land Use is shown in Figure 23. Detailed information about each type of land use category is shown in Table 3 and Table 4. Land Use categories are defined by The Norwegian Institute of Bioeconomy Research (NIBIO) (Norwegian Institute of Bioeconomy Research (NIBIO), 2019). There are eleven categories of area use, according to NIBIO. In the basins of interest, six of those categories are present, including

- Residential
- Transport (roads)
- Agriculture (original data for the agricultural area from NIBIO is divided into the three area types fully cultivated land, surface cultivated land and infield pasture; however, in this work, all agricultural area is considered to be one unit)
- Forest
- Open Land (From Norw.- "Åpen fastmark": Area that is not a bog, nor is it an agricultural land, forest, built-up area or transport.)
- Freshwater (lakes and ponds) (Norwegian Institute of Bioeconomy Research (NIBIO), 2019).

Knowing the Land Use type is necessary to determine the C coefficient.

By means of the Rational Method calculations described above, results in Table 5 were achieved. The results are presented as two types of runoff volume for each drainage basin with and without climate change allowance.

Figure 4 shows the flooding situation in the four selected areas before implementing GI.

Table 3 Land Use types for scenario 0 Ullandhaug-Hillevåg

SCENARIO 0 - LAND USE (ULLANDHAUD-HILLEVÅG)		
Residential area	58%	2.06 km^2
Transportation	13%	0.46 km^2
Agriculture	13%	0.46 km^2
Forest	9%	0.32 km^2
Open Land	7%	0.25 km^2
Total	**100%**	**3.56 km^2**

Table 4 Land Use types for scenario 1 Mariero-Hinna

SCENARIO 0 - LAND USE (MARIERO-HINNA)		
Residential area	61%	1.48 km^2
Transportation	9%	0.22 km^2
Agriculture	20%	0.48 km^2
Forest	7%	0.17 km^2
Open Land	2%	0.05 km^2
Fresh Water	1%	0.02 km^2
Total	**100%**	**2.42 km^2**

Table 5 Results of Rational Method calculations – Scenario 0

RESULTS OF RATIONAL METHOD CALCULATIONS – SCENARIO 0	ULLANDHAUD-HILLEVÅG	MARIERO-HINNA
RUNOFF IN A 100-YEAR EVENT	11.17 m^3/s	8.91 m^3/s
RUNOFF WITH A CLIMATE CHANGE ALLOWANCE	15.64 m^3/s	12.47 m^3/s

7.2 Scenario 1

Bioswales, Street trees, Stormwater Planters

Scenario 1 suggests the usage of smaller-scale green infrastructures such as Bioswales, Street trees and Stormwater Planters.

This work proposes bioswales in four locations shown in Figure 24. Each circle with a number represents an area that might benefit from retrofitting the bioswales.

Location 1 is a Stavanger University Hospital. This area has the potential to be greener and more conscious of stormwater management. Nowadays, the Hospital has a small number of trees and planters around all the buildings. However, parking lots and roads are entirely unporous, which leads to minor flooding and unnecessary load to sewage systems in storm events.

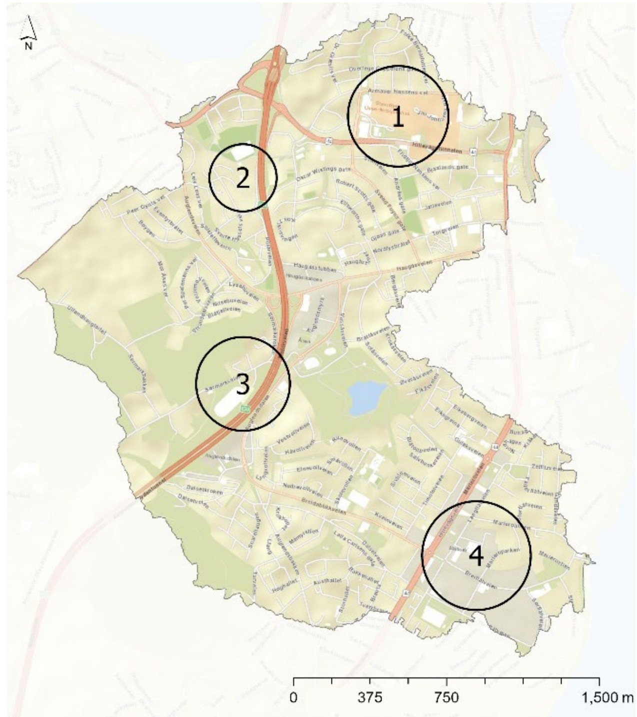

Figure 24 Four locations of proposed bioswales

Location 2 is a residential area between Lief Dietrichsons gate and Helmer Hansens gate. The location has six housing units. The space between the apartment blocks is relatively flat and covered with grass. There are no unique structures such as playgrounds, sports, or other recreational features. For that reason, the area has a good potential for retrofit, as it does not require demolition or other significant constructional changes.

Bioswales are proposed to be constructed along the existing walking paths and roads. (See Figure 25) Hence, pedestrians would not be forced to adapt to the new layout.

Location 3 is a parking lot in front of the Sørmarka Arena. It is presently divided by green strips with grass, bushes and smaller trees. Current strips do not provide efficient stormwater management due to their design. Compared to the flat strips, Bioswales have a better chance of capturing and treating the runoff.

For the first Scenario in the third location, bioswales are proposed to be located on the existing green strips on the parking lot and another swale along the Sørmarkaveien road. (See Figure 23) The swales on the parking lot are suggested to have the same cross-sectional characteristics (bottom and top width, longitudinal and transcending slopes).

Location 4 (Mariero) is represented by several warehouses and shopping centres. The area has several weaknesses regarding stormwater management, including a lack of greenery, flat grey roofs, and non-porous parking and roads. Bioswales in this area can be retrofitted along the existing roads and walking paths.

Currently, no model approaches are available to calculate the precise effect of urban trees on stormwater infiltration due to many complicated parameters and probable unforeseen circumstances such as wild and domesticated animal activities, soil pollution and many others (Konijnendijk, 2010). For that reason, a Rational method will be used to estimate the efficiency of the proposed trees in Stavanger.

This work selected two prominent locations to define the efficiency of trees in chosen drainage basins. First is a part of E39 road with an existing green pass on the median strip. The strip is approximately 1960 meters long and 4-6 meters wide. Currently, the pass is covered with grass, and there are no trees or bushes of any kind.

This part of the work aims to see how the stormwater retention would change if an existing grass cover were complemented by trees planted linearly along the median strip.

Trees can be planted linearly without any specific modifications in this location, or a more complicated structure, such as a tree trench (See Chapter 6.9.2), can be used. However, it can be complicated to estimate the hydrological effect of the trees. For that reason, in the calculations, the proposed GI will include trees without any additional construction.

Figure 23 shows the proposed location for both Bioswales and Stormwater Planters in the Stavanger University Hospital area, and this location is used further in the hydrological modelling and calculations

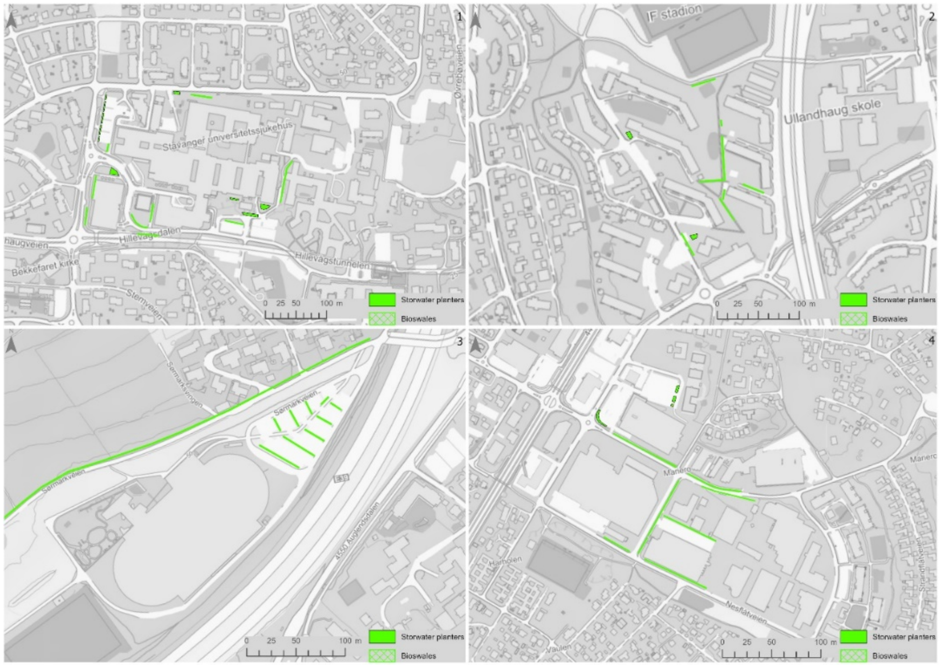

Figure 25 Proposed locations of Bioswales and Stormwater planters in 1 - University Hospital, 2 -a residential area in Ullandhaug, 3 - Sørmarka Arena, 4 - Mariero shopping centres

Figure 26 Is a cross-section of a proposed Bioswale; it shows clearly that the stormwater can be retained before it flows to the road, protecting the area downstream.

