



CHALMERS
UNIVERSITY OF TECHNOLOGY



Assessment of low impact development in road and street planning

Case study at Telthusbakken in central Oslo

Master of Science Thesis in the Master's Programme Infrastructure and Environmental Engineering

DANIEL HAMMERLID

Department of Civil and Environmental Engineering
Division of Geo Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
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Department of Civil and Environmental Engineering
Division of Geo and water Engineering
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover: Urban road and street section with integrated LID solutions
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SUMMARY

Climate change and urbanization puts heavy pressure on today's water systems due to increased rain intensities and development of impervious surfaces. As a result, cities and their road and street environment in urban Norway is subject to more frequent flooding and water related damages. Moreover, the urban watersheds are subject to various pollutants and thereof both short and long-term contamination, affecting both humans, animals and plants. Low impact development (LID) is a practise within stormwater management that in recent years has been recognized as most suitable to face these problems. The LID strategy aim at mimicking nature's way of managing water through infiltration, detention and storage. Using LID in the urban environment will decrease risk of flooding and water related damages, but also give rise to a more natural environment with several positive impacts on the citizens and urban ecosystems. This report was founded as Statens Vegvesen¹ was interesting in further investigation of LID for urban roads, streets and their environment. Moreover, it provides a general and easily understandable guide to the most important areas within LID, to make any stakeholder involved in a road or street project understand the concept and its possibilities. A case study at Telthusbakken exemplifies how to plan and apply for LID to enhance the stormwater management in an urban area.

Key words: Low impact development, stormwater management, infiltration, storage, detention, road, street, urban development

¹ Statens Vegvesen (The Norwegian Public Road Administration)

Utvärdering av lokal dagvattenhantering i väg-och gatuplanering
Fallstudie av Telthusbakken i centrala Oslo
Examensarbete inom masterprogrammet **Error! Reference source not found.**
DANIEL HAMMERLID
Institutionen för bygg- och miljöteknik
Avdelningen för geologi och geoteknik
Chalmers tekniska högskola

SAMMANFATTNING

Klimatförändring och urbanisering medför på grund av ökad regnintensitet och fortsatt utveckling av ogenomsläppliga markytor en tung belastning på dagens vattensystem. Detta resulterar i att väg och gatumiljöer i städer allt oftare blir översvämmade och drabbade av vattenrelaterade skador. Utöver detta är även de urbana vattenmiljöerna utsatta för olika typer föroreningar som har skadlig påverkan på människa, djur och växter, både på kort och lång sikt. Lokal omhändertagande av dagvatten (LOD) har under senare år blivit erkänd som den mest lämpade dagvattenstrategin för att hantera dessa problem. LOD strategin utgår från att efterlikna naturens sätt att ta hand om vatten, vilket görs genom att infiltrera, fördröja och lagra regnvatten lokalt på nedslagsplatsen. Användande av LOD i den urbana miljön leder till minskad risk för översvämningar och vattenrelaterade skador, en grönare och mer naturlig stadsmiljö, vilket har flertalet positiva effekter på stadens invånare och ekosystem. Denna rapport är en bred undersökning av LOD i den urbana miljön, med speciellt fokus på väg och gatumiljön. Rapporten utgör en generell och lättförstått guide till de mest relevanta områdena inom LOD-planering för att intressenter i väg- och gatuprojekt skall kunna få förståelse för LOD-konceptet och dess möjligheter. Fallstudien vid Telthusbakken visar på hur LOD kan planeras och användas för att förbättra dagvattenhanteringen i ett urbant område.

Nyckelord: Lokalt omhändertagande av dagvatten, dagvattenhantering, fördröjning, infiltration, lagring, väg, gata, stadsutveckling

ACRONYMS AND GLOSSARY LIST

Detention: Containment of stormwater within a structure or vegetated surface

EPA: United States Environmental Protection Agency

Erosion: Mechanical wearing and grinding of a surface or object

Green roof: Roofs with constructed to function like a vegetated surface

Groundwater: Water stored underground in soil pores and rock fractures

Groundwater recharge: Stormwater percolation all the way through the subgrade to the groundwater table

Hydrology: The science of waters

Impervious surface: Surface with no ability to let through water

Infiltration: Process in which water percolates a surface downwards

Low Impact Development (LID): Stormwater management practice that mimic nature's way of managing water locally

Native plants and soils: Undisturbed natural soils and plants with origin from the site

Natural habitat: Natural environment that support animal and plant life

NOU: Norges Offentlige Utredninger, The Norwegian Governmental Investigations

Permeable Pavement: Pavement structure with ability to infiltrate stormwater

Pretreatment: Removal of pollutants or sediments prior the stormwater enter a LID unit

Retrofit: Redesign of urban environment with new technology (LID)

Runoff: All precipitation that runs off land and man-made constructions

Sedimentation: The process of depositing sediments

Storage: Containment of water

Stormwater: All precipitation that fall on falls on man-made surfaces

Swale: Open drainage surface designed to infiltrate, detain and convey stormwater

Urbanization: Process of people moving into urban areas

Watershed: Geographic area that drains into a specific discharge point

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1. INTRODUCTION

Before urbanization expanded to what it is today in our modern society, precipitation was naturally infiltrated through vegetated surfaces, trapped by plants, trees or stored in watersheds. Nature was in balance (Kaufman, et al., 2011). As urbanization started to grow, the ability to infiltrate and store water at the surface way was gradually taken away due to the establishment of impermeable surfaces that followed construction of houses, roads, streets and other infrastructure. Moreover, the natural waterways and drainage patterns where starting to change (Butler & Davies, 2012).

Today, vast urbanization has created cities that comprises almost entirely of impermeable surfaces that have as little or no ability to infiltrate and store water at the surface. Instead, the conventional way of managing precipitation has been to rapidly catch and convey it in piped infrastructure underground (Norskt Vann, 2012)¹. Besides this, previously open streams have been put in pipes underground to give room for surface development (Norges Offentlige Utredninger, 2015)².

Concerning the Norwegian society, almost 80% of the population lives in urban environment and the number is rapidly growing. The high demand for property and land naturally creates a great need of new roads and streets, which further contribute to increased establishment of impermeable surfaces without capacity to hold and infiltrate water (Mays, 2001). Thus, larger accumulated amount of water will reach the piped infrastructure underground.

Along with urbanization, climate change has in recent years been recognized as the main threat to society (Grum, et al., 2006). Higher average temperatures, greater volume of precipitation and more frequently occurring high intensity rain are the characteristic impacts from climate change. Amongst these, the higher rain intensity has been pointed out as the particular concern (Oslo Kommune, 2013)³. The reason for this is that vast amount of stormwater reach the drainage systems rapidly, which during the most extreme weather events give rise to flooding in the urban environment. There are numerous issues related to these flood events such as damaged infrastructure and property, interrupted public mobility, delayed goods transportation and public safety. Besides the direct impact, flooding and stormwater related damages give rise to huge economic cost (Norges Offentlige Utredninger, 2015).

Besides affecting human life and infrastructure directly during flood events, stormwater also have negative impact on the urban ecosystems as pollutants are transported with the stormwater and discharged into the waters and soils during rain events (Burton & Pitt, 2002). Pollutants such as metals, PAH, salt, oil spill, torn particles from road, tyres, noise and vibration are of large concern in the urban road and street environment (Kempke, 2014). Moreover, infiltration of polluted stormwater runoff is of great concern as it risks long-term contamination of urban groundwater aquifers (Kidmose et al, 2015). Winter road operations involving de-icing components are also of particular concern in this matter as salts both dissolve itself and other pollutants and thus increase the pollutant mobility in soils (Pitt, 2000). Furthermore, intensive runoff and flood events can cause stability issues in soils and lead to geo-hazards such as landslides (Kaufman, et al., 2011).

¹ Norskt Vann (Norwegian Water): a non-profit organization representing the Norwegian Water Industry

² Norges Offentlige Utredninger (The Norwegian Governmental Investigations): a work group appointed by the government or larger public agencies to conduct studies of public interests.

³ Oslo Kommune (The Municipality of Oslo)

1.2 Background

Today, climate change is a realised threat to the Norwegian society in terms of increased flood risk and water related damages. The extent of the impacts are depending on the nation's willingness to act and adapt (Norsk klimaservicesenter, 2015). The changed climate have resulted in altered hydrological conditions, leading to increased rain intensities and change rain pattern with a more frequent return of the heaviest rain (Grum, et al., 2006). As much as 60% increase in intensity for short-term rains and around 30% in yearly precipitation is expected in the future. An indication of the change and its presents is that the 50-year rain has occurred three times in the past 5 years in some regions in Norway (Norges Offentlige Utredninger, 2015).

As counteract to climate change and the increased urban stormwater related issues, Norwegian stormwater strategies have changed focus to put larger emphasis on local stormwater management and the use of low impact development (LID) solutions (Norges Offentlige Utredninger, 2015). Local Stormwater management implies that water should be taken care of at the site where the precipitation falls, instead of conveying it towards an underground system. Furthermore, LID is the practise within local stormwater management that mimic nature's way of managing water (Norskt Vann, 2012). This includes infiltration, detention and storage of stormwater via natural vegetation, constructed grass-and bio swales, infiltration trenches, ponds, open waterways and permeable pavement structures (Norges Offentlige Utredninger, 2015). Hence, by using LID, it is possible to decrease the peak surface runoff and peak flows into the stormwater infrastructure (Sintef Byggeforskningsinstitut, 2012)⁴ and therefore also decrease the stormwater related property damage, flood risk and required maintenance of subsurface systems (EPA, 2002)⁵.

LID in urban environment is also a mean of developing green infrastructure in the urban environment that have the ability to improve the urban ecosystems for both human, animals and fauna in several ways (EPA, 2016). Water quality improvement in streams and watersheds occur as stormwater pollutants are trapped in vegetation or soils during the infiltration process (Boyd, 2000). Moreover, biodiversity is increasing when natural habitats are brought back to the urban environment on the expense of previously impermeable surfaces. Furthermore, the increased amount of vegetation also improves air quality, reduce noise and vibration in the urban environment (Calkings, 2011).

Vast development of LID in the urban environment requires collaboration among all urban stakeholders that are involved or affected by the development (Norges Offentlige Utredninger, 2015). Moreover, establishment of LID systems requires engineering skills and knowledge in how ground properties, hydrology, landscape planning and stormwater pollutants will affect and interact with the design, functionality and the construction of the systems (Urban design tools, 2007). With this as background, this thesis was formed to further investigate how LID can be a part of road and street planning and an important aspect in future urban planning. A case study at Telthusbakken in central Oslo will be conducted to exemplify how LID can improve road and street stormwater management and what aspects that are important to think of during the planning phase.

⁴ Sintef Byggeforsk: a private research institute conducting research within technical and economic fields within construction engineering.

⁵ EPA: United States Environmental Protection Agency

1.3 Aim and objective

This thesis came about as Statens Vegvesen and the thesis writer had interest in further investigation of how local stormwater management and LID can be a part in road and street planning in the urban environment. This includes the study on strategies, governing requirements and objectives in the planning phase, potential risk and benefits with LID.

The thesis should give a broad understanding of LID and its core features in road and street development. The goal is to create a compact and straightforward guide to LID that can be used and understood by all stakeholders involved in road and street projects. Moreover, a case study is conducted to exemplify how an urban site can be retrofitted to improve the stormwater management capacity.

A set of research questions stated below are the starting point in the investigation. These are not specifically chosen with the purpose of reaching a quantitative or definite answer, but to give a solid knowledge base and insight to the topic.

- What urban properties are governing the possibility to use stormwater infiltration for road and street stormwater management?
- What hydrological properties are governing the possibility to establish LID the road and street environment?
- What ground properties are relevant to investigate to decide the suitability of LID?
- What types of LID units are relevant to use in the urban road and street environment? What are the most relevant issues in stormwater management for urban road and street?
- Is there a national LID strategy for the road and street environment in Norway?
- What are the key features in a long-term sustainable strategy using LID?
- What are the keys to reach successful LID in road and street planning?
- What are the benefits and disadvantages with stormwater infiltration units?

1.4 Limitations

The objective of the report is broad and as each area in itself is a research field, it is therefore certain that not all relevant aspects can be covered. The report focus on aspects related to how LID can be a part in urban planning, specifically for roads and streets. For further reading about general drainage and water management in the road and street environment, the reader is recommended to study the road engineering handbook N200 Vegbygging (2014), chapter 4 from Statens Vegvesen.

The reader should keep in mind that the report is a guide meant to explore LID as a part in road and street stormwater management and not a report with technical focus. The reason for this is the wish of addressing a broad group in urban planning, including not only water engineers, but land and property owners, project managers, landscape planners and entrepreneurs as well.

Only simplified calculations are made in the case study and hence this does not fully conclude to what extent the LID solutions improve the site. The solutions are also chosen according to what I as a writer and researcher in the matter think would be most beneficial for the site and hence maybe not the most economic and realistic solution.

1.5 Method and approach

A literature study was chosen to be the primary source of information of the thesis. This because the thesis has a broad and open scope that somewhat requires a qualitative approach. Moreover, the choice of focusing on a literature study was made due to the wish of producing a report that can provide broad understanding in LID for all potential groups involved in a road and street project rather than investigate a specific area within the practise. Hence, the report is in many aspects a planners guide to low impact development, without direct technical focus.

Various sources such as books, reports and scientific papers from researches, private and public companies and agencies are used to gather information. However, for some parts of the thesis, it has been the aim to use local national information to increase the validation for the Norwegian urban environment. Therefore, some parts of the thesis is built up from guidebooks of practise, governmental agency reports and other institutions that have impact strategy and design of stormwater systems in Norway. A full day seminar on LID at Norway environmental agency and related report provided much relevant discussion input and study material with regards to Norwegian stormwater strategies.

The report is divided into six parts to make it easier for the reader to follow. The different parts and their objective are presented below.

Part I - Issues and challenges in stormwater management

Part I introduce the reader to the fundamental issues with stormwater. The purpose with this chapter is to enlighten the reader about the issues and its interconnection with the urban landscape and human activities.

Part II - The Low impact development practise and core strategies

Part II describes the strategies in stormwater management in Norway, the practise of low impact development and the most important aspects in planning for LID in road and street projects in the urban environment. The objective with this chapter is to give the reader an understanding of the LID strategies and their role in current and future urban development.

Part III – Planning objectives and review of LID units

Part III takes the reader through the most fundamental planning objectives during the establishment of LID units. Following this is a review of the most relevant LID units for the urban road and street environment, such as grass-and bio swales, permeable pavement, storage units and conveyance controls. The objective is to create necessary understanding of the LID practise and its potential within urban road and street development.

Part IV - Concluding the literature study

Part IV concludes the literature study by answering and analysing the founding questions stated in the aim and objectives in the thesis. The aim with this is to link the different parts of the literature study and provide the reader with a good overview of the thesis.

Part V - Case Study

Part V contains the case study at Telthusbakken in Oslo. This part is somewhat concluding the thesis as it in a simplified way demonstrates how an urban site can be retrofitted with LID to improve a critical stormwater situation. The purpose with the case study is to show that

relatively small-scale changes can make significant improvements by making use of the LID. The outline of the case study is stated in the four bullet points below.

- Analysis and description of site and current problem
- Select locations to retrofit with LID units and illustrate the strategy
- Simplified calculations to demonstrate capacity
- Conclude and discuss suitability for new solution

Part VI - Discussion and conclusion

Part VI contains discussion and conclusion around the thesis, the most important findings and the case study. The aim with the discussion is to give the reader a wider perspective on the topic by reasoning around some of the key changes and challenges for private and public stakeholders.

PART I – ISSUES AND CHALLENGES IN STORMWATER MANAGEMENT

Part I introduce the reader to the fundamental issues with stormwater. The purpose with this chapter is to enlighten the reader about the issues and its interconnection with the urban landscape and human activities.

2. URBAN STORMWATER RUNOFF

This chapter gives a brief introduction to stormwater issues that are related to urbanization and impervious surfaces.

The natural water cycle is expressing the interrelation between precipitation, infiltration, evapotranspiration, surface water storage and groundwater storage (Mays, 2001). The urban water cycle however is a modified version of the natural water cycle due to the characteristics of urbanization (Norskt Vann, 2012). The change mainly inherits from the development of impermeable surfaces and underground water systems (Hatt & Fletcher, 2004). Instead of natural infiltration of precipitation at the site where it lands, it accumulates on impervious surfaces and create stormwater runoff. Thus, the ability to infiltrate stormwater into subgrade and recharge groundwater aquifers is generally taken away in today's dense developed urban environments (Butler & Davies, 2012).

Studies have shown that as little as 5% of urban stormwater infiltrates into deep subgrade meanwhile, 10-15% infiltrates shallow subgrade or top layers in soil (Mays, 2001). Instead, large urban areas have extensive underground stormwater sewers for conveying stormwater from inlets to discharge points in various recipients (Norskt Vann, 2012).

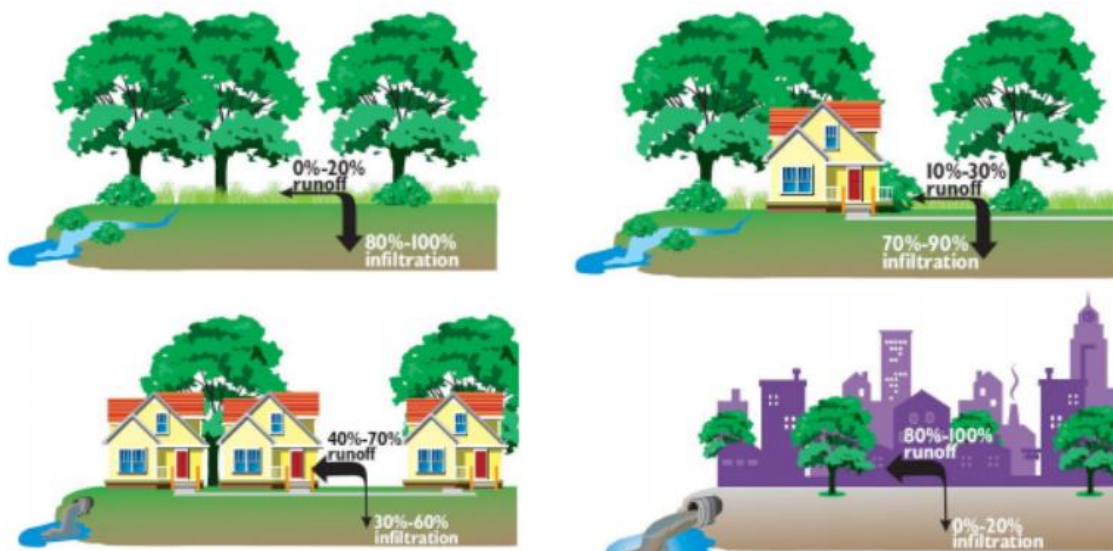


Figure 1: Illustration of how urban development affects the rate of infiltration in comparison to a natural environment (juneauwatersheds, n.d)

2.1 Runoff from road and street

Urban development and vast establishment of impervious surfaces have changed the runoff characteristics by increasing the stormwater volume, peak runoff and peak flow (Sintef Byggeforskningsinstitut, 2012). Moreover, these changes have altered urban drainage patterns

and waterways, increased the sediment movement and heavily decreased ability of natural groundwater recharge are other consequences (Kaufman, et al., 2011).

