Urban Stormwater Management in a Changing Climate: Potential of Low Impact Development Practices in Groningen.

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Abstract

This research explores the potential of Low Impact Development (LID) practices for urban stormwater management in the city of Groningen. This is done by examining the extent of urban stormwater management problems due to climate change, the capabilities of LID practices, and the policy of the responsible actors towards both of these issues. An extensive literature research on climate change impacts and the capabilities of LID practices was conducted. Interviews were held with experts in the field of LID and with a policy maker of the responsible actor. A policy analysis was conducted to draw the final conclusions.

Increasing amounts of stormwater runoff, flash floods and sewerage spillovers, as a result of climate change, urges responsible actors to reconsider urban stormwater management systems. The water quality of surface waters in Groningen is poor, and parts of the city are vulnerable to flooding during an event of extreme precipitation. Low Impact Development practices can reduce the impact and harm of stormwater runoff, flash floods and sewerage spillovers. This is achieved by managing stormwater as close as possible to the site where the precipitation falls. Here, by simulating or involving natural processes of retention and infiltration, runoff is reduced and pollutants are filtered out. Densely built areas, such as the inner city of Groningen, leave little space for LID practices to be implemented, thus decreasing the potential to reduce the impact of climate change on urban drainage. In new developments, the use of LID practices have the potential to maintain the hydrologic functioning of an undeveloped site, and thus not adding extra stormwater runoff to the conventional sewerage system.

The policy of the Groningen municipality recognizes the impact of climate change, and generally promotes LID practices for reducing urban stormwater runoff, but it does not mention it as a means to improve surface water quality.

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1. Introduction

Scientists predict that a certain level of climate change is inevitable (Hansen et al*.,* 2008). As a result, the changing climate will cause an increasing number of meteorological extremes. A recent study shows that in the North Sea region the likeliness of an extreme weather event, such as the occurrence of extreme precipitation, is to increase by a factor two or more due to climate change (KNMI, 2014). Moreover, intensities of precipitation extremes are on the rise and are expected to further intensify throughout North-Western Europe (IPCC, 2008; KNMI, 2011). In urban areas, high volumes of rainfall can cause sewerage spillovers and flash floods, as seen in Copenhagen in July 2011 and in Groningen on July 12th, 2010 (Montalto et al., 2007; Qin et al., 2013). Economic damage is evident: close to one billion Euro worth of insurance claims are linked to the 2011 Copenhagen flood (Copenhagen Adaptation Plan, 2011). Besides direct financial damage, floods as a result of heavy rainfall, as well as sewerage spillovers, are proven to be a cause of water and soil degradation (Burton and Pitt, 2001). As proven in recent years, most evidently in Copenhagen, the current urban stormwater management systems are insufficient in adapting to climate change, meaning that their designs need to be reconsidered. After concluding that the traditional 'repressive piped drainage systems' are failing, Jones and Macdonald (2006, p. 542) noticed that "[…] *alternative approaches to managing urban water are being sought in the light of these disciplinary failures.*", where 'alternative approaches' refer to, among others, Low Impact Development (LID). LID is recommended as a sustainable alternative to conventional urban drainage systems and can help to reduce spillovers and urban flooding and their large-scale negative effects (Dietz et al., 2007; Qin et al., 2013). LID is a land planning and engineering design approach that works with nature to manage stormwater as close to its source as possible. (Graham et al., 2004; Qin et al., 2013; USEPA, 2010). Studies show that LID can decrease runoff and pollutants, as well as reduce and delay peak flows of runoff (Dietz et al., 2007). The objective of this research is to explore the potential of LID practices for urban stormwater management in the North Sea city of Groningen, in the context of climate change adaptation.

1.1. Research motivation

Climate change urges the reconsideration of urban stormwater management systems and practices. The necessity for this is shown, for example, during and after the flash floods in Copenhagen in 2011. In this sense of urgency, a large variety of stormwater management practices and techniques arise and amplify, such as practices like swales, porous pavements and green roofs. The lack of a dominant system and strategy, and new concerns of flooding, ecosystems and urban sustainability, explained in chapter 2, makes successful implementation a complex process. Whereas the effectiveness of individual LID practices such as green roofs is relatively well studied, a lack of knowledge on the potential of LID as a whole decreases interest for widespread LID implementation in many urban areas (Ahiablame et al., 2013). Therefore, research on the municipal scale can be an addition to current knowledge about LID. The potential of LID practices should be studied, taking into account the uncertainties of both climate change and LID techniques themselves. Research should provide answers and tools for policy and decision makers, in order to help actors respond to climate change in an informed and expeditious manner.

1.2. Research goal

The goal of this research is to explore the potential of LID urban stormwater management practices in the North Sea region, and more specifically the city of Groningen, in the context of climate change adaptation.

1.3. Research questions

1.3.1. Main research question:

What potential do Low Impact Development practices have for urban stormwater management, in contribution to climate change adaptation in Groningen?

1.3.2. Sub-questions:

1. <u>Urban stormwater management</u>

To underline the relevance of this research, it is important to identify the problems that urban areas are facing with regards to their stormwater management systems. In order to do so, the following questions must be answered:

1.1. What causes urban areas to be increasingly vulnerable to heavy and extreme precipitation?

1.2. What role does the current stormwater management system play in this, and what effects does that have?

2. Low Impact Development

To explore the potential of LID practices in stormwater management, a framework of the current knowledge must be set:

2.1. What is Low Impact Development?

2.2. What practices are there and what are their characteristics?

2.3. What could the impact of LID practices on runoff and pollution be?

2.4. What are the limitations of LID practices?

3. Case study: Groningen

As a part of this research, the potential of LID practices in Groningen shall be explored, in the context of climate change adaptation:

3.1. What are the key vulnerabilities of Groningen towards the occurrence of heavy and extreme precipitation?

3.2. What factors affect these vulnerabilities, and how?

3.3. How are these vulnerabilities being addressed?

3.4. What potential do LID practices have to solve the problems arising from sub-questions 3.1 and 3.2?

3.5. To what extent are LID practices currently being advocated or promoted in the policy of the responsible actors?

3.6. What challenges can be identified?

1.4. Determining potential

According to the Oxford Dictionary, potential is defined as "*Having or showing the capacity to develop into something in the future"* (Oxford Dictionaries, 2014). Along the lines of the main research question, 'something' refers to 'a solution for the problems linked to urban stormwater management'. But, to explore the full potential of a solution, dealing with the core physical problem is not the only factor that has to be assessed. Economic factors, policy, ethics and aesthetics all influence the potential of a chosen solution. In this research, the included factors that determine potential are determined by a model based on the model of ‘Phases and subprocesses throughout the adaptation process’ by Moser and Ekstrom (2010). Figure 1.1 visualizes the position of the potential within the research focus. Moser and Ekstrom (2010, p. 22027) based their model on the “*phases of a rational decision-making process, including understanding the problem, planning adaptation actions, and managing the implementation of the selected option*”. There are three research pillars in this model: Problem, LID and Policy. Policy of the responsible actors is chosen as the third pillar, because policy is an important instrument in facilitating adaptation to climate change, and to protect species, habitats and culturally important resources (IPCC, 2007). The extent and understanding of the problem, the capability of the chosen option (which in this research are LID practices), and the recognition of both within policy make up the basis for determining the potential of LID practices for urban stormwater management in this research.

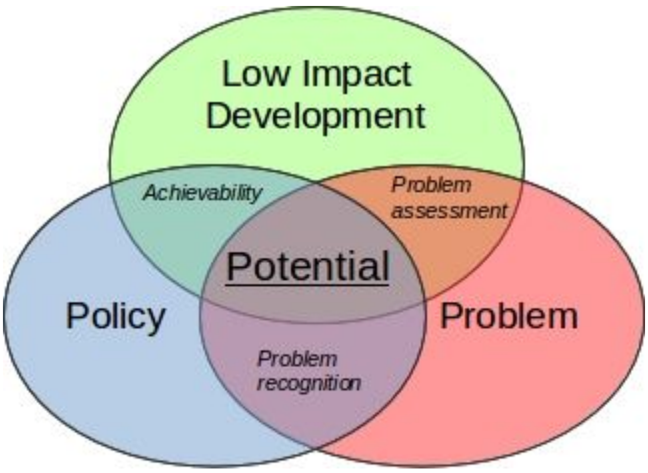


Figure 1.1: The potential of LID practices, based on Moser and Ekstrom (2010).

2. Theoretical framework

In the theoretical framework an introduction to climate change and adaptation is given, and the ‘Problem’ and ‘Low Impact Development’ pillars will be assessed.

2.1. Climate change and adaptation

The term ‘climate change’, as used in this paper, will refer to the definition used by United Nations Framework Convention on Climate Change (1992): “*Climate change is a change of* *climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.*” Evidence suggests that a certain degree of change in climate has become unavoidable and that built environments will need to function under climatic conditions different from the recent past (IPPC, 2007; Karl et al., 2009; Milly et al., 2008; USGCRP, 2009 in Pyke et al., 2011). In northwestern Europe, climate change is causing higher temperatures, sea level rising and a changing distribution and intensity of precipitation over the year, resulting in an increasing amount of both dry and wet periods (IPCC, 2008). Examples that indicate changing intensities are the events of extreme precipitation in Copenhagen in 2011 (150 millimeters in two hours), but also in the Netherlands, where in July and August 2010 multiple events of extreme precipitation occurred with intensities of up to 138 millimeters in 24 hours (Copenhagen Adaptation Plan, 2011; KNMI, 2010). Extreme precipitation is a precipitation event where more than 50mm falls within 24 hours (KNMI, 2014). Heavy precipitation is an event of more than 10mm in 24 hours (IPCC, 2007).

Even though much literature is available on the topic of climate change, there are still large gaps in our understanding of the process and thus our ability to make accurate predictions. Arnbjerg-Nielsen et al. (2013, p. 25) conclude:

> *“The scientific level of understanding of how climate change will impact urban drainage systems remains limited for two reasons. The first reason is our lack of understanding of how to quantify the impacts given our understanding of climate change. The second reason is our lack of understanding of how the urban drainage sector should react to the challenges that large changes in precipitation extremes will generate. […] Design and optimization of urban drainage infrastructure that considers climate change impacts and co-optimizes this with other objectives for a habitable city will become increasingly important in the future.”*

The measured climate change so far, such as increased temperatures, and most prominent research confirming the trend of climate change, both indicate the need for rapid action and for increased flexibility and robustness of our cities (Arnbjerg-Nielsen et al., 2013).

There is a general distinction between strategies to cope with climate change, namely mitigation and adaptation strategies (Short et al., 2012). The goal of mitigation strategies is to reduce the human impact on the climate, and thus preventing climate change from happening. Practices of mitigation are, for example, reducing CO^2 emissions by using sustainable energy resources. Alternatively, adaptation strategies are the adjustment of natural and human systems in response to actual and expected climatic changes and its effects, in order to moderate harm or exploit the consequential beneficial opportunities (IPCC, 2007). Within the context of this research the adjustment in human systems, or more specifically human designed water systems, is relevant. Studies show that public policy is an important instrument in facilitating adaptation to climate change, including decreasing the vulnerability of both people and infrastructure, supplying knowledge about the risks for public as well as private investments and decision making, and to protect species, habitats and culturally important resources (IPCC, 2007).

