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Urban Stormwater Management

A case study of the Deichman's street pilot project for Low Impact Development (LID) Stormwater Management in Oslo, Norway

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Landscape Architecture

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Photo 1.1

INFORMATION

TITLE Urban stormwater management: A case study of the Deichman's street pilot project for Low Impact Development (LID) Stormwater Management in Oslo, Norway

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Fig. 1.1

PREFACE

This Master's thesis was written for the Institute of Landscape Architecture at the Norwegian University of Life Sciences, and marks the completion of my Master's degree in Landscape Architecture. The thesis is weighted 30 credits (ECTS).

Through the course of my studies I have realized that my life long interest in sustainable development can be put to good use with a career in landscape architecture. My interest in solving challenges related to climate change has been sharpened by the interesting lectures and assignments at the university.

This thesis is an examination of Low Impact Development (LID) as a tool for stormwater management in urban settlements.

I have researched LID using a number of theoretical and practical approaches, including a review of relevant literature on the topic and field work at a LID project site in Oslo, Norway. The focus of my work has been to understand how LID works, and how it can be implemented in future stormwater management projects in urban environments. I have been interested in this topic for a number of years, having lived in several cities affected by increasingly heavy rainfall. Oslo, my current hometown, is frequently experiencing record-breaking rainfalls, and subsequent record-breaking damages to buildings, infrastructure and environments. Implementing on-site stormwater management in Norway is a relatively new field, and I want to contribute to the existing knowledge base by examining the site of my work in the summer of 2019, Deichman's street in Oslo. This thesis is written in English for academic accessibility reasons; most of the source material I have worked with is written in Norwegian, rendering it inaccessible to landscape architects, researchers and planners in other countries. Open access to research, including publishing in accessible languages, is an important tool for facing the challenges of global climate change. A Norwegian summary of this thesis will also be produced.

The aim of this thesis is to contribute to our understanding of the design solutions for stormwater management and present a list of recommendations for the planning, design and maintenance process that can ensure successful projects for future urban stormwater management projects in a Norwegian climate.

I would like to thank my thesis counselor, Ingrid Merete Ødegård, for helpful conversations around the organization and information needed for this thesis. Thanks also to Nevedda Sivakumar for being an excellent field partner in 2019, to Bent Braskerud for supervising our field work, participants in our questionnaires for providing invaluable insights, and everyone else who has contributed along the way.

This thesis was written entirely from home, as a result of the pandemic, which has been equal parts challenging and rewarding.

A special thank you to Åsmund for always supporting me.

Oslo, december 2020

Photo 1.2

ABSTRACT

One of the predicted impacts of global climate change in Norway is more frequent and heavier rains. The country is set to receive ‘wetter and wilder’ seasons, and experience damaging floods as a result. Sea levels will continue to rise, and warmer temperatures will cause precipitation that would normally fall as snow to be rain instead.

At the same time, close to 80% of Norway’s population live in urban settlements, and the country’s cities are expected to experience continued growth. Increased urbanization leads to a reduction in permeable surfaces, which leads to more urban runoff. Lastly, the water and sewerage networks in Norway are in a state of disrepair, with dimensions for handling waste and urban runoff from a century ago. These three factors - climate change, urbanization and pressed sewerage systems, are creating a negative aggregate effect on the quality of life, private and public property and critical infrastructure in Norway’s cities.

Low Impact Development (LID) comprises a series of measures for stormwater management that mimic natural hydrological processes and can be adapted to a built environment, as well as work with existing sewerage systems. This thesis seeks to examine how LID can more effectively be implemented in future stormwater management projects in urban settlements in Norway, and reviews relevant literature and frameworks, as well as a pilot project for urban LID stormwater management in Norway’s capitol city Oslo. The Deichman’s street project, which opened in 2016, is now in its fourth year of operations.

This pilot project for climate change relief in urban settlements was a collaboration between the Agency for Water and Wastewater Services in Oslo, the Urban Environment Agency and Asplan Viak, a consultancy company for engineering and architecture.

The project uses a number of LID measures, including rain gardens and permeable surfaces, to handle stormwater locally and delay water surges to the sewerage system. It also provides access to green spaces for residents, and demonstrates how ‘blue-green’ surface solutions, can be multifunctional. The answer to handling increased amounts of rain is not an either-or solution. Modern grey solutions, in terms of improved sewerage systems and water management are still needed, but should aim to work with LID solutions that offer flexibility and provide more services to the people and environment they are placed in.

By evaluating the Deichman’s street project, looking to other reference projects for rain gardens and LID stormwater management, and analyzing a selection of existing literature, this thesis seeks to translate findings into actionable measures for urban LID implementation in a Norwegian climate. The case study evaluates several aspects of the project, from design to performance and public perception. The research data were collected from June to July of 2019 on behalf of the Agency for Water and Wastewater Services in Oslo.

KEY TERMS

Biodiversity
Usually refers to life's variety and variability on Earth, in terms of the diverse populations of plants and animals found in various ecosystems.

Biofiltration
A type of bio-measure for treating contaminated stormwater runoff or other polluted water discharges using living material.

Bioretention
The process of collecting and filtering stormwater runoff, removing pollutants and sediments through natural processes.

Bioswale
Similar to rain gardens, bioswales are vegetated channels that collect and transport stormwater runoff from impermeable surfaces.

Catchment area
The land area where precipitation (rain, snow, sleet or other forms of water) collect and drain in to a common body of water or waterway. Catchment areas are often determined by topography.

Climate
An area's long-term weather average. The time period can range from months to millennia or longer, and areas can span from small (micro-climate) to large (global climate).

Climate change
Shifts in global weather patterns, both natural and man-made.

CSOs
Combined sewer overflows (CSOs) are the result of excess sewage and stormwater runoff exceeding the capacity of sewerage systems or sewage treatment plants.

Global warming
A scientifically accepted theory of man-made greenhouse emissions driving large-scale climate change, leading to an increase in global temperatures with far-reaching impacts on global weather systems.

Groundwater
All the water under the surface of the Earth that is stored in either the soil's pore spaces or crevasses in rock formations.

Hydraulic conductivity
Represented by K, hydraulic conductivity describes the ease with which fluids such as water move through pore spaces in soils, rocks and vascular plants, depending on that material's permeability, its degree of saturation and the fluid's viscosity and density.

Hydrological cycle
A description of water's movement from the atmosphere, to the earth's surface and below.

LID
Low-impact development is a similar term to SuDS, primarily used in North America, that describes a collection of measures for water management that mimic natural processes.

Rain garden
A vegetated bioretention measure for reducing the speed, volume and intensity of runoff from impermeable surfaces.

Return periods
Also known as a recurrence interval or a repeat interval, indicates the estimated average time between rain events. While return periods provide an average based on probability, a rainfall event with a return period of 100 years will not happen just once every 100 years or only once in 100 years.

Runoff
Excess water that runs along the ground's surface when it can no longer infiltrate into the ground. Runoff can come from rain, stormwater, meltwater from snow or other sources.

Saturated hydraulic conductivity
Represented by Ksat, saturated hydraulic conductivity describes the movement of fluids such as water through a saturated medium such as rock or soil.

Sewerage systems
The infrastructure that handles sewage, stormwater runoff and industrial waste through a series of pipes, manholes, pumps, chambers and treatment facilities.

Stormwater
Water that comes from rain or snow. Stormwater can infiltrate into the ground, be stored on its surface, evaporate back into the atmosphere or contribute to runoff.

SuDS
Sustainable urban drainage systems are a collection of measures for water management that mimic natural processes.

Surface water
All the water found on the surface of the Earth, such as lakes, rivers, creeks, swamps and other wetlands. Surface water can refer to both natural and man-made structures. Man-made surface water can include, lakes, rivers, dams and artificial wetlands.

Sustainable development
Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs, as coined by the 1987 Brundtland report Our Common Future.

Urbanization
The process of people moving from rural to urban settlements, concentrating populations, commerce and other social functions in central areas.

Weather
The state of an area's atmospheric conditions, weather is information about temperatures, precipitation activity and wind conditions.

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BACKGROUND

Primary thesis research question:

How can cities in Norway adapt to a wetter climate by implementing LID stormwater management?

OVERVIEW

Norway's cities are facing a three-fold challenge from the effects of climate change, urbanization and outdated sewage systems. As a response to these challenges, landscape architects are increasingly turning to 'blue-green' methods for stormwater management in urban landscapes, such as Low Impact Development, or LID[1]. While these methods are relatively new, they mimic natural processes in the hydrological cycle, and can be combined with existing traditional methods for stormwater management. Cities around the world are exploring these methods, and Norway is no exception.

CLIMATE CHANGE

As climate change continues to shape our global future, its effects can be felt in Norway in a number of ways, including more frequent and violent rains[2]. Norway's climate towards 2100 is predicted to be 'wetter, wilder and warmer', with a 4,5° C increase in average temperatures, an 18% increase in yearly rainfall, heavier and more frequent precipitation events and more flooding following rainfall events, combined with rising sea levels (Hanssen-Bauer, Førland et al., p.6). For individuals, cities and regions these precipitation events can have devastating consequences. Damages to personal property, buildings and critical infrastructure are all predicted to become more commonplace in Norway's future. As a direct result of these water damages Norway's residents could see zoning and building permissions become more restrictive, health risks arise and insurance premiums increase.

1 This thesis consistently refers to sustainable stormwater management practices as LID. While there are a number of other terms such as SuDS, GSI, GI, LID etc., for the purpose of clarity LID is used consistently throughout this thesis.

2 While precipitation can fall as both rain and snow, the focus of this thesis is on rainfall during the summer and autumn seasons, and strategies to mitigate the damaging effects of stormwater runoff.

URBANIZATION

Norway's cities are predicted to grow in population size and subsequently experience a densification of their urban settlements. Currently 82% of Norway's population reside in urban areas[3]. Urbanization can result in a reduction of permeable surface areas when previously permeable surfaces are developed for housing or industry demands. This results in more people, more buildings and less permeable surfaces for stormwater to infiltrate. Increased stormwater runoff poses a number of challenges to urban infrastructures- it can fill sewerage systems and cause back flow, it can carry pollutants to nearby waterways, and can cause damage to local ecosystems, personal property, buildings and other critical infrastructure.

Fig. 1.2

3 According to Statistics Norway, 82% of Norway's population currently reside in urban areas, and the trends indicate that this shift from rural to urban settlements will continue. The five largest urban settlements in Norway today are Oslo, Bergen, Trondheim, Stavanger and the Fredrikstad/Sarpsborg area (Statistics Norway, 2020).

TRADITIONAL STORMWATER MANAGEMENT

Today's stormwater management solutions in Norway's cities use major and minor systems. Major systems, or surface systems, comprise streets, gutters, ditches and various natural and open artificial channels, which are mainly used for extreme flood events. Minor systems, or subsurface sewer networks, carry 'normal' runoff volumes typically through the use of combined systems (Braskerud, Nie et al., p.207-208).

These are underground systems that carry stormwater runoff, sewage and industrial wastewater through the same pipe on separate levels, to a recipient such a treatment facility for wastewater. Many of the systems in place today are more than 100 years old. Systems that were built to handle waste volumes from a century ago are not prepared for increased stormwater from climate change. Previous research conducted in several Norwegian cities showed that «50-100% more buildings could end up damaged as a result of sewerage flooding» (ibid, p. 206). Oslo was able to replace its pipes at a rate of .45% per year in 2008, and indications are that the national rate is lower (Holvik 2011).

Photo 1.3

BLUE-GREEN STORMWATER MANAGEMENT

In order to meet the rising volumes of stormwater runoff in Norway's cities, landscape architects, engineers, planners and other professionals are turning to low impact development (LID) stormwater management solutions. These measures mimic natural processes for water retention and infiltration, and can either prevent stormwater from entering the sewerage system entirely, or retain stormwater and gradually release it into sewerage systems over time to avoid overwhelming them. These measures can have a significant positive impact on residents' quality of life in urban settlements, due to Norway's climate. Heavy rainfall, which occurs most frequently during the summer and autumn months, is the leading cause of sewerage overflow and pollution of local waterways and bodies of water. Frequently polluted water during the main season for outdoor water recreation is at odds with successful city planning (Lindholm, p. 83). LID measures include rain gardens, bioswales, permeable surfaces, green roofs and other bioretention features. The first rain garden was constructed in Norway in 2003, and one of the first LID stormwater management projects in an urban environment was the Deichman's street project, completed in 2016. In terms of impacts on urban planning and development, this field of study is relatively new, and landscape architects, engineers and planners need to spend time testing and refining methods for Norwegian conditions.

Photo. 1.4

WHY NOW? RECORD YEARS

In recent years, records for rainfall have been repeatedly broken in Norway's cities. Norway's capital city Oslo experienced 21 mm of rain in 20 minutes in June, 2019. January 2020 was the wettest January since record keeping began in 1900, and the second warmest January on record (Norwegian Meterological institute, 2020). The predicted effects of global climate change are being felt across the country.

Kraftig styrtregn, skadelige stormfloer og mer flått. Velkommen til Oslo i år 2100

Photo. 1.5 Predictions for Norway's climate towards 2100 have been visualized by the national public broadcaster, NRK. Their work is based on the climate report 'Climate in Norway 2100' from the Norwegian climate service center.

Skader for millioner etter ekstremregn i Oslo

Oslo ble i helgen rammet av kraftig regnskyll, som førte til oversvømmelser flere steder. Et forsikringsselskap melder om skader til over 2,5 millioner kroner.

Photo. 1.6 After an extreme rainfall event in august 2019, one insurance company reported they had recieved claims for over 2,5 million NOK in damages.

Styrtregn ga oversvømmelser i Oslo: - Folk ringer oss hele tiden

Oslo brann- og redningsetat opplyser at de har mottatt et hundretall henvendelse om vann i kjellere etter gårsdagens styrtregn.

Photo. 1.7 Another rainfall just one month later led to between 90-100 calls to emergency services for help with flooding in private homes. Several roads were forced to close, and the city of Oslo expected to receive upwards of 40mm rainfall in 6 hours.

DEICHMAN'S STREET

The City of Oslo refers to the Deichman's street upgrade as a pilot project for open stormwater management solutions, with the aim of providing valuable insights into stormwater management in cities with similar conditions to Oslo.

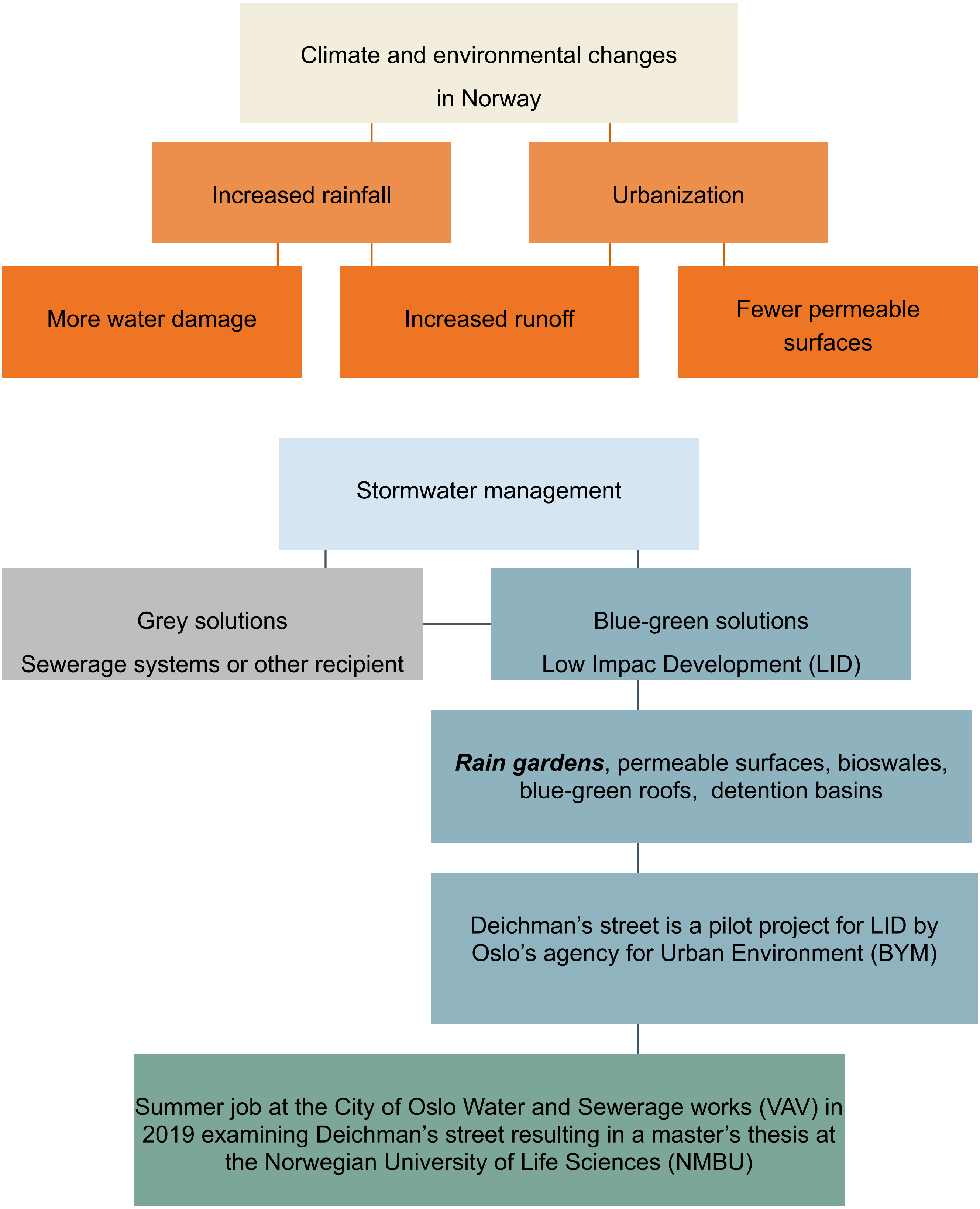
The project contains 9 rain gardens with different construction methods, soil compositions and plant selections. Permeable surfaces in the street infiltrate water on-site, while granite gutters to lead water off-site along safe flood routes during the heaviest rainfalls.

As a pilot project, the site offers valuable insights into what works, and what doesn't, in terms of open stormwater management in urban settlements. By testing the infiltration capacities of the rain gardens, gathering information from residents and passers-by, we are able to draw some conclusions about the project.

Then by looking at the frameworks, both international and national, further insights can be gained about the mechanisms working to ensure modern solutions to climate change challenges. Finally, by combining theoretical insights with practical knowledge and tested results, solid recommendations can be made to ensure better design, functionality and planning for future urban open stormwater management projects in Norway.

Photo. 1.8

SCHEMATIC OVERVIEW



"The landscape architect designs, plans and manages our surroundings... Today the discipline is governed by guiding ideals set forth in the UNs Sustainable development goals and the European Landscape Convention. Landscape architects can thereforecontribute to solving many current climate and environmental challenges, and developing places and landscapes to good social arenas."

-Description of landscape architecture as a discipline at NMBU

(own translation)

Fig. 1.3

RESEARCH QUESTIONS

PRIMARY

How can cities in Norway adapt to a wetter climate by implementing LID stormwater management?

SECONDARY

Why do Norway's cities need to be adapted to a wetter climate?

How are other comparable cities implementing LID to adapt their urban settlements to a wetter climate and what can Norway learn from their experiences?

What insights do the performance and perception of the Deichman's street project in Oslo provide for future LID projects in Norwegian cities?

How is LID stormwater management referred to in Norway's legal and strategic documents?

How is Oslo working to implement LID stormwater management?

What actionable measures can landscape architects take in future efforts to adapt cities in Norway to a wetter climate using LID stormwater management?

GOALS

The goal of this thesis is to provide a set of actionable measures that landscape architects, planners and other relevant parties can use when implementing future Low Impact Development (LID) stormwater management projects in urban settlements.

CONTRIBUTIONS

Gather relevant information for landscape architects and others involved in the planning and design og future raingardens and other LID projects in urban settings.

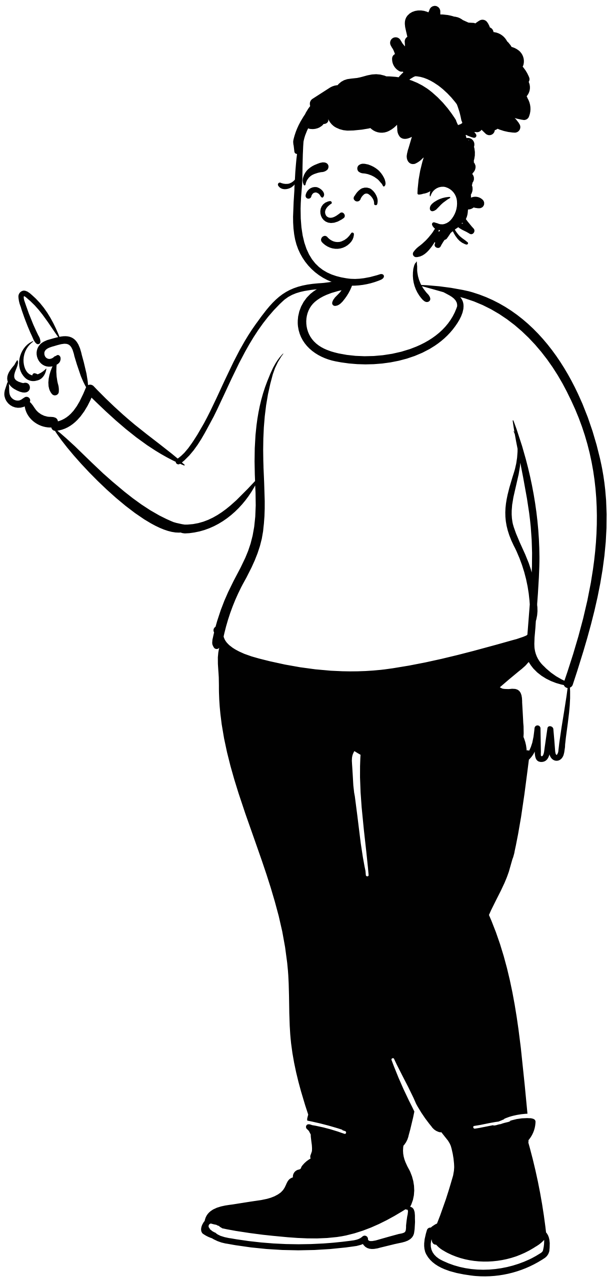


Fig. 1.4

METHODS

In order to create a list of actionable measures for future LID stormwater management, the following methods are used to gather and analyze relevant information

LITERATURE REVIEW
A literature review of selected frameworks and policies that pertain to Norway's work with LID stormwater management. Placing stormwater management in a larger context of global climate change and sustainable development.

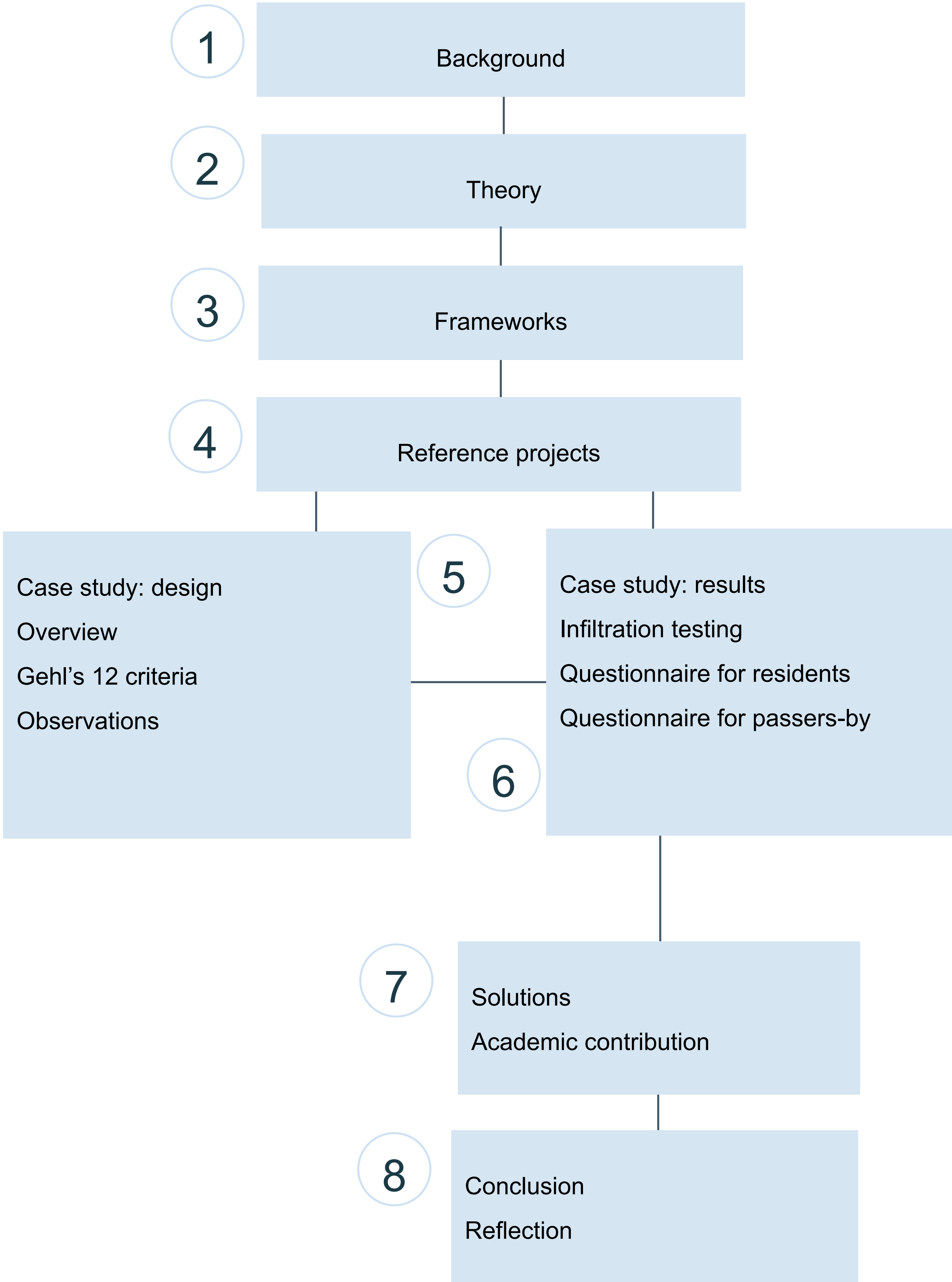
REFERENCE PROJECTS
Reviewing literature to highlight how other countries are working with LID stormwater management, in order to adapt relevant principles and processes to Norway.

QUESTIONNAIRES
Two questionnaires were created to gauge public perception of LID measures in Deichman's street. One of the questionnaires focused on passers-by and was conducted in the street, while the other questionnaire focused on residents of Deichman's street and their perceptions of the project.

FIELD WORK
Testing was conducted on-site in 2019, and consisted of testing the infiltration capacities of, and collecting soil samples from, each of the project's nine rain gardens on the case study project site. Artificial heavy rain scenarios were also conducted in this time period, on two of the rain gardens.

CASE STUDY
Explaining the principles of LID stormwater management in urban settlements using an existing project in Oslo as a case study.

STRUCTURE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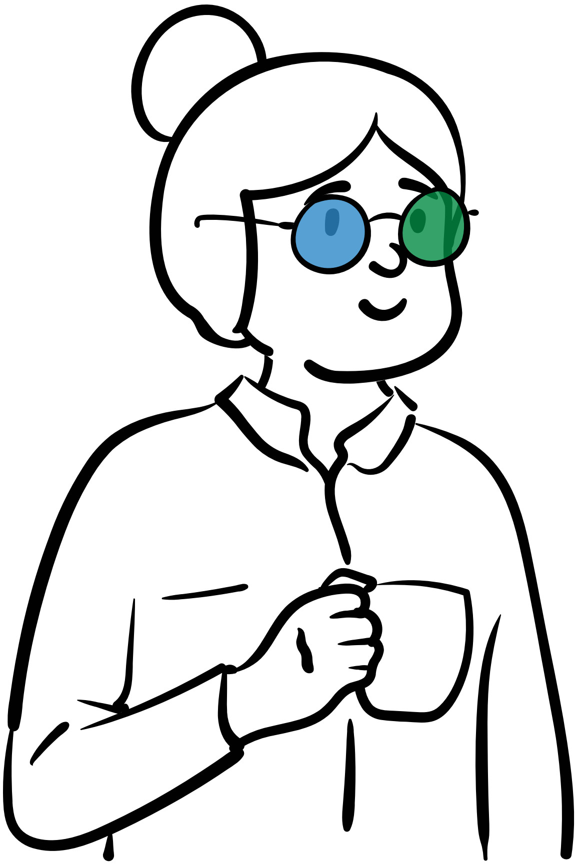


Fig. 1.5

GENERAL

The general purpose of this thesis is to gather relevant information about the challenges in urban stormwater management, and the ways in which landscape architects can work to mitigate the effects of climate change using modern stormwater management methods, and bring LID from plan to place, making it an integrated part of the urban landscape.

TIME FRAME

The work has taken place during two separate periods, spanning June 2019 to December 2020. The majority of the field work was conducted over a five week period from June to July of 2019. The remaining theoretical and analytical work was completed between August and December of 2020. In between field work and theoretical work, results were processed and further information was gathered.

THEMATIC

The topics discussed in this thesis are LID stormwater management as it relates to: climate change, urban settlements and traditional stormwater management in Norway. Limiting the scope of the thesis was essential in order to ensure significant coverage of each topic. Given more time, further research on plant selection for urban LID measures, instead of just recorded observations, would be beneficial.

An alternative approach to stormwater management is the main topic discussed in this thesis; the focus is centered on LID stormwater management, which is a method that is gaining traction in cities across Norway. While the method is new, it is widely discussed in local, regional and national strategies.

GEOGRAPHICAL

The main geographical focus area of the thesis is Oslo, Norway, with a particular focus on the case study area Deichman's street. While the thesis creates actionable measures for urban settlements in Norway, both the case study and theory sections center on Oslo, in order to highlight types of relevant information through one representative area. This choice is related to the field work, conducted in Oslo, and the capital's city position as leaders in LID implementation in the public sector. LID has traditionally been used in housing developments in both rural, semi-urban and urban settlements, but this thesis focuses on exploring the possibilities for LID integration in larger urban sewerage and stormwater management systems. However, as these types of projects are still relatively new in a Norwegian context, most of the literature on the subject deals with small-scale LID measures.

PERSPECTIVE

This thesis is written from a landscape architecture perspective, which means the theories, frameworks, results and solutions are meant to be understandable and applicable to landscape architecture as a field. Using a landscape architect's 'blue-green glasses' to process information about climate change, urbanization and stormwater management challenges into actionable measures for sustainable development in urban settlements.

2

THEORY

This section will address the following secondary research question:

Why do Norway's cities need to be adapted to a wetter climate?

Key topics

Climate, climate change, urbanization, stormwater management, public health, hydrological cycle, geology

THEORY

THEORY

As countries around the world continue to feel the effects of climate change, Norway is no exception.

CLIMATE

Climate typically refers to the average weather over a longer period of time. Scientists gather data over a 30-year period to create a climate normal which describes averages and deviations during that period which can be compared to previous data. Climate normals can be used to describe a wide array of variables. The current reference climate normal ran from 1961-1990, while the report ‘Climate in Norway - 2100’ cites 1971-2000 as its climate normal (Hanssen-Bauer, Førland et al. 2017).

Norway’s climate is temperate, meaning it’s varied and has defined seasons. Within the country variations are affected by changes in topography. Both temperate and polar climates can be found in Norway (Dannevig and Harstveit 2020). South-eastern Norway (Østlandet), where the the Oslo region is located, is sheltered by the country’s central mountain ranges, and receives less rainfall than the west coast (ibid). Norway’s coastal line, from Oslo to Troms have a temperate climate and mild winters (ibid). Factors that affect how much rain an area receives during the year are topography and wind patterns. Generally speaking, the west coast of Norway receives longer episodes of rainfall, and holds the top records for amount of rainfall over a 24-hour period. In the eastern part of the country, near Oslo, heavier short-term rain is more common (ibid). Rain is most common during the autumn, and least common during the end of winter and beginning of spring; for the Oslo region rain falls most commonly during the months of July and August (ibid).

What are some challenges involved in recording the climate? No systems are perfect, and in terms of measuring rainfall there are some specific challenges that complicate results. Summer and autumn storms common in cities such as Oslo, are often harder to predict, track and measure. Precipitation can fall in a very narrow width on the landscape below. This means there may not be a measuring station in place where most of the precipitation hits the ground (Mosevoll, p. 12). That means an area receiving a heavy downpour with no measuring station, will be recorded as receiving whatever amount of rain the nearest measuring station also received.

CLIMATE CHANGE

The average rainfall measured in mm/yr in Norway has increased by approximately 18% since 1900, with a marked increase after 1980 (Hanssen-Bauer, Førland et al., p. 6). Annual mean temperatures in Norway increased by +1.3° C between 1971-2000 (ibid). For the Oslo region, the increase has been significant, and concentrated to the summer and autumn months. This part of the country also experiences the highest number of intense rainfalls with a duration of one minute to one hour. As rainfall data are gathered, the information can be used to describe expected rainfall in a given area. That way, rainfall can be categorized in precipitation frequency intervals. For example, given a stable climate, a precipitation frequency interval of 100 years means a rainfall of that magnitude will occur on average once every 100 years or have a 1/100 likelihood of occurring any given year during that period. Cloud bursts are extreme rainfall events. Denmark's capital city Copenhagen experienced a devastating cloudburst event in 2011, where 120 millimeters of rain fell in just 2 hours. This resulted in over 80,000 insurance claims for a reported 6 billion DKK in damages (Bjerkholt, Buhler et al., p. 363). Copenhagens relatively flat terrain, combined with retailers in the city using basements for value storage, meant that water damage was excessive. Norway has had similar events, although no single events as damaging as Copenhagen's cloudburst. On August 12th, 2009, the storm Frida brought 70 mm of precipitation in 40 minutes to the Northern Eiker area, resulting in 2,000 incident reports totaling 150 million NOK in damages (ibid, p. 367). Over 100 residents were evacuated from the area, and the incident shows that rains of traditionally tropical intensity have already reached the Nordic countries (ibid, p. 369).

In order to measure these short bursts Norway uses weighing rain gauges or tipping bucket rain gauges. As rain gauges are fixed points on a map they do not always accurately reflect rainfall intensities, as local outbursts can be concentrated to areas with no active rain gauges.

RUNOFF

Norway experiences an average annual precipitation amount of 1600mm per year, of which 1100 mm becomes runoff, and 500 mm evaporates (Hanssen-Bauer, Førland et al., p. 7). These values are predicted to stay relatively stable, although global warming will increase runoff during the winter and spring seasons (ibid). With continued warming, runoff could be further reduced during the summer, although it will still pose a threat during heavy rainfall events, when infiltration and evaporation do not occur rapidly enough (ibid).

FLOODS

Norway experiences yearly spring floods when snow in higher altitudes melts and fills waterways with snowmelt. These meltwater floods are predicted to diminish over time, as temperatures rise (ibid). Interestingly, rivers primarily affected by snowmelt floods can see a decrease of nearly 50% in spring flooding events, while rivers primarily affected by rain floods can experience an increase of nearly 60% in flood magnitude (ibid). These shifts can have critical impacts on cities where historical settlement patterns were planned around close proximity to waterways for industry, transport and other resources. Many of Norway's cities also have significant topographical challenges when dealing with runoff, and these two factors combined could be devastating for certain urban settlement areas.

Photo. 2.1

URBANIZATION

Urbanization is the transfer of people, markets and services from rural to urban settlements (Butenschøn 2020). Norway's population is distributed in an 80/20 concentration; over 80% of the population reside in urban settlements[5], and approximately 20% of the population resides in rural settlements; globally 54% of the population resides in urban settlements (ibid).

Urbanization is a process with physical impacts. But what is being urbanized when cities expand? One answer to the question is rain catchment areas (Braskerud, Warner et al., p. 32). The process of urban expansion happens through legislation, planning or unexpected events. Urban settlements in Norway today need to plan for expansion upwards or outwards, in terms of land area usage. Placing changes in urban land use in the context of natural processes such as the hydrological cycle can force us to evaluate the effect of these changes in a new light.

5 This thesis follows the nordic understanding of an urban settlement as a densely populated area with 200 inhabitants. A city is understood as an area with 20,000 residents Thorsnæs, G. and H. Solerød (2018). By. Store Norske Leksikon.

Photo. 2.2

HYDROLOGICAL CYCLE

The hydrological cycle explains the ways in which water continuously moves between the atmosphere and the earth's surface (above and below) in its liquid, solid and gaseous states (vapor) (Tollan 2019).

Most of Earth's water mass exists as either atmospheric water, ice, fresh water or saline water. Some of the main processes for water's movement between the atmosphere, the earth's surface and its subsurface are precipitation (rain or snow), condensation, evaporation, surface runoff and infiltration. These processes can be directly affected by climate, and can in turn also affect the climate (ibid).

Some of the most important natural systems for handling stormwater in Norway are forests, swamps, wetlands, rivers and lakes (Aarestad, Bjerke et al., p. 20).

What happens to the hydrological cycle as a result of urbanization?

Available surfaces for infiltration are often removed as permeable surfaces are developed for urban functions such as housing or commerce. Urbanization takes place above and below ground, as areas being developed or re-developed also need sewerage systems, transportation and other critical functions to become a functioning part of the city.

The relationship between stormwater and groundwater needs to be a central topic when planning stormwater management. A balanced groundwater table can help a city's infrastructure, buildings and natural environment in a number of different ways.

Why do groundwater levels matter?

Groundwater levels fluctuate as a result of many influencing factors, but an extreme or rapid change in levels can have serious consequences for the natural and built environment.

Higher levels

More groundwater from rainfall leads to rising groundwater tables, which also means more groundwater leaking or seeping into sewage systems and reducing their overall capacity, which in turn increases the risk of flooding and overflow (Holvik, p. 93).

Lower levels

Exposure of building foundations to oxygen rich environments, leading to decay and damages to buildings (ibid).

The cycle cannot self-maintain in high pressure areas. With rapid urbanization, disruptions to the hydrological cycle cannot automatically be reversed. It requires a conscious effort to restore natural processes through deliberate legislation, planning and design. Local stormwater management has proved useful as a tool to restoring the natural hydrological cycle (Braskerud, Paus et al., p. 329).

In restoring the hydrological cycle in urban areas, working with water's natural movements, perpendicular to elevation lines, can be especially helpful. Combining natural flood routes with LID measures along those flood routes to minimize stormwater runoff and ensuring safe flood routes above ground will ensure climate-adapted cities whose infrastructure works to maintain the safety of its inhabitants, buildings and infrastructure. Several cities in Norway are working to chart their flood routes and make improvements.

Many notable features of Norway's geology are a product of the most recent ice age which ended lasted from 15,000 to 12,000 years ago, where Norway was covered in an ice sheet at times 3 kilometers thick (Bryhni and Hagen 2020). In order to understand an area's hydrological cycle, it can be useful to first study its geology.

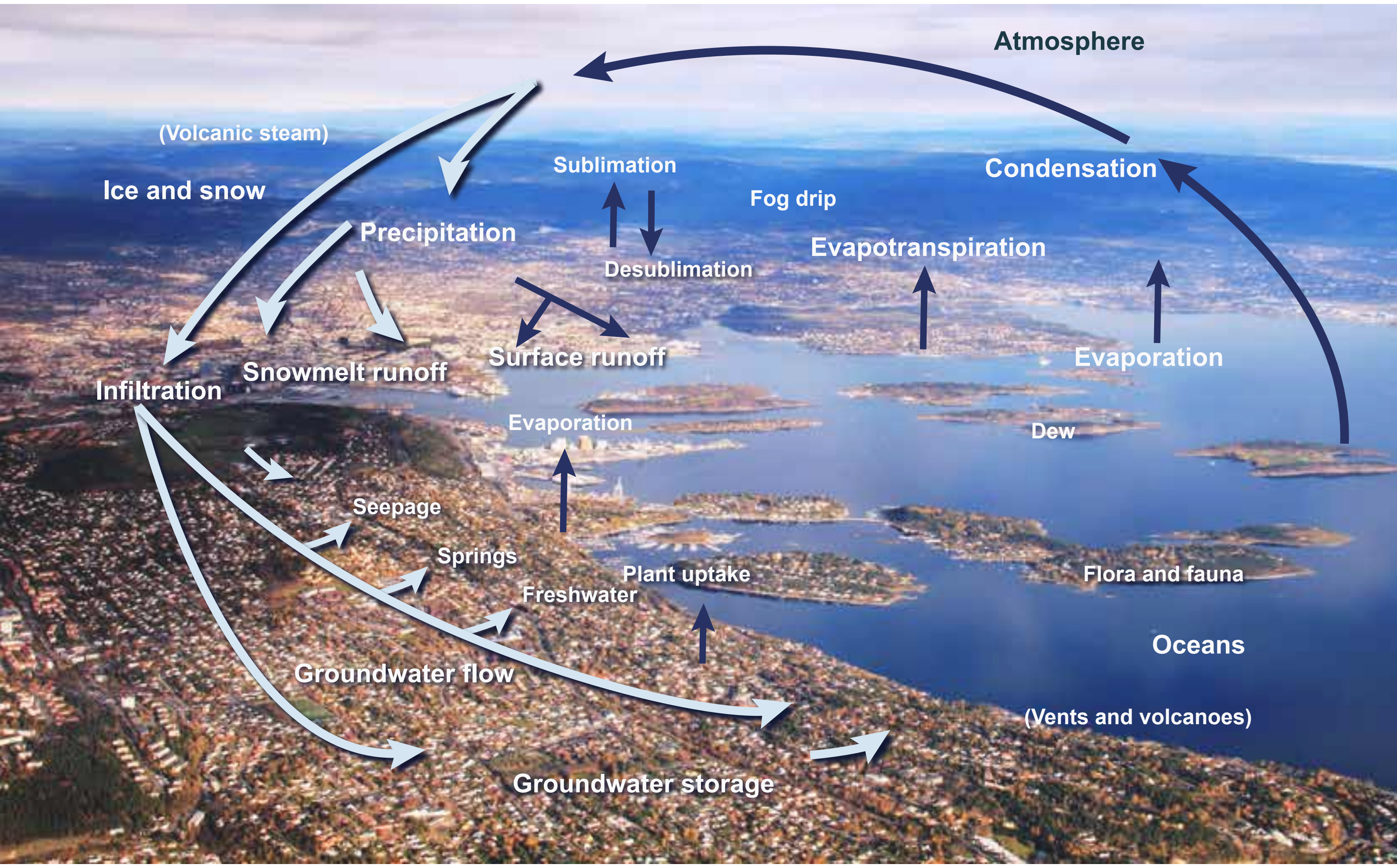


Fig. 2.4 Adapted from John Evans and Howard Periman, USGS - http-//ga.water.usgs.gov/edu/watercycle.html, Public Domain, https-//commons.wikimedia.org/w/index.php?curid=26818355. Bakground image by Chell Hill.

PUBLIC HEALTH

Polluted water- already an issue after heavy rainfall in Oslo. Not beneficial when trying to make a city livable and raise the standard of living for residents that officials have to discourage contact with the water for days after a heavy rainfall.

Access to green spaces in increasingly urbanized spaces is connected to public health. Important to have a walkable, accessible city with greenery nearby, especially as more people are living in cities.

Most of the city is already built, and with a wetter climate these buildings and adjacent areas are not equipped to handle the water.

Contaminated water as a result of sewerage overflow can lead polluted water in to nearby waterways, bodies of water or oceans, causing bacterial blooms, parasites and other unwanted microorganisms to spread (Cicero, p. 31). With a warmer climate and longer growth season for plants, the pollen season will be extended and pollen allergies can worsen (ibid). Small changes in temperature can change the optimal conditions for certain species to thrive. Another threat to public health and safety as a result of climate change is insect transmitted diseases. As Norway's climate becomes warmer, with milder winters and more humidity, insects such as ticks and mosquitoes can survive more of the year than they can now (ibid).

Landscape architects often work to create quality spaces for people, and frequently work to preserve or promote environmental qualities as well. Working with LID stormwater management in cities is an indirect way of working to facilitate recreation, a healthy environment and livable cities.

Photo. 2.3

TRADITIONAL STORMWATER MANAGEMENT

Stormwater is water that starts as rain or snow and runs off roofs, courtyards, parking spaces and streets. By sending stormwater in to rain gardens one is able to delay that water so the pipes under us do not get overloaded with too much water. A common issue for many European cities is an outdated sewerage system in terms of capacity.

«When combined sewer systems were introduced in 1855, they were hailed as a vast improvement over urban cesspool ditches that ran along city streets and spilled over when it rained. These networks of underground pipes were designed to dry out streets by collecting rainwater runoff, domestic sewage from newly invented flush toilets, and industrial waste-water all in the same pipe. Waste- and stormwater was then discharged directly into waterways; in the early twentieth century, sewage treatment plants were added to clean the wastewater before it hit streams. Combined sewer systems were—and still are—a great idea, with one catch: when too much stormwater is added to the flow of raw sewage, the result is frequently an overflow. These combined sewer overflows (CSOs) have become the focus of a debate regarding the best techniques to manage growing volumes of sewage and stormwater runoff…» (Tibbetts, p. 464)

As climate change brings more rainfall to several nordic cities, these limitations are made clear during heavy rainfall events, when stormwater runoff in combined sewer causes combined overflow in the sewage systems (Aaby and Lindholm, p. 323). In Norway, there have historically been no national standards for stormwater overflows. Combined sewer systems allow for the collection of different wastewater products in the same pipe, such as stormwater, sewage and industrial wastewater (EPA). What happens with heavy rainfall in these combined systems is that the volume of wastewater exceeds the pipe's capacity. This forces the now combined wastewater products back into the system and out through the lowest exit point, as combined sewer overflows (CSOs). In Norway these are typically in a building's basement. There are no national data sets for the number of households connected to combined systems in Norway (ibid, p. 323). To make matters worse, the effects of an increase in rainfall volume on traditional systems can often lead to a much higher increase in overflow volume. A 2007 study shows that a 16,7% increase in rain volume created a 64,3% increase in overflow (Aaby and Lindholm, p. 324). A similar modeled study in Helsingborg revealed that a 20% increase in rainfall would result in a 200% increase in overflow volume (ibid, p. 323). While traditional systems for stormwater management have been an improvement in society, adaptations to increased rainfall as a result of climate change is needed to avoid CSOs. According to Lindholm et al, 2007, «analyses from several research projects in

Norwegian cities have shown that in a future changed climate, 50-100% more buildings may be damaged because of sewerage flooding and an increase of 50-100% CSOs are predicted to be discharged from the combined sewers because of future changed climate.» Further uncertainties with traditional systems are «the real percentage of impermeable surfaces that are directly connected to the network, the overlay flow time (time of entry) and representative reliable precipitation data» (Lindholm, p. 223). It is important that landscape architects understand these weaknesses and points of uncertainty, and see the potential of having surface systems for stormwater management. Analysis suggests that «the traditional sewerage systems cannot handle future predicted rainfalls. Therefore, the 3-stage strategy with infiltration, delay and diversion of excess runoff needs to be a part of planning for stormwater management.» (Lindholm, p. 400). A number of cities in Norway have reached the same conclusion.

We are in the process of shifting our thinking from transporting waste away, to keeping necessary resources on-site. Landscape architects can be an important bridge between traditional 'grey' stormwater management solutions and newer 'blue-green' measures.

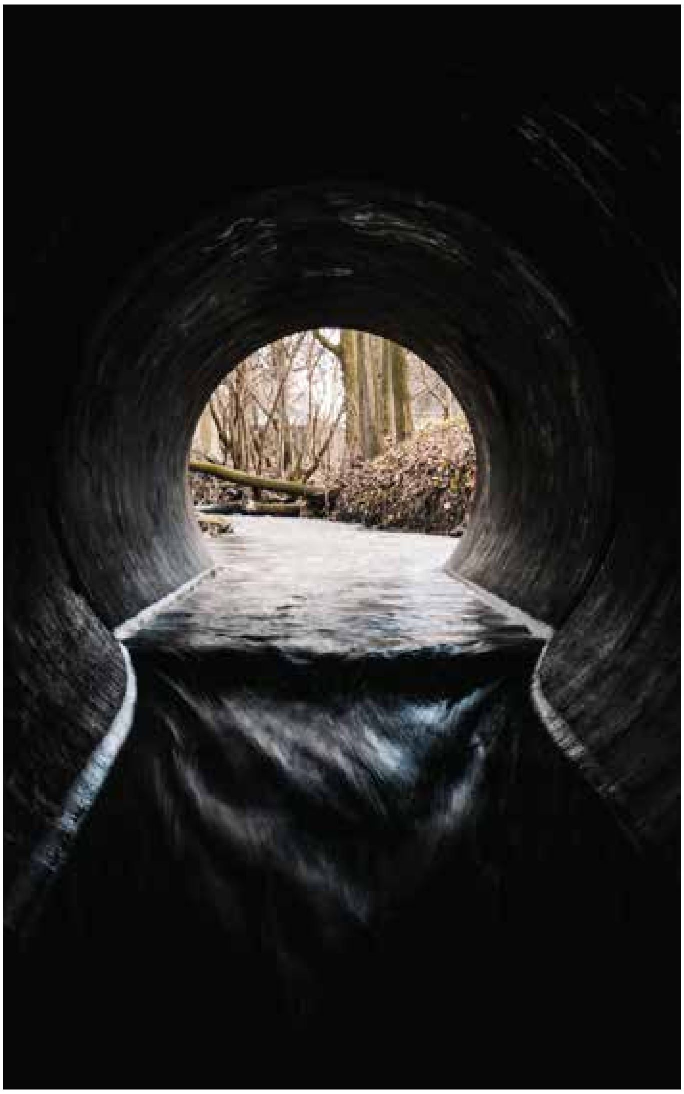


Photo. 2.4

LID STORMWATER MANAGEMENT

As a response to traditional stormwater management, Low Impact Development, or LID, was developed to treat stormwater in a more natural way. The approach mimics existing natural processes in the hydrological cycle with some artificial support. The term is an umbrella term encompassing a number of stormwater management measures such as; rain gardens, bioswales, green roofs, permeable surfaces and more. A brief introduction on these measures.

Rain gardens

A rain garden is a lowered planted area that retains storm water either permanently or temporarily. The filter medium in a rain garden needs to infiltrate water and sustain plant life (Braskerud and Paus, p. 61). If the only source of water for the rain garden is nutrient poor roof water, meaning rainfall that has only come in contact with nearby rooftops, then supplemental fertilizers can be especially helpful during the first operational years of the rain garden to ensure healthy plant growth (ibid, p. 65). Rain gardens are suited for areas with limited sewerage capacities (Bent C. Braskerud, p. 492). This means they can be helpful in both private gardens and densely populated urban settlements, as sewerage capacities for stormwater will be limited with future increases in rainfall.

Bioswales

A bioswale is similar to a rain garden, but facilitates movement of water.

Green roofs

Green roofs, or blue-green roofs, are vegetation structures on roof tops that allow rainfall to infiltrate.

Permeable surfaces

Permeable surfaces allow rainfall to infiltrate directly into the ground, either through gravel, permeable pavement, or other permeable materials, facilitating groundwater replenishment

These measures are flexible, and more easily expanded, repaired or replaced than traditional underground sewerage systems.

Implementation of LID has the potential to directly influence site hydrology, especially for smaller rain events. LID can delay runoff, as one study in a housing development in Watford, Connecticut showed, by 39 minutes, or six times more than a comparable surfaces with traditional stormwater management solutions (Braskerud, Warner et al., p. 38). Even when larger rains weren’t significantly delayed the total runoff was always reduced (ibid). Plan surface infrastructure as a part of stormwater management infrastructure, in terms of rain catchment areas, coverage, distance to waterways and other considerations. Combine stormwater management networks with other networks such as recreational infrastructure.

While winters are not unique to Norway, there is relatively little research on LID in winter situations. Some factors that can affect the performance of LID during Norway's coldest season are ground temperatures, water temperatures and plant selection (Holvik, p. 91). Specifically, frozen ground can no longer infiltrate water, which intensifies runoff and renders some LID measures, such as rain gardens, less effective. Also, more and heavier rainfall during the summer and autumn seasons means the ground will be saturated and incapable of infiltrating at the same rate as when it is dry (ibid). However, even in a frozen state, rain gardens can act as stormwater management measures; their surface area becomes the total infiltration area rather than surface area and soil depth. Trials show that even with concrete frosts, the rain gardens have a capacity for flood reduction (Braskerud, Bjerkholt et al., p. 500).

Photo. 2.5

SUMMARY

Secondary research question:

Why do Norway's cities need to be adapted to a wetter climate?