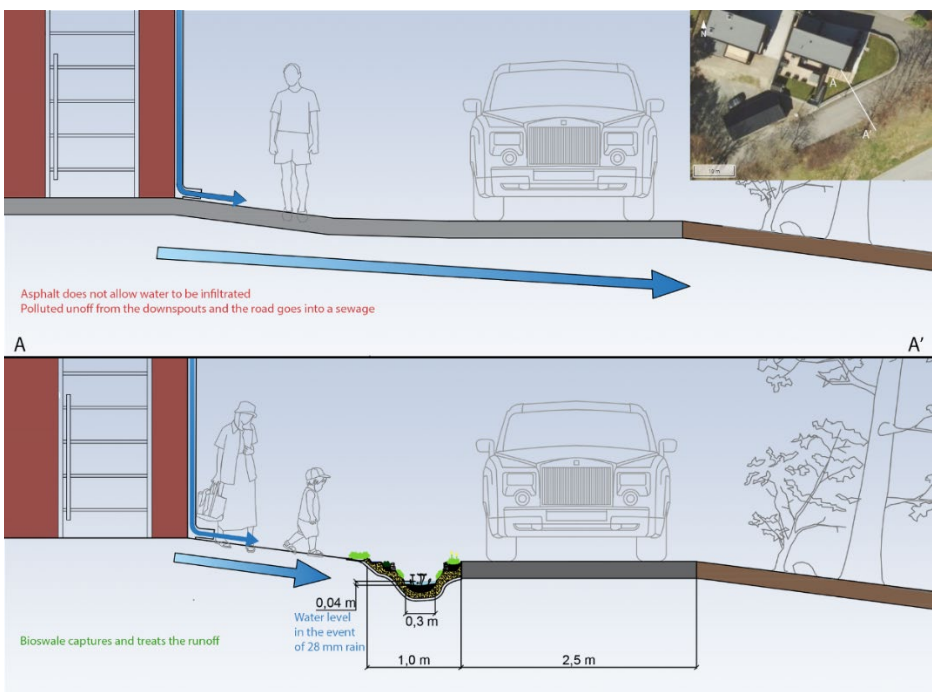

Figure 26 Cross-section of the proposed Bioswale in the Sørmarka arena area

7.3 Scenario 2

Figure 27 shows the proposed location for both Green roofs and permeable pavement, and this location is used further in the hydrological modelling and calculations.

Rainwater harvesting

Calculations for the efficiency of rainwater harvesting in regards to runoff reduction

Though considered a "green infrastructure", rainwater harvesting does not contain vegetation itself. To be able to include rainwater harvesting into Rational Method calculations, a rough estimate will be made based on literary sources for the areas of interest.

The calculations will assume that 2000 households in basin no.1 and 1000 households in drainage basin no.2 discussed in this study would adopt a rain harvesting system. As demonstrated in Table 3 and Table 4, residential area type takes more than 50% of the analysed basins or 2.08 km^2 in Ullandhaug-Hillevågand and 1.49 km^2 in Mariero-Hinna. It represents a significant fraction of all the surface runoff, as conventional roof surface has a large runoff coefficient (C=0.9). Spatial analysis of the existing houses in Stavanger shows that an average roof area is approximately 150 m^2. The investigation was carried out using the current maps of the residential area within the drainage basins no.1 and no.2.

According to several studies, different types of rainwater harvesting systems can capture up to 91% of runoff. (Gee & Hunt, 2016) (Petrucci et al., 2012) In other terms runoff coefficient for the housing units with Rainwater harvesting systems will be C=0.09 instead of C=0.9.

Using those data and a Rational Method, we can roughly estimate the effect of the proposed rainwater harvesting systems on the final runoff from each basin. The results for Scenario 2 can be found in Table 11.

Figure 27 Proposed locations of Green roofs and Permeable pavement in 1 - University Hospital, 2 -a residential area in Ullandhaug, 3 - Sørmarka Arena, 4 - Mariero shopping centres

7.4 Scenario 3

Scenario 3 combines all the proposed GI in the two catchments and additionally several Rain Gardens. The proposed location of Rain Gardens is shown in Figure 28.

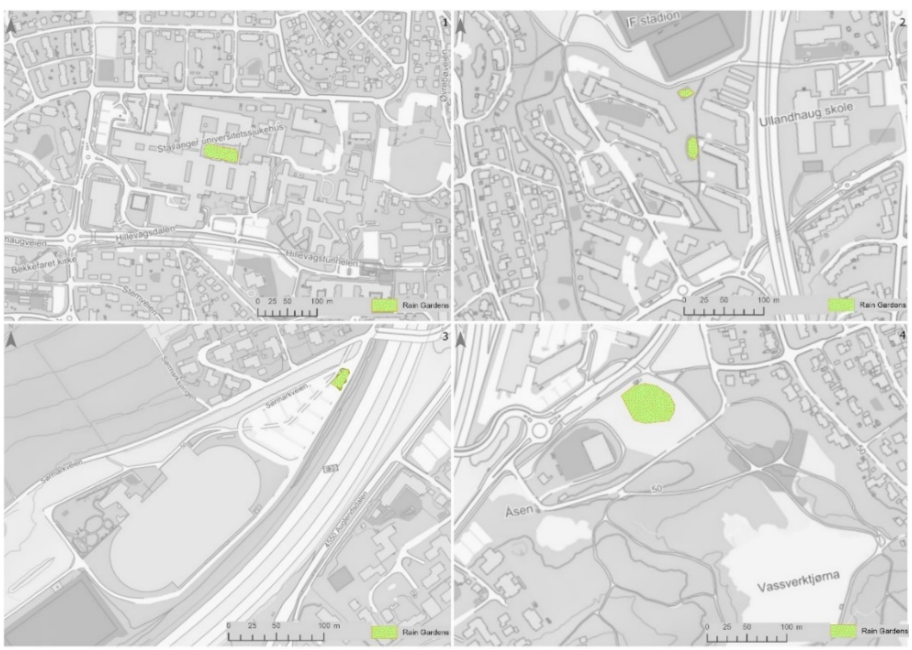

Figure 28 Proposed locations of Rain Gardens in 1 - University Hospital, 2 -a residential area in Ullandhaug, 3 - Sørmarka Arena, 4 - Park in Kristianlyst

The fourth location has been changed from the Shopping Mall to Park in Kristianlyst. This is because the previous location could not accommodate a Rain Garden and the Park had an appropriate place for that purpose.

An example cross-section of a Rain garden in area 2 (Residential) is shown in Figure 29; the other Rain Gardens have a similar construction, with a difference in a circumference or perimeter.

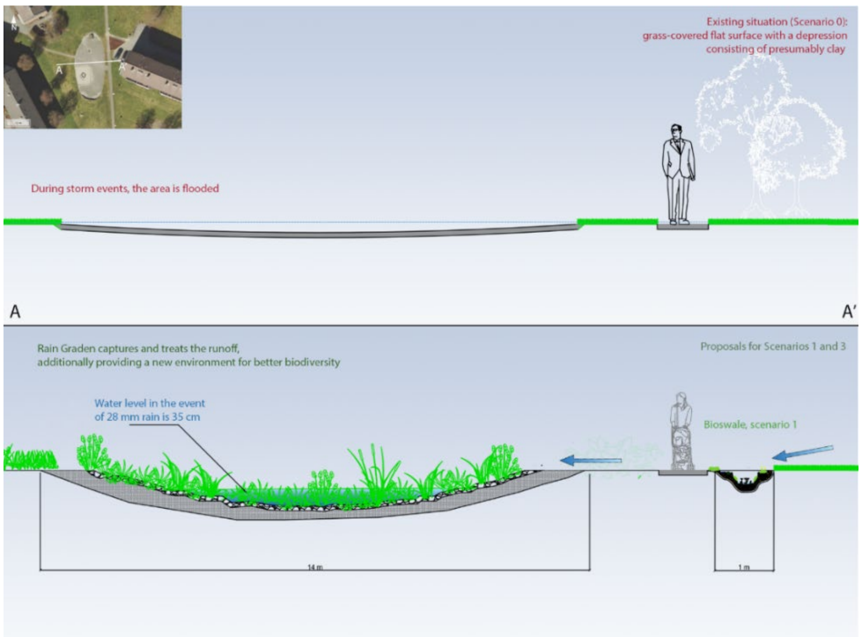

Figure 29 Cross-section of the proposed Rain Garden in the Residential area

8 Results

The results of the calculations and modelling are presented in this chapter.

Table 6 Land Use types for scenario 1 Ullandhaug-Hillevåg

Scenario 1 - Land Use (Ullandhaud-Hillevåg)		
Residential area	58.50%	2.08
Transportation	12.50%	0.45
Agriculture	13.50%	0.48
Forest	9.60%	0.34
Open Land	5.85%	0.21
Bioswales, stormwater planters, Street trees	0.05%	0.00178
Total	**100%**	**3.56 km2**

Table 4 Land Use types for scenario 1 Mariero-Hinna

Scenario 1 - Land Use (Mariero-Hinna)		
Residential area	61.70%	1.49
Transportation	9.40%	0.23
Agriculture	19.90%	0.48
Forest	7.00%	0.17
Open Land	1.95%	0.05
Fresh Water	1%	0.24
Bioswales, stormwater planters, Street trees	0.05%	0.0012
Total	**100%**	**2.42 km2**

Table 8 Results of Rational Method calculations – Scenario 1

Results of Rational Method Calculations – Scenario 1	Ullandhaud-Hillevåg	The difference compared to scenario 0 (%)	Mariero-Hinna	The difference compared to scenario 0 (%)
Runoff in a 100-year event	10.27 m^3/s	-8,0 %	8.81 m^3/s	-1 %
Runoff with a climate change allowance 40%	14.38 m^3/s	-8.0 %	12.35 m^3/s	-1 %

Table 8 shows the impact of the Bioswales, Stormwater Planters and Street trees on the initial runoff volume. For catchment no.1, the change is approximately 8%, and for catchment no.2, the difference is 1%.

Figure 30 shows the change in water depth during flooding with the application of Bioswales, stormwater planters and Street trees.