2.1.1 Increased stormwater volumes

Increased development of areas with impermeable surfaces in combination with intense heavy rain give rise to larger volumes of stormwater than before. The impact from this is; more frequent flooding and areal loss due to capacity issues, erosion on infrastructure installations, waterways and the creation of new drainage patterns. Moreover, this also mean that urban areas with combined sewer systems will convey larger stormwater volumes to treatment plants and hence decrease the available capacity to manage the more critical wastewater (Burton & Pitt, 2002).

2.1.2 Increased Peak runoff and peak flow

A higher peak runoff and peak flow has several negative effects on the urban environment including rapidly overloading drainage systems, wear and erosion on the landscape and infrastructural installations. In time, the eroded landscape give rise to new waterways and drainage patterns, which can cause unexpected capacity issues (Butler & Davies, 2012).

2.1.3 Decreased groundwater recharge

Urban development and impervious surfaces is the main factor behind the lack of groundwater recharge. Combined with heavy urban construction, this is one of the main sources for settlement problems in the urban. Moreover, the low groundwater recharge lead to a higher stormwater load on surrounding environment and thus an increased risk of flooding, erosion of the environment and changed waterways (MacMullan & Reich, 2007).

2.1.4 Increased and changed sediment load

Large stormwater volumes, more intense runoff and peak flow cause wear and erosion on the urban landscape. As a result, larger loads of torn particles and material reach and settle in both surface and subsurface water systems, which decrease the capacity in the systems. Hence, increased sediment load is an issue that can be related to the risk of flooding. As sediments are transported and settled above ground, they also create designated paths for the stormwater and thereby contribute to local erosion and changed waterways (Burton & Pitt, 2002).

3. URBAN STORMWATER IMPACT ON THE ENVIRONMENT

This chapter describes the most relevant stormwater pollutants found in the road and street environment and the risk of groundwater contamination during stormwater infiltration through soils.

Stormwater is defined as precipitation that lands on and run off manmade constructions (Norskt Vann, 2012). Thus, the amount of stormwater created and its impact on the urban ecosystems directly related to urban development. Many of the stormwater related issues such as flooding, pollution and erosion have serious consequences for the urban environment, which affect human, animals and nature (Statens Vegvesen, 2014).

3.1 Impacts on urban ecosystems

The human impact on the urban ecosystems, due to urban development, is divided into six different groups; Reduction, fragmentation, substitution, simplification, contamination and overgrowth (Kaufman, et al., 2011). Each of these groups have one or several negative impacts on the ecosystems. The table below shows how ecosystems in urban watersheds are affected by urbanization and human impact.

Table 1: Manmade impact on ecosystems and the origin of issues. Inspired by: (Kaufman, et al., 2011; Malmqvist, 2002)

Impact on ecosystem	Origin of issue
Reduction of area	Loss of habitat due to development of the urban landscape
Fragmentation	Stormwater constructions divides natural habitats
Substitution of species	Species more suited for the developed urban conditions replace original species
Reduced biodiversity	Less variety in species in water recipients as vegetation is chosen to fit human requirements
Contamination	Heavy metals, solids, organic/inorganic compounds and other pollutants contaminate the ecosystems and its inhabitants
Overgrowth	Leakage from water infrastructure and untreated stormwater into soil and water recipients lead to overgrowth due to excess of nutrients

3.2 Traffic impact on stormwater quality

Urban traffic has significant impact on the environment. The road pollutants can spread and influence the air quality and environment within a distance of 500 meters and settle at roads, streets, vegetated surfaces, roofs and directly in the urban watersheds. The amount of pollutants created and its spread varies depending on vehicle and fuel type, traffic density and traffic activity. Queuing situations are of particular concern in thus matter as NO_x gases and hydrocarbons creates ground-level ozone (EPA, 2016). Furthermore, combustion of vehicle fuel discharge sulphur and nitrogen dioxide, which contributes to acidification (lowering pH value). This can have major effects on receiving soil or water if it does not have sufficient buffer capacity (ability to withstand acid without changing pH too much). Moreover, torn particles from road, vehicle coach, tyres, noise and vibration are other sources of traffic related pollutants that have negative impact on both human and environment (Trafikverket, 2011).

3.2.1 Road Salt

Road salt is the number one risk when considering stormwater infiltration to groundwater. No matter the choice of treatment prior the infiltration, salt perchlorates both soil and the vadose zone to the groundwater (Burton & Pitt, 2002). As a highly solvable pollutant, salt easily

transported from the road during a rain event. Moreover, high levels of chlorides in the environment can be harmful for both the surface environment and the groundwater aquifers (Trafikverket, 2011) since it contributes to dissolving other pollutants.

3.2.2 Traffic accidents

Traffic accidents and leaking of hazardous liquids can have major impact on eco systems. In many cases, these accidents give rise to point source pollution, meaning the contamination stays at the site. However, if contamination is released on highly permeable ground connected to groundwater or surface watersheds, the spread can be extensive and treatment problematic (Jacobsen, 2014).

3.3 Pollutants in urban stormwater

Ecosystems in and around urban areas are subject to impact from a large variety of pollutants (Mays, 2001), which has led to urban runoff being recognized to be among the biggest threat to water environments (Malmqvist, 2002). It is a particularly important matter to address when planning for infiltration solutions due to the risk of surface, soil and groundwater contamination (Pitt, et al., 2001). Pollutants inherits from many different sources and human activities ranging from industrial operations, leaking wastewater pipes, construction process and material to private persons driving their car or doing their lawn mowing (EPA, 2015).

The pollutant concentration fluctuates between storm events due to the amount of pollutants that have time to accumulate, which in turn depends on the weather conditions (Egodawatta, 2007). Moreover, the rain intensity further governs how much of the accumulated pollutants that are released from the surface (Grebel, et al., 2013). In this matter, particle bound pollutants most often need higher rain intensities to follow the runoff compared to dissolved particles (Bjørklund, 2011).

Table 2: Overview of the most common pollutants in the road and street environment, their source and impact on the environment. Inspired by: (Kempke, 2014; Bjørklund, 2011; Norskt Vann, 2012)

Pollutant	Source of pollutant	Impact on the environment
Polycyclic aromatic hydrocarbons PAH	Incomplete combustion of fossil fuel and heating of organic material	Toxic for humans and animal
Metals	Construction material, wear of tyres, engines, vehicle erosion	Toxic for plants and animals (depending on type and concentration)
Petroleum hydrocarbons and oil products	Runoff from street and road, parking lots, spills and leakage	Toxic effect on nature and wildlife
Suspended solids	Construction material, vehicles, roads, streets, plants	Increased turbidity and transportation of pollutants
Nitrogen and phosphorus	Deposition from atmosphere, sewer overflow, human and animal waste	Risk of Eutrophication due to rapid and vast plant growth
Road salt	Winter operations using de-icing compounds on roads and streets	Risk of groundwater pollution and dissolving of other pollutants

3.3.1 Solids

Solids are categorised into four groups: grit, gross, suspended and dissolved. The gross solids consist of larger material such as paper, branches, building materials and various human waste. Grit is for example granular material such as sand, which is flushed down the drains during rain events. Suspended solids (SS) includes both organic and inorganic material, which are found in the stormwater (Butler & Davies, 2012). High concentrations affect the turbidity in the water, reduces light penetration and is therefore a threat aquatic life (Norskt Vann, 2012).

3.3.2 Nitrogen and Phosphorus

Nitrogen occurs naturally in all urban waters, either as organic, ammonia, nitrate or nitrite. In stormwater however organic and ammonia makes up the largest part (Butler & Davies, 2011). Phosphorus in stormwater is mainly related to animal and human faeces meanwhile nitrogen is released from decomposed vegetation. Excessive levels of these can cause harmful levels of algae growth in the water environment (Trafikverket, 2011).

3.3.3 Metals

A large number of metals can be found in urban stormwater. Copper, iron, zinc, and chrome to name a few (Kaufman, et al., 2011). The majority occur in particular form as a result of erosion and wear from building materials and vehicles. However, metals like copper and zinc do occur in their more toxic form, the dissolved state in urban waters (Norskt Vann, 2012). Heavy metals are mainly attached to suspended solids and the concentrations normally increase with decrease particle size of the solids (Herngren, et al., 2005).

3.3.4 Polycyclic aromatic hydrocarbons PAH

PAHs are organic pollutants built on carbon and hydrogen. They mainly occur as a rest product from combustion and heating of fossil fuel, but also in particles from worn asphalt and tyres (Trafikverket, 2011). The PAH are toxic, insoluble and creating emulsions and films on the water surface which does not let through oxygen. Hence, they are highly toxic to animal and aquatic ecosystems (Boyd, 2000). In stormwater, only a small part of PAH occurs in dissolved form meanwhile the major part is linked to suspended solids (Karlsson & Vikander, 2008).

3.3.5 Organic and inorganic compounds

Organic compounds can be found in both soluble and particle for in the stormwater. They are particles that easily oxidize into carbon dioxides, nitrates, sulphates and water. They do so in a chemical or biologically way (Butler & Davies, 2011). The level of organic material is indicated by the biological and chemical oxygen demand, BOD and COD respectively. To high levels of these will impact the aquatic environment and the water quality (Boyd, 2000). An important source of organic and inorganic pollution that has been acknowledged during later years is atmospheric deposition. These pollutants are separated into wet deposition due to precipitation and dry deposition from dust and gas that accumulates at the urban surface (Draaijers & Erisman, 1995).

3.4 Groundwater contamination from infiltrated road and street stormwater.

Groundwater contamination due to infiltrated of stormwater is a challenging area to address in road and street planning as the potential long-term effects on how ecosystems are impacted by infiltration are relatively unknown (Kidmose et al, 2015). However, studies have been made to evaluate the risks in relation to the most common occurring pollutants. The pollution risk from infiltrated stormwater varies with the type of urban activities that occur in an area and the way the stormwater is infiltrated (Pitt, 2000). As Table 4 show, the highest risk of contaminating the subgrade and groundwater follows the subsurface infiltration method. The main issue with this method is that the stormwater does not percolate any vegetative layer or soil prior reaching the subgrade. Thus, the opportunity of pollutant uptake that occurs during surface infiltration is bypassed (Philadelphia Water Department, 2015). Surface infiltration through a vegetative layer and infiltration soil generally have a good removal efficiency apart from salts and enteroviruses (Pitt, et al., 2001). Salt is of particular concern in the road and street environment in Nordic regions as it is frequently used during winter road operations and maintenance. As for today, there is no effective way of trapping and preventing salts from dissolving and percolate the subgrade (Burton & Pitt, 2002).

Table 3: Most critical stormwater pollutants concerning groundwater contamination potential (Pitt, et al., 2001).

Contamination risk concerning different infiltration methods				
Pollutant	Abundance in urban stormwater	Surface infiltration, no pre-treatment	Subsurface infiltration, no pre-treatment	Surface infiltration with sedimentation
Salt	High during winter	High	High	High
Metals				
Zinc	High	Low	High	Low
Nickel	High	Low	High	Low
Lead	Moderate	Low	Moderate	Low
Pathogens				
Enteroviruses	High	High	High	High
Organic compounds				
Pyrene	High	Moderate	High	Moderate
Fluoranthene	High	Moderate	High	Moderate
1,3-dichloro-benzene	High	Low	High	Low
Pesticides				
Chlordane	Moderate	Moderate	Moderate	Low
Lindane	Moderate	Moderate	Moderate	Low

3.5 Stormwater damage cost

The number of registered damages related to stormwater has seen massive increase in recent years. Two thirds of the damage cost relates to stormwater ingress in buildings and infrastructure, meanwhile failure or other issues in the stormwater system account for the rest. The total cost of the previous six years' extent to 4,3 billion NOK as a result of 105 605 stormwater related damage claims (Finance Norway, 2015).

Besides the direct cost of stormwater, worn out and under-dimensioned pipe systems are increasing the need large scale maintenance and renewal. Approximately 25% of the 16 000 km of stormwater pipes, 43 800 km of water pipes and 36 500 km of wastewater pipes are built with standards that does not meet the requirements of today. The accumulated cost for renewing these systems to sustainable future standards is approximated to 300 billion NOK (Sægrov, 2014).

Aside the direct financial cost for rebuild damaged infrastructure, housing and nature, there are other indirect costs, which are less tangible. These are long term environmental impacts and human health, trust and safety in the society (Citek & Hunt, 2013).

Table 4: Summary of direct and indirect damages related to urban stormwater. Together these have accounted for a total of 4,3 Billion NOK during the previous six years. (Norges Offentlige Utredninger, 2015; Citek & Hunt, 2013)

Direct and Indirect damage related to stormwater	
Damage	Resulting impact from damage
Damage and wear on road and street infrastructure	Damage due to heavy rain, flood events, frost heave, erosion lead to costly reparation and maintenance for road and street owner
Damaged and wear on buildings	Damage due to flooding, leakage and powerful runoff lead to costly reparation and maintenance for property owner
Damage and wear on vehicles	Damage and wear due to flooding and polluted runoff (mainly road salt) lead to cost for vehicle owners
Erosion of road and street environment	Damage, settlement and erosion due to water flow and flooding lead to cost of restoring watershed environment
Impact on industry transport and production	Cost arise as flooded roads and streets interrupts daily transportation of goods and material
Mobility loss for citizens	Closed roads and streets interrupts daily travelling, delaying travels to work
Polluted environment	Long term pollution lead to cost of remediation of water and soils
Health issues	Cost of sick days, medication, hospital service as public health is threatened during flood events

PART II – THE LOW IMPACT DEVELOPMENT PRACTISE AND CORE STRATEGIES

Part II describes the strategies in stormwater management in Norway, the practise of low impact development and the most important aspects in planning for LID in road and street projects in the urban environment. The objective with this chapter is to give the reader an understanding of the LID strategies and their role in current and future urban development.

4. STORMWATER STRATEGIES

This chapter is addressing sustainable stormwater management and the practise of low impact development.

Due to climate change and an increasing number urban stormwater related issues, new stormwater management strategies have been brought forward during recent years in order to develop long-term sustainable solutions for the urban environment (Oslo Kommune, 2013). These strategies are established on a national level in Norway and stated in the European Water Directive. Both the EU water directive and Norwegian Water Directive have concluded two general goals to ensure a healthy and sustainable future for water environments in Norway. To reach the stated goals, the overall objective is to develop well-functioning collaboration strategies among governmental agencies to work united behind the directive (Norges Offentlige Utredninger, 2015).

“Environmental goal: *The aim is to secure good water quality in all freshwater, coastal water and groundwater before the end of 2015. This means that the chemical, biological and hydrological condition, that is the amount of water and its physical design, should not differ largely compared to the conditions that would have been without the impact of human activity.”*

Management goal: *Management of hydrological fields should be implemented. This means that all water and water related activities that can affect the quantitative or qualitative conditions in the watershed should be seen and managed as one unit, no matter the municipality or country borders.”* (My translation from the Norwegian Water Directive.)

Following the Water Directive are three general stormwater related goals and objectives, concerning how to manage urban stormwater to ensure a sustainable urban development. These goals and objectives are also the foundation of today’s local stormwater management and LID (Norskt Vann, 2012; Norges Offentlige Utredninger, 2015; EPA, 2016).

Table 5: Goal and objective following the three principles of stormwater management (Norges Offentlige Utredninger, 2015; EPA, 2016).

The key three principles of stormwater management	
Goal	Objective
Prevent damage	Stormwater should be managed to satisfy security for urban life, infrastructure, health and environment
Use stormwater as a resource	Stormwater should be managed to create positive landscape elements and be used as a mean of recreation and wellbeing
Enhance ecosystems	With open waterways, ponds and increased amount of green areas, biological diversity be promoted and enhanced

4.1 Low impact development practise in stormwater management

Low Impact Development (LID) is the practise within local stormwater management that is recommended to make urban road and street environments more robust and adapted to meet future climate change. EPA (2014) defines LID as a way of managing land development or retrofitting development in harmony with the natural environment and thus, to the largest extent, enable natural stormwater management at its source. In a similar way, Norges Offentlige Utredninger (2015) defines LID as a stormwater management principle where stormwater should be managed at the place it is fallen down with methods that mimic nature's way of managing water and only involve man-made technical solutions if necessary. The reason for focusing on the local management is to enable volume control and pollution management directly and thus avoiding having few heavily loaded catchment and discharge points in the urban water system (Sintef Byggforskingsinstitut, 2012). In this way, stormwater related property damage, flood risk and wastewater system maintenance can be minimized (EPA, 2002). Moreover, establishing LID is as a way of transforming an urban environment to a greener infrastructure, where the benefits of robust climate adapted stormwater systems are combined with the enhanced natural environments (EPA, 2016) and increased land and property value (MacMullan & Reich, 2007). Figure 2 shows an example of LID that have been implemented in a dense urban environment.



Figure 2: LID in an urban environment includes green road and street barriers, vegetated public surfaces (Municipality of Washington DC, 2015).

The principles of LID are in broad terms founded on the following functions; source control & infiltration, treatment and retention & storage. The objectives of these functions and examples of units that can fulfil them are stated in Table 7.