We have learned that the processes of urbanization and climate change will affect the hydrological cycle in similar ways, which means the impacts of increased rainfall will be felt even more clearly. It also stresses the importance for municipalities to consider short- and longterm plans for integrated stormwater management (Braskerud, Nie et al., p. 212). The impact will be felt even harder by the ill-equipped sewerage systems in Norway's cities, built to solve 19th century problems, not 21st century challenges. However, there are systems in place to ease the strain on our sewerage systems, that mimic natural hydrological processes. These measures, known as low impact development, or LID, can be implemented in existing built environments as well as new developments. They are relatively flexible, provide multiple social, environmental and aesthetic services and yield high returns on investment compared to traditional systems. By combining the strengths of pre-existing systems and added benefits of new LID systems, Norway's cities can be well-equipped to deal with future challenges.

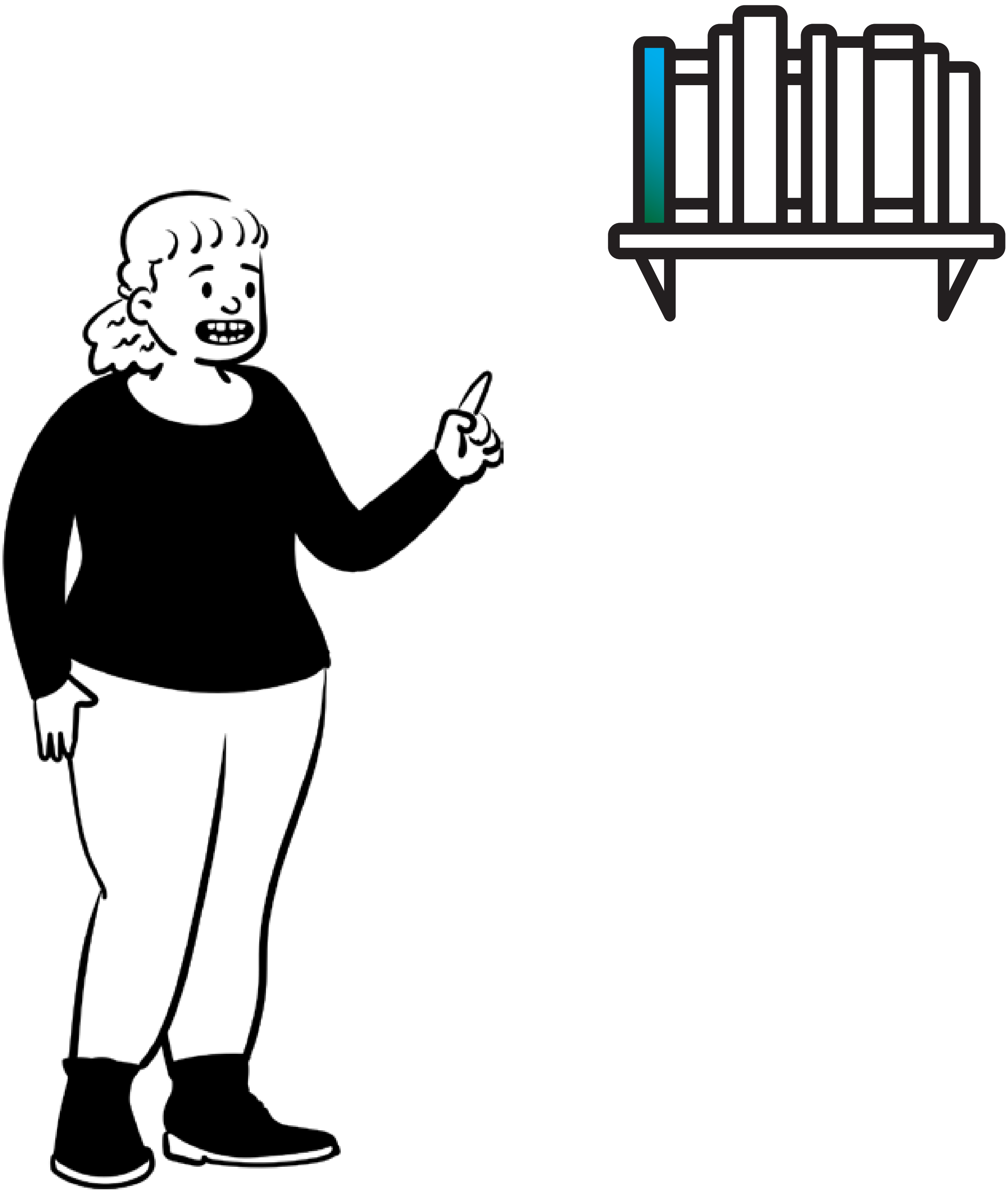


Fig. 2.9

3

FRAMEWORKS

This section adresses the following secondary research question:

How is LID stormwater management referred to in Norway’s legal and strategic documents?

FRAMEWORKS

FRAMEWORKS

This section discusses some of the main political and legal frameworks that impact stormwater management in Norway today.

Urban LID stormwater management is a relatively new field of study and practice in Norway, and it is therefore beneficial to assess the ways in which stormwater management is mentioned (or not) in the laws, regulations and strategies for of Norway.

INTERNATIONAL - UNITED NATIONS

Fig. 3.1

The United Nations have outlined 17 universal Sustainable Development goals . They are a series of goals to achieving social equality, eradicating hunger, preserving wildlife and more (United Nations, 2020). Norway has agreed to work towards achieving these goals and reports on the nation’s progress yearly.

Some of the relevant Sustainable development goals (SDGs)

“Goal # 6 Clean water and sanitation

6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate

Goal # 9 Industries, Innovation and Infrastructure

9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all

Goal # 11 Sustainable cities and communities

11.7 By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities

11.B By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels

Goal # 13 Climate action

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

13.2 Integrate climate change measures into national policies, strategies and planning

13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning" (ibid).

These goals highlight the importance of Norway's work to implement LID in urban settlements, in order to improve water quality, develop sustainably, provide access to green spaces and mitigate the effects of climate change. Future implementation of LID measures in urban settlements should use the SDGs as the overarching argument for implementing LID measures.

Fig. 3.2

Fig. 3.3

Fig. 3.4

Fig. 3.5

PARIS AGREEMENT

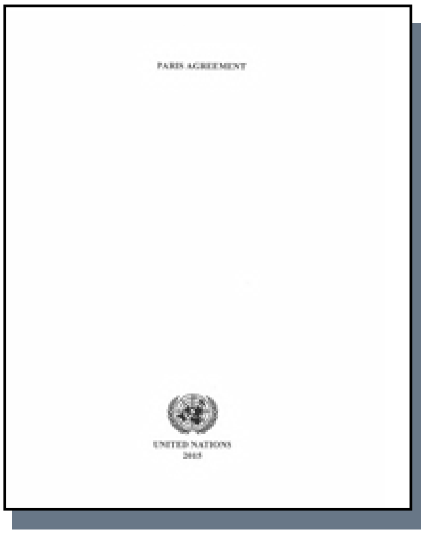


Fig. 3.6

An agreement «recognizing the need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge» (United Nations, 2015, p. 1). While the Paris agreement's primary goals are related to decreasing global greenhouse gas emissions, in order to slow anthropogenic, or man-made climate change, its purpose is to mitigate the effects of climate change that Norway faces, such as increased temperatures and increased rainfall. As Norway is one the agreement's signatories, the Norwegian government is working diligently to reduce greenhouse emissions and implement climate change mitigation measures where possible. The agreement also repeatedly acknowledges that different nations, whether developing or developed, will have varying levels of technology and economic resources to implement these changes. Norway's role as a developed nation is therefore to arguably to be at the forefront of developing and testing measures for continuous knowledge exchange.

CLIMATE CHANGE ACT

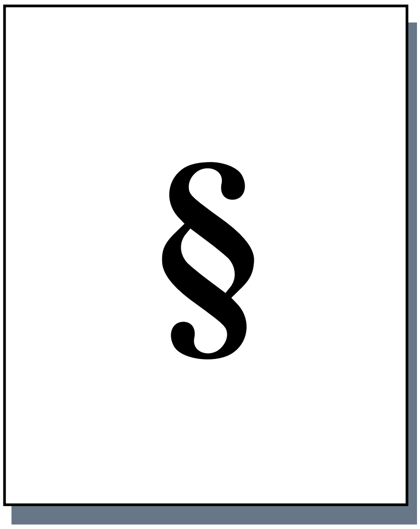


Fig. 3.7

The Norwegian government has decided that climate adaptation be given top priority and require cooperation at all levels of planning, from municipal to regional and national (state).

The purpose of the act is «to promote the implementation of Norway's climate targets as part of its process of transformation to a low-emission society by 2050. The purpose of this act is also to promote transparency and public debate on the status, direction and progress of this work.» (Climate change act, Ministry of Climate and Environment. 2018, section 1.) The act states the climate target set by the Norwegian government of a 40% reduction in greenhouse gases by 2030 compared to the reference year 1990 (ibid, section 2). The act also specifies annual scientific reporting to the government on a number of topics, therein «an account of how Norway is preparing for and adapting to climate change» (ibid, section 6).

THE WATER RESOURCES ACT

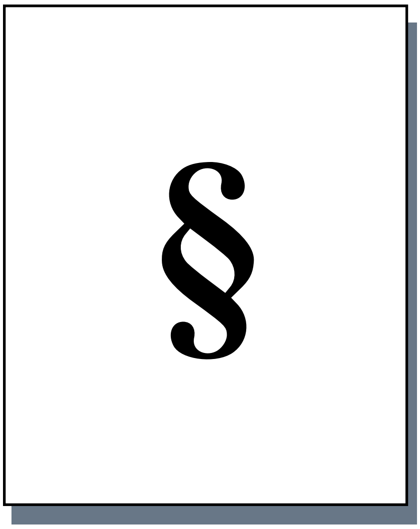


Fig. 3.8

How does stormwater management pertain to the Water Resources Act? If the strormwater management measure leads to runoff or other stormwater being led to bodies of water or waterways as defined by the Act, and their quality, flow or volume is subsequently impacted/affected, then stormwater management becomes liable to the Water Resources Act, and defined as a Waterway measure per §3 a), which states that «waterway measures: waterway facilities or other measures in the waterway that by their nature can impact water flow, water levels, alter the course of the waterway or its direction and speed or the physical and chemical water quality other than by pollution» (Oil and energy dept., 2001, changed 2018).

THE POLLUTION ACT

While the municipality is responsible for handling stormwater, it can only use water fees for handling stormwater in sewage systems, and not use funds from water fees for stormwater management surface systems. In some cases it is possible to finance through this model, but with the caveat that surface systems are being implemented to ease the burden of pre-existing sewage structure. «In summary, the water fee can only be used for financing measure to separate stormwater that is already connected to a drainage system (sp?), and can not be used to finance measures for handling stormwater before it drains into a sewage system.» (NEA, 2020). So how can municipalities in today's system finance surface stormwater solutions such as LID? They can allocate additional funds from their municipal budget, they can fundraise, or they can look at other available financing structures (ibid).

PLAN AND BUILDING ACT

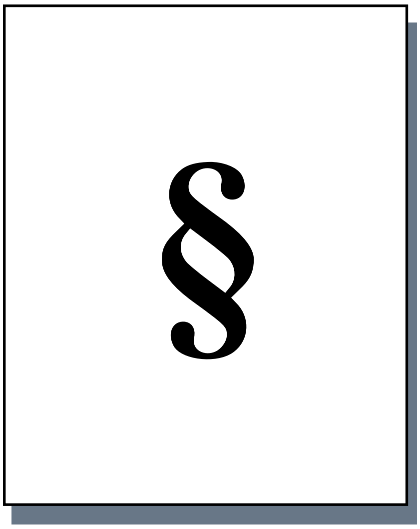


Fig. 3.9

The Plan and building act, rev. 2008, argues for a holistic approach to stormwater management, and exemplifies a changing attitude to the field.

§3-1. within the framework of §1-1 plans following the provisions of this act shall:

i) accomodate a holistic approach to stewardship of the water/hydrological cycle, with necessary infrastructure

«Municipalities have a duty of care to the hydrological cycle and water quality in their planning work, while using water as a resource for recreation, public health and other ecosystem services.»

-Norwegian Environment Agency

TEK 17

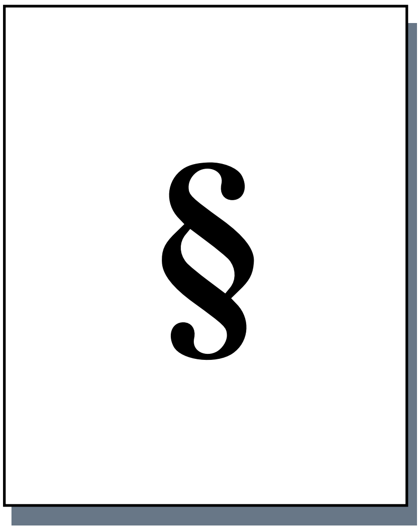


Fig. 3.9

TEK17, which describes the standards for buildings and developments in Norway, mentions stormwater management in the following terms:

§13-11. Specifies that stormwater should be lead away from building mass using terrain

§15-8. 1) Stormwater and drainage should be infiltrated or handled on-site wherever possible in order to secure a balanced water table and avoid overpowering the sewage systems.

2) leading stormwater and drainage should be done in a way that avoids flooding or other inconveniences during dimensioned rainfall.

The language of the next TEK should work to emphasize the importance of LID stormwater management in conjunction with traditional solutions.

CLIMATE STRATEGY FOR OSLO TOWARDS 2030

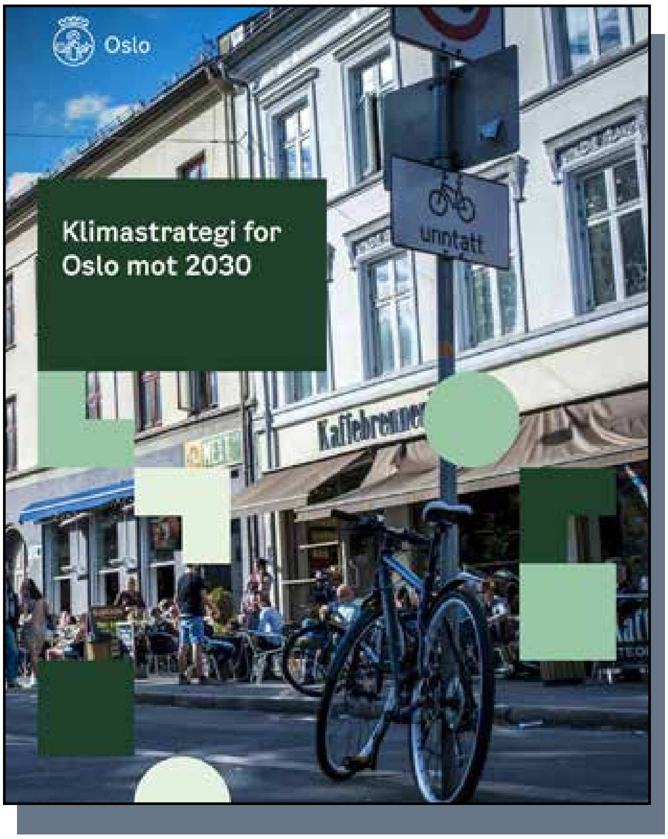


Fig. 3.10

Fig. 3.11 climate and energy strategy for Oslo

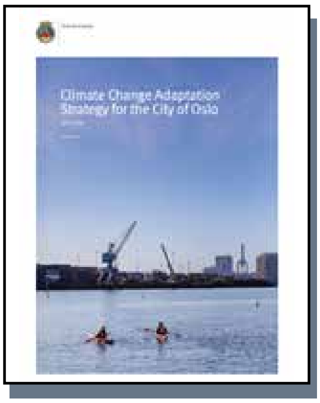


Fig. 3.12 climate change adaption stratefgy for the city of Oslo

The climate strategy for Oslo towards 2030 replaces both the climate and energy strategy for Oslo and the Climate Change Adaption strategy for the City of Oslo.

It outlines 16 main goals across three focus areas: energy, consumption and climate stewardship

Relevant sections

1- using Oslomarka (the green structures surrounding Oslo) as first line of defense

2- maintaining and restoring waterways

3- cyclical waste management structures

12- training and cooperation

13- create room for climate friendly innovation

14 climate budget

15- work more closely with other levels of government, state and regional, to ensure meeting climate targets

16- international cooperation in order to gather information, as well as sharing and own climate solutions internationally

Oslo's climate goals are linked to the UN Paris agreement and the UN sustainable development goals. (p.8)

Norway's national goal is to reduce climations by 40% by 2030 (compared to 1990-numbers) (p. 9)

By getting ahead in terms of product and sercvice innovation geared towards carbon neutrality, Norway aims to export climate solutions to a changing Europe. (p.9)

Oslo was Norway's first city to pass a climate adaptation strategy (p. 19). The aim of the strategy was to ensure that Oslo meets climate challenges by developing a climate resilient city (p.19). In the Oslo area avg. temp has risen by 1 degree and yearly rainfall has increased by 13% (p.19). Oslo will encounter more rain, flooding, risk of erosion and landslides (p.19). In addition, Oslo's valuable nature and rare species are threatened by a changing climate. (p. 19.)

Oslo wants to take a pro-active role in (preventative measures) against climate change. Build the city for resilience instead of fixing whatever breaks.

The city's limited space and pre-existing infrastructure need to be taken into consderiration when climate-proofing (p. 25). Maintenance of these existing structures is paramount.

«Strengthen climate-adapted solutions in the city's maintenance and operations work.» (p. 26)

«Strengthen ties between municipality and existing research communities examining climate solutions in the municipality» (p. 26).

«Ensure that new infrastructure is climate robust and that existing infrastructure is upgraded» (p. 26).

In terms of waste, the municipality want to work to ensure that stormwater does not end up in the sewage systems unnecessarily (p.48).

The strategy is thorough and a helpful example for other municipalities working to include LID stormwater management in their policies

BLUE-GREEN FACTOR (BGF)

Blue-green factor (BGF) is a guide to blue and green measures that can be implemented in planning to ensure that stormwater management and green infrastructure are prioritized in urbanization, transformation and development processes. It was developed by Bærum and Oslo municipality and introduced in 2014 (Leivestad and Skogvold, p. 146). It operates as a score sheet for measures that introduce blue and green elements into building projects, where certain measures, for instance ones that ensure on-site stormwater management, receive a higher score than others (Leivestad and Skogvold, p. 146).

ACTION PLAN FOR STORMWATER MANAGEMENT IN THE CITY OF OSLO

Fig. 3.13

The action plan for stormwater management was adopted in 2014, and provides a set of targets for how Oslo's stormwater management should be further developed and adapted towards 2030 (City of Oslo, p. 4). The plan highlights the benefits of having an open system/network of blue-green infrastructure solutions for stormwater management for purifying polluted stormwater (ibid, p. 6). It states that stormwater management on private property will be crucial to the city's successful handling of stormwater in the future (p. 9). The action plan has identified strategies and actions for future stormwater management in Oslo, as well as identifying the parties responsible for completing the actions, any partners they may have and an operative time frame.

"Tools for goal achievement:

- Developing and improving existing body of knowledge
- Preventing the consequences of stormwater astray
- Making municipal projects into model projects
- Establish closer working relationships
- Providing better guidance and information"

The strategy examines who should collaborate on developing guidelines and communications.

Photo 3.1 Oslo is no stranger to urban flooding due to stormwater runoff travelng rapidly along impermeable surface, seen here outside Oslo's school of Srchitecture and Design (AHO). The city's sloping terrain further accelarates the water's velocity (p. 5). Photo by Hanne Johnsrud.

The City of Oslo is a major developer and must lead by example. We must spearhead initiatives to obtain knowledge about stormwater solutions and the city's hydrology. Our best opportunity is to develop a number of municipal projects as pilots and model projects. To do so, we will need a common work method for planning and implementing projects, and we must be a demanding customer when projects are put to tender (ibid, p. 12)..

SUMMARY

Secondary research question:
How is LID stormwater management referred to in Norway's legal and strategic documents?

This section has looked closer at the frameworks for LID in international and local policies and laws. LID is a tool for combating the effects of climate change, which is a challenge that permeates many areas of development and planning in Norway. In agreement with international frameworks provided by the UN on sustainable development goals and the subsequent Paris agreement for tackling climate change, Norway has been working for years to provide guidelines for future development. The city of Oslo has a number of strategies, and while they have no cloudburst plan yet, the city has worked consistently to gather information about its next steps.

While some cities have strategies for stormwater management, there needs to be more emphasis on a national level in the country's laws, such as the plan and building act and TEK17 for demands on stormwater management in urban areas.

While smaller urban centers may not have the resources or knowledge base to form complete stormwater management strategies, this work needs to be done as rain catchment sites cover large areas and often cross municipal and regional borders. Upstream choices have downstream consequences, and by neglecting to develop holistic stormwater management strategies municipalities risk affecting neighboring areas, damaging natural resources or disrupting the hydrological cycle irreparably.

In addition, with responsibility for water resources placed on municipalities, smaller areas lacking resources may have a harder time creating strategies for climate resilience. Nationally certified training programs for further education should be formed and readily available, similar to teaching competency requirements.

Municpalities/regions or cities with shared waterways and rain catchment areas should form water committees with joint planning and discussion.

Fig. 3.17

4

REFERENCE PROJECTS

This section adresses the following secondary research question:

How are other comparable cities implementing LID to adapt their urban settlements to a wetter climate and what can Norway learn from their experiences?

REFERENCE PROJECTS

This chapter examines the practices of other countries with comparable climates to Norway that have relevant information and useful insights for future LID in urban spaces in Norway.

Urban LID stormwater management is a relatively new field of study and practice in Norway, and it is therefore beneficial to look to other countries to establish and encourage best practice in future planning processes.

The chosen reference projects are

1. Copenhagen The city of Copenhagen climate adaption plan

2. Malmö The city of Malmö’s cloudburst management plan

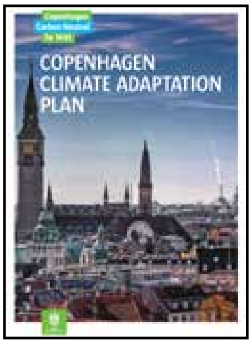
3. Lund Lund municipality’s stormwater management plan

4. Scotland Raingardens in built developments: 10,000 raingardens in Scotland

5. Seattle Green Stormwater Infrastructure in Seattle

6. Puget Sound, North America 12,000 rain gardens in Puget Sound

1.



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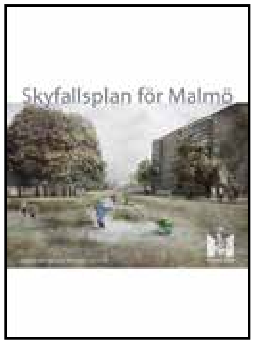

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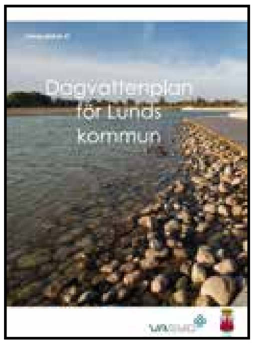

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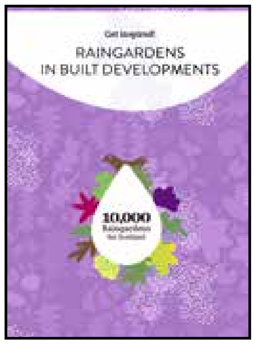


5.

6.

Figs. 4.1-4-6 Cover photos or representative images from the six reference projects (City of Copenhagen, 2011), (City of Malmö, 2017), (Lund municipality, 2018), (Central Scotland Green Network, accessed 2020), (City of Seattle, 2015), (12,000 Rain Gardens in Puget Sound, accessed 2020).

THE CITY OF COPENHAGEN CLIMATE ADAPTION PLAN

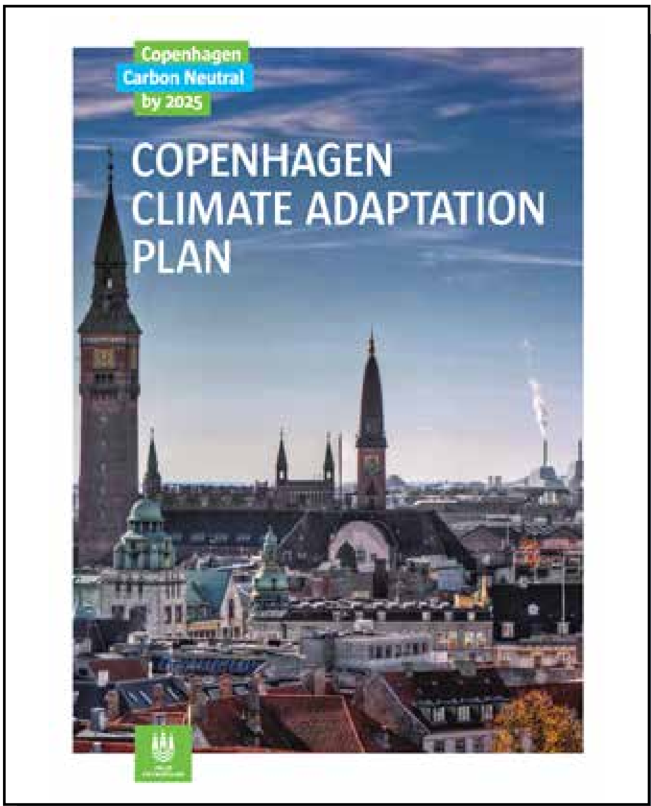


Fig. 4.1 (City of Copenhagen, 2011)

In 2011 Copenhagen released its climate adaption plan. The plan acts as a strategy to be used in all levels of planning measures related to climate change action. Copenhagen identifies primary and secondary challenges for the city as a result of climate change (City of Copenhagen 2011, p. 2).

Primary challenges

- **Increased and heavier future rainfalls**
- Rising sea levels

Secondary challenges

- Higher temperatures and urban heat islands
- Diminished or compromised groundwater
- Indirect consequences as a result of climate change such as increased air pollution and damp damage to buildings.

The strategy hightlights the importance of flexibility when implementing design and planning measures to ensure adaptability in the city's continued response to climate change. (Ibid., p. 12) One of the primary challenges facing Copenhagen is an increase in rainfall occurrence and duration. (Ibid., p. 13) The plan proposes several approaches to handle rainfall and cloudburst events in order to avoid damage to infrastructure and buildings, as well as avoid overloading the sewage system. (Ibid., p. 25)

As a solution, the climate action plan suggests blue-green infrastructure development because it can mitigate several of the city's challenges. (Ibid., p. 45). It points out that the use of green solutions, such as establishing green continuous networks, combined with several other measures, such as the city's sewage network, can provide cost-effective climate resilience measures in existing urban structures. (Ibid, p. 57). The plan suggests further actions, including the creation of interdisciplinary networks across public and private sectors, for topics such as sustainable urban drainage systems (SUDS) and incentives for prevention measures (ibid, p. 61).

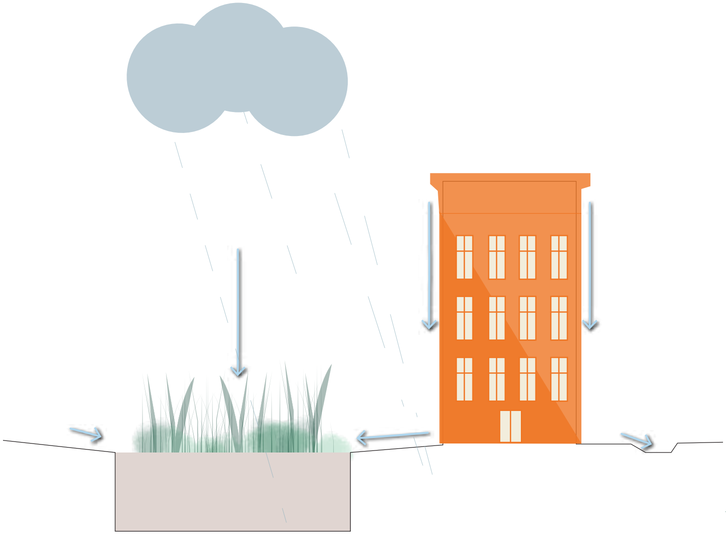


Fig. 4.7 Implementation of blue green infrastructure to work with the city's combined sewer systems is hightlighted as a key measure in the climate adaption plan (ibid, p. 45).

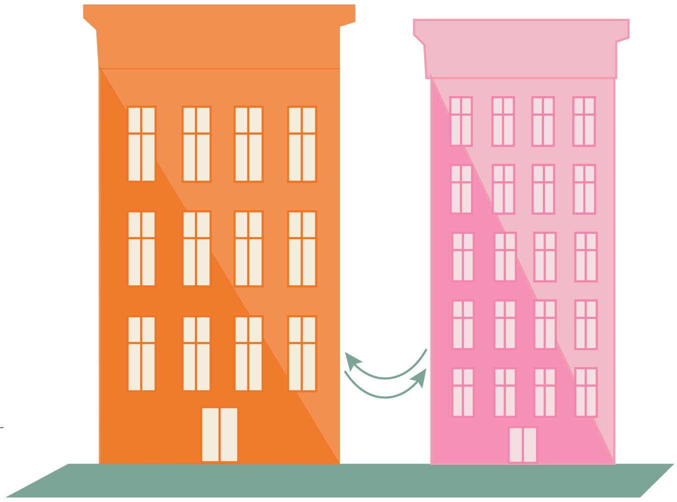


Fig 4.8 Creating interdisciplinary networks to further research and implementation of topics such as sea level rise, SUDS, protection of new urban areas, building adaption, and incentives for prevention. (ibid, p. 61).

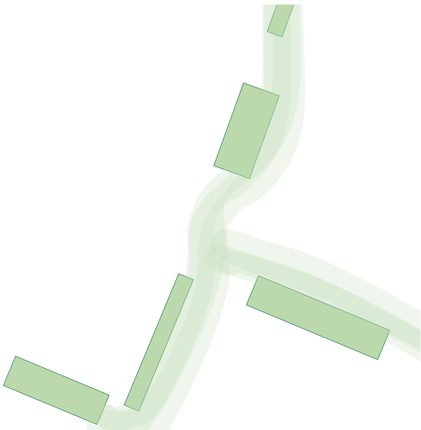


Fig 4.9 The climate action plan repeatedly highlights the need for green continuous networks to futher biodiversity efforts, manage drainwater sustainably and combat urban heat island effects in Copenhagen's future.

"Flexible climate adaptation therefore requires cross-cutting solutions focused on facing up to more of the challenges posed by future climate change. At the same time, climate adaptation should help in creating a city in which the quality of life of the population is paramount. Every time we have to consider what measures need to be taken to avert a risk, we must also consider what opportunities it presents to develop the city to the benefit of its population. The green approach is emphasised here as a major preventive instrument, as green measures can have a broad and multifaceted impact." (ibid, p. 57)

THE CITY OF MALMÖ'S CLOUDBURST MANAGEMENT PLAN

Fig. 4.2 (City of Malmö, 2017)

Main threats to Malmö and other municpalities, cloudbursts. The city has worked across municipal borders to create tenable stormwater management systems in new building developments. While securing an entire city against cloudbursts is a time-consuming and expensive process, the city has decided it cannot neglect this duty. Securing Malmö means implementing a series of measures, most of them on the surface. It requires knowledge about rainfall in private and public sectors for planning on private and public land. They have looked to Copenhagen and Göteborg who have both calculated the cost of handling cloudburst aftermath, both direct and indirect, exceed the cost of implementing measures to handle the cloudburst. (Ibid, p. 5). The plan points to urbanization and covering of waterways as one of the reasons flooding does more damage today than previously (ibid, p. 15).

The plan identifies multi-purpose measures as beneficial for local communities when handling stormwater on-site, especially considering increased densification of the urban core. (Ibid, p. 27) They aim to utilize on-site measures in combination with the sewage systems, and use topography with existing infrastructure to create safe flood routes (ibid, p. 31).

Photo 4.1 The use of rain gardens, for instance in Monbijou street, work to gather stormwater and create a better traffic environment (ibid, p. 36).

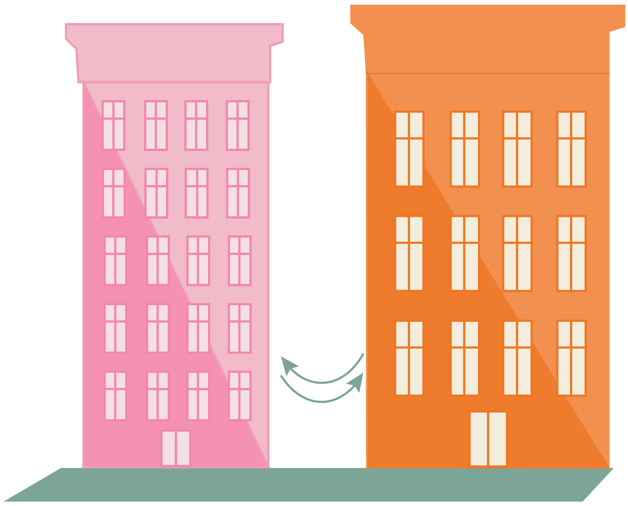


Fig. 4.11 Sharing responsibilities for planning, funding and implementation, the city of Malmö emphasizes the importance of cross-sector co-operation and an interdisciplinary approach to tackling the effects of climate change.

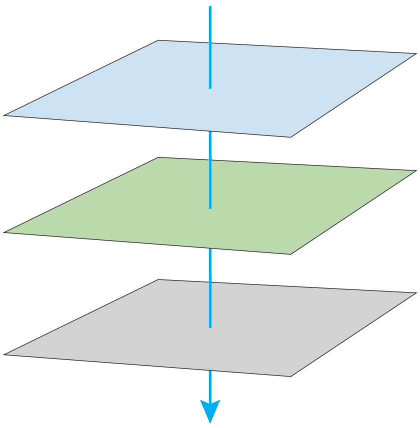


Fig. 4.12 Combining blue and green surface solutions for stormwater management with existing sub-surface grey solutions is pointed out as a factor for success by Malmö's cloudburst plan (ibid, p. 31).

"Cost calculations by the municipality of Copenhagen estimate that it will cost DKK 11 billion to complete the actions needed to prevent damages from cloudburst scenarios, if these actions are implemented as surface-level measures. Within this estimate, DKK 2,4 billion are private investments in the form of actions on development districts. If these actions were instead implemented as traditional sub-surface grey solutions, the cost estimate rises to DKK 20 billion." (ibid, p. 25)

LUND MUNICIPALITY'S STORMWATER MANAGEMENT PLAN

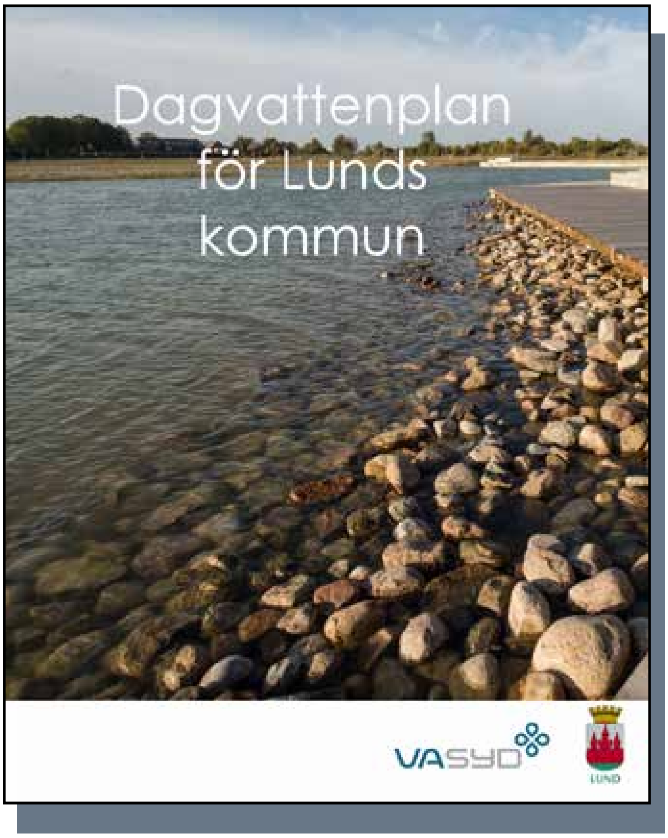


Fig. 4.3 (Lund municipality, 2018)

Lund has developed this stormwater management plan as a response to increased rainfall from climate change (p. 3) The plan aims to ensure that the hydrological and environmental status for its affected residents are improved, while working to ensure that stormwater management is made visible as a resource to the community in terms of aesthetic qualities, recreation and biodiversity (Ibid, p. 4). Similar to Copenhagen and Malmö, Lund's approach is to combine traditional sub-surface sewage systems with blue green surface solutions for stormwater management, rather than rely entirely on one system or the other (ibid, p. 6).

In terms of priotisation, Lund wants its stormwater management measures to provide ecosystem services and become a natural part of the built environment around it (ibid, p.9) The main priority of the plan is to avoid pollution of water systems from stormwater runoff (especially from roads and larger parking structures), and to manage these pollutants as close to their source as possible (ibid, p. 11). The plan suggests using existing green structures in the implementation of new measures, integrating stormwater management solutions as naturally as possible (ibid, p. 12). In already built environments, which often have constrained sewage systems, assessments must be made if there is to be further denisfication, and where possible work to implement LID such as green roofs, permeable surfaces, rain gardens etc (ibid, p. 14). Lund's strategy also calls attention to importance of planning for stormwater management, arguing that stormwater, rain catchment areas and infiltration capacities need to be considered from 'big picture' planning all the way through to detail planning (ibid, p. 16).

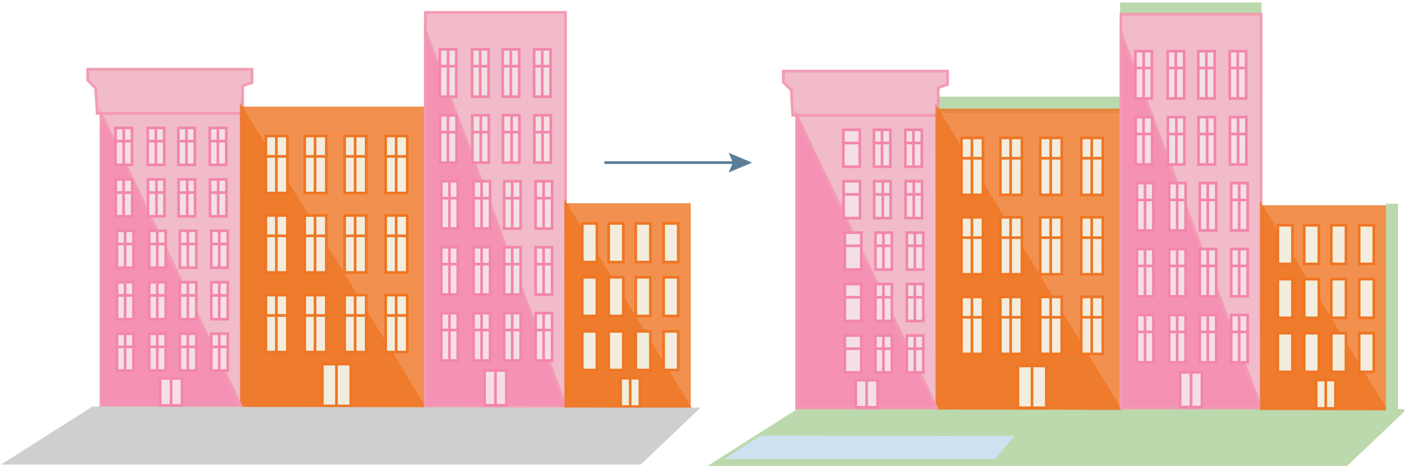


Fig 4.13 Ensuring that pre-existing developments are retrofitted with blue green stormwater management solutions which provide aesthetic, recreational and environmental benefits to the community (ibid, p. 9).

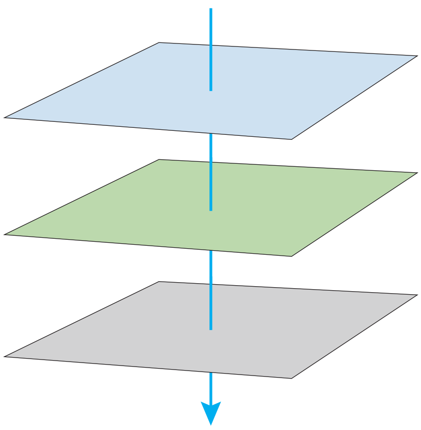


Fig. 4.12 Combining blue and green surface solutions for stormwater management with existing sub-surface grey solutions is pointed out as a factor for success in Lund's cloudburst plan (ibid, p. 6).

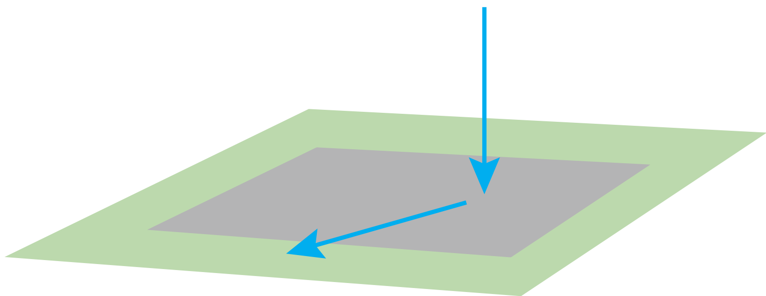


Fig. 4.14 Another priority for Lund is to contain and handle pollutants at their source, particularly from roads and parking spaces. Integrating blue and green solutions on-site can ensure that nearby waterways or other bodies of water are not unnecessarily polluted (ibid, p. 11).

**RAINGARDENS IN BUILT ENVIRONMENTS,
10,000 RAINGARDENS IN SCOTLAND**

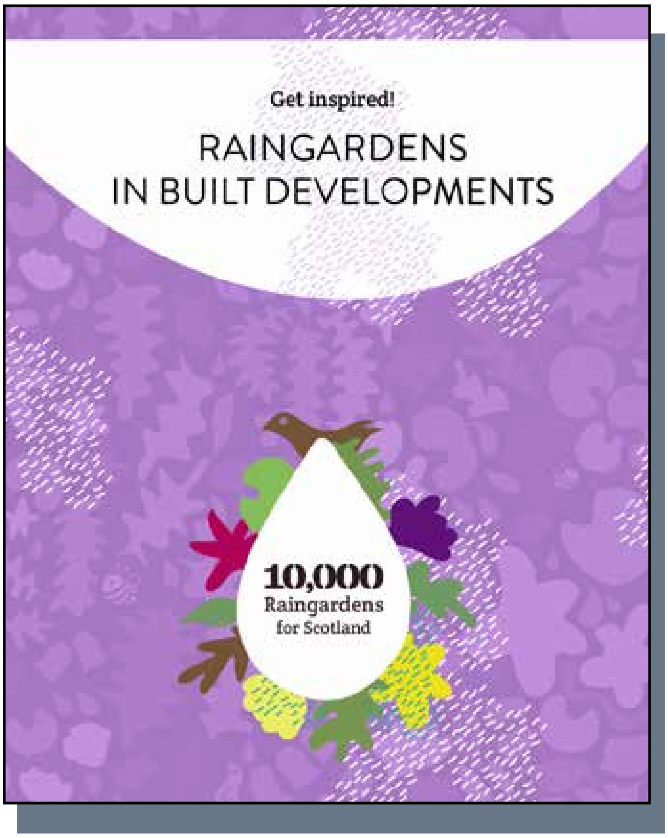


Fig. 4.4 (Central Scotland Green Network, accessed 2020)

The 10,000 rain gardens for Scotland initiative is a flagship project for SuDS in communities in Central Scotland. It is headed up by the Central Scotland Green Network Trust (CSGN) and aims to promote rain gardens for sustainable stormwater management, especially in urban areas. The project highlights several other benefits of rain gardens, including their environmental, aesthetic and recreational qualities (CSGN, p. 6). This campaign appears to have a community-centered approach, meaning its residents are the targets for information rather than local government. In order to highlight the flexibility of rain gardens and other LID options, the campaign has outlined five distinct arenas for rain gardens with individual characteristics for design and use; household rain gardens, school rain gardens, neighborhood rain gardens, leisure and retail park rain gardens and community rain gardens.

"Raingarden and SuDS features are best designed into developments from the start through a landscape led approach. By considering SuDS early, it is possible to weave raingarden features, and therefore green infrastructure, throughout a built development, capitalising on the benefits managing rainwater can offer. Pulling together a collaborative, multidisciplinary team, and including professionals such as landscape architects from the start of a project, is invaluable." (ibid, p. 18)

Fig. 4.15 Household

A message that even small measures contribute to stormwater management, and can provide added benefits for the affected area, however small. (Central Scotland Green Network, 20__)

Fig. 4.16 School

highlights the learning and educational opportunities, as well as potential for community-building by integrating rain gardens into the schoolyard (Central Scotland Green Network, 20__)

Fig. 4.17 Neighbourhood

On a larger scale, rain gardens can become part of larger networks for mobility and green infrastructure. (Central Scotland Green Network, 20__)

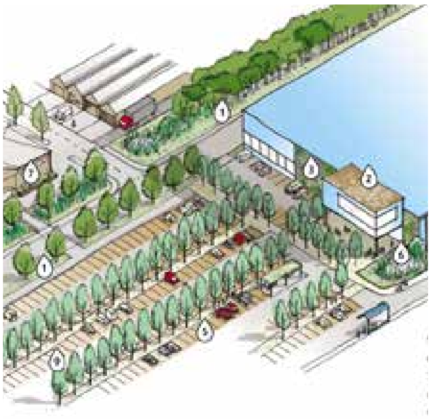


Fig. 4.18 Leisure & retail park

points out the opportunities of turning these largely impermeable surfaces and structure into places capable of handling stormwater on-site. (Central Scotland Green Network, 20__)

Fig. 4.19 Community

A targeted effort at building community participation and identity while also visualizing the hydrological cycle. (Central Scotland Green Network, 20__)

GREEN STORMWATER INFRASTRUCTURE IN SEATTLE

Fig. 4.5 (City of Seattle, 2015)

Pollution of local waterways is a call to action for Seattle, who have been working with green stormwater management solutions for 15 years, currently handling 100 million gallons of runoff with green measures (Seattle, 2015). With a goal of handling 700m gallons of runoff through GSI by 2025, and 400M by 2020, the city intends to use a variety of approaches; revising and and clarifying code requirements, refining standard practices, providing training, engaging community organizations, expand rebate programs for green infrastructure implementation, align GSI investments with other planned infrastructure investments in Seattle and look for external funding where available for GSI measures (ibid, p. ix).

“GSI, is defined as: A set of distributed stormwater best management practices that use or mimic natural processes to slow, infiltrate, evapotranspire, and/or harvest and reuse stormwater runoff from impervious surfaces, on or near the site where it is generated” (ibid, p. 2). As an early adapter of GSI, Seattle has identified the importance of leveraging infrastructure investment to provide further benefits to its communities; ensuring that green stormwater management provides added benefits to the community in terms of urban design, livability and environmental policy (ibid, p. 6). Suggested GSI tools include bioretention, rain gardens, stormwater cisterns, dispersion, dry wells, bio retention, green roofs, permeable paving and tree canopy expansion (ibid, p. 9). Similar to the 10 000 rain gardens in Scotland initiate, the city of Seattle implementation strategy for green stormwater management identifies different categories of GSI measures based on their suitability for private spaces, shared spaces and areas with restricted infiltration (ibid, p. 13).

Seattle has created a comprehensive approach to green stormwater management by including projects at all levels of funding and participation and placing them in one of four categories:

1. Projects required by stormwater code

Required for projects on land being redeveloped, both public or private. The developer can also be either a public agency or private entity (ibid, p. 17).

2. Retrofit projects: public utility led and funded

Projects for improvement that are funded by local drainage and/or wastewater utilities, such as Seattle Public Utilities (SPU) or King County Wastewater Treatment Division (WTD) (ibid, p. 17)

3. Retrofit projects incentivized by public utilities

Projects where development is led by property owners and then incentivized by SPU or WTD with funds from drainage rates as rebates or grants, similar to the projects in category 2 (ibid, p. 18).

4. Retrofit projects: non-utility led and funded

Lastly, these are projects on both private and public land that are developed and funded by «individuals or groups other than SPU and WTD. Insted, funding is sourced from private foundations, private developers, state or federal grants, and local agency funding via the municipal or county budget» (ibid, p. 18).

This strategy ensures accountability for public and private projects and a detailed overview of green stormwater management.

«Actively retrofitting impervious surfaces -- particularly publicly owned pollution-generating surfaces like our right-of-way system -- addresses legacy water pollution at an accelerated rate and delivers additional community benefits like improved pedestrian safety, a greener and more beautiful streetscape for all to enjoy, improved tree canopy and associated benefits like air quality and wildlife habitat, and improved climate resilience.» (Ibid, p. viii)

12,000 RAIN GARDENS IN PUGET SOUND

Fig. 4.6 (12,000 Rain Gardens in Puget Sound, accessed 2020).

This initiative falls under Seattle's green stormwater management strategy, as «3. non utility led and funded retrofit» (Seattle, 2015, p. 33).

Puget Sound is an inlet of the Pacific Ocean, located along the northwestern coast of the United States of America in the state of Washington (EPA, 2020). As Seattle borders Puget Sound, its polluted runoff negatively impacts the ecosystems and hydrology of the area (EPA, 2020). A partnership to help individuals and private organizations build and record rain gardens, with a goal of creating 12,000 in Puget Sound to collectively handle 160 million gallons of polluted stormwater runoff annually (12000 rain gardens, 2020). The project provides information and resources to simplify the process of creating a rain garden. Every step of the process is documented, from planning, to design, finding relevant rebates, grants and incentive programs and registering your rain garden on an interactive map.

INVOLVING THE COMMUNITY

Tapping in to the resources in a community when solving communal challenges. Relevant for Norway's 'dugnad spirit', alleviates pressure on strained public institutions.

1. Gather and organize information. Make the process of building a rain garden as easy as possible

2. Know your audience. Cater your content to your users, and create information for househlds, schools and larger community groups

3. Make a rain garden FAQ- remember this is the first time people may be encountering the concept of rain gardens or other LID.

4. Locate incentives- finding financial incentives for developers

5. Recruit and train- give community members the option to volunteer for your cause and provide testimony. Offer courses and workshops to spread knowledge

SUMMARY

Secondary research question:
How are other comparable cities implementing LID to adapt their urban settlements to a wetter climate and what can Norway learn from their experiences?

This section looks at some of the ways cities around the world are using LID for stormwater management. In an urban setting stormwater runoff velocity and amount can increase significantly with the reduction of permeable surfaces. Cities around the world have been working to combine the best practices of traditional stormwater management solutions and modern blue green solutions.

All stormwater cannot be managed entirely by one system, but utilizing the full potential of LID for urban stormwater management is a priority for many cities. Oslo can learn from established practioners, such as the city of Seattle, who have been practicing LID, or GSI for a number of years. The city has worked to delegate responsibilities for stormwater management by actively including its communities and creating a wealth of opportunities for implementing LID projects on public and private land.

Cities such as Copenhagen also repeatedly highlight the multi-functionality of these LID measures; they can provide value for many areas of city planning and development such as biodiversity, recreation and aesthetics, and can actively contribute to public health.

Norway's 'dugnadsånd', the nation's deeply rooted sense of volunteerism, is an untapped resource in LID projects in Norway's urban spaces. Similar projects to Scotland's 10,000 rain gardens campaign could engage and inspire communities in many of Norway's urban centers.