2.2. Urban stormwater management

Urban stormwater is defined as water runoff in urban areas, originating from precipitation (Burian and Edwards, 2002; Klok, 2012). The three main drivers of stormwater runoff volume are the amount of impervious cover, precipitation volume and event intensity (Pyke et al., 2011). The 19th century marks the beginning of modern stormwater management, with large scale improvement of sewerage systems throughout European and American cities (Burian and Edwards, 2002; Jones and Macdonald, 2007; Van Kammen en de Klerk, 2003). Where previously sewers were predominantly used for stormwater, and were left in an abandoned state, corporation of water-carriage sanitary waste collection into the sewers was introduced and becoming legalized. Burian and Edwards (2002, p. 10) write:

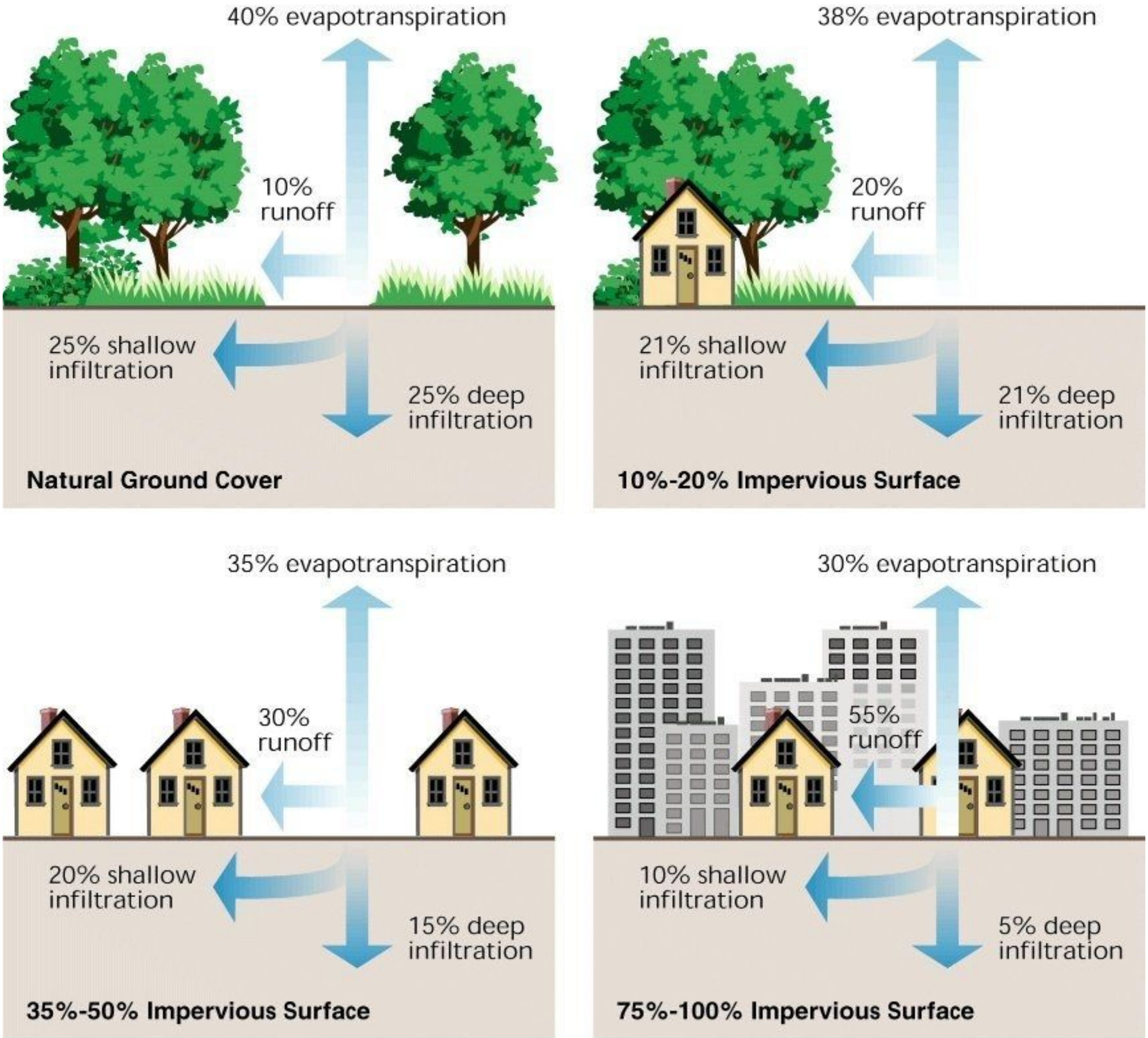
> *"The public perspective of urban drainage changed during the nineteenth century from a neglected afterthought to a vital public works system. The public also shifted their stance regarding funding the construction and maintenance of sewerage systems. The shift in public perspective was driven by many factors, but the most important was probably the scientific evidence accumulated during the second half of the century linking sanitary wastes and disease transmission. Municipal leaders, backed by strong public support, initiated massive projects to build comprehensive sewerage systems in the larger cities in Europe and the United States."*

This new combination of the two urban drainage fluids, stormwater and wastewater, in one sewerage pipe is called a combined sewerage system. This sewerage system type is characterized by pre-modern, rather repressive and disciplinary mechanisms, as an attempt to constrain and regulate it as much as possible (Jones and Macdonald, 2007). Stormwater is caught and transported out of the area through pipes as fast as possible, causing rapid flow responses leading to high peak flows during a storm event

(Semadeni-Davies et al., 2008). Throughout the 20th century, urban drainage in a combined sewerage system has become a dominant design and became also a meaningful public works system (Burian and Edwards, 2002).

2.2.1. Urban water cycle

Urban stormwater is part of the urban water cycle. In a natural situation, a large share of the stormwater evaporates from the soil, plants and trees. The remaining water drains in shallow and deeper grounds through porous soils, or runs off to other surface waters (Klaassen, 2011). The urban water cycle is different from the natural water cycle, mostly due to a difference in land cover type (Klok, 2012). The land cover types in urban space have a slow, or in some cases non-existent, infiltration rate. Roofs, paving and other impervious cover make up large parts of urban space, resulting in increasing runoff during and after rainfall. Dietz (2007) found evidence of an exponential correlation coefficient between impervious cover and runoff. This runoff is then guided to sewerage systems, where it is then, mostly along with wastewater from households, transported to a wastewater treatment plant (WWTP) (Klok, 2012). The disturbance of the natural water cycle due to urbanization is showed by figure 2.1 (FISRWG, 1998).



Relationship between impervious cover and surface runoff. Impervious cover in a watershed results in increased surface runoff.

Figure 2.1. (FISRWG, 1998).

If, during heavy rainfall, the amount of water transported through the sewerage system exceeds the WWTPs capacity, excess water from the sewerage system can be released on open waters with a so-called combined sewerage overflow (CSO). Such an event is called a spillover, the aim of which is to prevent stormwater runoff building up in low situated urban areas, which would possibly result in flooding. Figure 2.2 gives a simplified overview of the relevant processes of the urban water cycle.

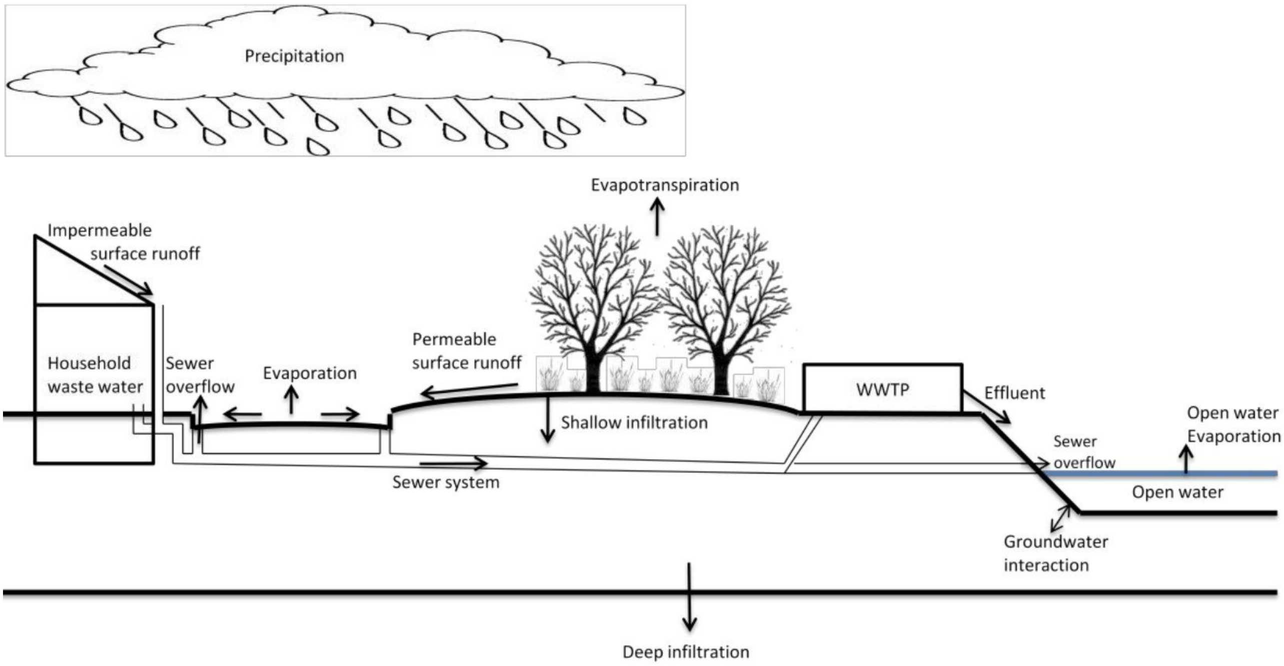


Figure 2.2. (Klok, 2012). Based on Noordhoff Atlasproducties, 2010; Shaw et al., 2011; Van Beek and Loucks, 2005.

Separated sewerage systems are a common improvement of the combined sewerage system. These systems can reduce CSOs, optimize the functioning of WWTPs, and increase stormwater management capacity. A separated sewerage system collects stormwater in so-called storm sewers, which are connected to surface waters that generally have a large retention capacity (Welker, 2008). Yet, urban stormwater runoff is not clean. Impervious cover is linked to a decrease in water quality when its share is up to 10-30 % (Wang et al., 2001). Scheuler (2009) found that watersheds with less than 5-10% impermeable cover are predicted to have full ecological functioning with good to excellent aquatic diversity. Increasing the impermeable area to a volume of over 10% leads to degradation of surface water and stream quality, and if impermeable cover exceeds 25% it results in poor water quality and low biodiversity (Scheuler, 2009). Typical pollutant loads of stormwater runoff are given in table 2.1, with data originating from the United States Environmental Protection Agency (USEPA) (1999).

Typical pollutant concentrations in urban storm-water runoff for different land uses			
	Median event mean concentration for land use		
Pollutant (units)	Residential	Mixed	Commercial
Biological oxygen demand (mg/L)	10	7.8	9.3
Chemical oxygen demand (mg/L)	73	65	57
Total suspended solids (mg/L)	101	67	69
Total lead (µg/L)	144	114	104
Total copper (µg/L)	33	27	29
Total zinc (µg/L)	135	154	226
Total Kjeldahl nitrogen (µg/L)	1900	1288	1179
Nitrate and nitrite (µg/L)	736	558	572
Total phosphorus (µg/L)	383	263	201
Soluble phosphorus (µg/L)	143	56	80

Table 2.1. Data from USEPA (1999)

2.2.2. Flash floods and spillovers

When the amount of stormwater exceeds the drainage capacity, the CSO will be activated. If the amount of stormwater still surpasses the capacity, urban flooding, or a so-called flash flood, may be the result. These CSOs and flash floods are a known cause of pollution, contamination, disruption of aquatic habitats, economic loss and health issues (NRC, 2008; Paul and Meyer, 2001; Qin et al., 2013; Roy et al., 2005; Walsh et al. 2005 in Pyke et al., 2011). With stormwater management systems that are typically designed to meet performance standards based on historical climate conditions, further urbanization and climate change are likely to increase the occurrences of flash floods and CSOs (Montalto et al., 2007, Pyke et al., 2011). The combination of heavy or extreme precipitation, and high temperatures has been linked to outbreaks of infectious diseases and malaria in Europe, as a result of insufficient urban drainage (Bezirtzoglou et al., 2011). Thus, there is an increasing need to improve drainage capacity to reduce the impact of extreme precipitation events (Qin et al., 2013). Reasoning on the embodiment of the capacity improvements, Burian and Edwards (2002, p. 13) give a bright indication on how our current understanding and perspective has evolved:

"During the second half of the 20th century regulatory elements were promulgated

[...], addressing urban drainage issues. Extensive monitoring efforts vastly improved the understanding of urban drainage quantity and quality characteristics. Regulations, monitoring, computer modeling, and environmental concerns have altered the perspective of urban drainage from a public health and nuisance flooding concern during the first half of the twentieth century into a public health and nuisance flooding with additional concerns for ecosystem protection and urban sustainability."