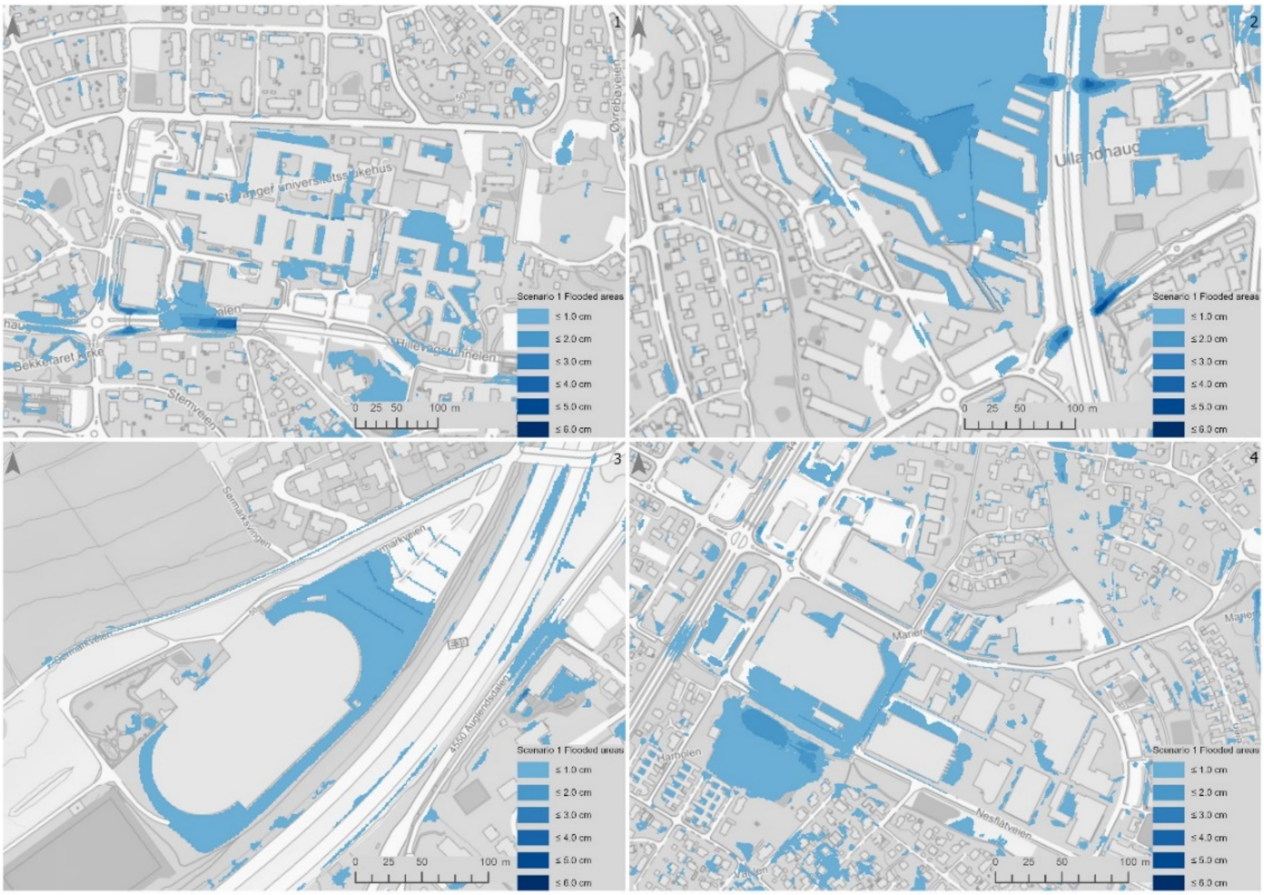

Figure 30 Flooded areas in the selected drainage basins Scenario 1

Table 9 Land Use types for scenario 2 Ullandhaug-Hillevåg

Scenario 2 - Land Use (Ullandhaud-Hillevåg)		
Residential area	50.08%	1.78 km^2
Transportation	11.07%	0.39 km^2
Agriculture	13.50%	0.48 km^2
Forest	9.60%	0.34 km^2
Open Land	5.85%	0.21 km^2
Bioswales, stormwater planters, Street trees, Green roofs, Permeable pavement	1.48%	0.053 km^2
Rainwater harvesting	8.42%	0.3 km^2
Total	**100%**	**3.56 km^2**

Table 50 Land Use types for scenario 2 Mariero-Hinna

Scenario 2 - Land Use (Mariero-Hinna)		
Residential area	55.5%	1.34 km^2
Transportation	6.28%	0.15 km^2
Agriculture	19.90%	0.48 km^2
Forest	7.00%	0.17 km^2
Open Land	1.0%	0.02 km^2
Fresh Water	1%	0.02 km^2
Bioswales, stormwater planters,Street trees, Green roofs, Permeable pavement	3.12%	0.08 km^2
Rainwater harvesting	6.2%	0.15 km^2
Total	**100%**	**2.42 km^2**

Table 11 Results of Rational Method calculations – Scenario 2

Results of Rational Method Calculations – Scenario 2	Ullandhaud-Hillevåg	The difference compared to scenario 0 (%)	Mariero-Hinna	The difference compared to scenario 0 (%)
Runoff in a 100-year event	10.13 m^3/s	-9.3%	8.11 m^3/s	-8.9%
Runoff with a climate change allowance	14.19 m^3/s	-9.3%	11.35 m^3/s	-8.9%

Table 11 shows the impact of the Bioswales, Stormwater Planters, Street trees, Green roofs and Permeable pavement on the initial runoff volume. For catchment no.1, the change is approximately 9.3%, and for catchment no.2, the difference is 8.9%.

Figure 31 shows the change in water depth during flooding with the application of Bioswales, stormwater planters, Street trees, Green roofs and and permeable pavement.

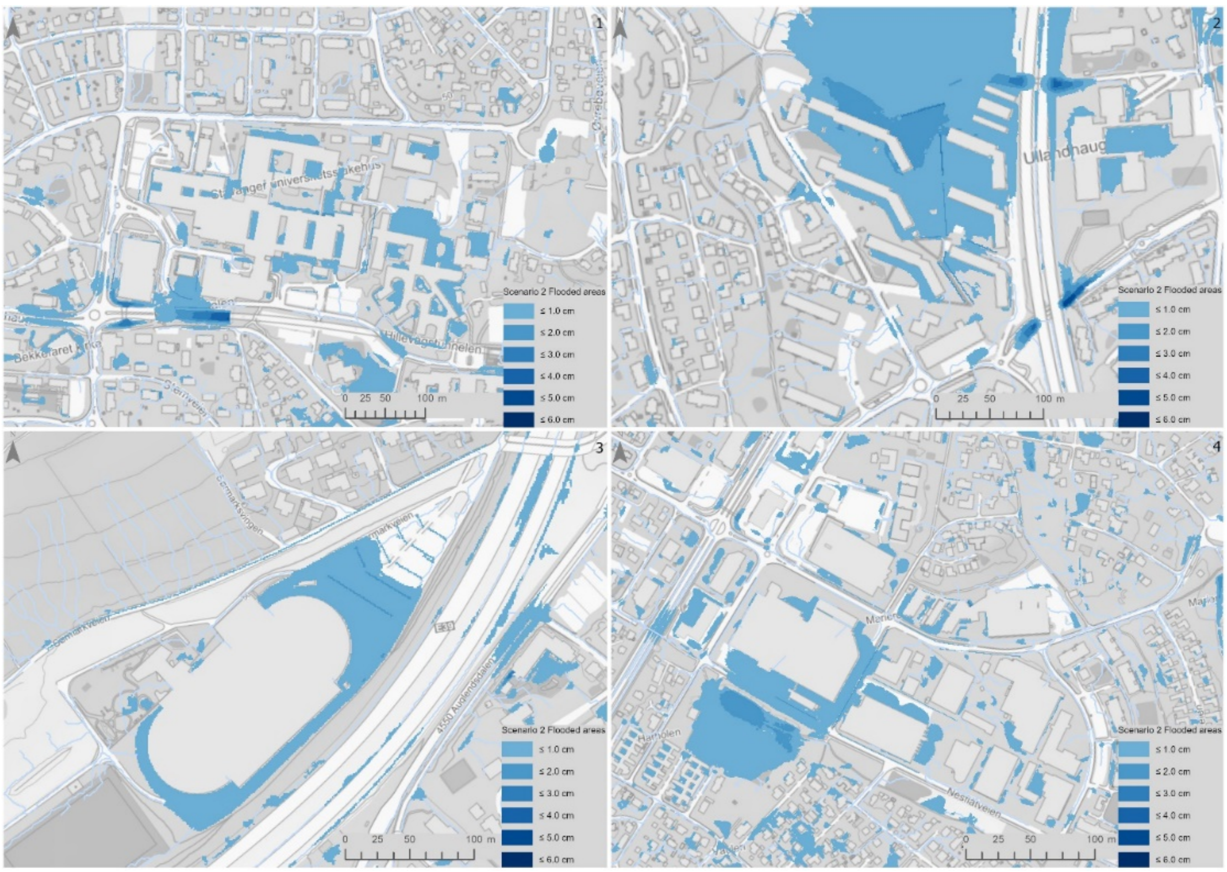

Figure 31 Flooded areas in the selected drainage basins Scenario 2

Table 12 Land Use types for scenario 3 Ullandhaug-Hillevåg

Scenario 3 - Land Use (Ullandhaud-Hillevåg)		
Residential area	50.08 %	1.78 km^2
Transportation	11.07 %	0.39 km^2
Agriculture	13.50 %	0.48 km^2
Forest	9.60%	0.34 km^2
Open Land	5.80%	0.20 km^2
Bioswales, stormwater planters, Green roofs, Permeable pavement, Rain Gardens	1.53%	0.054 km^2
Rainwater harvesting	8.42%	0.3 km^2
Total	**100%**	**3.56 km^2**