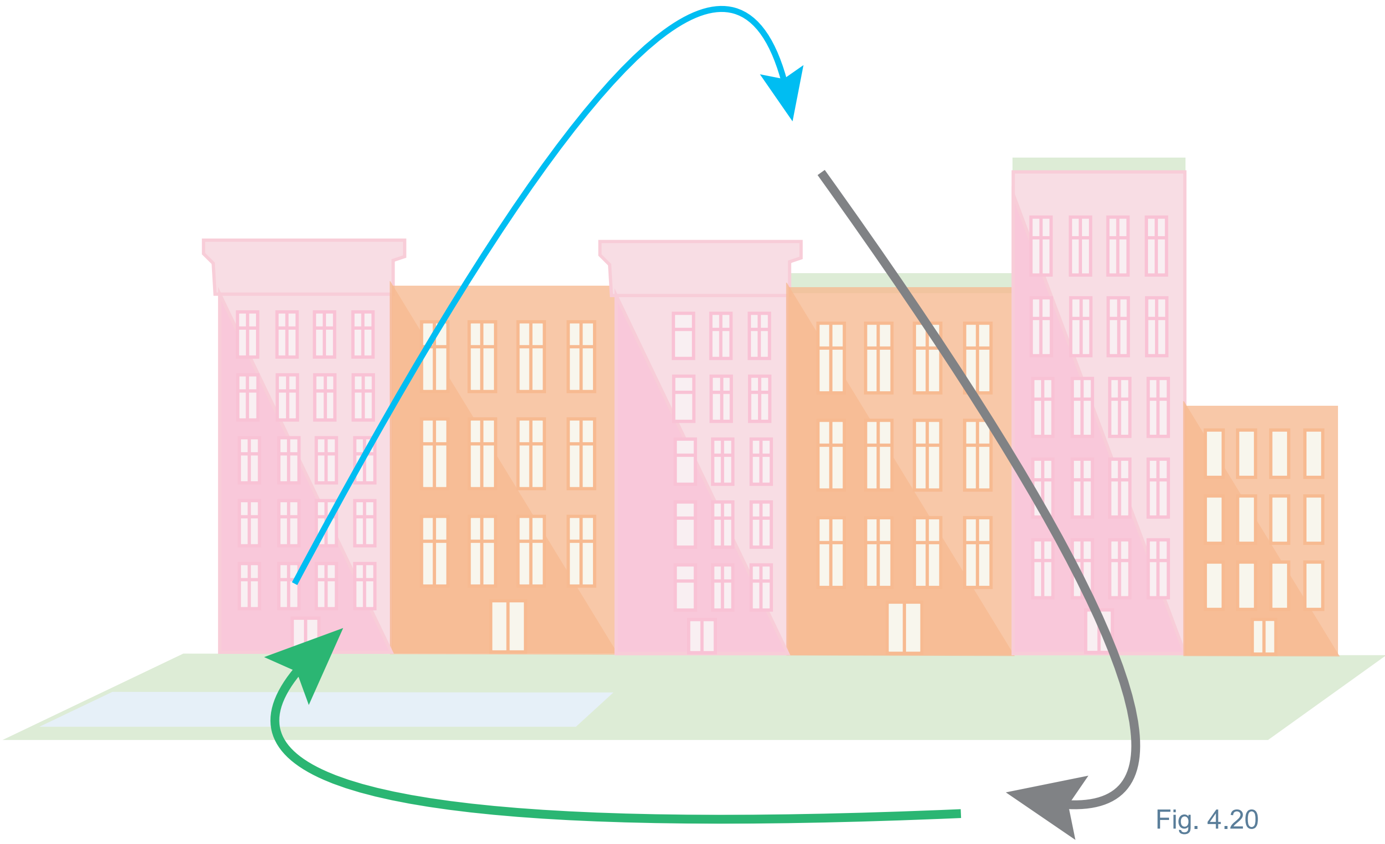


Fig. 4.20

5

CASE STUDY DESIGN

This section adresses the following secondary research question:

How is Oslo working to implement LID stormwater management?

INTRODUCTION

This chapter provides an introduction to the location and history of the Deichman's pilot project site. In understanding urban LID stormwater design for a Norwegian climate, the Deichman's street pilot project offers unique insights as the first project of its kind in Norway.

Each LID measure in the street has been explained and evaluated. The entire project has then been evaluated based on Jan Gehl's 12 quality criteria. The results offer a subjetive but informative assessment of the project as a whole and as an integrated element of urban planning and design.

PROJECT SITE

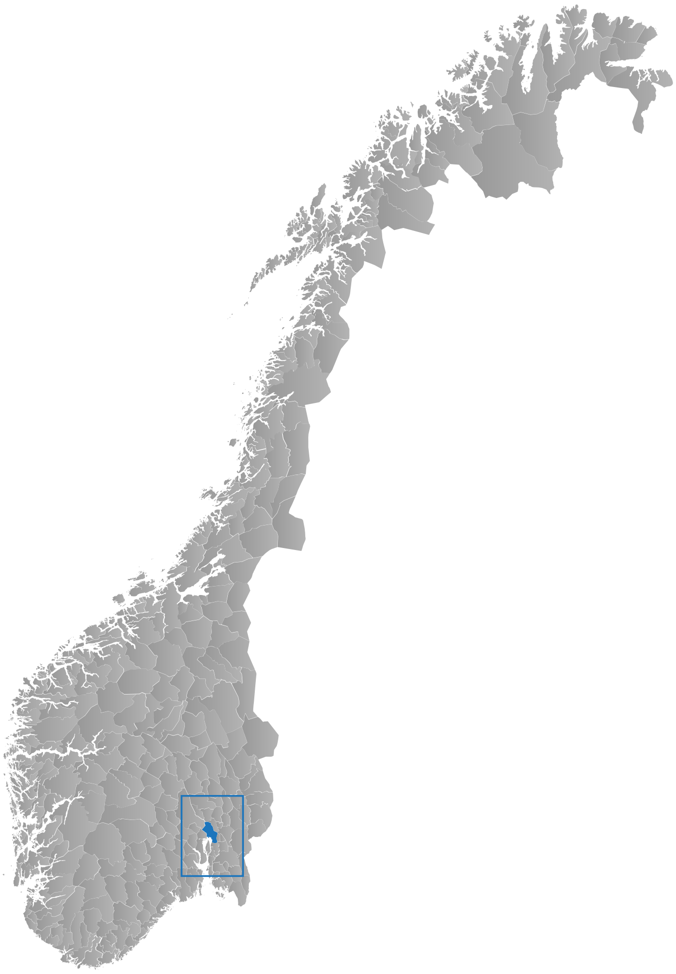
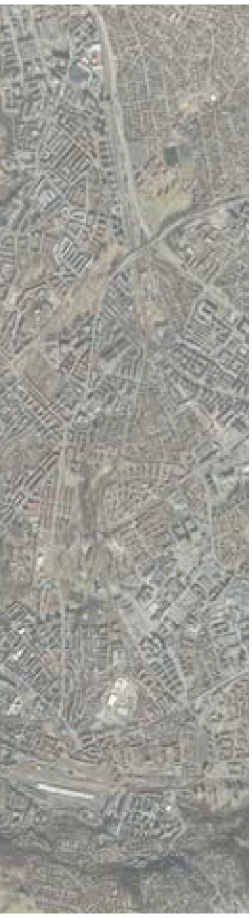


Fig. 5.2 The site of the pilot project is located in easter
capitol city Oslo. Oslo is both a city, municipality and



rn Norway, in the
county.

Fig. 5.3 Deichman's street is located just north of Oslo's city centre and west of the Aker River, in the boroughs of Grünerløkka and St. Hanshaugen. The project site is located in the borough of St. Hanshaugen. The street runs from Idun's street in the north to Krist park in the south, and is intersected by Rosted's street and Wilse's street. The buildings along Deichman's street are mainly residential, with some ground-floor commercial spaces. Møllergata primary school, a public school with approximately 300 students is located at the intersection of Deichman's street and Wilse's street.

DEICHMAN'S STREET TIMELINE

Photo 5.1

1860s

The Møllergata school, constructed in 1861. Photo shows the surface as unpaved, likely stamped earth. On either side of the road there are visible sidewalks with cobble stones and parallel paths of larger flat stones for horsedrawn carts. Both the street lamps and fence along the school building appear to be wrought iron or a similar material.

Many of the street's buildings are erected in the late 1800s.

1870-

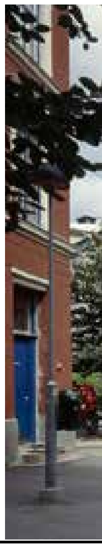


Photo 5

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5.2

1970-1980

9 work began to regulate the section chman's north of Rosted's street as a un', an early version of shared space tion in Norway. By 1982 the southern the street had also been re-zoned. The tion allowed for cars to access properties street but not use it as a thoroughfare, onally, parking was allowed on sections of eet.

1985 onwards, buildings are continuously rnised. Some changes are made to the or spaces but they are largely left in air.

2013-14

In 2013 a request to the planning authorities of Oslo with regards to upgrading the street is sent in by Asplan Viak.

2015

New requirements from the Water and Waste Water Management of Oslo. The project to upgrade the street is turned into a pilot project for handling surface water on-site.

2016

Building begins in spring of 2016 and is completed in august of the same year.

GEOLOGY

Oslo's geology was shaped by the last ice age. Most of the city was below sea level, and when the glaciers retreated the land began to rise. It is still rising today at a rate of approximately 5,1 mm/yr. Most of Oslo's city centre is covered in a thick layer of marine sediments such as clay, sand and gravel (Bryhni, 2017).

The buildings along Deichman's street were constructed in the late 1800s and are part of Oslo's 'brick city', a collection of more than 3,000 brick buildings from the 19th and early 20th century. Many of these buildings are constructed on stone foundations on top of wooden supports, which are submerged in oxygen-poor ground water and organic matter (PBE, 2019).

In many areas of the city these layers are several meters thick, making it difficult to reach the solid bedrock. Historically, these challenges were solved by building on top of wood or clay foundations. During the industrialization of the mid 1800s, Oslo's population grew by 120,000 inhabitants from 1845-1890. As a result, nearly 4,000 brick buildings were erected in the city between 1850-1920 (ibid).

These wooden constructions and foundations are preserved by the surrounding clay and groundwater. Problems arise when the groundwater levels drop and the foundations are exposed to oxygen which promotes decomposition and leads to settling damages throughout the building (ibid).

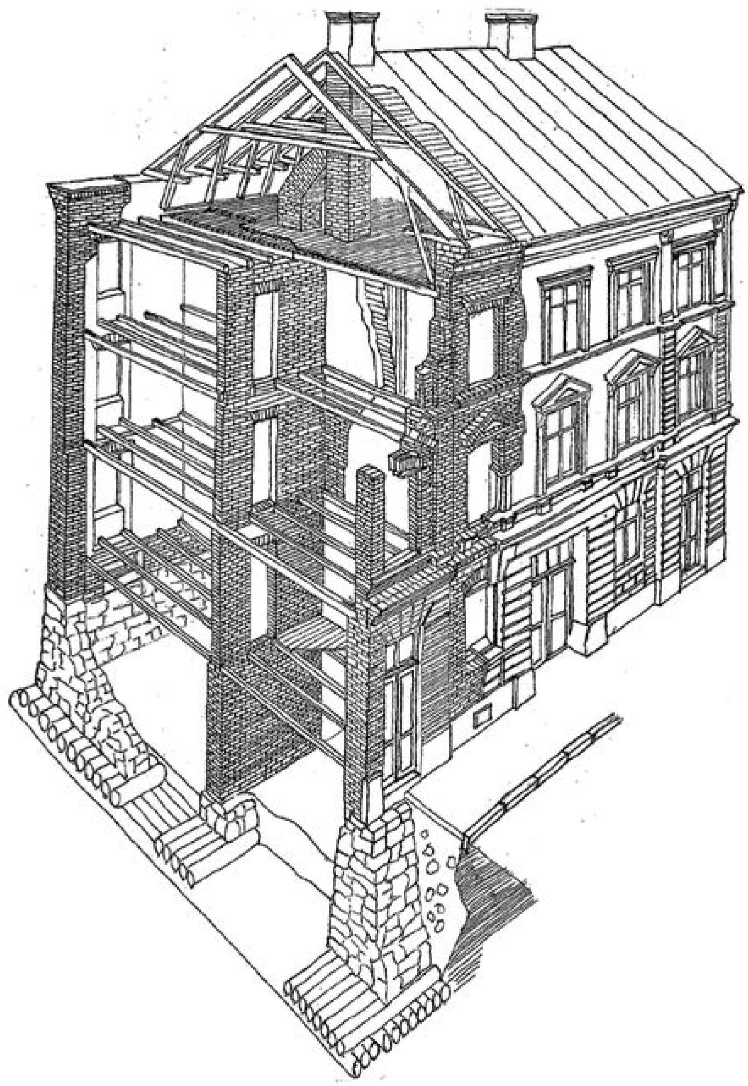
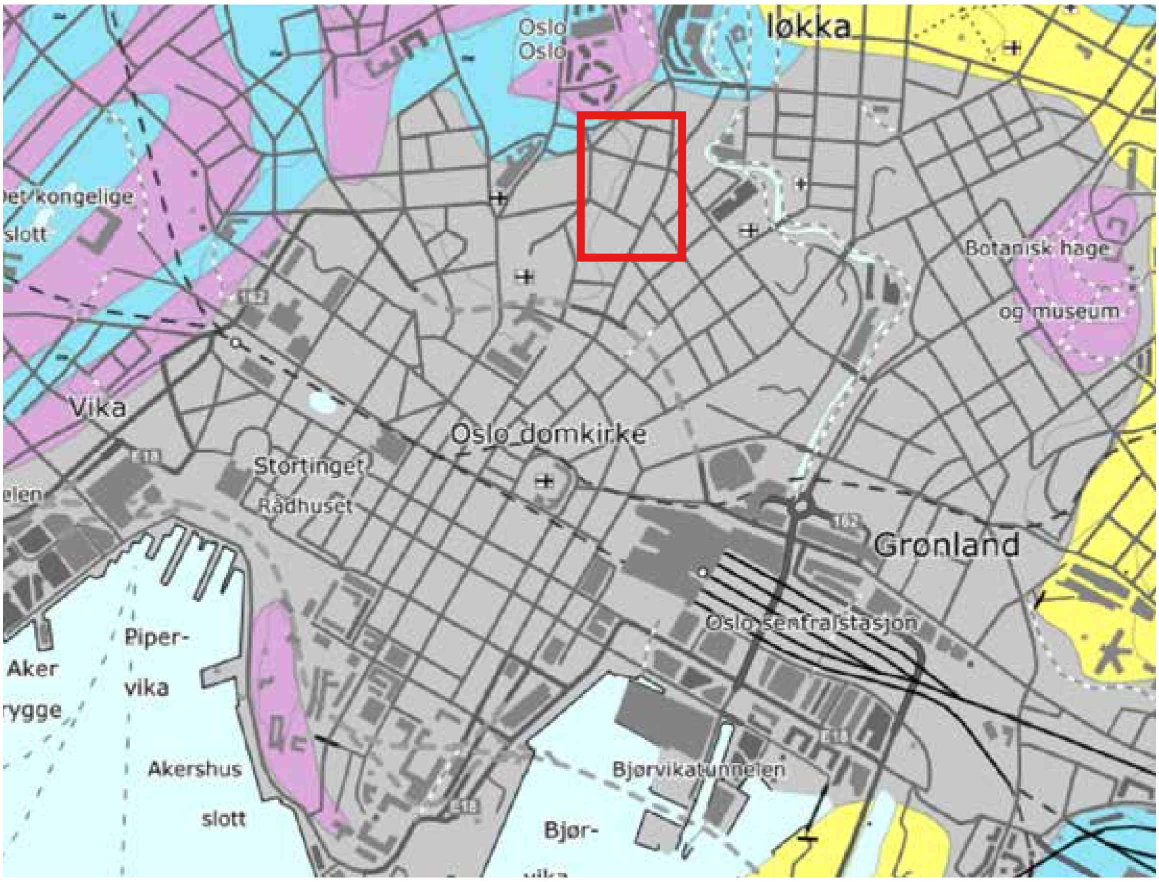


Fig. 5.6 *above: tShows the wooden foundations commonly found under 19th and early 20th century brick buildings in Oslo. IWhen exposed to oxygen- the y begin to decompose, and destabilize the buildings brick foundations (ibid).*

Fig. 5.7 *above, right facing page. Shows the composition of mass in Oslo 's city centre. Deichman's street is marked in the red square*

Fig. 5.8 *below, left facing page. Shows the closest bore holes (red circles) to Deichman's street, which indicate surface depth to bedrock. The depth from surface to bedrock varies from 4 to 20 metres in these boreholes.*


løkka
Oslo
Oslo
det kongelige
slott
Botanisk hage
og museum
Vika
Oslo domkirke
Stortinget
Rådhuset
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Oslo sentralstasjon
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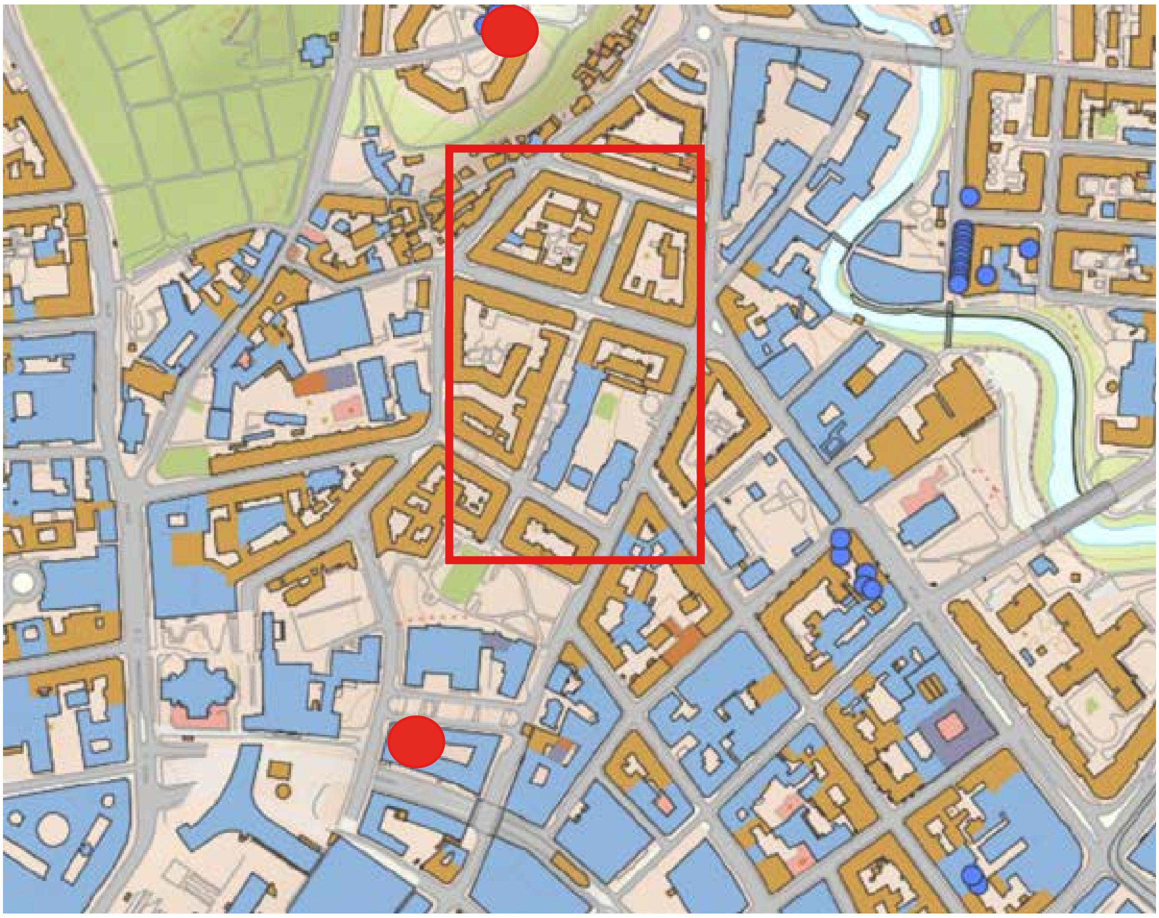


RAIN CATCHMENT AREA

Oslo's climate is temperate, with more frequent rainfall in the summer and autumn seasons.

The rain catchment area for Deichman's street can be expressed as the

Project area+rooftop area, which is approximately 6853 m2.

Where the area of rooftops accounts for appoximately 3135 m2.

The combined area of the nine rain gardens in the rain catchment area is approximately 230 m2 or 6,8% of the total approximate roof area or 3,3% of the total rain catchment area.

The area's topography slopes steeply from the west end of the project site to the east, but the slope on Deichman's street itself is minimal.

The figures to the right show the rain catchment area and total rain garden areas in Deichman's street.

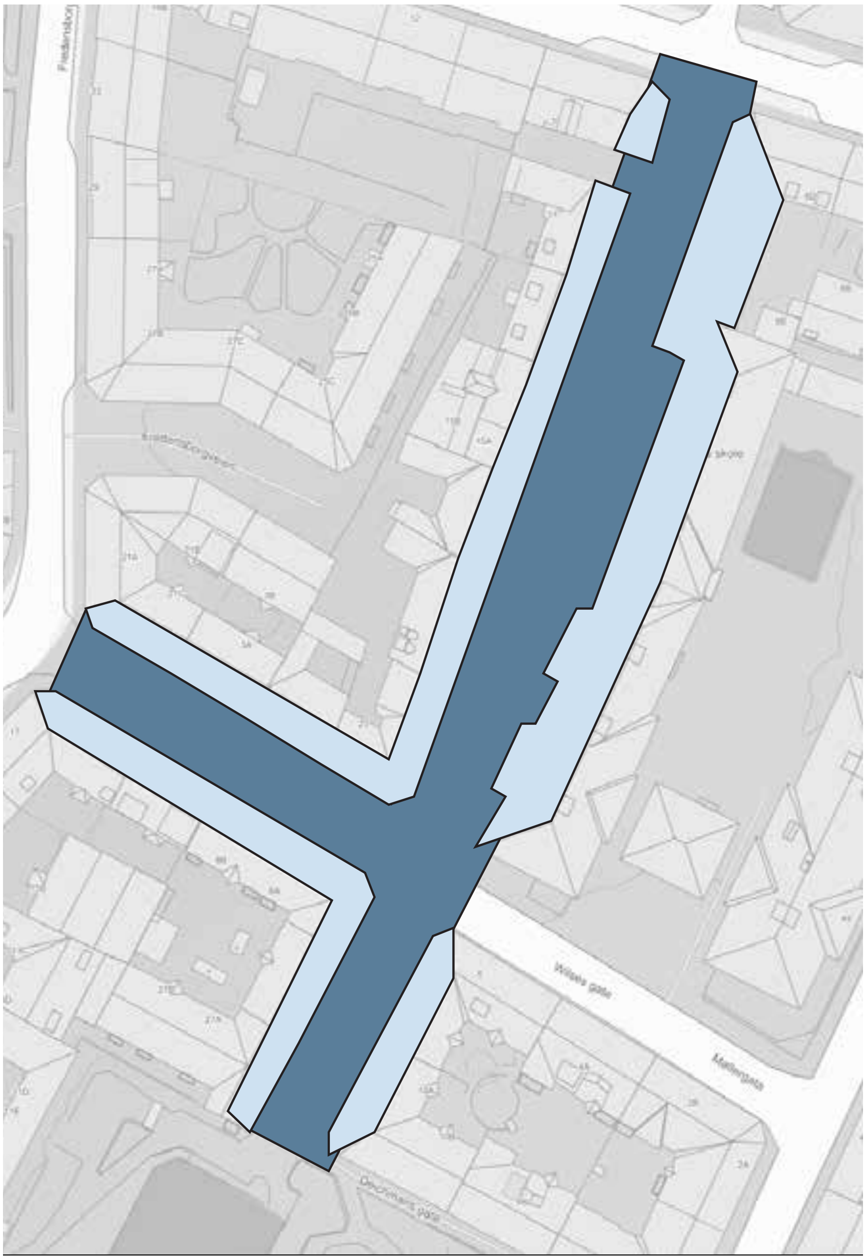


Fig. 5.9 Rain catchment area.

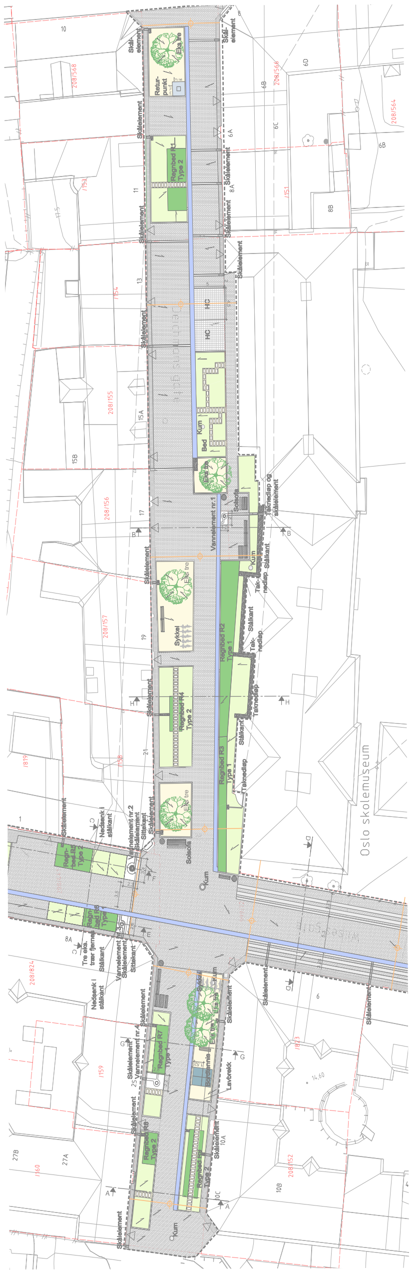
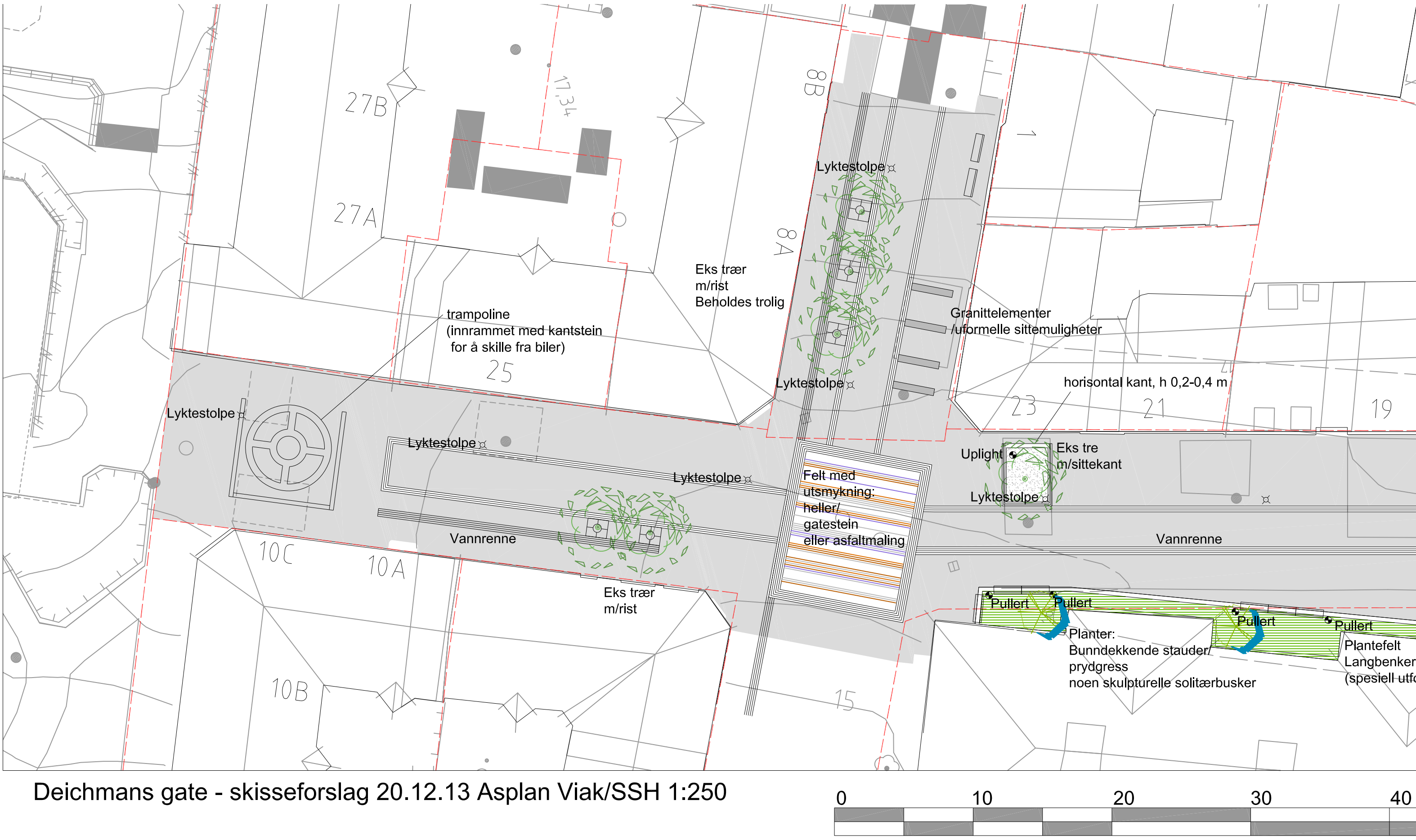


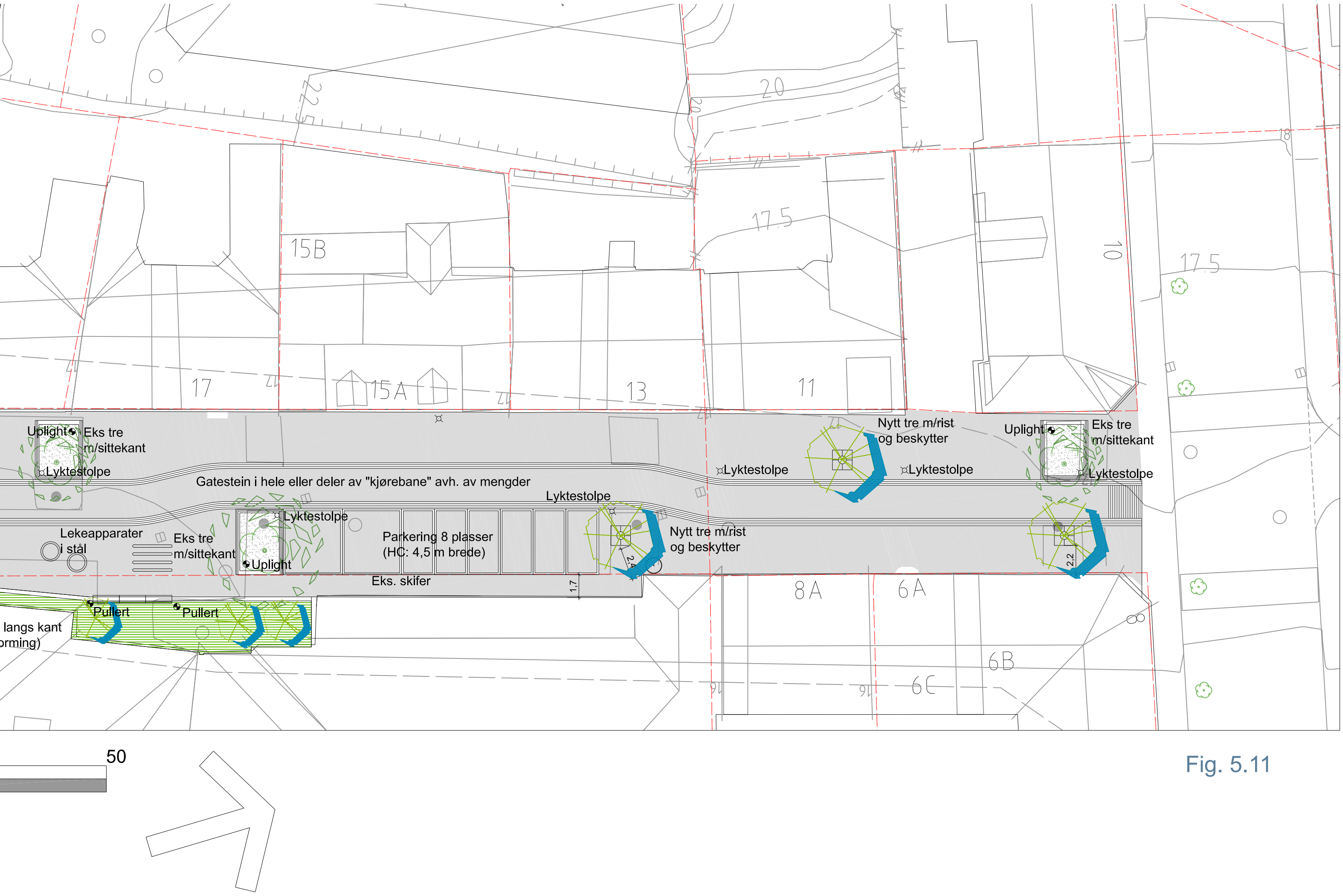
Fig. 5.10 Rain gardens in the rain catchment area of Deichman's street.

TRADITIONAL GREY STORMWATER MANAGEMENT SOLUTIONS



Deichmans gate - skisseforslag 20.12.13 Asplan Viak/SSH 1:250

The first draft for the street renewal project, before local authorities decided to make it a pilot project for surface water management. This proposal features a traditional underground water storage magazine, and no new planted areas or rain gardens, The street surface remains impermeable, and no efforts are made to handle stormwater locally.


Uplight
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Gatestein i hele eller deler av "kjørebane" avh. av mengder
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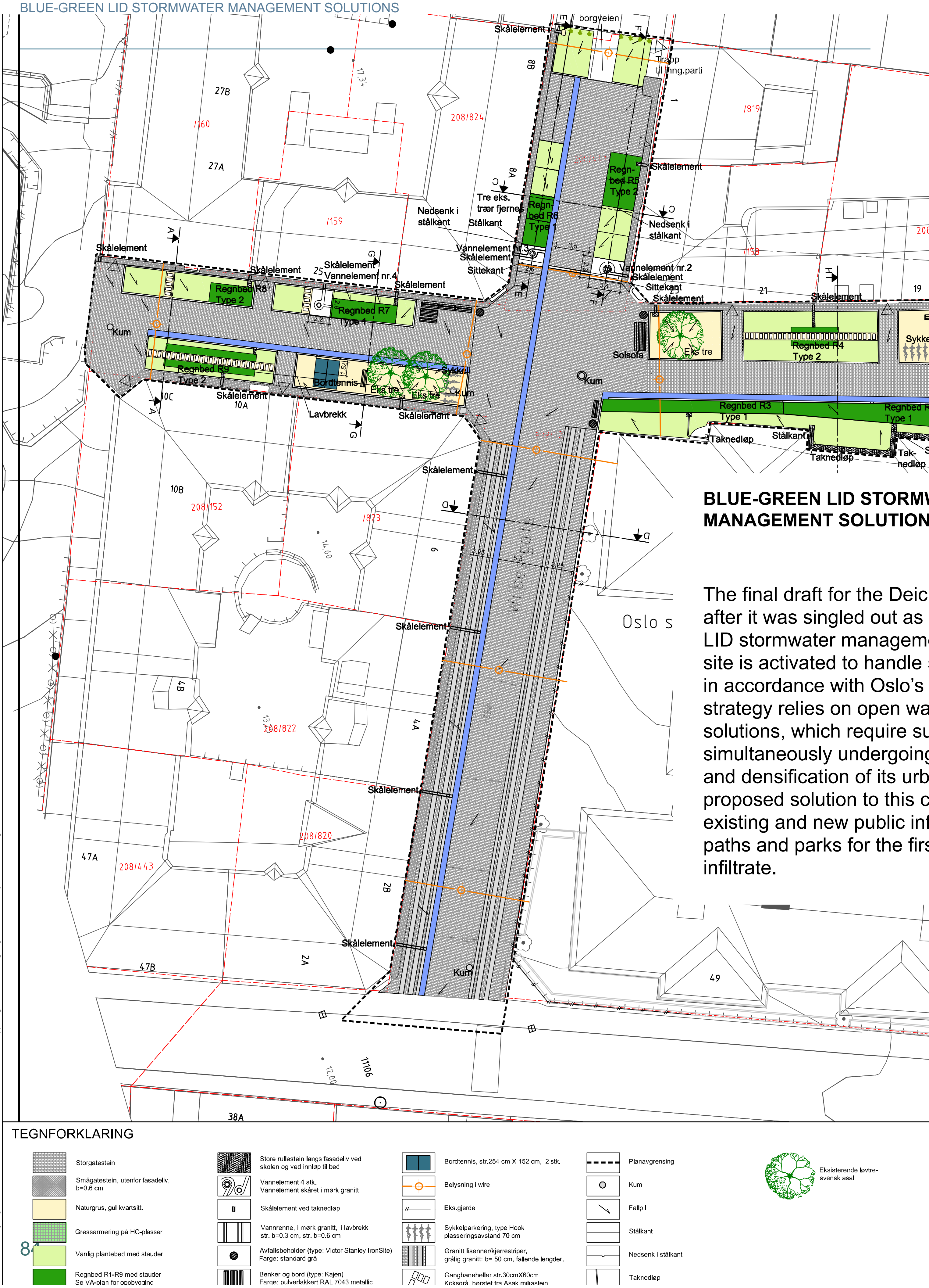
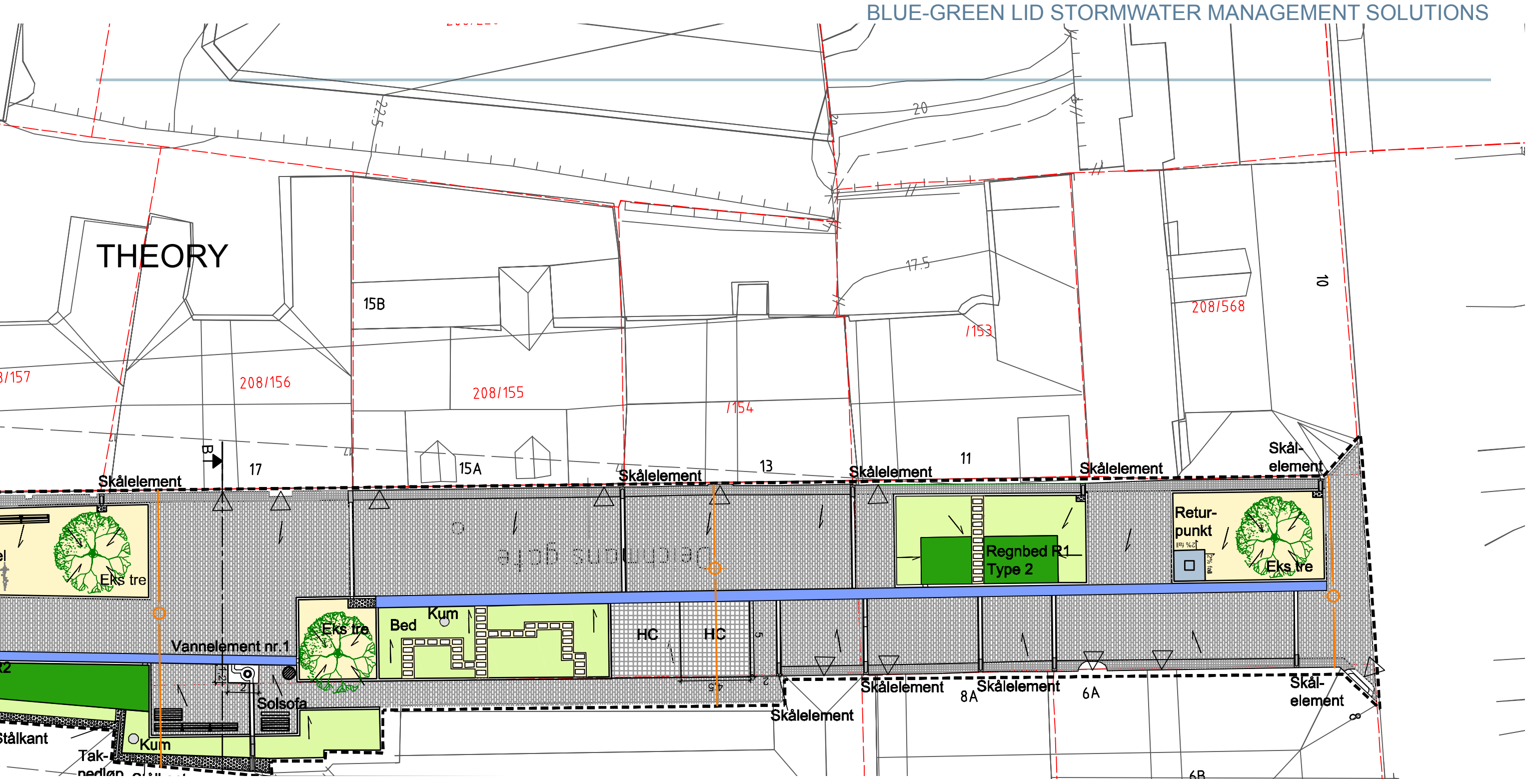
Fig. 5.11



BLUE-GREEN LID STORMW
MANAGEMENT SOLUTION

The final draft for the Deic
after it was singled out as
LID stormwater manageme
site is activated to handle
in accordance with Oslo's
strategy relies on open wa
solutions, which require su
simultaneously undergoing
and densification of its urb
proposed solution to this c
existing and new public inf
paths and parks for the firs
infiltrate.

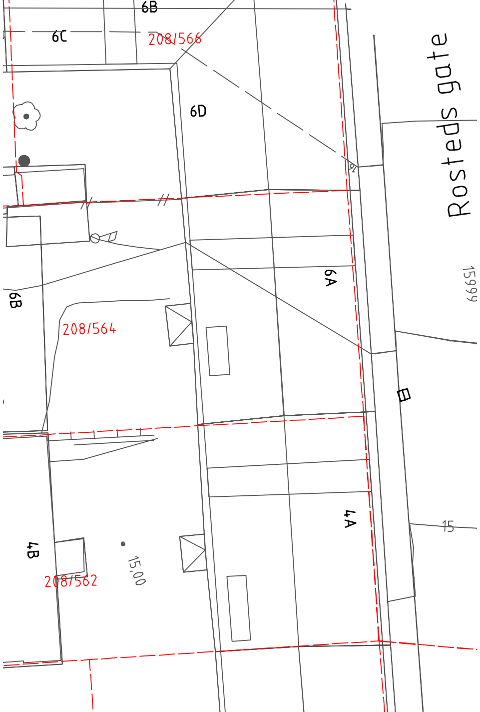
THEORY



WATER
S

hman's street project a pilot project for ent. Now the entire stormwater on-site, 3-step strategy. The ter-management urface area. Oslo is g rapid urbanization an centre. One hallenge is to use frastructure such as st stage, catch and

The second stage, delay and retain, is intended for heavier rainfall. The Deichman's street project covers the first two steps of the city's strategy on site as it comprises rain gardens, trees, and permeable surfaces. It follows the thrid stage of safely leading water along flood routes by leading overflowing water in gutters along Deichman's and Wilse's street.



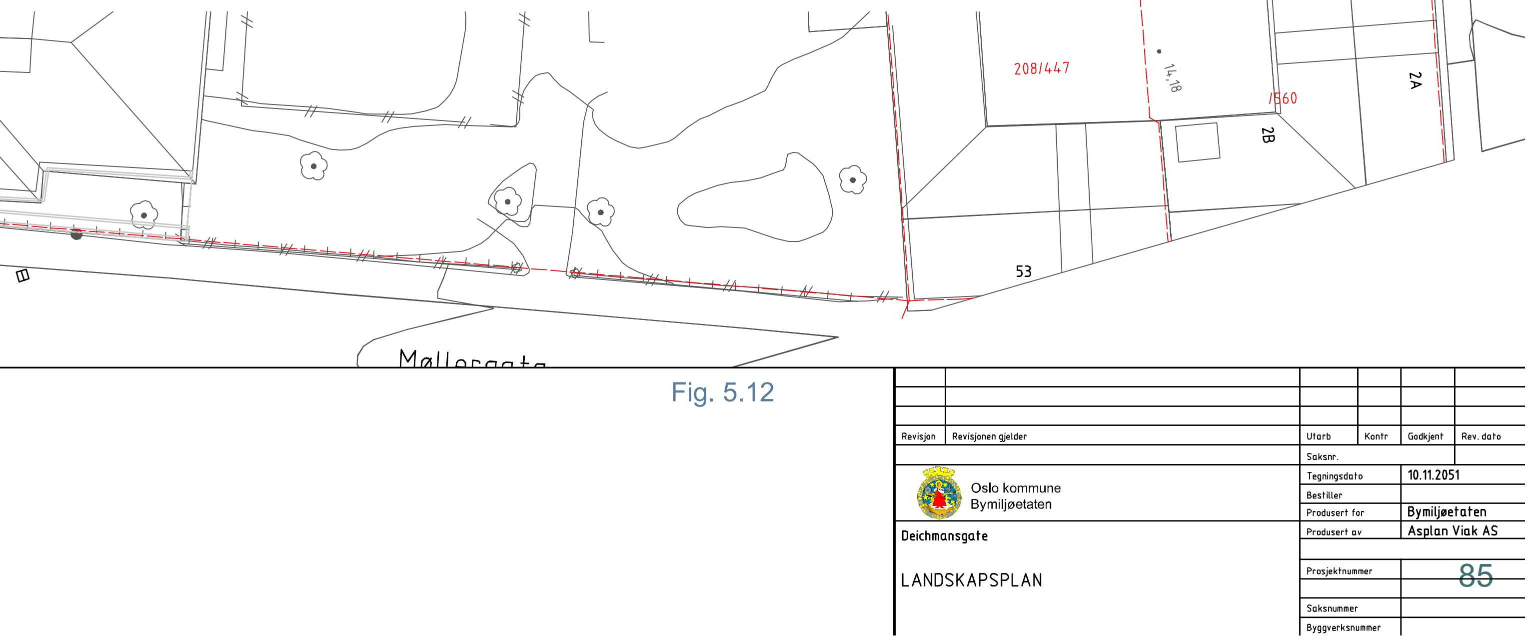


Fig. 5.12

RAIN GARDENS

TYPE 1

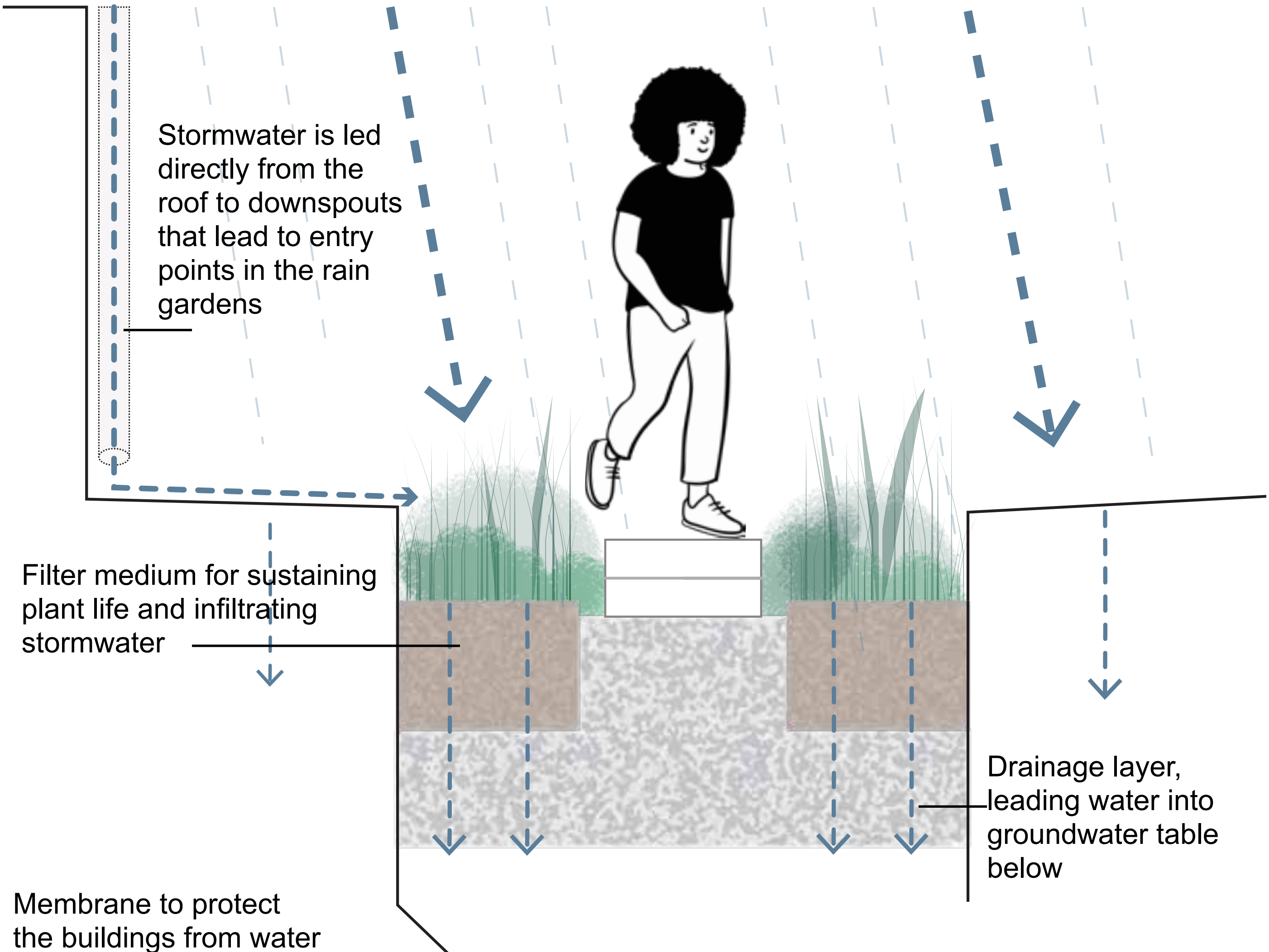
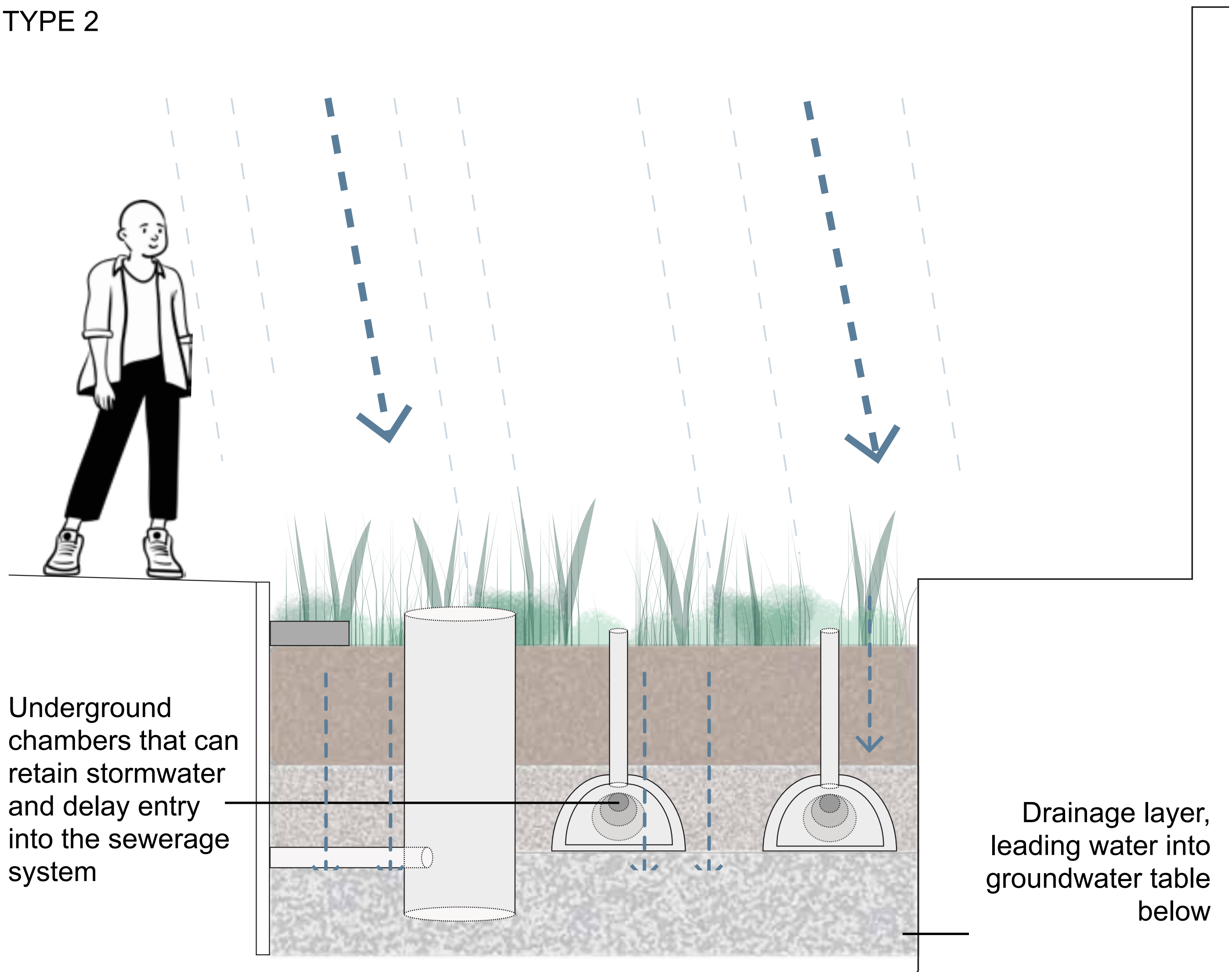


Fig. 5.13

There are two main construction principles for the rain gardens in Deichman’s street. The first version on the left leads surface water directly in to the ground to restore the groundwater levels in the area. The second version on the right is a high-capacity design which captures and stores surface water in underground chambers, only leading water into the sewage system when the chambers overflow.