Table 6: Functions of LID: (Boogaard, 2015; Minnesota Pollution Control Agency, 2016; Calkings, 2011; Statens Vegvesen, 2014)

The functions and objectives of LID systems and example of corresponding units		
Functions	Objectives	LID units
Source control & Infiltration	Decrease the amount of water reaching the drainage network and reduce the risk of downstream flooding	Green roofs, infiltration trenches, infiltration basins, rainwater harvesting units
Treatment	Remove pollutants from the surface water before entering the drains or being infiltrated to groundwater	Filters, sedimentation, open waters
Retention & Storage	Prevent stormwater from discharging into water recipients	Storage magazines, ponds, wetlands, roofs

4.1.1 Stormwater quantity management in LID

Stormwater quantity management in LID is governed by infiltration, detention, conveyance and water harvesting in the urban environment. Infiltration enables stormwater to percolate the subgrade towards groundwater or drainage system underneath. This process decreases the runoff volume and the total stormwater load coming from the road and street environment to the urban stormwater sewage system (EPA, 2016). When stormwater runoff is detained locally the peak runoff volume is reduced significantly to further relieve the stormwater sewage system (EPA, 2002). Another vital aspect of quantity management is to integrate the use of open waterways and ponds in the planning and design of the urban environment, as this single handily can decrease flood risk significantly (Norges Offentlige Utredninger, 2015).



Figure 3: Stormwater solutions with high volume capacity integrated in the urban environment (architectureau.com)

4.1.2 Stormwater quality management in LID

The stormwater runoff quality is often enhanced significantly by using LID solutions in the road and street environment (Zhou, 2014). Vegetated surfaces, biodegradation units, sedimentation and filtration manage the stormwater pollutants are examples of relevant units. The local conditions at the site where the LID units are constructed determines the design and choice of treatment components included in the system (Norskt Vann, 2012). Important aspects to consider is for example the street design, topography, groundwater regulations and the potential for infiltration (Statens Vegvesen, 2014).



Figure 4: LID solutions enabling a first treatment of runoff from urban road before it enters the sewers (architectureau.com)

4.2 The three step strategy in LID

The philosophy according to Norskt Vann and Oslo Kommune is to create sustainable stormwater systems that also are part of the visual urban environment. Included in this is the use of biological diversified infiltration units and the so-called three-step strategy of managing stormwater (Norskt Vann, 2012).

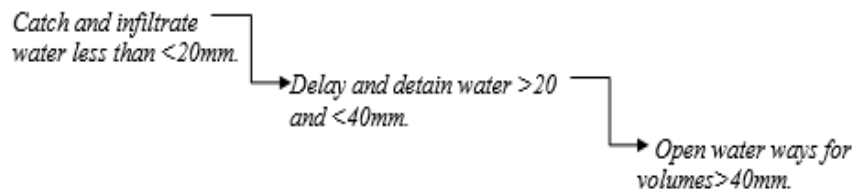


Figure 8. Three-way strategy. Drawn by Daniel Hammerlid, inspired by (Norskt Vann, 2012).

Step 1

The first step in the strategy is accomplished by using LID units such as green roofs, rain beds, grass-and bio swales, infiltration trenches and permeable pavements to mention a few. The aim is to make use of their ability to catch and infiltrate precipitation from rain events with less than 20 mm locally without discharging any water to subsurface stormwater systems. Thus, the practise in this step significantly reduce the amount of stormwater that reach and accumulates in piped systems and thereby decrease maintenance and operation cost (Norskt Vann, 2012).

Step 2

In the second step, focus lies on the use of rain beds, ponds, storage cells and other units with ability to hold and delay stormwater during rain events. The purpose is to control the runoff that builds up during rain events with 20-40 mm precipitation. By doing this, it is possible to achieve a balanced flow of stormwater and avoid flooding (Norskt Vann, 2012). Moreover, retention and storage is crucial to enable a controlled inlet discharge into the LID units to enable optimal function and avoid excessive wear (Philadelphia Water Department, 2015).

Step 3

The final step is accomplished by planning for open waterways with large capacity to convey stormwater. This is done by re-opening of buried streams, using local waterways, establishment of ponds and planning of roads and streets in a way so they can function as occasional flood ways. (Norskt Vann, 2012; Statens Vegvesen, 2014). If step 3 is executed right, most heavy rain events that exceed 40mm precipitation will be taken care of without harming the urban environment and put too much load onto the wastewater system (Oslo kommune, 2015).

4.3 LID planning objectives

A number of key components are vital to understand to be able to develop long-term sustainable stormwater solutions for urban road and street environments. Among the most important are the knowledge and understanding in how to adapt the four key objectives in LID (Norges Offentlige Utredninger, 2015). These are stated in the list below and explained in the following text.

LID objectives in the road and street environments:

- Conserve natural resources and use stormwater as a resource in the urban environment

- Minimize stormwater impact on the natural environment in the urban area
- Make use of stormwater infiltration to largest possible extent
- Plan for local storage and retention of stormwater

4.3.1 Conserve natural resources

This objective should be accomplished through using stormwater as a resource for society instead of treating it as a problem. Doing so means to include stormwater into urban project planning in an early stage so that local vegetation and waterways can be used as part of the stormwater solution and areal development simultaneously. Moreover, the objective is a mean to ensure that green areas and urban watersheds will stay untouched in a long-term perspective (Sintef Byggeforskningsinstitut, 2012). Natural waterways, native soils and mature trees are particularly important to preserve in the road and street environment as they have superior stormwater management abilities compared to any newly developed substitute (Credit Valley Conservation, 2015).

4.3.2 Minimize stormwater impacts on the natural environment

As stormwater management often alters the natural conditions at a site, the aim with this objective is to preserve and improve the natural ecosystems in the urban environment. A key factor in this is to re-open waterways and trying to use the drainage patterns and waterways that naturally flows through the site where a road or street is to be constructed. Another aspect is that urban development should be integrated in to vegetation and animal habitat and not the other way around, meaning that a project sometimes will have to alter its original plans if it will have a negative impact on the ecosystem where it is established (Norges Offentlige Utredninger, 2015).

4.3.3 Make use of stormwater infiltration to largest possible extent

This objective states that infiltration units should be the first choice to use in managing stormwater locally. Doing so will result in several benefits. Infiltration through vegetated surfaces and soils will enable natural water treatment as metals and other pollutant are attached to grass, soil material or in air voids. Moreover, infiltration units manage a controlled runoff by retaining and storing water, causing the peak runoff to the wastewater system to decrease significantly. An increased usage of infiltration units will also contribute to recharge urban groundwater and thereby potentially lower the risk for settlement during construction and long term loading from development (Oslo Kommune, 2013).

4.3.4 Use local retention and storage

Road or street development is one of the major contributors of stormwater runoff and high peak flows in the urban environment. By establishing storage and detention units, it is possible to manage the stormwater flow, as these units enable controlled and well-balanced conveyance. Storage and retention units can be established either as dedicated stormwater units or through adapting public space with a design that allows for storage and retention of stormwater (Norges Offentlige Utredninger, 2015). The importance of storage and retention cannot be overemphasized as optimal function and full runoff reduction only can be enabled if the inflow in the LID units is within the designed capacity (Stagge, et al., 2012).

4.4 Economics of LID

Compared to conventional piped infrastructure systems, LID systems have lower cost for water treatment, construction and maintenance. However, the sources of economic benefits are many and not only related to material and construction cost. Air quality improvement, energy savings, increased land value and increased groundwater recharge are also important benefits to recognize (EPA, 2013).

Awareness and understanding of the benefits can be a powerful decision support in the early stages of urban planning (Calarusse & Kloss, 2006). There are a number of decision-aid tools that are suitable to properly investigate and review these economic benefits. The three most common are Cost-Benefit Analysis (CBA), Cost-Effectiveness Analysis (CEA) and Life-Cycle Costing (LCC) (Zhou, 2014).

Key economic benefits with LID:

- Improved air and water quality
- Increased Urban land and property value
- Energy savings
- Increased groundwater recharge

4.4.1 Improved air and water quality

LID systems improve air and water quality by holding and filtering pollutants. This decrease the cost of air treatment facilities in buildings and the public health cost due to less air related diseases. Besides this, better air quality and healthier water environment enable urban development closer to roads, recreational activities in urban waters and thus a better use of the valuable urban land (EPA, 2013).

4.4.2 Increased urban land and property value

LID implies a greener infrastructure and enhanced aesthetic values in the urban area. Studies have shown that these values increase the property value enough to compensate the cost the loss of land due to LID establishment at the surface. Moreover, the reduced risk of flooding and stormwater related damages also adds to the value increase (Calarusse & Kloss, 2006).

4.4.3 Energy savings

The natural element in LID systems can provide a certain amount of temperature regulations which can help decrease the energy cost in the urban environment. Green roofs and trees planted along roads and street will stop radiation from reaching directly onto buildings during warm days. Moreover, a vegetated cover on roofs will provide for insulation during winter, which lower the cost of heating (MacMullan & Reich, 2007).

4.4.4 Increased groundwater recharge

As LID put large emphasis on infiltrating water locally the groundwater recharge increase significantly. As the groundwater aquifers are recharged, the cost of producing local drinking water will decrease both because greater quantities are available but also due to lower pumping cost as the groundwater table rises. Further economic benefits of groundwater recharge is the decreased risk of settlement and related damages (MacMullan & Reich, 2007).

4.5 National regulations to integrate LID on national level

Planning for sustainable stormwater management requires not only development of new stormwater units and design requirements but also the establishment of policies and governing laws that make sure the new paradigm of LID is embraced by society. As today, 60% of the municipalities in Norway states that they have insufficient capacity and resources to meet today's and future stormwater demand. Thus, the stormwater issues have significant impact on the urban social life as it is threatening both public welfare and economy due to costly flood events and frequent stormwater related damages.

To address the stormwater issues and climate adapt society, Norges Offentlige Utredninger, NOU (2015), has in a recently released report, concluded that LID is the way to develop long-

term sustainable urban development on a national and local level. Besides covering the need of new stormwater strategies, NOU 2015 also provided suggestions for new regulations, which purpose are to put focus on stormwater within all areas of urban planning. Five of the key regulation proposals are stated and explained in Table 8 and the following text.

Table 7: Proposed action and desired impact from the new stormwater regulations (Norges Offentlige Utredninger, 2015).

Action taken by municipality	Desired Impact
Economic regulations	To fund development and maintenance of stormwater systems and to create incentives for private LID investments
Faster tendering and construction process for LID proposals	Ease the establishment of new stormwater units in all construction processes
Regulate stormwater earlier in the construction process	Increase well thought through solutions with water quality and stormwater systems in focus
Construction regulations	Less harm to watersheds and its ecosystems. Increased security against system damages and conveyance interruption
Maintenance program for regular system service	Keep the wastewater systems functional at their best possible level
Public involvement	Public recognition and understanding will also result in increased establishment LID on private property

4.5.1 Economical regulations

The suggested economical regulations states that the municipality should develop a system for stormwater fees where a fixed price combined with a variable part cover up for the cost of managing and treating water. The purpose with this is to make everyone take part and pay for the service the municipality is providing. Development of new stormwater units follow the same principle, suggesting that the individual landowner should be economically responsible for stormwater management and making sure that proper treatment is managed at site. If not possible, the landowner should pay the corresponding cost for neighbouring landowner or stormwater system. Furthermore, it is proposed that municipalities should contribute and help to carry a part of the cost to encourage LID units in private households (Norges Offentlige Utredninger, 2015).

4.5.2 Stormwater process regulations

Norges Offentlige Utredninger (2015) suggest development of new national process regulations to promote LID as a response to the slow urban development approval process. The purpose is ease and benefit establishment of LID solutions for private and public property as well as road and street owners.

4.5.3 Planning at an early stage

Planning the LID system at an early stage in any land development project is essential to enable a strong focus on stormwater management. By regulating stormwater management and prioritize it in urban masterplans, a municipality can demand key establishments and stormwater strategies before giving approval in any development process. In doing so, investors and contractors must put emphasis on stormwater management, which will strengthen the sustainable development in the planning phase (Norges Offentlige Utredninger, 2015).

4.5.4 Construction regulations

Construction regulations is a way of promoting LID and a healthier water environment in the urban environment. Norges Offentlige Utredninger (2015) suggest new regulations that government or municipality should be able to use during future development. To name a few; declining construction within 100 meter of a watershed, construction within 4 meter of public

wastewater systems and regulate the minimum distance between the wastewater system pipe and lowest street intake to at least 0.9 meter.

4.5.5 Maintenance program

One of the most important areas to address when implementing LID on a large scale is to develop maintenance programs for regular system service. These will be specific to the chosen LID system design and hence require specified standard practises. Knowledge in the requirements is vital in both the planning and construction process as engineers must design the LID systems and its component to fit enable necessary maintenance. Moreover, the entrepreneurs will have to be aware of the same requirements when establishing the LID systems at site (Norges Offentlige Utredninger, 2015). Deviating from specified maintenance plans will potentially result in decreased function of the LID system and escalating stormwater issues in the urban area (Norges Offentlige Utredninger, 2015).

PART III – PLANNING OBJECTIVES AND REVIEW OF LOW IMPACT DEVELOPMENT UNITS IN THE ROAD AND STREET ENVIRONMENT

Part III takes the reader through the most fundamental planning objectives during the establishment of LID units. Following this is a review of the most relevant LID units for the urban road and street environment, such as grass- and bio swales, permeable pavement, storage units and conveyance controls.

5. PLANNING LID IN THE URBAN ROAD AND STREET ENVIRONMENT

Planning a LID system in the urban environment requires investigation and evaluation of site conditions and surroundings to conclude the most suitable design. Ground conditions, hydrology, site properties and treatment requirements are the fundamental areas to address (Toronto and Region Conservation Authority, 2010).

5.1 Assessment of ground conditions

Soil borings and sample analysis are critical prior the establishment of LID units in the road and street environment as the infiltration capacity mainly is governed by the porosity and permeability of the soil (Mays, 2001). Thus, a vital part in planning a road and street project and their stormwater system is assessing the site, mapping the soil and sediment type. The type of porosity to measure is the efficient porosity, which is the total volume of voids that can lead water through the soil mass (Shaw, 1994). A soil with high efficient porosity has good drainage capacity meanwhile a highly dense soil has the opposite (Butler & Davies, 2012). Permeability defines the capacity to lead water, expressed in m/s. A rule of thumb is that infiltration of stormwater should be done in masses with at least 10^{-6} m/s (Sintef Byggeforskningsinstitut, 2012). Studying sediment maps such as Figure 5 is highly recommended to enable a first judgement of the limitations and possibilities of LID at a site.

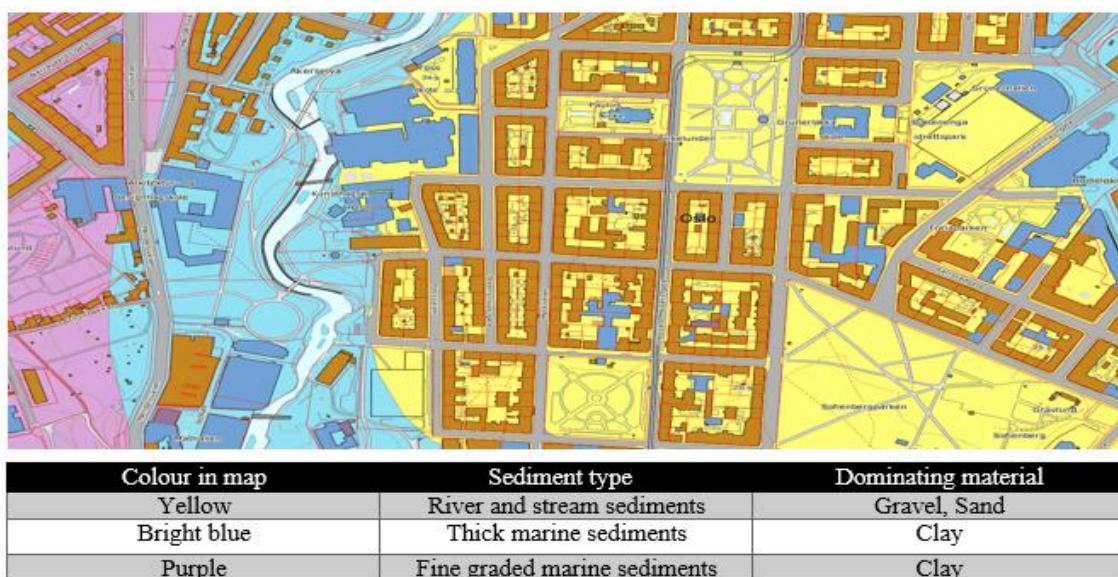


Figure 5: Example of sediment map to study when assessing ground conditions prior the establishment of a stormwater system (NGU, 2015).

5.1.1 Groundwater conditions

Establishment of LID units that infiltrate stormwater to groundwater requires assessment of groundwater conditions mainly for two reasons. First to ensure that groundwater does not perchlorate and flood the surface environment. Thus, a safety distance of 1.2 meter between the seasonal high groundwater table and the surface is recommended in many LID handbooks. Second, to prevent contamination of groundwater due to infiltrated pollutants. To avoid this, mapping of contaminated soil and pollutant movement from the road and street environment is a suitable strategy (City of Los Angeles Stormwater Department, 2011).

5.1.2 Topographical considerations

The topography at a location where a LID system is established must be mapped and evaluated concerning its surface drainage capacity, slope stability, available construction space and infiltration potential as all of these aspects and their interrelation are critical to understand when design the LID system (Butler & Davies, 2012).

The regular surface drainage in a dense urban area occurs when stormwater reach inlet points, gullies or urban watersheds. The speed and flow rate of this process is largely depending on the topography in and around the road and street constructions. Site assessment during rainfall is therefore highly recommended to get the best possible interpretation of how the local hydrology interact with the topography and slope. Ponding of water, flow patterns, lack of conveyance and off-site runoff are examples of key discoveries that can be detected during such assessment. Moreover, this will also enable an evaluation of the inlets, outlets and energy dissipaters. Failing to address these aspects can significantly increase the flood risk locally or in downstream from at site (Credit Valley Conservation, 2015).

Slope stability have a direct connection to the slope angle, soils type and structure. Moreover, it will be affected by the amount of water and the created flow-force. High flows of water will cause not only erosion, but also instability in steep sloped areas. Hence, LID systems must be established in a way that does not give rise to any geo-hazards such as slope failure (City of Los Angeles Stormwater Department, 2011).