Table 6 Land Use types for scenario 3 Mariero-Hinna

Scenario 3 - Land Use (Mariero-Hinna)		
Residential area	55.5%	1.34 km^2
Transportation	6.28%	0.15 km^2
Agriculture	19.90%	0.48 km^2
Forest	7.00%	0.17 km^2
Open Land	0.7%	0.02 km^2
Fresh Water	1%	0.02 km^2
Bioswales, stormwater planters, Green roofs, Permeable pavement, Rain Gardens	3.22%	0.08 km^2
Rainwater harvesting	6.2%	0.15 km^2
Total	**100%**	**2.42 km^2**

\

Table 14 Results of Rational Method calculations – Scenario 3

Results of Rational Method Calculations – Scenario 3	Ullandhaud-Hillevåg	The difference compared to scenario 0 (%)	Mariero-Hinna	The difference compared to scenario 0 (%)
Runoff in a 100-year event	10.12 m^3/s	-9.4%	8.10 m^3/s	-9.0%
Runoff with a climate change allowance	14.17 m^3/s	-9.4%	11.34 m^3/s	-9.0%

Table 14 shows the impact of the Bioswales, Stormwater Planters, Street trees, Green roofs, Permeable pavement and Rain Gardens on the initial runoff volume. For catchment no.1, the change is approximately 9.4%, and for catchment no.2, the difference is 9%. The volume change is not notable in comparison with Scenario 2; the reason behind this is that the surface area of the Rain Gardens is not significant, which has a direct connection to the runoff volume in the Rational Method.

The Rational Method calculation and Hydrological modelling results shown in Table 9, Table 12 and Table 16 and on maps in Figures 24, 26 and 30 prove the efficiency of the proposed GI. However, the difference in the surface runoff between the initial volume and the volume in Scenario 3 is not. This is caused mainly by the expanse of the proposed GI in relation to the overall catchment area. The smaller size of the NBS, such as bioswales, does not provide great runoff reduction compared to larger GI as green roofs.

For future studies, it is recommended to investigate smaller drainage basins in order to achieve more visible and accurate results.

Figures 32,33 and 34 show the change in flooding between scenarios 0 and 3 in three analysed areas with the most visible change. From the images, it is clear that GI can make a significant difference in these areas regarding stormwater management. In some areas, the water level changed up to 30 cm (Rain Gardens in Figure 31).

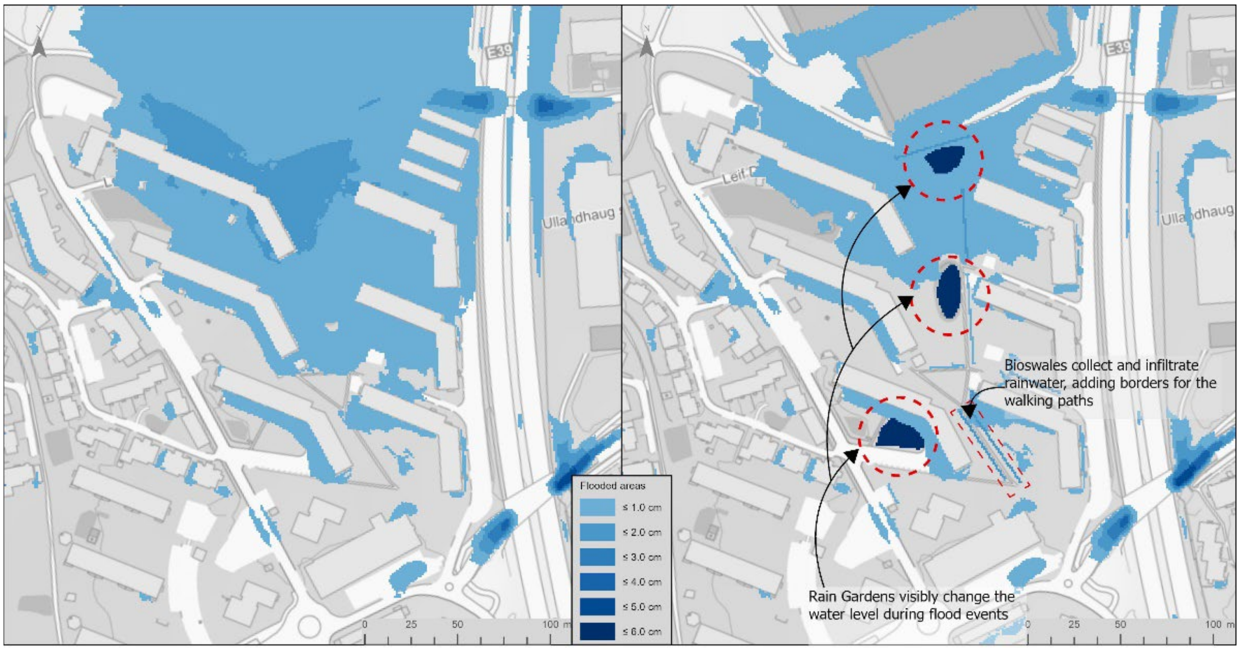

Figure 32 Comparison of flooded areas (Residential area) for Scenario 0 (left) and Scenario 3 (right)

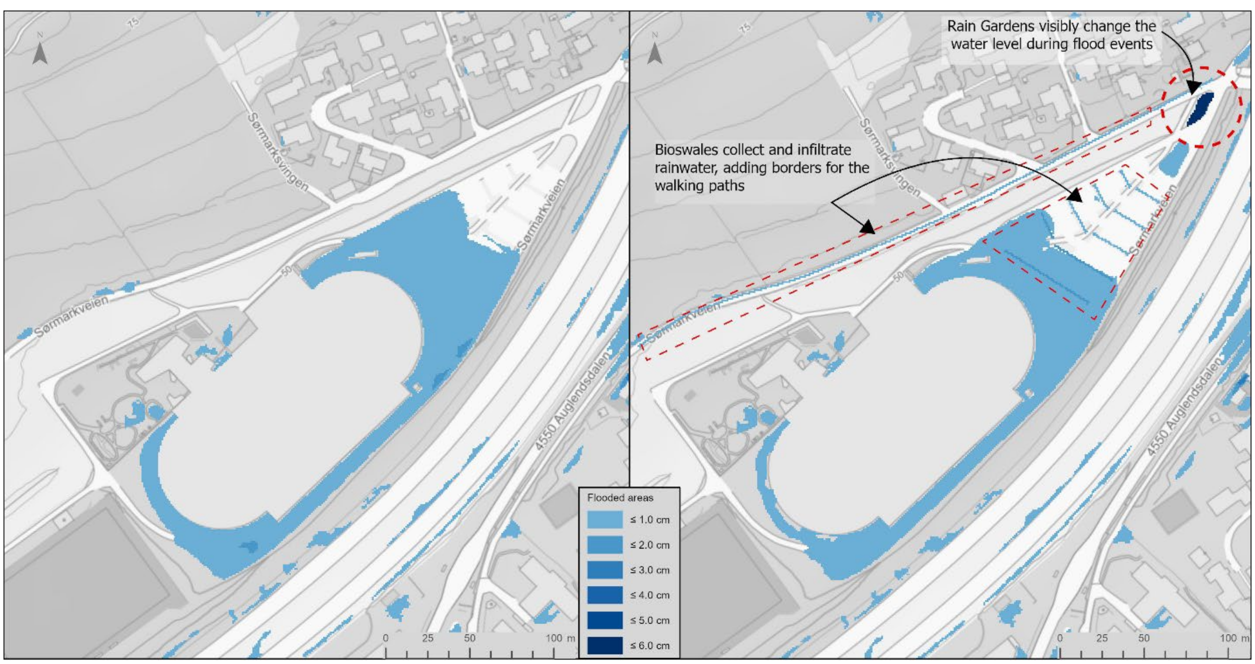

Figure 33 Comparison of flooded areas (Sørmarka Arena) for Scenario 0 (left) and Scenario 3 (right)

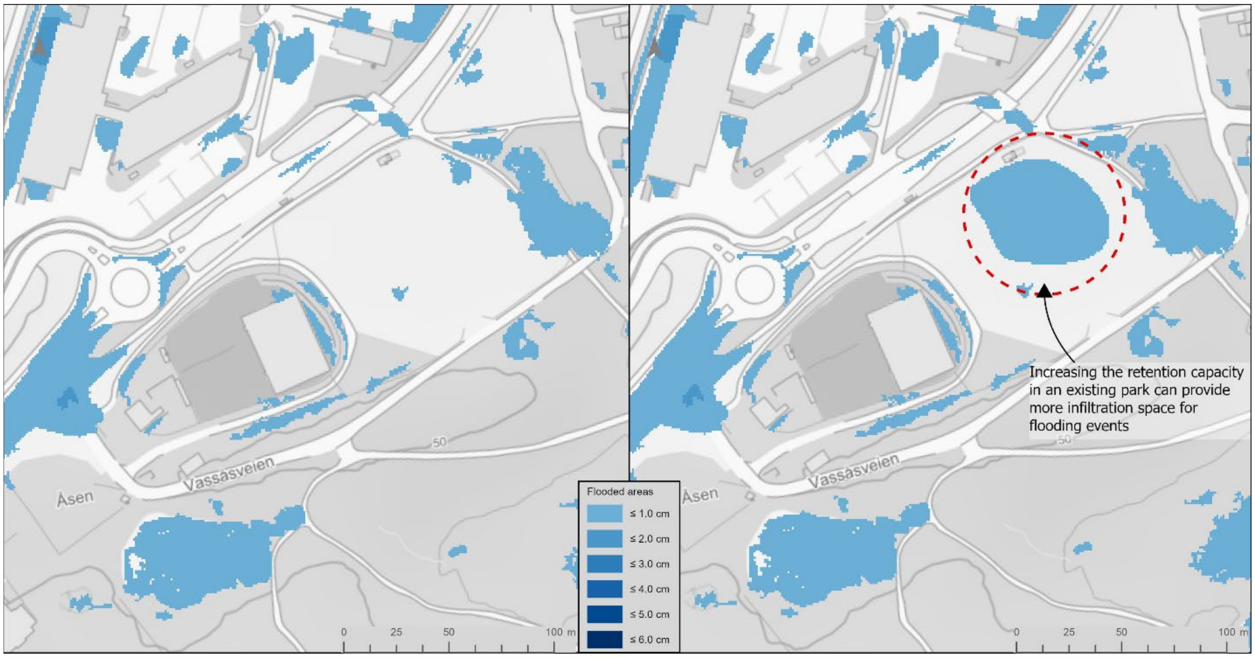

Figure 34 Comparison of flooded areas (Kristianslyst) for Scenario 0 (left) and Scenario 3 (right)

9 SWOT analysis for the proposed Scenarios

SWOT analysis for this thesis will be divided into three categories: environmental, social and economic, infrastructural, institutional and ecological, by the impact GI brings to cities. Neither infrastructural nor institutional strengths or opportunities nor social or ecological weaknesses or threats were found in the literature.