TYPE 2



Positive: Rain gardens are capable of retaining large amounts of water, and relieving pressure on sewerage systems when it rains.

Aesthetically pleasing during the spring and summer seasons.

Negative: Rain gardens require a significant amount of space.

They are aesthetically and functionally limited during the winter season.

The rain gardens in Deichman's street do not promote native biodiversity.

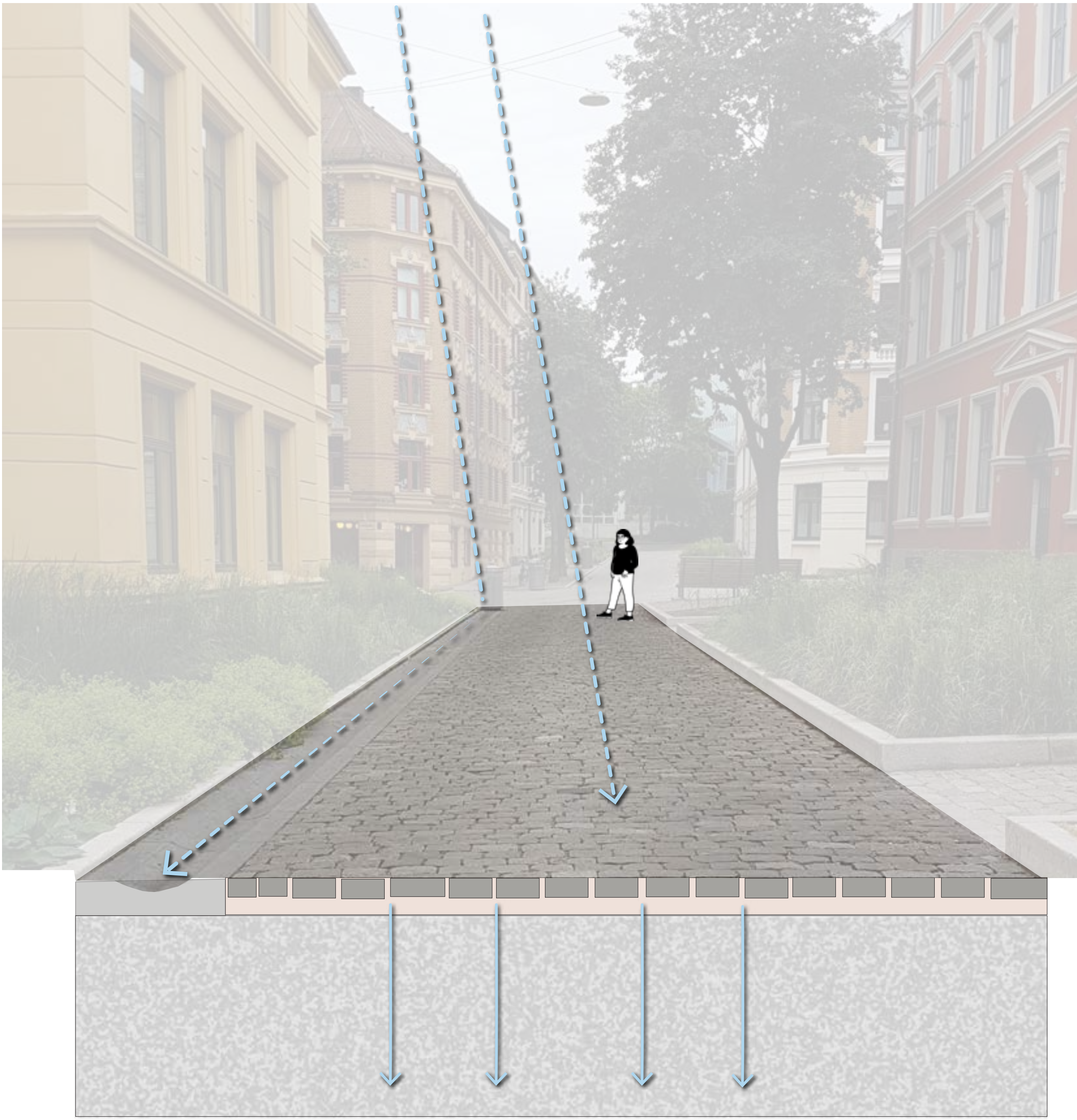
The treadstone paths through the rain gardens nvite foot traffic that adds an extra burden of maintenance.

Fig. 5.14

PERMEABLE SURFACES

COBBLESTONE

Fig. 5.15



The street surface of Deichman’s and Wilse’s street was restored to its original cobble stone surface. The cobbe stones are set in a layer of gravel on top of an infiltrating layer of rocks to allow infiltration of stormwwater directly into the ground below, maintaining groundwater levels in the area.

Positive:

Historically accurate and aesthetically compatible with its surroundings.

Provides a strengthened sense of identity for the area that connects the streets visual and historical identity with the surrounding buildings.

Indicate a mobility hierarchy that places pedestrians above vehicles and forces a shared-space approach to using the street.

Negative:

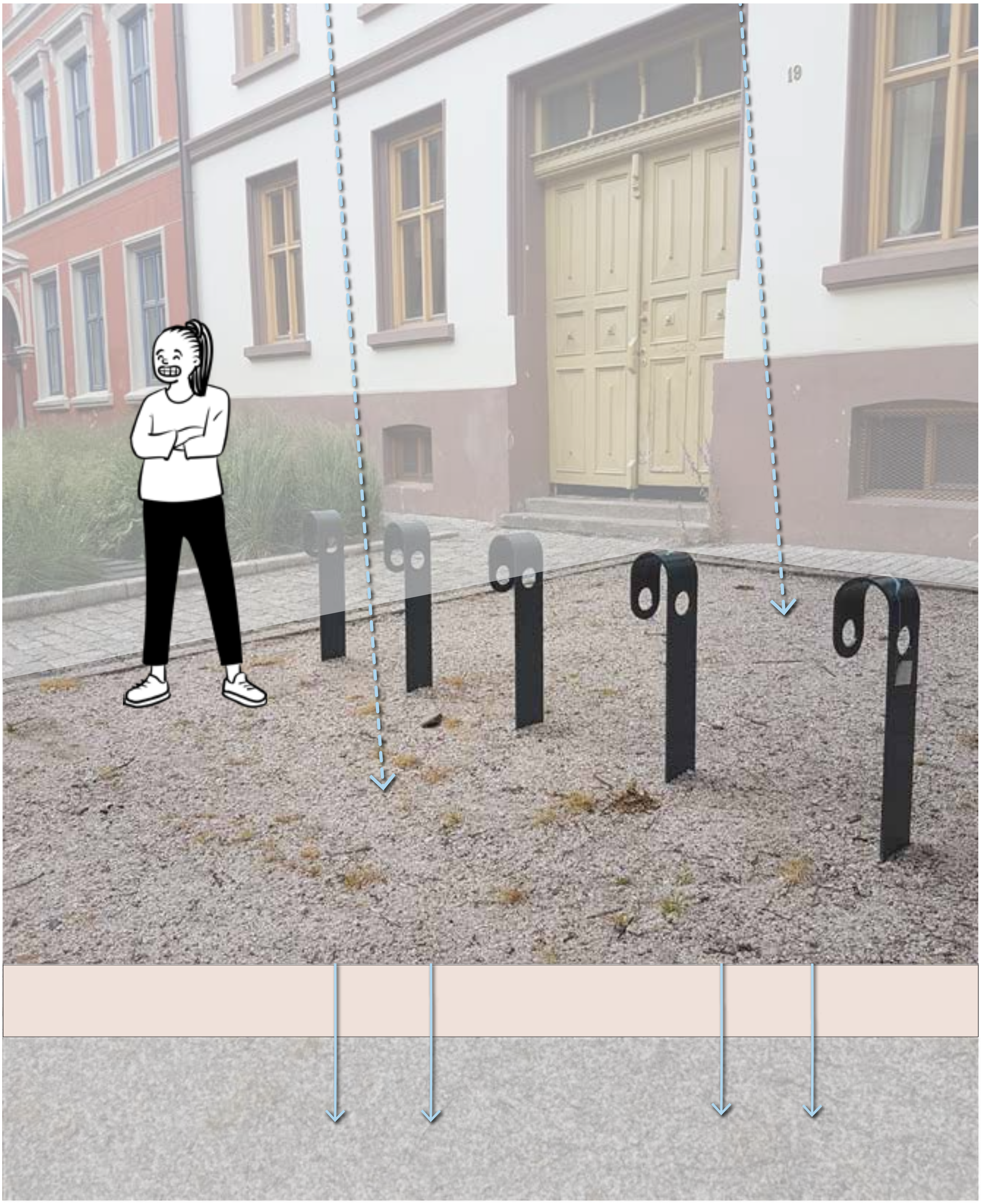
Filling the entire breadth of the street with cobble stone significantly reduces mobility for a wide user base, and does not encourage cycling, which is one of Oslo’s climate strategy goals.

Gravel between cobble stones is easy target for weeds and can also be flushed out during heavy rainfall or other high pressure events.

PERMEABLE SURFACES

GRAVEL

Fig. 5.16



The use of gravel as an infiltrating permeable surface is implemented under all the existing trees in Deichman’s street, the bicycle stands and furnished gathering points.

Positive: The gravel infiltrates a higher volume of water than impermeable surfaces, and connects to the historical identity of the street in a visually meaningful way.

Gravel is easily replaced or replenished as needed.

Negative: The gravel is not the most popular choice with residents, aesthetically.

Large volumes are transported along the granite gutters during precipitation events, rendering the gutters less effective.

The gravel is an easy target for weeds and require regular maintenance.

The gravel can potentially become impenetrable for water during the winter season if the ground freezes solid.

LEADING WATER

GRANITE GUTTERS

Fig. 5.17

The granite gutters along Deichman's and Wilse's street are part of the city's 3-step strategy for stormwater management, and are there to ensure that water is led safely and effectively to the rain gardens or along the designated flood routes during heavier rainfall. They also work to lead water efficiently from the downspouts in to the rain gardens and are a useful measure for light to moderate rainfall.

However, they are very easily blocked by debris, especially falling leaves from the asal trees during autumn, and gravel during heavier rainfall.

Not deep enough and to sharply angled to handle extreme water flows (see image)

LEADING WATER

WATER FEATURES

Fig. 5.18

The solid granite water features in Deichman’s street are an interactive way to visualize the hydrological cycle while leading water along safe flood routes and into the rain gardens.

Positive: They create an element of play for water during precipitation events.

Add a sculptural element to the street which can increase its aesthetic value.

Negative: The features were seen by residents as anonymous.

Not included in the initial three-year maintenance contract and therefore rarely cleaned

With the standing water left in the bottom of each features, they are a potential site for larvae (flies, mosquitoes etc) as they do not drain.

Their placement on ground level, make them less accessible.

GEHL'S 12 QUALITY CRITERIA

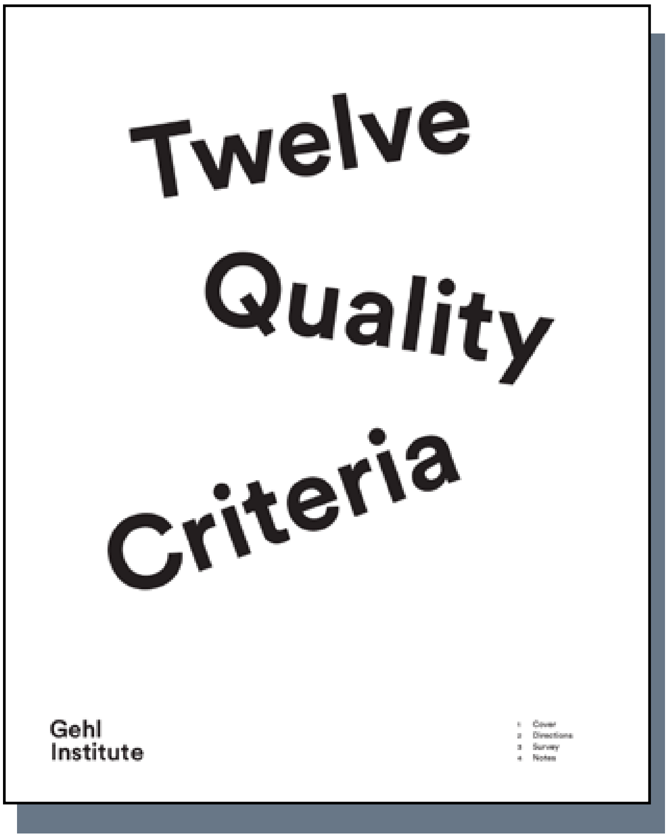


Fig. 5.19 Gehl architects, 2018.

Landscape architects need to consider the rooms of the outdoor spaces they design, and work to create visually pleasing sequences and spaces throughout the city. By examining before and after photos from Deichman's street, visual aspects of the upgrade can be assessed, to an extent. While the buildings on Deichman's street form the main visual frameworks, trees, foliage and other installations can also contribute to the sight lines, perspectives and new spaces.

In order to measure the effect of the upgrade in terms of impact on the area/visually and functionally, I have chosen to use Jan Ghel's 12 urban quality criteria. This is a method of visual evaluation for spaces which covers the topics protection, comfort and enjoyment (Gehl institute, 2018). Observations were made during the summer of 2019. Using these criteria is a helpful exercise in design analysis- how does the chosen design perform?

The method used is direct observation. Sitting or standing in the space and then evaluating, giving each criterium a score from 1 to 3, where 1 signifies 'no', 2 signifies 'in between' and 3 signifies 'yes'.

While the situation being assessed is the 'after' situation, pictures of the 'before' situation are provided for context.

TWELVE URBAN QUALITY CRITERIA

LOCATION: DEICHMAN'S STREET, OSLO, NORWAY

AVERAGE SCORE: 2,4

3 = **YES**
2 = **IN BETWEEN**
1 = **NO**

Protection	**Protection against traffic and accidents.** Do groups across age and ability experience traffic safety in the public space? Can one safely bike and walk without fear of being hit by a driver? 3	**Protection against harm by others.** Is the public space perceived to be safe both day and night? Are there people and activities at all hours of the day because the area has, for example, both residents and offices? Does the lighting provide safety at night as well as a good atmosphere? 2	**Protection against unpleasant sensory experience.** Are there noises, dust, smells, or other pollution? Does the public space function well when it's windy? Is there shelter from strong sun, rain, or minor flooding? 3
Comfort	**Options for mobility.** Is this space accessible? Are there physical elements that might limit or enhance personal mobility in the forms of walking, using of a wheelchair, or pushing a stroller? Is it evident how to move through the space without having to take an illogical detour? 1	**Options to stand and linger.** Does the place have features you can stay and lean on, like a façade that invites one to spend time next to it, a bus stop, a bench, a tree, or a small ledge or niche? 3	**Options for sitting.** Are there good primary seating options such as benches or chairs? Or is there only secondary seating such as a stair, seat wall, or the edge of a fountain? Are there adequate non-commercial seating options so that sitting does not require spending money? 3
Comfort	**Options for seeing.** Are seating options placed so there are interesting things to look at? 2	**Options for talking and listening/hearing.** Is it possible to have a conversation here? Is it evident that you have the option to sit together and have a conversation? 3	**Options for play, exercise, and activities.** Are there options to be active at multiple times of the day and year? 1
Enjoyment	**Scale.** Is the public space and the building that surrounds it at a human scale? If people are at the edges of the space, can we still relate to them as people or are they lost in their surroundings? 3	**Opportunities to enjoy the positive aspects of climate.** Are local climatic aspects such as wind and sun taken into account? Are there varied conditions for spending time in public spaces at different times of year? With this in mind, where are the seating options placed? Are they located entirely in the shadows or the sun? And how are they oriented/placed in relation to wind? Are they protected? 3	**Experience of aesthetic qualities and positive sensory experiences.** Is the public space beautiful? Is it evident that there is good design both in terms of how things are shaped, as well as their durability? 2

3

Fig. 5.20 Gehl architects, 2018.

Photo. 5.23 *Before: looking south towards Krist park.*

Photo. 5.24 *After: Rain garden 2 visible to the right side of the image. An extended stretch of gravel has been added on the left side of the street,.*

Photo. 5.25 *Before: looking east down Wilse's street, with Møllergata school on the left.*

Photo. 5.26 *After: the historic wrought iron fence and carriage tracks in the cobblestone street have been recreated. Several trees have been removed to restore the sidewalk and street widths.*

Photo. 5.27 *Before: looking north torwards Rosted's street.*

Photo. 5.28 *After: the existing green structures have been extended and converted to rain gardens, while remaining surface areas have been made permeable through the use of gravel and cobbelstones.*

Photo. 5.29 *Before: looking south from Idun's street.*

Photo. 5.30 *After: Rain garden 7(?) visible on the right side of the street. Also visible is one of several granite gutters leading to the rain gardens.*

Photo. 5.31 *Before: looking south with Møllergata school on the left. Visible standing water in the parking space in the left-hand corner and a clear low point along the middle of the street.*

Photo. 5.32 *After: surface water from the roof on the right is led to a gutter which feeds in to the rain garden (?) on the left.*

Photo. 5.33 *Before: looking west along Wilse's street towards Fredensborgveien.*

Photo. 5.34 *After: Three trees have been removed and replaced with tiered rain gardens and stone sculptures.*

SUMMARY

This section adresses the following secondary research question:

How is Oslo working to implement LID stormwater management?

This section examines the design choices made in the Deichman's street project and evaluates them based on Jan Gehl's 12 'human' criteria, as well as from a design perspective. The project as a whole is explained, with a closer look at the history of the project and its developments over time. Each of the stormwater management elements are described and assessed in terms of functionality, maintenance and aesthetic qualities, in order to give a thorough assessment of the project.

For its intended purposes of handling stormwater on-site in accordance with Oslo's three step strategy, the Deichman's street project performs well.

It's shortcomings are in its lack of multifunctional spaces and its reduced accessibility for pedestrians and cyclists (cobblestones).

However, in terms of its performance for people, the project has high overall score when assessed using Gehl's 12 criteria. The street has been transformed to a welcoming space, at least during the summer months, that prioritizes people over motorized vehicles.

Photo. 5.35

6

CASE STUDY RESULTS

This section adresses the following secondary research question:

How is Oslo working to implement LID stormwater management?

INTRODUCTION

This chapter will talk about the infiltration capacities of the 9 rain gardens and soil composition of earch rain garden. It will introduce and explain the MPD method, and use tables from excel to explain the performance of the individual rain gardens.

MODIFIED PHILLIP-DUNNE INFILTROMETER (MPD)

What do landscape architects need to know about infiltration capacities?

Closer to the engineering side of design, but important to know the principles and theory as it affects soil composition, plant choice, design and even size of rain garden/infiltration area.

Water infiltrates soil, and drains through.

To measure

MPD- description of method

MPD (Modified Pillip-Dunne Infiltrometer) is a method used to measure soil's hydroconductivity in an area (on the surface) by recording changes in water depths over time.

This method of measuring was chosen for Deichman's street because of it's relative simplicity.

How it works: a clear tube roughly 50 cm tall with an inner diameter of approx. 10 cm is required, with a measuring tape fastened to the outside of the tube.

Equipment: MPD tubes, small shovel, stopwatch or smart phone with stopwatch functionality, a rubber mallet, writing supplies.

1. Choose the site for the MPD tube and avoid placing it too close to pipes or other elements that can affect infiltration. In recording the infiltration capacities of the rain gardens in Deichman's street, an attempt was made to recreate the locations used in 2018 testing. However, the measurements given for site location were often inconsistent or non-existent, so a conscious effort was made to include entry points, middle sections and corners during our testing.

2. Remove an earth sample by digging and mixing soil from the top 5cm layer of soil, near the placement of the MPD tube. Label and set aside. This is an important step when looking at later results, when the soil sample is analyzed, a correction factor is applied to the infiltration rates to give a more accurate picture of them based on the soil composition (sand, clay etc will affect infiltration rates, so it is important to know if the soil is affecting infiltration or something else in the rain garden like aggregation, compaction etc).

3. Remove any large debris from the surface test site that would otherwise affect infiltration results. Using your hands (if soil is soft) or the rubber mallet, drive the tube approximately 5 cm in to the soil.

4. Fill the tube up with water and record the results- how much water has infiltrated in terms of cm- at a set time interval (for instance every 30, 60 or 120 seconds).

6. Once you receive the same result over a given period of time, the soil is saturated, and the results can be processed.

7. Apply the correction factor from the soil testing to the infiltration results to get a more accurate reading.

Photo 6.1 MPD infiltration testing tube.

RAIN GARDEN 1

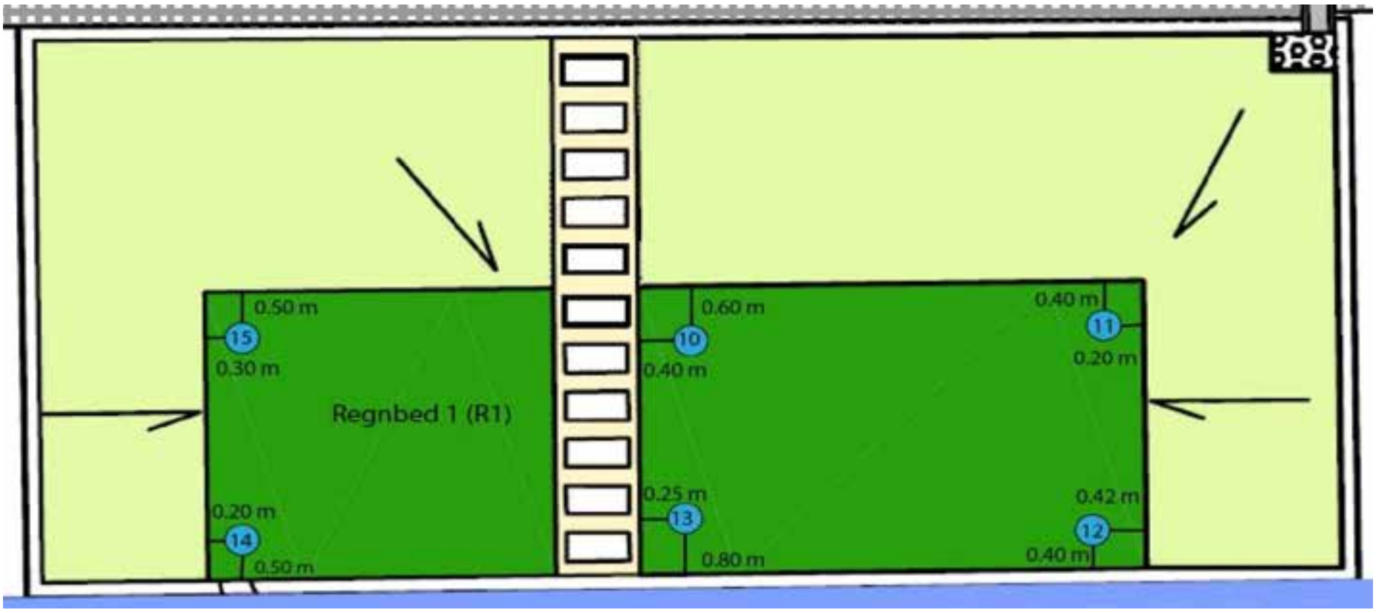


Fig. 6.1

Rain garden 1 is a type 2 rain garden (p.100) as shown in figure 6.1. Infiltration capacity testing was conducted June 24th, 2019 at six selected points of measurement. The results displayed in Table 6.1.a reveal that the highest rate of infiltration/infiltration speed was at the inlet/entrance to the rain garden, point DR10, fig 6.1, while measurement points further away had lower infiltration speeds/rates.

Measuring point	Rate of infiltration (cm/hr)	Ksat
DR10	120	96
DR11	30	24
DR12	24	19,2
DR13	30	24
DR14	120	96
DR15	30	24

Photo 6.2 MPD infiltration testing in rain garden 1

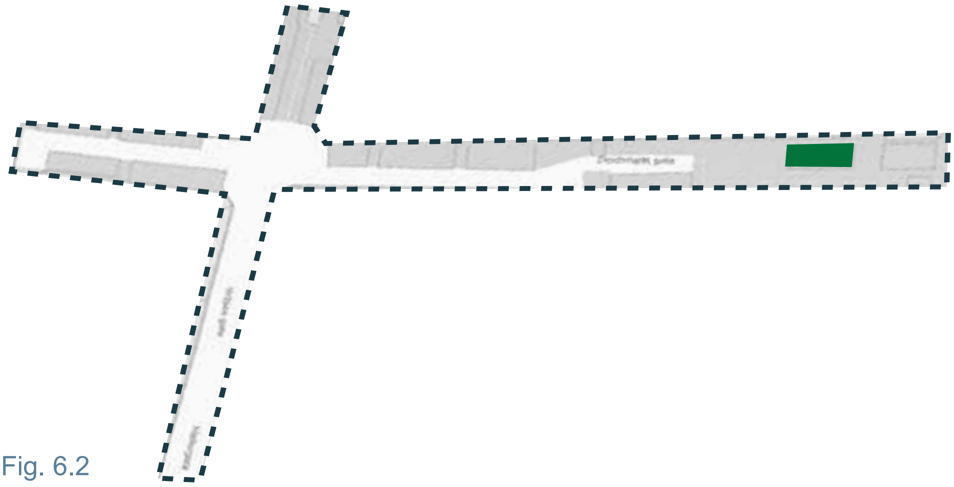


Fig. 6.2

Plants in rain garden 1

(Am) Alchemilla mollis

(CaO) Calamagrostis x acutiflora ‘Overdam’

(CmI) Carex morrowi 'Ice Dance’

(DcG) Deschampsia cespitosa ‘Goldschuleier’

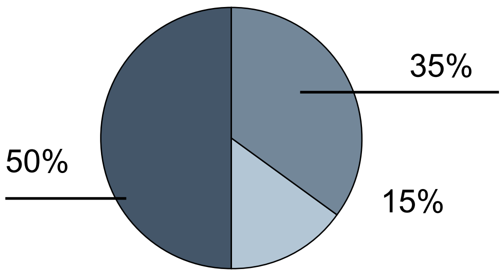
(HR) Helenium ‘Rubinzwerg'

(Sa) Sesleria autumnalis

(SoP) Sanguisorba officinalis ‘Purpurea’

(StW) Sanguisorba tenuifolia 'White Tanna

Fig. 6.3 Soil composition



Intended filter medium: 15% Oslo compost, 35% peat, 50% sand fraction 0,6-2mm.

RAIN GARDEN 2

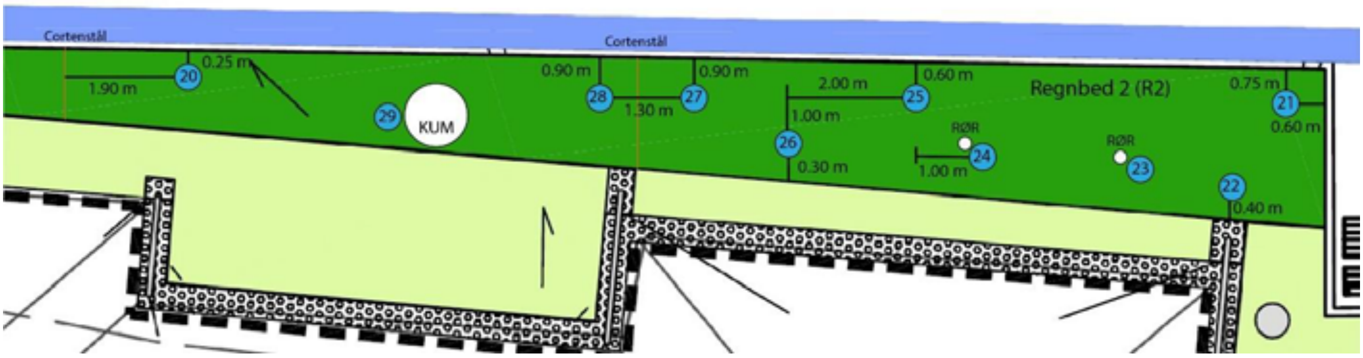


Fig. 6.4

Rain garden 2 is a type 1 rain garden (p. 98) as shown in figure 6.4. Infiltration capacity testing was conducted July 1st, 2019 at ten selected points of measurement. The measurement sites at points of entry are 21, 22 and 28. Measurement sites 23 and 24 are located near groundwater monitoring wells. Rain garden 2 is two-tiered, separated in its midsection by a perforated corten steel plate, which allows water to flow from the higher section of the rain garden to the lower section. The rain garden is also connected to rain garden 3 in a similar manner. The results displayed in Table 6.4.b reveal that the infiltration rates were largely stable with a Ksat of 24 cm/h (corrected value, using a factor of 0,8), with the exception of points 24 (Ksat 48), 25 (Ksat 9,6) and 26 (Ksat 14,4).

Measuring point	Rate of infiltration (cm/hr)	Ksat
DR20	30	24
DR21	30	24
DR22	30	24
DR23	30	24
DR24	60	48
DR25	12	9,6
DR26	18	14,4
DR27	30	24
DR28	30	24
DR29	30	24

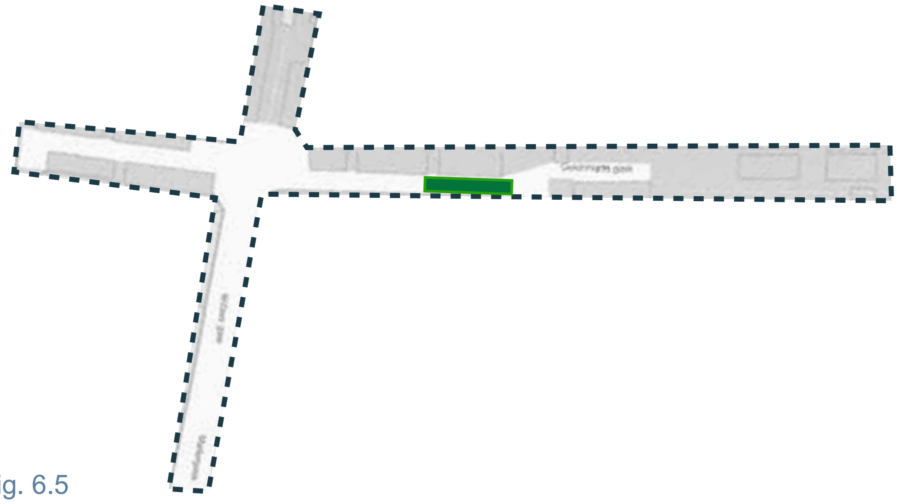


Fig. 6.5

Plants in rain gardens 2 & 3

(Am) Alchemilla mollis

(AmS) Astrantia major ‘Snow star’ -

(AjH) Anemone japonica ‘Honorine Jobert’ white

(CaO) Calamagrostis x acutiflora ‘Overdam’

(DcG) Deschampsia cespitosa ‘Goldschuleier’

(EpW) Echinacea purpurea ‘White Swan’

(Gr) Geranium renardii

(HG) Hosta ‘Guacamole’ - Hosta ‘Guacamole’

(HsE) Hosta sieboldiana ‘Elegans’

(IcB) Iris chrysographes ‘Black form’

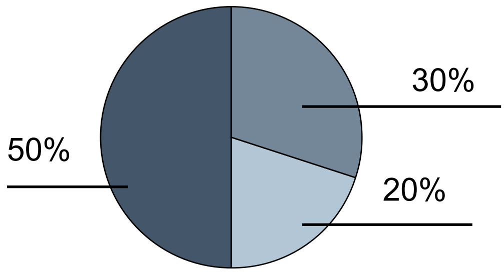
(Iwh) Iris white hybrid

(Ra) Rodgersia aesculifoli

(Sa) Sesleria autumnalis

(StW) Sanguisorba tenuifolia ‘White Tanna

Fig. 6.6 Soil composition



Intended filter medium: 30% Oslo compost, 20% peat, 50% sand, fraction 0,6-2mm

RAIN GARDEN 3

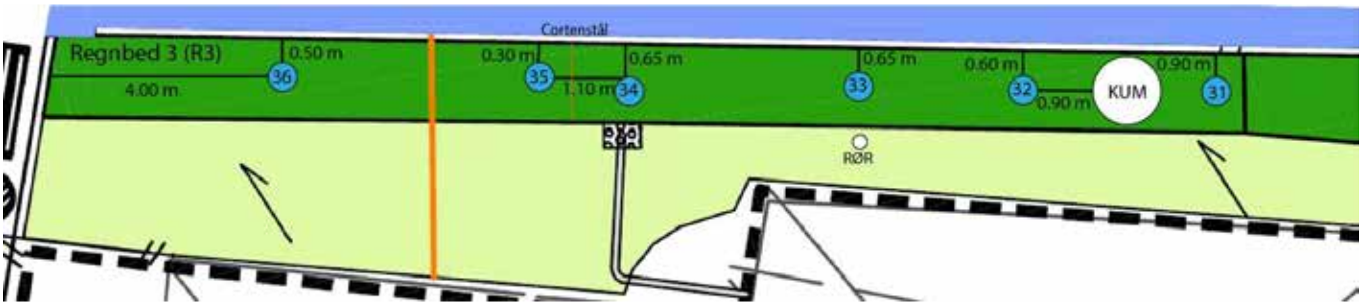


Fig. 6.7

Rain garden 3 is a type 1 rain garden (p. 98) as shown in figure 6.7. Infiltration capacity testing was conducted July 1st, 2019 at six selected points of measurement. The measurement sites at points of entry are 31 and 34. The results displayed in Table 6.7.c show that infiltration was lower at one entrance (measurement point 34) than the other (measurement point 31) by nearly 50%.

Measuring point	Rate of infiltration (cm/hr)	Ksat
DR31	30	24
DR32	60	48
DR33	30	24
DR34	18	14,4
DR35	24	19,2
DR36	18	14,4

Photo 6.3 Infrastructure in the rain garden

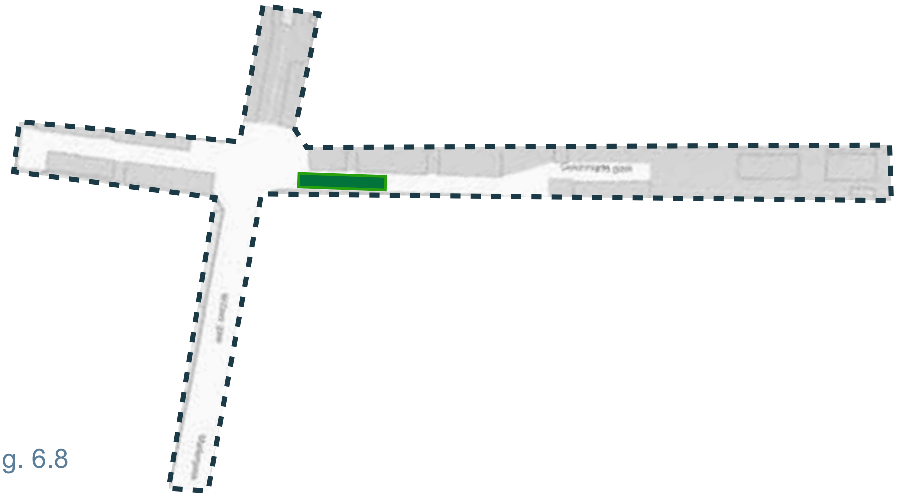
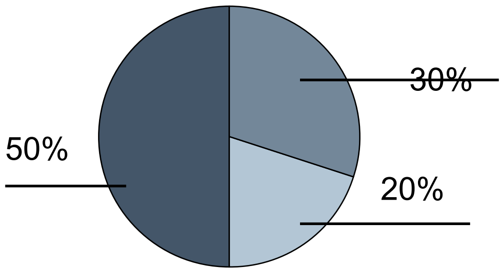


Fig. 6.8

For plant list, see pg. 133

Photo 6.4 Thriving Alchemilla mollis in rain gardens 2 & 3.

Fig. 6.9 Soil composition



Intended filter medium: 30% Oslo compost, 20% peat, 50% sand, fraction 0,6-2mm

RAIN GARDEN 4

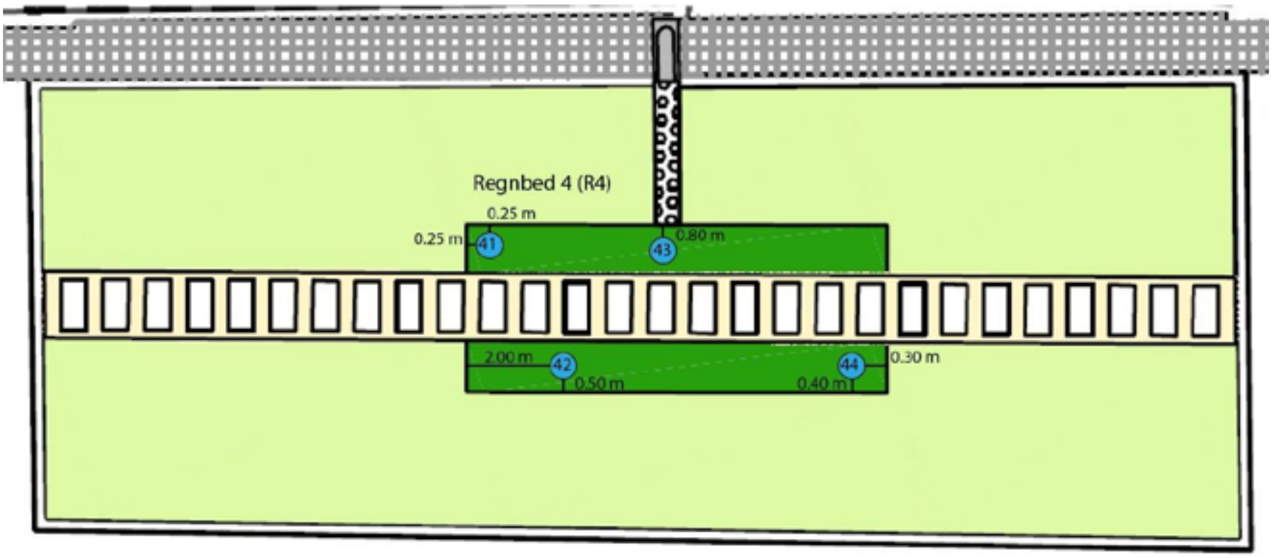


Fig. 6.10

Rain garden 4 is a type 2 rain garden (p. 100) as shown in figure 6.10. Infiltration capacity testing was conducted July 1st, 2019 at four selected points of measurement. The measurement site at a point of entry is 43. The results displayed in Table 6.10.d show that infiltration was high near the entry site and generally high for the entire rain garden.

Measuring point	Rate of infiltration (cm/hr)	Ksat
DR41	60	48
DR42	30	24
DR43	90	72
DR44	120	96

Photo 6.4 MPD-testing in rain garden number 4, the test tube is visible in the bottom left corner of the photo.

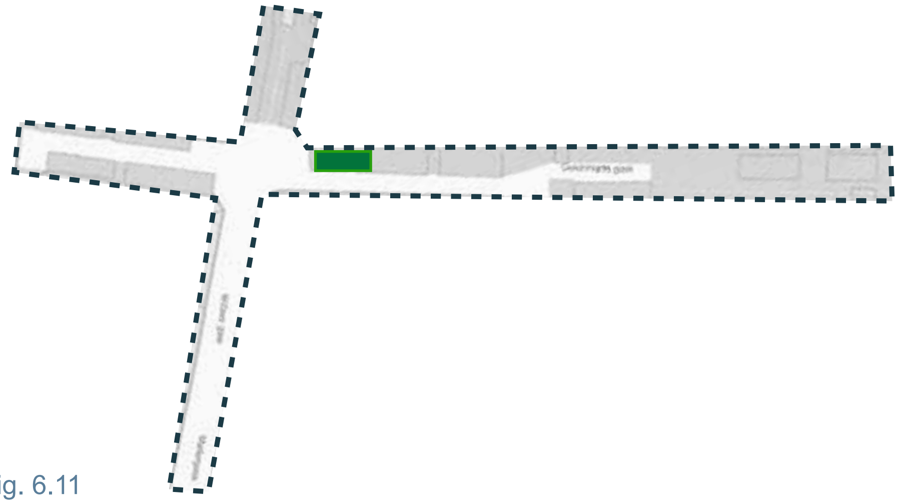


Fig. 6.11

Plants in rain garden 4

(CaO) Calamagrostis x acutiflora ‘Overdam’

(CmI) Carex morrowi ‘Ice Dance’

(DcG) Deschampsia cespitosa ‘Goldschuleier’

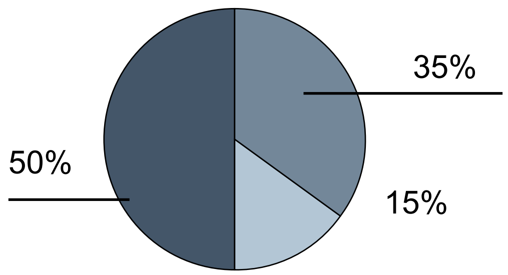
(EgS) Eryngium giganteum ‘Silver Ghost’

(EpW) Echinacea purpurea ‘White Swan’

(Sa) Sesleria autumnalis

(StW) Sanguisorba tenuifolia ‘White Tanna

Fig. 6.12 Soil composition



Intended filter medium: 15% Oslo compost, 35% peat, 50% sand fraction 0,6-2mm.

RAIN GARDEN 5

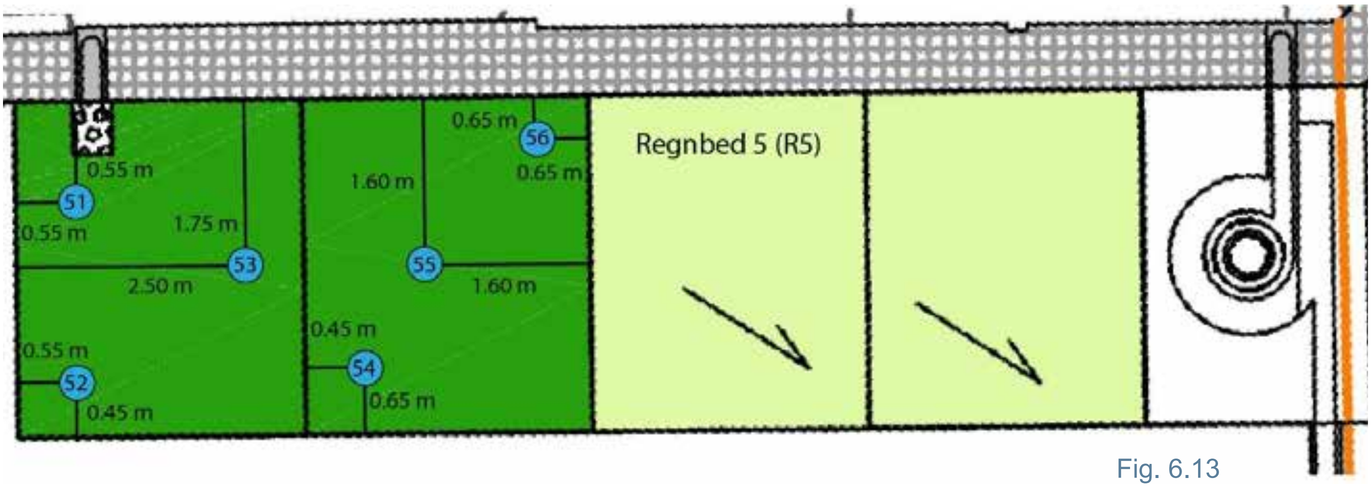


Fig. 6.13

Rain garden 5 is a type 2 rain garden (p.100) as shown in figure 6.13, and is sub-divided into two smaller rain gardens by a similar mechanism as rain garden 2. Infiltration capacity testing was conducted June 24th, 2019 at six selected points of measurement. The measurement site at a point of entry is 51. The results displayed in Table 6.13.e indicate that infiltration was generally good for the entire rain garden and exceptionally high for measurement point 56, which was furthest away from the point of entry. Possible reasons for this high rate of infiltration could be loose/ less compacted soil, poor root development or hidden leaching.

Measuring point	Rate of infiltration (cm/hr)	Ksat
DR51	30	24
DR52	30	24
DR53	60	48
DR54	30	24
DR55	60	48
DR56	300	240

Photo 6.5 MPD-testing in rain garden number 4, the test tube is visible in the bottom left corner of the photo.

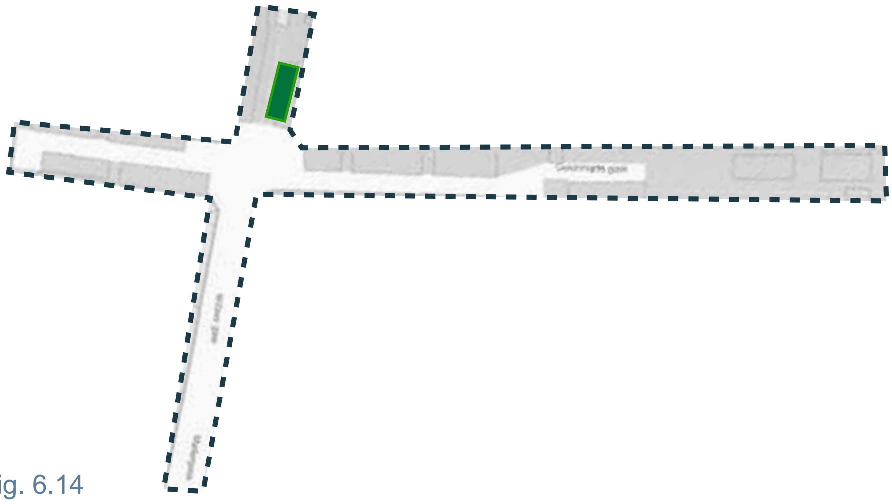


Fig. 6.14

Plants in rain garden 5

(AjH) Anemone japonica 'Honorine Jobert'

(AmS) Astrantia major 'Snow star'

CaO) Calamagrostis x acutiflora 'Overdam'

(CmI) Carex morrowi 'Ice Dance'

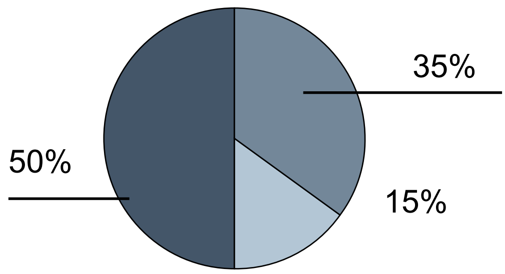
(Eb) Echinops bannaticus

(Gr) Geranium renardii

(HG) Hosta 'Guacamole'

(Iwh) Iris white hybrid

Fig. 6.15 Soil composition



Intended filter medium: 15% Oslo compost, 35% peat, 50% sand fraction 0,6-2mm.

RAIN GARDEN 6

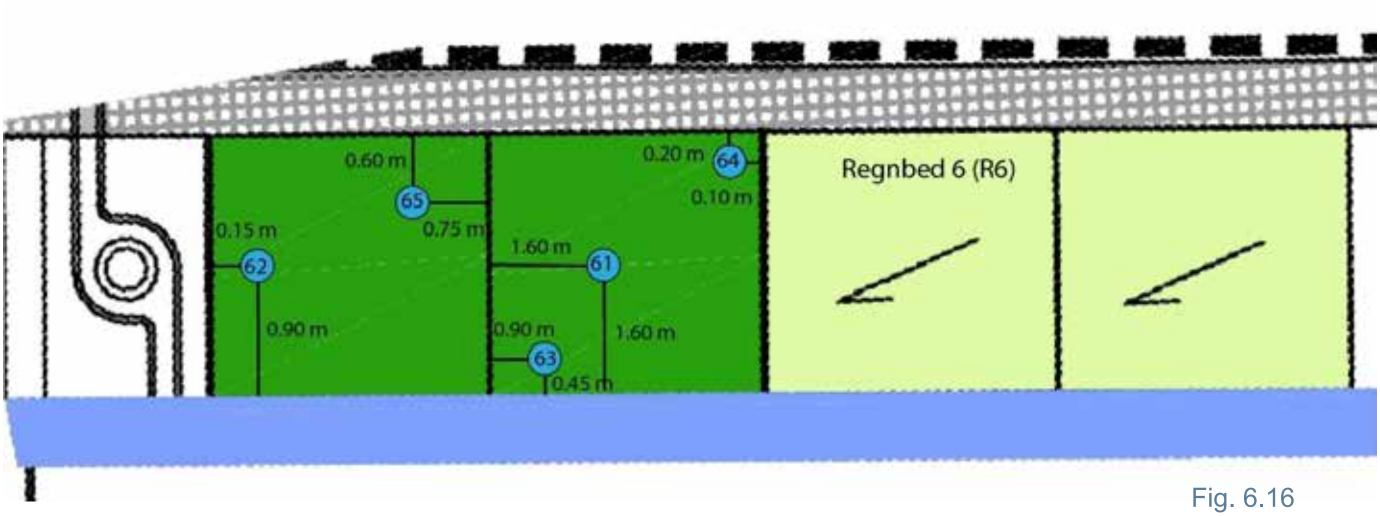


Fig. 6.16

Rain garden 6 is a type 1 rain garden (p.98) as shown in figure 6.16, and is sub-divided into two smaller rain gardens by a similar mechanism as rain gardens 2 and 5. Infiltration capacity testing was conducted June 24th, 2019 at five selected points of measurement. The measurement site at a point of entry is 62. The results displayed in Table 6.16.f are similar to the results in rain garden 5, in the sense that infiltration was generally good for the entire rain garden and noticeably higher for measurement point 64, which was furthest away from the point of entry. away from the point of entry. Possible reasons for this high rate of infiltration could be loose/less compacted soil, poor root development or hidden leaching.

Measuring point	Rate of infiltration (cm/hr)	Ksat
DR61	30	24
DR62	90	72
DR63	60	48
DR64	120	96
DR65	30	24

Photo 6.6 Testing in the lower two sections of the planted area. JRE

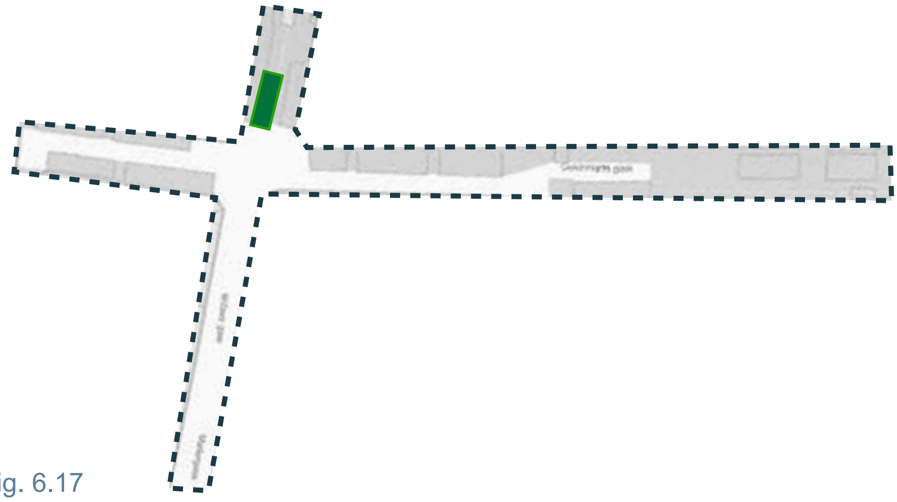


Fig. 6.17

Plants in rain garden 6

(AjH) Anemone japonica 'Honorine Jobert' white

(AmS) Astrantia major 'Snow star'

CaO) Calamagrostis x acutiflora 'Overdam'

(CmI) Carex morrowi 'Ice Dance'

(DcG) Deschampsia cespitosa 'Goldschuleier'

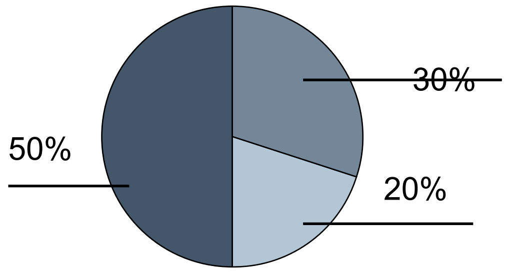
(Eb) Echinops bannaticus

(EgS) Eryngium giganteum 'Silver Ghost'

(Gr) Geranium renardii

(StW) Sanguisorba tenuifolia 'White Tanna

Fig. 6.18 Soil composition



Intended filter medium: 30% Oslo compost, 20% peat, 50% sand, fraction 0,6-2mm

RAIN GARDEN 7

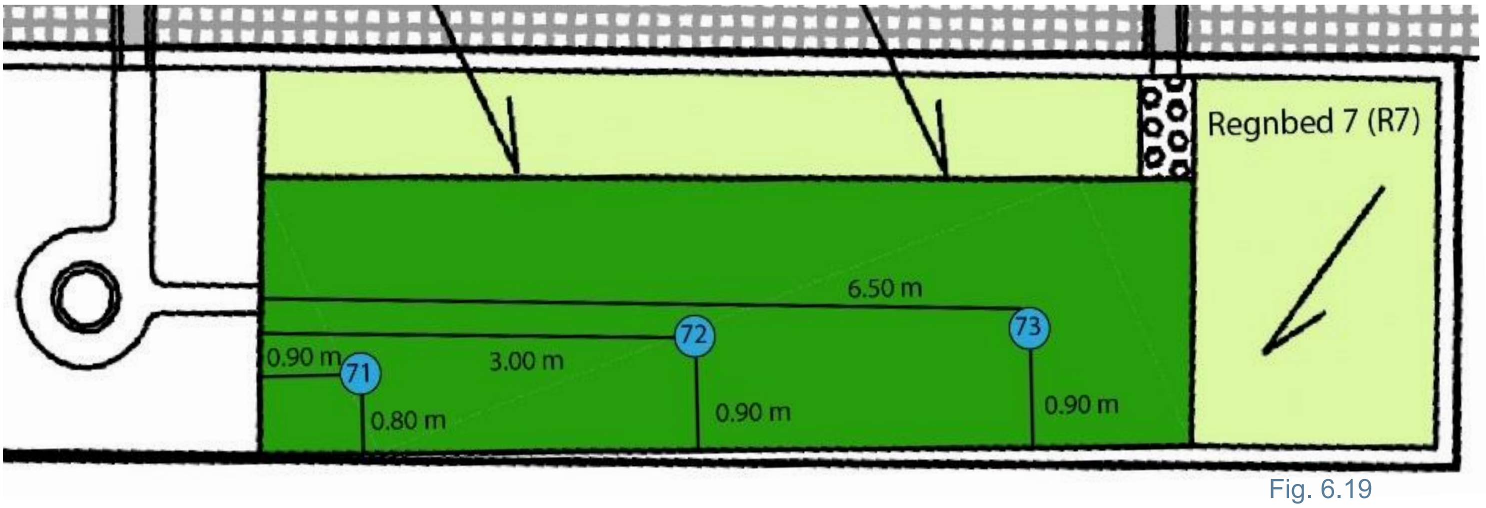


Fig. 6.19

Rain garden 7 is a type 1 rain garden (p. 98) as shown in figure 6.19. Infiltration capacity testing was conducted June 24th, 2019 at three selected points of measurement. The measurement sites at points of entry are 71 and 73. The results displayed in Table 6.19.g show identical rates of infiltration across all three measurement points.