The rate of infiltration is maximized on flat surfaces when the stormwater in given enough time to percolate soils. Too steep slopes will however cause the stormwater to flow in the top layer of the soil and never reach the groundwater (Mays, 2001). Moreover, many LID units have different optimal design considerations concerning surface slope. Thus, slope and slope angle is a site considerations that needs to be evaluated in detail to enable full capacity of a system (Toronto and Region Conservation Authority, 2010).

5.1.3 Soil structure

The soil structure is a significant component to refer to when assessing infiltration capacity in a soil (Mays, 2001). The most common types of aggregate setups are granular, blocky, prismatic and massive. Granular soils are characterised by a very weak or absence of cohesion. This makes water flowing easily between the particles as no larger aggregation of particles forms. Hence, granular soils are highly suitable for stormwater infiltration in terms of flow rate. Typical granular soils have a high content of sand and/or gravel. Massive soils, blocky and prismatic soils are often characterised with high clay content and are thereby dense, tight packed and does only allow very limited entrance of water and oxygen. Thus, these soils are not suitable for stormwater infiltration or vegetation systems (Wisconsin Department of Natural Resources Conservation Practise Standards, 2004).

The moisture content in a soil mass influences the infiltration performance during a rain event. This is explained by the degree of saturation, meaning that the previous rain event

plays an important role regarding the impact of the next one (Grebel, et al., 2013) A high moisture content mean less available pore space and thereby less capacity of managing runoff (Mays, 2001).

5.1.5 Soil infiltration rate

Three main mechanisms govern how well a soil infiltrate stormwater. These are; maximum rate of entry through surface, rate of water movement in the unsaturated zone and the rate of drainage in the saturated zone (Pitt, et al., 2001).

The infiltration rate is measured in-situ during saturated conditions to receive a conservative approximation of the infiltration rate at site. The rate of infiltration is always governed by the lowest performing layer (Butler & Davies, 2012). Knowing this is vital in the design and construction phase of any LID unit that includes infiltration, because the graded layers will clog, causing water to rise through the LID unit and penetrate the surface. Studying infiltration maps such as in Figure 6 below is highly recommended as a first step in assessing the infiltration potential at a LID site. Besides this, the infiltration rate should also be tested in situ at the site to provide accurate design input data.

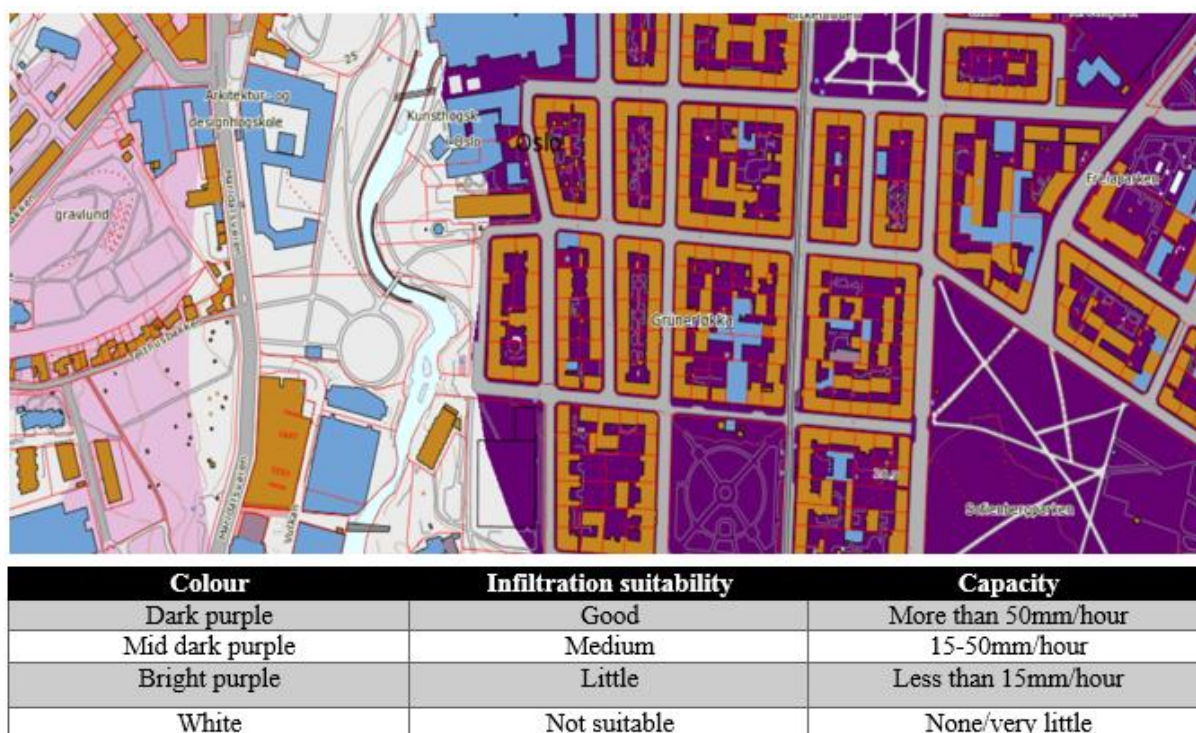


Figure 6. Map showing the soil infiltration suitability at a site in central Oslo. The map grading goes from from dark purple to white where dark is good capacity and white none (NGU, 2015)

5.1.6 Degree of soil compaction

Preservation of native or long term undisturbed soil to the largest possible extent is a key objective to aim at in any site development. This because the degree of compaction in a soil impact the amount of available pour space, why a dense packed soil has lower infiltration capacity than a porous soil. This is particularly important to be aware of during the planning and establishment of LID infiltration units as a highly compacted soil have similar runoff characteristics as an impervious surface (Credit Valley Conservation, 2015).

To ensure that the permeability of a soil is undisturbed and maximum infiltration capacity is reached, it is therefore important that heavy vehicles and material are kept out of the selected

area. Moreover, an undisturbed soil will provide the optimal conditions for vegetation growth, pollutant catchment and breakdown within the air voids (Vermont agency of natural resources, 2013). Hence, development of road or street structures should preferably not be established in areas with naturally permeable soils.

5.2 Assessment of precipitation and runoff volumes

Hydrological measurements along with flow and runoff calculations should be used to estimate the required capacity of the LID units and system. Based on the most relevant runoff type in the local area, one of the three alternatives in Table 11 below is recommended to use as dimensioning precipitation season.

Table 8: Dimensioning precipitation season to select input data to hydrological calculations (Norskt Vann, 2012)

Season	Description
Peak summer runoff	Heavy rain on dry and dense urban ground. Little runoff comes from semipermeable and permeable surfaces
Winter runoff	Runoff on frozen ground during long-term rain or snowmelt. Significant runoff from semi-and permeable surfaces
Fall runoff	Long-term rain on wet ground. Significant runoff from permeable surfaces

It is vital to study the waterways and runoff maps related to the site where the road or street is to be established. Doing this will allow for estimation of potential off-site runoff and hence correct input data to the design of the LID system. Besides this, knowledge of waterways and natural drainage makes it easier to determine where sediment loads and erosion issues might occur in the urban area (Miljødirektoratet, 2011). Figure 7 shows an example of a hydrological map that display natural waterways and their flows.



Figure 7: Hydrological map indicating natural waterways in Oslo (Nevina, 2015).

5.2.1 Runoff calculations

The regular methods that are used when calculating stormwater flow is the rational method, time area method or suitable software such as SWMM. Knowledge and skills on how to use these methods are critical in planning and designing LID units. The rational method is preferred only when calculating the peak hour runoff for areas smaller than 2 km² and involves the following factors: Runoff area, rain intensity, runoff coefficient and climate factor (Statens Vegvesen, 2011). The time-area method takes time into account, which means that the water release from different areas is not constant or simultaneous. The time of

concentration is independent of rain intensity and the velocity of the flow remains constant throughout the storm (Statens Vegvesen , 2011). Calculating the exact flow of water is a quite complicated matter following the large number of parameters that our environment holds. However, the design flow are based on gross approximations, thus making this method work well enough when planning the LID system (Butler & Davies, 2011).

5.4 Site considerations to address in the planning phase

As the road and street development is to be established, it is vital to consider if the construction might have any impact on the environmental conditions at the site. Hence, the proposed project plan should include an operation plan that ensure that the environment is undisturbed to the largest possible extent. This plan must be approved by the public water resource administration before construction can start (Statens Vegvesen , 2011).

There are a set of recommended decision-aid tools that can be used to ensure that as many aspects of the environmental impacts are covered and that an environmental friendly solutions are reached. Among the most common tools are the Environmental Impact Assessment (EIA), Material Flow Accounting (MFA) and Life Cycle Analysis (LCA) (Zhou, 2014).

Key site considerations:

- Investigate potential impact on current environmental conditions at site due to development
- Secure groundwater wells and water resources before development of site
- Assess new flood ways in the area
- Assess required drainage capacity at site
- Assess how the infiltration system should be connected to piped system

5.4.1 Connection to the conventional underground system

Depending on the required capacity, a road and street stormwater infiltration system can either be connected to a conventional underground water system with separate pipes or have separate diversion pipes to local storage units. If the required drainage capacity is significant, there should also be drainage pipes and overflow controls connected to a larger conveyance system such as open waterways, to avoid issues during heavy rain events (Statens Vegvesen, 2007). If these connections have insufficient design capacity and robustness there is a risk of operational failure and in the end flooding and significant environmental impact at site (Philadelphia Water Department, 2015).

5.4.2 Drainage and conveyance of stormwater

Road and street development often alters the natural drainage patterns in an area. This can cause significant changes in off-site stormwater volumes reaching a site and hence increase the flood risk and harm to the environment. Hence, development of road or street structures or other urban development for that matter should preferably be established in a way that does not interfere with the natural hydrology at site. However, if development must to this, outlet controls are necessary means to avoid flooding and damage of both the road and street structure and its environment (Credit Valley Conservation, 2015).

5.4.3 Investigate and develop most natural flood ways

The vast urban development sometimes limits the open surface space that is available for LID (Norges Offentlige Utredninger, 2015). It is therefore necessary to consider planning roads and streets as occasional flood ways during extreme weather events. Doing this requires

mapping of the natural drainage patterns and waterways both above and underground, as these reflect the potential flood ways and critical areas. Bypassing this assessment can result in significant risk of flooding at newly developed sites. The risk is particularly high in areas where previously open waters have been buried underground (Oslo kommune, 2015).

5.4.4 Securing groundwater wells and water resource quality

As road and street construction occurs in areas with groundwater resources or sensitive waters, an investigation and risk analysis of potential pollution and contamination should be conducted. The risks are that the new road development give rise to a significant increase of pollutants that reach these waters (Statens Vegvesen , 2011).

5.4.5. Assessing the stormwater treatment requirements

The main objective for a stormwater treatment train is to be able to handle the “first flush” volume which, depending on the size and type of catchment area (Bellucci, 2005) contains the most pollutants (Statens Vegvesen, 2014). The definition of first flush is that the peak flow of pollutant occurs before the peak flow of stormwater, resulting in approximately 80% of the total pollutant load should be flushed off during the first 30% of the rain event (Bertrand-Krajewski, et al., 1998). The factors that governs the concentration of pollutants are the time passed since last rain event, climate conditions and the amount of accumulated pollutants from the last rain event. (Statens Vegvesen, 2014).

The required treatment of the stormwater is at large depending on municipality regulations that often are related to the type of pollutants that are present in the area and how vulnerable the receiving waters are. Thus, emphasis on stormwater treatment can vary from normal to very high. Moreover, the treatment capacity of LID units is in many cases depending on pre-treatment in form of a first sedimentation. The main reason for this is to remove large particles that potentially can accumulate and clog infiltration surfaces in swales, permeable pavers or pipes.

5.5 Planning the LID treatment strategy

The planning of stormwater treatment in LID systems should be done at an early stage in any project. This include deciding the type of treatment solution, required hydraulic capacity and the requested treatment efficiency. The main principles to keep in mind concerning LID and stormwater treatment is that it is based on the three objectives prevention, source control and on-site treatment (Statens Vegvesen, 2014).

There are various treatment demands on the LID system described in road engineering handbook N200, which are important to satisfy (Statens Vegvesen, 2014).

Requirements to fulfil when planning stormwater treatment for a LID system:

- Dimensions of the storage requirements should be applied according to the downstream conditions and comply with the water quality demand at the recipient receiving the water
- The treatment unit should be constructed in a way that allow for a simple regular process and maintenance work. Regular processes that must be controlled are: in and outlet function, overflow mechanism and sludge removal
- The treatment unit should function all year
- The design of the treatment unit must be safe for humans, be suitable for the urban conditions and landscape. Movement of mass, change in terrain and establishment of vegetation are central parameters in this matter

- The treatment system must not receive stormwater runoff from natural environments since this water is considered to be an unnecessary load
- The treatment units should be equipped with overflow pipes to avoid flooding of the unit and unnecessary wear

5.5.1 Prevention of pollution

The starting point regarding stormwater treatment in LID is trying to prevent pollution spread and contamination through the use of regulations and site information. As an example, requirements of stormwater treatment at a construction site or factory can be demanded, meaning that the responsible company must show suitable and good enough stormwater solutions before and during its working process and its products (Minnesota Pollution Control Agency, 2016).

A common prevention method is to make use of education and information to enlighten the public concerning the importance of sustainable urban waters. This include promoting the use of minimum chemicals in the households, disposing pet waste, maintenance of vehicles. Other site measures of prevention is using signs indicating no littering, sensitive water area and prohibited activities (EPA, 2000).

5.5.2 Source control

Source control of stormwater states that good control at the site where precipitation falls will have significant impact on the runoff quality. Source control is divided into two categories, operational or structural. Operational source control includes maintenance procedures, inspections, prevention strategies and general “good housekeeping” to minimize the amount of pollutants in the water before it enters a stormwater system. Structural source control means that pollutants or the source of pollutants is managed with physical structures that prevents water contamination (USEPA United states enviromental protection agency, 2000).

5.5.3 On-site treatment of stormwater

Bio-retention ponds, grass -and bio swales, filter strips and sedimentation ponds are examples of LID units that can be used in a treatment train. Moreover, natural vegetation and plants provide for further treatment as well. By using local treatment, stormwater can be infiltrated into the subgrade at site or conveyed to urban watersheds, without risking contamination (Philadelphia Water Department, 2015). Moreover, an effective on-site treatment prevent accumulation of larger pollutant loads in the stormwater sewer network and therefore decrease the point discharge pollutant load. As an extra benefit, these kind of units also enhance aesthetic values and biodiversity at site (Toronto and Region Conservation Authority, 2010).

6. LID UNITS IN THE ROAD AND STREET ENVIRONMENT

This chapter look into some of the most suitable LID solutions for the road and street environment and related system components. This include solutions for infiltration, retention and storage of stormwater but also vital complements such as geotextiles, energy dissipaters inlets, outlets and soil support systems.

6.1 Grass- and bio swales

Swales are LID units that easily can be customized to fit into the wide range of site conditions in the urban road and street environment. They primarily serve as natural infiltration units, but also have significant retention, treatment and storage capacity (EPA, 2002). Depending on type, they can also be used as stormwater conveyers and occasional flood ways during extreme weather (Norges Offentlige Utredninger, 2015).

Swales have capacity to manage the majority of smaller rain events without discharging stormwater to any underground water infrastructure as long as the subgrade allow for infiltration. Moreover, they provide for a highly cost effective alternative compared to conventional underground infrastructure (MacMullan & Reich, 2007).

If ground conditions provide limited subgrade infiltration, the swales can be designed with permeable underdrains with geotextile filters to allow a controlled discharge. In cases when a site have unsuitable conditions for subgrade infiltration, the swales can be sealed with waterproof wrapping and rely completely on piped conveyance (Credit Valley Conservation, 2015).

The grass swale is typically built up with a vegetative layer with a majority grass and plants. The vegetation serve as a first water absorbent that also have significant pollutant removal qualities (Minnesota Pollution Control Agency, 2016). The second layer is typically a soil with a grading suitable for the local climate and desired infiltration rate. The soil layer infiltrates the water and further contributes to the pollutant removal. The third layer filters the stormwater before it reaches the bottom of the swale where it either is drained via outlets to a conveyance system or infiltrated to the subgrade (Philadelphia Water Department, 2015). Figure 8 shows two typical grass swales in urban environments.



Figure 8. Grass swale serving as stormwater unit and barrier between road and street (Fairfax county, 2016)

A bio swale is a LID unit that much like the grass swale designed to manage stormwater infiltration, treatment and retention. The unit have a top layer that can contain a wide range of

grass types and plants (City of San Diego Stormwater Department, 2011). Moreover, carefully selected soil layers enable significant pollutant reduction as the stormwater infiltrates the masses. The depth, choice of filler material and climate conditions are the main factors that govern the infiltration and treatment capacity of a bio-swale (Toronto and Region Conservation Authority, 2010). Figure 9 shows two examples of bio swales that are established in urban environments.



Figure 9: Left Figure: Bio-swale at a parking lot. Right Figure: Bio-swale alongside an urban road www.portlandoregon.gov, 2014.

6.1.2 Swales as occasional floodway

Grass swales can if necessary serve as floodway with high flood capacity, as long as the construction is established below road or street level. Using a bio swale as floodway should however be avoided at all cost since it is a more delicate construction. The security against floodwater overflow to the surrounding environment can be managed with outlets controls. These are also vital to ensure that still standing water is drained between rain events to avoid erosion and structural damage of the swale (Cowi AS, 2013).

6.1.3 Treatment capacity of a stormwater swale

The treatment capacity is in general good during all year in Nordic climate conditions, except for when permanent frost develops (Paus, 2013). The removal rates varies depending on the pollutant that is being studied, swale layer design and the retention time of the stormwater.

The vegetation in swales reduce the flow speed of the stormwater and thereby enable sedimentation of particles and a first treatment. Further treatment occur when the stormwater percolate the soil as pollutants are trapped in air voids and degraded by microorganisms living in the soil. Long retention times implies low flow rates in the swale and thereby increased settlement of particles. However, there is always a trade-off when choosing the swale filler material. To exemplify this, a fine graded sandy gravel soil for example has large infiltration capacity and should be chosen if infiltration rate is a priority. If pollutant removal instead is prioritised at site, a soil with more organic material should be used. Thus, achieving both high flow rates and high pollutant removal rates at the same time is not possible (Minnesota Pollution Control Agency, 2016).

Moreover, the choice of plants and grass type has significant impact on the removal capacity, which is why a biologist should be consulted during the planning phase (State of Oregon Department of Environmental Quality, 2003).