Venn diagrams represent the SWOT analysis results, and each statement is reviewed in this chapter under the corresponding Figures.

Strengths

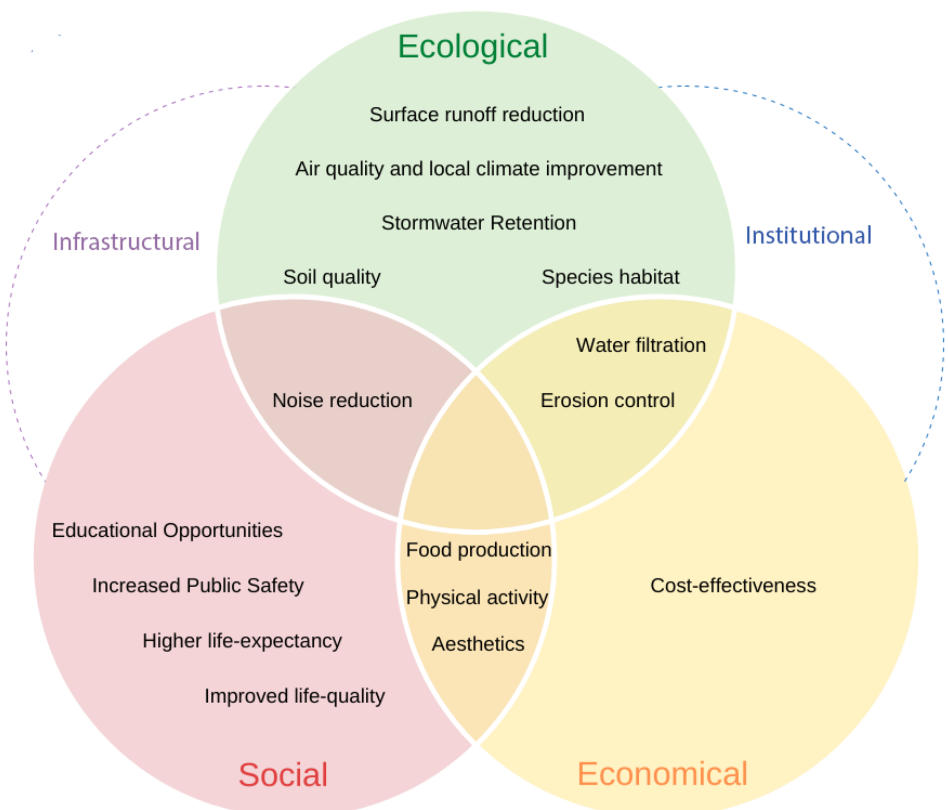

Figure 35 Venn diagram of GI strengths

- **Surface runoff reduction**

Data in Chapter XX prove that GI is highly efficient in reducing runoff (Brears, 2019) (Sýkorová et al., 2021).

- **Air quality and local climate improvement**

Vegetation has the ability to absorb dust and pollutants from the air. It also helps improve the local climate by increasing humidity and reducing the temperature (Brears, 2019) (Sýkorová et al., 2021).

- **Stormwater Retention** (Sýkorová et al., 2021).
- **Soil quality**

Infiltrated water can remove pollutants from the ground (Sýkorová et al., 2021) (Sinnett, Smith, & Burgess, 2015).

- **Species habitat**

Greenery provides new habitats for many species (Jayasooriya, Ng, Muthukumaran, & Perera, 2020). It is also "a place for pollinating insects, in the case of less mowed and meadow lawns." (Sýkorová et al., 2021).

- **Noise reduction**

Trees and bushes along roads are proven to reduce the noise. (Sinnett, Smith, & Burgess, 2015) (Kragh, 1981)

- **Water Filtration** (by bioswales and Rain Gardens see Chapter 6.9.7)
- **Erosion control**

Vegetation roots provide soil stability and decrease the chances of erosion (Brears, 2019) (Sýkorová et al., 2021).

- **Educational Opportunities**

Schools and kindergartens can use some of GI to make an informative lesson about ecology, hydrology and biodiversity (Brears, 2019).

- **Increased Public Safety**

Trees make roads seem narrow or curvier; thus, drivers tend to slow down in streets with more vegetation. Another way of increasing safety is to make an attractive place where more people would want to spend time. Criminal action has less chance of happening in crowded areas. GI helps to create such a place (Brears, 2019).

- **Higher life-expectancy**

A better, cleaner environment leads to a longer life. Additionally, parks encourage people to be active, which reduces "obesity, circulatory disease, chronic stress and asthma, particularly in underprivileged neighbourhoods." (Brears, 2019).

- **Improved life-quality**

Life quality is a concept which consists of many factors, including the previously mentioned ecological and social. It has been proven that residents are overall more satisfied in greener neighbourhoods (Brears, 2019) (Sinnett, Smith, & Burgess, 2015).

- **Food production**

GI such as green roofs or street trees can be used to grow fruits or vegetables. Production can be substantial to sustain neighbourhoods on larger scales and in the right climate conditions (Brears, 2019) (Sýkorová et al., 2021).

- **Physical activity** (Brears, 2019) (Sýkorová et al., 2021). (see "Higher life expectancy")
- **Aesthetics**

"Flowering, colourful detail and tremendous architectural impact provide interesting and shifting effects throughout the year" (Sýkorová et al., 2021).

- **Cost-effectiveness compared to traditional infrastructure**

As was presented in Chapter 5.4, in some cases, GI can offer a cheaper alternative to GYI when planned carefully. Traditional infrastructure usually has a much larger scale and takes several years to be completed. Material prices and labour costs can rise during this lengthy construction, making the project even more expensive. By contrast, the expenses of adopting GI are more stable regarding financial flow demands, which allows for more flexible funding (Brears, 2019).

Weaknesses

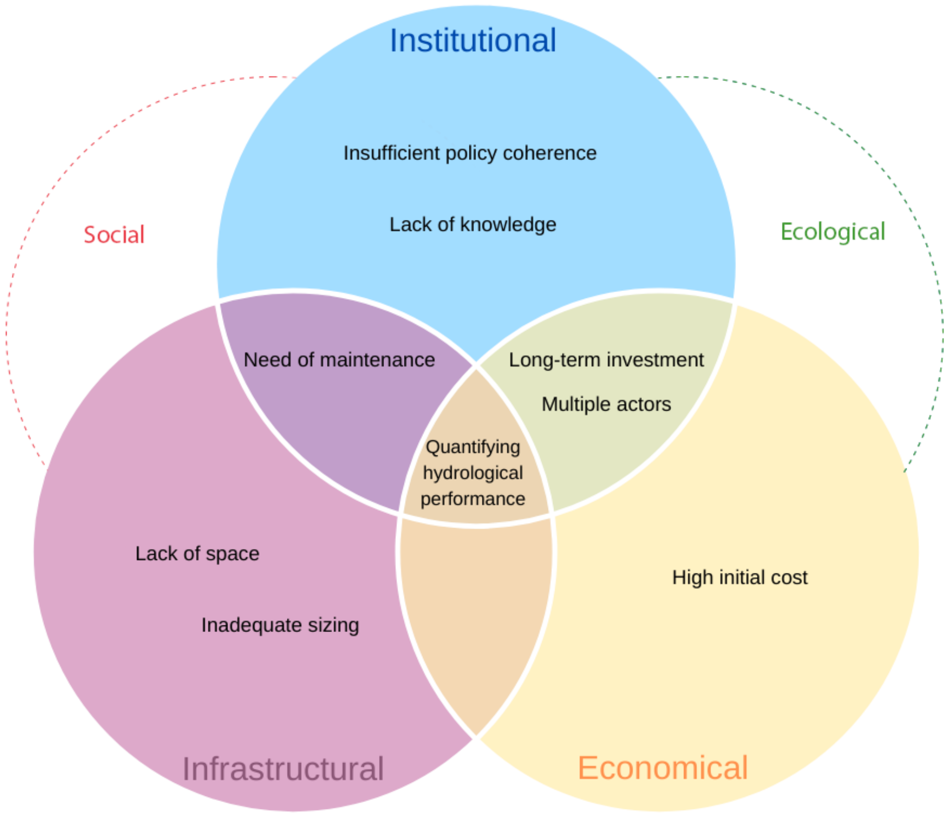

Figure 36 Venn diagram of GI weaknesses

- **Insufficient policy coherence**

GI is usually underestimated due to an absence of policy consistency for various hydrological cycle components, which frequently transcends jurisdictional boundaries and authorities (Brears, 2019) (Mguni, Herslund, & Jensen, 2016).