Semadeni-Davies et al. (2008) complement this by stating that a paradigm shift, from pipe-based systems towards LID, has occurred. Conventionally, the improvement of drainage capacity relies on the expansion and upgrading of the existing storm drainage system (Qin et al., 2013). Yet, as a result of research focused on relatively new concerns of flooding, ecosystems and urban sustainability, Low Impact Development is the recommended alternative to traditional stormwater management design. (Dietz, 2007; Monalto et al., 2007; Qin et al., 2013). LID will be further explored in chapter 2.3.

2.2.3. Other factors of impact on urban drainage

The amount of water that air can hold increases with temperature. Attema et al. (KNMI, 2014) found that precipitation intensities increase with an average of 11% per degree, whereas in de Bilt increases of 14% per degree have been measured (KNMI, 2009). Changing atmospheric patterns and increasing temperatures due to climate change infer that the intensities of precipitation events are to increase (IPCC, 2007; KNMI, 2014). Also, in recent decades the urban centers in Western Europe have continued to grow more densely, with more impervious covers as a result (Dietz, 2007; Semadenie-Davies et al., 2008). This leads to an increase in runoff following from the example in figure 3.1. Pyke et al. (2011) found evidence suggesting that stormwater runoff is most sensitive to changes in impervious cover, followed by changes in precipitation volume and event intensity. Combining the results from the study of Pike et al. (2011), a 10% increase in annual volume combined with a 5% intensity increase can result in a 45% increase in stormwater runoff. This can be offset by a decrease of 4% in impervious cover, which reduces runoff with the corresponding 45%.

2.3. Low Impact Development

LID is a collection of stormwater management techniques developed to address the urban runoff problem. Examples of LID practices are green roofs, permeable pavements, rain barrels and forms of bioretention. The term ‘Low Impact Development’ is generally used in the United States of America and Japan, but other terms for LID are also used. Sustainable Drainage Systems is commonly used in the United Kingdom and Water Sensitive Urban Design, is used in Australia and New Zealand. LID relies on distributed runoff management measures that seek to control stormwater volume at the source by reducing imperviousness and retaining, and by infiltrating and reusing rainwater at the developed site (Graham et al., 2004; Qin et al. 2013). Gill et al. (2007) found that LID is effective in moderating the potential impact of climate change by reducing surface runoff. Reducing, delaying and spreading out peak discharge of stormwater over time are characteristics of LID practices, as well as reducing pollution and contamination of stormwater runoff (Davis et al., 2003; Dietz, 2007). Therefore LID practices can reduce the amount of combined sewerage overflows (Dietz, 2007). This chapter will introduce and review studied LID practices.

2.3.1. Overview of practices and impacts

There are a large number of LID practices that have been studied on their effectiveness. Most studies are oriented at measuring the impact of an individual LID practice, for example a green roof. There are modeled studies, but also practical research has been conducted. Most studies focus on both the impact on runoff, and the reduction of pollutants in surface water.

- Bioretention

Bioretention is the practice of assigning certain space of land to accept stormwater. This space is a green-blue buffer that can be used in residential and commercial settings. The advantages of bioretention practices are a reduction of surface runoff, restoring groundwater recharge and pollutant treatment through a variety of natural processes, catalyzed by the specific planting of the site (Dietz, 2007).

Figure 2.3: Bioretention on unused space of a parking lot in Berlin. Image by Roelofs (2014).

Rushton (2001) found, in a 2 year study on an innovative parking lot in Florida, that bioretention applied as in figure 2.3 could reduce runoff by 30%, without reducing the car capacity of the parking site, compared to a traditional parking lot. The average runoff reduction is subject to the capacity of the design and can be up to 99%. Dietz and Clausen (2006) showed in their 24 month study that bioretention next to a building prevented 99% of roof runoff from leaving the site. Dietz (2007) found that bioretention practices very effectively reduce concentrations of heavy metals, such as zinc, copper and lead. Davis et al. (2003) found a reduction of zinc, copper and lead were all more than 95% at their testing site. Another study, by Chapman and Horner (2010), found that a street-side bioretention in Washington achieved 25-52% runoff retention in real-weather conditions. Bioretention has a broad spectrum of variations, such as swales, ditches and rain gardens. Some are dedicated to filtering and buffering of water, while others also have a primary function of infiltration.

- Green roofs

Green or vegetated roofs are roofs that are covered with a layer of soil and grass, plants or even trees. There is a general distinction between 'intensive' and 'extensive' green roofs (Mandema, 2008). Intensive green roofs have been around for a longer period of time, and consist of a thick layer of soil and heavy vegetation, requiring additional support for the buildings construction (Dietz, 2007). Extensive green roofs consist of thin and light soils and vegetation. In recent decades, the extensive green roof has been extensively developed and put into practice. Out of various research outcomes, Dietz (2007) found that the extensive green roof has an average runoff reduction of 62.8%, and that 60-70% runoff reduction is to be expected with implementation. Also, the retention capacity of the roof is not significantly determined by the thickness of the green roof's media, but also by the evapotranspiration of the surface. An additional characteristic of green roofs is their ability to reduce peak flow rates and increase the delay of this peak flow (Alfredo et al., 2010). Moran et al. (2004) found a reduction in peak flow of 87% and 78% compared to a reference roof, on two sites. VanWoert et al. (2005, p.1043) call green roofs a "*promising new technology to mitigate stormwater runoff quantity and quality […], that should be considered for all roofing projects, especially those projects in areas where stormwater management is a concern to city planners.*"

- Permeable pavements

Making pavements permeable creates a large infiltration and buffer capacity of stormwater in public or private space, without giving up on usable space for sidewalks, roads or parking space. Alternatives for traditional asphalt, concrete and blocks or grids have become available that have permeable characteristics, and thereby imitate, to a certain extent, natural infiltration processes. The permeable pavements are designed to let stormwater through, and optionally filter out contamination and pollution. There are several permeable pavement systems that are brought to the market, and development is continuing. As for concrete blocks or grids, Brattebo and Booth (2003) found after 6 years of research and testing on two systems, the so-called Turfstone® and UNI Eco-Stone®, virtually all of the precipitation infiltrated through the system, while also filtering out a significant amount of heavy metals like zinc and copper. Gilbert and Clausen (2006) tested the UNI Eco-Stone® also, for 22 months, and found that it reduced the runoff by 72% compared to an asphalt road nearby, and reduced the measured pollutants significantly. Permeable plastic grid pavings are useful for, for example, parking lots and driveways, and can be covered with different infill materials such as grass or gravel. Dreelin et al. (2006) found that the Grassy Paver™ parking lot reduced runoff with 93% compared to a near asphalt parking lot. Brabetto and Booth (2003) measured 4mm runoff during an 121mm storm event coming from a Grasspave® pavement, also significantly reducing copper and zinc concentrations. For road surfaces, permeable asphalt is also on the market. Initially it was developed to reduce the risk of hydroplaning, and the ability to reduce noise, but for infiltration reasons it has been further developed and improvements have been made (Dietz, 2007). The use of permeable asphalt results in significant reductions of pollutants (Rushton, 2001), as well as surface runoff (Collins, 2008).

- Combination of LID practices

Only a few studies were ever conducted on large-scale multi-practice implementation of LID, through modeling, and also through real-life experiments (Dietz and Clousen, 2007; Hood et al., 2007; Ahiablame et al., 2013). Dietz and Clausen (2007) studied the Jordan Cove Urban Watershed Project in Waterford, Connecticut, where two sites were developed with one site using a the traditional construction of 17 lots, and the other site where 12 lots were developed using LID practices, such as grassed swales, bioretention areas and permeable pavements. While the traditional site resulted in increased runoff and pollutant export compared to the undeveloped situation, the LID site showed no change in the amount of runoff, nor in pollutant levels. Also, a significantly higher runoff lag time was measured at the LID site, indicating that LID practices can maintain the hydrologic functioning of an undeveloped site (Dietz and Clausen, 2007; Hood et al., 2007). Ahiablame et al. (2013) modeled the effect of retrofitting rain barrels and porous pavements in currently existing built areas. With the various application levels (0.25 and 50 percent) of rain barrels and porous pavements, they found that it can reduce runoff by up to 12%. This reduction might sound small, but given the practices and the proportions of the studied receiving watershed, it could be the difference between dry feet and a flash flood (Ahiablame et al., 2013). On a testing site in AsanTanjung New city, Lee et al. (2012) found that the use of LID practices involving infiltration and retention can reduce runoff peak discharges of 50 and 100 year return period events with about 7-15%.

2.3.2. Limitations and challenges

The capabilities of LID were explored above. In this part, the limitations and difficulties of LID practices are examined.

- Bioretention

An obvious constraint to implementing bioretention is the amount of space this practice consumes. The potential of bioretention is limited in densely built areas, or areas with a soil that has a very limited infiltration capacity. In areas with limited infiltration capacity, an underdrain is placed, which, as well as under permeable pavements, has the advantage of a lower peak flow and smaller flow variations than that from asphalt surface during storms (Dietz, 2007; Fassman and Blackburn, 2010). Besides that, Dietz (2007) found that in some cases, bioretention practices can increase the phosphorus concentration of the water that infiltrates. Research on site should map whether increased phosphorus concentrations are harmful to the system, and if so, an alternative media should be used.

- Green roofs

Green roofs have several limitations, most of them conditional upon the construction the green roof is placed on. Retrofitting a green roof requires the construction to be able to withstand the extra weight. Thinner media does not decrease the retention capacity of a green roof significantly, but media of 5 centimeters have been found to expose the vegetation to frost damage (Boivin et al., 2001). This phenomenon is also subject to the climate conditions of the site.

- Permeable Pavements

There are multiple concerns when it comes to permeable pavements. First, permeable pavements usually require relatively more maintenance than conventional pavements, to prevent clogging. Permeable asphalt need to be cleaned out with vacuum suction at a specified interval, to maintain the desired infiltration capacity and clean out the contaminants (Dietz, 2007). Without proper maintenance the infiltration rate of permeable pavements can fall to less than the European performance criteria of 97.2 mm/h, as Lucke et al. (2013) found in their tests. Also, with direct infiltration, calamities such as an oil spill or chloride infiltration can contaminate the soil and travel through shallow groundwater. This concern should be taken into account by decision makers.

- Others

There are several issues that can hinder complete implementation of LID practices. Some examples are zoning and regulatory statutes, such as the accessibility of emergency equipment or garbage trucks. Also health concerns as a result of mosquito breeding in the ponding of water, or a lack of understanding of and prejudice towards LID practices can hinder implementation (Davis, 2005). With LID practices being effective in filtering pollutants, the accumulation of these pollutants in the LID facility, must be taken care of. This is a concern of maintenance and ownership that must be organized before implementation (Davis, 2005). Evidence suggests that LID is very successful in controlling stormwater for small storms, yet is unable to fully dissolve runoff in extreme events and therefore cannot fully substitute other forms of stormwater management (Damdoram et al., 2010).

2.3.3. Additional impacts

Evidence suggests that, besides reducing urban runoff, pollution, and contaminant quantities, LID practices have a positive effect on reducing urban heat stress, particulate matter and erosion (Davis, 2005; Kleerekoper, 2011). The reuse of harvested rainwater can reduce the demand of scarce, clean drinking water, and green roofs can improve isolation of buildings, reducing energy demands. These effects are not considered in this research.