Measuring point	Rate of infiltration (cm/hr)	Ksat
DR71	60	48
DR72	60	48
DR73	60	48

Photo 6.7 What MPD-testing near one of the entry points in rain garden 7 looks like.

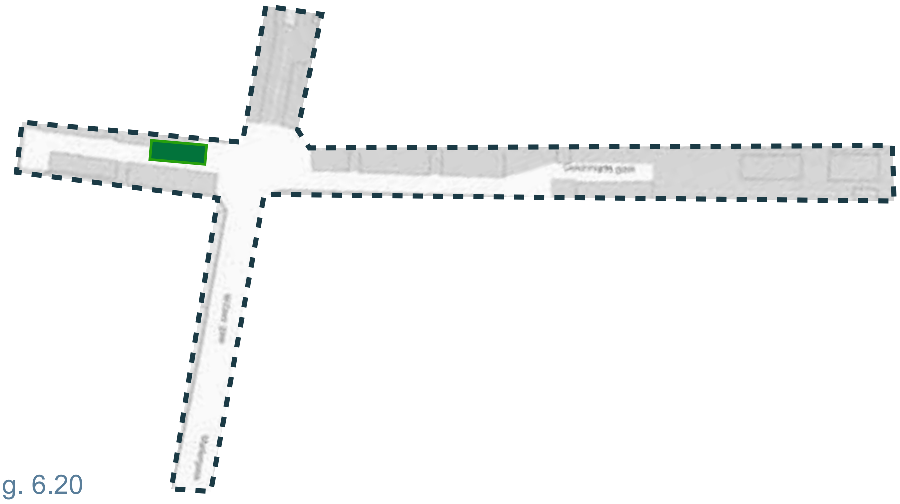


Fig. 6.20

Plants in rain garden 7

(Am) Alchemilla mollis

(CaO) Calamagrostis x acutiflora 'Overdam'

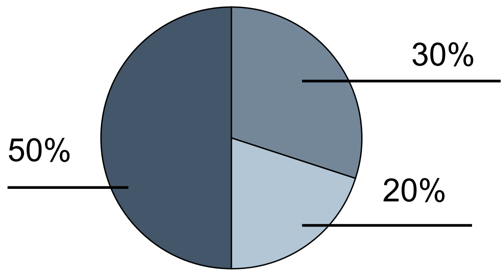
(DcG) Deschampsia cespitosa 'Goldschuleier'

(EgS) Eryngium giganteum 'Silver Ghost'

(Sa) Sesleria autumnalis

(SoP) Sanguisorba officinalis 'Purpurea'

Fig. 21 Soil composition



Intended filter medium: 30% Oslo compost, 20% peat, 50% sand, fraction 0,6-2mm

RAIN GARDEN 8

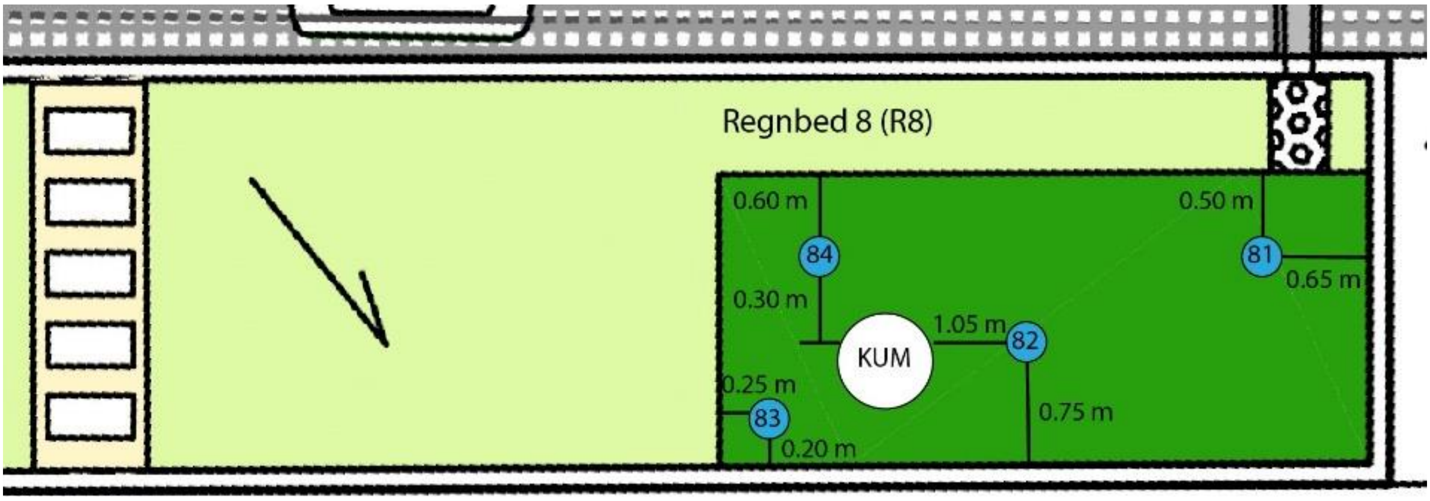


Fig. 6.22

Rain garden 8 is a type 2 rain garden (p. 100) as shown in figure 6.22. Infiltration capacity testing was conducted June 21st, 2019 at four selected points of measurement. The measurement site at a point of entry is 81. The results displayed in Table 6.22.h reveal identical rates of infiltration across three of the measurement points and a higher rate of infiltration at measurement point 83, which is located furthest from a point of entry. Possible explanations for this higher rate of infiltration could be loose/less compacted soil, poor root development or hidden leaching.

Measuring point	Rate of infiltration (cm/hr)	Ksat
DR81	30	24
DR82	30	24
DR83	60	48
DR84	30	24

Photo 6.8 A view of rain garden 8, looking east along Deichman's street. JRE

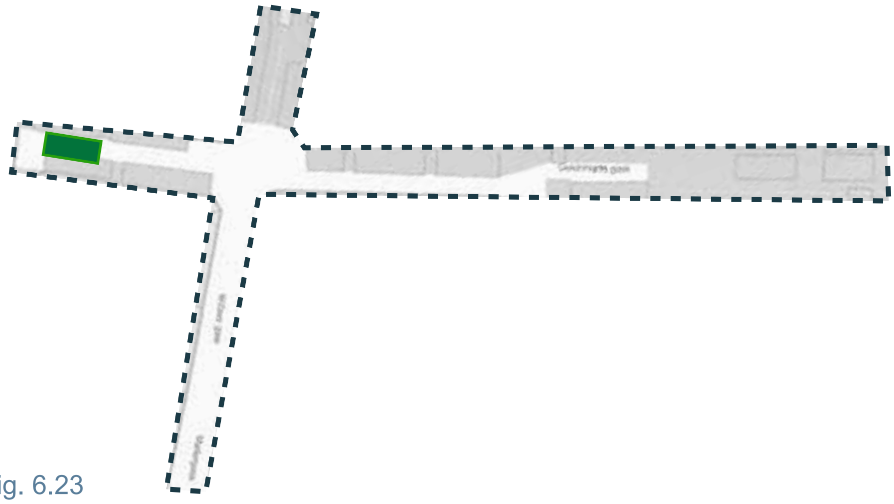


Fig. 6.23

Plants in rain garden 8

(Am) Alchemilla mollis

(CaO) Calamagrostis x acutiflora ‘Overdam’

(CmI) Carex morrowi ‘Ice Dance’

(DcG) Deschampsia cespitosa ‘Goldschuleier’

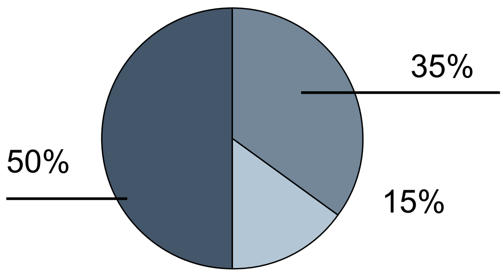
(HR) Helenium ‘Rubinzwerg’

(NrS) Nepeta rasemosa ‘Snowflake’

(Sa) Sesleria autumnalis

(SoP) Sanguisorba officinalis ‘Purpurea’

Fig. 24 Soil composition



Intended filter medium: 15% Oslo compost, 35% peat, 50% sand fraction 0,6-2mm.

RAIN GARDEN 9

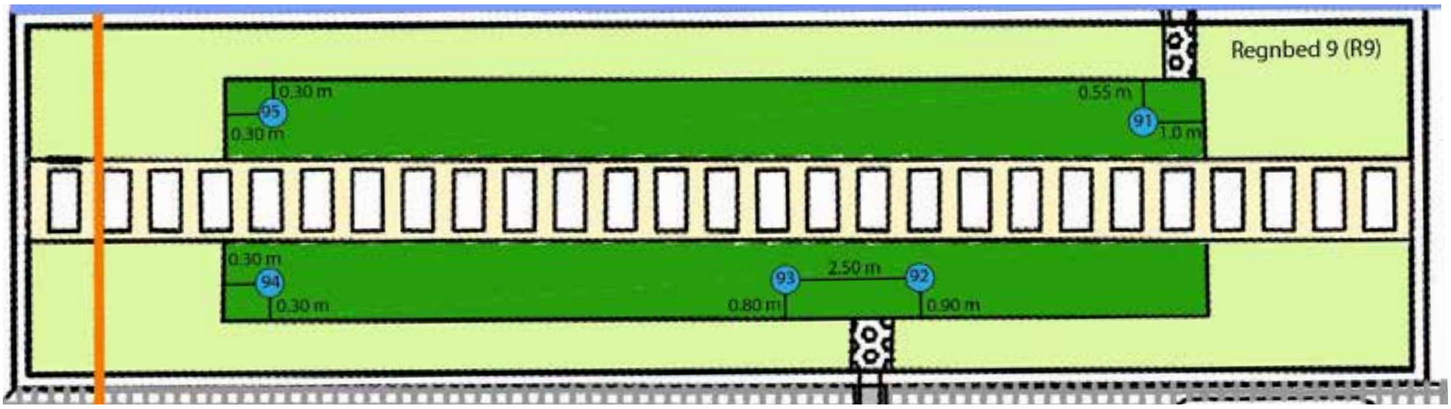


Fig. 6.25

Rain garden 9 is a type 2 rain garden (p.100) as shown in figure 6.25. Infiltration capacity testing was conducted June 21st, 2019 at five selected points of measurement. The measurement sites at points of entry are 91 (entry point 1) 92 and 93 (entry point 2). The results displayed in Table 6.25.i reveal a wide range of infiltration rates for the rain garden, and variations in the infiltration rates near the entry points. The lowest infiltration rate was located near entry point 1.

Measuring point	Rate of infiltration (cm/hr)	Ksat
DR91	6	4,8
DR92	108	86,4
DR93	30	24
DR94	60	48
DR95	120	96

Photo 6.9 MPD-testing in rain garden 9. Pouring the water too quickly can cause soil particles to mix with the water, as seen in the photo.

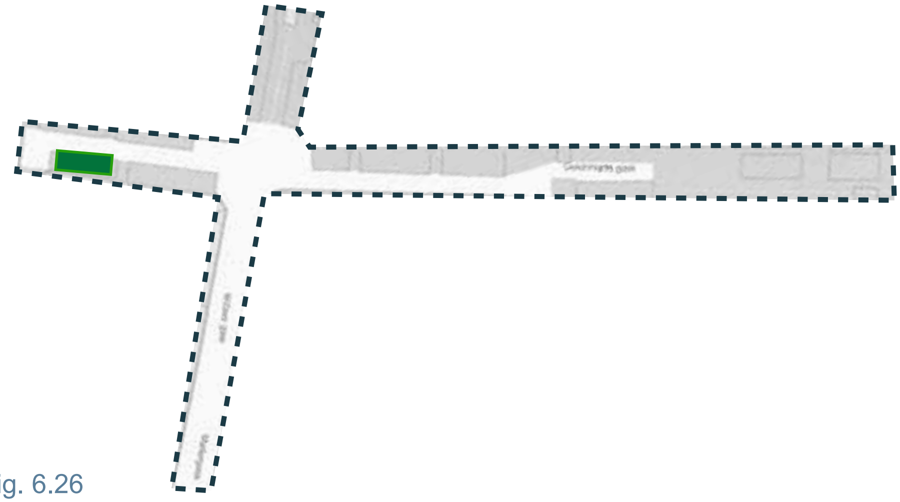


Fig. 6.26

Plants in rain garden 9

(CaO) Calamagrostis x acutiflora 'Overdam'

(CmI) Carex morrowi 'Ice Dance'

(DcG) Deschampsia cespitosa 'Goldschuleier'

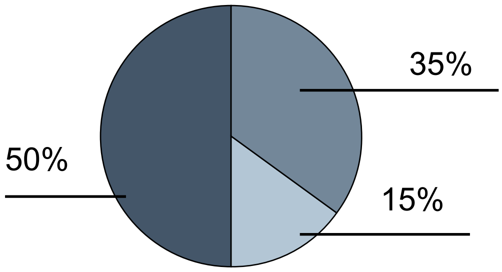
(EpW) Echinacea purpurea 'White Swan'

(HR) Helenium 'Rubinzwerg'

(NrS) Nepeta rasemosa 'Snowflake'

(SoP) Sanguisorba officinalis 'Purpurea'

Fig. 6.27 Soil composition



Intended filter medium: 15% Oslo compost, 35% peat, 50% sand fraction 0,6-2mm.

SUMMARY

What can we learn from these infiltration rate results?

We can learn whether or not the soil mixture specified by the landscape architect has an acceptable rate of infiltration.

We can see if there are problem areas in the rain gardens based on infiltration rates, and can modify the design of the rain garden on-site or for future projects.

Over time we can measure whether infiltration gets better or worse, and use that as an indicator of soil/plant/root health.

Before we draw conclusions we need to look at potential sources for error in our results. What can affect infiltration rates? A variety of factors can affect infiltration measurements. The method used to measure infiltration, the modified Philip Dunne, has some of the following weaknesses:

- tube placement. If the tube is inserted into the ground at an angle, the water in the tube will not be level with the ground surface and this can skew the readings.
- water force. Repeatedly pouring large quantities of water from a height on to a small surface area affects the ground surface. In some cases, water can bring smaller particles up from the soil and into the water in the tube, causing the particles to settle at the bottom of the tube and slow down infiltration rates.
-
- horizontal flow. The MPD method does not prevent water from leeching sideways and saturating the soil around the tube. Therefore, it can appear as if water is being infiltrated into the ground at a faster rate than is accurate.
- human error. Reading off measurements incorrectly or at the wrong time, can alter the results.
- While the plant selection for Deichman's street is included, observations and maintenace reports proved inconclusive to make suggestions about their performance in urban LID measures.

SIMULATED RAIN

There were several flood tests conducted on two of the rain gardens to see how they would perform during normal and heavy rainfalls. Picured (right) is an early test that revealed an uneven rain garden and a minor sink hole.

While these tests were not a part of the research for this thesis, they provided valuable insights into the performance of the rain gardens in Deichman's street.

Photo 6.10 Simulating heavier rainfalls in rain garden 1, with the help of Oslo's fire department.

Photo 6.10.a Simulating heavier rainfalls in rain garden 7, with the help of Oslo's fire department.

QUESTIONNAIRES

During the 2019 summer research period, two questionnaires were conducted; one aimed at casual passers-by through the area and one for residents of DG. The aims of the questionnaires were similar, as they attempted to gauge how people ranked the various changes made to the street. They also sought to inform people about the functionality of the rain garden and determine whether people would prefer rain gardens over other amenities

The residents were also asked to answer questions about the construction process, public information, and increased or perceived increased value of apartments on the street after the upgrades were completed.

The results from the questionnaire reveal the important role information plays in public perception. Several residents expressed their surprise at the functionality of the rain gardens.

Beboere i Deichmans gate

Oslo

Vi inviterer deg til å delta i en spørreundersøkelse vi håper du som beboer i Deichmans gate vil svare på. Det tar kun 2-3 minutter og din deltagelse er frivillig. Alle opplysninger vil bli behandlet konfidensielt og anonymt/anonymisert.

Oslo kommune ønsker å utvikle byen i en grønnere retning, hvor Deichmanns gate er et eksempel på dette. Gata ble renovert mellom 2016 og 2017, og vi ønsker å vurdere hvordan de ulike delene i gaten oppleves av dere som beboere. Dette er viktig informasjon for videreutvikling av liknende gater i byen.

Data blir kun brukt i sammenheng med forskning fra forskningspartnerne i Vann- og avløpsetaten (VAV) og Norges vassdrags- og energidirektorat (NVE).

Ved å fylle ut spørreskjema samtykker du til at du er villig til å delta i studien.

Har du spørsmål til prosjektet eller spørreundersøkelsen kan du henvende deg til:

Mallory Petersen, e-post: mallory.petersen.chamberlain@nmbu.no

Nevedda Sivakumar, e-post: nevedda.sivakumar@nmbu.no

Bent Braskerud, e-post: bent.braskerud@vav.oslo.kommune.no

Fig. 6.29

Deichmans gate forbipasserende

Vi inviterer deg til å delta i en spørreundersøkelse som vi håper du som beboer i Deichmans gate vil svare på. Det tar kun 2-3 minutter og din deltagelse er frivillig. Alle opplysninger vil bli behandlet konfidensielt.

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Mallory Petersen, e-post: mallory.petersen@vav.oslo.kommune.no

Nevedda Sivakumar, e-post: nevedda.sivakumar@vav.oslo.kommune.no

Fig. 6.30

The questionnaire for the residents of Deichman's street was created during 2019 and was used to assess how residents felt about the enite upgrade of the street. It also included a separate section about rain gardens and their usefulness, in order to gauge the public's perception of stormwater management in their area.

Beboere i Deichmans gate

Oslo

Vi inviterer deg til å delta i en spørreundersøkelse vi håper du som beboer i Deichmans gate vil svare på. Det tar kun 2-3 minutter og din deltagelse er frivillig. Alle opplysninger vil bli behandlet konfidensielt og anonymt/anonymisert.

Oslo kommune ønsker å utvikle byen i en grønnere retning, hvor Deichmanns gate er et eksempel på dette. Gata ble renovert mellom 2016 og 2017, og vi ønsker å vurdere hvordan de ulike delene i gaten oppleves av dere som beboere. Dette er viktig informasjon for videreutvikling av liknende gater i byen.

Data blir kun brukt i sammenheng med forskning fra forskningspartnerne i Vann- og avløpsetaten (VAV) og Norges vassdrags- og energidirektorat (NVE).

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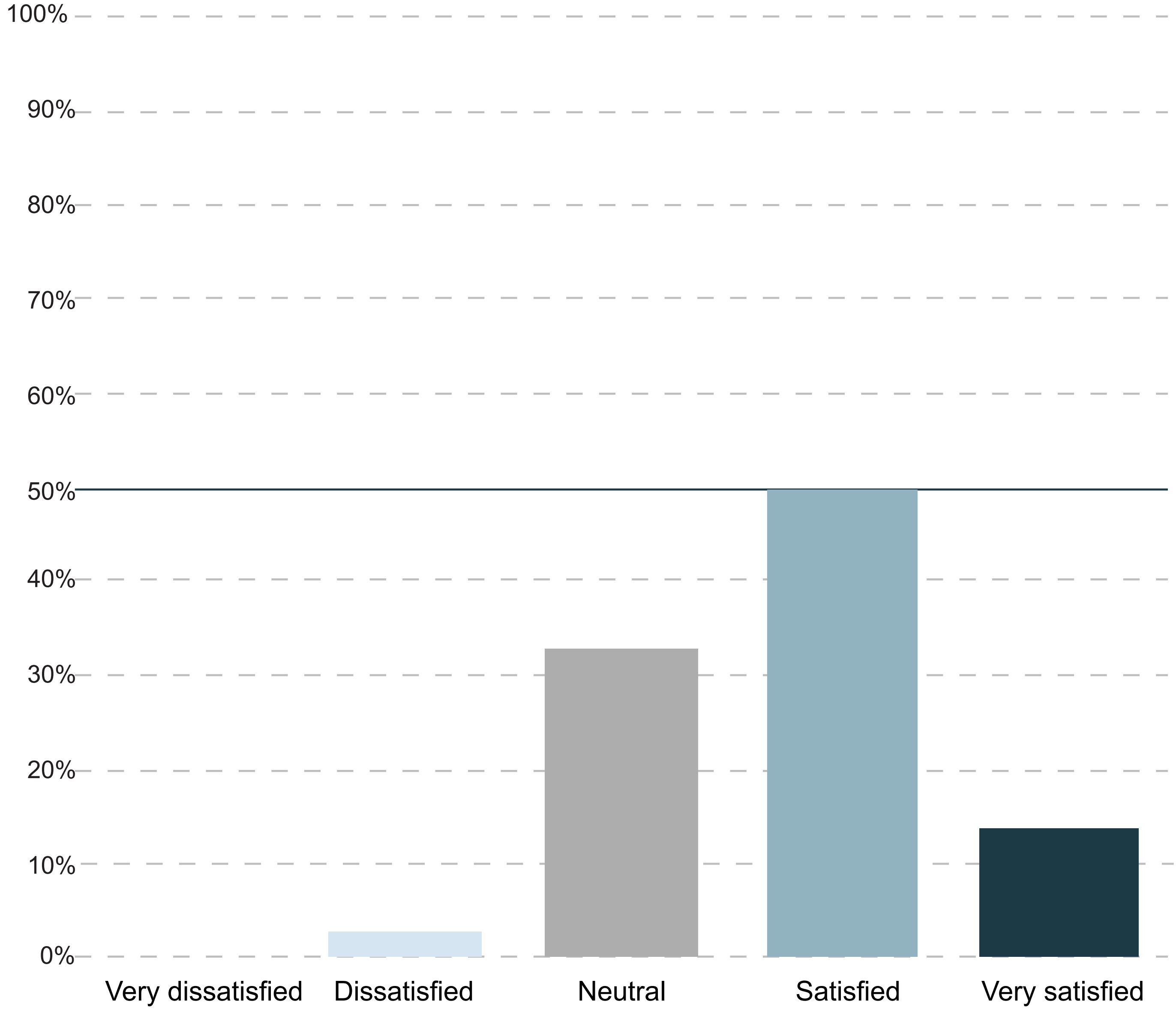
Bent Braskerud, e-post: bent.braskerud@vav.oslo.kommune.no

Fig. 6.31


Residential: surveyed
Residential: not surveyed
School: not surveyed
DS project perimeter
Rosteds gate
Mollergata skole
Mollergata
Wilses gate
Osterhaus' gate
N
1:1000/A4

Fig. 6.32

Fig. 6.33 How satisfied are you with the stone spheres in Deichman's street?



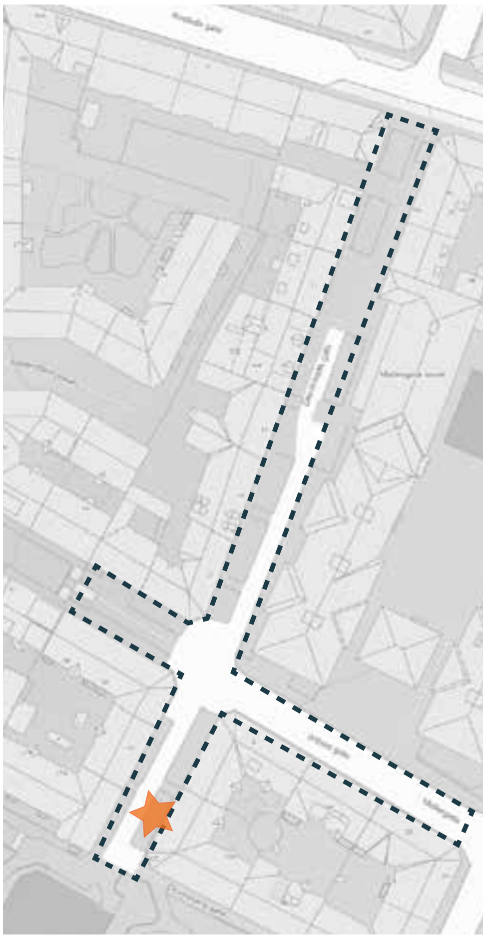


Fig. 6.34

Photo 6.11

STONE SPHERES

The residents of Deichman's street had no further comments about the decorative stone spheres placed in the south-east corner of the project area. They receive a largely positive rating, with over 60 percent of respondents choosing 'satisfied' or 'very satisfied'. Jan Gehl argues that aesthetics are crucial to a city, arguing that «at eye level the good city provides opportunities for walking, meeting and expression, and that means it must provide good scale and good climate … In contrast, work with the city's visual quality is more general… visual quality involves total visual expression – aesthetics, design and architecture.» (Gehl, J. 2010, p.176). The stone spheres serve as an interactive aesthetic element on a permeable gravel surface, thus combining

Fig. 6.35 How satisfied are you with the trees in Deichman's street?

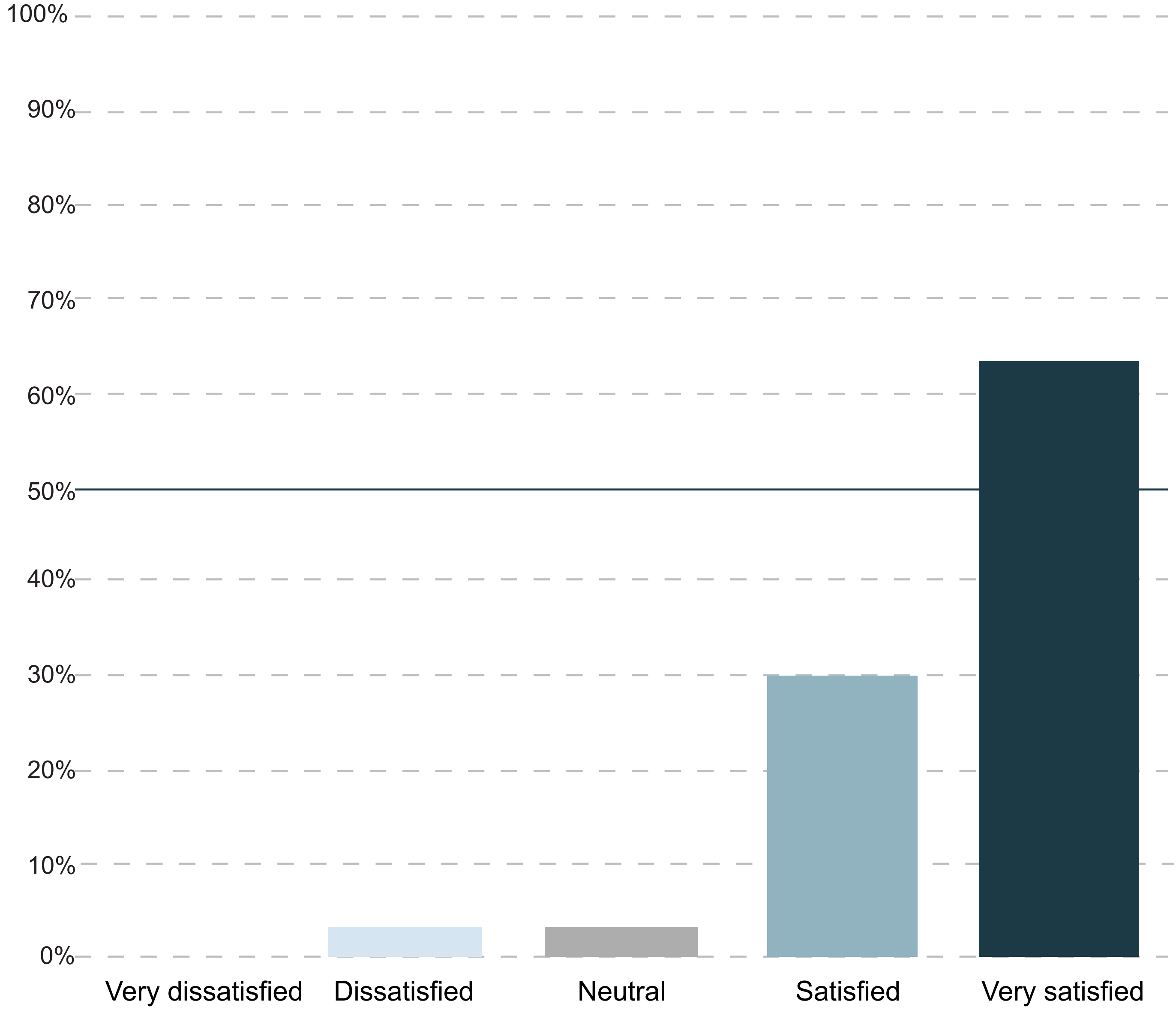


Fig. 6.36

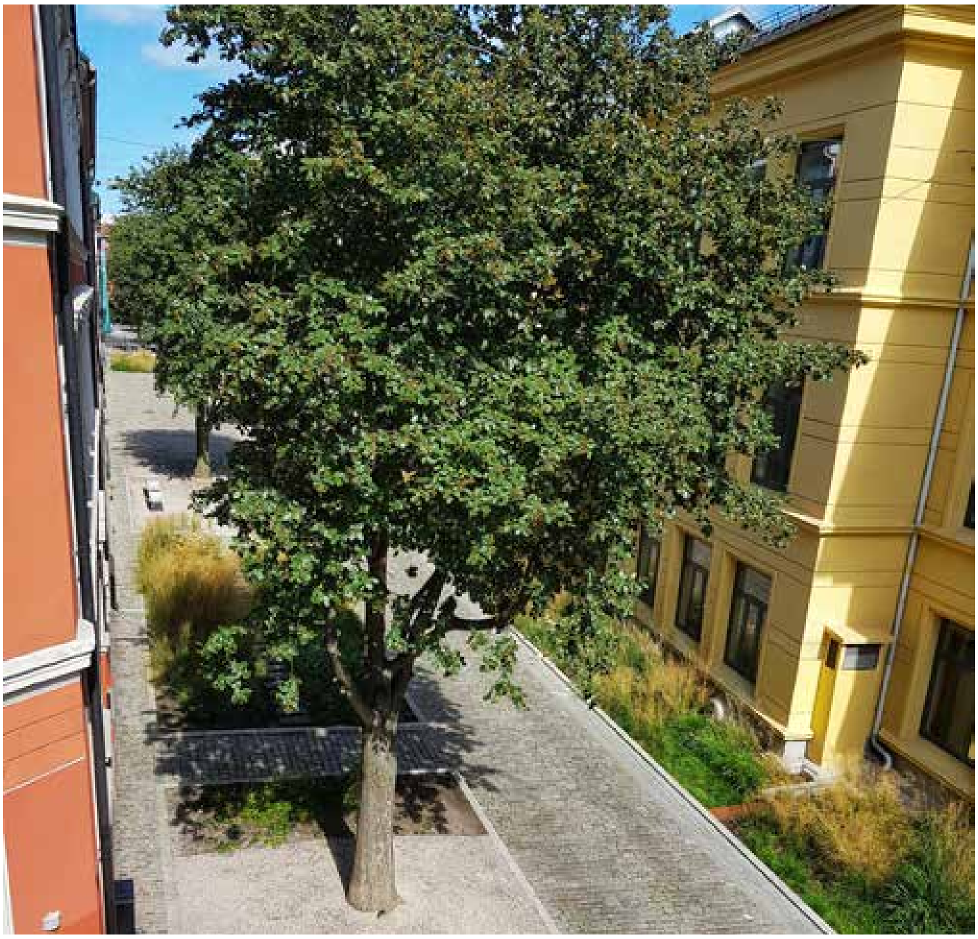


Photo 6.11

TREES

Of the 36 surveyed residents, 94 percent stated they were ‘satisfied’ or ‘very satisfied’ with the trees in Deichman’s street. While the trees were not planted as part of the project, some were pruned and others were removed entirely as a result of maintenance and design solutions for the street’s upgrade. One of the residents commented that they were «not happy to see the trees get pruned and in some cases cut down», while another stated they «would prefer more trees and fewer benches.»

Fig. 6.37 How satisfied are you with gravel under the trees in Deichman's street?

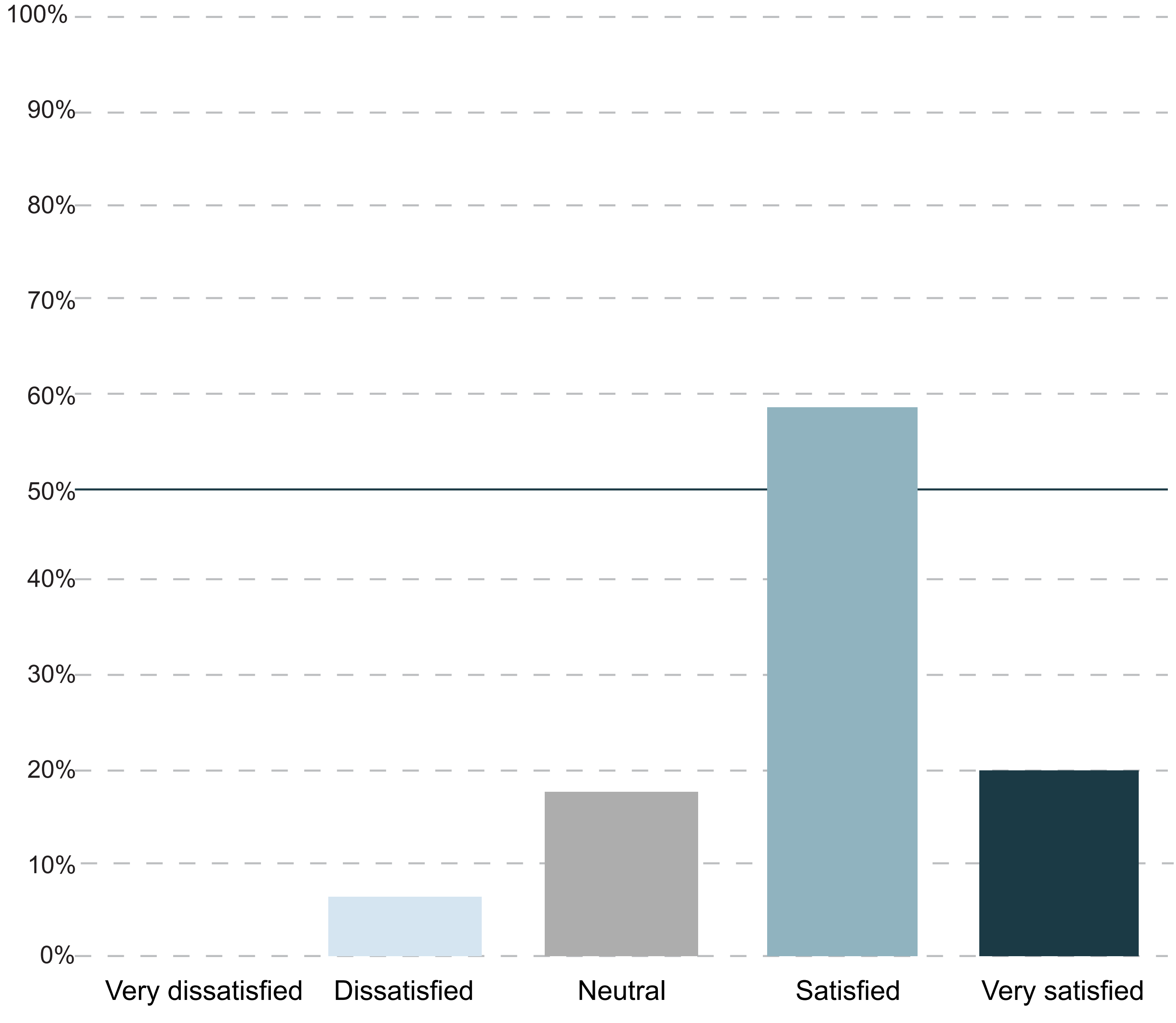


Fig. 6.38

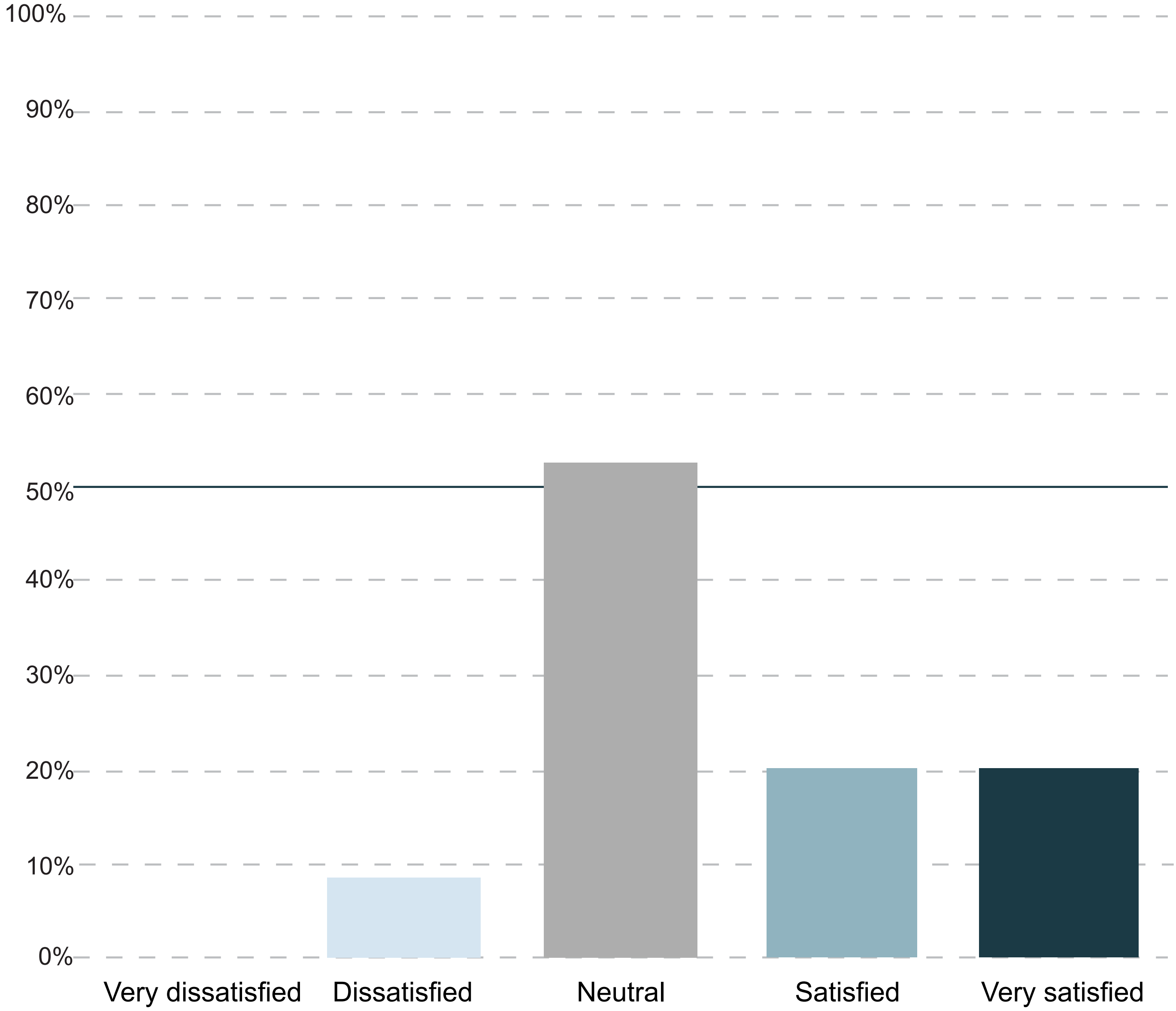
Photo 6.12

GRAVEL UNDER TREES

Nearly 80 percent of the surveyed residents were 'satisified' or 'very satisfied' with gravel under the trees in Deichman's street. By creating a larger impermeable surface under each individual tree, the upgrade ensures more water to the trees during rainfall and reduces the need for artificial watering. It also increases the amount of stormwater that infiltrates on-site and replenishes the groundwater table.

Some of the residents commented that «greenery under the trees looks better» and that they «would prefer grass under the trees instead of gravel», indicating that despite increased amounts of greenery in the street, more is still welcomed, or at least

Fig. 6.39 How satisfied are you with the bicycle stands in Deichman’s street?



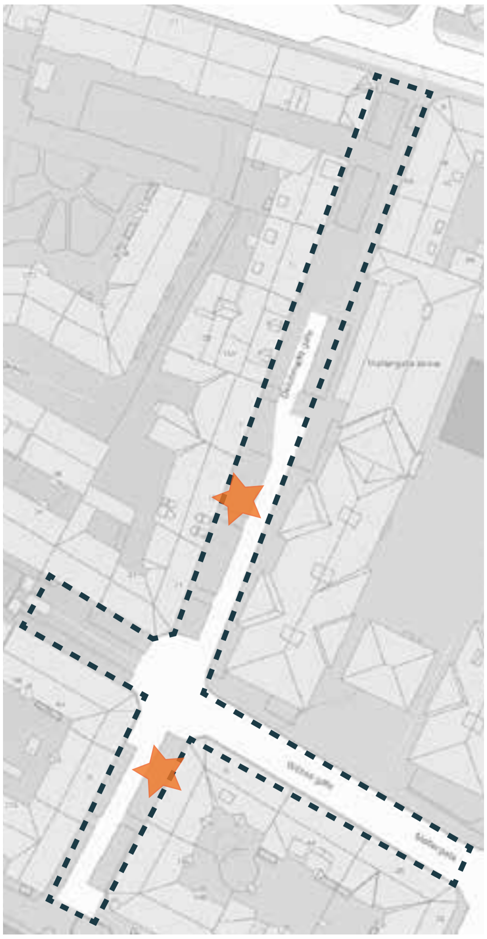


Fig. 6.40

Photo 6.13

BICYCLE STANDS

The bicycle stands had the lowest approval rating of all the design choices in Deichman's street, with just under 40 percent of the residents responding positively when asked about them. Several residents noted that they did not use the bicycle stands on the street at all, stating «bicycles are often stolen from the street» and that «it would have been better to use the space for more seating.» One resident elaborated that «I do not use the bicycle stands in the streets, I prefer storing my bike in my building's private courtyard.» Bicycle theft is a common occurrence in Oslo and Norway; in 2019 12,657 reports for stolen bicycles were filed.[1]

1 https://akersposten.no/12-657-sykkeltyverier-enorme-morketall/19.4678 Frende anslår at bare én av fire politianmelder sykkeltyveri, og aksjonsgruppen Ikke Stjel Sykkelen Min mener

Fig. 6.41 How satisfied are you with the planted areas in Deichman's street?

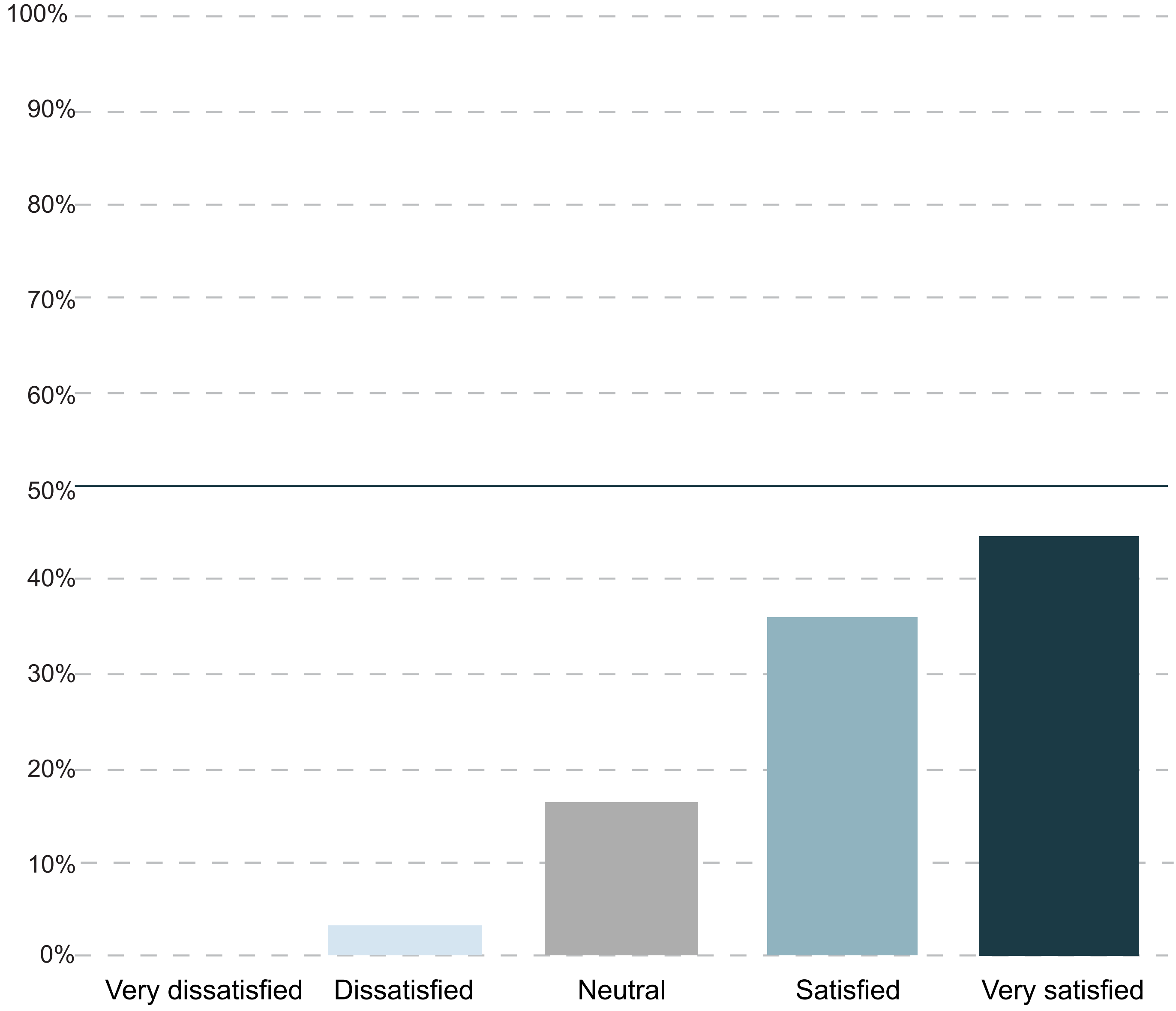


Fig. 6.42

Photo 6.14

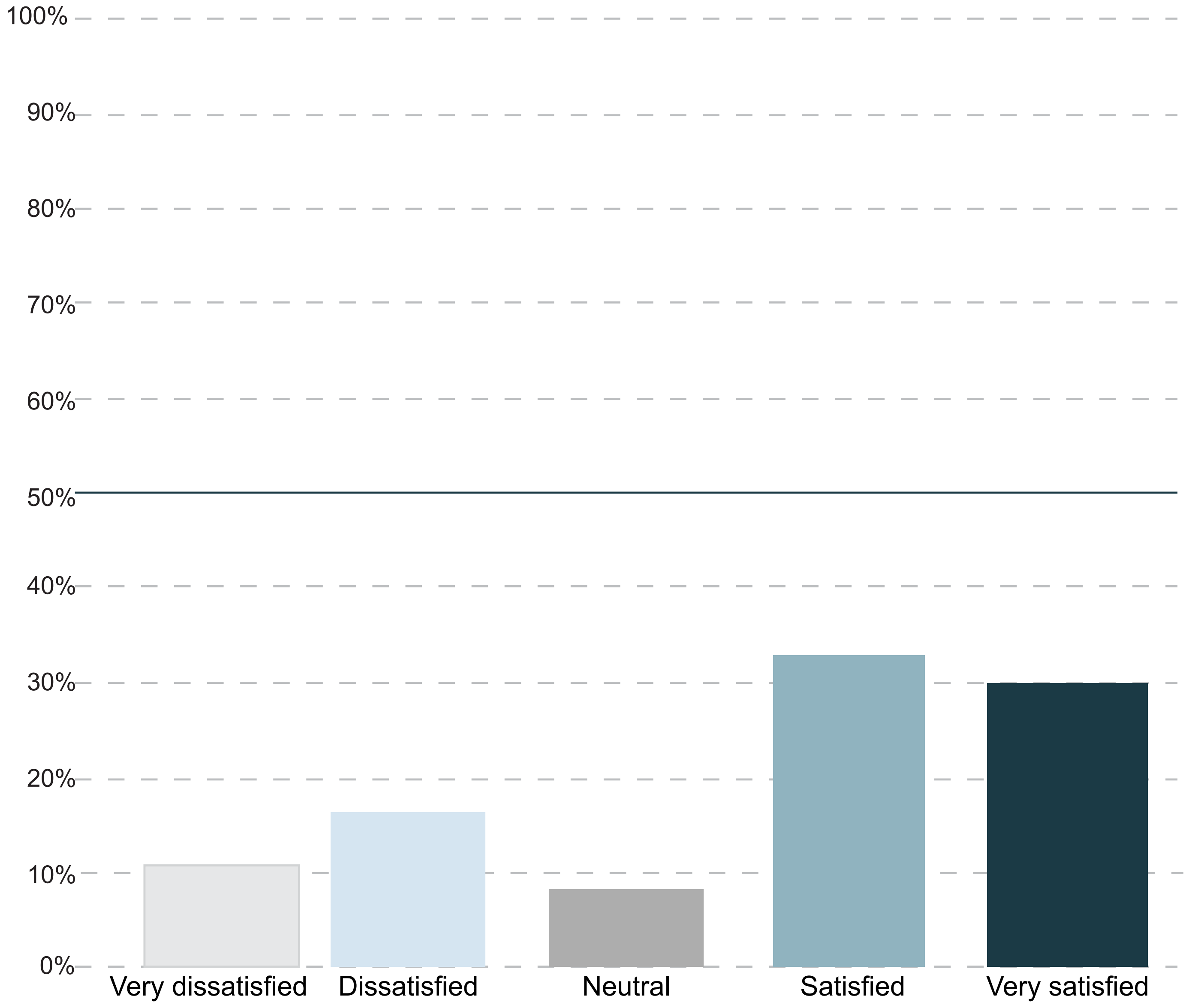
PLANTED AREAS

In this section of the questionnaire there is no distinction made between the rain gardens and other planted areas in Deichman's street, as they have a similar appearance. 44 percent of the respondents said they were 'very satisfied' with the planted areas. 80 percent of those who answered to some degree satisfied with the planted areas. However, some residents questioned the appearance of these areas, stating that «the plant selection is very green, there appears to be little variation,» and that «the planted areas look wild and unkempt/overgrown». Others commented on maintenance issues, such as the weathering steel providing the framework for the planted areas, noting that it «gets covered in graffiti and looks shabby when no measures are taken to

"One of the rain gardens looks sparsely planted. I want to plant something there myself but I'm not sure it's allowed."