- **Lack of knowledge**

GI is still a relatively new discipline, and there are not enough specialists and sources in order to make it a common tool in urban planning. Furthermore, "many communities are either unaware of the benefits of BGI or believe it is more expensive or difficult to implement than traditional grey infrastructure" (Brears, 2019) (Mguni, Herslund, & Jensen, 2016).

- **Need for maintenance**

Vegetation needs to be maintained regularly to fulfil its many functions. Particularly Bioswales require trimming and regular inspections (Mguni, Herslund, & Jensen, 2016).

- **Long-term investment**

Compared to conventional GYI, GI is considered a long-time investment, as it takes some time for vegetation to settle and grow to its full hydrological potential. For that reason, authorities are usually sceptical of GI implementation (Brears, 2019) (Mguni, Herslund, & Jensen, 2016).

- **Multiple actors**

Like any other part of the urban planning, GI projects involve numerous actors, making them vulnerable to different, occasionally negative or neutral opinions on the non-traditional stormwater management solutions. This fact can slow the process down or even stop it entirely due to the lack of interest (Brears, 2019) (Mguni, Herslund, & Jensen, 2016).

- **Quantifying hydrological performance**

It is very challenging to quantify the hydrological performance of GI, especially on a larger urban scale. Cities have a large number of various structures, land use types, and other (sometimes unpredictable) factors, which make it very time-consuming to make a conclusive hydrological model (Brears, 2019) (Mguni, Herslund, & Jensen, 2016).

- **Lack of space**

"Implementation of GI can be limited by the lack of physical space in urban areas; for example, detention ponds are suitable for suburban areas but are often too large to make them feasible for city centres. In addition, retrofitting is difficult, particularly in high-density areas" (Brears, 2019).

- **Inadequate sizing**

Bioswales and rain gardens, if planned poorly, can overflow and flood the surroundings (Brears, 2019).

- **High initial cost** (Brears, 2019). (See "Long-term investment")

Opportunities

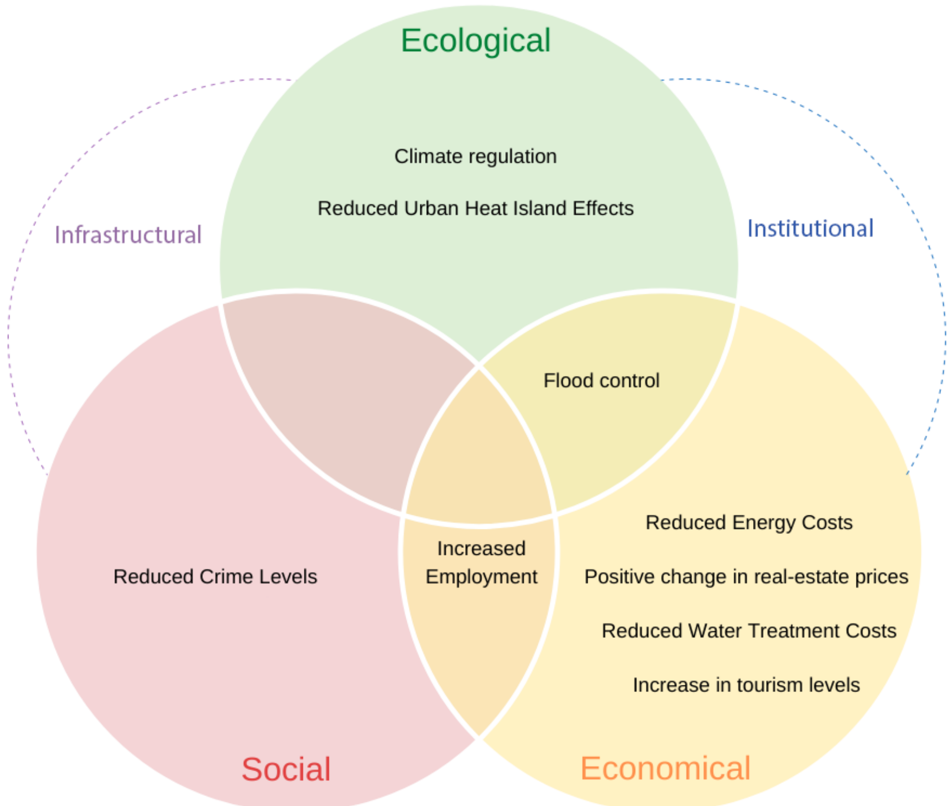

Figure 37 Venn diagram of GI opportunities

- **Climate regulation** (Brears, 2019) (Sýkorová et al., 2021). (See "Air quality and local climate improvement.")
- **Reduced Urban Heat Island effects**

When cities replace green spaces with large amounts of sidewalks, dwellings, and other surfaces that absorb and hold heat, urban heat islands develop. High rises and side streets also capture and amplify excess heat from automobiles, industries, and air conditioners. BGI can help alleviate the impacts of urban heat islands by increasing the quantity of urban green space and vegetation (Brears, 2019).

- **Flood Control** (Sýkorová et al., 2021). (See "Surface runoff reduction" and "Stormwater Retention")
- **Reduced Crime Levels** (Brears, 2019). (See "Increased Public Safety")
- **Increased Employment**

Maintenance and installation of the GI make an opportunity to provide more working places for local residents (Brears, 2019) (Mguni, Herslund, & Jensen, 2016).

- **Reduced Energy Costs**

Green roofs offer insulation and shading, thus decreasing the electricity consumption needed for heating and cooling. By elevating groundwater levels, Rain gardens can cut the amount of energy required for pumping. Moreover, rainwater harvesting systems are able to purify water for further use (Brears, 2019).

- **Positive change in real-estate prices** (See "Aesthetics").

More attractive places create more significant interest in housing, leading to higher prices. (Brears, 2019) (Sýkorová et al., 2021)

- **Reduced Water Treatment Costs** (See "Water Filtration") (Brears, 2019) (Sýkorová et al., 2021)
- **Increase in tourism levels**

Similarly to "Positive change in real-estate prices." attractive places are of interest not only to local residents but also to tourists. (Brears, 2019) (Sýkorová et al., 2021)

Threats

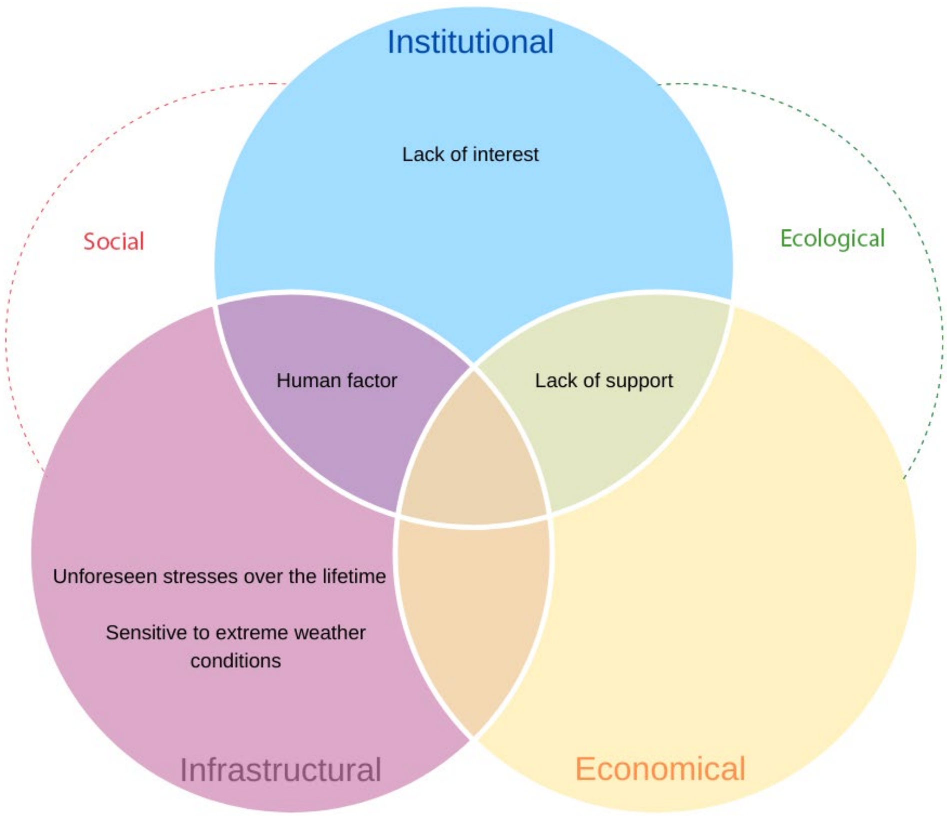

Figure 38 Venn diagram of GI threats

- **Lack of interest** (See" Insufficient policy coherence". "Lack of knowledge", "Long-term investment")

As GI is a long-term investment and not much is known about this stormwater management system, it can cause a lack of interest from the authorities.

- **Human Factor**

A dismissive attitude of pedestrians can cause physical problems with the vegetation, for instance., flower picking, walking the pets on the green structures etc.

- **Lack of support (**See "Insufficient policy coherence". "Lack of knowledge", "Long-term investment", "Lack of interest")

- **Unforeseen stresses over the lifetime** (See "Human factor")

Additionally, besides the "Human factor", stresses for the GI can include the usage of road salt, which is harmful to the greenery.

- **Sensitive to extreme weather conditions**

Even though GI is an excellent stormwater management tool, extreme weather conditions can be fatal for them. Severe floods such as 200-year and up can cause critical damage to the GI.