3. Conceptual model

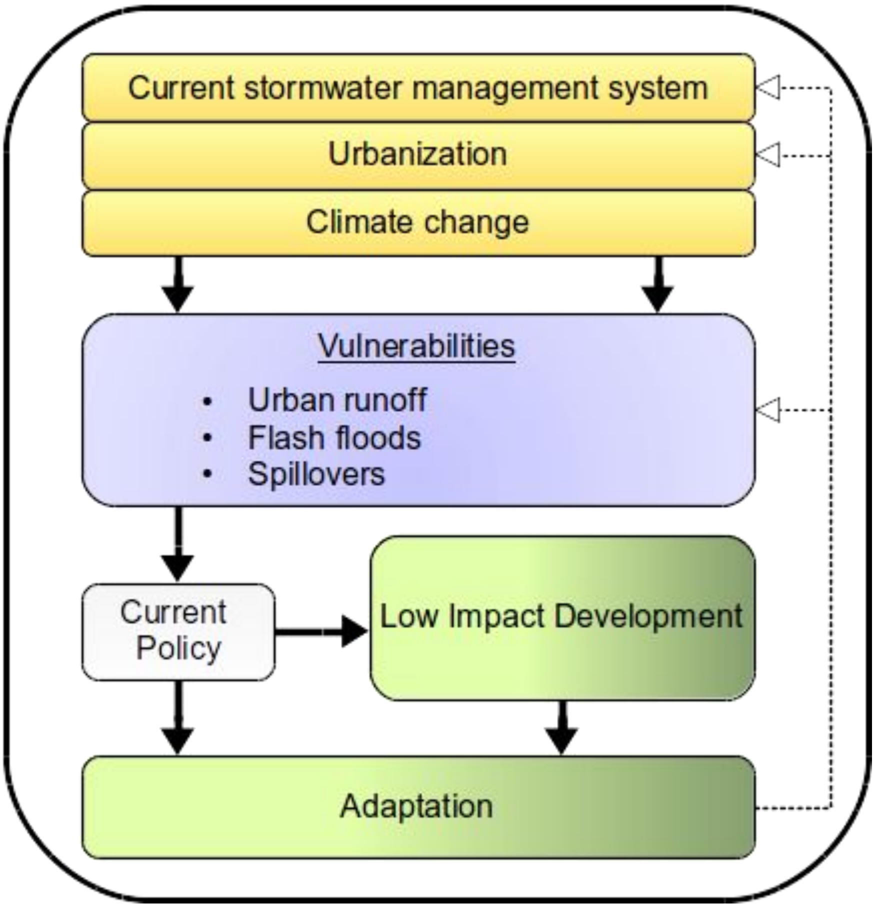


Figure 3.1: Conceptual Model

The conceptual model visualizes how climate change, urbanization, and the current stormwater management system affect the vulnerabilities of urban space. These vulnerabilities result in urban runoff, spillovers and flash floods, causing social and economic damage, as well as damage to nature, for example damage to ecological systems as a result of water and soil degradation. This can be seen as the ‘Problem’ pillar in the model used to determine the potential of LID practices (see figure 1.1). In order to adapt and react to these vulnerabilities, policy formulates a strategy, influenced by the current and prospected future situation (the ‘Policy’ pillar). Low Impact Development has potential to affect and reduce the vulnerabilities, but its potential is subject to policy as well (the ‘LID’ pillar).

4. Methodology

4.1. Approaches in geographical research

In geographical research, the researcher can employ a qualitative or quantitative research approach or a combination of the two (Clifford et al., 2010). Either approach is suitable for both extensive as intensive research designs. Within quantitative research, large amounts of data, for example gathered through questionnaires, is used, and statistical methods can then underpin and determine a certain pattern. Qualitative data is created mostly through smaller numbers, but therefore creates more space for exploring meanings, emotions, intentions and values. Both quantitative and qualitative approaches are important within the discipline of geography and they should not be viewed as conflicting opposites. In geographical research it is important not to look at research methods as either/or questions, but it is most often desirable to mix methods, also known as multi-method or mixed method research, or triangulation (Clifford et al., 2010; O’Leary, 2010). Triangulation is a research strategy where the researcher aims to confirm results by consulting multiple and varied sources. It is part of the researcher’s tool kit to rectify reliability of results (Clifford et al., 2010). The selected methods should try and maximize an understanding of the research question.

4.2. Positioning the research question

This research is at the crossroads of multiple disciplines, such as meteorology, for climate change, physical geography and other natural sciences for the impact of climate change and the potential of LID, and social sciences on the act of policy. Literature on climate change, urban stormwater management and Low Impact Development will be assessed, but questions of e.g. power and governance are left aside. A multi-method research is chosen, consisting of a literature research, interviews and policy analysis. The aspiration is to seek for a form of triangulation between and within literature and expert opinions, and to compare these findings to the policy of the responsible actors. According to O’Leary (2010), there are two kinds of multi-method approaches: one where the research either has a qualitative perspective while tolerating quantitative data, or one where the research has a quantitative perspective with toleration of qualitative data. This research will use a multi-method approach with a qualitative perspective, with the toleration of quantitative, or results coming from quantitative data. A multi-method research is necessary to cover all aspects of the research question and acquire a maximum understanding of it.

4.3. Methods of data collection

- Literature research

A literature research has been conducted to understand what other researchers have discovered, put the further research in context and to legitimize arguments used to answer the main research question. These are three relevant arguments for a literature research, mentioned in the 'Ten Arguments of Reading for Research' by Blaxter et al. (2006, in Clifford et al., 2010). Chapter Two represents this literature research, and answers the sub-questions 1.1, 1.2 and 2.1, 2.2, 2.3 and 2.4 respectively.

- Case study

In the demarcated case study, locally specific information relevant to the topic will be gathered and analyzed through interviews and review of policy documents. Geographical systems are complex and affected by historical and geographical contingencies, indeterminism or singularity (Schumm, 1991, in Rice, 2010). This means that, while there are general similarities between objects, there is always variation in any given situation, making each case a little different from another case. A case study can be valuable for research in multiple ways. Francis (1999) outlines how a case study can be the source of practical information on potential solutions to difficult problems. This description is in line with the motivation and goal of this research, namely contributing to knowledge about combined LID practices, in order to aid successful implementation given the complex circumstances. This is done by exploring LID practices on a practical, in this case municipal, scale.

- Interviews

An interview is a verbal interchange with a person of interest for the research (Longhurst, 2010). The goal is to elicit information from the person of interest by asking questions which may be prepared. The interview used in this research will be semi-structured. The aim of the semi-structured interview is to offer the participant the opportunity to explore issues they feel are important (Longhurst, 2010). Semi-structured interviews will be conducted with experts to gather knowledge used for answering the sub-questions concerning the case study. O'leary (2010) states that experts are key informants, with the experience, position, and knowledge to share valuable and relevant information with a researcher.

Five interviews have been conducted, with experts in both the public and private sectors. The questions can be found in appendix A. For the extensive interview question list and the transcriptions please contact the researcher through the contact details provided in the Colofon. Anne Helbig is responsible for municipal policy on urban drainage in Groningen. Floris Boogaard is an LID expert at Tauw European Consultants and Engineers and PhD researcher at the Delft University of Technology. Jaap Klein is head of the Urban Watermanagement department at Witteveen+Bos Engineering and Consulting. Remco Visser is an advisor of Watermanagement at Grontmij. Reinhard Hövel is from the OOWV, a German public body responsible for managing urban drainage and water supply in large parts of the Oldenburg region.

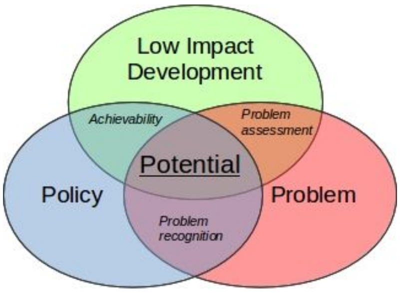
4.4. Ethical aspects and discussion

The interviewed experts all have given their permission for this publication. The interviews took place face-to-face at the expert's offices, and lasted between 30 minutes and one hour. Apart from the interview with Hövel, which was conducted in English, all the interviews were held in Dutch. This means that the expert's quotes in this research are translated from Dutch to English. Therefore, the quotes are not the literal formulations of the experts, and the researcher cannot guarantee that no mistakes in the translation were made. The interview questions were aimed at the professional career and knowledge of the expert. Ethical aspects were taken into consideration and interviewee was free to refuse to answer questions, yet this did not appear to be an issue. There was a general atmosphere of informality and shared interest and passion for the topic.

This research focuses on the problems that urban stormwater management is facing, and the potential of LID practices. This inevitably means that there are aspects which received less attention. The three main pillars of 'Problem', 'LID' and 'Policy' receive the most attention, yet there are important factors, such as power and finance, that received less emphasis. This is mainly due to time restrictions of this research. Other research should assess the potential of LID through the factors that have been left out in this study.

5. Findings

First, an introduction to the case will be given. After that, the research follows the model of determining potential (Figure 1.1). The 'Problem' pillar will be further assessed first, followed by the 'Low Impact Development' and 'Policy' pillars. When the policy is scrutinized, the challenges to utilize the potential are explored and lastly the sub-conclusions of the three pillars to determine potential are formulated.



Recurrence of figure 1.1: The potential of LID practices, based on Moser and Ekstrom (2010).

5.1. Case introduction

Groningen is a city in the Netherlands, situated at the northernmost part of the 'Hondsrug' push moraine, about 30 kilometers from the North Sea. With 198,000 inhabitants (CBS, 2014) it is the biggest city in the northern Netherlands. Figure 5.1 shows the location of the city. In the Netherlands, municipalities are responsible for managing the sewerage system up until the sewerage reaches a wastewater treatment plant (see figure 2.2). Since 2009, the municipality is also responsible for stormwater and groundwater management, and they can be held accountable for it by means of the 'waterwet', or 'water law'. Yet, the municipality has power to set certain standards for drainage, applicable towards plot owners, through the laws 'Bekostiging en Verankering Gemeentelijke Watertaken' since 2008 and the 'Waterwet' since 2009 (GWRP, 2014). The ownership of the surface waters is fragmented over space, and is divided between the municipality, the waterboards Noorderzijlvest and Hunze en Aa's, and several smaller actors, with the water boards being the general authority on water quality demands (GWRP, 2014). During the case study, answers towards the 'three factors of potential' (Problem - Policy - LID), determined in the methodology, were explored. Firstly, the problem shall be framed, then the potential of LID practices towards solving the problem, and in the end policy aspects will be reviewed.

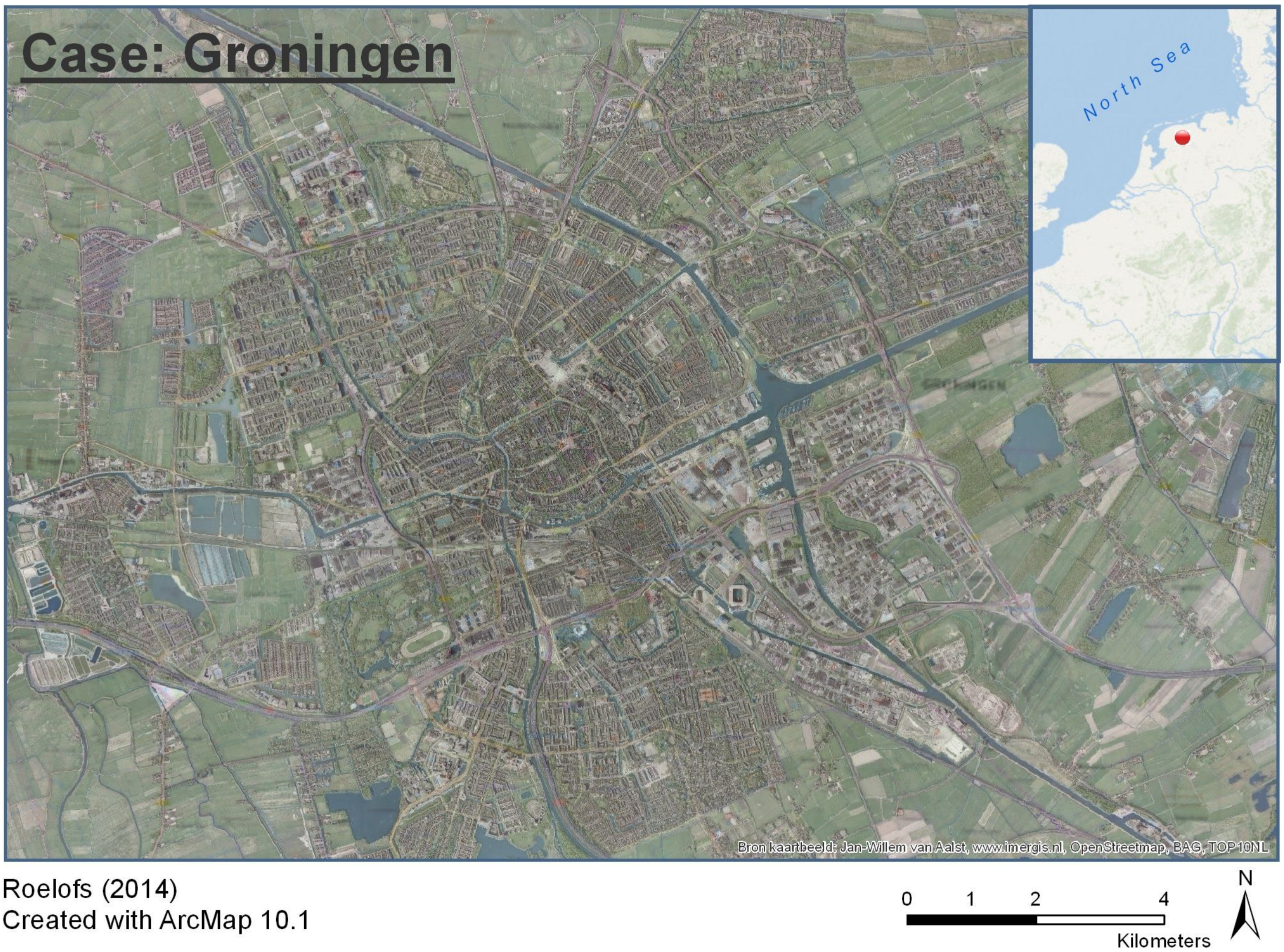


Figure 5.1

5.2. Problem

"Responding to climate change will require identifying key vulnerabilities of the build environment and developing adaptive strategies for reducing the risk of harmful impacts" (Pyke et al., 2011).