-Deichman's street resident

Fig. 6.43 How satisfied are you with the benches in Deichman's street?



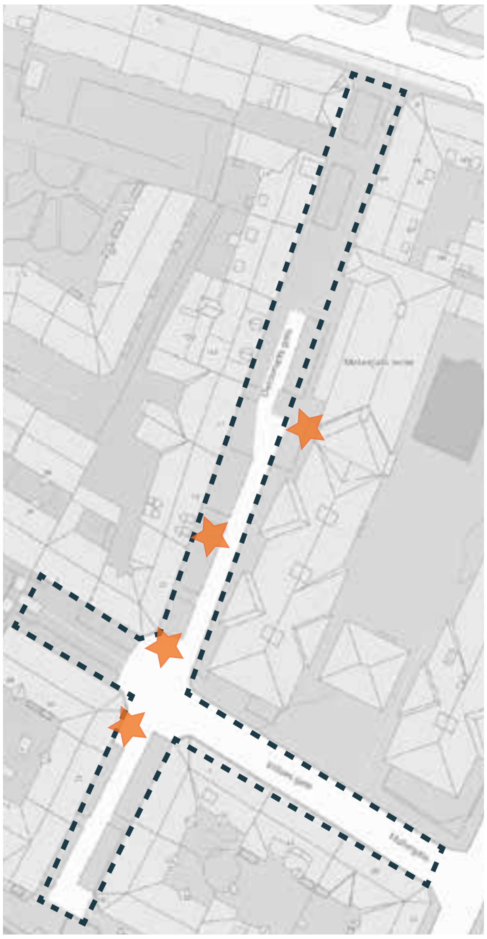


Fig. 6.44

Photo 6.15

BENCHES

27 percent of respondents were ‘dissatisfied’ or ‘very dissatisfied’ with the benches in Deichman’s street. From the long-form comment section and discussions with residents, we were able to identify two main sources for these sentiments; noise complaints and maintenance issues. A number of residents noted that «the areas with benches get loud and noisy, often late into the night», and that «the area surrounding the benches gets messy.» As others pointed out, «the benches are frequently destroyed.» This latter claim has been verified by several sources; some of the benches have been replaced up to four times due to damages.

Fig. 6.45 How satisfied are you with the water sculptures in Deichman's street?

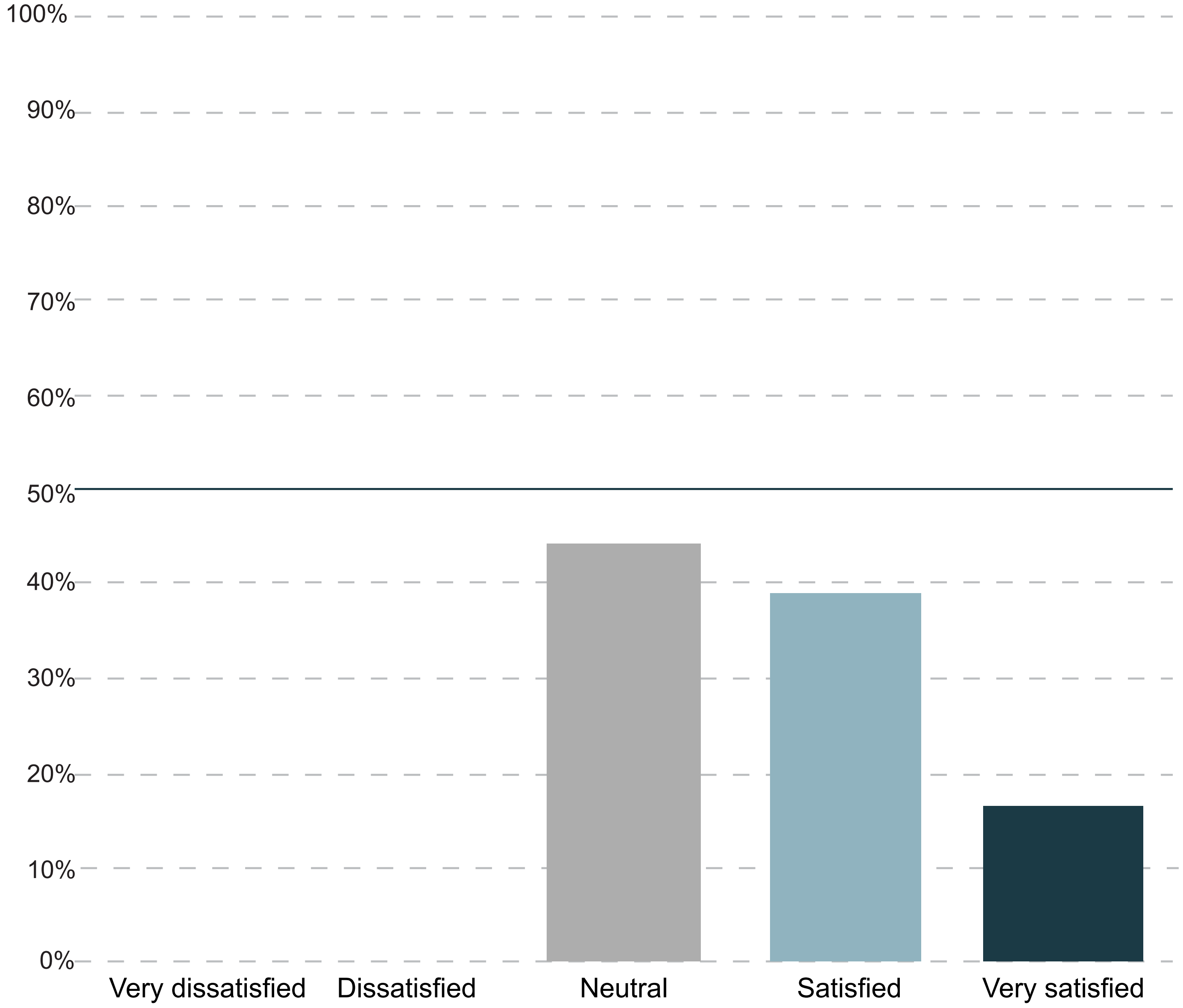


Fig. 6.46

Photo 6.16

WATER SCULPTURES

While none of the respondents rated the water sculptures negatively, close to 50 percent had a neutral opinion of them. Some residents pointed out that «the water features are very anonymous», and another commented «(the designers) could have put something else there instead». Regarding maintenance once resident pointed out «the water features need to be cleaned.»

Fig. 6.47 How satisfied are you with treadstone paths through the planted areas in Deichman's street?

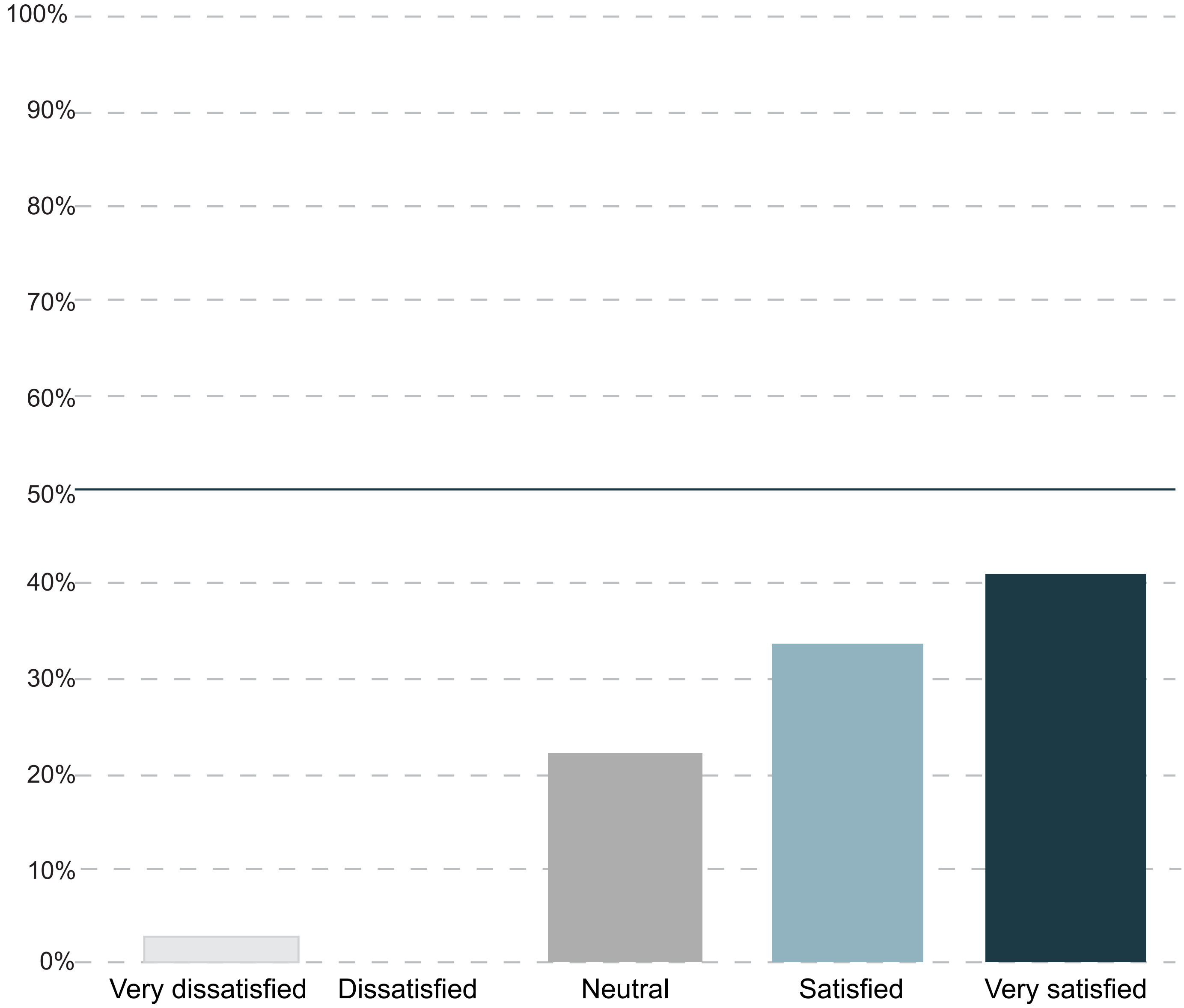


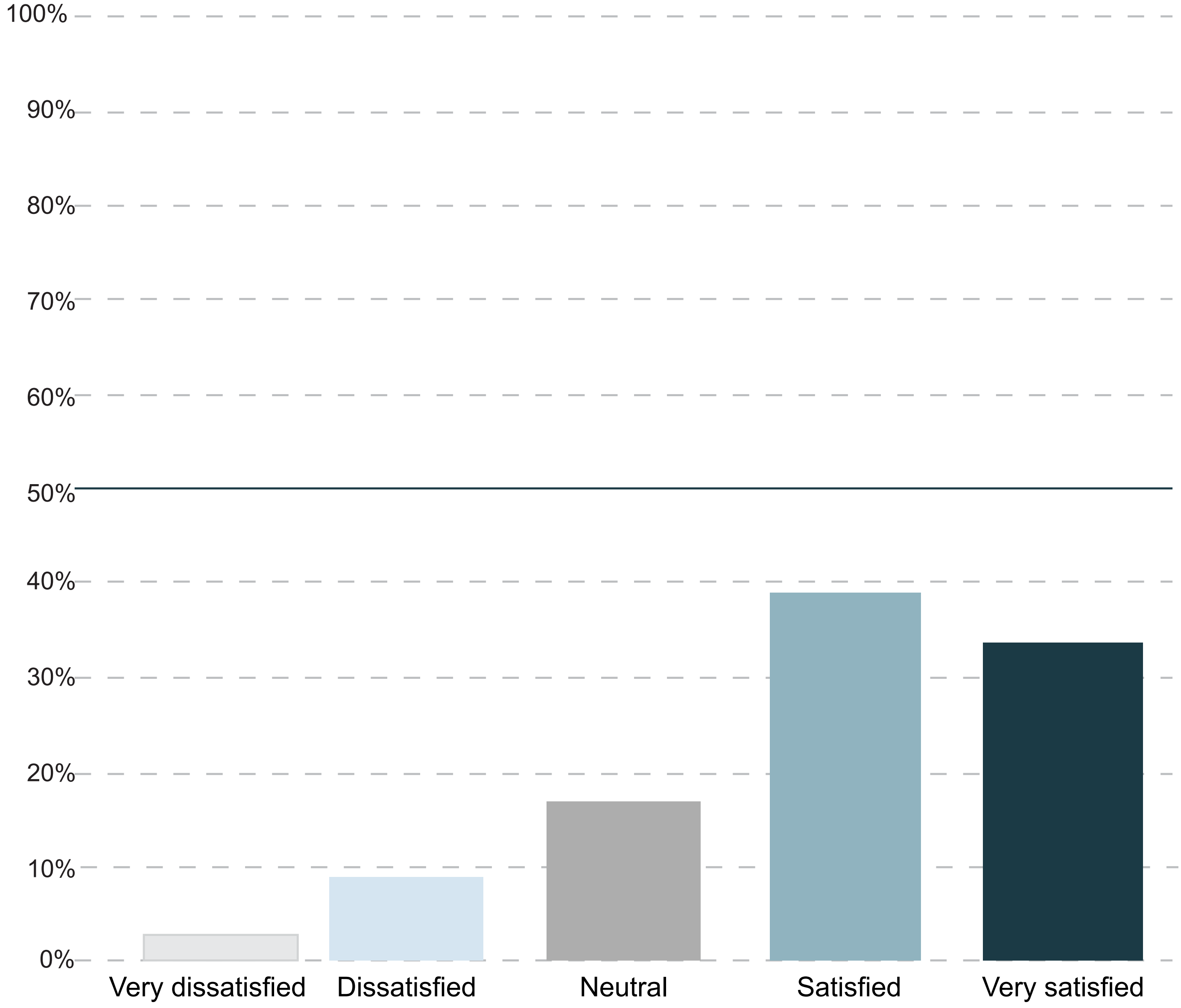
Fig. 6.48

Photo 6.17

TREADSTONE PATHS

A majority of respondents said they were ‘very satisfied’ with the treadstone paths through the planted areas in Deichman’s street. Over 70 percent of the respondents were positive to the design choice. Some However, some residents commented that «the paths are not used that often» and that they didn’t «see they point of having the paths…they aren’t maintained.»

Fig.6.49 How satisfied are you with the cobble stone surface of Deichman's street?



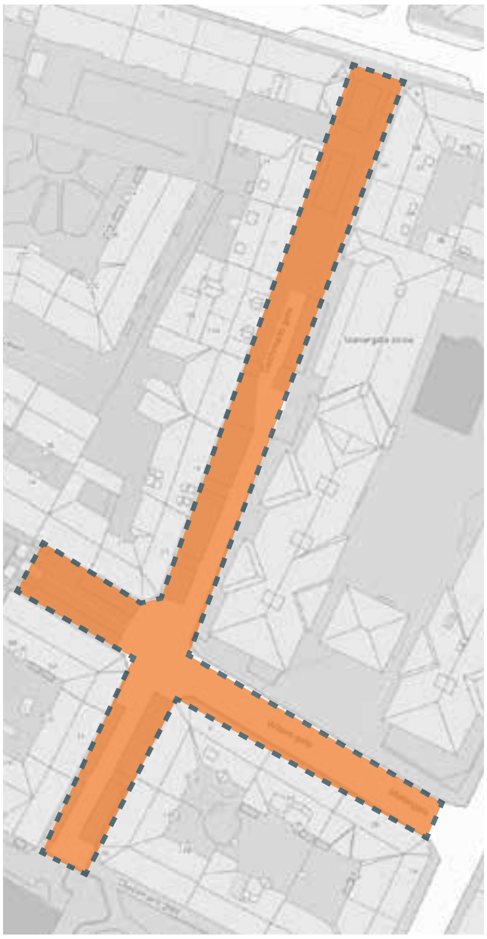


Fig. 6.50

Photo 6.18

COBBLE STONE SURFACE

While more than 50 percent of residents surveyed were ‘satisfied’ or ‘very satisfied’ with the cobble stones in Deichman’s street, the street surface also received the highest number of comments. Residents were quick to point out the inconveniences afforded with cobble stones, citing they were not compatible with cycling, luggage wheels, high heels, cars and anyone with mobility issues. Several of the residents commented that «the cobble stones are noisy», and suggested that «it would be beneficial with some tracks that had an even surface.» Over 10 percent responded that they were ‘dissatisfied’ or ‘very dissatisfied’ with the cobble stone surface.

RAIN GARDENS

This section of the questionnaire explains what a rain garden is before asking residents whether they think rain gardens are a positive or a negative measure to have in their neighborhood.

From the questionnaire:

A rain garden is a lowered planted area that retains storm water either permanently or temporarily.

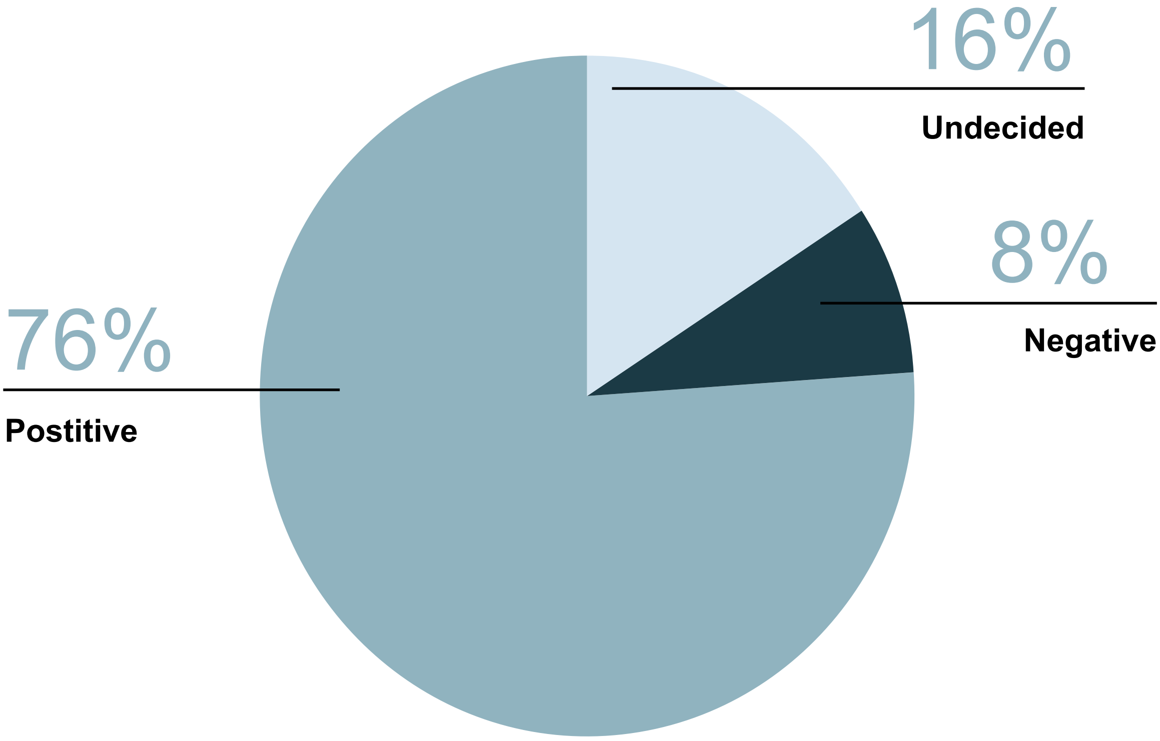
Storm water is water that starts as rain or snow and runs off roofs, courtyards, parking spaces and streets. By sending storm water in to rain gardens one is able to delay that water so the pipes under us do not get overloaded with too much water. Rain gardens are a measure that can prevent flooding in basements, for instance, in addition to filtering the water.

However, rain gardens require surface area in the

I Deichmans gate er det bygget 9 regnbed.
Et regnbed er en type nedsenket plantebed som holder igjen overvann enten helt eller midlertidig.
15.9.2020 QuestBack
https://web2.questback.com/Quests/QuestDesigner/PreviewPage.aspx?QuestId=5369800&sid=DACbAWA2n4&PPK=vlwkcgxilw 13/15
Overvann er vann som kommer fra hustak, gårdsplasser, P-areal og vei.
Ved å sende overvannet inn i regnbed forsinker man vannet så rørene under oss ikke blir overbelastet med formye vann. Dette er tiltak som kan forhindre oversvømmelser i kjellere og lignende, i tillegg til at vannet renses.Samtidig tar regnbed plass i gata.
Synes du det er positivt eller negativt med regnbed der du bor?

Fig. 6.51

Fig. 6.52 Do you think rain gardens are a positive or negative measure in your neighborhood?



"Very positive to this suggestion, functionally and asethetically."

"Solely positive, eliminates traffic and noise, and makes the city greener."

"Don't know enough about them to have an opinion. Probably nice in other streets, the measures taken seem to work for this street and gives it a nicer appearance than it had before."

"Haven't thought that they take up a lot of space, there used to be a lot of illegally parked cars that we no longer have to deal with."

"Not well-maintained, the planting work looks shabby."

"They're nice, they add some additional greenery beyond just trees."

"A good implementation, (I) have previously observed stormwater problems in Møllergata."

Fig. 6.53 Rain gardens are an important measure

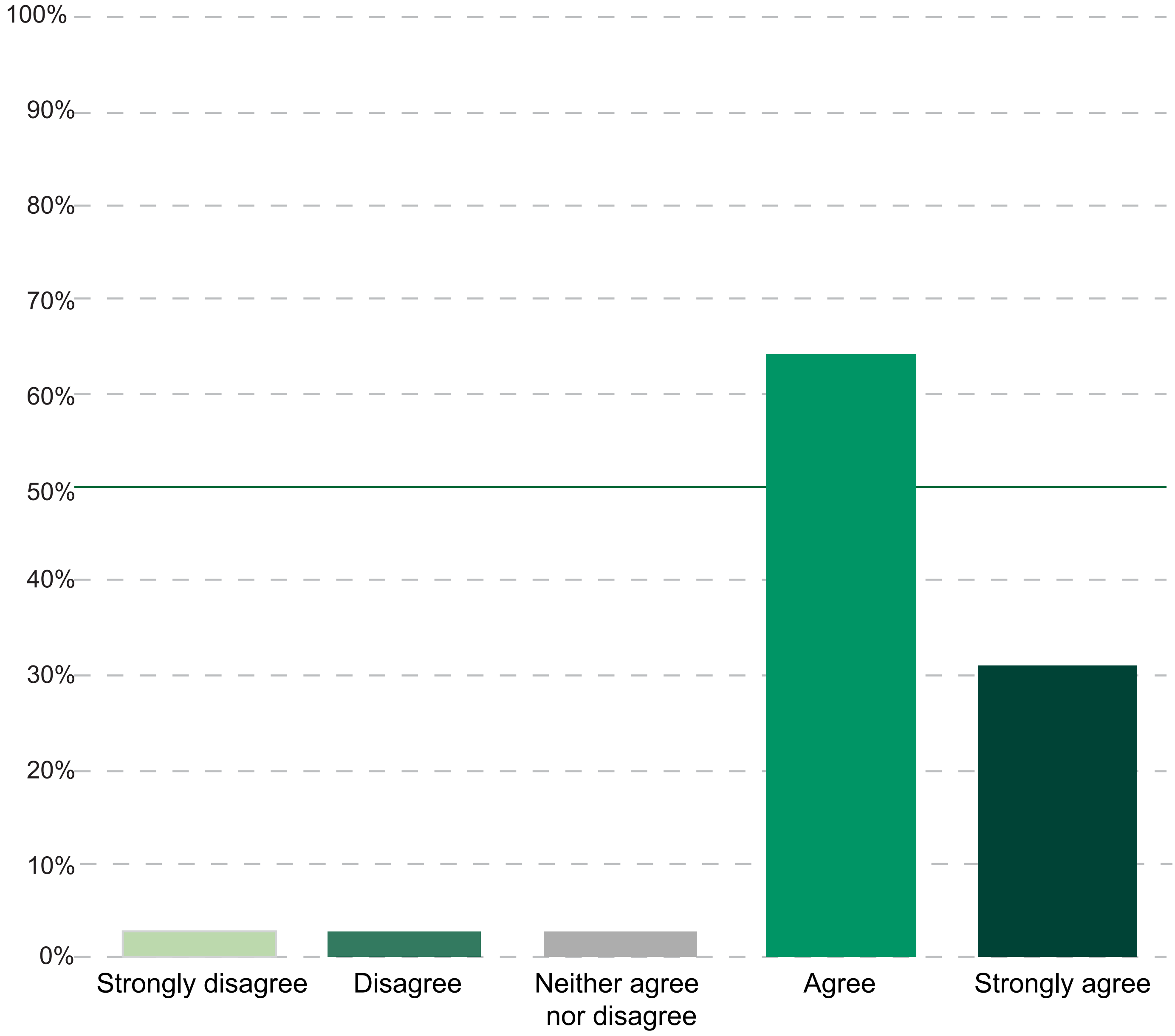


Fig. 6.54 Installing rain gardens is money well spent by the City/Municipality of Oslo

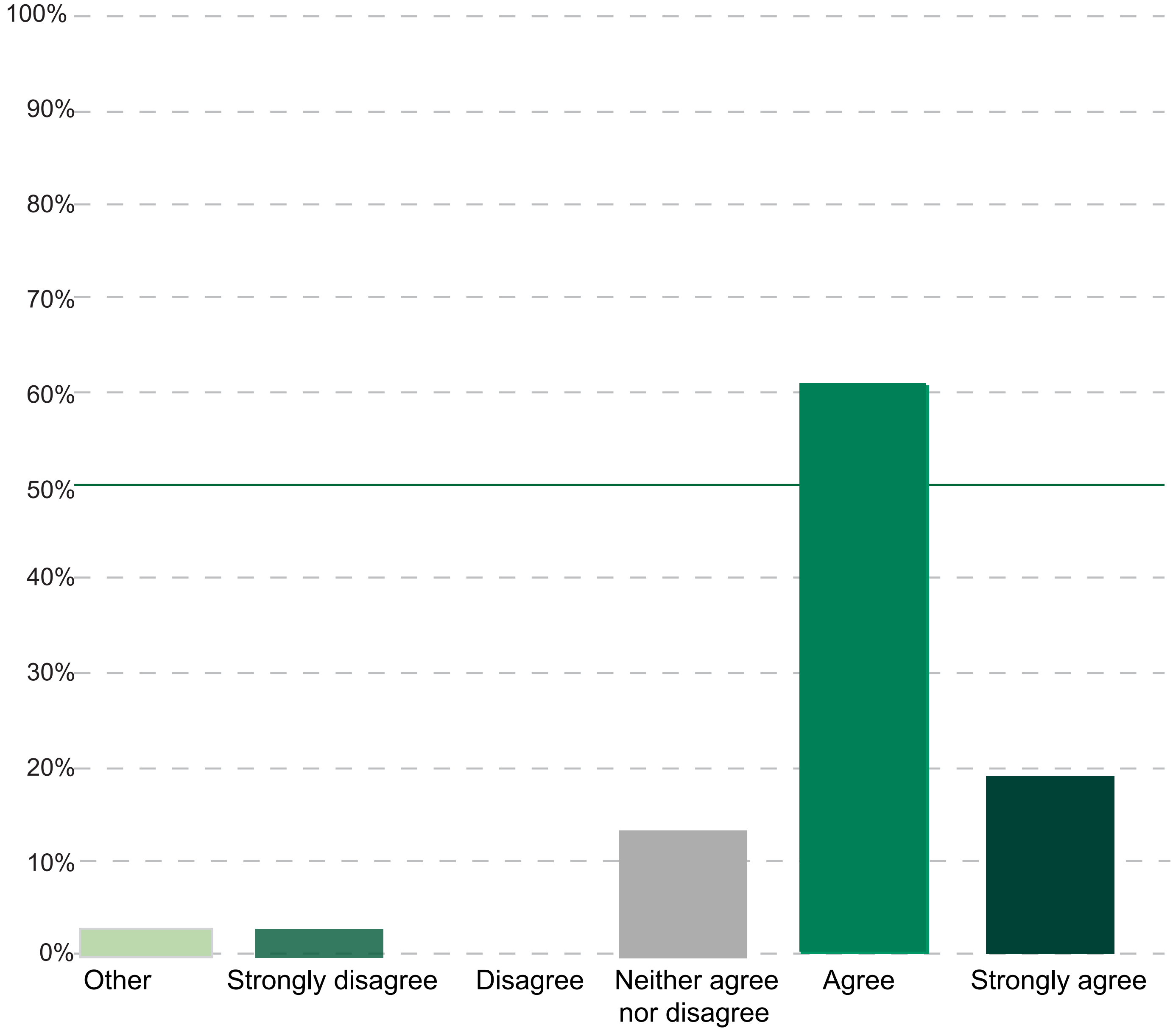


Fig. 6.55 I think adding parking spaces is more important than adding rain gardens to the street.

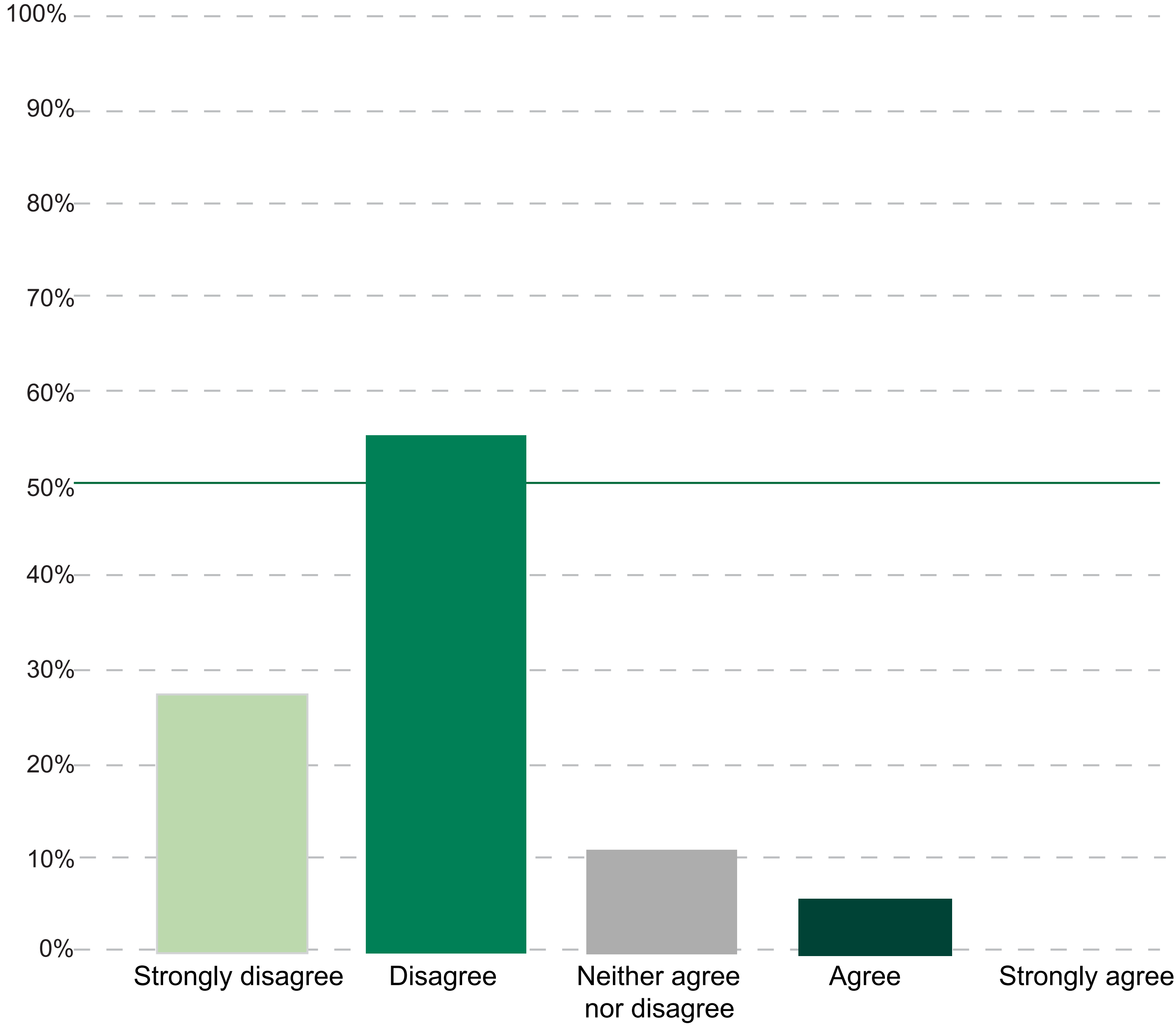


Fig. 6.56 Did you live on Deichman's street prior to its upgrade in 2016?

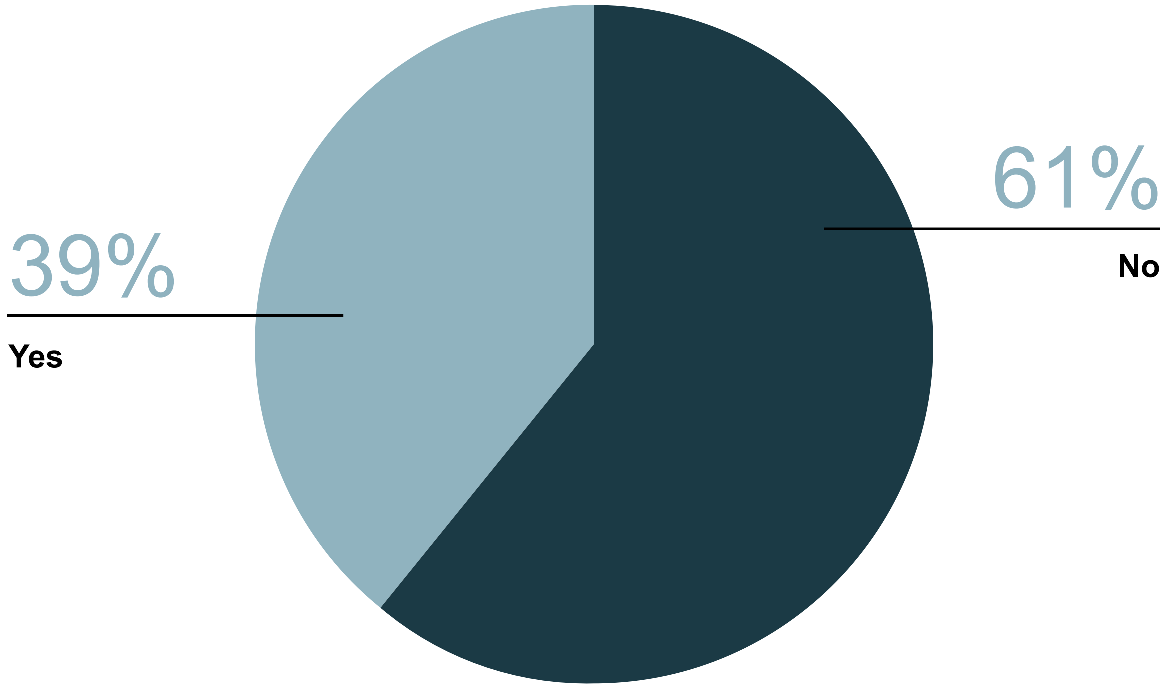


Fig. 6.56 If you answered 'yes' to the previous question, what was your experience of the building process for the upgrade of Deichman's street? Did any part of the process stand out to you positively or negatively?

"Very noisy durng the summer, and took far too long. Our windows got very dirty during the process."

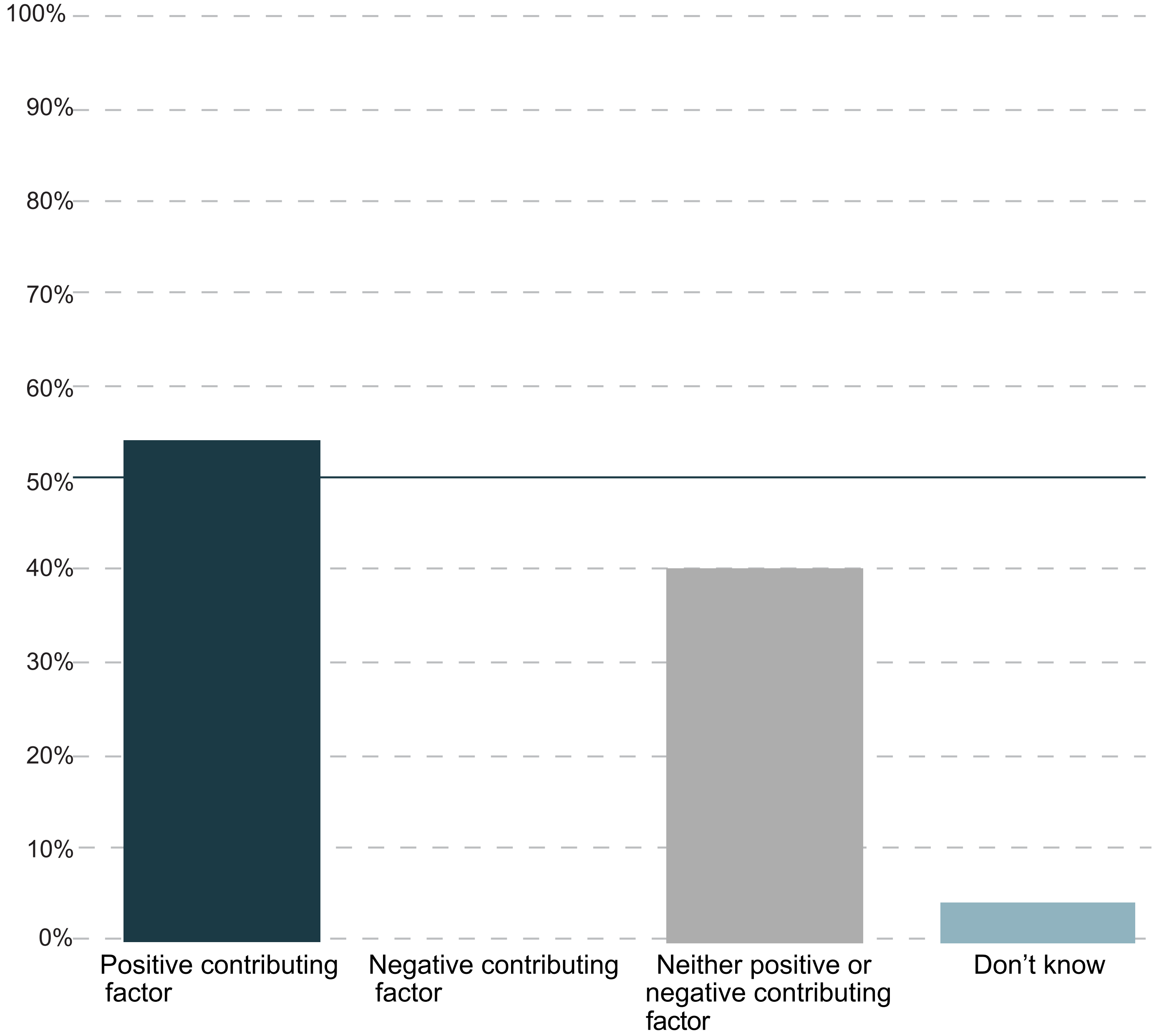
"Cannot remember anything negative during the building period. The contractor seemed professional and skilled. Of course the process was noisy and access to the buildings was a little tricky at times, but not as much as I had feared."

"(I) felt the residents were well-informed, an open meeting for residents was held which was nice."

"(The building process) lasted a while but the excavation work was done in several rounds which made the it feel prolonged."

"There was a lot of noise, but not more than one can expect. (The building process) lasted a long time."

Fig.6.57 If you answered ‘no’ to the previous question, to what extent was the upgrade of Deichman’s street a factor in your decision to buy or rent in this area?



SUMMARY

The results from the questionnaire provide a valuable insight to the publics prefrences. They reveal how challenging the democratization of our outdoor spaces can be in dense urban settlements, and highlight the importance of increasing community involvement for stormwater management and blue-green infrastructures.

PASSERS-BY

This questionnaire was conducted in order to gain some insight from those who use the street on any given day. First, they were asked to rank the various features of Deichman's street from 1st to 8th place, subjectively ranking the features based on their own opinion.

Then, they were given information about rain gardens and asked whether they would want a similar measure installed in the area where they lived. There were 29 respondents in total.

Deichmans gate forbipasserende

Vi inviterer deg til å delta i en spørreundersøkelse som vi håper du som beboer i Deichmans gate vil svare på. Det tar kun 2-3 minutter og din deltagelse er frivillig. Alle opplysninger vil bli behandlet konfidensielt.

Data blir kun brukt i sammenheng med forskning fra forskningspartnerne i Vann- og avløpsetaten (VAV) og Norges vassdrags- og energidirektorat (NVE). Ved å fylle ut spørreskjema samtykker du til at du er villig til å delta i studien.

Har du spørsmål til prosjektet eller spørreundersøkelsen kan du henvende deg til:

Bent Braskerud, e-post: bent.braskerud@vav.oslo.kommune.no

Mallory Petersen, e-post: mallory.petersen@vav.oslo.kommune.no

Nevedda Sivakumar, e-post: nevedda.sivakumar@vav.oslo.kommune.no

Fig. 6.58

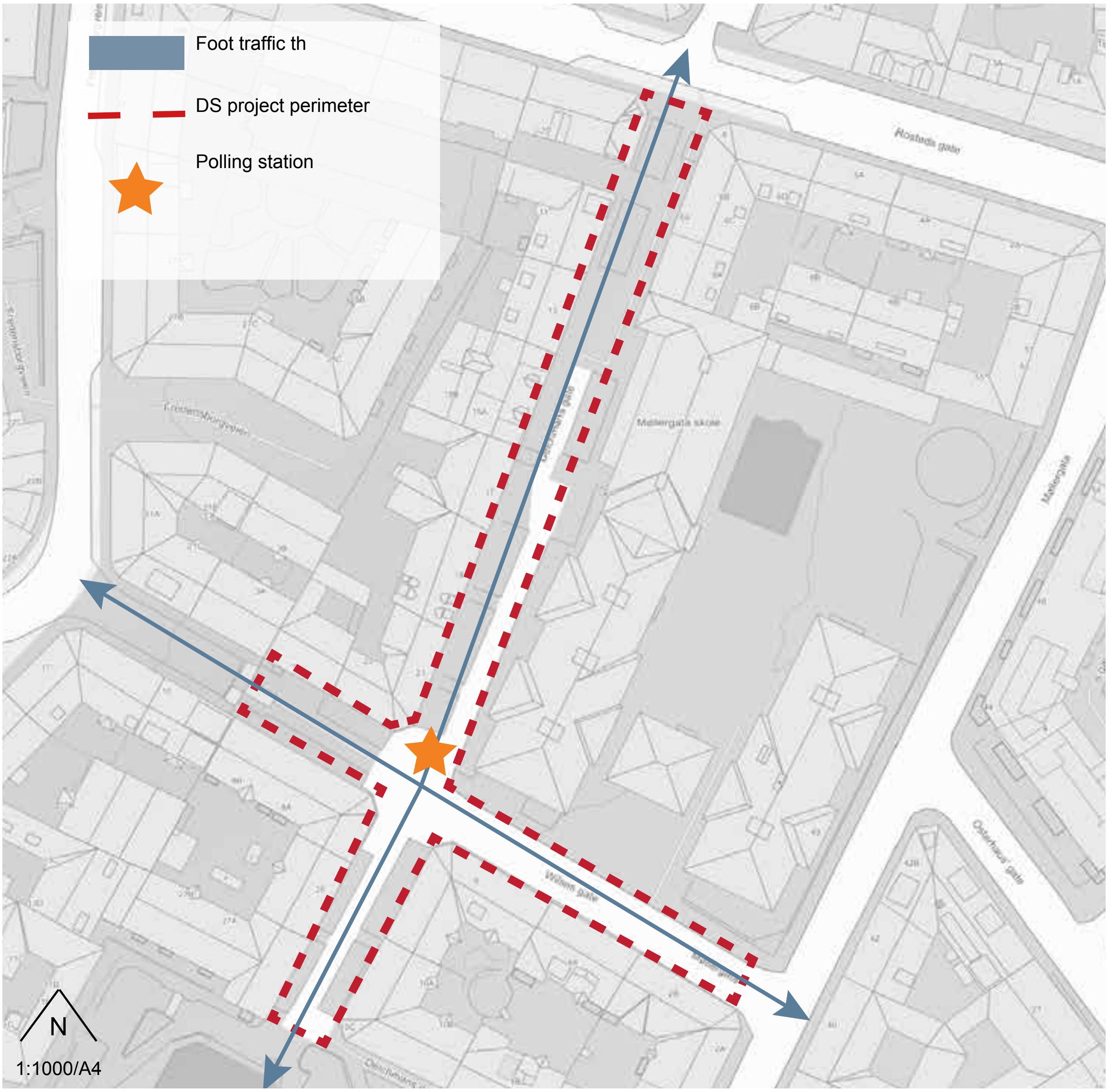
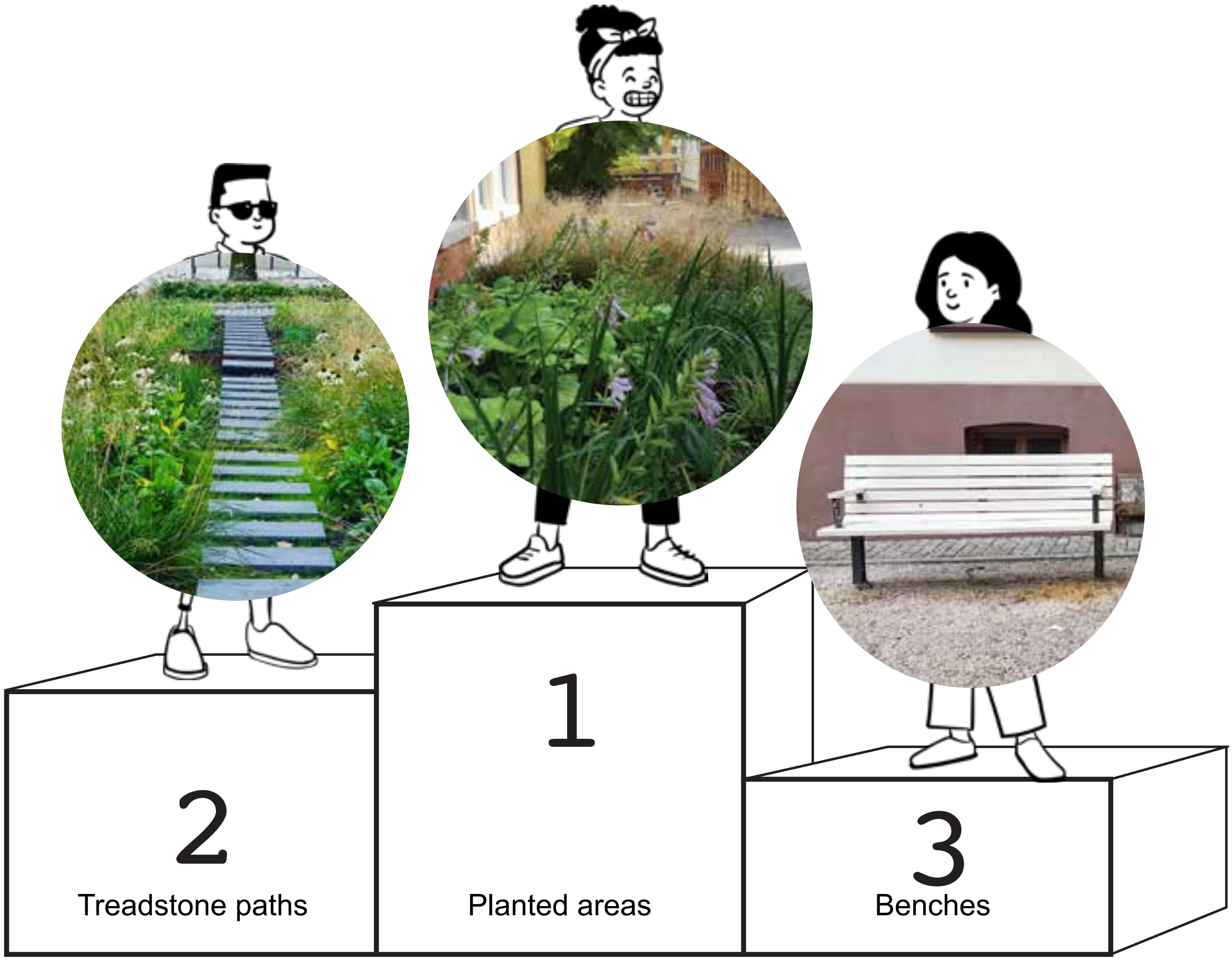

Foot traffic th
DS project perimeter
Polling station
N
1:1000/A4

Fig. 6.59

Fig. 6.60 Rank the features of Deichman's street from 1st to 8th place based on your personal preference.



Ranking the features of Deichman's street based on personal preference, most people ranked the planted areas as their favorite feature, followed by the treadstone paths through the planted areas and the benches. At the bottom of the ranking are the bicycle stands, gravel areas under the trees and and the water sculptures. There appears to be no significant correlation between the purpose of the feature- aesthetic, functional or both, when ranking the various measures.

4th place Stone spheres

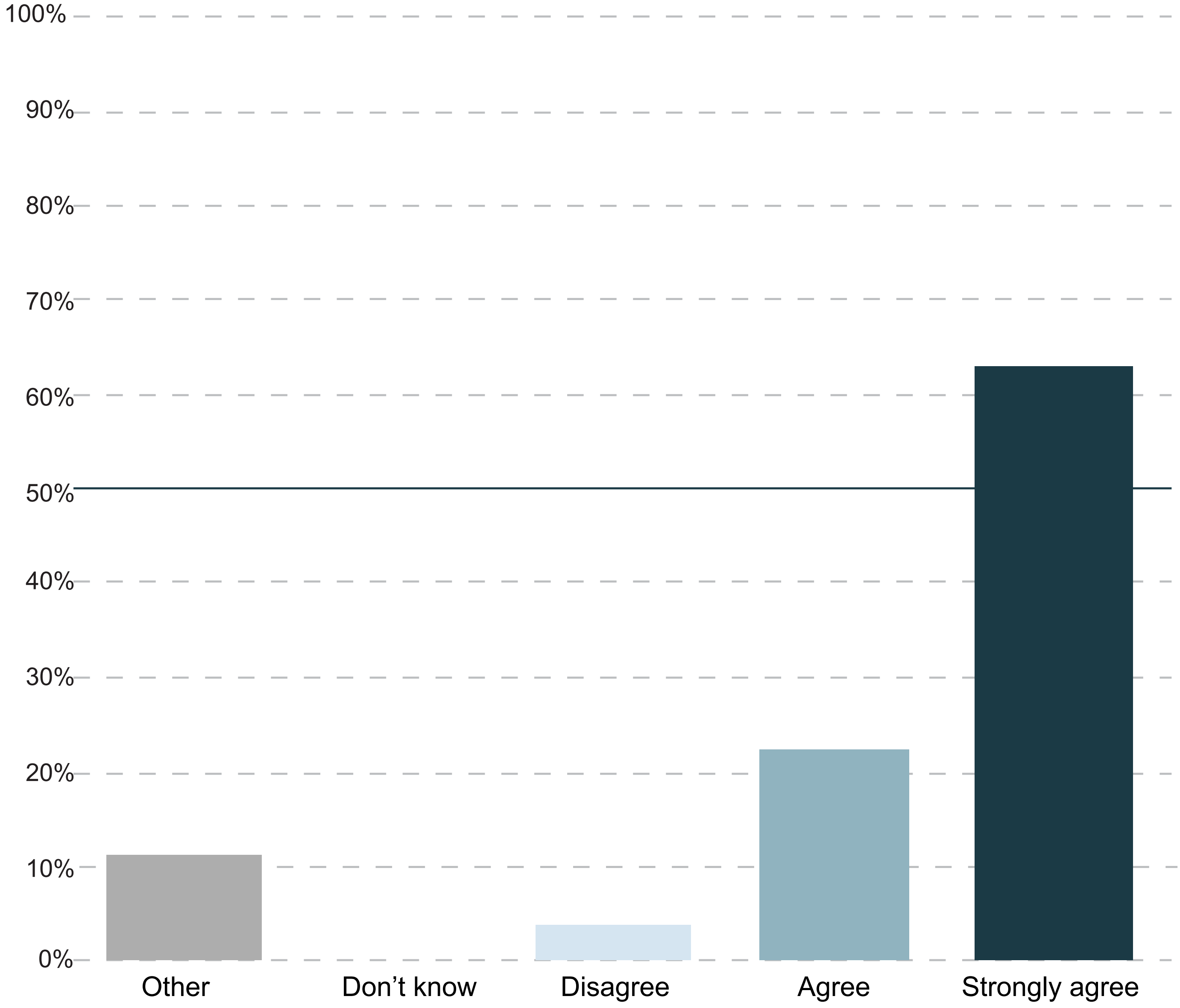
5th place Cobble stones

6th place Water sculptures

7th place Gravel areas under trees

8th place Bicycle stands

Fig. 6.61 Do you want similar measures where you live/in your area?