10 Blue-Green Factor

In this thesis, the Blue-Green Factor is used to compare the Scenarios proposed in Chapter 10 and their impact on the coverage of the studied areas (See Figure 39). This analysis was divided into four parts by the main zones with the most significant extent of the proposed GI. These zones would be referred to as **1-Hospital** (The Stavanger University Hospital), **2-Residential** (residential area between Lief Dietrichsons gate and Helmer Hansens gate. The location has six housing units.), **3-Sørmarka Arena** (including the parking lot and a part of Sørmarkveien), **4- Breiflåtveien** (shopping malls and warehouses along the Breiflåtveien). (See Figure 40)

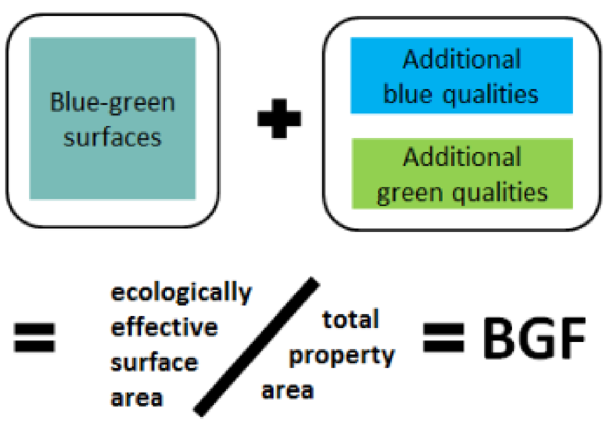

Figure 39 Blue-green factor calculation Barton, D. N., Stange, E., & Fongar, C. (n.d.).

The results of the BGF analysis are presented in Table 17. The results show that the difference between Scenario 0 and 1 is minimal. The reason behind it is that the Method for the BGF calculation considers the area of the structures. Considering that Scenario 1 proposes the retrofit of such structures as Bioswales and Stormwater Planters, we can assume that the green space would not change significantly. Nevertheless, the most considerable difference in BGF is seen between Scenarios 1 and two. Here, again the area is coming into the account. Scenario 2 uses Green roofs and Permeable pavement as a stormwater mitigation unit; both are usually considerably more extensive than Bioswales and Stormwater Planters.

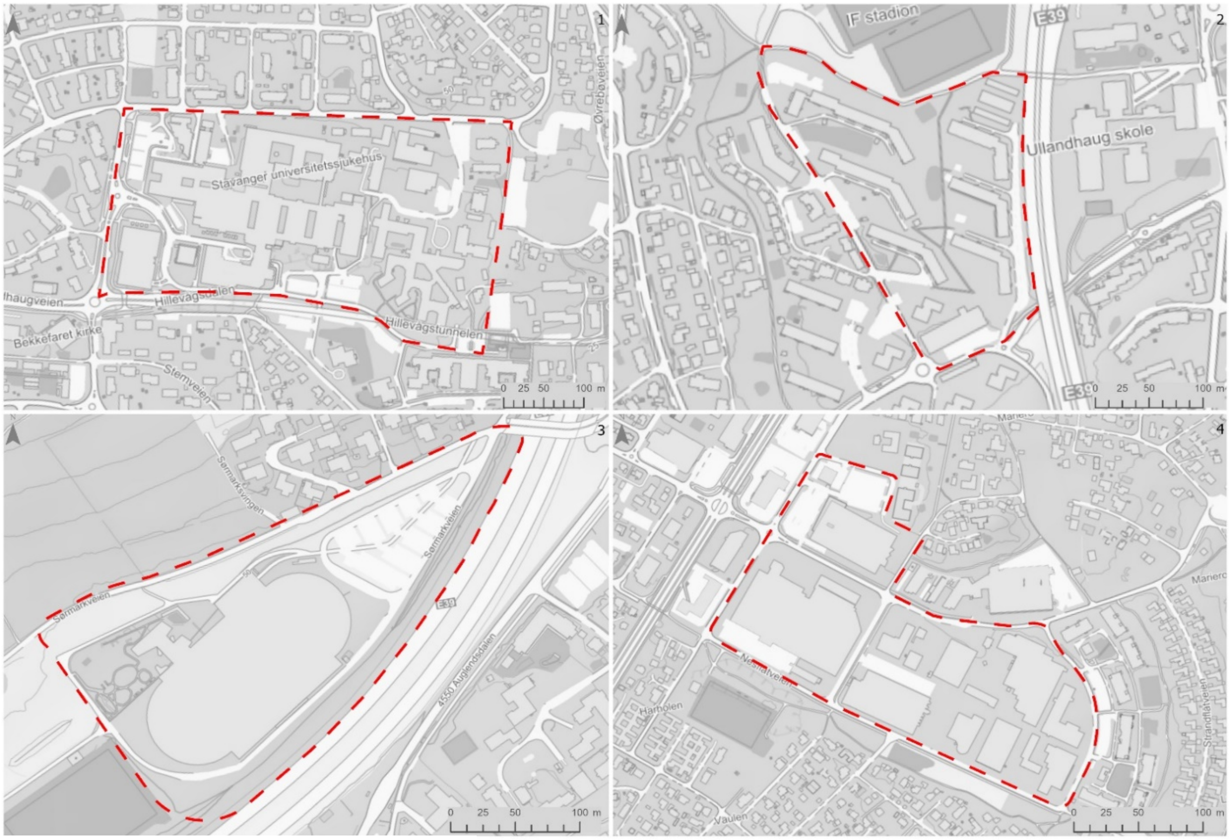

Figure 40 Chosen zones for BGF analysis

Table 15 BGF analysis results

BGF 1 Hospital	
Scenario 0	0.17
Scenario 1	0.17
Scenario 2	0.20
Scenario 3	0.22

BGF 2 Residential	
Scenario 0	0.21
Scenario 1	0.21
Scenario 2	0.23
Scenario 3	0.23

BGF 3 Arena	
Scenario 0	0.15
Scenario 1	0.15
Scenario 2	0.22
Scenario 3	0.22

BGF 4 Breiflåtveien	
Scenario 0	0.14
Scenario 1	0.15
Scenario 2	0.22
Scenario 3	-

It is important to note that area 4 is not considering Scenario 3. This is due to the fact that Scenario 3 takes into account Rain Gardens and there were no Rain Gardens proposed in Area 4.

Blue-Green Factor gives a comprehensive overview of the land cover and its infiltration qualities. However, in this project, the BGF analysis does not provide precise results as the calculations rely largely on the area of the Blue-Green Structures. The main focus of this work is to consider a retrofit of the Green infrastructures, which generally does not bring significant land cover changes.

11 Discussion

According to the analysis results and the literature review, Green Infrastructure has good potential for runoff volume reduction. Although the change in runoff volume calculated using the Rational Method is not more than 9.4% compared to Scenario 0 (See Table 18), water depth during storm events has changed visibly. More extensive GI measures can achieve better results in runoff volume reduction in larger quantities.

Table 16 Runoff volumes in different scenarios

Catchment \ Scenario	0	1	2	3
Ullandhaug	11.17 m^3/s	10.27 m^3/s (-8.0%)	10.13 m^3/s (-9.3%)	10.12 m^3/s (-9.4%)
Mariero	8.91 m^3/s	8.81 m^3/s (-1%)	8.11 m^3/s (-8.9%)	8.1 m^3/s (-8.9%)

The disadvantages of GI were discussed in the SWOT analysis chapter. The main disadvantages that can be highlighted are the lack of interest from authorities and lack of knowledge about the topic. These two are perhaps the main limitations for the successful citywide implementation of the NBS such as GI.

Despite the amount of GI types, NBS alone cannot manage the increased precipitation and flooding. From a stormwater management perspective, several possibilities can be explored in order to facilitate sustainable solutions. A stormwater treatment train is a complex of different nature procedures for stormwater filtration and infiltration (Wong & Eadie, 2000). Each step of the "train" prepares the water for the next stage. Different methods can be used in various stages, including chemical, hydraulic, biological and physical, to achieve the best water quality at the end of the process (Minnesota Stormwater Manual, 2012). Another possibility is a complimentary usage of the GI along with the existing GYI. It can mean retrofitting the new GI or constructing completely new structures replacing some grey features.

Compared to the traditional grey infrastructure, GI needs time to achieve its full hydrological potential. The benefits of some types of GI may increase over the years; for instance, for some trees, it can take several hundreds of years (Sinnett, Smith, & Burgess, 2015). The timescale can be a decisive factor for politicians and other stakeholders in development projects, as GI becomes an investment which will pay out only in a certain time. The hydrological analysis in this work was carried out assuming that all proposed GI has achieved its full hydrological potential.

The hydrological calculations used in this work should be seen as a pure estimation, not a precise prediction of the efficiency of the proposed measures. This inaccuracy was primarily affected by the chosen area of study. The proposed GI has a macro-scale effect that can be less perceptible in two large drainage basins. Therefore, examining smaller catchments is favourable for the subsequent studies to get more accurate results. Other factors affecting the precision of the efficiency estimation can be the physical parameters of the area, for instance, soil type or a detailed examination of the activities in the area (and how it can possibly affect the location and stormwater management abilities of the GI).

Despite the probable inaccuracy in the results, the study still brings new insight into the existing knowledge about NBS as a stormwater management solution, especially in the city of Stavanger. It is necessary to continue the research to get more accurate and applicable results and draw the attention of the public and authorities to the non-standard flood mitigation methods.

12 Recommendations for Policy Making

As mentioned in the SWOT analysis, NBS, particularly GI, has almost no priority in the planning processes. The reason is a lack of knowledge and interest, perhaps even disbelief in their efficiency. While the number of regulations and policies promoting green spaces in the cities has grown in the last two decades, GI is still seen as an optional feature with limited recreational or aesthetic functions. Studies similar to this one aim to present the GI in a new light and display its multifunctionality in an effort to draw the attention of all actors included in the planning process.

A further priority should be the public inclusion in decision-making about NBS instead of limiting it to the authorities. This way, the community will have a sense of ownership over the new green developments. This will allow the resources to be managed for and administered by the public rather than relying solely on recurring financing from the state or local government (Wong & Eadie, 2000).