6.1.4 Maintenance and life length of a swale

A swale needs regular maintenance to work properly and to last throughout its designed lifetime. This include keeping the grass and plants at an optimal length, repairing damaged spots with new soil or plants and seed quickly after the issue has been discovered, keep the site clear of debris and finally water the swale if there are seasonal occurrence of drought (Philadelphia Water Department, 2015). Moreover, it is crucial to remove accumulated sediment in the bottom of the swale as it otherwise loose both treatment capacity and. A swale will have a very long lifetime if a good maintenance program with these is being followed (Minnesota Pollution Control Agency, 2016).

6.1.5 Key advantages and disadvantages with Swales

The most significant advantages and disadvantages with grass swales and bio-swales are listed below and concluded from: (Minnesota Pollution Control Agency, 2016; Philadelphia Water Department, 2015; Sustainable Technologies, 2016; Bodin-Sköld, et al., 2014).

Key advantages:

- Reduce runoff volumes due to infiltration, storage and retention
- Easy to establish and incorporate in urban road and street environments
- Relatively good pollutant removal
- Provide occasional floodwater storage (grass swales only)
- Low maintenance cost
- Recognized as a cost effective alternative to conventional stormwater infrastructure
- Improves aesthetics in its environment

Key disadvantages:

- Highly depending on other LID units to function well during heavy rain
- Less robust than conventional systems
- Requires open space in the urban environment
- In need of regular maintenance to operate efficiently

6.2 Permeable pavements

A permeable pavement is a structure that can be used to serve the purpose of managing stormwater through infiltration and detention. At the same time, it fills the function as bearing structure for urban roads and streetse (Toronto and Region Conservation Authority, 2010). The preferred sources of runoff are areas such as low trafficked roads, pedestrian streets, residential streets and parking lots (Minnesota Pollution Control Agency, 2016). Figure 10 shows example of parking lots that have been constructed with permeable surfaces.



Figure 10: A selection of permeable pavement establishment in the urban environment (Sustainable Technologies, 2016)

6.2.1 The design of permeable pavement structures

There are three main types of permeable pavement structures, based on the ability to infiltrate stormwater to the subgrade. The different types are: structures with full infiltration, partly infiltration or no infiltration (Sustainable Technologies, 2016).

The infiltration capacity varies with depth of the structure, type underlying sediments, material choice, type of geotextile and compaction degree. Full infiltration structures should not be constructed on fill soils because of soils unproven infiltration capacity and lower stability (Minnesota Pollution Control Agency, 2016).

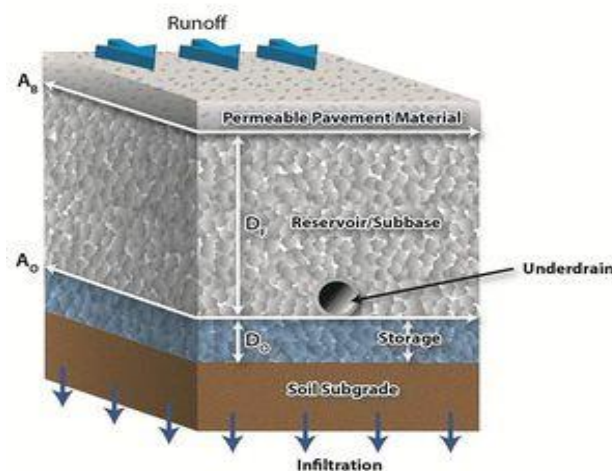


Figure 11: Basic design of a permeable pavement structure (Minnesota Pollution Control Agency, 2016).

The infiltration structure is normally built up on three to four layers. The top layer of a structure consists of paving material that either is permeable itself or has permeable joints.

Secondly, there is a subbase layer of aggregates to provide an even surface for the pavement and to spread out the load evenly downwards. This layer serves as both infiltration layer and storage unit. In a structure with no infiltration to subgrade, a waterproof membrane can seal the bottom layer and thus all stormwater is conveyed via drainage pipes (Minnesota Pollution Control Agency, 2016). Sealing the bottom is preferred when the stormwater has too high concentration of pollutants or if the yearly high groundwater table is at a height that risk water intrusion in the pavement. Another important design consideration is to ensure that the drainage pipes are one-sided perforated pipes. In this way, stormwater only enter the pipe if water is rising from the bottom and up (National Ready Mixed Concrete Association, 2011).

6.2.2 Construction and operational considerations for permeable pavement

Optimal function of a permeable pavement requires regular inspection to ensure that the pavement is clean from debris, vegetation growth, sediments and drained properly between the rain events to avoid clogging (Philadelphia Water Department, 2015). The drainage functionality is inspected through inspection pipes and is particularly important to carry out after the winter season when potential settlements might have occurred (National Ready Mixed Concrete Association, 2011).

Permeable pavement works without any significant issues during winter operation as long as the material mix is chosen correctly (Philadelphia Water Department, 2015). Moreover, studies have proven that snow melts faster on permeable pavers than on regular ground and since it normally drains within two days and have a degree of built in flexibility, freeze and thaw are normally not issues of concern. The permeable surface should not receive stormwater from soils and surfaces with high concentration of particles as these could clog the structure. Ploughing of the permeable pavement should only occur without the blades scraping the surface. Besides this, applying sand, salt, or other de-icing chemicals the surface or at its runoff source should not avoided (Minnesota Pollution Control Agency, 2016).

6.2.3 Key advantages and disadvantages with permeable pavement

The key advantages and disadvantages with permeable pavements are listed below. These are concluded from: (Sustainable Technologies, 2016; National Ready Mixed Concrete Association, 2011; Philadelphia Water Department, 2015; Minnesota Pollution Control Agency, 2016)

Key advantages:

- Reduce runoff volumes from impervious surfaces
- Does not require open space in the urban environment
- Can be applied in many types of areas such as pedestrian street, bicycle lanes, parking lots, light traffic roads and playgrounds
- Allow for groundwater recharge and water recharge to urban trees and soils

Key disadvantages:

- Highly depending on other LID units to function
- Less robust than conventional systems.
- Severely decreased function if compressed by heavy load
- In need of regular maintenance
- Prone to clogging when subject to soil runoff

6.3 LID storage and retention solutions for road and street environment

To enable successful implementation of LID, it is important to have sufficient storage or holding capacity within the system. This because infiltration, filtering, sedimentation units require a certain amount of time to infiltrate stormwater and remove pollutants. Delaying water in open or closed storage is also a natural way of reducing the peak runoff (Sintef Byggeforskningsinstitut, 2012).

Storage facilities can be constructed either below or above ground as dedicated magazines, dry or wet ponds or as urban areas that have multidisciplinary functions (Butler & Davies, 2012).

6.3.1 Storage cells

Infiltration and detention of water in aggregate beds are often requiring a significant amount of depth and space due to limitations in pore space. A relatively new solution to address this is stormwater storage cells. The cells have a much larger capacity than conventional infiltration and detention trenches and pits due to a porosity of 90 % and above (Bodin-Sköld, et al., 2014). The design allows for space efficient construction and installation that allow retention, storage and infiltration solution for any kind of urban area that are not subject to heavy load (Ramböll, 2013).

When ground conditions does not approve for groundwater infiltration, the cells retains and stores stormwater until the stored volume reaches the level of an overflow pipe, which convey excess water away from the unit. If soil and sediment conditions approve for infiltration to subgrade, the storage cells are wrapped with a permeable geotextile to ensure that solids do not enter the units and to enable a certain amount of treatment from the incoming stormwater (Bodin-Sköld, et al., 2014). Figure 12 exemplifies how stormwater cells can be established beneath the road or street surface.



Figure 12: Stormwater cells storing and retaining water under urban roads (casaeclima, 2014)

6.3.1.1 Key advantages and disadvantages with storage cells

The key advantages and disadvantages with stormwater cells are listed below and compiled from: (Bodin-Sköld, et al., 2014; Ramböll, 2013; Butler & Davies, 2012)

Key advantage:

- Large retention and storage ability
- Infiltrate stormwater to subgrade
- Does not require open surface space
- Cost effective

Key disadvantages:

- Depending on pre-treatment units to function, mainly to avoid clogging
- Difficult to access for repairs

6.3.2 Multifunctional urban retention and storage surfaces

Development of multifunctional areas in the urban environment is a key component in controlling large volumes of stormwater during heavy rain events. The idea is to enable stormwater management from as many urban areas as possible. Designing playgrounds, athletic fields or other public areas with potential to act as occasional storage surfaces at various location in the urban area is therefore a cost effective way for significantly decrease the flood risk (Calkings, 2011). Figure 13 illustrates how an urban playground can serve as occasional retention and storage units during rain events.



Figure 13: Urban playground used as stormwater unit during small and extensive rain events (webecoist, 2014)

6.3.3 Green roofs

The urban area often has limited possibility to establish green areas or ponds in the road and street environment. Thus, green roofs can be an alternative that fills the natural function of detaining water and reduce the runoff during rain events (Berndtsson, 2010). A rough estimation is that a green roof is able to hold 50-80 % of the rain events throughout the year (Sintef Byggforsk, 2013). The performance is however depending on the type of roof, roof

area, vegetation, degree of saturation and permeability in the vegetation and soil (Wilkinson, et al., 2014).

Green roofs are divided into extensive and intensive roof types, where extensive has shallow vegetated surface (sedum roof) and intensive has a thick vegetated surfaces with a mix of plants and aggregates (Jaffal, et al., 2011). The extensive roofs are primarily dedicated to stormwater management and insulation of buildings. As they are shallow constructions, it is mainly the retention qualities that make them a useful LID component as they can be installed on any kind of sloped roof. The intensive roofs have greater soil depth, a larger variety of plants and great potential for both storage and retention. They typically require flat roof surfaces and are built up on several layers to enable stormwater storage without harming the building (Calkings, 2011). Figure 14 exemplifies the design of extensive and extensive green roofs respectively.



Figure 14: Extensive and intensive green roof setups in urban environment (left figure: www.access-irrigation.co.uk, right figure: greenroofs.com).

The functionalities of green roofs make them a suitable part in a stormwater management plan in a road and street environment (Sintef Byggforsk, 2013). They can decrease the incoming runoff load on road and street drainage system as well as the main wastewater system, which in turn decrease the risk of flooding and wear on the system (Berndtsson, 2010). Moreover, the vegetated surfaces contribute to noise reduction and improved air quality that makes it most relevant along roads in the urban environment. Other positive impacts are energy savings due to increased building insulation and radiation, improved natural habitats and aesthetical improvement (Jaffal, et al., 2011).

6.3.3.1 Key advantages and disadvantages with green roofs

The most significant advantages and disadvantages with stormwater cells are listed below and compiled from: (*Minnesota Pollution Control Agency, 2016; Philadelphia Water Department, 2015; Sintef Byggforsk, 2013; Sustainable Technologies, 2016*)

Key advantage:

- Decrease the roof runoff to the road and street environment
- Improves aesthetics in its environment
- Increase urban biodiversity by providing habitat
- Provides insulation for buildings
- Reduce noise and vibration in the urban environment

- Improves air quality
- Low maintenance need

Key disadvantages:

- Implies a greater roof load and thereby the need of more robust construction and building cost
- Can cause leakage into buildings
- Difficult to access for repairs on base membrane

6.4 Controlled stormwater conveyance towards and from the LID system

Controlled conveyance of stormwater from roads and street towards and from the LID units are crucial to enable full functionality and avoid excessive wear. This challenge can be managed with the use of energy dissipaters, inlet controls and outlet controls.

6.4.1 Energy dissipaters

LID units are less robust constructions than conventional piped infrastructure and therefore more prone to erosion damages. Erosion issues normally occur during the transition from pipe to vegetated surface or directly in soils during high runoff velocity and turbulent flows. The problem is particularly common when there is a concentrated outflow of runoff in the LID unit (Das, et al., 2015). Energy dissipaters can therefore be an important device that reduces the erosive damage on the LID structures that might occur during heavy rain events. They range from robust concrete structures to small local solutions that erupt the stormwater flow from a road or street before it enters a LID unit, pond or water recipient (Philadelphia Water Department, 2015). Figure 15 below exemplifies two different energy dissipaters.



Figure 15: Left figure: energy dissipater that reduce the runoff velocity to a bio-swale. Right figure: Large energy dissipater at highway with high capacity to manage stormwater (www.omahastormwater.org).

6.4.2 Inlet controls

Inlets are structures that convey stormwater and provides a first screening of the runoff and thus an opportunity to prevent debris, trash, sediments and floatables from the road or street to enter the LID system. Inlet type varies from the classic manhole to gutters, racks, paved opening, screens to suspended catch basins and filters (New York City Department of Environmental Protection, 2012). Inlets are a key component in any urban stormwater system as it besides screening also provides robust transition from any urban surface towards LID

units, channels, streams and underground systems. Moreover, good inlet design and discharge control into the LID units enable optimal function and avoids excessive wear (Philadelphia Water Department, 2015). Figure 16 below exemplifies two different types of inlets in the urban road and street environment.



Figure 16: Inlets provide conveyance to and from LID units in the urban environment (www.portlandoregon.gov).

6.5.3 Outlet controls

Outlets are structures that regulate the release of stormwater towards and from a LID unit. Within LID, they are particularly important as overflow conveyers and to make sure that LID units store and drain stormwater as intended. Malfunctioning outlet controls can otherwise give rise to increased flood risk in the road and street environment. Examples of structures range from perforated drainage pipes, weirs, overflow devices, level spreaders to open water solutions (Philadelphia Water Department, 2015).

Smart design of outlets enable a controlled water discharge from runoff surfaces towards LID units and in the next step discharge from the LID units towards a recipient (New York City Department of Environmental Protection, 2012). Figure 17 below exemplifies two different outlet controls.



Figure 17: Left figure: Overflow riser to convey excess water from the bio-swale. Right figure: outlet weirs providing controlled conveyance of stormwater towards a recipient (flicker.com, Picture by: Hive mind).

6.5.4 Perforated pipe infiltration

Underground installations with perforated pipes, also called exfiltration systems, can be an alternative to use when the possibilities of surface infiltration are limited. The perforated pipe installations are highly adaptable to conventional inlets but are limited in removal capacity. Thus, they are recommended to receive stormwater runoff from surfaces with low pollutant concentration such as roofs, sidewalks and low trafficked roads. Their main benefit aside from not requiring any surface space is that they enable groundwater recharge and decrease stream erosion since the water is conveyed via robust inlets and discharged underground.

6.5.5 Soil support systems

Soil infiltration requires a certain minimum soil permeability to enable good infiltration. However, sometimes the road or street structure is in need of structural support from the soil, which implies that it has to be compacted. Soil support systems can be a valuable tool in these cases, as they secure structural stability without soil compaction and loss of permeability. The soil support systems are constructed as single or networks or crates that each hold a specific amount of soil and support the structural capacity of that soil mass (much like the stormwater cells in chapter 5.3.1).

The main benefits with soil support systems besides the preserved infiltration rate and structural support is that they also provide a beneficial subgrade environment for tree root systems. Figure 18 below shows the establishment of soil support structure in the urban environment.



Figure 18: Installation of soil support structure along urban road

Inlets can be designed to fit Nordic regions by being equipped by locking mechanisms that allow them to close during winter road operations and thereby minimize the amount of road salt that infiltrate the subgrade. Figure 19 below shows an example of a bio-swale structure with locking mechanism.



Figure 19: A locking mechanism in a bio swale to prevent discharge of stormwater runoff (flicker.com, Picture by: Hive mind)

6.6 Geotextiles

Particle intrusion, freeze and thaw issues are three major issues that need to be prevented to avoid decrease functionality and life-length of any LID construction. Freeze and thaw issues occur due to stormwater percolation of the road and street construction, meanwhile particle intrusion naturally occur from eroded vegetated surfaces. Geotextiles offers a solution to these issues as they, depending on type, have the ability to filter stormwater or waterproof the LID units (Toronto and Region Conservation Authority, 2010).

6.6.1 Preventing particle intrusion and waterproofing LID units

It is crucial to prevent stormwater intrusion from a LID unit into the roads, streets or buildings. This can be ensured by applying impermeable geotextiles (also called impervious liners) as a separating layer between the LID unit and the surrounding constructions. Moreover, waterproof wrapping of the LID units is also a mean of additional flood proofing if

outlet controls should malfunction because water is allowed to rise higher within the unit without releasing any water to the surrounding (Philadelphia Water Department, 2015).

A geotextile is a fine graded filter that allows water infiltration and at the same time prevent particle intrusion. As it prevents particles from entering the LID units, it thereby decreases the risk of clogging (Toronto and Region Conservation Authority, 2010). Furthermore, geotextiles can also have water-treating functionality. However, this requires selection of fine graded textiles that need controlled flow rates. Thus a trade-off between infiltration and treatment capacity must be made. (National Ready Mixed Concrete Association, 2011). Figure 20 below shows to different sites where geotextiles are used.



Figure 20: Left figure: Geotextiles in road trench to infiltrate runoff and increase the flood capacity (www.coletanche.com). Right figure: Geotextile used around storage cells to prevent leakage from the storage cell and particle intrusion from the soil (wwtonline.co.uk).

PART IV – CONCLUDING AND ANALYSING THE LITERATURE STUDY

Part IV concludes the literature study by answering and analysing the founding questions stated in the aim and objectives in the thesis. The aim with this is to link the different parts of the literature study and provide the reader with a good overview of the thesis.

7. CONCLUDING THE RESEARCH QUESTIONS OF THE THESIS

This chapter will give concise answers to the questions stated in the aim and objective in the report in. Largest emphasis is put on a risk-benefit analysis regarding the LID. The purpose of this is to conclude the literature study for the reader to make it easier to keep the information in mind.

7.1 What urban properties govern the possibility to use LID for road and street stormwater management?

Infiltration, storage, detention and floodway capacity can be developed within almost any urban feature, especially if it is incorporated in the urban planning at an early stage. Thus, the municipality development plan and regulations will have much to say in terms of making it possible to use LID for road and street stormwater management. Urban constructions such as buildings, streets, roads can all be equipped with various LID components that will improve the stormwater management in the road and street environment.

The design of the urban road and street network in relation to the terrain it is constructed in have significant impact on the local runoff characteristics and the amount of off-site runoff that potentially could accumulate into problematic volumes. Thus, this relation is vital to understand when planning LID and any other urban development for that matter.