This section of the questionnaire explains what a rain garden is before asking whether respondents want similar measures in their area.

From the questionnaire:

A rain garden is a lowered planted area that retains storm water either permanently or temporarily.

Storm water is water that starts as rain or snow and runs off roofs, courtyards, parking spaces and streets. By sending storm water in to rain gardens one is able to delay that water so the pipes under us do not get overloaded with too much water. Rain gardens are a measure that can prevent flooding in basements, for instance.

SUMMARY

Results from the questionnaire for passers-by indicate that green spaces are preferable elements to have in a city. Results also indicate that the majority of people are very positive to the idea of having LID measures for stormwater management implemented where they live.

7

SOLUTIONS

This section adresses the following secondary research question:

What actionable measures can landscape architects take in future efforts to adapt cities in Norway to a wetter climate using LID stormwater management?

This thesis has examined the following research questions

CHAPTER 2

Why do Norway's cities need to be adapted to a wetter climate?

CHAPTER 3

How is LID stormwater management referred to in Norway's legal and strategic documents?

CHAPTER 4

How are other comparable cities implementing LID to adapt their urban settlements to a wetter climate and what can Norway learn from their experiences?

CHAPTER 5

What insights do the performance and perception of the Deichman's street project in Oslo provide for future LID projects in Norwegian cities?

CHAPTER 6

Why do Norway's cities need to be adapted to a wetter climate?

This section will present solutions based on findings in the respective chapters.

Landscape architects need to view urban planning and development through their blue-green glasses. Combining aesthetics, social and environmental aspects.

The role of the landscape architect is to shape, plan and manage our surroundings (NMBU course description, 2020). Our studies at NMBU prepare us for a role in society as advocates for good outdoor spaces (ibid). The field of landscape architecture has experienced a shift over the centuries from providing garden design for a privileged few to solving global climate and sustainability challenges for society, but the process remains the same; conduct a thorough analysis of the space and it's users, and translate those analyses into solutions.

As the findings come from every stage of the process, from legislation to design, so do the solutions. They are still shown through the lens of the landscape architect, rather than the policy maker or engineer, however some solutions call for the landscape architect to step outside of their comfort zone, for instance in using one's voice to call on politicians to adopt policies or organizing residents to be stewards of their neighborhoods.

As landscape architecture is a holistic discipline, these solutions also take a holistic approach to improving the process of solving climate challenges through LID stormwater management. Similarly, there is no one-size-fits-all solution for LID design, although some further standardization and classification can be helpful.

The findings are catecorized under the following areas, but are all tools that landscape architects can use in LID implementation:

COMMUNITY INVOLVEMENT

FRAMEWORKS

PLANNING

DESIGN

MEASURE	STAGE
Signage	Community involvement
Maintenance manuals for residents	Community involvement
Blue-green newsletter	Community involvement
Recruit future advocates	Community involvement
Incentives for rain garden	Community involvement
Advocacy work	Frameworks
Pilot project status	Frameworks
Training programs	Frameworks
National LID database	Frameworks
Cloudburst plans	Frameworks
Blue-Green poster	Planning
Norwegian standard	Design
LID classification system	Design
Research driven design	Design

Fig. 7.1

SIGNAGE

Several residents in Deichman's street expressed that they did not know enough about LID measures such as rain gardens to form an opinion of them. Installing simple signs in urban areas with high rates of pedestrian traffic can facilitate the spread of knowledge among the general public. If more people are made familiar with the mechanics of LID and rain gardens, interest and demand can grow as well. Additionally, residents may share information with friends, family and acquaintances, and let information travel to other urban centers. Signs could include information about which LID measures have been implemented, how LID works with existing systems and why we need to use LID measures to meet the challenge of increased rainfall as a result of climate change. Visuals could include a cross section of the measure, for instance a rain garden. Signage could also include a map of the area's flood routes and network of blue-green infrastructure. Other helpful visualizations could be volumes of water handled by the measure. For example; «this rain garden can handle x liters per hour, or approximately x bath tubs full of water - every hour». More informal comparisons can engage a younger audience and help visualize complex information about the hydrological cycle and LID measure performance. If the city has incentive programs for LID measures or further resources, a web link and QR-code can be provided.

PRIMARY EFFECT
Creating more awareness of LID measures in communities.

SECONDARY EFFECTS
Empowering communities and citizens to engage with their outdoor spaces.

SECONDARY EFFECTS
Sourcing available funding.

BASIS
Findings in chapter 7 suggest that people want to be involved in the management of their outdoor spaces.

MAINTENANCE MANUALS FOR RESIDENTS

As a measure to increase community involvement in stormwater management projects, landscape architects can create maintenance manuals for LID projects in their neighborhood. For municpal projects a standard three-year maintenance contract is often drawn up and adopted. However, involving residents with the maintenance of LID measures can foster a sense of ownership and responsibility. Norway has a national average for home-ownership of 77% (SSB), in cities such as Oslo the percentage is closer to 74.3% (SSB).

In addition, co-operative home ownership associations are common in urban settlements, where one or more apartment buildings form the association. These associations regularly organize volunteer maintenance work for the residents to participate in, consisting of indoor and outdoor maintenance work in the associations communal spaces and surroundings. Creating an easy-to-use maintenance manual for co-ops to use during these volunteer maintenance sessions could foster a sense of ownership for LID measures in urban settlements, raise awareness of LID projects and contribute to the upkeep of functionality of the measures.

An example e-manual for Deichman’s street could look like this:

Oslo

MAINTENANCE MANUAL
FOR RESIDENTS OF DEICHMAN'S AND WILSE'S STREET

Contact point: *provides contact information for the person or department in charge of the project*

Information about LID: *a general introduction to stormwater, stormwater management and LID, with more detailed information about the local measure*

Checklist for suggested maintenance work: Divided into seasons, many co-ops carry out their scheduled volunteer maintenance sessions in the spring and autumn, if only once a year then typically in the spring or autumn seasons.

Spring and autumn maintenance suggestions

Remove garbage and larger debris from the area

Register and report any damages to the contact point or relevant authority

Remove any larger gravel deposits (used for added traction on streets and sidewalks in icy or snowy conditions) from the LID measures, paying special attention to entry and exit points for water, and flood routes.

Rain gardens: clear out and clean sedimentation chambers at rain garden entry points

Permeable surfaces: remove any weeds or debris

Gutters: clear out any gravel, foliage or other debris to ensure a clear flow path for water.

Other water features: clear out and clean.

Flood routes: remove any gravel, foliage or debris to ensure a clear flow path for water.

Fig. 7.2

THE BLUE-GREEN E-NEWSLETTER
A newsletter for updates regarding local blue-green infrastructure

WHY
In order to build community engagement for LID stormwater development, creating information that is easily shared and archived can be a helpful tool. Today's technology has a multitude of channels and methods for spreading information tailored to its users.

HOW
By creating a blue-green newsletter at a municipal level, local government can share news about projects, incentives, upcoming meetings, courses, presentations and other relevant information. Why a newsletter? Its format allows for platform independency, meaning the sender does not need to format content for multiple media platforms. Newsletters can easily be distributed to individual recipients or large groups. The blue green newsletter could be sent to schools in the area, and become part of class discussion, or get delivered to the neighborhood care home where residents and their families can plan their next outing to visit a recently completed project nearby.

PRIMARY EFFECT
Creating more awareness of LID measures in communities.

SECONDARY EFFECTS
Empowering communities and citizens to engage with their outdoor spaces.

SECONDARY EFFECTS
Sourcing available funding.

BASIS
Findings in chapter 7 suggest that people want to be involved in the management of their outdoor spaces.

Fig. 7.3

RECRUIT FUTURE ADVOCATES
Using existing programs to promote and spread information about LID stormwater management

WHY
In order to build community engagement for LID stormwater development.

HOW
A national organization named The Pole Hunt (Stolpejakten) is working to promote an increase in physical activity for the general population of Norway (Stolpejakten, 2020). A series of wooden poles are placed in different places across the country, and each pole has a unique QR-code attached to it. Participants have to find the pole and scan the code to register it as 'found'. Various sports organizations and physical activity groups sponsor poles in their area, and have limited release dates for the latest pole maps, and a set time frame for finding as many as possible. Local municipalities could sponsor and release their own set of poles to highlight the LID stormwater management measures nearby. Connecting with already established programs can be a useful way to engage the public and spread information about the importance of blue-green infrastructure.

PRIMARY EFFECT
Creating more awareness of LID measures in communities.

SECONDARY EFFECTS
Empowering communities and citizens to engage with their outdoor spaces.

SECONDARY EFFECTS
Sourcing available funding.

BASIS
Findings in chapter 7 suggest that people want to be involved in the management of their outdoor spaces.

INCENTIVES FOR RAIN GARDENS
Providing incentives for residents in urban settlements to implement LID in their neighbourhoods.

WHY
Can be seen as a community building exercise. In cities such as Seattle, WA, blue-green stormwater management sees incentives and community efforts as a category of stormwater management work. Inviting the public to implement LID measures where they live can have impacts beyond the immediate neighborhood. Many of the challenges with traditional stormwater management can be traced to systems receiving more than they can handle. By removing some of this extra pressure in one area, the rest of the connected areas can feel the impact too.

HOW
Create local, regional or national funds that communities can apply to for grants and LID implementation projects. The grants can also be offered as rebates. In a long-term perspective, money for these initiatives could be partially sponsered by water fees.

PRIMARY EFFECT
Creating more LID measures in communities

SECONDARY EFFECTS
Empowering communities and citizens to shape their outdoor spaces.

SECONDARY EFFECTS
Sourcing available funding.

BASIS
Findings in chapter 7 suggest that people want to be involved in the management of their outdoor spaces.

Photo. 7.1

ADVOCACY
One tool landscape architects often underutilize is advocacy for their field outside of work.

WHY
Opinion pieces in local media outlets can have a powerful impact on public understanding and perception. An example of public awareness resulting from media coverage is the term ‘microplastic’. A relatively unknown term in Norway until 2017, when media coverage of the topic in Norway grew exponentially. Documentaries, investigative journalism, op-ed pieces in national newspapers all contributed to expose the threat micro plastics pose to our environments, wildlife and public health. This year, state-owned media broadcaster NRK chose the World Wildlife Fund (WWF) and their campaign to ‘fight plastic in our oceans’ as the beneficiary of its yearly national charity fundraiser.

HOW
Entering public forums for debate. Appealing to politicians and lawmakers about relevant changes to strategies, policies, laws and acts.

PRIMARY EFFECT
Increase awareness of the current challenges and solutions for LID stormwater management.

SECONDARY EFFECTS
Engage average citizens to educate themselves on stormwater management, the hydrological cycle and inspire them to contribute to the solution.

Empower landscape architects to stake a claim as catalysts for sustainable development in urban settlements.

LIMITATIONS
Landscape architecture is a narrow professional field in Norway, and some landscape architects may worry that voicing critical opinions could sour business relationships. A valid concern in a limited market, but using our outdoor voices is still important.

BASIS
Findings in chapter 4 and 6 revealed that we need to spread information about climate change challenges and solutions.

Photo. 7.2

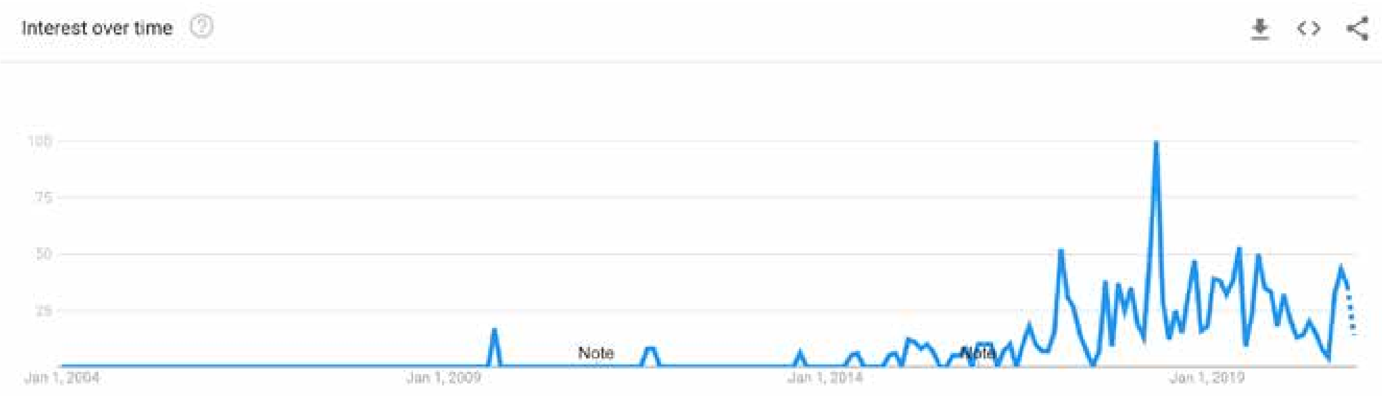


Fig. 7.2 that shows Google search results for the ter m ‘mikroplast’ in Norway between 2004 and today.

PILOT PROJECT STATUS
Create a certification for projects that signify them at a national level as pilot projects for LID stormwater management.

WHY
The Deichman's street project was repeatedly cited as a pilot project for LID stormwater management because it was an early adaptation of open urban stormwater management practices in Norway. Design, plant selection, soil composition and construction details were chosen to generate research and results on the efficacy of LID in urban settlements. However, since its opening in 2016 research potential has been lost.

HOW
Create a conditional certification whereby a project can be certified as a 'pilot project' when it outlines research projects before completion.

PRIMARY EFFECT
Can start important long-term studies early on, and generate results that can be openly shared with a wider audience.

SECONDARY EFFECTS
Can help municipalities with more limited funds or knowledge gain insight into tried and tested solutions in a Norwegian climate, and can inform the regulation, planning and design processes for future LID projects in urban settlements.

LIMITATIONS
While a private company may be unable to provide open access to every design detail in a project, a general overview of what has worked well and what has been challenging can still be incredibly helpful information.

BASIS
Findings in chapter 4 suggest that special programs for research and development can provide important insights for future planning.

Photo. 7.3

TRAINING PROGRAMS
Creating national training programs for landscape architects to learn more about LID in urban settlements.

WHY
As research develops and climate change progresses, the role of the landscape architect is also evolving. In order to meet future demands, landscape architects need to stay on top of the latest research. In terms of stormwater management, the shift from grey to blue-green and grey solutions means more landscape architects will be involved in the stormwater management decisions for urban settlements and entire cities.

HOW
Create certification courses that landscape architects can complete part-time or full-time.

PRIMARY EFFECT
Creates equal access to an updated knowledge base and new research regarding stormwater management. While larger firms may already offer similar programs, and regularly scheduled field trips to see new projects, smaller companies, single-person business ventures or financially small municipalities may not have the same opportunities.

SECONDARY EFFECT
Increases landscape architecture competency on a national level.

LIMITATIONS
Constraints in resources and available time may prohibit some landscape architects from participating in courses.

BASIS
Findings in chapter 2 reveal that the shift from grey to blue-green stormwater management needs to permeate the field of landscape architecture in the coming years so we can become a natural partner in stormwater management.

Photo. 7.4

NATIONAL LID DATABASE
Create an open, free-access and interactive national database of low impact development projects.

WHY
Enables landscape architects, and anyone else interested in low impact development to learn more about the subject and see examples in Norway. While many examples are listed in countless reports, presentations and pamphlets, a geographical overview of these projects is a user-friendly and efficient tool for gathering information in the early stages of planning.

HOW
Connect the database to either a national organization, department or ministry site that allows users to see the location and general information about a LID measure. Allow professionals and private citizens to upload projects, and create a standardized submission form for new entries. Ensure contact details for further information are listed, and any relevant links with more details about the project are provided.

PRIMARY EFFECT
Democratizes access to information and spreads awareness about low impact development stormwater management practices.

SECONDARY EFFECT
Simplifies the early stages of planning and design by gathering relevant reference projects in one place.

LIMITATIONS
Potential for poor quality control of submissions.

BASIS
Findings in chapter 3 indicate that there is a large amount of information about stormwater management and reference projects, but to make that information easily accessible helpful tools such as interactive databases can be useful.

Photo. 7.5

CLOUDBURST PLANS
Compose cloudburst plans for Norway's urban settlements

WHY
Climate change predictions indicate that Norway is headed towards a warmer, wetter and wilder average climate. Extreme rainfall events have already happened across the country, and in neighboring Nordic countries. Other countries such as Denmark and Sweden have created cloudburst plans to highlight planning and design strategies for flood mitigation

HOW
Create strategies for flood mitigation in urban settlements during and after cloudburst events.

PRIMARY EFFECT
Protect the health and well-being of residents, while also protecting critical infrastructure and personal and public property.

SECONDARY EFFECTS
Forces cities to consider stormwater management in all levels of planning and development.

LIMITATIONS
If fundamental information is missing, such an overview of local flood routes, then the resulting strategy will also be lacking. However, starting the process is important for future planning.

BASIS
Findings in chapter 4 indicate that other countries have come further in their work to safeguard their urban settlements from heavy rainfall events, and that it is time for Norway to follow suit.

Photo. 7.6

BLUE-GREEN POSTER
An analytical tool for landscape architects to plan multi-functional blue-green infrastructures, introduced in 1987. Uses the rain catchment area as the unit of planning, and combines environmental values and functions with social values and functions as well as technical values and functions (Thoren, 2016).

WHY
While there is no shortage of reports and strategies for stormwater management, there are fewer available tools for analyzing the landscape and planning for blue-green infrastructure. By using this approach, focus is on the blue and green elements in a landscape as well as how different land use areas interact.

HOW
Creating a series of thematic maps of the planning area (topography, infiltration potential, geology, land use and runoff effect). Areas are ranked within each thematic map and then intersect them to create a meta-map with designated areas for blue-green infrastructures.

PRIMARY EFFECT
Creates a map of potential areas for blue-green infrastructure that can also be multi-functional.

SECONDARY EFFECT
Allows planning other infrastructure while maintaining a focus on blue-green solutions.

LIMITATIONS
Sometimes it is hard to predict how much water the ground in urban settlements can infiltrate (ibid).

BASIS
Findings in chapter 3 indicate that Norway has a number of helpful strategies for implementing LID stormwater management but not as many practical tools for landscape architects to use in the planning process that directly deal with stormwater management issues in a holistic perspective.

Photo. 7.7

NORWEGIAN STANDARD
Create guidelines for LID measures in Standards Norway (SN). SN is one of Norway's three standardization bodies that works with creating standards for the physical implementations that landscape architects create.

WHY
By standardizing approaches and securing quality standards, landscape architects can work to ensure that future urban LID measures are built with quality processes and materials. Creating standards also provides broader access to using LID in urban settlements.

HOW
Assemble an interdisciplinary team of landscape architects, engineers and planners to create a set of standards for urban LID measures such as green roofs, rain gardens and bioswales.

PRIMARY EFFECT
Ensure that information is up to date with the latest research in Norway and that instructions are written for successful lid in urban Norwegian conditions.

SECONDARY EFFECT
Integrates current research into future design processes.

LIMITATIONS
Standards Norway is a professional tool, with paid access to information, which could prevent some parties from benefitting from further research. However, standards are an invaluable tool for landscape architects working to implement designs.

BASIS
Findings in chapter 3 and 4 suggest that Norway's progress with LID measure implementation is still in its early stages. By standardizing now, Norway is in a position to strengthen its competency significantly.

standard norge

Norsk Standard

NS-EN 12056-4

ICS 91.140.80
Språk: Norsk

LOD-tiltak
Utforming og dimensjoner

LID measures for stormwater managment
Part XX: Rain gardens, bioswales and green roofs

Fig. 7.5

LID CLASSIFICATION SYSTEM

Create a three-tiered classification system for LID measures that provides information about the level of daily use, wear and tear the measures can receive. Design choices for LID in Norway today are often based on literature from rain gardens and other measures in private gardens or areas with less use. By indicating a grade 1, 2 or 3 for the area the design can reflect the intended daily use.

WHY
Limitations Using LID successfully in urban settlements requires a classification system for LID that separates intensity of use. In the same way sewerage systems have different dimensions for different volumes and uses, or outdoor spaces are constructed differently depending on their surroundings, our understanding of LID measures also needs to be upgraded beyond the examples found in literature today.

HOW
The classification system can lay some ground rules for further design work, with measures in Grade 3 requiring reinforcement in the filter medium to avoid soil compression damages.

Grade 1 - for private residences and other private outdoor spaces such as roofs or courtyards.

Grade 2 - for semi-private or public urban settlements, including but not limited to: public parks, courtyards, roofs, streets and sidewalks

Grade 3 - for densely populated urban settlements, public parks school yards and playgrounds, roofs, streets and sidewalks

The classification system would categorize Deichman’s street project as a grade 2 project, as it is located on a relatively quiet street with little traffic.

PRIMARY EFFECT
Create parameters for design work that ensure the measure works as intended.

SECONDARY EFFECT
Can lead to lower maintenance costs over time.

BASIS
Findings in chapter 5 & 6 indicate that the LID measures in Deichman’s street are not optimized for their location in terms of wear and everyday use.

Photo. 7.8

RESEARCH-DRIVEN DESIGN
Using tools like the National LID database to connect researchers and designers working with LID measures.

WHY
Using research to support our design choices may sound obvious, but sometimes a site-design becomes so popular it influences future design processes. Without stopping to research the effectiveness of the design and its functionality, we risk re-iterating poor design choices, or assuming that popularity = quality.

HOW
Designers need to challenge themselves to form connections with researchers, and use an interdisciplinary approach when creating future urban LID measures. This could be a practical application for the national LID database mentioned above, where landscape architects looking to design a LID measure can connect with researchers.

PRIMARY EFFECT
Secures well-functioning urban LID measures.

SECONDARY EFFECT
Secures an interdisciplinary approach to the design process from an early stage.

LIMITATIONS
Time and resource constraints in the design process are some of the main barriers.

BASIS
Findings in chapter 7 suggest that scientific research, such as infiltration testing, can ensure better design practices .

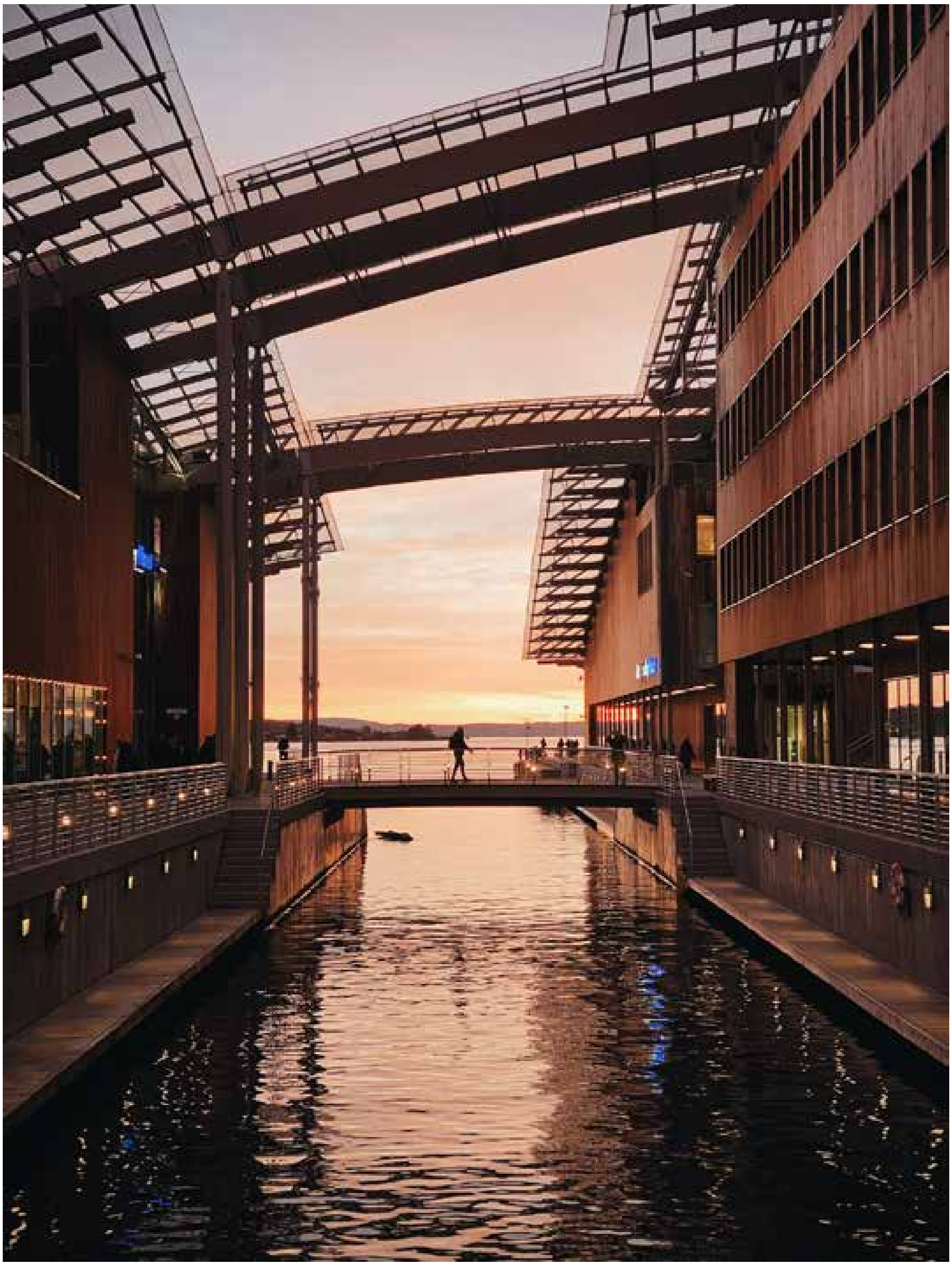


Photo. 7.9

8

CONCLUSION

This section adresses the following primary research question:

How can cities in Norway adapt to a wetter climate by implementing LID stormwater management?

CONCLUSION

This thesis researches the main challenges of stormwater management in urban settlements. It looks at modern approaches to stormwater management, and presents a set of actionable measures that landscape architects can use in the planning, design and maintenance of stormwater management measures in future urban LID projects in Norway's cities/urban settlements. In explaining what the challenges are, and possible methods of solving those challenges, the thesis also presents new research findings from a pilot project for LID stormwater management in Norway's capital city, Oslo. By gathering information from this project, and looking at Norway's existing legislation and frameworks for stormwater management, the resulting solutions are placed in a context of landscape architecture and current practice. In examining barriers to LID stormwater management many planners and designers point to a lack of information/ knowledge in their municpalities. LID stormwater management is still in a relatively early stage in Norway, but results are starting to come in. Translating those results into actionable measures for future projects is crucial if Norway intends to meet its climate targets and greenhouse gas reduction targets, and implement sustainable development into urban planning and design.

We have learned more about the triple threat facing Norway's cities and urban areas; namely more and heavier rainfall due to climate change, a reduction in permeable surfaces through urbanization processes and sewerage systems with no additional capacity.

We have also learned more about Low Impact Development as a tool for stormwater management, and how it can be implemented in urban settlements.

Through field work with the Deichman's street pilot project we have learned more about how these LID measures work, and how they are perceived by residents.

These findings have been translated into solutions for future projects to ensure that LID stormwater management becomes a helpful tool in Norway's municipal toolbox. These solutions create room for LID measures to do more than stormwater management. They engage communities, create livable cities and contribute blue and green elements to urban settlements. They also reflect the challenges of creating public infrastructure, and show how many priorities can come together in a small area. Traditional stormwater management has been out of sight and monolithic in its aim, LID stormwater management, as part of the visible cityscape, needs to work harder to prove its worth.

LEARNING OUTCOMES

Through the process of researching and completing this assignment I have learned more about Norway's current challenges with stormwater management. While this thesis is not project-based in the sense that it presents a site design, it is centered around one specific project in Oslo. It discusses current theories and analyzes frameworks- both international and local. It uses findings from literature, field work and other sources to come up with a set of solutions to current barriers in LID stormwater management work

In writing this thesis I have learned how to plan a research project, gather and analyze relevant information and translate my findings into academic contributions. I have followed a research process from theory to conclusion using relevant methods for my research.

In the process I have gained insight into how Norway's stormwater treatment operates today, and what challenges climate change poses to these systems. I have also learned more about the aggregate effects of climate change, urbanization and faulty sewerage systems. My work has shown that the use of LID in stormwater management is a relevant topic, and one that needs to be developed continuously as the field of stormwater management continues to evolve.

CHALLENGES

The biggest challenge in writing this thesis is being confident in work and my academic contribution to the field of landscape architecture.

Deciding what to keep was also a significant challenge when creating final drafts of this assignment. Through the course of my work with Deichman's street, I have become increasingly interested in Norway's sewerage systems and operations underground. However, writing from a landscape architecture perspective, it did not make sense to include too much material on these topics, and focus instead on relevant topics for our field of study.

Writing during a pandemic, and spending almost every day since the middle of March in the same spot, is incredibly challenging. Sitting at home without my classmates to talk to on a daily basis has been a lonely existence. Fears over Covid-19, worrying about friends and family abroad and entering the job market at an uncertain time are all concerns that have affected my work. It became important for me to submit my thesis on time, to the best of my abilities, and I am looking forward to a restored sense of normalcy in the years to come.

WHAT COULD BE DONE DIFFERENTLY?

With more time, I would have done more field work in Deichman's street to gather infiltration results for colder seasons. I would also have like to conduct follow-up surveys of residents and passers-by to see if attitudes to LID measures in their area changed with the changing seasons.

I would also have liked to test one or more of my solutions, and maybe worked on building an early version of the interactive national LID database.

FURTHER RESEARCH QUESTIONS

I would recommend that research continues in Deichman's street to see how infiltration rates change over time. It would also be interesting to see how plant compositions change over time in the various rain gardens and planted areas.

With a tangibly changing climate, it would be interesting to revisit Deichman's street in 5, 10 and 15 years time to see how the selected dimensions for the rain gardens are holding up. Are they still working for stages 1 & 2 of Oslo's 3-stage plan?

Photo. 7.10

FIGURE LIST

PHOTO LIST

1.1 Craig Whitehead/Unsplash (2018) [digital photograph]. Available from: https://unsplash.com/photos/GMSlf2w-w3U (Accessed 25.10.2020).
1.2 Mallory P. Chamberlain
1.3 Dagbladet/Norsk Folkemuseum (2014) [digital photograph]. Available from: https://digitaltmuseum.no/011013630656/flom-oslo-13-08-1957-oversvommelse-gate-under-vann (Accessed 09.09.2020).
1.4 Janicke Ramfjord Egeberg, Asplan Viak. [digital photograph]
1.5 Vårt Oslo (2020) [screen capture]. Available from: https://vartoslo.no/artsdatabanken-fns-klimapanel-klimaendringene/kraftig-styrtregn-skadelige-stormfloer-og-mer-flatt-velkommen-til-oslo-i-ar-2100/272209 (Accessed 29.11.2020).
1.6 NTB/e24 (2019) [screen capture]. Available from: https://e24.no/privatoekonomi/i/GGe9nB/skader-for-millioner-etter-ekstremregn-i-oslo (Accessed 25.08.2020).
1.7 NRK (2019) [screen capture]. Available from: https://www.aftenposten.no/oslo/i/Joq036/styrtregn-ga-oversvoemmelser-i-oslo-folk-ringer-oss-hele-tiden (Accessed 25.08.2020).
1.8 Nevedda Sivakumar [digital photograph]
2.1Ål Nik/Unsplash (2018). Available from: https-//unsplash.com/photos/5DX7ap7WI-8
2.2 Rob Curran/Unsplash (2017). Available from: https-//unsplash.com/photos/sUXXO3xPBYo/info
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2.4 Kevin Maillefer/Unsplash (2020). Available from: https-//unsplash.com/photos/6pNcx5Mh9cI
2.5 Mallory P. Chamberlain

3.1 Hanne Johnsrud (2014) [digital photograph]. From The Action Plan for Stormwater Management in the City of Oslo

4.1 (2017) [screen grab]. From the Skyfallsplan for Malmö.

5.1 Unknown author (approx. 1910). [Digital photograph] Available from: https://digitaltmuseum.no/011014562902/mollergata-skole
5.2 Rune Aavik (1993). [Digital photograph]. Available from: https://digitaltmuseum.no/011014301028/gatetun-i-deichmans-gate-ved-mollergata-skole
5.23-5.34 Google maps
5.35 Janicke Ramfjord Egeberg, Asplan Viak. [Digital photograph].

6.1 Mallory P. Chamberlain
6.2 Nevedda Sivakumar [Digital photograph].
6.3 Mallory P. Chamberlain
6.4 Mallory P. Chamberlain
6.5 Nevedda Sivakumar [Digital photograph].
6.6 Janicke Ramfjord Egeberg, Asplan Viak. [Digital photograph].
6.7 Nevedda Sivakumar [Digital photograph].
6.8 Janicke Ramfjord Egeberg, Asplan Viak. [Digital photograph].
6.9 Mallory P. Chamberlain
6.10 Nevedda Sivakumar [Digital photograph].
6.10.a Janicke Ramfjord Egeberg, Asplan Viak. [Digital photograph].
6.11 Mallory P. Chamberlain
6.12 Janicke Ramfjord Egeberg, Asplan Viak. [Digital photograph].
6.13-6.18 Mallory P. Chamberlain

7.1 Daniel Funes Fuentes/Unsplash (2017). Available from: https-//unsplash.com/photos/TyLw3IQALMs
7.2 Darya Tryfanava/Unsplash (2019). Available from: https-//unsplash.com/photos/4OFAEg9mxFc
7.3 Nick Night/Unsplash (2020). Available from: https-//unsplash.com/photos/-7ApLF3vbEg
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7.7 Deilia Giandeini/Unsplash (2019). Available from: https-//unsplash.com/photos/6y8TlqNj9Uc
7.8 Jacek Dylag/Unsplash (2019). Available from: https-//unsplash.com/photos/tERXiNBHWcw
7.9 Phil Aicken/Unsplash (2019) Available from: https-//unsplash.com/photos/ry_yTIzNj-M
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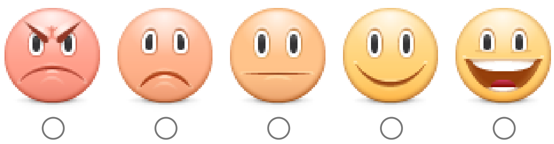
APPENDIX A
QUESTIONNAIRE FOR RESIDENTS

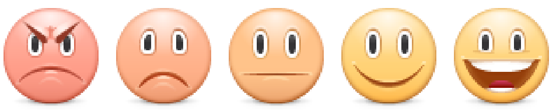
Created and processed by Mallory P. Chamberlain and Nevedda Sivakumar, 2019.

Mellom 2016 og 2017 ble Deichmans gate renovert. Vi vil gjerne få vite hva du som beboer synes om de ulike elementene som ble satt inn.

1) Hvor fornøyd er du med steinkulene i Deichmans gate?

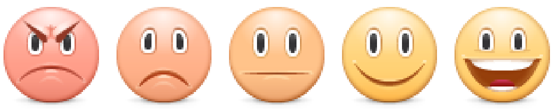


2) Hvor fornøyd er du med grus under trærne i Deichmans gate?



○ ○ ○ ○ ○

3) Hvor fornøyd er du med trærne i Deichmans gate?



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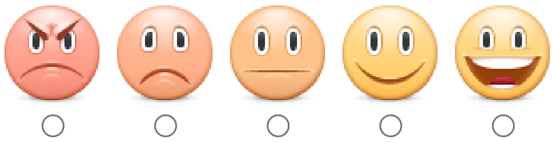
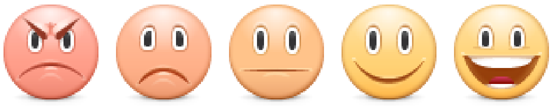
4) Hvor fornøyd er du med sykkelstativene i Deichmans gate?



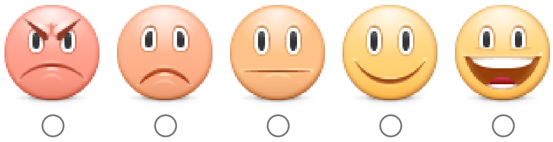
5) Hvor fornøyd er du med bedene i Deichmans gate?



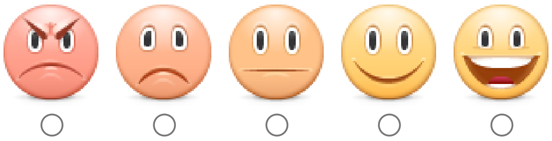
○ ○ ○ ○ ○

6) Har du noen kommentarer til disse elementene (steinkuler, grus, trær, sykkelstativ, bed)?

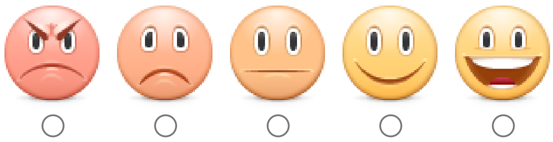
7) Hvor fornøyd er du med benkene i Deichmans gate?



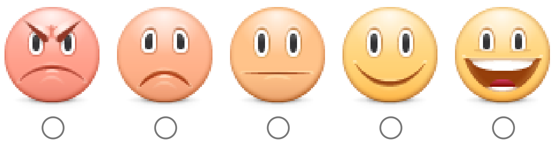
8) Hvor fornøyd er du med vannskulpturene i Deichmans gate?



9) hvor fornøyd er du med stier gjennom bedene?



10) Hvor fornøyd er du med overflaten på veiene i Deichmans gate?



11) Har du noen kommentarer til disse elementene (benk, vannskulptur, stier gjennom bed, overflate vei)?

I Deichmans gate er det bygget 9 regnbed.

Et regnbed er en type nedsenket plantebed som holder igjen overvann enten helt eller midlertidig.

Overvann er vann som kommer fra hustak, gårdsplasser, P-areal og vei.

Ved å sende overvannet inn i regnbed forsinker man vannet så rørene under oss ikke blir overbelastet med for mye vann. Dette er tiltak som kan forhindre oversvømmelser i kjellere og lignende, i tillegg til at vannet renses. Samtidig tar regnbed plass i gata.

Synes du det er positivt eller negativt med regnbed der du bor?

12) Synes du det er positivt eller negativt med regnbed der du bor?

13) Regnbed er et viktig tiltak

- ○ Helt enig
- ○ Enig
- ○ Nøytral
- ○ Uenig
- ○ Helt uenig

14) Det er riktig bruk av kommunens penger å legge inn regnbed.

- ○ Helt enig
- ○ Enig
- ○ Nøytral
- ○ Uenig
- ○ Helt uenig
- ○ Annet

15) Jeg føler ubehag ved at regnbedene brukes som pissoar

- ○ Helt enig
- ○ Enig
- ○ Nøytral
- ○ Uenig
- ○ Helt uenig

16) Jeg synes parkeringsplasser er viktigere enn regnbed i gata.

- ○ Helt enig
- ○ Enig
- ○ Nøytral
- ○ Uenig
- ○ Helt uenig

17) Kommentarer til påstandene.

18) Flyttet du hit før oppgraderingen av Deichmans gate i 2016?

- ○ Ja
- ○ Nei

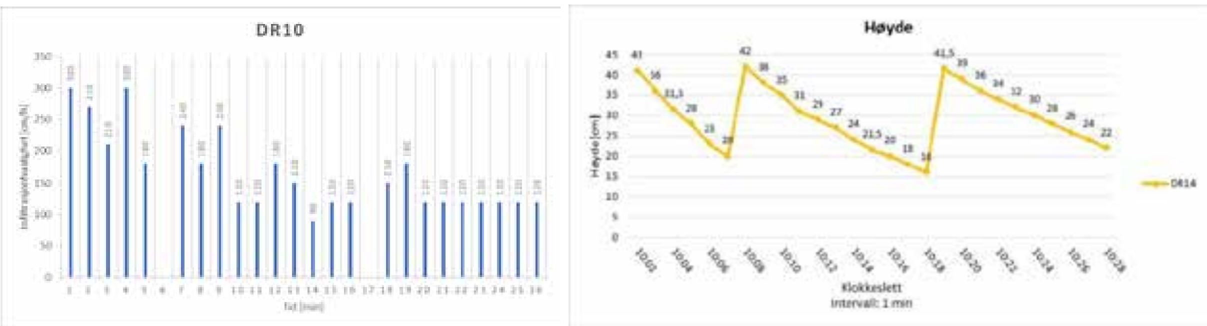
19) Hvordan opplevde du byggeprosessen under oppgraderingen av Deichmans gate? Var det spesielle ting som utmerket seg, enten positive eller negative?

20) Var oppgraderingene i Deichmans gate en påvirkende faktor i avgjørelsen din om å kjøpe eller leie i området?

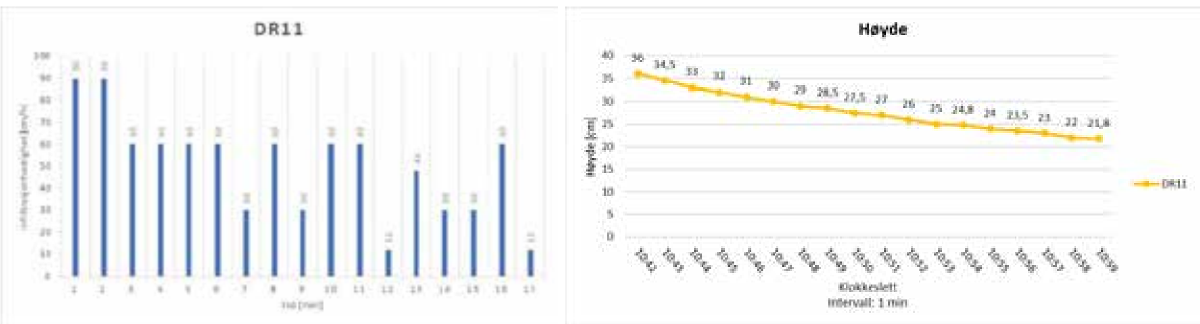
- ◯ Ja, det var en positiv påvirkende faktor
- ◯ Nei, det var en negativ motvirkende faktor
- ◯ Det var hverken positiv eller negativ påvirkende faktor
- ◯ Vet ikke

APPENDIX B
INFILTRATION TESTING RESULTS

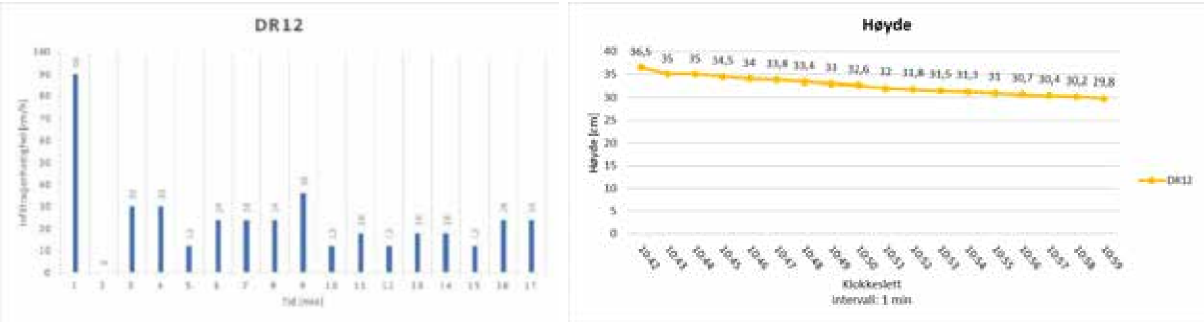
Recorded and processed by Mallory P. Chamberlain and Nevedda Sivakumar, 2019.



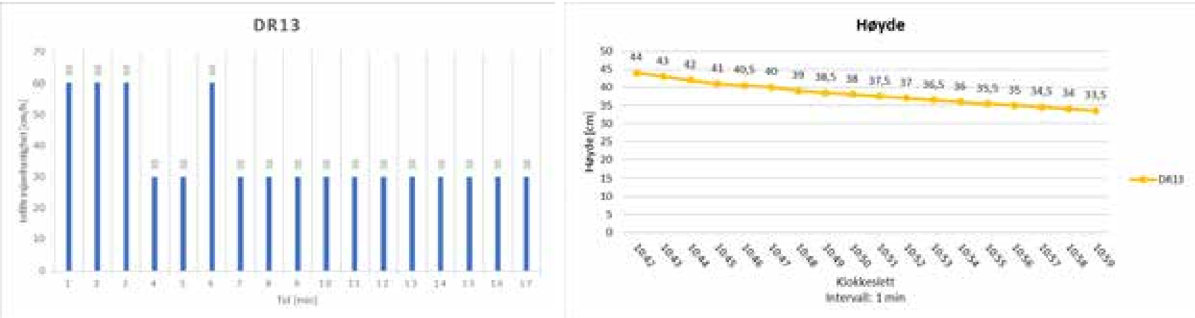
Figur 4: Diagrammene representerer 1. måling for regnbed 1, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 2 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 120 cm/h.



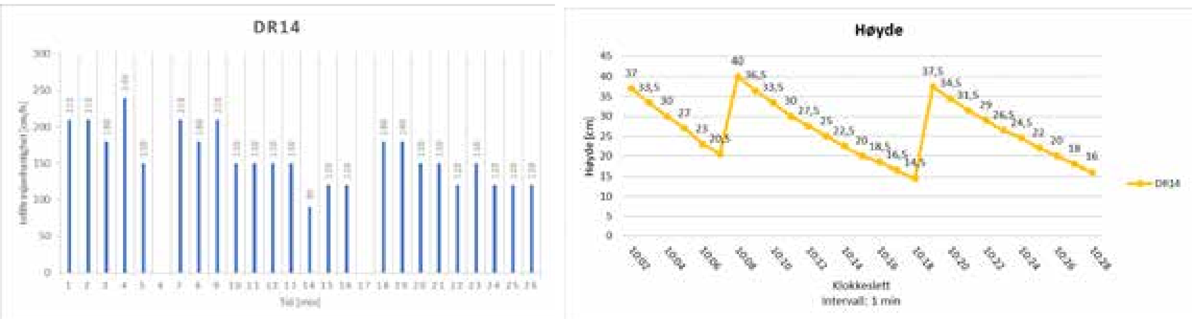
Figur 5: Diagrammene representerer 2. måling for regnbed 1, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



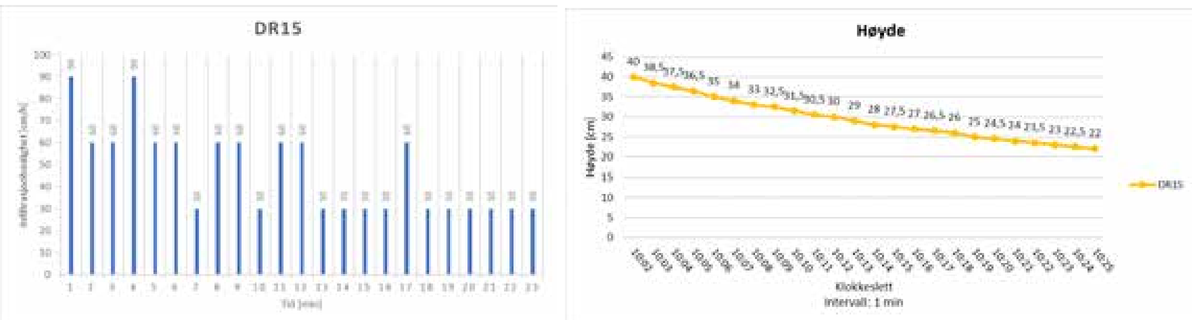
Figur 6: Diagrammene representerer 3. måling for regnbed 1, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 24 cm/h.



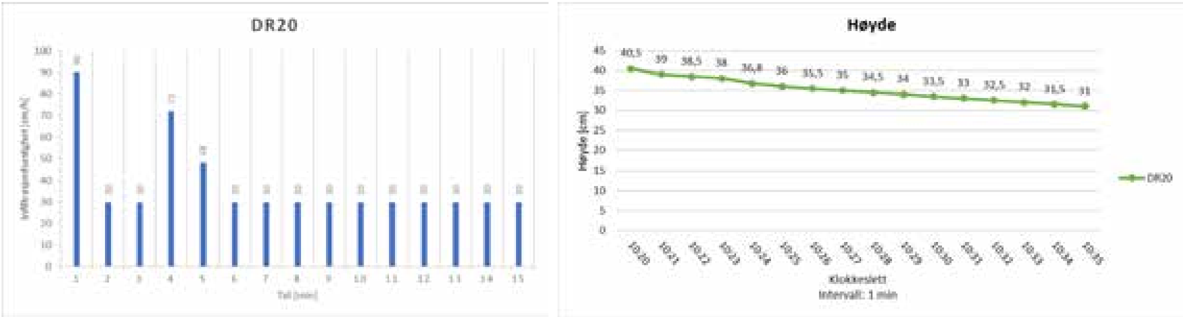
Figur 7: Diagrammene representerer 4. måling for regnbed 1, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



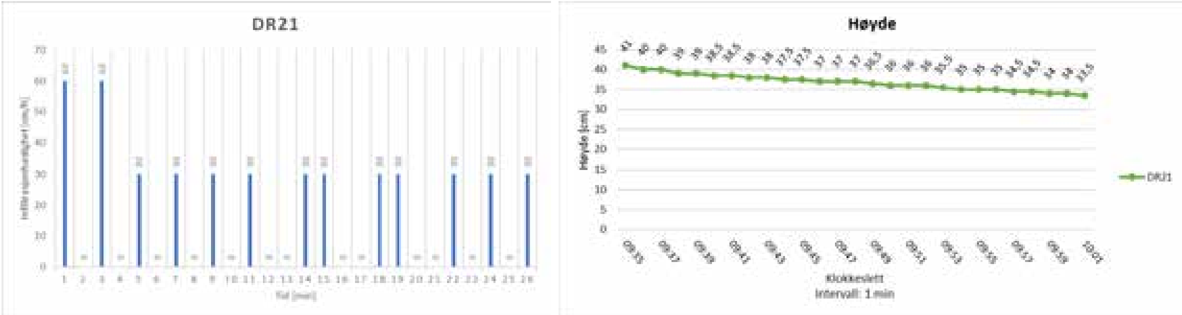
Figur 8: Diagrammene representerer 5. måling for regnbed 1, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 2 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 120 cm/h.