Assessing the problem, a review of the current problems and vulnerabilities is conducted first, after which the factors that have influence on these vulnerabilities are looked at.

5.2.1. Vulnerabilities towards precipitation

The impact of extreme precipitation on the city of Groningen became visible on the 12th of July, 2010. During this event, 44mm of precipitation fell within 15 minutes, 51.7mm in 75 minutes, flooding parts of the city such as the Meeuwerderweg, Singelweg and the

Oostersingel (Bennink and Wolthuis, 2011). On this event, and the vulnerabilities of Groningen towards extreme precipitation, Helbig (Municipality of Groningen) (2014) comments: *“Indeed there are a couple of locations vulnerable to flooding. […] The sewerage system is not designed to withstand extreme precipitation, so we can never keep the stormwater within the system in such events. One notices that the water simply can't be drained and is flooding the streets as a result. During the event on the 12th of July, 2010, multiple locations stood out being flooded. [...] For example, the street of Gedempte Zuiderdiep, is at a low point, during the event of July 12th it was completely under water, but the water did not enter the buildings. If intensities were just a little higher that would be a different story.”*

Helbig (2014) continues with historical benefits that Groningen has on urban drainage: *“If you look at other Dutch cities, I think we are lucky that our sewerage system is relatively robust. In the past a decision has been made for relatively large pipes, and throughout time this decision has been continued. [...] Also, the city doesn't know a lot of elevation differences, that helps as well. This was not the case at the Oosterpoortbuurt, where the water from the whole neighborhood collected at the lowest point, the Meeuwerderweg. This is also not the case in the center, which is situated at the northern end of the Hondsrug, a relatively high place. The water flows into the surrounding canals, except at the Gedempte Zuiderdiep, making it a bottleneck. […] Our beneficial situation aside, the city of Groningen has been left relatively off the hook when it comes to the amount of precipitation extremes we have had here.”*

The historically grown, beneficial situation, and the low number of precipitation extremes have also been noticed by Boogaard (LID expert and researcher) (2014): *“If you look at the River neighborhood in Amsterdam for example, it suggests that it has a lot of surface waters, but in reality it has much fewer surface waters than an average neighborhood in Groningen. So in general, Groningen is in a good position, but they have been lucky so far having less extreme events than Amsterdam for example.”*

Earlier, in 2007, the municipality of Groningen published the so-called 'Stedelijke Wateropgave' (SWO), which freely translated means 'Urban Watertask'. This report is a result of an agreement between the municipalities, water boards and provinces in the northeast of the Netherlands, where they agreed upon clearly settling the water tasks and responsibilities in the region. The SWO is focused on the city of Groningen, where as in anywhere in the Netherlands, the municipality is responsible for urban drainage. According to municipal sewerage plans of Groningen, the sewerage is designed to withstand a two-year return period event (GWRP, 2014). This means that the sewerage system should be able to handle an event, with an intensity expected to return one every two years, without the occurrence of any nuisance. A two year return rain event is set to have precipitation of 19.8mm in an hour (Bennink and Wolthuis, 2011). The SWO continues with exploring the impact of extreme precipitation in the city, by modeling 100 year return events. The 100 year return event consists of 55mm in four and 79mm in 24 hours. Figure 5.2 (SWO, 2007) shows show the vulnerable areas that Helbig (2014) is referring to; the areas that will experience a flash flood during a 100 year return event.

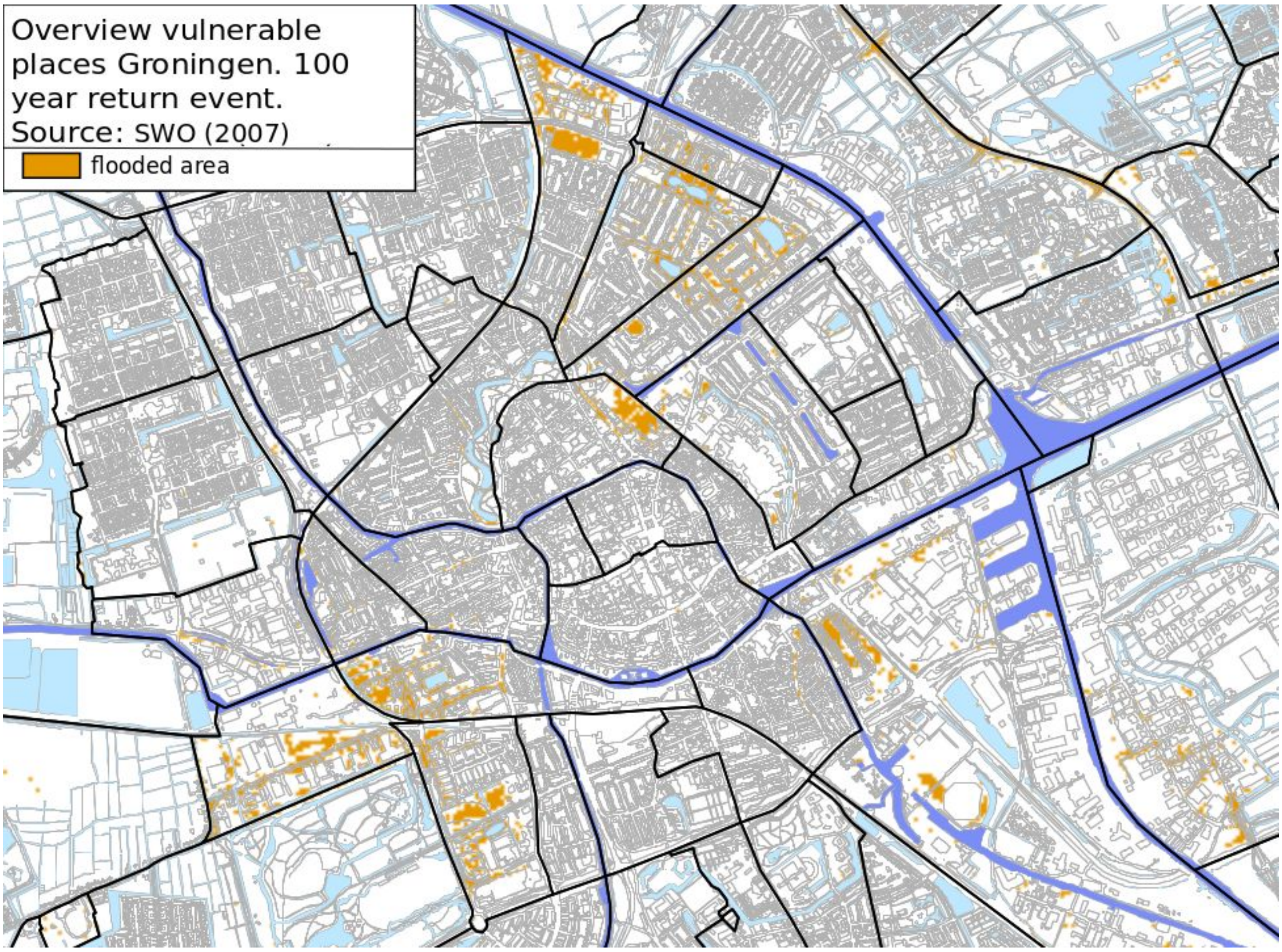


Figure 5.2. (SWO, 2007)

5.2.2. Water quality

In 2004 and 2010 research was conducted by Boonstra et al. (2010), towards the quality of surface waters in Groningen, the so called Ecoscan stadswateren gemeente Groningen (ESGG), or 'Ecoscan Urban Surface Waters Groningen'. Where most of the research was focused on the aesthetic elements of the surface waters, little attention was paid towards the natural quality of the water and the soil itself. Yet, one of the main conclusions of the

2010 report was that the ecology of the surface waters, literally translated, *"leaves much to be desired"* (Boonstra et al., 2010, p. 63). The surface waters of Groningen have all been appointed a certain function, to which different environmental norms and quality standards apply. Helbig (Municipality of Groningen) (2014) comments on the quality of surface waters in Groningen: *"About 25% of the sewerage in Groningen uses a separated system, which means 75% is still a combined sewerage system with CSOs*[i]*, which is still quite a lot. […] In general, our swimming waters meet the norm, and so do most of our city ponds. Yet, if we would allocate certain waters a different function, they would not always meet the norms. In general the quality is OK, let me put it that way, but there is room for improvement and that is something we strive for."* Another municipal document on the water quality of surface waters is far less positive: "*The water quality of our city ponds in general is moderate to bad. They get polluted through CSOs during rainfall events, and are not connected with other ponds, causing the water flow and refreshment to be insufficient.*"(GWRP, 2014, p. 34)

The findings about the water quality of surface waters in Groningen correspond with the literature, where Wang et al., (2001) and Scheuler (2009) found that urbanization is linked with a decrease of water quality of surface waters. With a share of 75% of combined sewerage, following Qin et al. (2013) and Pyke et al. (2011), it suggests that heavy rainfall and CSOs are the cause of this poor water quality. Disruption of aquatic habitats and damage to the natural environment are a result (Paul and Meyer, 2001), which according to Burian and Edwards (2002) has become an important concern. An overview of CSOs and a map of the sewerage system typology can be found in appendix B and C.

5.2.3. Climate change in Groningen

In the past century, there was an increase of 20% in precipitation in the Netherlands (PBL, 2012). Scenarios predict more precipitation in the winter period, while the trend in the summer period is hard to predict. Yet, the predictions all indicate that the number of extremes will increase throughout the year (Attema and Lenderink, 2014; IPCC, 2008; PBL, 2012). A recent study shows that in the North Sea region, climate change impact on extreme events could be considerable, increasing the probability of extreme events by a factor two or more (Attema and Lenkerink, 2014). In other words, the amount of extreme precipitation events is likely to double. The Dutch Meteorological Institute (KNMI) deals with the uncertainties of climate change predictions by making scenarios. In four scenarios (G,

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[i] Combined Sewerage Overflows, see p.11

G+. W, W+), ranging from little to severe plausible climate change, the KNMI tries to map what such climate change would involve (KNMI, 2006). In a subsequent report, the KNMI added that with the strong temperature rise measured in Western Europe so far, it would be wise for policy makers to adapt policy and measures to the scenarios involving the most severe plausible climate change (W/W+ scenarios), since they have become more likely than the tempered G/G+ scenarios (KNMI, 2009). Van den Hurk et al. (2007) reviewed the climate change predictions, and concluded a rise of 3°C is the projected mean. Combining these findings with increasing precipitation intensities of 11-14% per degree Celsius found by KNMI (2009; 2014), Lenderink et al. (2011) projected that the Netherlands may face up to a 50% increase of the intensity of hourly precipitation extremes.