Green roofs on urban buildings will decrease the off-site runoff to the road and street environment and significantly relief the urban stormwater sewer system. Integrating green roofs into a stormwater management plan for an urban road and street project should therefore be considered as most relevant. Not only will the stormwater be managed in a sustainable way, but also potentially huge cost savings will arise due to much lesser need of underground infrastructure.

Grass- and bio swales and permeable pavement are other examples of LID units which have the capacity of further decrease the amount of stormwater that reach the underground installations and urban watersheds. The success of these are highly related to the present urban properties as space constraints in combination with human activities, industries, gas stations and other naturally occurring components in the urban environment limits the suitability LID units to a certain extent.

A road or street can be designed as floodway for further increase the capacity to manage extreme weather. The suitability of this is however is much depending on the design of the road and street network as the stormwater runoff must be conveyed safely and have possibility to safely discharge into a recipient. Open streams, dry ponds or public multifunctional surfaces are examples of suitable receivers of this water. Open streams in particular have been subject to discussion as urban developers during many years have buried them in pipes underground and thus taken away much of the stormwater management

abilities. Multifunctional surfaces can be playgrounds, skate parks or outdoor sport fields that are designed and constructed to receive and store stormwater.

Preservation of native and natural soils, green areas and trees in particular have proven to provide excellent stormwater management abilities which makes them a key component in any robust road and street stormwater system.

An obvious limitation to the possibility of establish LID is when underground installations such as electric cables, heating systems and piped infrastructure does not allow for new development without major costly interruption or risk taking. In these cases, it is better to use the conventional system and provide upstream environment with LID solutions.

Traffic and winter road operations are another aspect that limits the suitability of LID and subgrade infiltration due to the release of various pollutants in the road and street environment. Traffic mainly gives rise to pollutants such as metals, solids, petroleum components, PAH and BOD/COD while winter road operation induce salt. All of these pollutants are harmful to the urban ecosystems and careful analysis of contamination risk should always be conducted.

7.2 What hydrological aspects are governing the LID planning for the road and street environment?

Urban hydrology comprise of the movement, distribution and quality of urban waters, which include both surface water and groundwater. Surface water is the water in streams, lakes, rivers and wetlands, meanwhile the groundwater is water trapped in soil and bedrock beneath the atmospheric pressure zone. Both these are governing the possibility of establishing LID units. Significant infiltration requires a specific minimum depth to the annual high groundwater table to make sure that the stormwater does not contaminate the groundwater. Moreover, local conditions in surface waters are closely related to the build-up of sediments, flood capacity and transportation of pollutants. Thus, using surface waters in a smart way and carefully evaluate its properties is an important part in any urban LID system.

Re-opening of streams that have been buried in pipes is a particularly cost effective way of significantly reducing the flood risk and improves the general stormwater conveyance in urban areas. Moreover, it also contributes to enhancing the natural environment and improves the aesthetic values locally.

Evaluating the drainage patterns and natural waterways in the urban environment are another vital area to address as development of road and street project, both will affect and be affected of it. Interrupting a natural water way will create new drainage patterns and lead to changes in the off-site runoff at other sites. Thus, awareness of upcoming urban development is important when dimensioning the LID units to avoid unexpected capacity shortages.

Studying the drainage patterns and waterways will also enable conclusions regarding vulnerable sites in terms of flood risk and hence the need of storage and retention upstream from the location. Because of this, mapping and evaluation of the urban hydrological conditions is an important part in LID planning. A site assessment during rainfall is also a relevant investigation to conduct since it gives the planner and water engineer a good sense of the site as it is possible to see how runoff flows along the streets, if there is any ponding water and how the present environment act during the rainfall.

Precipitation varies depending on the location of the site, it is important to find relevant measurement station that can provide accurate rain data for input to LID system design and capacity requirement. As climate change continues with high uncertainty, it is vital to follow up and measure the precipitation to calibrate expected rainfall and climate coefficients to produce accurate models for prediction valid Intensity-Flow charts used in flow calculations.

7.3 What ground properties are relevant to investigate to decide the suitability of stormwater infiltration?

There are a number of ground properties to assess prior establishing LID solutions in road and street environments. Geological maps are for example relevant so study as a first step in the planning process. The geological maps show soil masses and corresponding infiltration capacity and hence they can give a planner a good sense of the site in terms of suitability for groundwater infiltration. A rule of thumb is that infiltration of stormwater only should occur in masses with at least 10^{-6} m/s and hence, a soil with corresponding infiltration rate above 15 mm/hour can be considered as suitable.

To get proper values, a solid data collection from boring test is required from the relevant urban areas as the groundwater table varies locally depending on factors such as topography, geology and urban development. Depth to groundwater is of particular concern, as the water table must not reach within 1.2 meters of the surface. The deciding parameter in this matter is the study of the annual high groundwater table. Moreover, the soil samples will indicate whether the soil is contaminated and in need of remediation before any infiltration unit is established.

It is highly important to understand that urban development disturbs and interfere with native soils and other natural elements. The soil compaction is most relevant to investigate, as a dense packed soil will have permeability and infiltration capacity close to that of impermeable surfaces. Hence, if a soil test shows a high degree of compaction it is necessary to change it or mix it with gravel or sand to enable infiltration.

The topography sets a limit of a maximum preferred slope for infiltration surfaces to enable the stormwater to percolate vertically. Steep slopes will carry water in the top layers when flow velocities are too high for vertical infiltration. Moreover, the topography have significant impact on the runoff characteristics and the creation of off-site runoff which is why understanding of the relation between hydrology, topography and the urban development is absolutely necessary. Designing LID units in the road and street network without taking these aspects into account simultaneously is in many cases the original source behind flood events and stormwater related damages.

In countries that have a cold season, the ground investigations must be conducted to avoid frozen ground issues such as frost heave and partly lost infiltration capacity of the LID units. The soil type and mix is typically the main cause of issue in this matter and failing to address this can cause ponding of stormwater at the surface and in worst case local flooding.

7.4 What are the most relevant issues related to stormwater quantity and quality in the urban road and street environment?

The main issue that are creating today's and future challenges in stormwater management are the combined impact of climate change, urban design and activities including the design of conventional stormwater sewer system adds to the problematic situation.

Climate change is the cause behind the increased rain intensities that give rise to high peak discharge flows, which lead to capacity and erosion issues on both surface and subsurface structures. During the heaviest rain events, the capacity shortage in stormwater sewers becomes critical for the urban inhabitants as flood event occur, creating both direct and indirect damage on property, infrastructure and ecosystems.

The urban design with its dominance of impervious surfaces and underground stormwater sewers carries an equally large part of the problem. Impervious surfaces prevent local subgrade infiltration and give rise to fast runoff and large accumulated stormwater volumes that are caught by road and street inlets. The design and characteristics of the stormwater sewers further supporting a very fast conveyance of stormwater that lead to few heavily loaded discharge points in the subsurface network.

Unhealthy urban watersheds mainly suffer from pollutants such as metals, solids, petroleum components, PAH and BOD/COD coming from human activities such as traffic and construction. Moreover, the Norway and other Nordic countries have a problem related to winter road operation as de-icing road-salt give rise to increased pollutant spread in vegetation, soil and water. This can ultimately lead to increased groundwater contamination as no natural treatment mechanism can catch and hold large salt quantities.

7.5 How does stormwater management in Norway address LID in road and street development?

There is not yet any national law or master plan regarding LID for road and street development in Norway. However, Norges Offentlige Utredninger have developed new regulation suggestions on how to form this and the proposals are now up for public hearing. Thus, there will probably be a national master plan in place within a near future. Aside from this, there is a consensus and understanding of the issues with stormwater and that adaption of the urban road and street environment is needed to meet future demands.

Many municipalities have developed LID strategies where the tree step strategy and a general green infrastructure approach is in focus. This strategy implies focus on infiltration, detention and conveyance of stormwater in open waterways meanwhile the green infrastructure approach aims at using available urban land in a smart way to manage stormwater.

7.6 What are the keys to successful implement LID in road and street planning?

Besides the obvious requirements of knowledge that have been stated in the previous answers, the establishing of LID nationwide in urban areas will require development of national regulations and standards that planners and contractors should follow. Regulations to ease the procurement and construction process of LID project would have significant impact on the rate of implementation and ensure that road and street stakeholders find value in LID.

Implementation of LID on full scale in municipality master plans would be a gentle way of forcing planners to improve their knowledge in stormwater and LID. Furthermore, collaboration between stakeholders in the road and street environment is essential to make the transition towards LID as smooth as possible. This includes public and corporate understanding and acceptance of why economic regulations arise and why they must be responsible for the runoff and pollution created within their environment. If acceptance is reached on all levels of society, the urban environment will see a natural growth in LID units and preservation of the natural environment.

Experience from abroad have shown positive results from these kind of regulations and thus, the likelihood of successfully implementing similar ones in Norway are high.

8. ANALYSIS OF BENEFITS AND POTENTIAL SETBACKS WITH LID

This chapter will look further into and analyse some of the key benefits and potential setbacks with LID. The idea with this chapter is to provide an overview of aspects and considerations that are important to keep in mind.

8.1 Benefit analysis of LID solutions in road and street environment

Decreasing the amount of stormwater that reach the regular wastewater system and end up in the watershed will have positive effects on the infrastructure, water quantity, quality and the connected ecosystem. The key benefits are stated in Table 13 below and further discussed in the following text.

Table 9: Summary of potential benefits to society as a result of LID on a large scale in the urban environment.

Potential beneficial impact of using LID	Outcome
Decreased load on the road/street main drainage and stormwater system	Less risk of surface flooding of road/street and less risk of wastewater system flooding leading to sewage overflow due to less and slower runoff. This also have positive economic, social impact as flood damages has a high cost, and the mobility level are maintained
Decreased wear on the piped stormwater system	Less maintenance cost, leaking from piped system and cost of constructing new systems as the old ones' fail. Maintenance and new construction moreover usually creates mobility issues within the city
Groundwater recharge	Higher groundwater levels in the urban area and thereby better resistance against settlement on roads and streets
Less pollutants reaching the watersheds	Healthier water environment and ecosystems as metals and organic pollutants stays in their infiltration media
Less erosion of stream and riverbeds	Healthier water environment, ecosystems and less risk of slope failure along riverbeds
Retaining natural drainage patterns	Less point source load in the wastewater system which easy potential downstream problems in sloped areas
Traffic safety improvement	Vegetated LID units can serve as barriers between pedestrians, bicyclist and motorized vehicle. Moreover, the crash impact on a vegetated surface is far less than a paved one. In comparison to regular grey toned paving, the natural vegetation colour has higher visibility in daylight
Improved aesthetic values	Social improvement for the city citizens as green and vegetation add to the comfort for human beings
Economic improvement for society	LID contribute to increased land and property value, human wellbeing, lower cost for infrastructure development and maintenance

8.1.1 Improved capacity during extreme weather

LID result in less stormwater reaching the underground water infrastructure due to increased local infiltration, retention and storage. The fact that LID units can be completely disconnected from the stormwater sewers result in much less accumulated stormwater volumes in the sewers.

All systems might not have the capacity to manage extreme weather on its own, but the collaboration between current water systems and LID systems will together meet the demands. The key feature in LID concerning extreme weather is to make use of the retention qualities of vegetated areas, combined with open waterways such as streams, rivers and streets designed with flood ways. Any city would therefore benefit from re-opening streams that have been buried in pipes and/or covered by impervious surface and thus enabling a

significant flood capacity improvement. Moreover, widespread implementation of green roofs would reduce property runoff to road and street, which makes it a powerful LID component to use for controlling the peak flow on the ground.

8.1.2 Decreased wear on the stormwater sewage system

When stormwater is managed directly in the road and street environment, the urban water cycle becomes increasingly similar to what was before development. As more stormwater soaks into the ground instead of being conveyed underground, LID result in less capacity shortages and malfunctioning of the stormwater sewage during storm events. This is otherwise particularly common in areas where previously open water ways have been buried underground in pipes.

Disconnection from the conventional stormwater sewage decreases the accumulated runoff volumes from the road and streets. During extreme weather, this result in less critical and decreased numbers of combined sewage overflows and thus a less pollutant discharge into the aquatic environment.

Finally, LID decreases the wear of the stormwater sewage system. This result in less costly maintenance on pipes and pipe connections, which in turn decreases mobility interruption on the urban roads and streets. As the pipes and its connections are subject to less load the likelihood of extensive leakage is also minimized.

8.1.3 Economic benefits with LID

As LID expand in an urban environment, a number of economic benefits arise. Knowledge of these are crucial as economic aspects often are of great concern when planning the urban development. The economic benefit that comes with LID implementation will therefore support the growth of contractors with strong environmental focus. Moreover, private citizens will probably increase their investment in LID if they are aware of the increased property value that comes with it. The key economic benefits that arise from increased LID in the urban environment are stated in Table 14.

Table 10: Economic benefits connected to large scale LID implementation in the urban area

Impact due to increased LID	Economic benefits
Reduced flood risk	Increased private and public land and property value
Improved natural environment	Increase of property value and wellbeing among urban citizens
Increased heat trapping	Lower energy cost for property owners
Improved water quality in watersheds	Increased property value for properties close to watershed
Reduced amount of water reaching the wastewater system and treatment plants	Lower cost of system maintenance and treating water as wear on components decrease.
Reduced load on wastewater system	Less pollutant leaking and hence less cost of remediate soils
Decreased dependence on piped wastewater systems	Lower cost of infrastructure

8.1.4 Groundwater recharge

Local infiltration of stormwater is a key objective in any LID system. By infiltrating stormwater locally, the groundwater recharge increase significantly and a number of benefits arise. When the groundwater aquifers are recharged, the cost of producing local drinking water will decrease both because greater quantities are available, but also due to lower pumping cost as the groundwater table rises. To fully making use of this benefit, it is vital to infiltrate water without risking contamination to extent where drinking water treatment becomes too expensive and inefficient. Other benefits of groundwater recharge is the

decreased risk of settlement and related damages to the urban infrastructure, which normally give rise to expensive maintenance, decreased mobility and comfort loss.

8.1.5 Environmental benefits with LID

The environmental perspective is one of the essential parts in why LID is gaining more credibility. It has been widely accepted that urban areas must strive to restore water quality in rivers, streams and other water recipients as they today and in the past have been subject to heavy irresponsible pollution by man.

LID will ensure a certain degree of pollutant removal from road and street stormwater, which in turn give a recipient discharge with much better quality and a healthier ecosystem. LID will also decrease the amount of impermeable surface in the urban area and give rise to less powerful runoff. This leads to less erosion and sediment transportation vegetated areas, stream and riverbeds and preserving of ecosystems in the road and street environment.

Preserving the natural environment and enhance the urban ecosystems are two main objectives with LID. Naturally, this give rise to a more careful management of the environment and emphasis on reshaping its original waterways. Re-opening streams that have been buried into pipes might be one of the most important operations concerning these objectives. It enables a much higher conveyance capacity and at the same time a natural aquatic habitat and aesthetic improvement of the urban environment.

8.1.6 Public benefits

There are benefits that come as an indirect result of LID. Among the most important to recognize are the increased wellbeing, aesthetics and biodiversity that are a result from more natural elements and open space in the urban environment. Improved aesthetics and open space LID solutions create recreational areas for the urban citizens, which in turn might lead to more people getting out and enjoying the local environment. Moreover, the increased amount of natural environment preserves the health and biodiversity in the urban ecosystems. LID also has positive impact on the air quality in the road and street environment since carbon and air pollutants are trapped in vegetated surfaces. Moreover, the increased amount of natural elements can lead to significant noise reduction and hence decreased stress among the urban inhabitants.

8.2 Limitations and setbacks of LID in road and street environment

Although LID generally provides robust sustainable stormwater management, there are some potential limitations and setback, which are important to consider during the planning of a LID system. These are mainly not related to LID itself, but the surrounding that limits its ability. Table 15 states some of the potential limitations and setbacks with LID. Some of these are also further explained in the following text.

Table 11: Potential setbacks with LID.

Potential setbacks	Explanation
Polluted infiltration media	Soil and vegetation, which infiltrates the water, will hold a high level of pollutants. Thus, it might not be suitable to infiltration surfaces as recreation areas for humans.
Groundwater pollution	Infiltrating untreated stormwater means risk of polluting groundwater with metals, petroleum components, PAH and solids to mention a few.
Depth requirements	There should at least be 1.2 m separating the surface and the yearly high water table to safely infiltrate stormwater into subgrade and groundwater. Thus, this might limit the sites suitable for subgrade infiltration.
Areal loss in the city centre	Landowners or municipalities might see an economical downside in not developing valuable land.
Uncertainty in long term effects on groundwater	As infiltration for groundwater recharge has not been used during a long period in urban areas, there are many uncertainties of its potential impact on the groundwater quality.
Insufficient capacity during heavy rain	Most LID units does not possess the capacity of managing heavy rain events alone and are in need of complementary units such as storage crates, ponds and regular wastewater systems.
Traffic safety	Swales and vegetated traffic islands might not possess the same traffic safety potential in terms of separating the traffic as regular paved traffic islands and lane separators.

8.2.1 Groundwater pollution

LID is in most cases improving the stormwater quality and thus decreasing the risk of polluting the environment. However, as road and street stormwater holds a large amount of pollutants there is a risk of infiltrating pollutants into the subgrade that eventually reach the groundwater. This could potentially cause long-term negative effects on the groundwater quality in the urban area, as there is no efficient way to treat polluted groundwater at site.

The potential issue of infiltrating pollutants are especially high in Nordic regions during winter when de-icing components are used for winter road maintenance. Road salt is particularly problematic as it dissolves both itself and other pollutants, which make the percolation process easier. As today, there is no efficient way of managing this pollutant.

8.2.2 Areal loss

Development of LID systems in the urban environment is in general requiring a certain amount of land. Hence, there might be a conflict between stakeholders when valuable land has to be given up for stormwater system development.

8.2.3 Traffic safety issues

LID in the road and street environment are not by definition related to risk. However, infiltration trenches at some sites might require significant depth to enable full infiltration capacity and prevent water from rising above the frost secure depth. This in turn can give rise to dangerous swerving accidents for both vehicles and bicyclist.