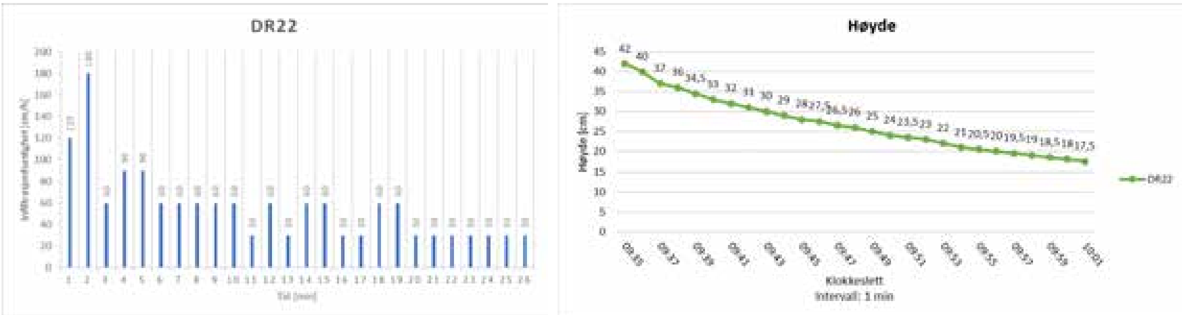
Figur 9: Diagrammene representerer 1. måling for regnbed 1, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



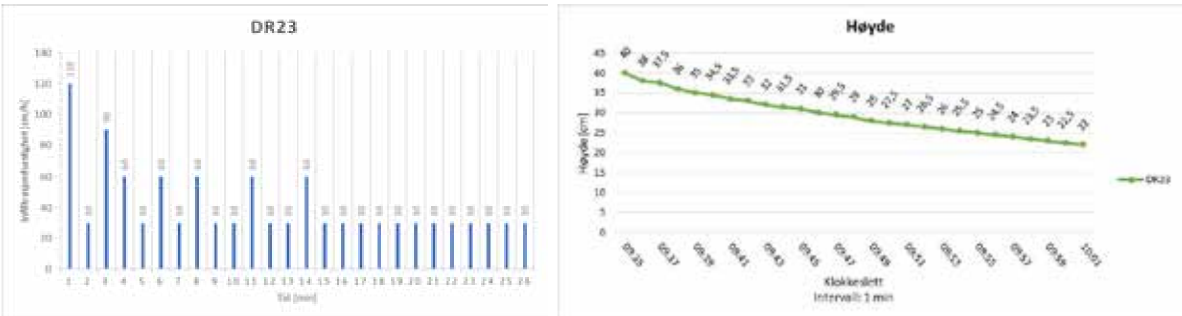
Figur 11: Diagrammene representerer 1. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



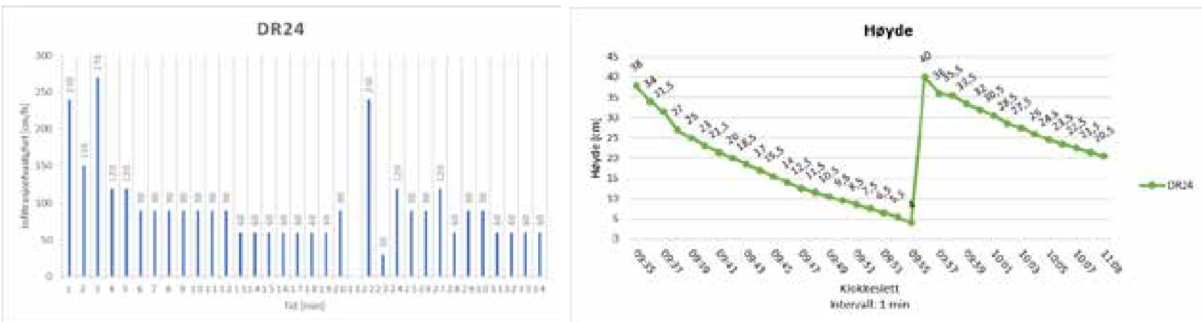
Figur 12: Diagrammene representerer 2. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



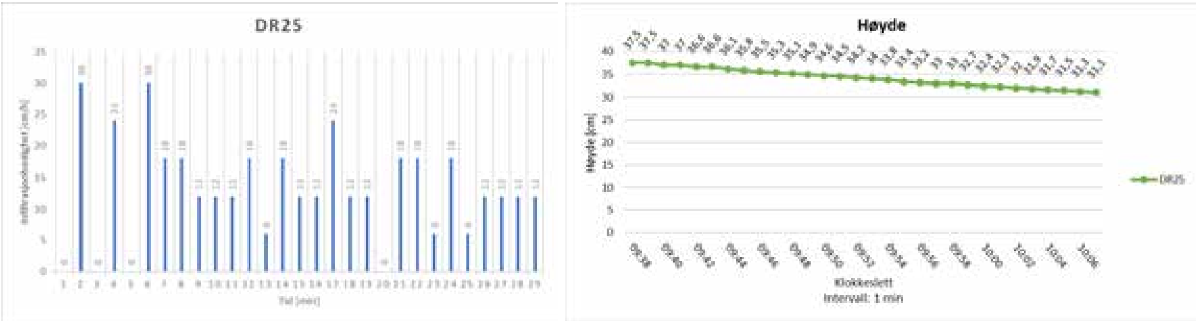
Figur 13: Diagrammene representerer 3. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



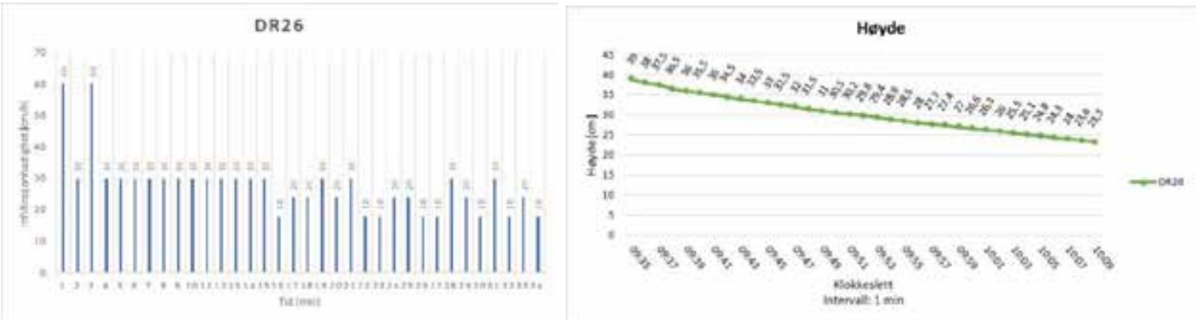
Figur 14: Diagrammene representerer 4. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



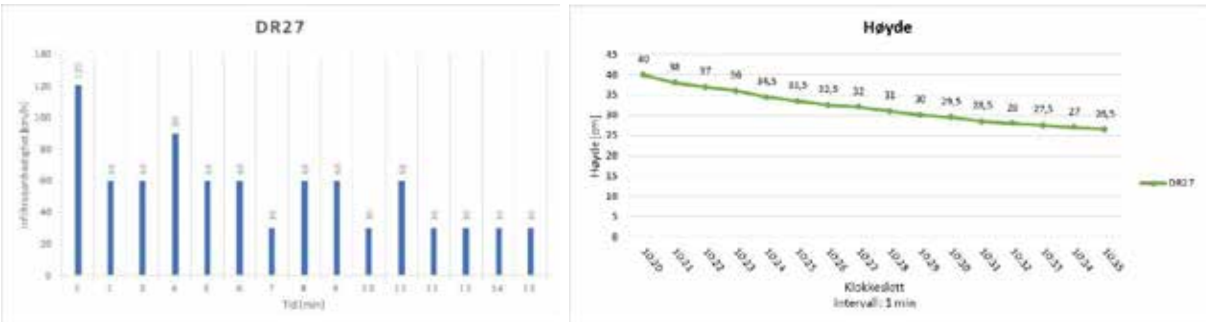
Figur 15: Diagrammene representerer 5. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 1 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 60 cm/h.



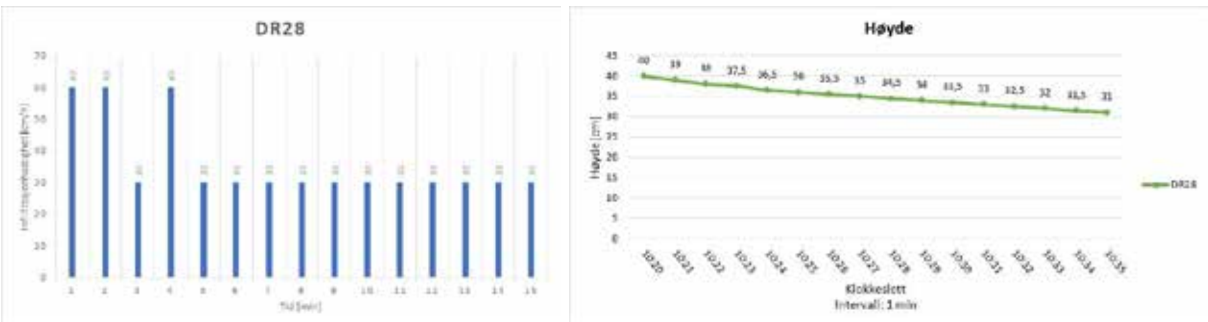
Figur 16: Diagrammene representerer 6. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 12 cm/h.



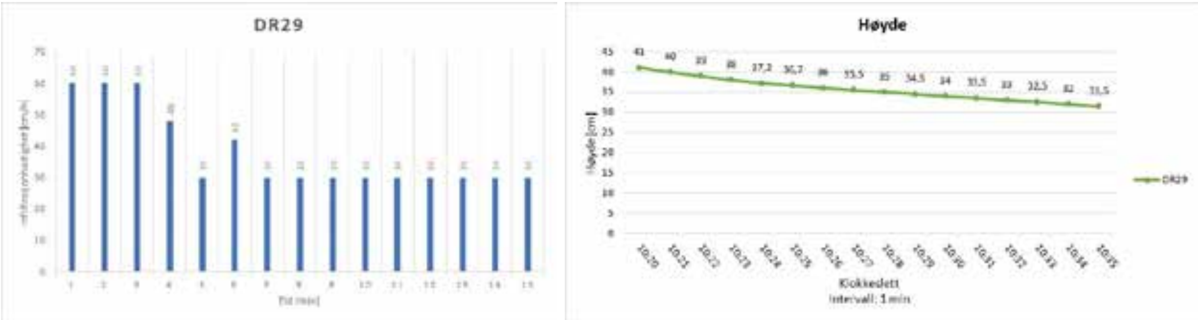
Figur 17: Diagrammene representerer 7. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 18 cm/h.



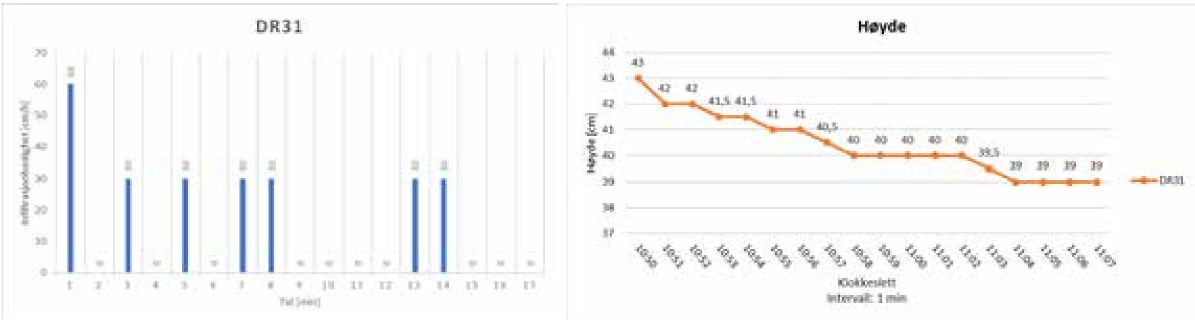
Figur 18: Diagrammene representerer 8. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



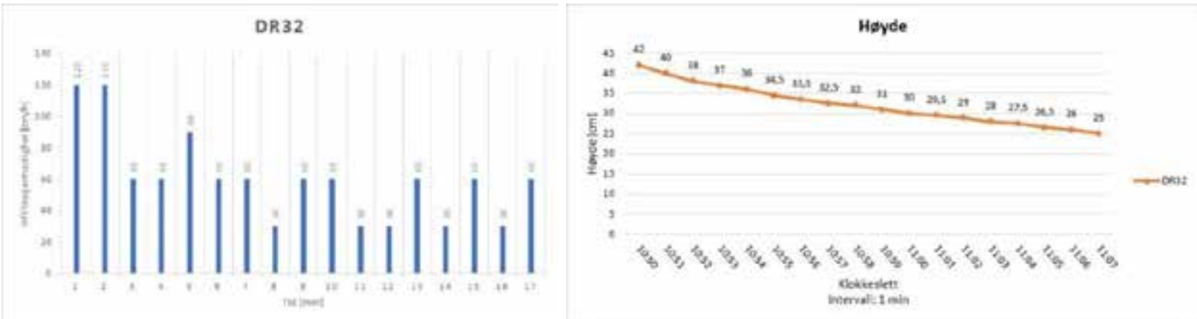
Figur 19: Diagrammene representerer 9. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



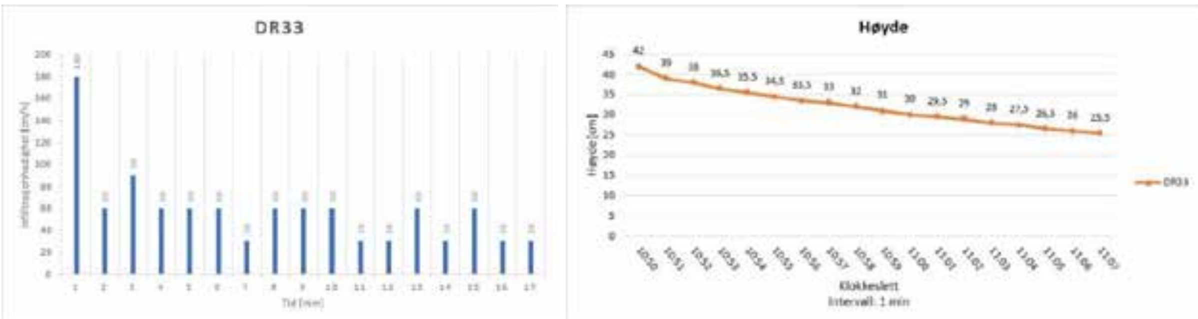
Figur 20: Diagrammene representerer 10. måling for regnbed 2, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h



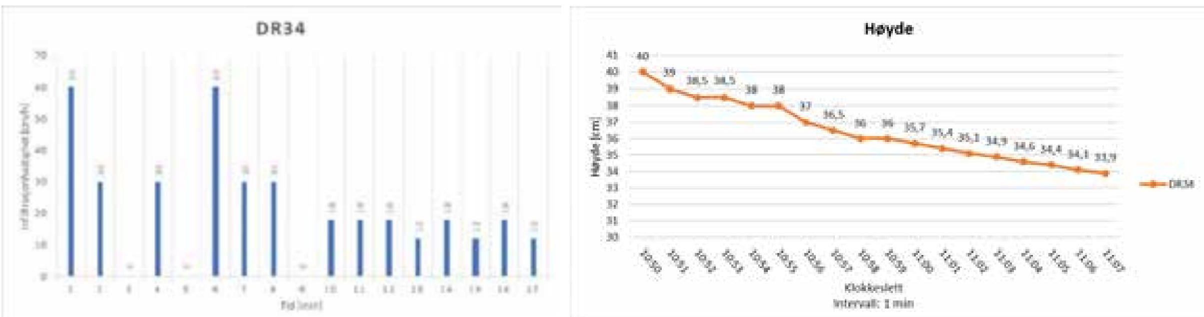
Figur 22: Diagrammene representerer 1. måling for regnbed 3, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.

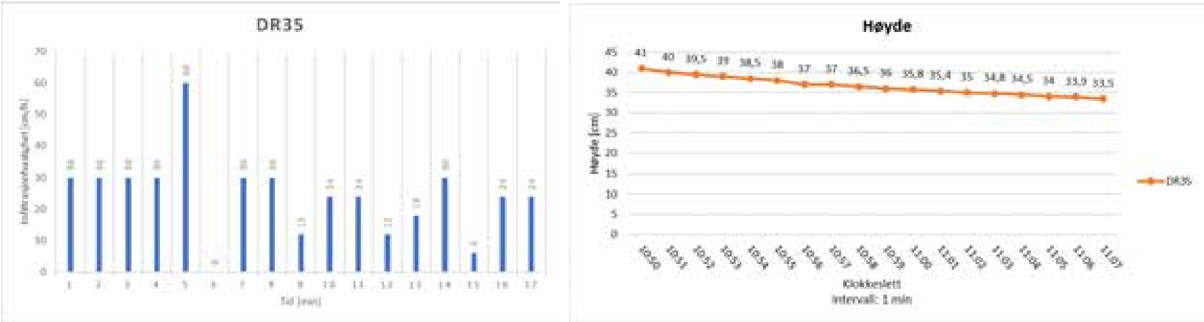


Figur 23: Diagrammene representerer 2. måling for regnbed 3, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 60 cm/h.

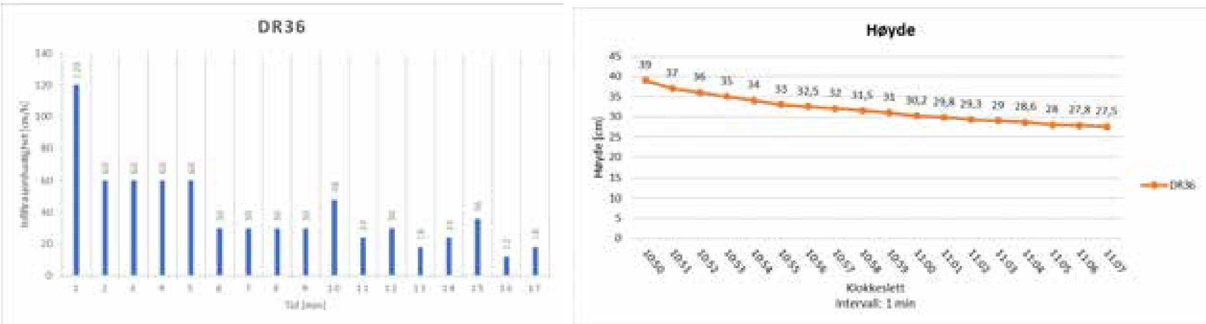


Figur 24: Diagrammene representerer 3. måling for regnbed 3, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.

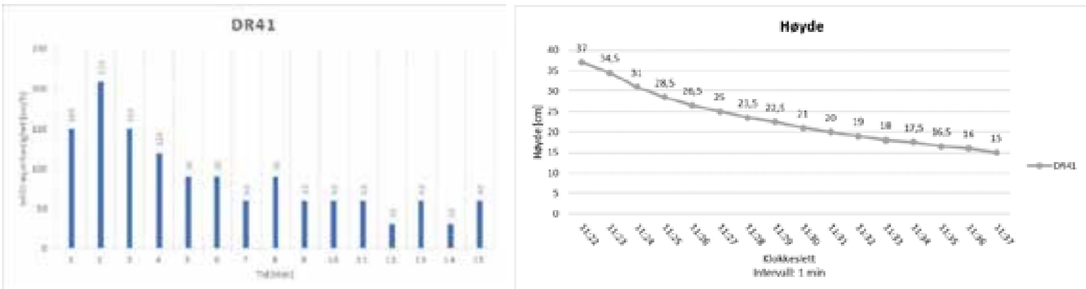




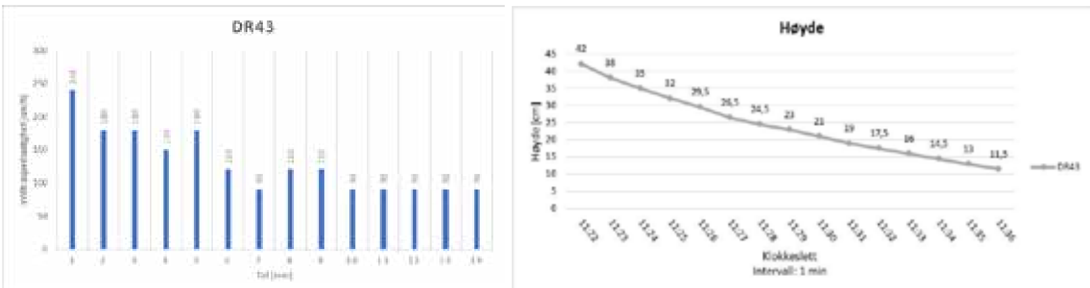
Figur 26: Diagrammene representerer 5. måling for regnbed 3, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 24 cm/h.



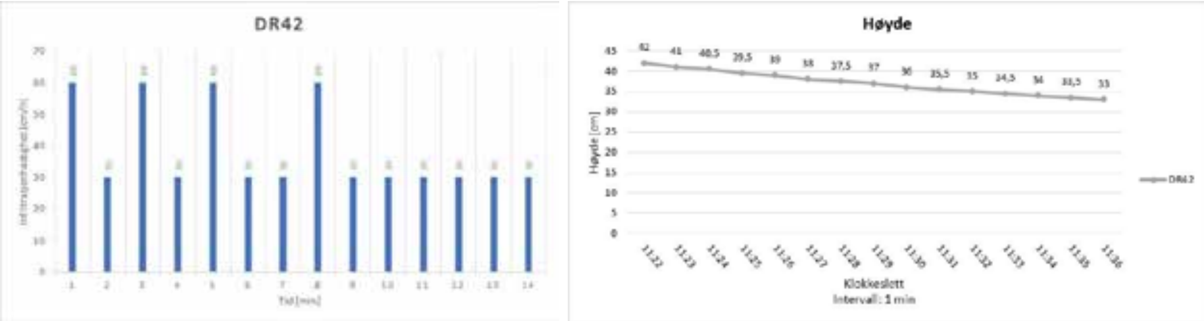
Figur 27: Diagrammene representerer 6. måling for regnbed 3, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 18 cm/h.



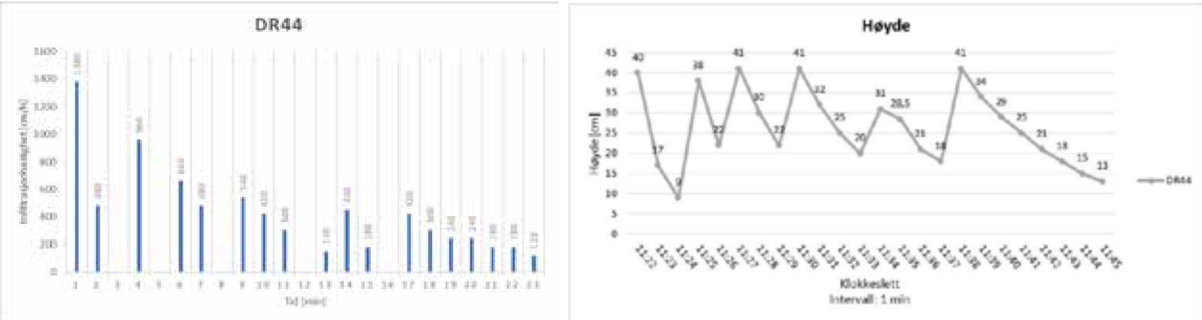
Figur 29: Diagrammene representerer 1. måling for regnbed 4, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 60 cm/h.



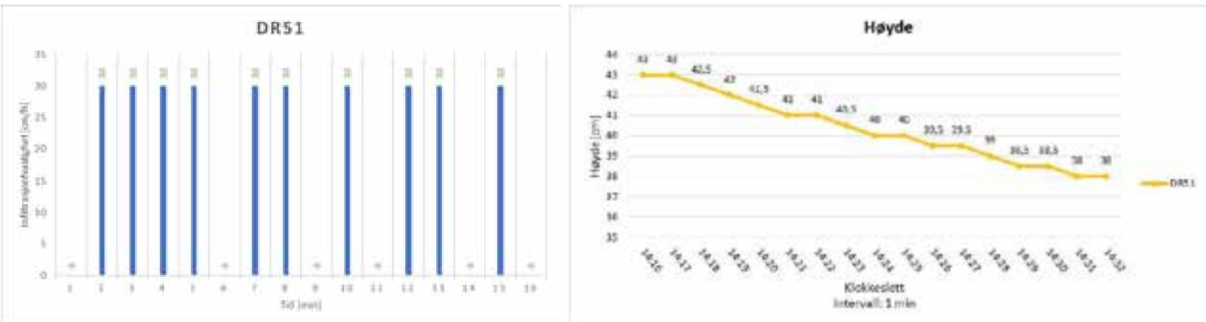
Figur 30: Diagrammene representerer 1. måling for regnbed 4, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 90 cm/h.



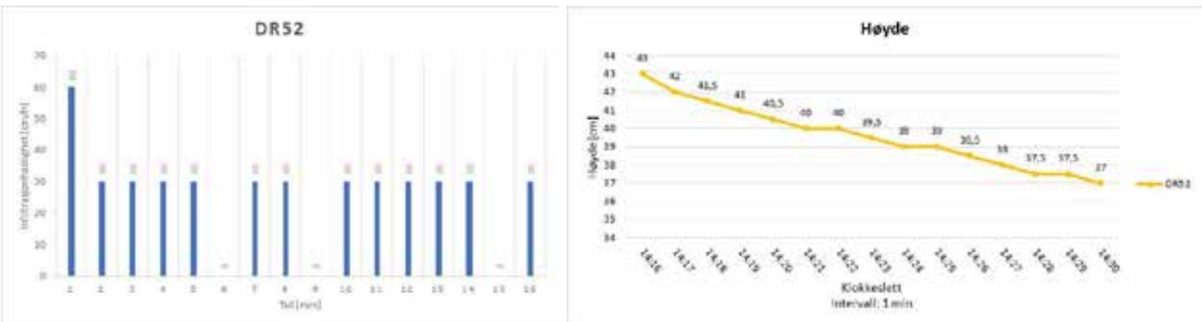
Figur 31: Diagrammene representerer 2. måling for regnbed 4, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



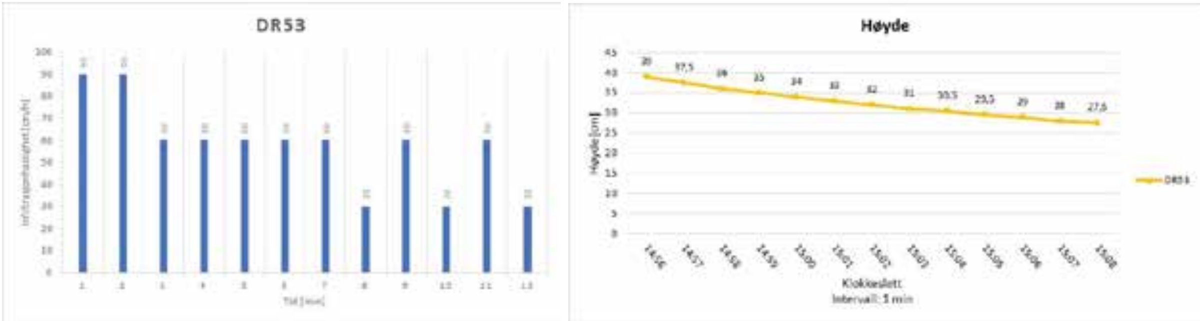
Figur 32: Diagrammene representerer 4. måling for regnbed 4, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 5 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 120 cm/h.



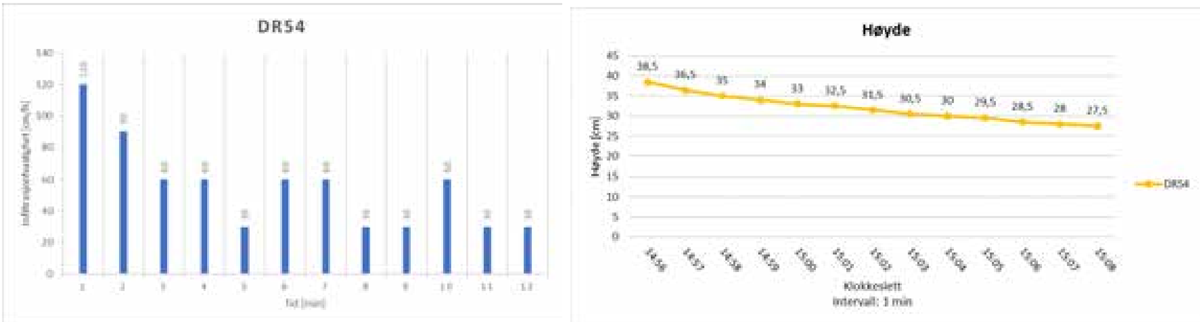
Figur 34: Diagrammene representerer 1. måling for regnbed 5, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



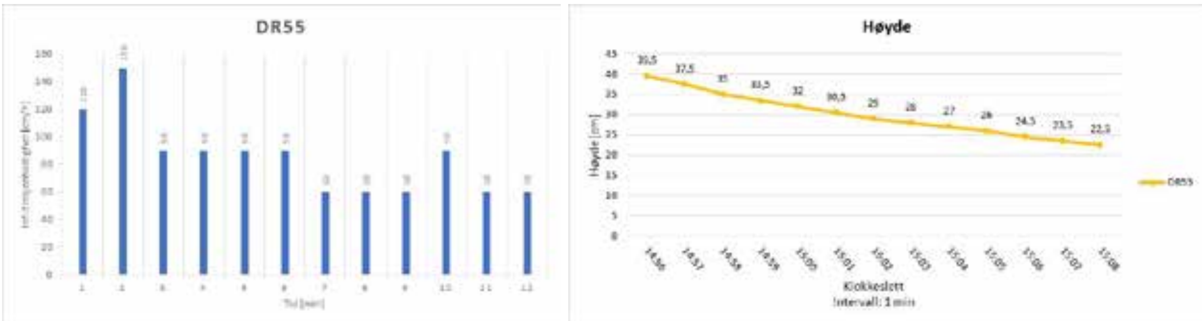
Figur 35: Diagrammene representerer 2. måling for regnbed 5, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



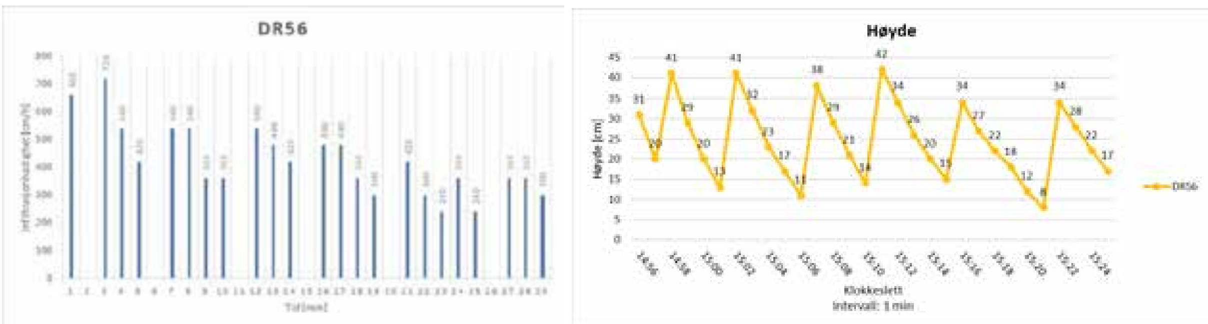
Figur 36: Diagrammene representerer 3. måling for regnbed 5, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 60 cm/h.



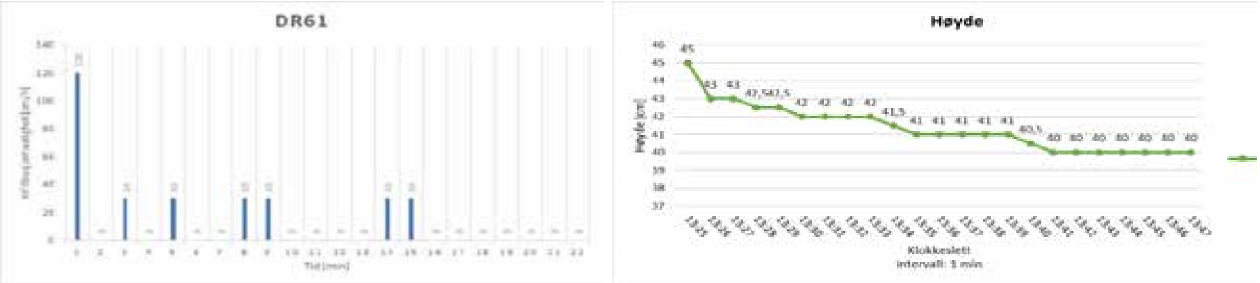
Figur 37: Diagrammene representerer 4. måling for regnbed 5, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



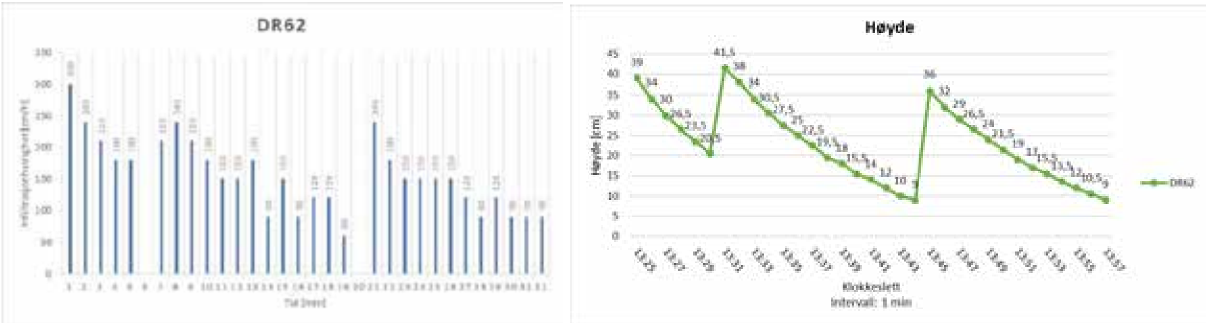
Figur 38: Diagrammene representerer 5. måling for regnbed 5, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 60 cm/h.



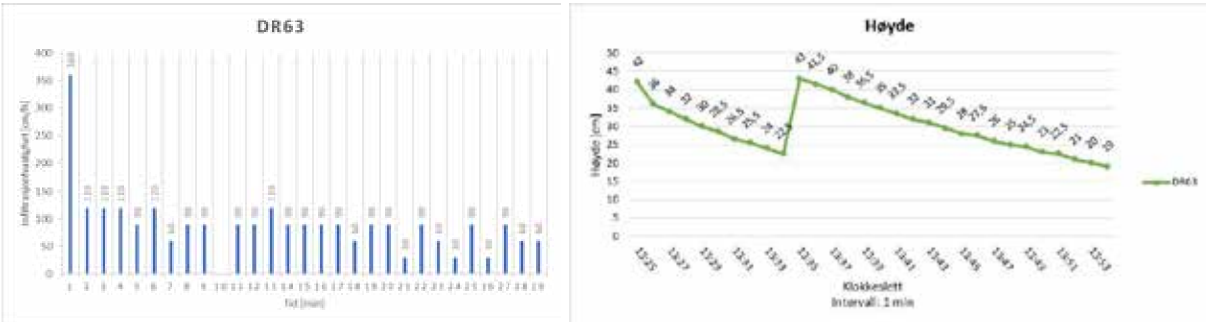
Figur 39: Diagrammene representerer 6. måling for regnbed 5, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 6 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 300 cm/h.



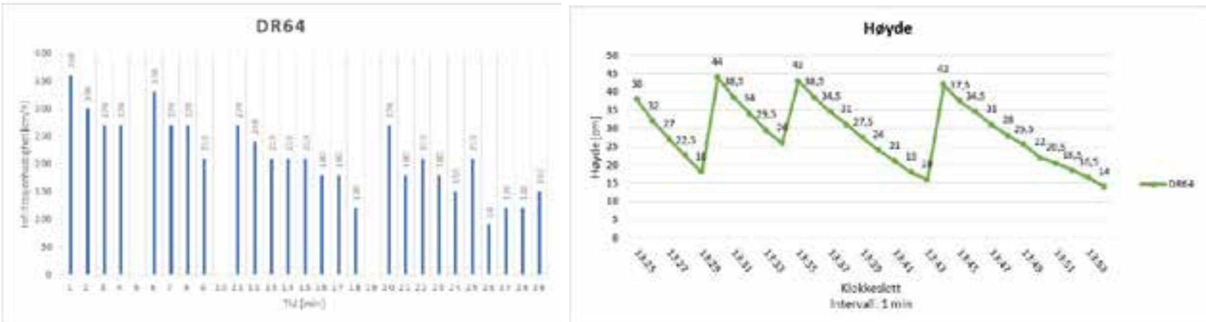
Figur 41: Diagrammene representerer 1. måling for regnbed 6, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



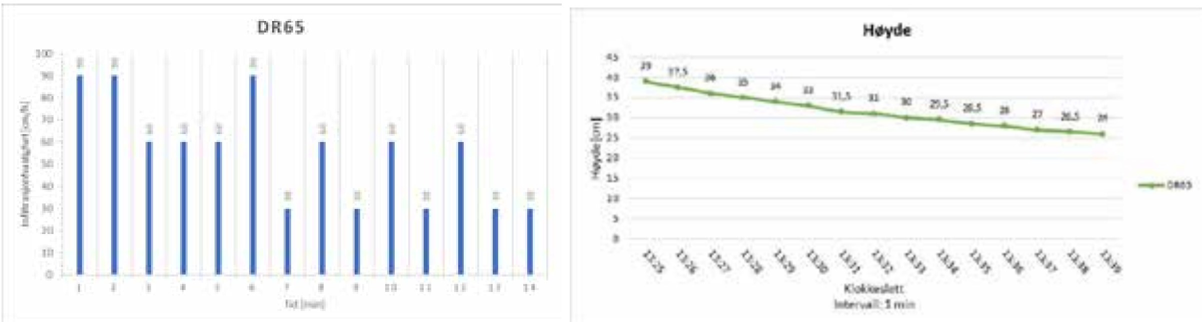
Figur 42: Diagrammene representerer 2. måling for regnbed 6, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 2 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 90 cm/h.



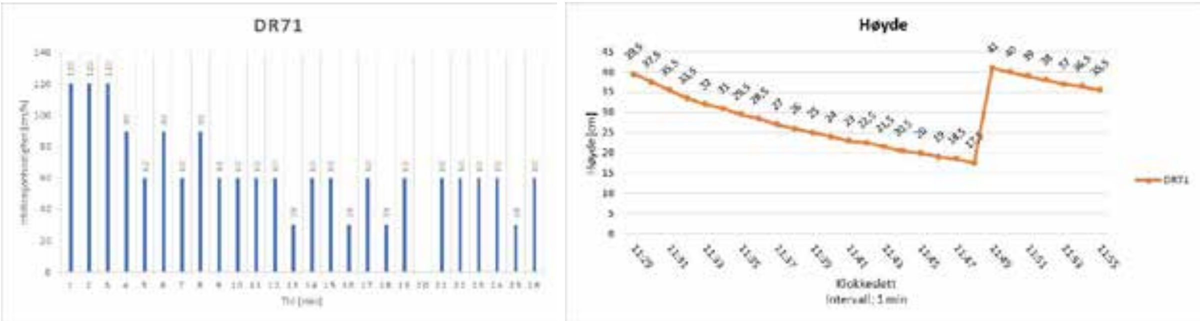
Figur 43: Diagrammene representerer 3. måling for regnbed 6, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 1 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 60 cm/h.



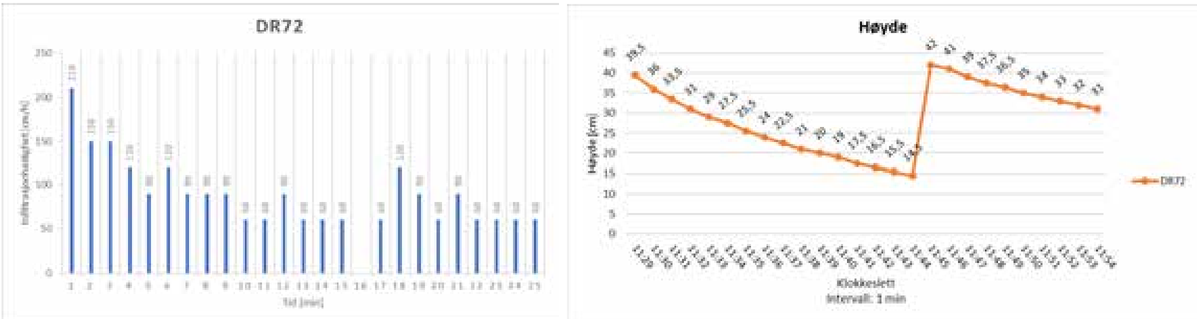
Figur 44: Diagrammene representerer 4. måling for regnbed 6, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 3 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 120 cm/h.



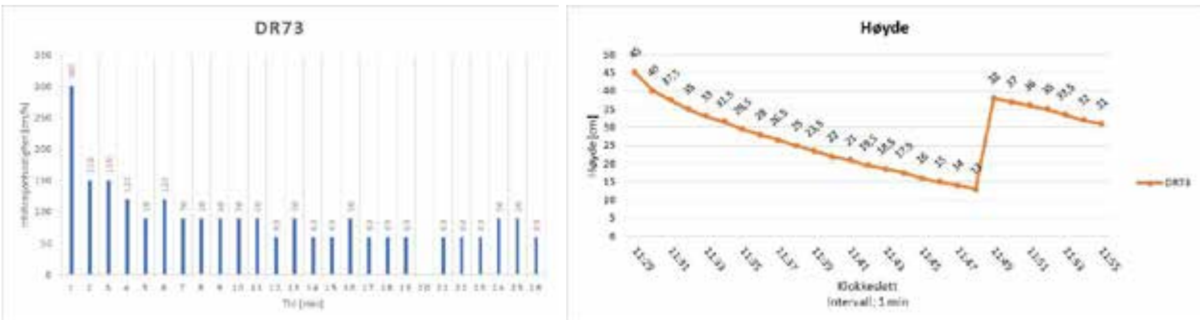
Figur 45: Diagrammene representerer 5. måling for regnbed 6, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



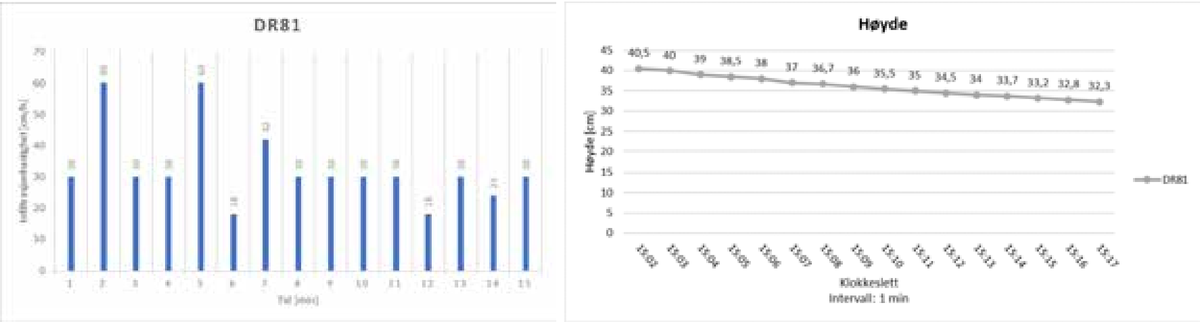
Figur 47: Diagrammene representerer 1. måling for regnbed 7, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 1 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 60 cm/h.



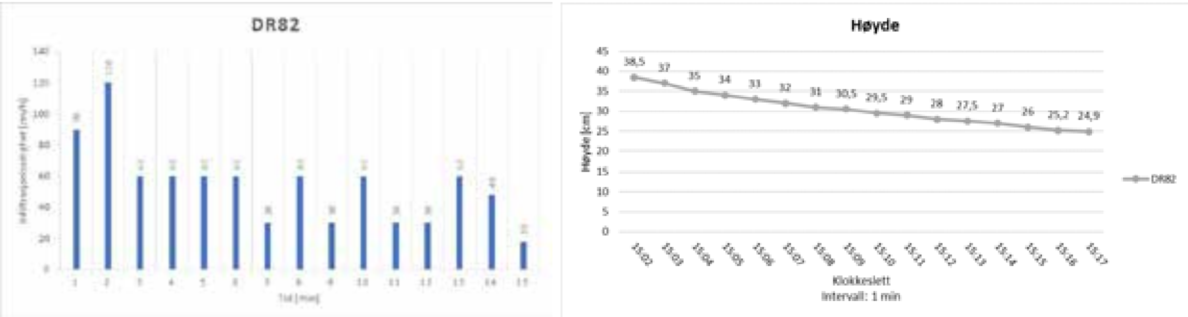
Figur 48: Diagrammene representerer 2. måling for regnbed 7, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 1 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 60 cm/h.



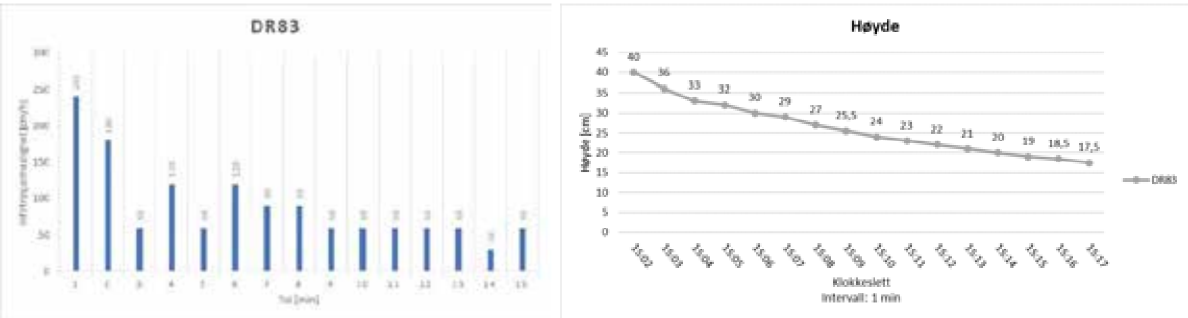
Figur 49: Diagrammene representerer 3. måling for regnbed 7, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 1 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 60 cm/h.



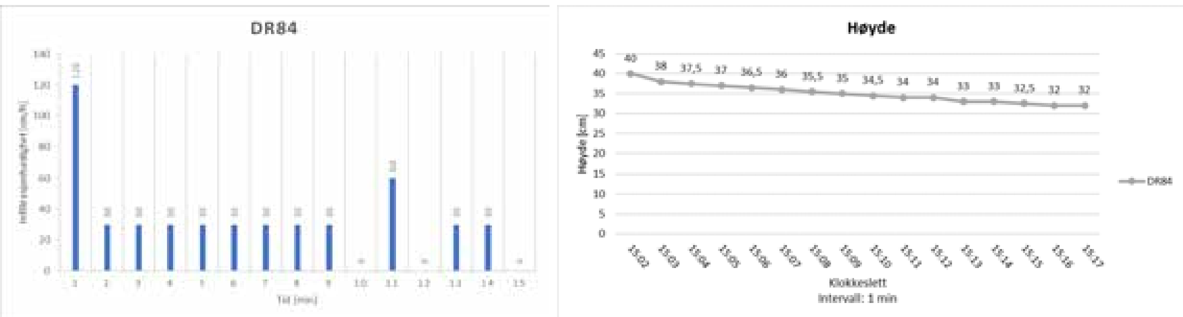
Figur 51: Diagrammene representerer 1. måling for regnbed 8, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



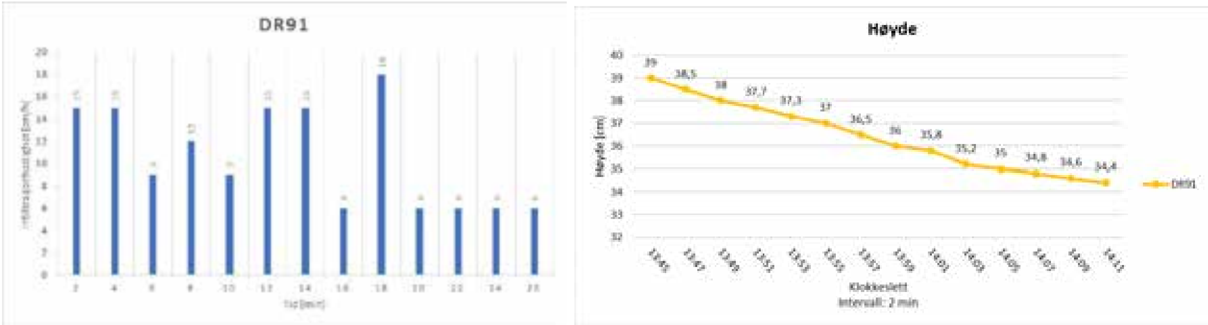
Figur 52: Diagrammene representerer 2. måling for regnbed 8, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



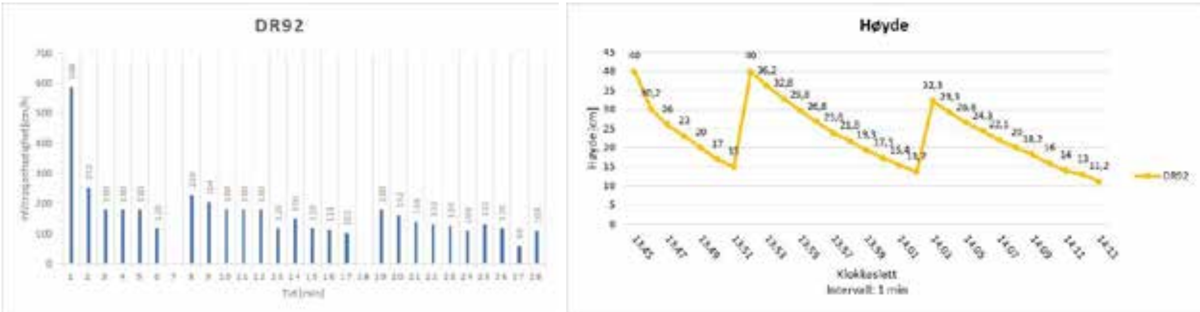
Figur 53: Diagrammene representerer 3. måling for regnbed 8, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 60 cm/h.



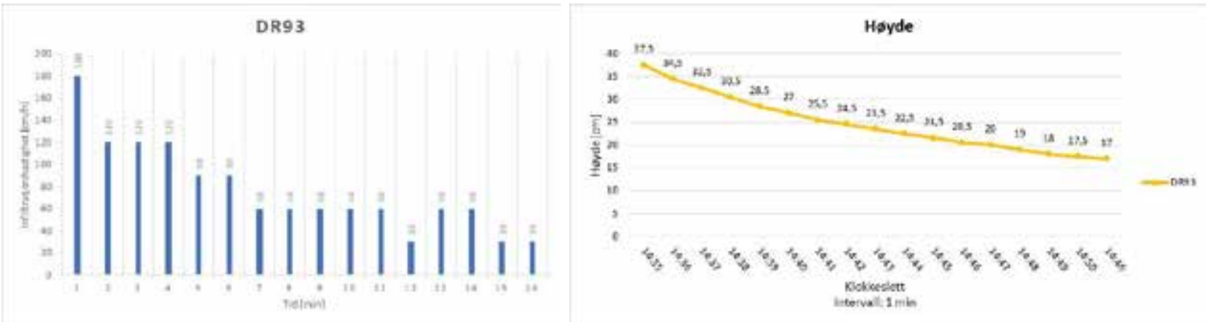
Figur 54: Diagrammene representerer 4. måling for regnbed 8, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



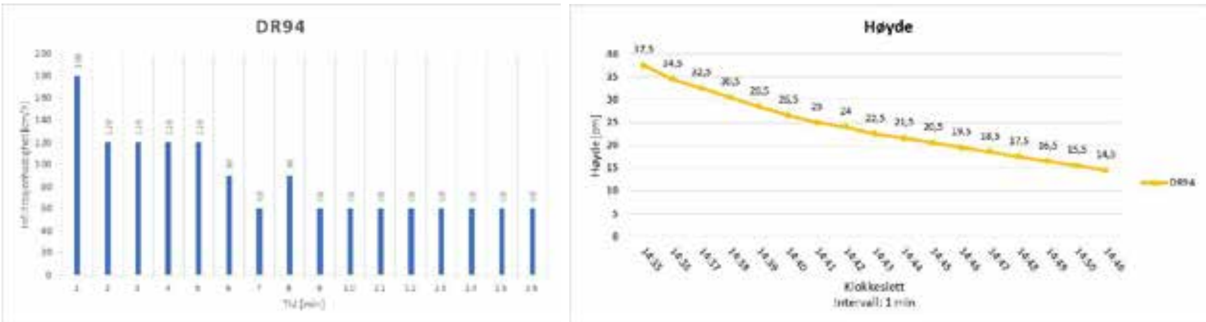
Figur 56: Diagrammene representerer 1. måling for regnbed 9, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 6 cm/h.



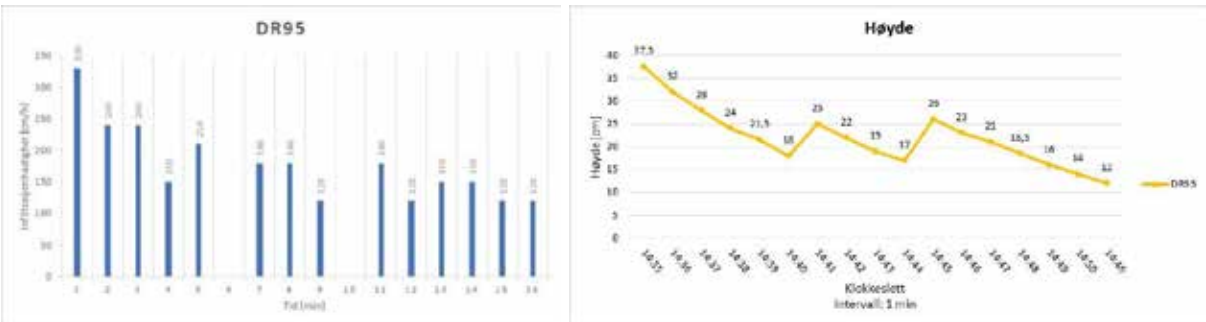
Figur 57: Diagrammene representerer 2. måling for regnbed 9, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 2 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 108 cm/h.



Figur 58: Diagrammene representerer 3. måling for regnbed 9, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 30 cm/h.



Figur 59: Diagrammene representerer 4. måling for regnbed 9, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Infiltrasjonshastighet ≈ 60 cm/h.



Figur 60: Diagrammene representerer 5. måling for regnbed 9, og viser infiltrasjonshastighet (venstre) og endring i vannhøyde (høyre). Det er utført 2 påfyll av vann under denne målingen. Infiltrasjonshastighet ≈ 120 cm/h.

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