5.2.4. Urbanization

Urbanization and impermeable surfaces go hand in hand, as shown in chapter 2.2, with increasing runoff as a result. The preliminary results of Zwaagstra (2014) suggest that in the last 15 years the share of impermeable surfaces in developed areas of Groningen has risen by 2 - 5%. This may not sound like a lot, but considering the exponential correlation found by Dietz (2007), and realizing that on the scale of a 25 acre neighborhood it is almost 3 football fields of added impermeable cover (Zwaagstra. 2014). It is a hardly negligible addition of stormwater entering the urban stormwater management system. The preliminary results Zwaagstra's study are in line with the experiences of Klein (Head of the Urban Watermanagement department at Witteveen+Bos Engineering and Consulting) (2014), who noticed that he "*[...] often experiences that the stormwater quantities are getting higher than initially calculated*".

5.2.5. Impact of climate change and urbanization on urban stormwater management in Groningen

The 'Stedelijke Wateropgave' report continues with modeling a 100 year return event +10% climate scenario, consisting of 61mm in four and 87mm in 24 hours respectively. The result of the flooding is visible on figure 5.3. There is a noticeable difference between the standard 100 year return event, with a much greater area being flooded. Also, the inner city has several low situated, weak locations. Helbig (2014) recognizes this and adds: *"The areas sensitive to urban flooding will have increased nuisance if precipitation extremes will occur more often. […] Chances are, that if such events will increase in intensity, that the* *water also enter stores and houses."*

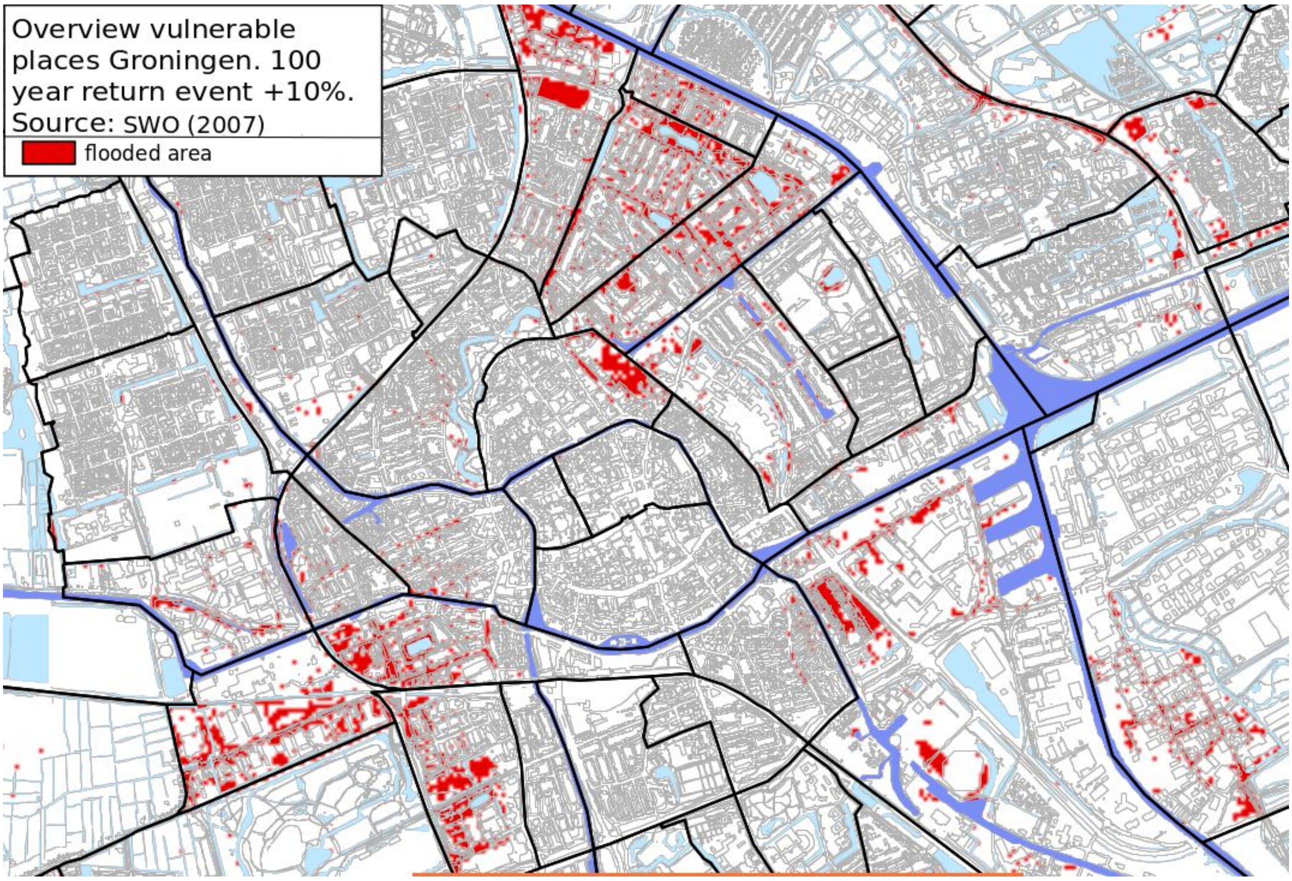

Figure 5.3. (SWO, 2007)

Another model to plot the impact of extreme precipitation is WOLK, developed by the TAUW consultancy. This model has also been used in the Groningen case, see figure 5.4. In this model, modeled on the city's center, the impact of an event of extreme precipitation comparable to the event in Copenhagen in 2011 is projected. Boogaard (2014): *"The maps resulting from the WOLK model in Groningen tell us what would happen if, for example, an event of extreme precipitation as seen in Copenhagen, 150mm in two hours, would occur. What we can see is that, for example, the Gedempte Zuiderdiep will flood. This is not very surprising, since all urban stormwater runoff flows to the Gedempte Zuiderdiep. If one knows this will happen during such an event, I think the municipality has the duty of care to react. Groningen has been lucky so far, but this summer there is yet another opportunity for such an event.*" Both Boogaard (2014) and Visser (Advisor of Watermanagement at Grontmij) (2014) advise municipalities to look beyond the scope of standardized climate scenarios. They advocate using models to explore what would happen if an event similar to Copenhagen (150mm in two hours) would occur, and take measures. This can be justified, considering that the climate scenario of a 100 year return event +10% is set at 87mm in 24 hours, and that intensities of 138mm on August 26th, 2010 (KNMI, 2010), have been measured. Also, as mentioned earlier, literature suggests that a 100 year return event might happen more often, and have an increased intensity far above the +10% scenario (Attema and Lenderink, 2014).

Figure 5.4. WOLK Groningen. Light blue to red colors indicate an increasing accumulation of water. *(Tauw European Consultants and Engineers, 2014).*

Visser (2014) is concerned about the situation in the inner cities, remarking that the inner city of Groningen consists of practically 100% hardened surface. According to Visser (2014) the inner cities will experience more nuisance from urban flooding when robust measures are left out. Klein (2014) sees positive sides to urbanization: *“Urbanization often has a positive effect when it concerns developments within the built areas. It facilitates the improvement of the former situation. […] In an old inner city it is common for the situation of the urban drainage system that it is not up to the current standard. A new development, even if it is infill development, often results in an improvement of the urban drainage system.”*

5.3. Low Impact Development

In addition to the potential of LID practices described in the theoretical framework, the experts also see the similar potential. Boogaard (2014) notes that it is proven that all forms of LID practices can have a positive effect on reducing urban stormwater runoff and pollutants, reduce and delay peak flows, and thus improve water quality of surface waters in general. Helbig (2014) comments: *The solution lies not in the continuous upscaling of sewerage pipes. That is too costly, and there is simply not enough space in the ground to do so."* In general, regarding the advantages of LID practices over conventional piped draining, Boogaard (2014) concludes that "*There is substantial added value if we change the way we handle stormwater, both in mitigating and adapting to climate change*".

5.3.1. New developments

For the development of new neighborhoods, the experts are positive about the potential of LID to maintain the hydrologic functioning of an undeveloped site such as literature from Dietz and Clausen (2007) and Hood et al. (2007) suggests. Boogaard (2014) refers to progress that has been made with the implementation of the so-called 'wadi' system, a form of bioretention and infiltration. After he introduced the system in the Netherlands 15 years ago, over two-third of the municipalities in the Netherlands are now working with this system. With such progress, Boogaard believes that autarkic towns become a reality within the foreseeable future, with a prominent role for LID. "*Factually it is possible, we used to live like that in the early days. […] If you just look at green roofs, which have become very popular, there are over a thousand different types of green roofs"* (Boogaard, 2014). Visser (2014) sees the same potential, but adds that the potential is subject to the local specificities of the site: "*The subsurface has to be suitable for drainage, this is not the case everywhere. Yet, there are many areas where infiltration is perfectly possible and where LID can provide clean stormwater runoff to other surface waters. […] You can't infiltrate on every parcel, but what you can do is create retention ponds on every parcel. I am in favor of that, and reusing the water for toilet flushing or the washing machine for example. [...] One example of this* [maintain the hydrologic functioning of an undeveloped site] *is a neighborhood in the Dalfsen municipality that we are developing now, where in principle, all the stormwater is being kept within the area of the development. Only in a 100 year return event runoff has to be drained.*" Visser adds that it is common for municipalities to demand a certain form of filtering of stormwater before it enters other surface waters because "*[...] if for example a calamity occurs, a system such as a wadi, can catch up most of the* *contamination. A wadi is then relatively easy to restore, but if the contaminant was to flow straight into a pond or river, the problem could be much worse."*

5.3.2. Built areas

In addition to new developments, other areas with high potential for all LID practices are the early post-war neighborhoods. These were built shortly after World War II, between the 1950's and 1970's, and are characterized by spacious green strips between two or more story high flats. "*Neighborhoods from the 1960's are very spacious, making implementation of LID practices no problem."* (Klein, 2014). Looking at the situation in Groningen, those are essentially these areas that host the great amount of surface waters that Boogaard (2014) refers to, and that according to Boonstra et al. (2010, p. 63) have an ecology that *"leaves much to be desired"*. These are neighborhoods like Paddepoel, where Boonstra et al. (2010) found that the ecological situation of the two measured surface waters were 'very bad' and 'bad', being the two lowest categories of water quality in that research, and where a combined sewerage system is used (GWRP, 2014).

A real challenge of urban stormwater management lies within the inner cities and relatively older densely built neighborhoods. As mentioned previously, inner cities are densely built and thus have a high share of impermeable surfaces, making then more vulnerable to climate change and extreme precipitation. LID practices that take up a lot of space, like bioretention practices, have limited potential. Visser (2014) mentions that subsurface solutions are among the few solutions in such densely built areas, like subsurface infiltration systems. The potential depends in the situation of the local soil: "*[...] like when you have a situation on very sandy soils. For example in Putten* [NL]*, they are going to disconnect stormwater drains from the sewerage on 37,5 acres of built space. They will pursue to infiltrate all the water on site, which should be perfectly doable there, if the facilities are properly accommodated. This is happening in more municipalities, where they implement infiltration storm drains.*" (Visser, 2014). Also, permeable pavements could be among the solutions: *"Permeable pavements is a system that is improving over time. Municipalities aren't keen on implementation yet, due to high sensitivity of the practice for clogging and uncertain lifetime of the pavement. Improvements are made in durability and maintenance. I foresee that it will be a useful practice in the future. The impact depends on the subsurface, but also with shallow infiltration it is useful to reduce and delay peak flows of runoff."* (Visser, 2014).