8.2.4 Design and operations requirements

LID units require knowledge in both design and maintenance operations that are site and climate specific. Hence, there is a potential risk in implementing widespread LID unless proper design standards and maintenance plans are at hand. This is especially important in Nordic climate conditions as freeze and thaw issues otherwise risk putting a system out of function. Moreover, LID infiltration solutions have a set of requirements with regards to ground conditions, topography and hydrology that limits the possibility of widespread development. This in itself is not a setback with LID, but they are sources of limitation.

8.2.5 Conveyance problems and flood risk

A LID system might not always have the capacity to manage extreme weather events and are therefore depending on a well thought through connection to a piped system. Included in this is also proper maintenance of energy dissipaters, inlets, outlets and weirs. If these connections are not maintained properly, there is risk of flood related issues when LID units clog or when pipes are worn out.

8.2.6 Lack of treatment capacity

When the urban surrounding require significant treatment of stormwater or does not allow for optimal design, due to space constraints, unfavourable ground conditions or specific human activities. In these cases, LID units are often depending on more expensive technical treatment units to provide pre-treatment and avoid the release of polluted discharge. Moreover, pre-treatment is in some cases also necessary to avoid high levels of particle intrusion and sediment settlement in the LID unit. Thus, some people might argue for that LID units are to depending on technical solution to provide robust stormwater management.

PART V – CASE STUDY AT TELTHUSBAKKEN

Part IV contains the case study at Telthusbakken in Oslo. This part is somewhat concluding the thesis as it in a simplified way demonstrates how an urban site can be retrofitted with LID to improve a critical stormwater situation. The purpose with the case study is to show that relatively small-scale changes can make significant improvements by making use of the LID.

9. STORMWATER MANAGEMENT AT TELTHUSBAKKEN

The case site is located along Maridalsveien at Telthusbakken in central Oslo. The site has been chosen for investigation as it represents many of the key factors that create stormwater related issues today. These factors are; high degree of impervious surfaces, problematic topography, lack of storage and retention, runoff from roofs and under dimensioned underground infrastructure.

9.1 Introducing the site and the sources of stormwater issues

Telthusbakken has been frequently flooded during recent years, which has caused interruption in daily mobility among the citizens in Oslo, damages on adjacent properties and the road construction itself. Figure 21 below shows a flood event at the site that occurred during heavy summer rains.



Figure 21: Flood event at Telthusbakken as a result of heavy summer rains (Osloby.no)

The reason for Telthusbakken being a complicated site with frequent flooding is most certain a mix of a number of factors. These do not cause any issues on their own but together they occasionally result in very problematic situations. The core issues are stated below.

Impervious surfaces and conveyance issues

There is dense urban development at the site, consisting of housing, roads and streets and parking lots, which makes up and almost entirely impervious surrounding. Thus, the high degree of imperviousness contributes to fast runoff and large runoff during heavy rain events as there is a complete lack of surfaces with retention and storage capacity. Lack of conveyance of stormwater from road and street to inlets and the few vegetated surfaces is another factor. The result is that large stormwater flows accumulate along the road with which

in the end cause downstream problems. Figure 22 shows the runoff directions from the surrounding towards the critical site.

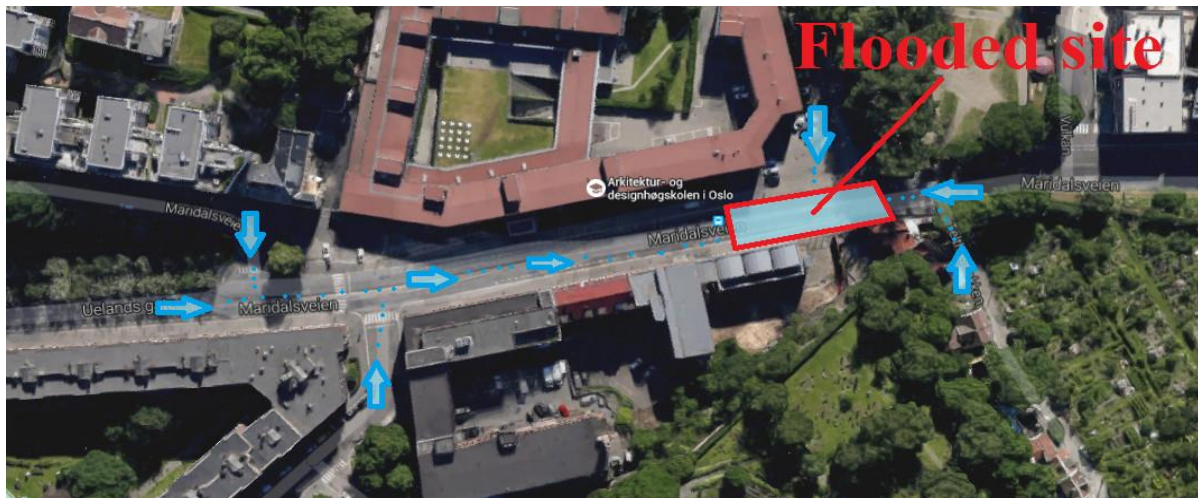


Figure 22: Map indicating the runoff flow directions at site (map from google maps, illustration made by Daniel Hammerlid)

Topography and urban planning at site

Several connected/adjacent sloped streets convey stormwater rapidly to the site. This shows the importance of well thought through urban planning and awareness of that accumulated runoff can cause problematic off-site runoff in the close surrounding. The topography is certainly an issue since the majority of the surrounding is sloped towards the road and street. The currently problematic site is particularly vulnerable as it is the lowest point in the area. The map in Figure 23 shows the topographical characteristics and related flow directions at site.



Figure 23: Topographic map at Telthusbakken. The red lines are level curves and the blue arrows indicate the corresponding flow direction of water (NGU, 2015)

Capacity issues in the underground water system

Most likely, the site and its environment has a stormwater system designed in a time when less development was at place. Bypassing this consideration when the development rapidly increased during recent years is potentially one of the main sources of why the designed capacity is insufficient.

9.2 Evaluation of the site conditions

The ground conditions at the site is vital to study to decide whether it is possible to infiltrate stormwater into the subgrade and towards groundwater. As described in chapter 4, the subgrade properties that are required to establish natural infiltration are a soil with permeability higher than 10^{-6} m/s. The two maps in Figure 24 and Figure 25 are gathered from The Norwegian Geological Surveys and shows sediment type and corresponding infiltration capacity at Telthusbakken.



Figure 24: Sediment map indicating thick and fine graded marine sediments at site. The marked surface indicates the critical area (NGU, 2015)

The sediment map indicates that the area along Maridalsveien and the critical site at Telthusbakken consist of thick marine sediments (bright blue) and fine graded sediments (purple). The dominating material is various type of clay. Quick clay is among these present types.

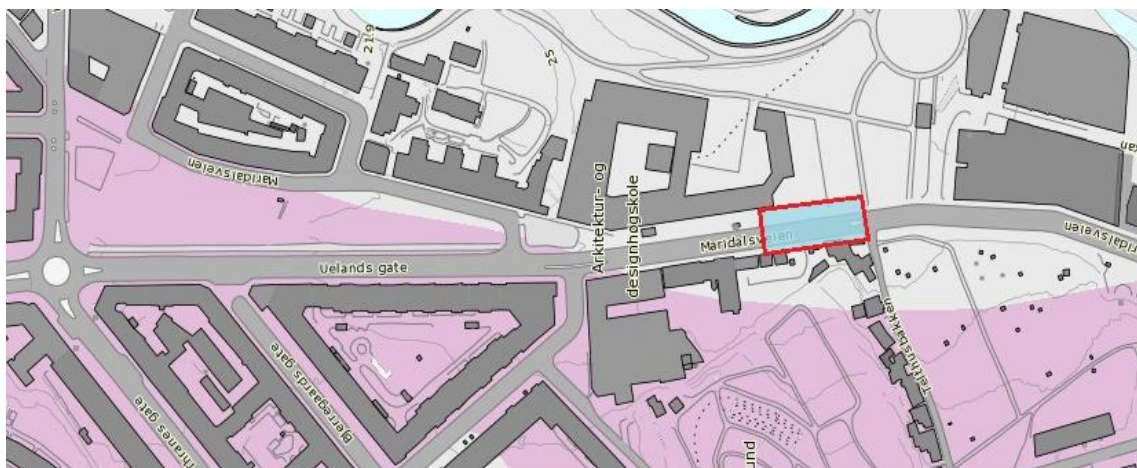


Figure 25: Mapping of infiltration capacity show that the area is dominated by soils with little or no infiltration capacity. The marked surface indicates the critical area (NGU, 2015)

Table 12: Ground conditions not suitable for infiltration according to maps gathered at Norwegian Geological institute.

Mapping ground conditions and infiltration capacity at Telthusbakken				
Colour in infiltration map	Colour in sediment map	Sediment	Dominating material	Infiltration capacity
White/grey	Bright blue	Thick marine sediments	Clay	Very low
Purple/pink	Purple	Fine graded marine sediments	Clay	None/spots of infiltration potential

The sediments, which are dominated by clay, indicates permeability much lower than the recommended limit of 10^{-6} m/s. Moreover, clay is highly likely to give rise to frost related issues during the winter season. The site can therefore be considered not suitable for subgrade infiltration as the permeability and infiltration rate is too low. The objective of implementing a LID system at the site must therefore be to reduce runoff by enabling good retention and storage of stormwater.

Normally, soil boring test and analysis would be suitable to conclude in a case like this, but since the subgrade does not allow for infiltration, it seems reasonable to skip this to decrease project cost. Another reason for not allowing infiltration to the subgrade is that road salt is used frequently during winter season to keep the bicycle fields clear of ice and snow. Thus, subgrade infiltration from road and street at Telthusbakken would potentially pollute the subgrade and soil sediments

9.3 Planning the new LID strategy at Telthusbakken

The new suggested strategy is in line with the Norwegian stormwater strategy that strive to manage as much stormwater as possible locally at the site where it falls, instead of conveying it directly into the subsurface stormwater system. As the possibility of subgrade infiltration is ruled out for this case, the strategy aims at maximizing storing and retention at Telthusbakken by using various LID units. However, infiltration will still be vital concerning pollutant removal. As this site is frequently flooded the aim is to reduce the flood risk but in doing so also establish a solid sustainable everyday LID system.

Three spots that have considerable storage and retention potential have been chosen to be re-designed into LID units. These are marked out with yellow numbers on the map below and showed in Figure 26.

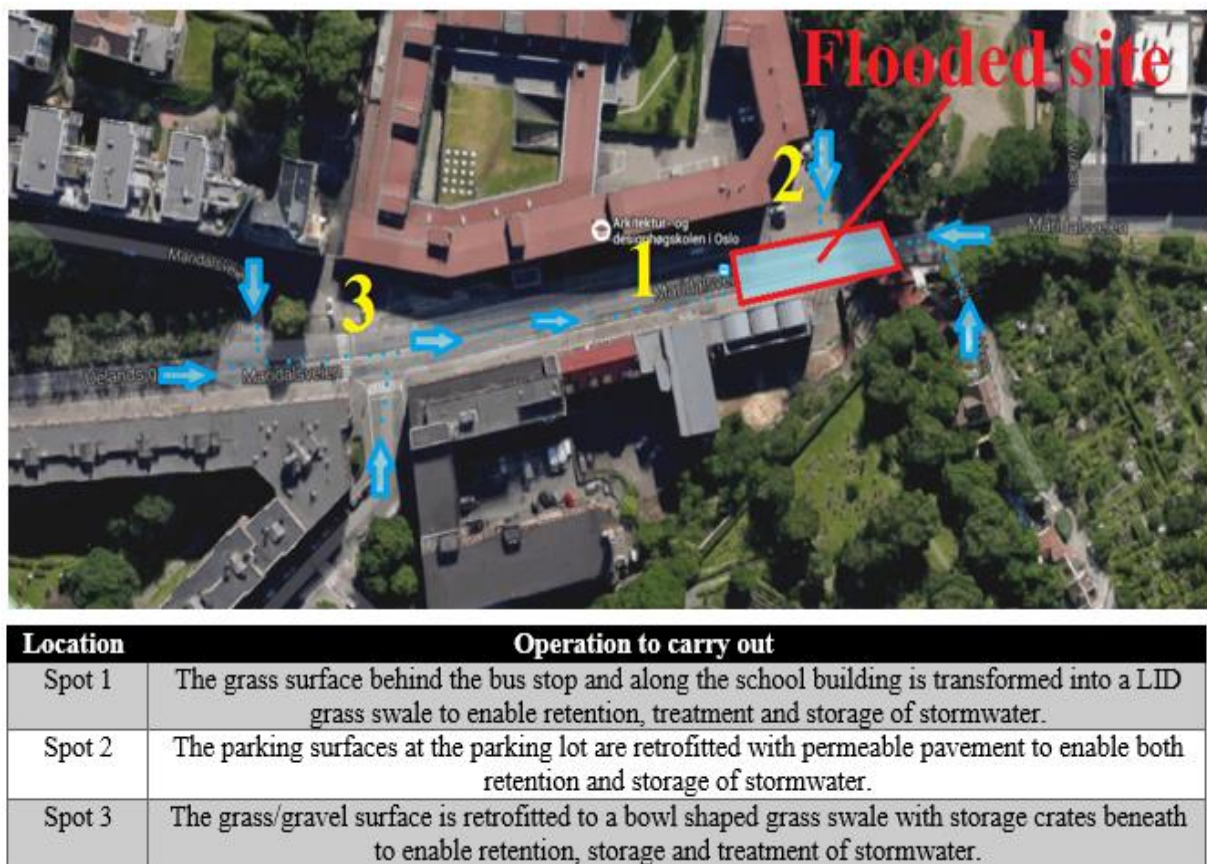


Figure 26: Spot 1,2,3 indicates the locations of new LID units, flow direction of the runoff and where the critical site is. (1) Parking lot (2), Grass area along the school building (3)

The re-design of these spots will provide increased treatment, retention and storage of stormwater during rain events at Telthusbakken. By selecting these solutions, the key functions of LID described in previous chapters are achieved. Further reading about grass swale, permeable pavement and storage cells can be found in chapter 6.

Aside from redesigning the three surfaces on the spots, a new conveyance system must be established in the area to ensure that stormwater reach the LID units and do so in a balanced way. Inlet controls must therefore be installed in the street, with inclination towards the LID units. Moreover, outlet controls should also be implemented into each of the units to avoid flooding and enable controlled discharge of stormwater.

Figure 27 shows what the three spots at Telthusbakken look like prior being redesigned into LID units.



Figure 27: Spot 1,2 and 3 prior being retrofitted into LID units.

9.3.1 Spot 1 – Retrofitting a vegetated area

The grass surface behind the bus stop and along the university building is not directly causing problem at the site. However, this surface holds great potential as a stormwater unit without being used. As today, the surface only manages water falling directly to the surface due to the lack of inlets. Moreover, the soil also holds a high content of clay and hence it does not very effective in terms of infiltration.

The idea is to convert this surface it into a proper LID grass swale that can manage much of the runoff created at the near site. Moreover, it will also manage much of the roof runoff from the adjacent building.

The area measures 300 m² but as a safety distance of 1 m to the university building is chosen, 240 m² of grass swale will be available. The result is an efficient infiltration surface with the ability to treat, retain and store stormwater. Inlets from road and street must also have inclination towards the swale to enable conveyance of water.

During average rain events, the grass swale can provide for solid stormwater management and release water in a very low pace. There will most likely never discharge any stormwater to the underground water system during small to normal rain events. To enable the swale to store significant amounts of stormwater on its surface during heavy rain events there would have to be waterproof wrapping along the sides to avoid percolation to the surrounding environment. Moreover, outlet controls will be a key function to avoid overflow from the swale. Figure 28 illustrates the grass swale. Further reading regarding swales is found in chapter 6.1.



Figure 28: Illustration of established 300 m² grass swale behind the bus stop and along the school building (Image by: Daniel Hammerlid).

Key benefits with grass swale at Spot 1:

- Retention of stormwater (Reduced stormwater discharge and peak runoff)
- Storage of stormwater (Reduced stormwater discharge and peak runoff)
- Treatment of stormwater (Improved stormwater quality)
- Aesthetical improvement (Increased biodiversity)
- Enhanced natural environment
- Space efficient (Do not occupy any extra open surface)

9.3.2 Spot 2 – Retrofitting a parking lot

The parking lot impact the site as it is made up of 100% impervious area, sloped towards the flood risk area and have one of its two gullies out of function as a result of settlements. The parking space for regular vehicles area are changed to permeable paving to allow for infiltration, retention and some storage of stormwater.

Converting all parking spaces (2,3m x 4,5m) will allow for 370 m² of new infiltration surface and hence a significantly improved retention and relief to the piped system during heavy rain.

Permeable pavement outside the marked parking lots is avoided, as it is likely that heavy vehicles will compact the paving, decrease functionality and create need for frequent maintenance.

To ensure that pollutant does not reach the water system, the pavement structure must incorporate the right choice of geotextile and subbase. The correct choice of geotextile will prevent particle intrusion, meanwhile the subbase will trap potential oil spills. To prevent stillstanding stormwater within the structures a robust outlet system must be established underneath. Figure 29 illustrates the permeable parking surfaces. Further reading regarding permeable pavement is found in chapter 6.2.



Figure 29: Illustrating location for establishment of 370 m² permeable pavement at parking lots (Image by: Daniel Hammerlid).

Key benefits with permeable pavement at Spot 2:

- Retention of stormwater (Reduced stormwater discharge and peak runoff)
- Storage of stormwater (Reduced stormwater discharge and peak runoff)
- Treatment of stormwater (Reduced discharge of pollutants to a certain extent)
- Space efficient (Underground construction)

9.3.3 Spot 3 – Retrofitting a gravel surface

This spot is the one located farthest away from the critical site. Today it consists of a 70 m² poorly maintained grass and gravel surface with no other purpose than being a barrier between a smaller parking and two pedestrian streets. Located roughly 100 meters from the critical zone further down the road, this site makes a suitable spot for establishing a grass swale with storage cells beneath to provide stormwater treatment, retention and storage.

Estimated result of the retrofitting of this site is that the whole surface of 70 m² will be able to act as a grass swale. To exemplify the use of the storage cells an installation with capacity of 15 m³ can be fitted underneath.