Stormwater should be seen not as a waste that should be eliminated from the site but as a landscape feature with multiple functions. "Ecological, aesthetic, recreational, educational" functions can be achieved by multi-disciplinary communication of the professionals. Typically each GI type is designed and planned by engineers or landscape architects, depending on the project. Better communication between all the actors, including city planners and authorities, will lead to a more efficient and multifunctional GI (Wong & Eadie, 2000).

13 Conclusion

This study analysed the potential efficiency of green infrastructure in stormwater management in Stavanger, Norway. The effects of GI on fluvial flooding were studied on a macro-scale of two drainage basins in this paper, using the Rational method calculations and hydrological modelling with HEC-Ras software. These methods helped address this thesis's central question: What is the possible impact of green infrastructure on flood reduction in the urban environment of Stavanger? The study found that depending on the types of GI, the water levels and runoff volumes can be significantly reduced if planned correctly. The runoff volumes lowered by 9.4% in basin no.1 and 8.9% in basin no.2; the values can be improved by implementing larger-scale GI in smaller catchments. The water levels changed visibly in all of the analysed zones, proving the efficiency of the GI in stormwater management in urban areas.

Secondary questions were addressed along with the main question. All the proposed scenarios were based on Stavanger's current state of development. They were designed to be retrofitted, thus not bringing large physical changes to the terrain and being potentially less costly. Retrofitting GI was presented in similar case studies, and all of them were successful not only in stormwater retention but in bringing other GI's benefits to life as well.

The question: How can the existing GI handle the event of extreme precipitation? is answered by analysing the flood situation with the current land-use types. The flood risk is great in both basins, especially in large, unporous, flat spaces, such as parking lots, flat roofs and roads. Current GI cannot handle the increasing climate change precipitation. Stavanger Municipality's environmental goals include the increasing amount of green spaces in the city; however, from the studied literature, the objectives seem to have only a micro-scale perspective, which will not be able to manage floods alone.

Additionally, the benefits beyond stormwater management and disadvantages were studied with the SWOT analysis. A blue-green factor analysis was conducted with the aim of examining the infiltration qualities in the areas with proposed changes.

GI are viable stormwater management solutions with numerous benefits for society and the environment. Combining traditional and green water management tools can help achieve sustainable development and prepare for the new demands that climate change brings to the city.

Recommendations for the following studies are to continue the investigation of the hydrological effects of GI in cities with high precipitation in order to gain more knowledge about the topic. Additionally it can be beneficial to choose a smaller catchment size in an effort to examine the area in more detail.

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Appendix 1 Sewage types in Mariero

Legend: red lines are combined sewers, and green are separate sanitary sewages.

Appendix 2 Sewage types in the area of Stavanger University Hospital

Legend: red lines are combined sewers, and green are separate sanitary sewages.

Appendix 3 Table used for Blue-Green Factor calculation

Value	Symbol	Factor	Description	Areal m²	BGF
BLUE-GREEN FACTOR (BGF) Collaborative project between Bærum and Oslo municipality as part of the program Cities of the Future. Prepared for Bærum and Oslo municipality by Dronninga landskap, COWI and CF Møller. Revised Oslo Municipality 28.01.2014.					
			PLOT AREA (INCLUDING BUILT AREA). FILL IN THE PLOT AREA:	0.00	
		1. BLUE-GREEN SURFACES			
1		OPEN PERMANENT WATER MIRROR THAT DELAYES RAINWATER	Permanent water levels that are supplied with rainwater from the site, regardless of whether this is a canal with a concrete base, a stream with green banks or another type of water level. Only the water level itself is counted.	0	0
0.3		PARTLY PERMEABLE SURFACES SUCH AS GRAVEL, SINGLE AND GRASS ARMED COVER	Hard surfaces with permeability, which ensure infiltration. For example, grass reinforcement of concrete, gravel or shingle. Does not apply to surfaces over underlying hard coverings if the soil depth is less than 80 cm.	0	0
0.2		IMPERMEABLE SURFACES WITH DRAINAGE TO VEGETATION AREAS OR OPEN DISTRIBUTION STORAGE	For example. concrete, asphalt, roof surfaces and paving stones. Calculated for area corresponding to the size of the vegetation surface that receives the water. Displacement magazine must have a capacity according to municipal requirements for discharges to public sewerage networks.	0	0
0.1		IMPERMEABLE SURFACES WITH DRAINAGE TO LOCAL SURFACE SYSTEM UNDER TERRAIN	For example. concrete, asphalt, roof surfaces with drainage that is led to facilities under terrain for diversion and cleaning of the surface water. This also applies to underground solutions with combined irrigation of trees. The entire area counts provided that the diversion magazine is according to municipal requirements for discharges to public sewerage networks.	0	0
1		SURFACES WITH VEGETATION CONNECTED WITH EARTH OR NATURAL BEDROCK IN DAY	Vegetation that grows in soil and has contact with the soil below. Favourable for the development of flora and fauna and for water that can draw down to the groundwater. The point also applies to natural boulders and boulders.	0	0
0.8		SURFACE WITH VEGETATION, NOT CONNECTED WITH SOIL> 80 cm	Vegetation that grows in soil at min. 80 cm deep, but which has no contact with the ground / ground below; e.g. on top of a garage or roof. The depth is large enough for larger trees to grow.	0	0
0.6		SURFACE WITH VEGETATION, NOT CONNECTED WITH SOIL 40-80 cm	As above, but with 40-80 cm of soil so that hedges, large shrubs and small and medium-sized trees can grow.	0	0
0.4		SURFACE WITH VEGETATION, NOT CONNECTED WITH SOIL 20-40 cm	As above, but with 20-40 cm of soil for possible growth of perennials and small shrubs.	0	0
0.2		SURFACE WITH VEGETATION, NOT CONNECTED WITH SOIL 3-20 cm	As above, but with 3-20 cm of soil, for possible growth of sedum, grass, and ground cover.	0	0
		2. BLUE AND GREEN ADDITIONAL QUALITIES. GIVE EXTRA POINTS. THE SAME AREA CAN THEREFORE BE COUNTED SEVERAL TIMES.			
		BLUE ADDITIONAL QUALITIES			
0.3		NATURAL WIDTHS FOR WATER MIRRORS	Open water level with natural widths is included in this category if it is available for flora / fauna at ground level and has a natural bottom substrate and edge zone. For example: stream, canal and pond with green banks. The area calculated is the width of the water surface.	0	0
0.3		RAINBED OR EQUIVALENT	Vegetation area that functions as a rain bed or similarly planted infiltration solution that collects, disperses and infiltrates rainwater into the soil / soil. This does not apply to permanent water levels and diversion pools that are counted in blue areas.	0	0
		GREEN ADDITIONAL QUALITIES, THE POINTS UNDER (TREES) MUST BE FILLED IN AS PIECES		STK	
1		EXISTING LARGE TREES> 10 m	Existing large trees; over 10 m. Factor: 25 m² / tree.	0	0
0.8		EXISTING TREES EXPECTED TO GROW> 10 m	Existing trees that are over 10 meters high. Forest trees, deciduous trees and park trees, such as; elm, ash, birch, oak, linden, maple, chestnut, pine and many more. It is expected that the tree will have enough soil to grow (min 100 cm). Factor: 25 m² / three (x 0.8).	0	0
0.6		EXISTING TREES WHICH GET SMALL / MEDIUM SIZE (5-10 m)	Existing trees that are 5-10 meters high. Ornamental trees and fruit trees, e.g. apal, cherries, magnolia, pear tree, robinia and many more. Also applies to trimmed trees. It is expected that the tree will have enough soil to grow (min. 60 cm). Factor: 16 m² / tre (x 0.6).	0	0
0.7		NEWLY PLANTED TREES WHICH ARE EXPECTED TO GROW> 10 m	Trees that grow over 10 meters tall. Art: See two columns above. It is expected that the tree will have enough soil to grow (min 100 cm). Factor: 25 m² / tre (x 0.7).	0	0
0.5		NEWLY PLANTED TREES EXPECTED TO BE SMALL / MEDIUM SIZE (5-10 m)	Trees that grow 5-10 meters tall. Art: See two columns above. It is expected that the tree will have enough soil to grow (min. 60 cm). Factor: 16 m² / tre (x 0.5).	0	0
		THE POINTS BELOW MUST BE COMPLETED AS m²		Areal m²	
0.6		LOCAL VEGETATION	Establishment or protection of surfaces with a large element of valuable plant species that are part of the local, historical natural and cultural landscape.		0
0.4		HEDGES, SHRUBS AND MULTI-STEMMED TREES	Hedges, shrubs and multi-stemmed trees are calculated as a maximum for the drip zone of the shrub, the extent of the crown.	0	0
0.4		GREEN WALLS	For climbing plants and other green walls, the wall area is calculated which is expected to be covered within 5 years (maximum 10 m in height for climbing plants).	0	0
0.3		PERENNIALS AND GROUND COVER	Does not apply to lawn or sedum.	0	0
0.1		CONNECTED GREEN AREAS OVER 75 m²	Continuous green area that is larger than 75 m², such as large lawns, plantations or other.	0	0
					0
		THE POINTS BELOW MUST BE COMPLETED WITH THE NUMBER 0.05		0.05	
0.05		CONNECTION TO EXISTING BLUE-GREEN STRUCTURE	If blue and / or green elements in the area are connected to existing blue-green structure outside the area. The connection must be clear. For example, a stream opening, a connection to an existing canal or water level, a floodway, the extension of an avenue or a wood, the merging of several courtyards with free movement between them. This gives a general addition of 0.05 in BGF.	0	0
		TOTAL BLUE-GREEN FACTOR (BGF)			**0**