Klein (2014), too, is aiming at subsurface solutions for inner cities, but also highlights using parking space as water buffers. Since the center of Groningen is dominantly car and car-park free, this solution has little potential in Groningen. Yet, Klein (2014) says great care should be taken with using subsurface infiltration systems. There are known cases, where due to a lack of monitoring of the functioning of these systems, they ended up being completely clogged, or polluting the subsurface. Klein (2014) argues that it is wise to not look at one solution, but to look at the entire spectrum of solutions, and which solutions suit the local specificities the best. Looking at the conclusions and recommendations of the SWO (2007), one can see they are completely in line with the experts visions: *“In old parts of the city, the task to increase stormwater buffer capacity isn't easy. […] Implementation of subsurface buffers, permeable pavement or subsurface infiltration systems on suitable locations are the appropriate measures.*”

5.4. Policy

Public policy is an important instrument in facilitating both adaptation to climate change, including decreasing vulnerability of people and infrastructure, supplying knowledge about the risks for public as well as private investments and decision making, and to protect species, habitats and culturally important resources (IPCC, 2007). Therefore, the policy of the responsible actor, the municipality, towards urban stormwater management is explored. The aim is to find to what extent the currently identified problems are being recognized, and if policy allows or stimulates LID practices.

Being responsible for urban stormwater management, the sewerage system, and groundwater quality, the municipality is obliged to formulate a plan every four years on the maintenance and development of the urban drainage system. Helbig (2014) calls it the 'route planner' of how the city manages its water, and how it anticipates on developments like climate change. It is called the Groningen Water and Sewerage Plan (GWRP) and has recently been adopted by the municipality for the 2014 – 2018 period. Helbig (2014) continues with the 'Stedelijke Wateropgave' (SWO) (2007), mentioning that this document is used with every new development. When there is a development ahead, the municipality uses the opportunity to see if the risk of flash floods can be reduced by combining efforts during the construction, and thus making such adjustments more cost efficient. The SWO explored the impact of a 100 year return event, plus a climate change scenario, indicating the awareness of the municipality towards the problem of extreme precipitation and climate change. As far as the acceptance of flooding is concerned, Helbig (2014) comments: "*Factually the policy says that some water on the streets every now and then is acceptable, up until the moment it enters buildings. That is not considered acceptable. Also, the mixing of stormwater with sewage on the street is not acceptable."* Helbig (2014) continues that during reconstructions or the development of new properties, focus lies upon processing stormwater locally. Resulting from the knowledge that green roofs can hold stormwater, municipal subsidies have been introduced for green roof developments (Helbig, 2014).

In the plans of the GWRP (2014, p. 34), the section on the water quality of surface waters is straight to the point: "*The water quality of our city ponds in general is moderate to bad. They get polluted through CSOs during rainfall events, and are not connected with other ponds, causing the water flow and refreshment to be insufficient.*" The plan aims at introducing more separated sewers and physically connecting the ponds. LID practices are not mentioned here. The plans for improving the water quality for the city's other surface water, owned by multiple actors, recognize the importance of 'reducing the pollution' (GWRP, 2014, p. 35), yet again reducing CSOs, but also improving the banks of water bodies are the targeted measures for improvement.

The municipal ambitions towards precipitation, stated in the GWRP (2014, p. 23), are in line with the philosophy behind LID practices: "*Precipitation is a clean source of water. […] we aim at collecting precipitation as close to the area where it is cached. […] Due to the high water quality of precipitation, we aim to promote using this source among companies and home owners. We want to stimulate home owners to keep precipitation out of the sewerage as much as possible, by subsidizing green roofs.*"

An example of policy on an even lower scale are the land-use plans. These are documents created by the municipality for every subdistrict, and include policy and strategy of developments in the particular district. Land-use plans state for example what kind of land use is allowed, and what quality and methods are desirable in the different aspects of use of space. The document is binding for both authorities as well as civilians (Rijksoverheid, 2014). By examining land-use plans, it can be seen whether municipal policy is translated into the other lower, sub-levels of planning. In doing so, the land-use plans of the neighborhoods Paddepoel, Selwerd and Tuinwijk (2010), and the Oosterparkwijk (2012) are examined. In both land-use plans, Low Impact Development is mentioned as the preferred practice of water management during urban renewal and new developments. "*During new developments, infill developments and redevelopment, the effects of the increase in impermeable surfaces have to be considered. Urbanization creates more runoff, flowing off in increased speeds. […] Compensation in the form of added surface water is required. As a rule of thumb, 10% of the amount of added hardened surface shall be compensated with surface water. The rules of sustainable urban drainage apply, catching and buffering water within the site. Compensation can also be realized in the form of infiltration systems or permeable pavements. […] The local specificities of the soil determine whether these methods can be used. In short, it means that increased hardened surface may not cause increased stormwater runoff in the area."* (Bestemmingsplan Paddepoel, Selwerd en Tuinwijk, 2010, p. 61-62).

The land-use plan of the Oosterparkwijk (2012, p. 76-77) takes it a step further by directly promoting LID to prevent drought, and reduce and delay peak flows of runoff: "*One of the disadvantages of further urbanization is that no precipitation can infiltrate on site. Ground water levels decrease, and drought can occur. […] Through the use of infiltration systems and permeable pavements, water can recharge groundwater levels. […] Creating green roofs can buffer stormwater and help delay the discharge of stormwater runoff.*" The land-use plans of the inner city of Groningen (2014) provides more information on urban drainage ground water levels. The groundwater levels in the inner city are between 1.43 and 1.93 meters below the surface. This is relatively low, and easily meets the 1 meter norm for inner cities, indicating that there is potential for LID practices such as permeable pavements and other infiltration systems. Yet, only green roofs are mentioned here as a recommendation for new developments (Bestemmingsplan Binnenstad, 2014).

5.5. Challenges

In order to utilize the potential of LID practices, it is relevant to explore the challenges that come with it. "What challenges can be identified, and how can they be dealt with?" is the question that the experts were asked.

When it comes to understanding the problem, Helbig (2014) noticed that the models that generate maps with data on weaknesses towards precipitation extremes have improved over time, and that models have different outcomes. Therefore, the map created in the SWO will be revised, hopefully making their efforts more effective. Boogaard (2014) highlights the importance of local specificities: "*[...] in general, it happened too often that we literally copied a certain LID practice, without considering the differences in a local geohydrological system. When it comes to sustainable water management, you can't just copy and paste designs.*" Klein (2014) is concerned about the great amount of diversification of practices, making management and maintenance of the system too complex for local authorities. Visser (2014) foresees a certain form a centralization towards the practices, in order to keep the urban drainage system manageable, also for smaller municipalities.

Both Boogaard (2014) and Visser (2014) mention that the planning process is still too fragmented. Boogaard (2014) is familiar with the subsidies for green roofs in Groningen, but states that there is a lack of a structural vision and a goal towards what they want to achieve with it, for example a vision on the amount of square meter or percentage of green roofs they are aiming at. As a result, implementation is scattered and the impacts of such programs are hard to quantify. Visser (2014) warns of the marginalization of LID practices, where they are often considered in a late phase of the design process of developments. As a result of that, some wadis have been designed too small, and are being overloaded with water, causing disrupted systems with rotten grass (Visser, 2014). Klein (2014) adds to this the vulnerability of LID practices in the phasing of realization of plans: "*A conventional system works the moment you put the pipes in the ground, whereas LID practices are more sensitive, and work best when the whole development has been realized."* The phasing of construction requires extra care when LID practices are used. Within planning and development, the power of project developers combined with financial aspects are a major factor and challenge: "*There are many municipalities who want to have, for example, green roofs in a new neighborhood. The project developer just sees it as extra costs, and wants the cheapest possible build. Partly due to the financial crisis, municipalities are happy to sell land, and then it is hard to stick to the principle of green roofs. Then, an option would be to implement that principle in regulations.*" (Visser, 2014).

Other challenges that Klein (2014) and Boogaard (2014) experienced concern rules derived from policy and permits. Klein (2014) states that if you follow the rules strictly, it is hard not to end up with conventional methods using separated sewers, to avoid surface water quality regulations and concerns. But, he adds, it improved in recent years. Visser (2014) has similar experiences, and uses Leidsche Rijn, a new neighborhood in Utrecht, where the plan was to reuse intercepted water in homes as an example: "*The fear for* *accidentally connecting the wrong water pipes with another, and the concerns of that for public health, made that the implementation was aborted.*" Boogaard (2014) experienced difficulties gaining the needed permits with the introduction of new practices, for example when he introduced the 'wadi' system in the Netherlands.

5.6. Sub-conclusions

5.6.1. Sub-conclusions of the 'Problem' pillar

Climate change projections vary in a wide range. The general trend is that it will become warmer and wetter in Groningen (IPCC, 2007; KNMI 2006; KNMI 2009), with more extreme precipitation events, up to a factor two or more (Attema and Lenkerink, 2014; IPCC 2008; PBL, 2012), and intensities on the rise up to 50% (KNMI 2009; KNMI 2014; Lenderink et al., 2011). The city of Groningen is vulnerable towards extreme precipitation and this is recognized within its policy (GWRP, 2014, Helbig, 2014; SWO, 2007). The weaknesses of the current urban stormwater management system in the city is causing poor surface water quality as a result of CSOs and urban runoff (GWRP, 2014; Boonstra et al., 2010), and the possibility of flash floods (Boogaard, 2014; GWRP, 2014; SWO, 2007), resulting in social, economic and natural damage (e.g. Burton and Pitt, 2001; Copenhagen Adaptation Plan, 2011). The findings suggest that urbanization is not part of the problem, where new developments or infill developments within the built environment may not cause increased stormwater runoff, and is potentially a motivation to implement a separated sewerage system, or to improve the current situation of urban stormwater management (e.g. GWRP, 2011; Visser, 2014; Bestemmingsplan Paddepoel, Selwerd en Tuinwijk, 2010).

5.6.2. Sub-conclusions of the 'LID' pillar

LID practices decrease urban runoff and its pollution, and reduce and delay peak flows of urban stormwater discharge, which can help reducing the amount of CSOs (e.g. Dietz, 2007). Local specificities of, e.g. the subsurface, influence the capabilities of LID practices (Visser, 2014). Therefore, LID practices cannot be fully copied, but need to be adjusted and assessed for the local situation (Boogaard, 2014). In the inner city for example, little space is available for practices like bioretention, but the case study suggests that permeable pavements and subsurface infiltration systems are potential options here (Klein, 2014; SWO, 2007; Visser, 2014). Studies show that even partially retrofitting LID practices in urban areas can reduce urban runoff with 7-15% (Ahiablame et al., 2013; Lee et al. 2012).

This means LID practices cannot fully replace conventional sewerage systems in historically built areas, but can contribute to the adaptive capacity and robustness of the urban drainage system in the city as a whole, along with conventional practices. Less dense neighborhoods, for example neighborhoods from the 60's, have more space for bioretention practices (Klein, 2014), which could help improve the poor surface water quality in these areas as shown e.g. by Davis et al. (2003). For new developments, LID practices can maintain the hydrologic functioning of an undeveloped site (Boogaard, 2014; Dietz and Clausen, 2007; Hood et al., 2007; Visser, 2014).

5.6.3. Sub-conclusions of the 'Policy' pillar

The municipality recognizes the problem of climate change and the cities vulnerabilities to precipitation (GWRP, 2014; Helbig, 2014; SWO, 2007). The policy of the municipality of Groningen promotes LID practices in regards to urban stormwater management. In contrast to literature, which suggests that LID practices are effective in reducing the amount of CSOs and therefore improving surface water quality (e.g. Dietz, 2007), LID practices are not mentioned as a means to improve surface water quality in any of the reviewed policy documents. Land-use plans have paved the way for LID practices to be implemented during new or renovation developments.

6. Conclusions

6.1. Conclusion

In this research, an answer to the main question: "What potential do Low Impact Development practices have for urban stormwater management, in contribution to climate change adaptation in Groningen?", is explored. This is done by assessing the three defined pillars of potential: 'Problem', 'Low Impact Development', and 'Policy' (see figure 1.1). The final conclusion is an aggregation of the sub-conclusions from chapter five.

With 75% of the urban drainage system consisting of a combined sewerage system, Groningen is undeniably vulnerable towards precipitation. The weaknesses of the current urban stormwater management system in the city is causing poor surface water quality, mainly as a result of combined sewerage overflows which are linked to environmental damage. During an event of extreme precipitation, flash floods can occur in Groningen. Flash floods result in economic, social and environmental damage. Climate change in Groningen results in more and intensified, heavy and extreme precipitation, enhancing the pressure on the current urban stormwater management system. LID practices decrease urban runoff and its pollution, and reduce and delay peak flows of urban stormwater discharge, which can result in a reduction of the amount of combined sewerage overflows. With new developments, combined LID practices can maintain the hydrologic functioning of an undeveloped site. In built areas, such as the inner city of Groningen, LID practices can help even out the negative effects of climate change to a certain degree, and therefore increase the adaptive capacity of Groningen. The policy of the municipality of Groningen promotes LID practices in regards to urban stormwater management, but does not mention it as a means to improve surface water quality, therefore slightly reducing the potential for LID practices in Groningen.