This establishment will during normal rain events provide robust stormwater management with infiltration, treatment, retention and storage at site and most likely only release stormwater during very heavy rain events. To enable a controlled discharge of stormwater into the swale and maximize infiltration to the storage cells inlets will have to spread out the flow through the swale. Moreover, as with Spot 1, the swale will have to be equipped with outlet controls to avoid overflow and enable drainage of the storage cells between the rain events. Figure 30 illustrates the grass swale and placement of storage cells. Further reading regarding swales and storage cell is found in chapter 6.1 and 7.4 respectively.



Figure 30: Illustration of the 70 m² grass swale with storage cells with 15 m³ -storage capacity beneath (Image by: Daniel Hammerlid).

Key benefits with grass swale at Spot 1:

- Retention of stormwater (Reduced stormwater discharge and peak runoff)
- Storage of stormwater (Reduced stormwater discharge and peak runoff)
- Treatment of stormwater (Improved stormwater quality)
- Aesthetical improvement
- Enhanced natural environment (Increased biodiversity)
- Space efficient (Do not occupy any extra open surface)

9.4 Important considerations during construction and maintenance of the LID units

The functionality of LID units is much depending on correct executed construction and well-planned maintenance. Apart from general common sense, a few aspects are particularly important to consider. These are listed below and based on: (Credit Valley Conservation, 2015; Minnesota Pollution Control Agency, 2016; Toronto and Region Conservation Authority, 2010) and (EPA, 2016).

Key construction considerations when establishing LID:

- Accurate grading of the different soil layers in the swale is essential to enable percolation of water. Doing this wrong will result in clogging of the layers and flooding of the swale within a shorter period. A full rebuild is then required to regain functionality
- Construction machines and heavy stockpiles of material should be kept out of the site to avoid compaction of the soil. Compacting the soil will reduce the porosity and permeability of the soil significantly and hence reduce the infiltration capacity
- The site must be protected from stormwater runoff during construction to avoid erosion and sedimentation of particles. This could otherwise cause stability issues and clogging of the lower part of the swale, which normally is protected from solids with a geotextile wrapping
- A good quality waterproof wrapping along the slopes of the swale is recommended to avoid water from infiltrating adjacent road/street body or building. If, and only if doing so, the required frost secure depth can be bypassed
- Inlet and outlet controls should be installed and tested to ensure a controlled discharge of stormwater, towards and from the LID units. This is crucial to enable optimal function and avoid excessive wear and maintenance

Key maintenance considerations when establishing LID:

- The grass height should be maintained at a correct height to enable maximum capacity with regards to pollutant treatment and flow rate in the swale
- Inspection for erosion and damages on the grass or soil should be done on a regular yearly basis. Damages must be repaired quickest possible to regain original operational efficiency
- Keep site clear of trash and debris to enable the water to flow and percolate the swale properly. Evaluate the performance of the swale and chose another type of grass if necessary
- Remove accumulated sediment at the bottom of the swale when 25% of the capacity has been used. This is important as the swale otherwise loose both treatment capacity and function as occasional open storage unit
- Clean grids on a regular basis is suitable as it makes sure that conveyance of the stormwater works as intended. Grids containing leaves, grit or trash would

9.5 Retention and storage capacity assessment for the suggested system during a heavy rain event

To put the theoretical storage potential of the new solutions into context, a set of simplified calculations and assumptions has been made to access a critical situation. A rain event where 20 mm of precipitation falls within an hour has been chosen. This because 20 mm/hour is a lower limit where the metrological institute issues a warning for heavy rain (yr.no, 2014). A catchment area of 1.2 acres, covering only the road and street has been chosen to represent the calculation example. The selected area is displayed in Figure 31.



Figure 31: Assumed contributing drainage area of 1.2 acres from road and street (norgebilder.no).

Assumptions and prerequisites prior calculation:

- Inlet and outlet controls enable optimal discharge of stormwater towards, and from the LID units
- Only stormwater from the road and street marked in the map above reach these units
- The permeable parking does only manage water falling on the parking surface
- Still standing water in the swales is allowed to rise 10 cm on average in the swale, before managed by outlet controls

A runoff coefficient of 0.9 was used along with a rainfall intensity of 20 mm per hour and a drainage area of 1.2 acres. The rational method was then used to calculate the peak discharge flow at site to 24 l/s. Further reading about the rational method can be found in Appendix I.

When large flows are produced during a rain event like this, infiltration is not the main task for the stormwater system. Instead retention and storage is in focus to relief the wastewater system during the peak flow period and hence trying to prevent that flooding occur.

At the site, 15 m³ of storage capacity has been established in the form of crates. Added to this is the fact that both the larger grass swale has a storage capacity of 31 m³. Thus, the available storage capacity in the grass swales and storage crates is 46 m³. The theoretical retention time can therefore be calculated to 31.9 minutes by dividing the total storage with the peak discharge. The theoretical retention time of 31.9 minutes for the two grass swales and the storage crates, enable a significant relief on the underground water system during a rain event of this calibre..

9.6 Concluding the case study

The suggested LID solutions at Telthusbakken provide 680 m² of new infiltration surface with capacity to treat, retain and store water. This will result in a significant reduction in the peak load at the site but also a LID system that can manage all normal rain events during the year.

Table 16: Summary of actions taken and related impact at site

Location	LID unit	Impact
Spot 1	Grass Swale	250 m ² of grass swale with capacity to infiltrate, treat, retain and store water in its soil. Moreover, it can act as occasional surface storage unit during extreme weather.
Spot 2	Permeable pavement	370 m ² of new infiltration surface with capacity to infiltrate, retain and store water.
Spot 3	Grass swale & storage cells	60 m ² of grass swale with capacity to infiltrate, treat, retain and store water in its soil. At least 15 m ³ of storage capacity in crates underneath

The case study is a simplified way of showing the potential of LID it does however bring light to very important aspects in stormwater management. By establishing storage and retention at Telthusbakken, the three spots enable a significant reduction in the peak flow on the surface and accumulated runoff that reach the underground system. Unfortunately was that the subgrade did not approve for extensive infiltration which would have given a significant capacity increase in the system. However, a few changes like this does potentially make the site much less prone to flooding and stormwater related damages.

The swales in particular are a cost effective way to improve both stormwater management and the aesthetics in the environment at Telthusbakken. Moreover, the spots suggested for constructed does not fulfil any specific use and thus retrofitting these would not cause issues or have impact on any stakeholder. Normally inlets and outlets are planned in detail in a full-scale project as any LID unit, or conventional system for that matter, will fail without these being carefully designed. These considerations are probably not given enough though attention in urban planning the source of erosion damages and flooding often is under dimensioned inlet and outlet controls rather than the LID unit or pipe itself.

PART VI – DISCUSSION AND CONCLUSIONS

Part V contains discussion and conclusion around the thesis, the most important findings and the case study.

10. DISCUSSION AND CONCLUSIONS

This discussion incorporates my thoughts around the topics that has been studied and analysed throughout the report.

LID has a great potential to improve stormwater management in the urban environment and for road and street in particular. Road and street planning will naturally have to evolve along with the public and private stakeholders to enable a robust and sustainable development. However, this is no longer a problem as the need and understanding of climate adaption and environmental care has come a long way during the recent years. The discussion will take on five relevant subjects to conclude and somewhat give a more informal approach to the thesis.

10.1 LID in road and street planning

LID is the new paradigm in stormwater management in Norway. It is also somewhat a breaking point in not only water management for road and street planners but infrastructure and society development as a whole. The reason is that large parts of present water systems connected to roads and streets in the urban areas are old and in need of maintenance or replacement. The estimated cost of the required improvement is several billions of Norwegian kroner (NOK). Due to this, it seems like an obvious choice to construct and control the water with new stormwater solutions separated or partly separated from the old systems and thereby reach a cost effective solution. Besides this, the conventional stormwater sewage systems have several times proven not capable of meeting the vast and high intensity rains of today, which makes it highly likely that the flood issues will grow exponentially if major changes are not at place when as the impact of climate change increase. However, with this being said, the importance of current underground infrastructure installations should not by any means be underestimated as they will play an important role in areas where LID establishment is unsuitable and as overflow conveyers from the LID units.

The benefits that comes with increased use of LID differs depending on the view of the stakeholders. In water management, the main stakeholders are the municipality, the citizens of the city, animals and plants living of the water and the environment. However, many of the benefits are interconnected, which gives a multiple of positive impacts which should be enough to convince any stakeholder no matter is money or environmental wellbeing is on the agenda.

To start with, the obvious benefit with LID will be improved stormwater management in the urban environment as road and street runoff from each area is controlled and managed locally largely instead of being conveyed to underground system where its volume is accumulated together with runoff from other areas. Decreased point discharges and less pressure on the underground infrastructure will thereby naturally give better resistance to flooding and stormwater related damages. Moreover, LID implies stormwater treatment with natural methods such as percolation through grass, soils and vegetative filters. Thus, both stormwater quantity and quality management is improved by LID.

To take another subject into discussion and explain the potential of LID, one can argue for LID in road and street planning will enhance the urban environment aesthetically as the amount of vegetation and open waters increase. Following this is increased wellbeing as humans thrive in a more natural environment and green infrastructure when less affected by noise and air pollution. Enhanced natural infrastructure and green areas further have positive impacts on fauna and biodiversity in the urban ecosystem and hence living conditions for both humans and animals improve. The chain of positive effects does not end here since LID also has proven to increase property and land value in the urban area.

10.2 Changes in urban planning and stormwater regulations due to LID

The planning phase for road and street construction in Norway will see a change regarding project that affect the water environments. Rather than road and street planners having to consider water environments as a challenge for the construction, they will probably have to consider it as the governing element in planning and design. From my point of view this will result in a health priority change where humans rather than colonising and shaping the water environment to their needs have to live in symbiosis with its natural ways.

New regulations must most likely be incorporated in Norwegian law to ensure that society unite behind coming water regulations since the faithfulness to a new era in water management most likely will disappear the moment some actors choose not to follow. As new laws are realised, the positive benefit that follows will be that companies strive to minimize ecosystem impact as a mean of taking advantage in the tendering process of a project and product marketing.

Private property owners are other stakeholders that will be affected, as they might be regulations that imply that they must manage their own stormwater or pay a fee for it. One might think that such requirements will be a setback and economic loss, but LID have actually proven to increase land and property value due to improvement of the living environment, increased safety against flooding and water related damages. Thus, it will most likely be an economic benefit for property investors.

Property owners are definitely one of the key stakeholders to reach a sustainable stormwater future for urban areas. This because large scale of private establishments of swales, green roofs and other LID units has such enormous potential to manage precipitation and decrease the amount of water that reach the road and street environment. In my opinion, municipalities should therefore carefully build the economic regulations and ensure support to property owners who contributes to stormwater management. This is probably not of any concern since the government have been positive to subsidize green electricity and electric cars during recent years.

Most certain, emphasis on LID will be high during the coming years and as the scale of implementation grow, the practise will be incorporated on many levels within urban planning and require increased collaboration among public agencies, private companies and citizens. Thus, the importance of mutual understanding of why LID should be implemented cannot be overemphasised. Moreover, it is important that politicians realise that this change is necessary and stays on a strict line without letting monetary interest from private investors form the development.

10.3 New design and operations due to LID

Stormwater infiltration units are delicate constructions in terms of design and process requirements. To give an example, a number of aspects determines if a LID unit have good or bad operational efficiency. Among these are soil compaction, ground inclination at the site,

choice and proportion of filler media, storage capacity, properly installed overflow pipes, protection of particle intrusion to mention a few. Just by looking at these aspects, one can realise a number of new potential sources of error in the construction process. Hence, there is a need of developing new standards for design, construction and maintenance to ensure that LID units work as intended and that planners and construction contractors have access to the necessary information. It would be wise for municipalities to build a database, start mapping, collecting data, analysing, and draw conclusions on which LID solution that are suitable in certain areas and so on. This would ease the planning process since a developer then know what stormwater solution that is preferred/requested for the specific area and hence start to build a suitable LID solution for the proposed development. The same database would naturally include flood risk maps and other useful information.

10.4 Concerns regarding LID

The risk of contamination are always an important aspect to consider when planning for LID solutions. Most pollutants can be managed with well though through treatment trains but the issue with regards to road salt stands alone as the single most challenging pollutant from road and street environment.

There is a delicate trade off in this matter as road salt is used to keep streets free from snow and ice and hence enhance mobility and traffic safety during winter season. The drawback on the other hand is potential contamination of groundwater as salt infiltrate soils and at the same time increase the mobility of other pollutants.

In my opinion there are two main options to make regarding this problem. The first alternative is to stop using salt unless it is necessary and accept the decreased mobility during winter. In the majority of cases, lower speed limits and responsible driving should be enough to avoid any concern in the matter. The second alternative is to strictly use salt in areas where groundwater contamination is not a concern. This could for example be in dense urban regions lying in the low part of a catchment area with a steady flow to the sea as recipient. Thereby salt intrusion will cause contamination on water that quite soon will end up reaching salt waters.

10.5 Statens Vegvesen and LID

Statens Vegvesen have to be a leading actor in establishing LID solutions and adapt existing and future road and street drainage systems to a higher standard than of today. After all, it is the impervious roads and streets in our urban environment that makes up much of the runoff that cause stormwater related problems today. Changing the classic road and street planning approach to fit in LID requires investments and development of new standards to bridge the knowledge gap that naturally occur as a result of new regulations, design and operations.

Project planners must incorporate the stormwater planning at an early stage in the project to ensure that road or street projects have minimum impact on surrounding ecosystems throughout its lifetime. To make this possible, it is in turn necessary that the customer, which often is a municipality, at least have the same intention and basic understanding of LID and the need of robust stormwater systems. Water Engineers have a responsibility to promote and incorporate the LID practise in the best possible way by enlightening colleagues and company leaders about the practise, its benefits and role in our society. The same applies for landscape architects and technical designers, which must plan the road, street and their environment according to the most suitable LID solution.

Practical concerns regarding LID in the road and street environment are the space constraints underground where cable networks for electricity, heating and waste stations are established.

This will most certainly limit the possibility of constructing LID units without harming the other installations. Again, this proves the importance of planning for stormwater management at very early stages and that Statens Vegvesen and other agencies must collaborate in the project development.

Furthermore, it is important that Statens Vegvesen conduct their road and street project with the purpose to fit the road and street designs into the existing terrain. The purpose with this is to enable the best possible “hydrological landscape” and don’t interrupt well-functioning drainage patterns. Planning for this will also decrease the need of underground infrastructure and new stream way erosion. Mapping and evaluating current drainage systems on urban roads and streets would be a good start since this will give an overlook on which roads and streets that can be retrofitted with LID systems within a near future. Doing this will also enable more efficient, secure and experienced project development for new roads or streets.

With regards to preserving and enhancing the natural environment when planning the road and streets, it is relevant to discuss the possibilities of decreasing the road and street width to enable larger green areas. This would naturally have to reduce the available parking lots in the urban area and thereby most likely give rise to complaints among some citizens. However, it can be argued for that reduced use of private vehicles in central urban areas already is an on-going process. LID therefore is another incentive to push this objective forward. Planning sidewalks and bicycle lanes could possibly be another way of enabling more green infrastructure as people often stick to one side of the street.

It is uncertain if man can have any impact on the process of climate change. However, it is definitely certain that we can change the way we plan and develop roads and streets and their environment, and thereby adapt our society to enable sustainable stormwater management. Implementation of LID creates many significant benefits for both human and nature and therefore, no matter if climate change will increase or decrease its impact, it will be a beneficial way to approach the future. No matter the professionals at Statens Vegvesen, the project planners, traffic planners, road and street design engineers, water engineers, landscape architects, could all play an important role in contributing to a sustainable future for the road and street environment.

10.6 Conclusions

LID holds, by the use of local infiltration, retention and storage of stormwater, a great potential in enabling sustainable development of the road and street environment. Equally important is that LID also will transform the urban landscape towards a greener infrastructure and enhance the natural environment in urban areas, which will benefit all stakeholders in the urban ecosystem. Besides this, LID is somewhat a necessary transition from the conventional underground water systems as these have proven insufficient and are in need of vast maintenance and upgrade that implies a huge maintenance cost. Project developers and planners must incorporate stormwater planning at an early stage in all projects to allow it to be a governing element in the process and let water engineers and landscape planners work out the best possible solution. Moreover, urban properties, ground conditions, pollutants and human activities are among the key aspects to consider during the planning phase, but the true challenge is to unite the private and public stakeholders behind a common and responsible LID strategy. If this succeeds and private people establish LID units on their own properties, the sum of all local small scale systems will accumulate to a cost efficient and robust urban stormwater system.

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Appendix I

THE RATIONAL METHOD

The rational method is preferred only when calculating the peak hour runoff and involves the following factors: Area, rain intensity, runoff coefficient and climate factor which adds up to the flow equation: $Q = C * i * A * C_f$. Runoff factor C is used to express the relationship between precipitation and runoff for volume and peak runoff. (Norskt Vann, 2012).

Tabell 2: Runoff coefficients for different surfaces (Statens Vegvesen , 2011).

Surface type	Runoff coefficient
Concrete, asphalt, rock	0,6-0,9
Gravel	0,3-0,7
Park areas	0,2-0,4
Dense vegetation	0,2-0,5

Aside from this, the runoff coefficient should be increased when looking at return periods longer than ten years due to future climate change (Statens Vegvesen , 2011).

Tabell 3: Table 12 Increased runoff coefficient correlated to return period (Statens Vegvesen , 2011).

Return period (years)	Factor to add
25	1,1
50	1,2
100	1,25
200	1,3

To make a valid calculation of the rational method it is necessary to calculate the time of concentration “ t_c ” (in minutes). The time of concentration is set equal to the duration time of the rain, making it possible to address the Intensity-Duration Curve (IDC). The formula for urban fields is: $t_c = 0,02 * L^{1,15} * H^{-0,39}$ where L is the field length from outlet to the most distant point and H is the difference between the highest elevation and the outlet elevation. Climate factor “ C_f ” is expressing the expected increase in flow due to climate change. Hence it is varying depending on climate zone (Statens Vegvesen , 2011).

Tabell 4: The table below shows an example for an installation with 100 expected lifetime

Lifetime	Return period	Factor to add
100	10	1,3
	100	1,4
	200	1,5

The precipitation factor i is expressing the amount of rain in that falls during a rain event in l/s*acre. It is often divided into a number of periods to enable calculation of peak flow and accumulated flow. Rain series that stretch over a long period is to prefer (Statens Vegvesen , 2011).