6.2. Recommendations

During the process of this research, new questions arose, resulting in the following recommendations:

- In the inner city, stormwater management is at a relatively high level, being able to cope with a 100 year return event. Yet, climate change may urge the municipality to improve the stormwater management situation at the bottlenecks. Land-use plans for the inner city do not make any notice of LID practices apart from green roofs. A single green roof will not significantly improve the situation of urban drainage in the inner city. Further research could provide insight on the impact of combined, or large-scale, LID practice implementation, like permeable pavements and subsurface infiltration systems.

- Where literature strongly recommends LID practices as a means to improve surface water quality, municipal policy does not mention or recognize this. Therefore a recommendation towards the municipality and other actors to assess whether this is equitable.

- The final recommendation is again directed at the municipality. Literature suggests that quantities and intensities of severe or extreme precipitation will rise stronger than the 100 year return event +10% scenario. Following Helbig (2014) and Visser (2014), the municipality is recommended to look beyond the scope of standardized climate scenarios. This can enhance the knowledge of the municipality of its vulnerabilities towards precipitation, and therefore improve or strengthen municipal policy and action, resulting in a better adaptive capacity of the city.

6.3. Reflection

6.3.1. Process

LID is a broad concept that knows many practices. Potential, alike, has a meaning which needs to be bounded for research. Combined with the explorative character of this research, it was a challenge to determine the factors to be assessed. For example, financial aspects have been left out, and could be considered in a further research. The literature research took a relatively long time. The amount of time given for the research meant that interviews were conducted while the literature research was not completed yet. Therefore the interviews could have been invigorated when the researcher's knowledge was at a higher developed state. One of the initial ideas was to gather enough information for a comparative research with Groningen and Oldenburg. Therefore, an interview has been conducted in Germany on the Oldenburg case. In the end, due to time restrictions, the case of Oldenburg, and the interview, have been left out. It would be interesting if next year, a student taking part in the Trilateral Bachelor Thesis project, pursues to continue the gathering of information on the Oldenburg case and comes to the comparative aspect.

In general, the process went smoothly and has been very informative for the researcher for his personal academic development.

6.3.2. Content

Five interviews have been conducted, but only one of them with a person responsible for the policy of the municipality. The case study could have been invigorated if more interviews were conducted with people of the municipality or water boards. Three interviews were conducted with experts of LID. These interviews were of added value for answering questions regarding the problem and the potential of LID, but added little knowledge to the specific case study, generating more generalized answers applicable to the situation in northwestern Europe. The same goes for the impact of LID practices, which are a given with each practice, based on literature. The precise impact of LID practices on detailed areas of the case cannot be answered by the researcher, where he lacks knowledge and skills. For climate change impacts and the case's vulnerabilities towards heavy and extreme precipitation, the answers were more detailed. In summary, the case study is more explorative and broad than initially hoped for.

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Appendix A: Interview guide

Introduction:

- Ask permission to start recording, start recording
- Introduction of interviewer and research theme
- Confidentiality, and permission for recording and publication of findings
- Introduction and professional background of interviewee

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1. Interview with Anne Helbig*

- What are the vulnerabilities of Groningen towards extreme precipitation?
- Which parts are vulnerable and why?
- What is the municipality doing about that? What is its policy towards stormwater management?
- What will the impact of climate change be on the city?
- How is the municipality anticipating towards climate change?

Is the municipality considering LID practices? If yes, how, where and why?

2. Interviews with urban stormwater management experts*

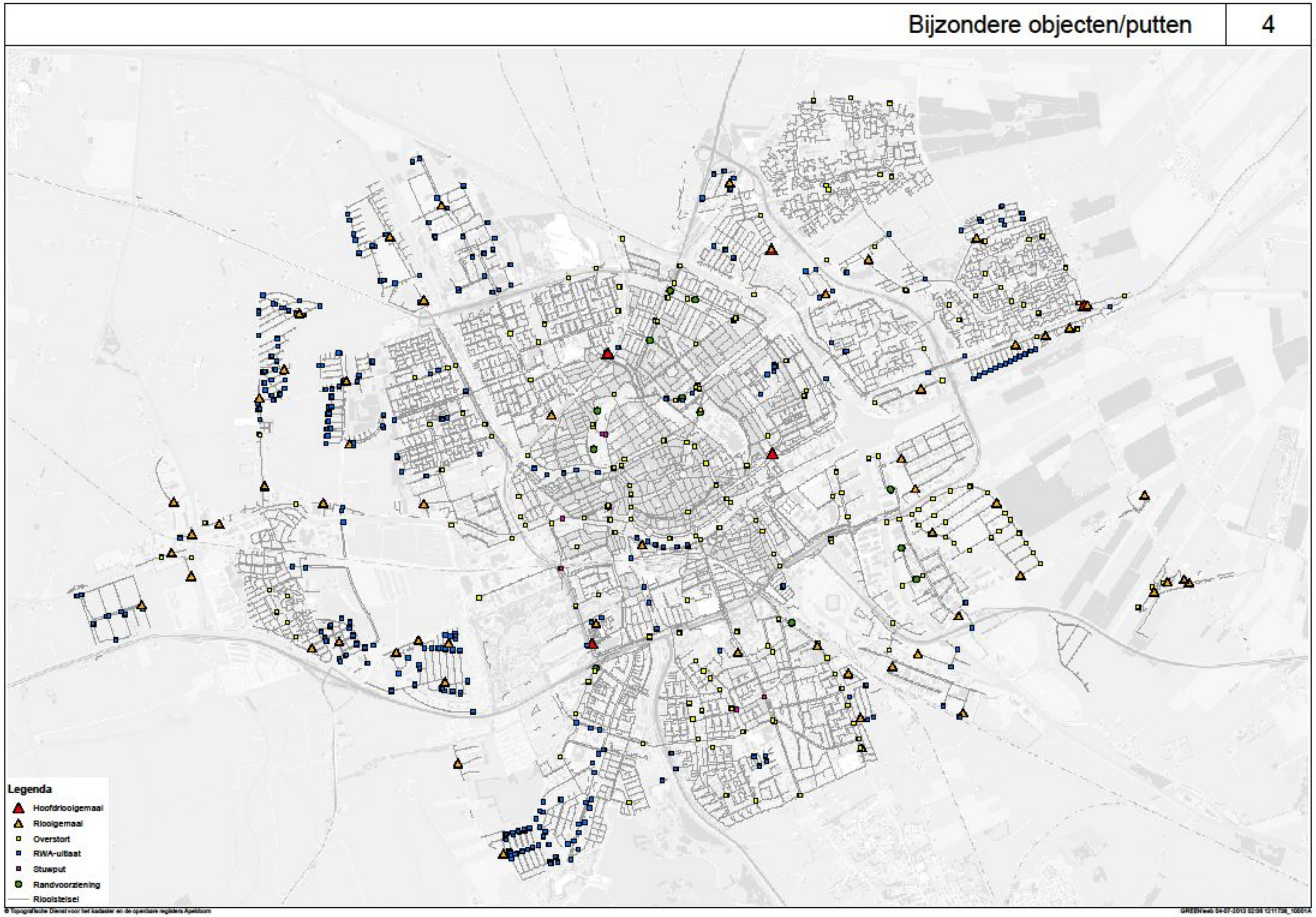
- What effect will climate change have on urban stormwater management (in Groningen)?
- What potential do LID practices have for urban stormwater management have (in Groningen)...
    - as a whole?
    - in built space?
    - with new developments?
- Where does this potential end?
- Which problems have you encountered with the planning, implementation and management of LID practices?

Rounding off:

- Ask if the interviewee has questions or remarks
- Ask if the interviewee wants to be informed about the outcomes and final result
- Thank the interviewee for his/her time and collaboration

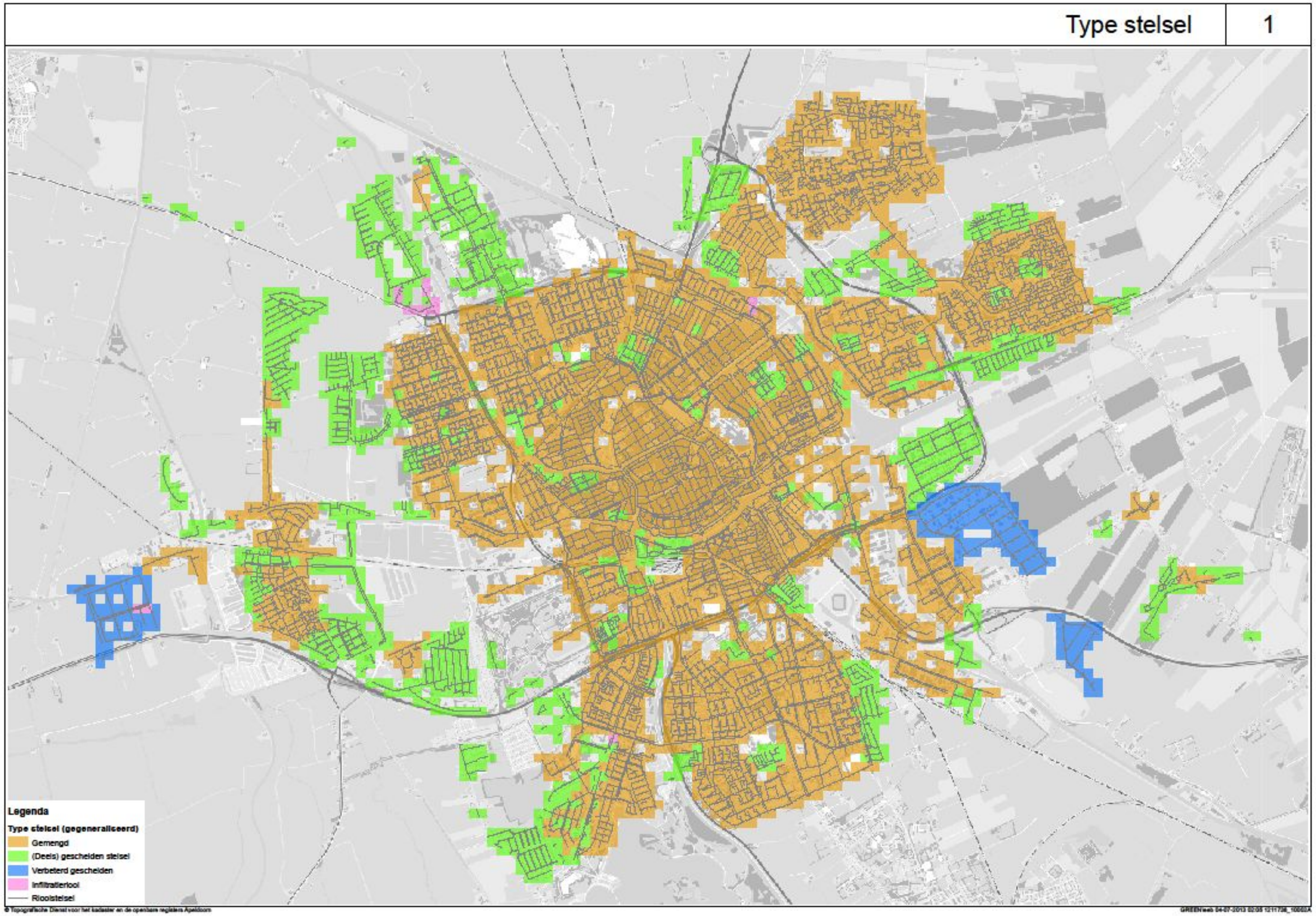
* This is a simplified list. For the entire list and transcription of the interview, please contact the researcher.

Appendix B: Locations of CSOs



GWRP (2014)

Appendix C: Sewerage system type



GWRP (2014)